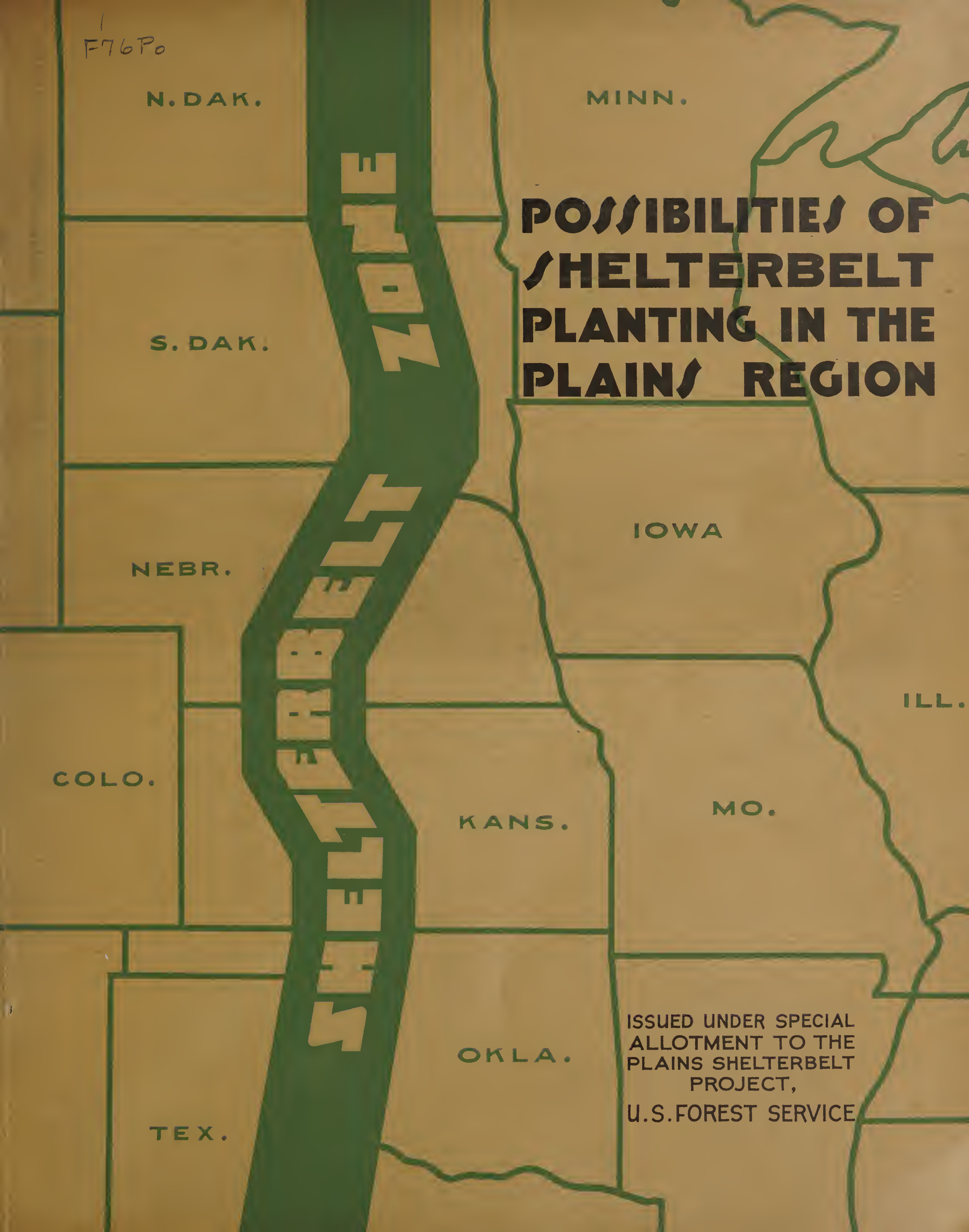

POSSIBILITIES OF SHELTERBELT PLANTING IN THE PLAINS REGION

ISSUED UNDER SPECIAL ALLOTMENT TO THE PLAINS SHELTERBELT PROJECT,
U.S. FOREST SERVICE

POSSIBILITIES OF SHELTERBELT PLANTING IN THE PLAINS REGION

A Study of Tree Planting for Protective and Ameliorative Purposes
as Recently Begun in the Shelterbelt Zone of North and South Dakota, Nebraska
Kansas, Oklahoma, and Texas by the Forest Service; together with
Information as to Climate, Soils, and Other Conditions
Affecting Land Use and Tree Growth in the Region

Prepared under the direction of
THE LAKE STATES FOREST EXPERIMENT STATION
UNITED STATES FOREST SERVICE

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Frontispiece.—Shelterbelts for farmsteads and field protection—a view in formerly treeless country in South Dakota.

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POSSIBILITIES OF SHELTERBELT PLANTING IN THE PLAINS REGION

Section 1.—THE PROBLEM

By F. A. Silcox, *Chief, Forest Service*

To alleviate the economic condition of the people in the Plains region has become one of the major concerns of the Department of Agriculture. The situation there has assumed the aspects of a national calamity as a result of the severe climatic and economic conditions of the past few years. In the spring of 1934 the seriousness of the situation was dramatically brought home to the country as a whole by great dust storms, nature's own manifestation of land disorders, which arose in the Great Plains region and blanketed almost the entire eastern half of our country.

Early in 1934 Congress appropriated $528,000,000 for the relief of the inhabitants of the drought-stricken Plains. As part of the huge program of relief and rehabilitation thus inaugurated, there was made public in June 1934 a proposal of the Government to plant shelterbelts on about 1,000,000 acres of farm land within a 100-mile-wide zone extending through the prairie-plains region from the Canadian border into the Texas Panhandle. This proposal was but a revival and definite formulation of a plan in which the President had been interested personally for some time, and which had been under consideration by the several bureaus of the Department of Agriculture since August 1933.

The factors leading to the present distress in the Plains region are not entirely of recent origin. True, the present economic situation and the abnormal drought of the past few years have brought matters to a head. But man has been laying the pitfall for his own disaster for many years through improper land use. Through the stimulus of high prices during the "war years", thousands of acres of grassland were broken by the plow. Under normal price conditions such areas are distinctly submarginal for farming and become a liability. This overextension of agriculture, aside from social ills such as tax delinquency and lower standards of living to which it contributed, exposed huge areas of cultivated land to the drying action of the sun and wind. It formed a vast breeding ground for destructive dust storms, which strip the fertile topsoil from areas where it is valuable and deposit it in others where it becomes a liability, which blow the sown crops out of the earth in one locality and smother them in another, and which, with the added physical distress that they produce, contribute markedly toward lowering the morale of the people. The increased area of plowed land forced thousands of herds of cattle and sheep onto other and poorer areas, led to overgrazing and consequent destruction of the protective grassy cover, and further enlarged the area of origin of dust and other calamitous drought effects.

Thoughtful citizens are coming to realize that the old American policy of unlimited, undirected, and often wasteful land use cannot continue longer without grave consequences, and must be replaced by united, intelligent effort toward a more rational and balanced utilization of all our natural resources.

This report, while confined chiefly to the field of shelterbelt forestation, has been prepared with the conviction that full and wise use of our whole land resource is vital to the future welfare of the region and the Nation, and with the recognition that shelterbelt development is only one phase of Plains management, a phase that must be developed in harmony with the entire land-use pattern of the region.

Tree planting as a measure for improving Plains conditions has received attention since the advent of the early settlers. Trees grouped together as windbreaks or shelterbelts are credited with the improvement of physical conditions, probably most tangibly expressed as the protection of crops and crop land. A larger and more vital value, however, and one that cannot be expressed in physical terms or realized by those who have not experienced life in the prairie-plains region, is the reinforcement of the people's morale that comes with shade from sun glare, shelter from the ever-prevailing winds, the improved appearance of the countryside, a greater pride in ownership, and a real increase in value of the farmstead—all culminating in a general sense of being at home on the land.

The Forest Service was given the task of carrying out the proposed program of shelterbelt planting. This task very naturally divides itself into two parts: (1) The investigative or exploratory phase, and (2) the administrative phase, concerned with the actual execution of the work.

Before planting operations could begin, it was necessary to answer certain fundamental questions of urgent importance: Can shelter belts be established successfully in the Plains region, and if so, where is such establishment most feasible, and where will it accomplish the greatest good? As a necessity for general orientation, the Forest Service during 1934 and early 1935 conducted explorations of the climate, soils, native vegetation, and results of past planting in the prairie-plains region of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas. These, together with consideration of economic factors, information on tree enemies, and certain pertinent documentary material descriptive of the region, supplemented by the accumulated trial-and-error experience of past windbreak planters, defined the possibilities of shelterbelt planting, provided a broad program for shelterbelt development in the region, and afforded a more or less empirical basis upon which to proceed immediately. The results of these investigations, with which the body of the present report is very largely concerned, formed the basis of active planting operations that began in the spring of this year (1935) with the definite organization and launching of the Plains Shelterbelt Project.

During this first season's work 125 miles of field shelterbelts were planted in strips 8 rods wide having an area of 16 acres per mile, or 2,000 acres in all. In addition 4,800 acres were planted in the form of windbreaks around farmsteads. The total area, 6,800 acres, probably equals or exceeds the area planted within the Plains region during the entire preceding decade. This initial planting was in addition to the collection of seed supplies and the establishment of nurseries. Seedlings are now growing and land has been selected and prepared for the planting of some 30,000 acres in the spring of 1936, which area will comprise 1,400 miles of field shelterbelts and about 6,400 acres of plantations around farmsteads.

Expanded planting operations must be guided at every step by specific experimental activities. The suitability of soils for individual plantings must be determined. A quantitative expression of the effect of shelterbelts on climatic factors and crops, under different conditions, must be sought. Experimental plantings must be established for determining more accurately the proper orientation, width, and structure of shelterbelts, and the intervals at which planting, as it assumes its final pattern in different parts of the region, will be most effective for protection.

In supplying and presenting factual information, and in formulating programs and recommendations, many agencies and individuals have participated. These include, besides the Forest Service, such bureaus of the Department of Agriculture as Chemistry and Soils, Soil Conservation Service, Weather, Plant Industry, Biological Survey, Entomology and Plant Quarantine; also the conservation and survey division of the University of Nebraska and State officials and private individuals throughout the region.

The conditions and trends which are reflected in the report have changed in the past and will change in the future. The facts are not presented in minute detail but in their broader aspects, and with a considerable margin of conservatism in drawing conclusions. It is highly undesirable at this stage that the program of shelterbelt development be cast in any rigid mold. On the contrary, our policy should be sufficiently flexible to take advantage of changing conditions and increasing knowledge. The outlines of the situation are sufficiently clear so that the program herein recommended can be presented with full assurance that it is justified and, in fact, essential for the public welfare.

Section 2.—WHAT THE STUDY DISCLOSES

By Raphael Zon, *Director, Lake States Forest Experiment Station, Forest Service*

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THE REGION

The Great Plains region comprises about 30 percent of the continental United States. From a line through central Minnesota and Iowa, along the eastern boundary of Kansas, and southward along the ninety-fifth meridian to the Gulf of Mexico, it extends westward to the Rocky Mountains. This area is grassland except along stream courses where there is a natural growth of trees. The region is divided throughout its length from north to south into two units of almost equal size, the tall-grass prairie to the east, and the short-grass plains to the west.

Climatically it is a transition zone between the humid region to the east and the semiarid region to the west, embracing all gradations between the two. Broadly speaking, however, it is characterized by low annual precipitation occurring mostly during the summer, frequent droughts, great range in temperature extremes, low humidities, and almost constant winds of comparatively high velocities. The land surface varies from level to rolling. The typical soils of the region are the Chernozem and chestnut-colored soils, with considerable areas of dune sand in certain localities.

More specifically the climatic conditions become less favorable for plant growth from east to west. Although precipitation increases from north to south, evaporation also increases. Average daily relative humidities vary from 50 to 75 percent, showing a more or less regular decrease from east to west, and being lowest in the southwest and highest in the southeast. The evaporation from a free-water surface ranges approximately from 29 to 56 inches for the 6 warm months, April to September. The annual mean temperature ranges quite regularly from about 70° F. in lower Texas to 36° at the Canadian border. Average mean temperatures for January vary from −10° in the northeastern part of the region (the coldest area of the United States) to 45° in the south. The mean July maximum temperatures range from 78° in the north to over 100° near the mouth of the Rio Grande. Within any given season, temperature changes are sharp.

The average wind velocities in the region are 10 to 12 miles per hour, the highest average, 14 miles per hour, occurring on the High Plains of Texas. Hot, desiccating winds are of frequent occurrence in summer. In the winter, cold winds and blizzards are common. In spring the region is often visited by dust storms.

Agriculture becomes more hazardous from east to west and changes from grain production to grazing. The frequency of droughts of 4 months' duration for the last 40-year period ranges from 18 to 20 in the east to 40 in the extreme southwest. The average annual precipitation varies at the north from 21 inches in the east to 14 inches in the west and at the south from 36 inches in the east to 16 inches in the west.

AMELIORATION OF CONDITIONS A PRESSING NEED

As settlement increased and advanced farther west, and as increasingly larger areas of the original sod were broken by the plow, the recurrence of droughts and dust storms resulted in increasing economic losses and human discomfort and suffering. The drought of the last few years clearly brought into focus the need for a coordinated attack on the stern forces of nature and for a planned use of the Plains region if it is to continue as the granary of the United States. Without such united, intelligent effort, there will be further inevitable decline in the physical and economic conditions of life within the region. Coordinated effort must involve land adjustment, control of grazing, diversification of agriculture, water conservation and the building of ponds and reservoirs, shelterbelt and other forms of tree planting, strip cropping, terracing, and the development of new varieties of cereals and soil-binding grasses.

This report deals with only one aspect of the broad program, namely, tree planting.

BLEAK LANDSCAPES TRANSFORMED

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FIGURE 1.—Shelterbelts break the monotony of the plains and lend attraction to the farm home: *A*, A bleak, unprotected farm group: *B*, Trees lend a homelike, sheltered aspect to this farm. (See text, p. 8.)

FEASIBILITY OF PLANTING DEMONSTRATED

Although occasional plans have been advanced in the past for water conservation and some other improvements, one measure of amelioration, tree planting, has received attention for a long time. Private initiative, stimulated by Government aid through the Timber Culture Act of 1873, Kincaid distribution as provided in the Agricultural Appropriation Act of 1911, the establishment of the plains field stations in 1913, the Clarke-McNary Act of 1924, and various State tree-bounty laws, accounted for the planting of about 700,000 acres of trees in the Plains region, chiefly in the form of timber claims or as windbreaks. Many of these plantations received little or no care and have since disappeared; many others stand today as witnesses to the foresight of tree-planting pioneers.

Although trees do not naturally grow in the grassland except along watercourses, groves may be and have been established and maintained with the aid of man. With irrigation, tree growth is of course possible throughout the entire prairie-plains region. Experience, however, demonstrates that even without irrigation tree planting is feasible over much of the Plains area if proper precautions are taken, and it demonstrates further that such planting may contribute to the improvement of living and working conditions. That same experience also demonstrates that the sporadic efforts of individuals in the States must be systematically correlated and concentrated before any region-wide effects can be expected.

WHERE SHELTERBELT PLANTING IS MOST ADVISABLE

The grassland region for the most part does not lend itself to the planting of solid bodies of forest. The low annual precipitation occurring mostly during the summer may be sufficient for annual crops, but perennial trees and shrubs must depend for their existence on a supply of subsoil moisture which, in the fine-textured soils of the Plains, is often lacking. For this reason only along the " breaks " and ravines, or on sandy soils, where there is a supply of subsoil moisture available to the roots of the trees, can solid bodies of forest be established. Over most of the Plains, tree plantings, to provide protection against wind and storm without impoverishing the subsoil-moisture supply, should take the form of strips, known as " shelterbelts ", around fields, farmsteads, and schoolhouses. Such strips do not impose a heavy drain on subsoil moisture. By proper cultivation of the soil on either side, and by the shelterbelt's own ability to accumulate drifted snow to melt in the spring, an actual increase of available moisture is provided for the trees' growth and maintenance.

Shelterbelt planting is advisable, in general, wherever climatic conditions do not forbid tree growth and where agriculture is sufficiently developed and needs the protective influence of such windbreaks. In the light of past experience, shelterbelt planting is advisable on a large scale east of a line marked by 16 inches of annual precipitation in the north and 22 inches in the southern portion of the Plains region. West of this line extensive planting of shelterbelts is considered somewhat hazardous and will require more careful selection of site and species, although there are places in eastern Colorado, Wyoming, and Montana, where shelterbelts are growing well.

In the more easterly part of the prairie-plains region, conditions for tree growth are more favorable; agriculture has been long established, many groves have already been planted by farmers, and this condition will undoubtedly continue in the future. Between the western climatic limit which is generally unfavorable to tree growth, and the eastern portion of the prairie-plains where planting is easy and already well developed, there is a relatively narrow north-south belt within which agriculture, although now beset by many handicaps, holds out the promise of becoming thoroughly established if protective tree planting and other ameliorative measures are given their proper function on the land. This, on the whole, is a zone of fertile prairie soil and is an important part of the granary of the United States. Shelterbelts are fitted directly into its pattern of land use, and their planting should be encouraged. It is within this particular territory that the shelterbelt zone, with which this report is largely concerned, has been marked out for development—because here the soil, the rainfall, and other natural conditions point to the success of the undertaking, while the conditions of agriculture mark it as urgently needed.

THE SHELTERBELT ZONE

On the basis of the accumulated experience of past shelterbelt planters, further supplemented by surveys carried out during 1934 and 1935 which furnished a correlated region-wide knowledge of the climate, soils, native vegetation, and results of past planting—the present shelterbelt zone (fig. 2) in which such planting is to be encouraged has been delimited. This zone is 100 miles wide and, roughly, 1,150 miles long and is confined to the transition zone between the tall-grass prairie and short-grass plains. As shown on the map, the axis of this zone roughly follows the ninety-ninth meridian, touching Devils Lake in North Dakota, Mitchell in South Dakota, Lexington in Nebraska, Kinsley in Kansas, and Mangum in Oklahoma. Its western limit is generally within the precipitation boundary marked by 16 inches of precipitation annually in the north and 22 inches, to allow for greater evaporation, in the south.

Within the boundaries of the zone thus designated there are areas where the character of the soil may, as it actually does on limited areas, either preclude forest planting altogether or dictate variations in the manner of planting. Within the zone there are some 114,700 square miles of land. This can be classified, according to soil and suitability for shelterbelt planting, as follows:

- 66,400 square miles of fine-textured soils—so-called " hard land." Generally, it is good agricultural land, but not all of it is suitable for forest planting. It may be subdivided thus:
  - 36,700 square miles of uplands; shelterbelt planting difficult.
  - 24,900 square miles, principally in the eastern part of the belt, well suited to shelterbelt planting.
  - 4,800 square miles of claypan land and alkali basins, unsuited to tree growth.
- 29,900 square miles, consisting mostly of sandy loams, which is good agricultural land and all favorable for shelterbelt planting.

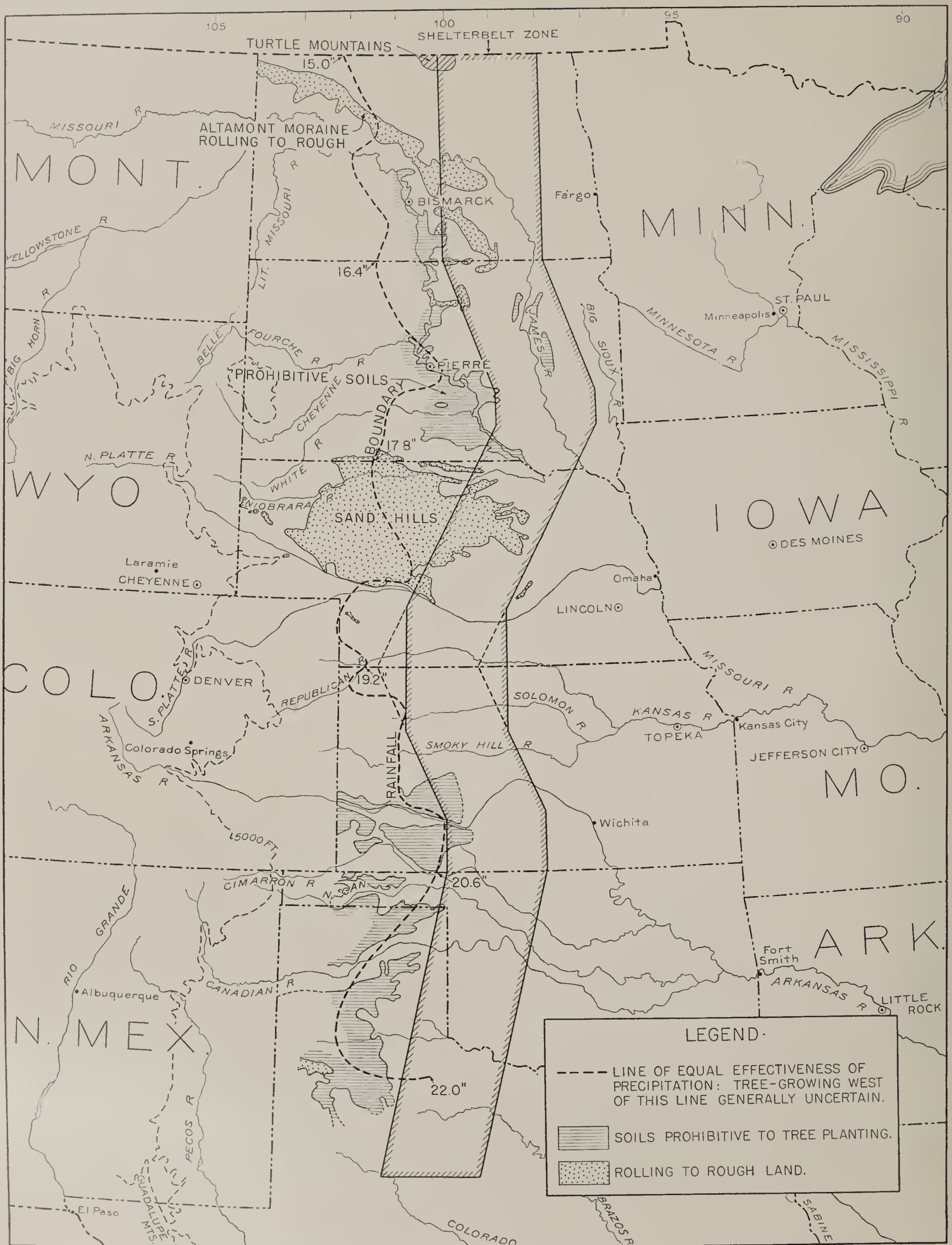

Figure 2.—Location of the shelterbelt zone, with factors limiting its westward extension.

800 square miles of coarse, gravelly soils, relatively unfavorable for tree growth.
13,000 square miles of "breaks" or rough land. Of this:
5,000 square miles are favorable for shelterbelt planting.
8,000 square miles are difficult to plant.
4,600 square miles of sand hills, well suited for forest planting in solid blocks.

Of the total area, some 56 percent lends itself to shelterbelt planting, about 39 percent is difficult to plant, and 5 percent is entirely unfit for planting. It is evident, therefore, that there can be no continuous parallel forest strips, but each planting must be adapted to the soil conditions of the individual farm or farms which it is to protect, and must be oriented according to the damaging winds prevailing in each locality.

The sand hills, which present the most favorable conditions from the standpoint of soil moisture and on some of which the ground water is within reach of trees, lend themselves best to planting in solid forest blocks. A good illustration of such planting is found in the sand hills of Nebraska, where the Forest Service has planted successfully some 20 square miles. About 410 square miles have recently been authorized for purchase by the Federal Government in North Dakota for this type of planting.

Planting in the breaks and gullies will be largely for the purpose of conserving water and checking soil erosion. It will usually be confined to the slopes and active gullies and will follow narrow ravines.

On the "hard land", planting will be mostly in the form of windbreaks around farmsteads and schools.

EFFECTS OF SHELTERBELTS

The need for the protection of farmsteads, orchards, and fields in the Plains region against winds is almost universally recognized.

To shelterbelts there have been attributed popularly such effects as decreasing the range of temperature fluctuations, attracting more rainfall, increasing the retention of snow and providing a more uniform distribution of it, reducing wind velocities and blowing of soil, reducing evaporation, increasing soil moisture, raising the water table, increasing agricultural yields, and, from the human standpoint, providing a more livable and beautiful environment. Quite definite scientific proof has been furnished as to some of these effects; others are more difficult of evaluation.

The actual effects of shelterbelts on crop yields are, so far as they have been measured, largely favorable. Further tests and experiments are needed for the better scientific guidance of the project as it develops. It will be advisable to measure crop yields on experimental fields protected by shelterbelts of various densities, composition, and orientation, under both wet and dry climatic cycles, and to compare these results with those obtained under similar conditions on fields which have been unprotected by shelterbelts. Most observations made in this country have been confined to shelterbelts already established, of variable composition, density, and extent, and on fields planted to a single crop in one place and another crop in another place.

Long records from foreign experiment stations clearly indicate that the effect of shelterbelts may be to increase grain-crop yields by as much as 25 percent both in grain and straw. In the United States the evidence is generally favorable to the shelterbelt, but, considering that most of our shelterbelts are defective in their density, orientation, and extent, further observations and experiments must be conducted before a proper rating can be made of the degree of benefit that should be expected.

The effect of windbreaks varies with the occurrence of wet and dry years. During the wet years their effect, being a means of protection against damage by drought, is at the minimum. During moderately dry years this effect is at its maximum; within reasonable limits the beneficial effect increases with the increase in drought. Under extreme conditions of prolonged drought, however, shelterbelts may fail completely to save the crops, and themselves may be decimated. It is for this reason that the public planting effort must proceed with the best advisement of science and experience, and with due regard to regional and local conditions. Essential factors of survival have been too often neglected in the past.

Meteorologists and foresters agree [1] that the physical conditions of air and earth, which cannot be altered appreciably by human agencies, basically control the climates of the various regions of the world. Extensive climatic controls are changed only through the slow process of nature operating leisurely through many centuries. While the planting of trees will not change climatic conditions as a whole, it will alleviate or modify many unfavorable features of existing conditions, principally through the diminution of the surface velocity of the wind by the successive forested strips. Also the trees undoubtedly would help in some situations to conserve soil moisture to some extent, at least, by retarding run-off and evaporation and lessening erosion.

Man, in many ways, has modified the effects of climate and has alleviated some of its unfavorable aspects. For example, the planting of windbreaks in California to protect orchards from the damaging effects of desiccating winds, and the use of literally millions of orchard heaters for the protection of fruit from frost damage have not changed California's climate in the least, but they have made some localities of the State safer places in which to grow fruit. Many other examples of this kind might be cited. It must be remembered that such modifications of existing conditions are the primary results sought, rather than an appreciable change in the climate as measured by general conditions of temperature, sunshine, or rainfall.

The whole question, therefore, of the effect of shelterbelt planting on the climate of large regions is largely of academic interest. More to the point are its local benefits. The effect of shelterbelts on retarding or modifying the movement of surface wind is definitely recognized. This effect has been proved experimentally to extend to a distance equal approximately to 20 times the height of the trees on the leeward side, and for a shorter distance—not definitely established—on the windward side.

The retardation of the surface wind movement produces a chain of physical effects. Evaporation from

[1] In response to numerous inquiries, this statement as to climatic effects is made jointly by the Weather Bureau and the Forest Service.

the land immediately adjoining the shelterbelt is reduced. The transpiration from the vegetation is lessened. The drifting of snow is checked, and the blowing of the soil is retarded.

A dense shelterbelt about the farmstead accomplishes three definite benefits: Protection of the home against cold winds with a measurable saving of fuel, protection of stock to an extent definitely appreciable, and prevention of snow drifting within the area sheltered.

The protection of gardens and orchards, which is generally accomplished by surrounding them on at least three sides with trees, frequently permits the growing of fruits and vegetables which otherwise would never mature in the dry Plains region.

From the human standpoint, shelterbelt planting, by adding beauty to the landscape, breaking up the monotony of the Plains, and satisfying the craving for growing trees in a treeless region, has an immeasurable value in happiness and contentment (fig. 1); from a more commercial point of view, it adds considerably to property values.

The mechanical protection afforded by windbreaks is perhaps more definitely effective in preventing wind erosion locally than in any other way. To accomplish this, shelterbelts must be either reasonably close together or supplemented by strip cropping, or other methods of direct soil protection, to be effective. They cannot be expected to prevent dust storms, which may originate hundreds of miles away in areas too dry for tree growth.

Although shelterbelts are planted chiefly for local protection of farmstead and soil against wind and storm, they have provided and will continue to furnish considerable quantities of fence posts and fuel wood. Such products are of particular value in the Plains region.

The effect of shelterbelts on wildlife cannot be ignored. In addition to providing a haven from the elements and natural enemies, many tree species also furnish food in the form of seeds and fruits.

In addition to shelterbelts around fields and farmsteads, the planting of large blocks of trees on sand hills and to a lesser extent along breaks of streams and gullies will produce some very considerable benefits. They will protect watersheds, produce a valuable wood supply, and provide very important recreational and wildlife values.

How soon will the benefits of shelterbelts begin to be felt? From past experience it can safely be said that at the end of 5 years the shelterbelts will have reached sufficient height to have some degree of effectiveness in retarding surface wind movement and obstructing drifting snow and soil.

ESTABLISHMENT OF SHELTERBELTS

It must be realized that, even when the proper soil types and tree species are available, shelterbelts cannot be established successfully in the zone without painstaking care and considerable cost.

ORIENTATION

In general, the east-west orientation of shelterbelts is most effective for protection against summer winds but will not provide complete protection during other seasons or even against the quartering winds which frequently occur during the summer. Because of the variability in direction of damaging winds, both east-west and north-south orientations should be used. A shelterbelt on two sides of each field over a large area would amount, practically, to protection on all sides.

FREQUENCY

To be fully effective, shelterbelts should be established at intervals not greater than one-quarter mile. The present distance of 1 mile is only a beginning, which must be supplemented later by private or State plantings.

KINDS OF BELTS

Three general kinds of planting are considered:

1. The typical field shelterbelt, which is to make up the bulk of the planting, under the Plains shelterbelt project, should be a planted strip 8 rods wide. The area to be acquired and fenced should be 10 rods wide, so as to provide room for later cultivation and the spread of the roots and crowns, embracing 20 acres in each mile of strip. Under some circumstances, narrower belts, down to single rows, may be used. It is estimated that 1,282,120 acres, all on favorable soils, should be planted to field shelterbelts.

2. On more difficult soils, where the establishment of trees is likely to be more expensive, yet where the need is great, the plan should be to aid farmers in establishing windbreaks around the farmstead through cooperative agreements. For this purpose 897,880 acres should be planted.

3. There are approximately 4,099,000 acres of land within the shelterbelt zone which should be placed under forest and range management to prevent erosion and to protect critical areas from cultivation and overgrazing. Some 400,000 acres of this area should be planted to more or less solid blocks of trees.

Except after very careful planning and with the cooperation of the State highway departments, shelterbelts will not for the present be planted along highways because of possible interference with highway purposes. But, in view of the growing demand for roadside beautification, such planting should be undertaken at once on an experimental scale and the details worked out.

SPECIES

The choice of species will depend upon such factors as adaptability to climate and soil, silvical value, economic value, and susceptibility to damage by pests.

The following species have been found to be of most wide-spread usefulness, each over a large area within the zone: Green ash, hackberry, cottonwood, American elm, Chinese elm, tamarisk, Russian-olive, caragana, honeylocust, Osage-orange, eastern red cedar, and Rocky Mountain red cedar. Complete information on species suitable for planting will be found in a later section (p. 17).

The collection of seed of desirable species should be made only from suitable native trees or others of known climatic adaptation. Species introduced for experimental purposes should not be used extensively until their suitability for shelterbelt planting has been proved. North-south limitations should be observed in the movement of seed from one locality to another, and localized collection of seed and planting of stock should be stressed.

Planting stock will have to be produced both under contract in private nurseries within the shelterbelt States and in Government nurseries already present or to be established within the area. Good, hardy stock grown with the minimum feasible amounts of water and artificial care must be produced. For the hardwood species, which will make up approximately 85 percent of the planting, stock 12 to 24 inches in height, 1 to 2 years old, is most satisfactory. Coniferous stock will be smaller and should be transplant stock 2 to 5 years old.

DESIGN AND COMPOSITION OF SHELTERBELTS

The typical field shelterbelt should be rooflike in cross section. In the center, the peak of the roof, there should be tall trees flanked successively by shorter trees, conifers, and tall shrubs, with low shrubs forming the eaves of the roof on the outside. This type of belt makes for the greatest impenetrability to the wind for the longest period of time, has a fine appearance, and provides valuable food and cover for wildlife. A considerable mixture of species is preferred because of different qualities of usefulness: Rate of growth, form of crown, longevity, and reduction of insect and disease hazards.

Close spacing of the trees within the shelterbelts should be preferred. The advantages of close spacing are: (1) Allowance for inevitable early losses; (2) early closure of crowns, thus shutting out weed growth and ending the period of cultivation; (3) mutual protection of the trees; and (4) creation of the densest possible wind barrier. Close spacing implies the making of thinnings as needed and does not mean a crowded stand of trees at maturity.

GROUND PREPARATION, PLANTING, AND FUTURE CARE

For successful shelterbelt establishment it is mandatory that the ground be prepared at least 1 year in advance of planting. This process ordinarily builds up a sufficient reserve of soil moisture to establish the newly planted trees, and with careful cultivation during each of the first 4 or 5 years after planting should see them well on their way toward vigorous growth. After this period, conservation of moisture is to be effected mainly through the accumulation of litter, and this is one of the most important reasons for having the plantations as dense as possible. Cultivation should be done frequently the first year, when there is no protection for the soil, and should be diminished gradually until it is given up after about the fifth year, when it becomes impossible to put machinery between the trees.

Careful methods of planting, giving good root distribution, and providing for good root development are necessary. For this purpose the youngest possible hardy stock is desirable. Planting, almost without exception, should be done in the spring, since the winters on the plains are generally too open and fall conditions too dry to permit of fall planting.

PROTECTION OF SHELTERBELTS

It is absolutely necessary that shelterbelts be fenced to protect them from livestock. Grazing and trampling by stock is one of the most serious causes of the dying out of windbreak plantations. The maintenance of these fences over most of the region will be one of the largest items in the future care of the plantations.

Jack rabbits and other rodents also cause much damage which may be minimized by snaring, poisoning, hunting, the use of repellents, and other recognized measures of control.

General precautions against the spread of insects and diseases in nursery stock and planted trees should be taken. As far as possible, tree species immune to serious pests should be used in planting, and possible losses should be guarded against further by the use of stock of local origin planted on sites to which it is best adapted. Special methods of control will have to be resorted to in case of serious infestations by insects.

The danger of fire loss is not as great as in most forest regions. There are possibilities of damage, however, from spreading stubble fires, and these will have to be prevented as far as possible by keeping the fences free of accumulating debris, by cultivation of the surrounding strips, and by educating the public against uncontrolled fires.

LAND OWNERSHIP

Considering the long-time nature of the project, highly stabilized control of the land dedicated to the shelterbelts is essential. Such control can be maintained in the following ways:

1. Ownership in fee simple by the Government. This is the most highly stabilized form of control. Such control may be acquired through either purchase or donation. Certain reservations, in most cases involving mineral rights, may be made as the need is indicated by local conditions.
2. Grant or purchase of perpetual easements.
3. Leases.
4. Cooperative agreements, by which the owner, in consideration of the benefits from shelterbelt planting, agrees to a plan of cooperation with the Government that will satisfactorily assure the future of the shelterbelt project on land retained by the present owner.

It will be necessary to use each of these methods of land control as circumstances dictate.

RECOMMENDATIONS

The general effect of shelterbelts is not the creation of more rainfall over the area covered by tree growth, but the more economic use and conservation of the available rainfall. Shelterbelt planting is not a cure-all of unfavorable climatic conditions in the Plains region. It should be considered as part of a much broader program of water conservation, soil-erosion control, terracing, strip cropping, and other measures tending to hold moisture and to conserve it in the soil.

Although past experience and recent studies have revealed certain desirable procedures for shelterbelt establishment, nevertheless it is essential that the plan should not be rigid. It must be kept sufficiently flexible to adapt itself to such changes as new experience and local sentiment indicate as desirable.

Further investigations, particularly into the effects of shelterbelts on crop yields and physical factors, should be carried on. For this purpose a Great Plains forest experiment station should be established to study the forest problems of the region as a whole. Shelterbelt studies can be made best on experimental areas comprising several sections of land more or less uniform as to topography and soil conditions. On such areas there should be established shelterbelts of different widths, densities, orientations, and compositions, and their effects upon physical factors and crops studied under controlled conditions. Since the development of such experimental shelterbelts, even though established immediately, will require several years to produce measurable effects, it is recommended that immediate investigations be undertaken to study the effect of existing shelterbelts, supplemented by artificial windbreaks or barriers to provide a variety of conditions.

Shelterbelts once established will not be perpetual, but will need care and renewal if they are to serve the purposes for which they were intended. Provision should be made, therefore, to insure the permanence of shelterbelt planting, and to encourage it on suitable sites to both the east and the west of the present shelterbelt zone. This can be accomplished best if the Plains shelterbelt project be expanded into a regional forestry enterprise similar to those now in existence in other parts of the country. In other words, the Great Plains should be organized as a distinct forest region. The regional forest activities then should be coordinated with the other forestry activities of the shelterbelt States. Private and State planting could be encouraged and all forest activities in the region developed in harmony toward definite objectives.

FIGURE 3.—Relief map of the Plains region, with shelterbelt zone boundaries superimposed.

Section 3.—THE SHELTERBELT ZONE: A BRIEF GEOGRAPHIC DESCRIPTION

By F. A. Hayes, *senior soil scientist, Bureau of Chemistry and Soils*

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The shelterbelt zone is not a naturally molded geographic entity like an island, a river basin, or a range of mountains. It cuts across both geographical boundaries and State lines. It is an administrative area whose bounds are defined by an economic and social objective.

Nevertheless, the location and the limits of the shelterbelt zone had to be submitted to one critical test of nature—the possibility of growing trees. The adaptation of the project to a practicable geographic framework was therefore a matter of primary and urgent importance, involving intensive studies or special surveys of certain conditions—soil, climate, topography, ground water, vegetative growth, and others—throughout the general area in which shelterbelt planting was and is desirable; all to the end that the zone delimited for operations should present a satisfactory working balance between needs and possibilities, such as would insure optimum results for the undertaking as a whole.

The results of these various investigations are recorded in their proper places hereafter. A thorough consideration of the findings, as made, raised many questions—what rainfall should control, what soils should be avoided, what native plants should serve as " indicators ", what areas could or must be left without protection, and the like. In studying these various problems, the zone was several times adjusted or shifted for miles in one part or another. It was extended, contracted, deflected, or straightened as conditions seemed to dictate, so that the present outlines differ materially from the tentative pattern with which the study began and which may have been noticed at earlier or later stages of its development in various newspaper accounts.

Even so, the zone should now be understood as nothing more than a projection or ground plan of certain natural conditions. These are conditions that evidently combine to insure the successful planting and growth of shelterbelts—within the region that most needs them and under the methods which the Forest Service proposes to follow in establishing them. Inside this zone, land acquisition for shelterbelt planting can proceed as the speed of the project requires; but the area is not yet so definitely fixed by metes and bounds that it cannot be further altered or modified, should sound and advised judgment later so dictate.

The results of the location process thus far will be seen in figure 3, in which the zone boundaries are superimposed on a relief map of the Great Plains region. This map will afford the best background for a brief geographical summary of the zone itself.

POSITION AND DIMENSIONS

The shelterbelt zone extends from the Canadian boundary of North Dakota to a line just north of Abilene, in Texas. In the extreme north it centers approximately on the ninety-ninth meridian, and it does not depart entirely from that meridian except for about 100 miles in the extreme south, where the departure is westward.

The width of the zone is everywhere 100 miles from east to west; its length is approximately 1,150 miles. It includes portions of North Dakota, South Dakota, Nebraska, Kansas, Oklahoma, and Texas.

CLIMATE

The climate of the shelterbelt zone is of the middle-latitude, continental type characterized by a wide range in temperature, a rather low precipitation which decreases westward, and a high rate of evaporation.

In the northern part, the winters are long and cold, and the summers hot; the spring is cool and rainy, and the fall is long, with moderate temperatures and only occasional rainfall. The mean annual precipitation is 24 to 16 inches (east to west). The mean annual temperature is about 36° F., and the free-water evaporation loss during the warm season averages about 30 inches. The soil remains frozen to a depth of 3 or 4 feet for long periods during the winter months.

In the southern part of the zone, owing to lower latitude and proximity to the Gulf, the temperature range between summer and winter is less pronounced. Erratic temperature changes are common, however, particularly in the winters, on account of " northers ", which may cause fluctuations as great as 50° or 60° F. within a few hours. The mean annual precipitation is here 29 to 22 inches, east to west; the mean annual temperature is about 60° F., and for the warm season, the free-water evaporation is approximately 53 inches. During the winter the soil freezes intermittently, but only for short periods and seldom to a depth greater than 1 foot.

In the central part of the zone, climatic conditions are intermediate between those existing in the northern and southern parts.

Of climatic factors, the two most potent in enforcing the need for shelterbelt planting are drought and wind. These phenomena are discussed fully in the later section on climatic factors. It need only be said here that the zone, as a whole, is open to the almost constant sweep of winds; and that it is subject to recurrent droughts of protracted and culminating intensity, aggravated by the nonreceptive character of many of the soils. (See also, section on Soil and Forest Relationships, pp. 111 to 153.)

In the north, winds and cold weather have long taught the lesson of the shelterbelt's value to the farmer and his stock. Recently in both North and South, drought, dust, soil blowing, and the mortality of many groves has given the impetus to better planned, better organized, and generally more scientific shelterbelt planting and maintenance. Everywhere, planting will have to be guided by due regard to species and soil, and care of the growing trees must follow the lines laid down by successful experience in similar situations.

TOPOGRAPHY

The general surface in the region which includes the shelterbelt zone is a broad, nearly level to hilly plain, sloping gently eastward from the Rocky Mountains. Most of this plain is mantled with deposits of varying thickness laid down in past ages by ice sheets, water, or wind, although some areas occur in which the bedrock is at or near the surface. The plain is crossed by several major streams flowing eastward or southward, including the Missouri, James, Niobrara, Platte, Arkansas, and Canadian rivers, all of which have carved rather deep valleys. Tributaries to the rivers have produced considerable bodies of rough land. Strips of flat alluvial land occur along the drainage ways.

Practically the entire region has good surface drainage; in the rougher parts run-off is rapid, and erosion may be severe. Extensive areas are so nearly level that surface drainage is slow and erosion is negligible, but the only poorly drained areas are on the bottom lands and in numerous small depressions on the uplands and terraces.

NORTHERN SECTION

The part of the zone lying north of the Nebraska-South Dakota boundary, comprising approximately the northern one-third of it, has a typical glacial topography. It is characterized as a whole by a generally rolling surface, modified in many places by rough morainic hills and ridges, large areas of nearly level land, and numerous basinlike depressions formerly occupied by lakes or ponds, some of which still contain water.

The most prominent features of this section are the Altamont Moraine, the Turtle Mountains, and the old basins of glacial Lakes Souris and Dakota (fig. 3).

The Altamont Moraine in North Dakota crosses the western boundary of the shelterbelt zone about 100 miles south of the Canadian Border and extends in a general eastward and southern direction to the South Dakota line, where it returns westward nearly to the Missouri River. Across South Dakota it follows the east littoral of the Missouri, in a very meandering and indistinct course, marked by numerous lobes. It crosses the eastern boundary of the zone at the southeast corner of South Dakota. This moraine marks the western and southern margins of a major glaciation. In North Dakota it forms a fairly continuous rough belt, 10 to 15 miles wide, of boulder-strewn hills and ridges, some of which rise several hundred feet above the smoother bordering lands. In South Dakota it is represented generally by a broad, slightly elevated, and strongly rolling to hilly belt distinguished from the surrounding land mostly by its rougher and more stony surface. It has definite local development, however, in counties all along the western boundary of the zone; in these places its surface is comparable to that of its rougher portions in North Dakota.

The Turtle Mountains are a high, plateaulike area at the extreme northwest corner of the shelterbelt zone. This area is an outlier of the old Missouri Plateau, from which it was separated by differential erosion. It stands 400 to 600 feet above the surrounding land and is occupied by numerous morainic hills and ridges and a number of lakes. It is mostly forest-covered.

The Souris and Dakota Basins represent the beds of lakes formed by ice barriers which blocked the drainage ways during the glacial period. The Souris Basin lies largely west of the shelterbelt zone and extends into Canada. The bed of Lake Dakota is a broad north-south basin extending across the zone in the north half of South Dakota and terminating across the North Dakota line. Stone-free sediment carried into these lakes was spread evenly over their beds. The more silty and clayey sediments occupy almost level areas, but the sandy deposits have been whipped by wind into a choppy, dunelike topography in many places.

The ice-laid material which covers most of the shelterbelt zone through the Dakotas is variable in thickness and composition. It consists chiefly of clay, silt, and fine or coarse sands mixed in varying proportions from place to place. Gravel and boulders of various sizes are usually present, in some localities comprising the bulk of the material. The deposit is very limy, frequently containing as much as 10 percent of calcium carbonate.

Along the Missouri River, generally west of the zone, erosion has removed the glacial mantle and severely acted upon the underlying Cretaceous shales known as the Pierre formation, producing an extremely rough and broken topography. Within the zone the only intrusion of this formation, with its extremely difficult soils, is a sharp salient occurring at the South Dakota-Nebraska line.

CENTRAL SECTION

The central section of the shelterbelt zone, as hereafter referred to, may conveniently be considered as that part lying in Nebraska and generally north of the Arkansas River in Kansas. It includes parts of the sand-hill areas in Nebraska and of the loess-mantled plains which cover most of southern Nebraska and northwestern Kansas (fig. 3). Areas of uplands capped either by gravel or loess occur in the extreme northern part of Nebraska, and a considerable body of sandy, naturally subirrigated hay lands lies within the zone northeast of the main sand-hill area.

Apart from the sand hills and dissected areas bordering valleys, the central section of the zone has a nearly level to gently rolling surface, dotted by numerous shallow depressions in which storm water accumulates. It is crossed by the broad and rather deep east-west valleys of the Niobrara, Platte, Republican, and Smoky Hill Rivers and is further dissected by their tributaries. Most of the tributary valleys are narrow, shallow, and widely spaced, but in several large areas they are close together and sharply incised to depths ranging from 30 to more than 100 feet. The latter conditions are especially pronounced along the Republican Valley in southwestern Nebraska and in adjacent areas of Kansas. Here the prevailing level terrain is altered to a series of narrow, flat-topped upland tongues, separated by drainage ways whose canyon walls are often nearly vertical.

The sand-hill region comprises an outstanding feature of the Nebraska topography. It occupies more than 20,000 square miles of that State and consists of a series of irregularly distributed hills and ridges separated by valleys and pockets. Lakes or ponds occur in many of the lower situations. The sandy material is unstable, but, owing to its native grass cover, it is not subject to destructive wind erosion except locally.

Another striking feature of the shelterbelt zone in southern Nebraska and northern Kansas is the vast expanse of level to slightly rolling country mantled by loess. The loess consists of wind-blown material—mostly a fine, floury silt—deposited during Pleistocene times, the original source of which was loosely consolidated Tertiary formations to the west. Uncounted billions of tons of this material were blown in upon previously existing land forms, tending to level out the relief by thicker accumulations in the lower, more protected areas, and to create a generally flat topography. The soil is fertile and thoroughly adapted (in normal seasons) to wheat growing, which prevails on a tremendous scale. These loess soils, as a whole, are listed in the difficult class for tree growing, yet they include many areas where trees have been and can be planted with success. (See Soil and Forest Relationships, pp. 111 to 153; also, Review of Early Tree Planting Activities, pp. 51 to 57.)

SOUTHERN SECTION

The southern section of the shelterbelt zone includes parts of central and southwestern Kansas and western Oklahoma, a narrow sector of the Texas Panhandle area, and part of the northwestern section of Texas known as the "rolling plains." The typical High or Staked Plains, an extremely level formation similar in surface features to level lands in the central section, have been left largely outside the zone in Texas (fig. 3). They are developed on rather fine-textured Tertiary materials. These High Plains, with several interruptions, extend northeast across western Oklahoma to the Arkansas River in southwestern Kansas and, less distinctly, beyond.

The rolling plains lie several hundred feet below the High Plains to the west and are separated from them, especially in northern Texas, by a steeply sloping and extremely gullied escarpment, generally known as "the breaks." The land east of the escarpment is roughened by numerous drainage ways. Its surface is strongly rolling to hilly, with a general eastward slope. Here prolonged erosion has in most places removed the thick Tertiary deposits upon which the higher plain is formed and also the immediate underlying formations down to the "Red Beds" of Triassic and Permian age. These consist chiefly of red, limy, soft sandstones and sandy shales, containing in places rather thick beds of gypsum. Over large areas, they lie at such shallow depths that they give the land a decidedly reddish color. In many places wind and water have removed the finer materials from the surface of the Red Beds, and the residual sands have been piled by the wind into hills and ridges, creating a topography similar to that in the Nebraska sand hills, but less extensive. At present, a negligible part of the sand is subject to active wind erosion.

FOREST AND GRASSLAND

The native vegetation of the shelterbelt zone consists mainly of grasses. Woodland occurs in narrow, intermittent strips along all the larger and many of the smaller drainage ways. It also covers most of the area occupied by the Turtle Mountains, as previously noted. Elsewhere there are few trees except in some of the situations where the water table is within reach of tree roots and on some of the more sandy lands, where the moisture is sufficient to support tree growth even during prolonged droughts. Trees, largely of native stock, have been planted at many places, notably in the Nebraska sand hills, where a national forest and a tree nursery have been successfully established. (See Review of Early Tree Planting, pp. 51 to 57.)

Native grasses include both the tall and short species characteristic of mixed prairie. The distribution of these species is determined largely by the amount of the precipitation and the effectiveness of soils in absorbing and holding the water which falls on them. These factors, and the importance of the mixed-prairie grass type as delimiting the westward reach of the shelterbelt zone, are particularly noted under Soil and Forest Relationships of the Shelterbelt Zone and Native Vegetation of the Region (pp. 155 to 174).

In the eastern part of the zone where precipitation is highest, and in the northern part where the evaporation loss is relatively low, practically all the soils not otherwise used are able to support a dominantly tall-grass cover. This cover decreases in density southward, in accordance with the diminishing effectiveness of the precipitation in response to a greater evaporation loss.

In the zone proper, tall grasses are dominant only in valleys and on sandy soils, generally giving way westward to short grasses through the relatively narrow transitional zone of mixed prairie. Large and dense stands of tall, sod-forming grasses, such as occur in the big-bluestem prairies of Minnesota, Iowa, and Missouri, are rarely seen on typical upland soils, the nearest approach to such a type being found at the northern end of the zone and along its eastern edge from Kansas northward. Even here, on most of the heavier soils, the tall grasses intermingle with or give way entirely to grama grass. Along the east side of the zone, from about the Nebraska-Kansas line south, dry soil conditions brought about by a high evaporation have forced the tall grasses, chiefly prairie beardgrass, to assume the bunch habit of growth. To the west, grama and buffalo grasses become increasingly dominant as vegetative conditions verge closer and closer upon those of the typical short-grass country.

Section 4.—THE PROPOSED TREE PLANTATIONS—THEIR ESTABLISHMENT AND MANAGEMENT

By D. S. Olson, *in charge Planting and Nurseries, Plains Shelterbelt Project, Forest Service*, and J. H. Stoeckeler, *junior forester, Lake States Forest Experiment Station, Forest Service*

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The scheme of planting within the shelterbelt zone will vary according to soil types, land use, optimum benefits to be derived from various kinds of planting, and other factors. Of the gross area within the zone, much of the land will not be planted or served by planting, either because the land will be occupied by towns or cities, because landowners will not wish to lease or sell their property for shelterbelt purposes, because the land is not suitable for tree growth, or for other reasons. Three general kinds of planting are considered:

(1) The typical field shelterbelt, with which this report is primarily concerned, will be a planted strip 8 rods (132 feet) wide, comprising 16 acres in the length of 1 mile. The area of land to be acquired for such a shelterbelt, however, will be 10 rods wide, so as to provide on each side the space needed for cultivation and for the spread of the roots and crowns of the trees. There will thus be 20 acres in each mile of strip. The strip will be adequately fenced. It is estimated that 1,282,120 acres, all on favorable soils, will be planted to field shelterbelts.

(2) On more difficult soils, where the establishment of trees is likely to be more expensive, yet where the need is great, it is the plan to aid farmers through cooperative agreements in the establishment, on a cooperative basis, of farmstead windbreaks. For this purpose it is estimated that 897,880 acres should be planted.

(3) Approximately 4,099,000 acres of land within the shelterbelt zone should be placed under forest and range management to prevent erosion and to permit of the protection of critical areas from cultivation and overgrazing. Of this area, about 400,000 acres should be planted more or less solidly, the plantings varying from relatively small blocks along the river breaks to more extensive tracts, on which planting should be done for watershed protection, timber production, and other uses (see fig. 4). Table 1 shows the distribution, by States, of the estimated acreage of the first two classes of planting, and table 2 shows the distribution of the estimated acreage in the third class, also by States.

Table 1.—*Acreages within zone proposed for shelterbelts and farmstead plantings*

State	Field shelterbelts on favorable soil	Farmstead plantings on difficult soil	Total
	Acres	*Acres*	*Acres*
North Dakota	192, 780	209, 280	402, 060
South Dakota	152, 200	211, 180	363, 380
Nebraska	265, 720	127, 940	393, 660
Kansas	203, 860	190, 660	394, 520
Oklahoma	221, 120	72, 820	293, 940
Texas	246, 440	86, 000	332, 440
Total	1, 282, 120	897, 880	2, 180, 000

Table 2.—*Acreages within zone proposed for block planting and forest management*

State	Area for planting	General character of area	Purpose for which area is suitable
	Acres		
North Dakota	262, 000	Turtle Mountains	National-forest purposes.
	21, 000	Souris Lake bed	Do.
South Dakota	197, 000	Dakota Lake bed and sandy areas.	Partial planting and range management.
Nebraska	102, 000	Sand hills	Block plantings of about 25 square miles each.
Kansas	307, 000	River breaks and other rough areas.	Partial planting and range management.
Oklahoma	1, 590, 000	do	Do.
Texas	1, 620, 000	do	Do.
Total	4, 099, 000		

There is need for much investigation and scientific research. For some portions of the shelterbelt zone there is an accumulation of experience and knowledge of planting and nursery work that leaves little question as to the practicability and desirability of tree planting, or as to the methods to be employed. In other portions of the region, however, experience and knowledge are inadequate to the needs of a large and difficult project, and several years should be spent in experiment and field tests before work in such localities is developed to its full proportions. Administrative problems of some magnitude must also be solved. Pending their solution, the expansion of operations should be held within conservative limits in order to avoid waste and inefficiency.

SIZE AND EXTENT OF INDIVIDUAL SHELTERBELTS

The length of a strip will be determined largely by the ownership status of the land, the type of soil, and the willingness of the landowner to have such plantings made. It is improbable that a single belt of trees will be continuous for more than 1 mile without a break or an offset. Gates and passageway through the belt must be provided at reasonable intervals as required.

FIGURE 4.—Plantings on the Nebraska National Forest. Ponderosa pine at left; jack pine at right. F209910

It has already been stated that the typical field shelterbelt will be planted 8 rods wide. This does not imply, however, that plantings 3 to 6 rods in width may not be used, where belts of such width will meet all practical requirements.

Field shelterbelts, at least in the initial stages of the program, will be kept a mile or more apart as a means of distributing equitably the benefits of planting.

SUPPLEMENTARY PLANTING BY PRIVATE EFFORT AND BY STATES

Many shelterbelts have been planted in the past by private effort, often supplemented by State and Federal cooperation. Most of this planting has been around farm buildings, because the farmer has felt that he would receive the greatest return from trees near his home, and because in that location he could more conveniently care for his plantings than elsewhere. Even so, the total amount of planting done thus far, either around the homes or around the fields, has been relatively small because of the cash outlay for stock and labor required in planting and cultivating, and because of discouragement following occasional failures.

Increased planting by individuals can be expected under the impetus of an organized movement. A large increase in orders was reported by nurserymen during the winter of 1934–35, this being attributed to the publicity given the Government shelterbelt project. Despite such increases, however, planting in the Plains region for years to come will in all probability be limited to areas around garden spots and farmsteads. To the east of the designated shelterbelt zone, where moisture conditions are more favorable, an increase in planting to protect cultivated fields can be expected. The latter, however, will probably not be forthcoming until benefits from the shelterbelt planting to the west are manifest, and until there is general dissemination of information on all phases of shelterbelt planting. Such supplemental planting through private or State effort can then be expected within the zone, also, and it can be expected to increase to the extent that farmers have ready money for the purchase of planting stock. Intermediate strips and strips at right angles to shelterbelts planted by the Government, subdividing farm units, will, it is hoped, be planted through such effort. Better composition and maintenance of plantations than in the past and more careful selection of the stock may also be expected. It is only natural, then, that an expansion of Clarke-McNary work should ensue, and that the State forestry departments should be called upon for more and more planting stock.

LOCATION OF SHELTERBELTS WITH RELATION TO FIELDS, ROADS, AND BUILDINGS

The Government shelterbelt will ordinarily be along quarter or forty lines in the interior of sections. In some cases the belt for its full width will be located entirely on one side of such boundary lines to simplify acquisition work. Plantings will not be placed too close to roads, because of the danger of drifting snow. Field shelterbelts will usually be confined to the better agricultural soils. The more difficult planting sites, such as coarse, droughty soils, alkali spots, claypan soils, heavy clays, and undrained basins, will usually be avoided. Some experimental plantings on such sites will, however, be made on a sufficient scale to give at least tentative solutions to the problem of selection of species, preparation of soil, and subsequent care of the plantations.

No field shelterbelt planting is now contemplated on areas that are classified as grazing land, which often occupy the rougher, more rolling, and more arid parts of the shelterbelt zone.

Shelterbelt plantings around farmsteads will be planned to give maximum protection to buildings and gardens. This will mean that their shape, composition, length, and width, as well as their distance from buildings and gardens, will have to be varied to suit conditions as found.

Prevailing wind direction will to some extent determine the orientation and location of all types of shelterbelts.

PREPARATION OF GROUND

Experience has already shown that, to insure the successful establishment of any tree planting on the Plains, the initial step is adequate ground preparation prior to planting. The purpose of this advance preparation is to reduce the drain on soil moisture by weeds, and to create conditions favorable to the absorption of precipitation and to the conserving of a reserve supply of moisture for the trees to draw upon for the first few seasons. After the trees are once established, and their crowns are sufficiently developed to shade the ground, they will compete successfully with other vegetation, and will conserve moisture themselves—through absorption and retention of water in the porous leaf litter and humus developed, through the accumulation of drifting snow, and through the reduction of surface evaporation.

Summer fallowing will be standard practice, but will be varied in application and will be combined with other measures of moisture and soil conservation.

SPECIES TO BE PLANTED

The survival, growth, effectiveness, and longevity of the shelterbelts will depend to a large extent on the proper selection of species and their use in certain combinations on the different planting sites.

Fortunately, records and observations relating to thousands of groves have been accumulated during a period of many years by various Federal and State agencies engaged in tree planting and are now available for study. An untold number of groves of various ages, planted by individual farmers, remain yet to be studied. Some farm plantings were eminently successful; others were complete failures. Much of the success or failure of past effort can be traced to one of two factors—namely, selection of species and subsequent care.

The results of wide observation and experience in the several States of the shelterbelt zone as to the adaptation of species to different soils and planting sites and their proper arrangement in the shelterbelt cross section are shown in tables 3 to 7, intended to be used as a practical field-planting guide.

The tables do not include all species that may have use in shelterbelt planting. Other species, both native and introduced, will be tried experimentally and used more extensively as soon as they prove their value in field planting.

TABLE 3.—*Recommended tree and shrub species, their arrangement in shelterbelts, and their adaptation to soils*

NORTH DAKOTA

Group and species	Sequence of rows [1]	Approximate height and position in shelterbelt									Adaptation to soil classes [2]							Remarks
											Uplands			Terraces				
		Under 15 feet	10–25 feet	20–35 feet	30–50 feet	Over 50 feet	30–50 feet	20–35 feet	10–25 feet	Under 15 feet	Sands [3]	Sandy loams [4]	Fine-textured soils [5]	Sands [3]	Sandy loams [4]	Fine-textured soils [5]	Low wet soils	
Hardwoods:																		
Cottonwood (*Populus* sp.)	1					X					Ga	Fb	Fb	G	G	F+	G	a Keep off dunes. b Will be short-lived.
European white willow (*Salix alba* L.)	2					X					—	—	—	—	—	—	G	
Dwarf Asiatic elm (*Ulmus pumila* L.)	3				X		X				F	G	G	F	G	G	F	
American elm (*Ulmus americana* L.)	4				X		X				F	G	F	F	G	G	G	
Golden willow (*Salix alba vitellina* (L.) Stokes)	5				X		X				a	a	—	a	a	—	G	a Could be used where water table is within 10 feet.
Honeylocust (*Gleditsia triacanthos* L.)	6				X		X				—	E	E	E	E	E	E	Use only in south half of State.
Hackberry (*Celtis occidentalis* L.)	7				X		X				G	G	G	G	G	G	G	
Green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.).	8				X		X				G	G	G	G	G	G	G	
Bur oak (*Quercus macrocarpa* Michx.)	9				X		X				E	E	E	E	E	E	E	
Conifers:																		
Ponderosa pine (*Pinus ponderosa* Laws.)	10			X				X			G–	G–	F	G–	G	F	—	Ordinarily use not more than 2 rows; keep 10 feet from adjoining rows of hardwoods.
Scotch pine (*Pinus sylvestris* L.)	11			X							E	E	E	E	E	E	E	Use experimentally till good seed source is found. Keep 10 feet from adjoining rows of hardwoods.
Blue spruce (*Picea pungens* Engelm.)	12			X							—	F+	F	—	F+	F+	F	Keep 10 feet from adjoining rows of hardwoods.
Douglas fir (*Pseudotsuga taxifolia* (La M.) Britt.).	13			X							E	E	E	E	E	E	E	Do.
Eastern red cedar (*Juniperus virginiana* L.)	14			X				X			F+	G	G	G	G	G	E	Ordinarily use not over 2 rows; keep 10 feet from adjoining rows of hardwoods.
Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.).	15			X				X			F+	G	G	G	G	G	E	Do.
Tall shrubs:																		
Laurel willow (*Salix pentandra* L.)	16		X						X		a	a	—	a	a	—	G	a Could be used where water table is within 10 feet.
Russian-olive (*Elaeagnus angustifolia* L.)	17		X						X		G–	G	G	G	G	G	G	
Buffaloberry (*Shepherdia argentea* Nutt.)	18		X						X		E	G	G	E	G	G	—	Suckering sometimes considered objectionable.
Siberian pea-tree (*Caragana arborescens* Lam)	19		X						X		—	G	G	—	G	G	—	
Choke cherry (*Prunus virginiana* L.)	20		X						X		Ga	G	G	Ga	G	G	G	a Possibly should use seed collected from parent trees growing on sand.
Serviceberry (*Amelanchier canadensis* (L.) Medicus).	21		X						X		E	E	E	E	E	E	E	
Hawthorn (*Crataegus* sp.)	22		X						X		E	E	E	E	E	E	E	Keep away from red cedars because of cedar apple rust.
Wild plum (*Prunus americana* Marsh.)	23		X						X		F	F	F–	F	F	F	G	Use only in short sections of 3 or 4 dozen plants.
Low shrubs:																		
Tatarian honeysuckle (*Lonicera tatarica* L.)	24	X								X	E	G	G	E	G	G	E	
Nannyberry (*Viburnum lentago* L.)	25	X								X	E	E	E	E	E	E	E	
Lilac (*Syringa* sp.)	26	X								X	F	G	G	F	G	G	E	Particularly desirable for appearance value.
Western snowberry (*Symphoricarpos occidentalis* Hook.)	27	X								X	E	E	E	E	E	E	E	
		North or east	Orientation							South or west								

[1] From center line of shelterbelt outward, any species having a larger number in this column will be planted in 1 or more rows outside the row or rows of any species having a smaller number. Ordinarily 1 or more species will be selected from each of the 4 groups indicated in the first column.

[2] Meaning of symbols: G, good adaptation to soil indicated; F, fair; E, for experimental use in very small amount; —, poor, do not use; + or –, somewhat better or poorer than letter rating. Small letters refer to remarks in same line in last column. It is assumed that the following soils will be avoided, except experimentally: Coarse droughty gravels, claypan soils, undrained alkaline basins (buffalo wallows), shale-derived upland soils along Missouri River.

[3] Includes sands, loamy sands, and loamy fine sands.

[4] Includes sandy loams and fine sandy loams.

[5] Includes all soils of finer texture than the above; i. e., very fine sandy loams, loams, silt loams, silty clay loams, clay loams, clays.

TABLE 4.—*Recommended tree and shrub species, their arrangement in shelterbelts, and their adaptation to soils*

SOUTH DAKOTA

Group and species	Sequence of rows [1]	Approximate height and position in shelterbelt									Adaptation to soil classes [2]							Remarks
											Uplands			Terraces			Low wet soils	
		Under 15 feet	10–25 feet	20–35 feet	30–50 feet	Over 50 feet	30–50 feet	20–35 feet	10–25 feet	Under 15 feet	Sands [3]	Sandy loams [4]	Fine-textured soils [5]	Sands [3]	Sandy loams [4]	Fine-textured soils [5]		
Hardwoods:																		
Cottonwood (*Populus* sp.)	1					X					Ga	Fb	Fb	G	G	F+	G	a Keep off dunes. b Could be used as temporary row or 2 on uplands.
European white willow (*Salix alba* L.)	2					X					—	—	—	—	—	—	G	
Dwarf Asiatic elm (*Ulmus pumila* L.)	3				X		X				Fa	G	G	G	G	G	G	a Keep off dunes.
American elm (*Ulmus americana* L.)	4				X		X				Fa	G	F	F	G	G	G	Do.
Hackberry (*Celtis occidentalis* L.)	5				X		X				G	G	G	G	G	G	G	
Honeylocust (*Gleditsia triacanthos* L.)	6				X		X				F–	F–	F	G	F+	F	G	Use sparingly in northern half of State.
Green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.)	7				X		X				—	Fa	Fa	G	G	G	G	a Use not more than 2 to 4 rows on uplands because of possible borer damage.
Black walnut (*Juglans nigra* L.)	8				X		X				—	Ea	Ea	—	F	F+	F+	a Use only in eastern half of shelterbelt zone, occasionally elsewhere in rich soils.
Bur oak (*Quercus macrocarpa* Michx.)	9				X		X				E	E	E	E	E	E	E	Use only in small quantities until it can be propagated successfully.
Conifers:																		
Ponderosa pine (*Pinus ponderosa* Laws.)	10			X				X			G–	G–	F	G–	G	F	—	Ordinarily use not more than 2 rows; keep 10 feet from adjoining rows of hardwoods.
Scotch pine (*Pinus sylvestris* L.)	11			X							E	E	E	E	E	E	E	Use experimentally until good seed source is found. Keep 10 feet from adjoining rows of hardwoods.
Austrian pine (*Pinus nigra austriaca* Schneid.)	12			X							E	E	E	E	E	E	E	Do.
Blue spruce (*Picea pungens* Engelm.)	13			X							—	F	F	—	F+	F+	F+	Use not more than 1 row. Keep 10 feet from hardwood rows.
Eastern red cedar (*Juniperus virginiana* L.)	14			X				X			F+	G	G	G	G	G	G	Ordinarily use not over 2 rows. Keep 10 feet from hardwood rows.
Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.)	15			X				X			F+	G	G	G	G	G	G	Do.
Tall shrubs:																		
Russian mulberry (*Morus alba tatarica* (L.) Loudon).	16		X						X		F+	G	F	G	G	G	G	Use only in southern one-third of State.
Russian-olive (*Elaeagnus angustifolia* L.)	17		X						X		G–	G	G	G	G	G	G	
Buffaloberry (*Shepherdia argentea* Nutt.)	18		X						X		E	G	G	E	G	G	—	Suckering sometimes objectionable.
Siberian pea-tree (*Caragana arborescens* Lam.).	19		X						X		—	G	G	—	G	G	—	
Choke cherry (*Prunus virginiana* L.)	20		X						X		G	G	G	G	G	G	G	
Serviceberry (*Amelanchier canadensis* (L.) Medicus).	21		X						X		E	E	E	E	E	E	E	
Hawthorn (*Crataegus* sp.)	22		X						X		E	E	E	E	E	E	E	Use not more than 1 row; keep away from cedar because of cedar apple rust.
Wild plum (*Prunus americana* Marsh.)	23		X						X		F	F	F–	F	F	F	G	
Low shrubs:																		
Tatarian honeysuckle (*Lonicera tatarica* L.)	24	X								X	E	G	F	E	G	G	F+	
Nannyberry (*Viburnum lentago* L.)	25	X								X	E	E	E	E	E	E	E	
Lilac (*Syringa* sp.)	26	X								X	F	G	G	G	G	G	G	Use mainly for appearance value in clumps or short sections.
Western snowberry (*Symphoricarpos occidentalis* Hook.).	27	X								X	E	E	E	E	E	E	E	
Sumac (*Rhus* sp.)	28	X								X	E	E	E	E	E	E	E	
		North or east	Orientation							South or west								

[1] From center line of shelterbelt outward, any species having a larger number in this column will be planted in 1 or more rows outside the row or rows of any species having a smaller number. Ordinarily 1 or more species will be selected from each of the 4 groups indicated in the first column.

[2] Meaning of symbols: G, good adaptation to soil indicated; F, fair; E, for experimental use in very small amount; —, poor, do not use; + or –, somewhat better or poorer than letter rating. Small letters refer to remarks in same line in last column. It is assumed that the following soils will be avoided, except experimentally: Coarse droughty gravels, claypan soils, undrained alkaline basins (buffalo wallows), shale-derived upland soils along Missouri River.

[3] Includes sands, loamy sands, and loamy fine sands.

[4] Includes sandy loams and fine sandy loams.

[5] Includes all soils of finer texture than the above; i. e., very fine sandy loams, loams, silt loams, silty clay loams, clay loams, clays.

TABLE 5.—*Recommended tree and shrub species, their arrangement in shelter belts, and their adaptation to soils*

NEBRASKA

Group and species	Sequence of rows [1]	Approximate height and position in shelterbelt: Under 15 feet	10–25 feet	20–40 feet	30–50 feet	Over 50 feet	30–50 feet	20–40 feet	10–25 feet	Under 15 feet	Adaptation to soil classes [2]: Uplands: Sands [3]	Uplands: Sandy loams [4]	Uplands: Fine-textured soils [5]	Terraces: Sands [3]	Terraces: Sandy loams [4]	Terraces: Fine-textured soils [5]	Low wet soils	Remarks
Hardwoods:																		
Cottonwood (*Populus* sp.)	1					X					Fa	Fa	Fa	G+	G+	G	G+	a Can use on uplands as 1 or 2 temporary rows; do not use on upland hard lands south of Platte River.
European white willow (*Salix alba* L.)	2					X					—	—	—	G	G	G	G	
Dwarf Asiatic elm (*Ulmus pumila* L.)	3				X		X				G	G	G	G	G	G	E	
Honeylocust (*Gleditsia triacanthos* L.)	4				X		X				Fa	F	F	F	G	G	G	a Does fairly well on fine loamy sands; keep off pure sands.
American elm (*Ulmus americana* L.)	5				X		X				—	F	F	F	G	G	G	
Sycamore (*Plantanus occidentalis* L.)	6				X		X				—	—	—	—	E	E	E	
Coffeetree (*Gymnocladus dioicus* (L.) Koch)	7				X		X				—	—	—	—	E	E	E	
Hackberry (*Celtis occidentalis* L.)	8				X		X				G	G	G	G	G	G	G	
Green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.).	9				X		X				—	Fa	Fa	G	G	G	G	a Subject to borer damage especially in western half of State; use not more than 2 rows on uplands.
Black walnut (*Juglans nigra* L.)	10				X		X				—	(a)	(a)	—	F+	F+	F+	a Could use in small amounts on uplands in eastern half of shelterbelt zone.
Black locust (*Robinia pseudoacacia* L.)	11				X		X				—	—	—	F+	G	F+	G	Subject to severe borer damage on uplands; good for gully planting.
Hardy catalpa (*Catalpa speciosa* Warder)	12				X		X				—	—	—	F	F+	F+	G	Use only in southern one-third of State.
Bur oak (*Quercus macrocarpa* Michx.)	13				X		X				E	E	E	E	E	E	E	
Osage-orange (*Toxylon pomiferum* Raf.)	14				X		X				—	F	F	—	G	G	G	Use sparingly on uplands and in northern half of State.
Russian mulberry (*Morus alba tatarica* (L.) Loudon)	15				X		X				F	F	F	G	G	G	G	
Conifers:																		
Ponderosa pine (*Pinus ponderosa* Laws)	16			X				X			F+	F+	F	G	G	F+	—	Ordinarily 2 rows are enough; keep 10 feet from adjoining rows of hardwoods.
Scotch pine (*Pinus sylvestris* L.)	17			X				X			E	E	E	E	E	E	E	Use experimentally until good seed source is found. Keep 10 feet from adjoining rows of hardwoods.
Austrianpine (*Pinus nigra austriaca* Schneid)	18			X				X			—	F	F	—	F+	F+	E	Keep 10 feet from adjoining hardwoods.
Limber pine (*Pinus flexilis* James)	19			X							E	E	E	E	E	E	E	Use Nebraska seed. Otherwise as above.
Blue spruce (*Picea pungens* Engelm.)	20			X							—	F	F	—	F+	F+	F	Use not more than 1 row. Otherwise as above.
Eastern red cedar (*Juniperus virginiana* L.)	21			X				X			G	G	G	G	G	G	E	Ordinarily use not more than 2 rows. Otherwise as above.
Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.)	22			X				X			G	G	G	G	G	G	E	Do.
Tall shrubs:																		
Golden willow (*Salix alba vitellina* (L.) Stokes).	23		X						X		—	—	—	—	—	—	G	
Russian-olive (*Elaeagnus angustifolia* L.)	24		X						X		F+	G	G	G	G	G	G	
Siberian pea-tree (*Caragana arborescens* L.)	25		X						X		—	G	G	—	G	G	—	Good especially in northern half of State.
Choke cherry (*Prunus virginiana* L.)	26		X						X		G	G	G	G	G	G	G	Spreads by suckering; valuable for gully planting.
Buffaloberry (*Shepherdia argentea* Nutt.)	27		X						X		E	E	E	E	E	E	—	Suckering sometimes objectionable.
Nannyberry (*Viburnum lentago* L.)	28		X						X		—	—	—	—	E	E	E	
Serviceberry (*Amelanchier canadensis* (L.) Medicus).	29		X						X		E	E	E	E	E	E	E	
Low shrubs:																		
Hawthorn (*Crataegus* sp).	30	X								X	E	E	E	E	E	E	E	Use not over 1 row; is host to cedar apple rust. Keep away from cedar.
Wild plum (*Prunus americana* Marsh.)	31	X								X	G	G	G	G	G	G	G	Use for appearance value at ends of rows, near roads, etc.
Lilac (*Syringa* sp.)	32	X								X	F+	G	G	F+	G	G	E	
Western snowberry (*Symphoricarpos occidentalis* Hook.).	33	X								X	E	E	E	E	E	E	E	
Sumac (*Rhus* sp.)	34	X								X	E	F	F	E	F	F	E	Use at ends of rows, near roads, gates, etc.
		North or east	Orientation							South or west								

[1] From center line of shelterbelt outward, any species having a larger number in this column will be planted in 1 or more rows outside the row or rows of any species having a smaller number. Ordinarily 1 or more species will be selected from each of the 4 groups indicated in the first column.

[2] Meaning of symbols: G, good adaptation to soil indicated; F, fair; E, for experimental use in very small amount; ——, poor, do not use; + or –, somewhat better or poorer than letter rating. Small letters refer to remarks in same line in last column. It is assumed that the following soils will be avoided, except experimentally: Coarse droughty gravels, claypan soils, undrained alkaline basins (buffalo wallows), shale-derived upland soils along Missouri River.

[3] Includes sands, loamy sands, and loamy fine sands.

[4] Includes sandy loams and fine sandy loams.

[5] Includes all soils of finer texture than the above; i. e., very fine sandy loams, loams, silt loams, silty clay loams, clay loams, clays.

TABLE 6.—*Recommended tree and shrub species, their arrangement in shelterbelts, and their adaptation to soils*

KANSAS

Group and species	Sequence of rows [1]	Approximate height and position in shelterbelt									Adaptation to soil classes [2]							Remarks
											Uplands			Terraces			Low wet soils	
		Under 15 feet	10–25 feet	20–40 feet	30–50 feet	Over 50 feet	30–50 feet	20–40 feet	10–25 feet	Under 15 feet	Sands [3]	Sandy loams [4]	Fine-textured soils [5]	Sands [3]	Sandy loams [4]	Fine-textured soils [5]		
Hardwoods:																		
Cottonwood (*Populus* sp.)	1					X					Fa	Fa	—	F+	F+	F+	G	a Does fairly well on uplands in eastern part of shelterbelt zone.
English elm (*Ulmus campestris* L.)	2				X		X					E	E	E	E	E	E	
Dwarf Asiatic elm (*Ulmus pumila* L.)	3				X		X				F+	G	G	F+	G	G	E	
Hackberry (*Celtis occidentalis* L.)	4				X		X				G	G	G	G	G	G	G	
Coffeetree (*Gymnocladus dioicus* (L.) Koch.)	5				X		X				—	E	E	—	F	F	F	
Honeylocust (*Gleditsia triacanthos* L.)	6				X		X				E	G	G	E	G	G	G	
American elm (*Ulmus americana* L.)	7				X		X				E	F−	F	E	F+	F+	F+	
Sycamore (*Plantanus occidentalis* L.)	8				X		X				—	—	—	—	F	F	F	
Russian mulberry (*Morus alba tatarica* (L.) Loudon).	9				X		X				E	G	G	F	G	G	E	
Black locust (*Robinia pseudoacacia* L.)	10				X		X				a	a	—	F	F	F	G	a Can be used sparingly on uplands in southeast part of zone; use liberally in gully planting.
Green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.).	11				X		X				—	a	a	—	F	F	G	a Could be used to some extent in eastern half of zone. Borer damage usually severe on uplands.
Black walnut (*Juglans nigra* L.)	12				X		X				—	E	E	—	F	F	F	
Ailanthus (*Ailanthus altissima* (Mill.) Swingle).	13				X		X				E	F−	F−	E	F	F	E	
Hardy catalpa (*Catalpa speciosa* Warder)	14				X		X				—	a	—	F	F+	F+	F	a Could be used in eastern half of zone wherever water table is close to surface.
Bur oak (*Quercus macrocarpa* Michx.)	15				X		X				E	E	E	E	E	E	E	
Osage-orange (*Toxylon pomiferum* Raf.)	16				X		X				E	G	G	F	G	G	G	
Apricot (*Prunus* sp.)	17				X		X				E	G	G	E	G	G	E	
Pecan (*Hicoria pecan* (Marsh.) (Britt.)	18				X		X				—	E	E	—	E	E	E	Use only in southeast part of zone.
Western soapberry (*Sapindus drummondii* H. and A.).	19				X		X				F+	F	F	G	F+	F+	G	Use only in southern one-third of State.
Conifers:																		
Ponderosa pine (*Pinus ponderosa* Laws.)	20			X							F	F	E	F	F	E	—	Ordinarily 1 row is enough; keep 10 feet from adjoining rows of hardwoods.
Austrian pine (*Pinus nigra austriaca* Schneid.	21			X							E	E	E	E	E	E	E	Do.
Eastern red cedar (*Juniperus virginiana* L.).	22			X				X			F	G	G	G	G	G	E	Ordinarily use not over 2 rows; keep 10 feet from adjoining rows of hardwoods.
Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.).	23			X				X			F	G	G	G	G	G	E	Do.
Tall shrubs:																		
Redbud (*Cercis canadensis* L.)	24		X						X		—	F	F	—	F+	F+	E	
Russian-olive (*Elaeagnus angustifolia* L.)	25		X						X		F+	G	G	G	G	G	G	
Wild plum (*Prunus americana* Marsh.)	26		X						X		—	F	F	—	F	F	F	
Choke cherry (*Prunus virginiana* L.)	27		X						X		G	G	G	G	G	G	G	Good for gully planting because of suckering.
Tamarisk (*Tamarix* sp.)	28		X						X		G	G	G	G	G	G	G	Use sparingly in north half of State.
Roughleaf dogwood (*Cornus asperifolia* Michx.)	29		X						X		—	F	F	F	F	F	G	
Low shrubs:																		
American elder (*Sambucus canadensis* L.)	30	X								X	—	—	—	—	F−	F−	F+	
Lilac (*Syringa* sp.)	31	X								X	E	G	G	E	G	G	E	Use for appearance value near roads, gates, ends of rows.
Slender golden currant (*Ribes aureum* Pursh.)	32	X								X	E	G	G	E	G	G	G	
Lemonade sumac (*Rhus trilobata* Nutt.)	33	X								X	E	F	F	F	F	F	E	Do.
Sand plum (*Prunus angustifolia watsonii* Waugh.)	34	X								X	G+	G+	F	G+	G+	F	—	
		North or east	Orientation							South or west								

[1] From center line of shelterbelt outward, any species having a larger number in this column will be planted in 1 or more rows outside the row or rows of any species having a smaller number. Ordinarily 1 or more species will be selected from each of the 4 groups indicated in the first column.

[2] Meaning of symbols: G, good adaptation to soil indicated; F, fair; E, for experimental use in very small amount; ——, poor, do not use; + or −, somewhat better or poorer than letter rating. Small letters refer to remarks in same line in last column. It is assumed that the following soils will be avoided, except experimentally: Coarse gravel soils, undrained basins (buffalo wallows), shale-derived clays, alkaline basins, claypan soils.

[3] Includes sands, loamy sands, and loamy fine sands.

[4] Includes sandy loams and fine sandy loams.

[5] Includes all soils of finer texture than the above; i. e., very fine sandy loams, loams, silt loams, silty clay loams, clay loams, clays.

TABLE 7.—*Recommended tree and shrub species, their arrangement in shelterbelts, and their adaptation to soils*

TEXAS AND OKLAHOMA

Group and species	Sequence of rows [1]	Approximate height and position in shelterbelt: Under 15 feet	10–25 feet	20–40 feet	30–50 feet	Over 50 feet	30–50 feet	20–40 feet	10–25 feet	Under 15 feet	Adaptation to soil classes [2]: Uplands: Sands [3]	Uplands: Sandy loams [4]	Uplands: Fine-textured soils [5]	Terraces: Sands [3]	Terraces: Sandy loams [4]	Terraces: Fine-textured soils [5]	Low wet soils	Remarks
Hardwoods:																		
Cottonwood (*Populus* sp.)	1					X					Fa	Fa	—	F	G	G+	G	a Use 3 rows throughout Oklahoma part of shelterbelt zone.
Sycamore (*Plantanus occidentalis* L.)	2				X		X				—	F	F	F	F+	F+	F+	
Dwarf Asiatic elm (*Ulmus pumila* L.)	3				X		X				F	G	G	G	G	G	E	Subject to cotton-root rot infection.
Honeylocust (*Gleditsia triacanthos* L.)	4				X		X				E	G	G	F+	G	G	G	
American elm (*Ulmus americana* L.)	5				X		X				E	F+	F+	F+	F+	F+	F+	
Russian mulberry (*Morus alba tatarica* (L.) Loud.)	6				X		X				F	G	G	F	G	G	F	Do.
Paloblanco (*Celtis reticulata* Torr.)	7				X		X				G	G	G	G	G	G	G	
Osage-orange (*Toxylon pomiferum* Raf.)	8				X		X				F–	G	F+	F+	G	G	E	
Black locust (*Robinia pseudoacacia* L.)	9			X				X			a	a	—	F+	G	F	F	a Can be used on uplands if water table is within 15 feet. Borer damage very prevalent.
Hardy catalpa (*Catalpa speciosa* Warder)	10			X				X			—	—	—	E	F+	F+	G	
Chinese elm (*Ulmus parvifolia* Jacq.)	11			X				X			G	G	G	G	G	G	E	
Black walnut (*Juglans nigra* L.)	12			X				X			—	F	F	—	F+	F+	E	
Little walnut (*Juglans rupestris* Engelm.)	13			X				X			—	F	F	—	F+	F+	E	
Green ash (*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.).	14			X				X			—	F+	F	—	F+	F+	F+	
Ailanthus (*Ailanthus altissima* (Mill.) Swingle).	15			X				X			E	F	E	F	F+	F+	E	Suckering sometimes objectionable.
Coffeetree (*Gymnocladus dioicus* (L.) Koch)	16			X				X			—	—	—	—	F+	F+	E	
Pecan (*Hicoria pecan* (Marsh.) Britt.)	17			X				X			—	E	E	—	E	E	E	
Post oak (*Quercus stellata* Wang.)	18			X				X			E	E	E	E	E	E	E	
Conifers:																		
Austrian pine (*Pinus nigra austriaca* Schneid.).	19			X				X			E	E	E	E	E	E	E	
Ponderosa pine (*Pinus ponderosa* Laws.)	20			X				X			F	F+	F	F+	F+	F	—	Ordinarily use not over 1 row.
Scotch pine (*Pinus sylvestris* L.)	21			X				X			E	E	E	E	E	E	E	
Arizona cypress (*Cupressus arizonica* Greene)	22			X				X			E	G	G	E	G	G	E	Keep south of latitude of Wellington, Tex.
Eastern red cedar (*Juniperus virginiana* L.)	23			X				X			G	G	G	G	G	G	E	
Rocky Mountain red cedar (*Juniperus scopulorum* Sarg.).	24			X				X			G	G	G	G	G	G	E	
One-seed juniper (*Juniperus monosperma* (Engelm.) Sarg.).	25			X				X			F+	G	G	F+	G	G	E	
Redberry juniper (*Juniperus pinchotii* Sudw.).	26			X				X			G	G	G	G	G	G	E	
Oriental arborvitæ (*Thuja orientalis* L.)	27		X						X		E	F	F	E	F	F	E	
Tall shrubs:																		
Apricot (*Prunus* sp.)	28		X						X		E	G	G	E	G	G	E	
Redbud (*Cercis canadensis* L.)	29		X						X		E	F+	F	F	G	G	E	
Western soapberry (*Sapindus drummondii* H. and A.).	30		X						X		G	G	F+	G	G	G	G	
Gum elastic (*Bumelia lanuginosa* (Michx.) Pers.).	31		X						X		—	—	—	F	F	F	E	
Texas pistache (*Pistacia texana* Swingle)	32		X						X		E	E	E	E	E	E	E	Subject to cotton-root rot infection.
Russian-olive (*Elaeagnus angustifolia* L.)	33		X						X		F+	G	G	G	G	G	G	
Roughleaf dogwood (*Cornus asperifolia* Michx.).	34		X						X		E	E	E	F+	F+	F+	E	
Low shrubs:																		
Desertwillow (*Chilopsis linearis* (Cavanilles de Candolle).	35	X								X	E	G	G	E	G	G	—	
Tamarisk (*Tamarix gallica* L.)	36	X								X	G	G	G	G	G	G	G	
Lilac (*Syringa* sp.)	37	X								X	F+	G	G	G	G	G	E	Do.
Hawthorn (*Crataegus* sp.)	38	X								X	E	E	E	E	E	E	E	
Chickasaw plum (*Prunus angustifolia* Marsh.).	39	X								X	F–	F	F	F+	F+	F+	E	
Sumac (*Rhus* sp.)	40	X								X	E	F	F–	G–	G+	F+	E	
Coralberry (*Symphoricarpos orbiculatus* Muench.).	41	X								X	—	E	E	E	F+	F+	E	
		North or east	Orientation							South or west								

[1] From center line of shelterbelt outward, any species having a larger number in this column will be planted in 1 or more rows outside the row or rows of any species having a smaller number. Ordinarily 1 or more species will be selected from each of the 4 groups indicated in the first column.

[2] Meaning of symbols: G, good adaptation to soil indicated; F, fair; E, for experimental use in very small amount: ——, poor, do not use; + or –, somewhat better or poorer than letter rating. Small letters refer to remarks in same line in last column. It is assumed that the following soils will be avoided, except experimentally: Coarse gravel soils, undrained basins (buffalo wallows), shale-derived clays, alkaline basins, claypan soils.

[3] Includes sands, loamy sands, and loamy fine sands.

[4] Includes sandy loams and fine sandy loams.

[5] Includes all soils of finer texture than the above; i. e., very fine sandy loams, loams, silt loams, silty clay loams, clay loams, clays.

In using the tables, the field man must first determine the soil group with which he is concerned, after which he will usually select one or more species from each of the four groups (column 1)—hardwoods, conifers, tall shrubs, and low shrubs. Selections will be limited mostly to species given ratings of G or F+. If possible, a wide variety of species should be used. Ordinarily no one species should make up more than 50 percent—preferably not more than 30 percent—of the total number of trees planted.

The table can be used for shelterbelts with a range in width from 3 to 30 rows, although the usual number of rows will vary between 10 and 20, depending on the total width of the strip of land available, the spacing of the trees, and the function of the shelterbelt.

Arrangement of species in the cross section of the shelterbelt is shown by a system of crosses (X), supplemented by a column of numbers. The positions of each species as indicated were determined largely from a knowledge of what the ultimate height of each will be under a given set of soil and moisture conditions.

A pictorial cross section of a typical 8-rod shelterbelt, showing the relative positions and heights of hardwoods, conifers, and shrubs, is given in figure 5.

Among the factors to be considered in selecting species which appear in the table, besides climatic and soil adaptability, are the following:

1. Silvical value.
   Ultimate height, density (value as windbreak), amount of leaf litter produced, growth rate through entire life of tree, longevity, wind firmness, resistance to wind breakage, tolerance, moisture requirement, ease of establishment in difficult years, susceptibility to sleet and hail damage, snow breakage (in northern half of zone), and sand cutting and degree of protection needed for survival and growth.
2. Economic value.
   Value of wood as fence posts, lumber, or fuel; edible fruit, berries, or nuts produced; value as a snow fence.
3. Susceptibilty to damage.
   By insects, including borers, defoliators, bark beetles, blister beetles, tip moths, and others.
   By diseases; a species may itself be susceptible to a certain disease, and it may also be an alternate host for some disease of cereals, fruit trees, etc.
   By rodents, such as rabbits and gophers.
4. Aesthetic value.
   Certain species used in combination are valued for their beautiful appearance. This point should be given special consideration along roads, at park or forest entrances, and around buildings.
5. Value as cover and food for wildlife.
6. Cost of producing planting stock.
7. Years of maintenance necessary before cultivation can be dispensed with.
8. Special values.
   In gully-control work, species such as black locust and chokecherry are valuable because they grow fast, root deeply, are excellent soil binders, and spread by suckering.

COLLECTION OF SEED

Throughout the shelterbelt zone, there are many people who supplement their farm income by collecting seed for nurseries and seed dealers. A new source of income will be opened to such persons by the shelterbelt project. Personnel will be employed for seed collection as required. By establishing a few central depots, a large quantity of seed can be collected at minimum cost.

Since nearly all of the species to be used produce seed in the fall, most of the collection work will be done in the fall and winter. Exceptions are American elm, dwarf Asiatic elm, apricot, and caragana. Seed of these species must be collected when ripe in the spring or early summer, since the seed does not remain on the trees.

Germination tests for the purpose of determining the amount of viable seed on hand and the quantity to be sown in the nursery will be made. Such tests will be made in sufficient detail to determine also for the several species the differences in viability between seed lots collected in separate localities or from representative trees. Through this information it will be possible to determine where to collect the best seed. Extraction or cleaning of the seed will be done at the centrally located seed stations. This may best be handled in connection with winter storage of the seed prior to sowing. In order to obtain satisfactory germination in the seed bed, it is necessary to stratify (layer in moist sand over winter) the following: Hackberry, bur oak, walnut, apricot, soapberry, mulberry, Russian-olive, choke cherry, hawthorn, buffaloberry,

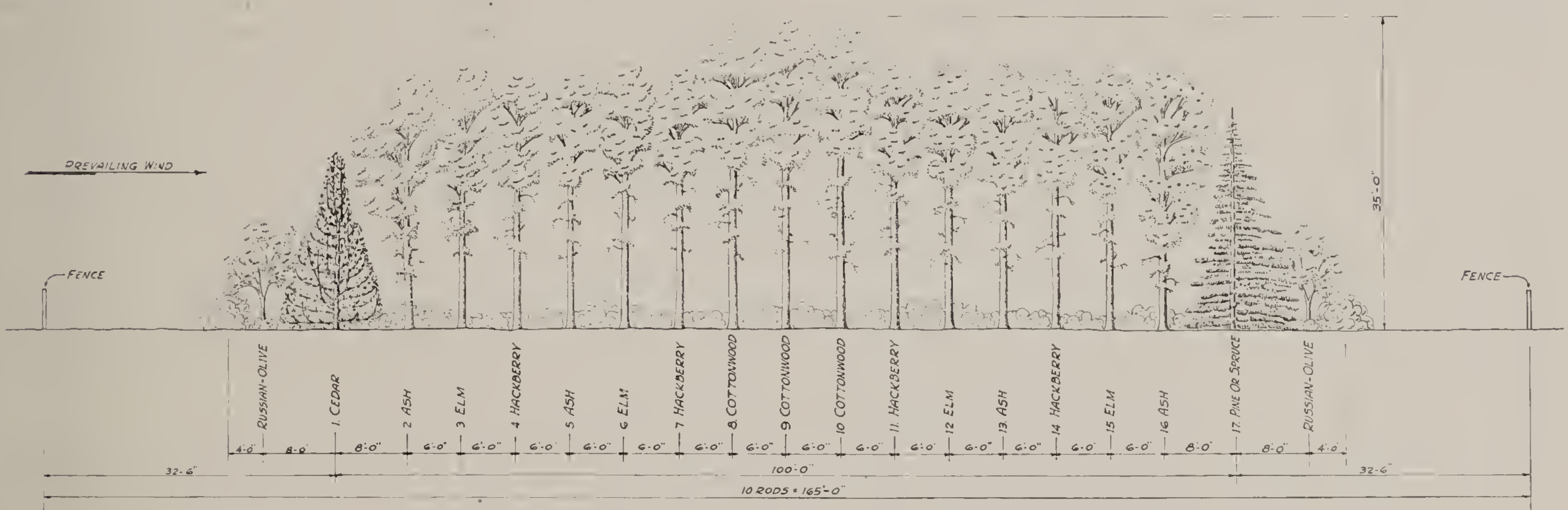

FIGURE 5.—Cross section of 17-row shelterbelt on 8-rod strip, with sand trap and roadway on either side.

and juniper. Storage at a constant temperature for a definite length of time is desirable for some species, particularly juniper. In the absence of prior treatment of such seed, germination in the seed bed is irregular, and an additional year is required in growing the stock.

The seed used will be mostly from native trees of good form and of known climatic adaptation. Species introduced for experimental purposes will not be used on a large scale until they have been proved suitable for shelterbelt planting. Latitudinal limitations will be observed in the movement of seed from one locality to another, in order to retain the adaptation a species has acquired for a particular environment. In many cases localized collection of seed and planting of trees grown from it will be advisable.

It has nevertheless been found necessary to go outside the zone to secure a part of the seed, particularly of Chinese elms. Careful study has been given climatic conditions under which parent stock is growing, and those sources where conditions are not comparable to the ultimate location of the trees have been eliminated.

GROWING NURSERY STOCK

As a measure of efficiency and economy, full use will be made of available facilities in existing commercial nurseries. Fully developed land will be leased and will be placed under the care of nurserymen employed by the Forest Service for that purpose. Under this arrangement all operations—sowing, cultivation, irrigation, digging, and storing—will be under direct Government supervision. The importance of producing the best possible quality of planting stock justifies as complete control as can be maintained.

Nurseries outside the shelterbelt States except for rare exceptions will not be used, since the different growing conditions bring up additional problems of acclimatization, transportation of seed and stock, and supervision and overhead. The distribution of existing nurseries may not be entirely satisfactory, however, and the establishment of Government-owned nurseries may be necessary in some localities in order to eliminate excessive transportation costs. Also, it is probable that Government nurseries will be needed for the propagation of difficult species, particularly conifers, and at least one Government-owned nursery in each State is desirable in which to check costs and production of deciduous species in the commercial nurseries.

SIZE OF TREES TO BE PLANTED

The best size of deciduous-tree seedlings for the shelterbelt planting is 12 to 24 inches in height above the ground. Modifications will, of course, have to be made to suit local conditions. In the Southern States, Chinese elm 1-year stock, for example, will in some cases be more than double this size, owing to the long growing season. In that part of the region the problem will be to avoid excessive size. In the Dakotas, on the other hand, in order to obtain the desired size, it will be necessary to use 2-year seedlings of some species—for instance, green ash, American elm, hackberry, choke cherry, plum, and sumac.

Most evergreens will be produced for planting as either 2-year or 3-year stock throughout the entire shelterbelt zone. Even then they will average much smaller than the hardwood stock, rarely over 12 inches in height.

The 12- to 24-inch hardwood seedlings are desirable for shelterbelt planting because in this size the proper balance is usually obtained between roots and tops without pruning of either. When seedlings of this size are dug, the root system remains practically intact, without undue injury of any kind. Furthermore, the seedlings can be planted in the field much more rapidly and cheaply than those of other sizes. As seedlings grow older and larger, the roots spread out and when dug are mutilated or cut off, so that pruning of both roots and tops becomes necessary.

In general, it is safe to say that 1- to 2-year stock of this size will give 30 percent better survival than the larger 3- to 4-year seedlings. Root rots and other fungi often attack trees that are cut and mutilated, and eventually cause their death. It has also been observed that 12- to 24-inch seedlings will equal or exceed the larger seedlings in size at the end of several seasons' growth, a result which follows because the larger seedlings must necessarily recover from the shock of pruning and must also develop a new system of feeder roots before substantial top growth can take place.

Direct seeding of some species such as the walnuts and oaks has proved a successful means of establishing trees in parts of the region. These species develop strong tap roots in the nursery and are generally difficult to transplant as seedlings.

The use of cuttings will be limited to the propagation of low shrubs in cases where seeding is impracticable.

TIME REQUIRED TO ESTABLISH SHELTERBELTS

About 85 percent of the trees to be planted are of hardwood species, which are inherently capable of faster growth than those of the coniferous species making up the remaining small percentage. Even 3 years after planting in the shelterbelt, the faster growing species will often reach a height of 4 to 6 feet, sufficient to impede alike the movement of drifting snow and of soil. After 5 years, species such as dwarf Asiatic elm, cottonwood, green ash, and caragana, even in the rigorous climate of the extreme North, may be expected to attain a height of 8 to 14 feet and a crown spread of 4 to 6 feet, sufficient to break the force of the wind appreciably and to harbor bird life. Thus it may be safely predicted, on the basis of experience and observation, that at 5 years shelterbelts of the type planned will have become definitely established and will have achieved some degree of effectiveness, the trees being firmly rooted and their crowns sufficiently developed to form a nearly continuous canopy, sloping to the ground on each side of the shelterbelt. Cedars and shrubs of lower growth will be planted in the outside rows.

SPACING OF TREES

Spacing of trees within the belt will not necessarily be identical throughout the zone. Experiments conducted by the Northern Great Plains Field Station of the Bureau of Plant Industry at Mandan, N. Dak., show conclusively that, under the conditions of that section, a relatively close spacing is much superior to wide spacing. This conclusion is substantiated by field observations of groves planted by farmers in both North Dakota and South Dakota. In Nebraska and southward a slightly wider spacing is recommended.

In the Dakotas, interior rows of deciduous trees will be planted 4 to 6 feet apart in rows 8 to 10 feet apart; conifers and tall shrubs, 4 feet apart, in rows 8 to 10 feet apart; low shrubs (in outside rows) will be 2 to 4 feet apart in rows 8 feet apart.

From Nebraska southward through Kansas and Oklahoma and into Texas, interior rows of deciduous trees will be planted 4 to 6 feet apart in rows 8 to 12 feet apart; conifers, 4 to 6 feet apart in rows 10 to 12 feet apart; tall shrubs, 4 feet apart in rows 8 to 10 feet apart; low shrubs, 2 to 4 feet apart in rows 8 to 10 feet apart.

It has been observed that relatively close spacing usually assures, in a much shorter time than is required with wide spacing, a "forest cover" condition, in which the competition of grass and weeds inside the grove is reduced to a minimum by the closed crown canopy and the mulch of leaves and litter formed on the ground. The sooner the crowns of the trees begin to interlace, the sooner cultivation of interior rows, which is an item of appreciable cost, can be dispensed with. The outside of the strips will, in many instances, have to be cultivated for the entire life of the grove.

One of the most important factors in attaining a mulch of leaves and forest litter is the establishment of several outside rows of dense, low shrubby growth of species like caragana or choke cherry. This is absolutely necessary if any considerable portion of the fallen material is to be retained in the grove; otherwise, leaves will be blown out by the wind, exposing the ground to evaporation and the invasion of weeds and grass whose presence will materially shorten the life of the trees.

CARE OF SHELTERBELTS

Trees in the Plains region must necessarily be treated as a crop. Experience has proved that under ordinary upland plains conditions they will not survive trampling by livestock or competition by grass or weeds. Fencing and cultivation are therefore a positive necessity.

The care of shelterbelts falls into three general classifications—fence maintenance, soil cultivation, and tree culture.

Fence maintenance will consist of replacement of posts, tightening of wire, and removal of tumble weeds. The latter may so increase wind pressure on fences as to cause pulling of wire and loosening of staples; they also present a dangerous fire hazard. Current inspection will be needed to prevent livestock from trespassing. It is hoped that replacement of posts will not be necessary for many years, since creosote-treated posts or those of durable species will be used.

Cultivation is extremely important in establishing shelterbelts and serves its best purpose when done as soon after heavy summer rains as it is possible to work the soil. Cultivation aerates the soil, puts it in better condition for holding soil moisture, and removes weed competition.

The close spacing specified for the shelterbelt as a means of quickly establishing a dense overhead of foliage precludes cultivation of the interior for longer than 3 or 4 years. Under ordinary conditions, the number of cultivations should be about 4, 3, 2, and 1 for years from the first to the fourth, successively. After the third or fourth year only conifers and the outside fallow strip will have to be cultivated. The latter should be given 1 or 2 thorough cultivations each year indefinitely, to prevent the encroachment of sod and weeds.

The spring-tooth harrow and the duck-foot cultivator have long been recognized as the most desirable implements for tree culture on the plains. The spring-tooth harrow is the better of the two, since, not running on wheels, it will pass under the low-growing limbs. The common single-disk harrow is objectionable because it leaves the soil in ridges piled against the rows of trees. Tandem disk harrows remove this objectionable feature.

From Nebraska south, the common cultivating implements cannot be used in less than 10-foot spacing. Consequently, narrower implements will have to be acquired especially for the shelterbelt work instead of depending on equipment available locally on farms.

If good nursery stock is used, and if planting is followed by a season of abundant moisture, the plantation thus established will require very little, if any, subsequent pruning. Under such conditions the tree will develop one main trunk and maintain it throughout its life. If, however, inferior planting stock is used, and if as a result of dry weather or rodent injury the trees sprout from below, a considerable amount of pruning will be required to maintain the shape and appearance of the tree. In general, the rule of pruning, applying only to the interior rows of tall-growing trees, should be to maintain one main trunk with a minimum of pruning. Natural pruning will dispose of the lower limbs as the trees grow in height. The low-growing trees and shrubs should not be pruned of side branches under any circumstances. It is often desirable, however, to trim the tops of such shrubs as caragana in order to stimulate development of additional sprouts and limbs, and thus assure a tighter hedge formation.

Tree culture will include removal of diseased and dead trees, and such measures as are necessary to prevent or control insect infestations or other pests. In some cases, thinning to release suppressed growth will be needed. This phase of the work will require special attention and supervision by technically trained men.

SPECIAL PROTECTIVE MEASURES

PROTECTION AGAINST LIVESTOCK

Farm animals will have valuable shelter and protection in the lee of shelterbelts, but not within them. Livestock damage has been a principal cause of premature deterioration in many of the earlier windbreaks and shelterbelts. Protection against livestock will be provided by fencing. Adequate preservative treatment of wood posts will be provided.

PROTECTION AGAINST RODENTS [2]

Protection of recently established shelterbelts against rodents, particularly jack rabbits, will be a problem of the first magnitude. These rabbits often cause severe damage to young trees of certain species, such as dwarf Asiatic elm, bur oak, cottonwood, and willows, by cutting them off at the ground or snow surface. They may completely girdle trees 10 or more years of age. Such damage generally is caused in winter and early spring, when the animals' usual food supply is scarcest.

Other rodent pests to be controlled in the shelterbelt zone are cottontail rabbits, pocket gophers, various species of mice, ground squirrels, and prairie dogs.

Control measures against rodent pests, where needed, will be along the following lines:

Organizing and carrying on rabbit drives.
Trapping.
Use of repellent sprays.
Use of poison sprays and baits. (In using these, extreme care will be exercised in order that domestic animals and desirable birds shall suffer an absolute minimum of loss.)

To use the various control measures most effectively, surveys will be conducted to determine relative populations of the various species in different parts of each State. Data are also needed on the extent of daily and seasonal movement of each species, in order to determine the distance to which control should extend on each side of the planted strips. Such data can be obtained by trapping or shooting all the rodents of a given species on an area of definitely known acreage.

Research work will also be necessary to develop sprays that will be repellent to rodents and still not be injurious to the young trees.

DISEASE PREVENTION AND CONTROL [3]

Prevention or control of disease is in some cases a critical factor in the successful development of trees. The most important pathological problems that can be foreseen in the beginning of the shelterbelt project are briefly summarized.

Coniferous seed-bed diseases.—Damping-off or root rot of coniferous seedlings may be disastrous. In general, adjustment of the acidity of the seed-bed soil has proved a satisfactory means of control. Aluminum sulphate or sulphuric acid applied at the time of sowing, or sulphur applied several weeks before sowing, has been effective in increasing the soil acidity to a point unfavorable to the growth of parasitic fungi. Usually the problem of acidification must be solved independently for each nursery site.

Red cedar seedling blight.—While eastern red cedar (*Juniperus virginiana*) seedlings are not seriously damaged by damping-off and root rot, they are frequently attacked by a blight caused by the fungus *Phomopsis juniperovora*, which commonly kills young seedlings and is generally more severe during moist seasons. In some years older trees are damaged. In its early stages the blight has been satisfactorily controlled by frequent applications of mercuric sprays. Once the blight becomes established, however, spraying has not been found so effective. Since the density of seedlings in the seed beds is an important factor in control of the blight, red cedar should not be grown at a density greater than 40 seedlings per square foot. The *Phomopsis* blight will probably be most severe from Nebraska southward.

Chinese elm root rot.—A rot of *Ulmus pumila* and *U. parvifolia* caused by *Chalaropsis thielavioides* has been found to result in considerable damage to the roots of these plants. The disease appears to originate in the seed beds and is generally intensified under storage or shipping conditions. Seedlings are the most severely damaged, although the roots of older trees are also infected and have caused some losses in field plantings. How much this root rot will influence survival in the shelterbelt plantings is at present unknown. Until further information is available as to its prevalence and its specific control, the roots of all dwarf Asiatic and Chinese elm seedlings will be dipped in a mercuric chloride solution (1 part of mercuric chloride to 500 parts of water) for 2 minutes prior to shipping the seedlings. It has been found that this treatment will hold the disease in check for approximately 10 days.

American elm wilt.—A wilt of *Ulmus americana* caused by a species of *Cephalosporium* appears to cause some damage, in Nebraska at least. Chinese elms are immune to this disease. No definite control measures are known other than the eradication of infected seedlings or trees.

Poplar canker.—A Cytospora canker holds a considerable threat to poplars throughout the shelterbelt zone. The most effective means of control is by the excision of the infected parts. If stem canker occurs on seedlings, they should be destroyed and burned as soon as possible.

Cedar apple rust.—It is well known that the so-called "cedars" (*Juniperus* spp.) are alternate host to the cedar apple rust. Since, however, the shelterbelts are not expected to traverse commercial apple-growing territory, it does not appear justifiable to restrict the use of the junipers to any large extent, although some restriction may be necessary in a few sections where home-grown apples are of importance. The rust is already present in some parts of the region and many planted cedars will probably become infected. While they will generally not be damaged seriously by the rust, the presence of the galls does reduce the growth rate of infected trees to some extent.

It is quite clear, however, that no other alternate hosts of the cedar apple rust should be used in the shelterbelt plantings with the cedars, such as hawthorn or wild crab apple. The use of such trees in close proximity to each other would be unwise and would probably lead to a considerable reduction in the growth rates of each host and a general intensification of the rust.

Buckthorn rust.—Buckthorn is an alternate host for the crown rust of oats. Studies by plant pathologists in North Dakota and South Dakota have shown that this rust is most abundant in regions of heaviest precipitation; hence the farther east the shelterbelts are planted, the more questionable will become the use of buckthorn. The fact that oats are not grown at present in an area should not in itself remove the question concerning the use of buskthorn, since certain

[2] By F. E. Garlough, Bureau of Biological Survey.
[3] By Ernest Wright, associate pathologist, Bureau of Plant Industry.

native grasses may also become infected and may in this way carry the rust from year to year.

Texas root rot.—That portion of the shelterbelt zone beginning about 50 miles north of the Red River and east of Jackson County, Okla., and extending thence south and west, is an area known to be sporadically infected with the Texas root rot. This rot attacks a great number of tree species and will probably cause serious losses in shelterbelt plantings unless precautions are taken. A few tree species are immune to infection, and some others are very resistant. Pending a thorough survey and mapping of the region affected, it is safer to use only immune or resistant species. Species known to be immune are hackberry, Osage-orange, and sycamore. Among resistant species are eastern red cedar and pecan, though the latter is susceptible in the seedling stage. There are in all probability many others in the immune or resistant class, but until the species situation is more fully tested out, planting in this area should proceed with caution.

The following are especially susceptible to infection and should not be used: Chinese and dwarf Asiatic elms, lilac, Russian mulberry, and *Pistacia*.

CONTROL OF INSECT PESTS

Among the more important insect pests that have been observed and reported in or near the shelterbelt zone are the following:

Leaf eaters: Cankerworms (*Alsophila* and *Paleacrita*), blister beetles (*Meloidae*), grasshoppers.

Cambium-wood insects: Locust borer (*Cyllene robiniae*), carpenter moth (*Prionoxystus robiniae*).

Sap-sucking insects : Aphids (*Aphididae*), cicada (*Tibicina septendecim*), scale (*Coccidae*).

Meristem insects of terminal parts: Pine tip moths (*Rhyacionia*).

Meristem insects feeding on root: White grubs (*Phyllophaga*).

Meristem insects of cambium region: Flathead borers (*Buprestidae*), roundhead borers (*Cerambycidae*), various bark beetles (*Scolytidae*).

The most serious problems will, as far as is known, be encountered with borers and with certain species which defoliate the trees. Control of the former will necessarily be accomplished mostly by silvicultural measures. The defoliators can be controlled by sprays and poison bait.

As shelterbelt planting advances there will be definite need of guidance by entomologists in determining other species of insect pests present in given areas, the magnitude and stage of infestation and practical control measures to be used. A thorough preliminary survey should be conducted to determine more exactly the present status of the insect problem.

Among measures that offer promise in the control of various insects are the following, some of which are also of value in controlling or minimizing possible damage from diseases:

Close inspection of all nursery stock.

Proper preparation of the planting site and cultivation of the young stand. This will give the trees a vigorous start and insure a larger measure of resistance to insect pests.

Use of a wide variety of species in each shelterbelt. Strips should ordinarily consist of from 3 to 8 species of trees. As already stated, ordinarily no one species should comprise more than 30 to 50 percent of the total number of trees in the shelterbelt.

Sparing use or entire elimination of certain species in planting areas where an insect pest is in an epidemic stage. Green ash, for example, shows severe damage from the carpenter worm in parts of South Dakota, Nebraska, and Kansas.

Selection of species that will grow most vigorously on a given planting site or soil type. It has been observed that black locust planted on dry upland sites in western Nebraska, Kansas, Oklahoma, and in the Texas Panhandle, is invariably severely damaged and often killed by the locust borer (*Cyllene robiniae*). When planted in low, moist sites, as along stream courses, gullies, and areas of shallow water table, it is much more vigorous and is less subject to borer attack, and the trees which are infested recover much more quickly.

Close spacing.—Less damage will occur from many insect infestations if a dense crown canopy excludes direct sunlight.

Periodic inspection of windbreaks, to detect sporadic infestations; taking the proper steps in control by use of sprays and poisons, or removing and burning infested material.

Introduction of parasites which are known to keep certain insects in check.

Encouragement of insectivorous birds.—The shelterbelts themselves, by providing nesting places, protection, and food, will unquestionably have a favorable influence on the population of insectivorous birds. Feeding of birds during severe winter weather can be resorted to.

Control of fire and grazing.—Since both fire and grazing weaken the resistance of trees, careful control should be maintained to prevent injury to the shelterbelt from these causes.

COSTS OF ESTABLISHING SHELTERBELTS

The cost of planting will vary widely according to the type of planting and according to local conditions existing at the time and place of planting. Costs will, further, be affected by conditions surrounding the production of nursery stock. Many new elements must be considered, concerning which there is relatively little exact information, such as land leases, fence construction, and various forms of protection. In general, the cost of field shelterbelt planting will be considerably higher than for either farmstead or block planting. Considering all three types, it is estimated that the average cost will be $30 per acre, including the production of nursery stock and the care of plantations, especially the field shelterbelts, for a period of 5 years after planting.

Section 5.—LAND ACQUISITION

By L. F. Kneipp, *assistant chief, Forest Service,* and A. A. Simpson, *in charge of Lands, Plains Shelterbelt Project, Forest Service*

CONTENTS

The lands of the shelterbelt zone, approximately 115,000 square miles in extent, may be classified, broadly, as follows:

1. Sandy, "light" soils, and fine-textured soils in areas of adequate rainfall, favorable for tree growth, 48 percent, or 54,800 square miles. The character and use of these soils is such as to justify the planting of typical field shelterbelts.
2. Fine-textured, "hard" soils, relatively unfavorable for tree growth, with only a limited supply of available moisture, 32 percent, or 36,700 square miles. The planting of field shelterbelts on such lands would be more expensive, the hazard greater, and the possible benefits less than on coarser, lighter soils.
3. Coarse-textured soils, relatively unfavorable for tree growth, with only a limited capacity for holding moisture, less than 1 percent, or 800 square miles.
4. Rough land, 11 percent, or 13,000 square miles. A very considerable proportion of these lands are suitable for planting in solid bodies, principally in gullies and along the breaks of stream valleys.
5. Sand hills, 4 percent, or 4,600 square miles. These areas, which include the sand hills of Nebraska, lend themselves generally to forest planting in solid bodies. They are not suitable for cultivation and in their present condition are more valuable for grazing. The total acreage which ultimately should be planted will depend upon the extent to which the work may be accomplished with labor employed primarily for relief purposes over a period of years, and upon the demonstrated value of existing plantations.
6. Alkali lands, "buffalo wallows," and other lands not suited to forest planting, 4 percent, or 4,800 square miles.

Lands in class 2, the hard-soil group, present certain variations in degree of difficulty. On such lands the planting policy may be modified in accordance with the conditions found. In many instances planting will be practical only if confined to the margins of farmsteads, where the trees may be given the intensive care essential to their successful establishment, and where their value will be largely social in character. Interspersed among the soils making up this group, however, are many small areas—too small to be mapped separately—on which very favorable soil conditions exist. Where such areas are found, typical field shelterbelts can be planted.

Lands in class 6 should be wholly excluded from consideration because of the insuperable obstacles to successful planting.

Lands in classes 1, 3, and 4 are those to which a Federal policy of management and control will be directly applicable, and to which the following discussion is specifically related.

ESTABLISHMENT OF TENURE

An extensive and expensive program of afforestation by the Federal Government can be justified only by a reasonable presumption of permanency and long-enduring public benefit. Certainty and stability of land tenure and use throughout the full period required for the realization of the benefits and objectives of the forest-planting work consequently is an indispensable requirement. A project which requires a half century for the full realization of its public benefits cannot be predicated upon rights of land occupancy subject to termination or drastic modification at the end of a decade.

Subject possibly to the procurement of additional legal authority, four general methods of establishing certain and stable land tenure are available, viz:

(1) Leases for reasonable minimum periods, containing a specific contractual stipulation for extensions of the lease upon request of the United States Government and payment of the stipulated rentals, and also a specific contractual stipulation that at any time within the lease period or extension thereof the Government shall have the right to purchase the described lands or specified rights therein at a certain stipulated price per acre or other unit of area.

(2) Purchases of easements, under which the right of the Government to occupy the described lands for forest purposes shall be dominant over any and all other rights of occupancy, but with a provision for reversion or termination of easement if the lands are not so occupied by the Government during a certain prescribed minimum period, and for continued use by the holder of the fee or his grantees until such time as the Government initiates active occupancy of the lands.

(3) Donations of lands in fee by the owners thereof for certain specifically defined forms of Federal use and management.

(4) Purchases of lands in fee simple for permanent Federal ownership and management.

In the case of leased lands the Government may at any time during the lease period or extension thereof determine whether the success of the plantation and the interest of the owner of the fee in its perpetuation and the probability of continued interest by successors of the current owner offer adequate promise that the established forest will be permanently maintained and properly managed. In such event, should it then appear to be in the public interest, upon execution by the landowner of a cooperative agreement for such maintenance and management of the forest, the Government may waive its rights of extension or purchase of the lands, thus releasing them to the owner thereof.

In the case of lands subject to an easement or right of use acquired by purchase, the Government upon determination that the interest of the owner of the fee, or his successors, in the perpetuation of the forest offers adequate promise that the established forest will be permanently maintained and properly managed, and upon the execution of a cooperative agreement to that effect by the owner of the fee, may relinquish its easement or right of use in the lands, should such action appear to be in the public interest.

In the case of donated lands, the reasonable presumption is that the donor was motivated by the expectation and desire that the lands should remain in the permanent ownership of the United States and that the Government would maintain upon them certain conditions of forest growth and management. Where that is the case, permanent Federal ownership would be dictated. When the donor so desires, however, deeds of donation properly may include a clause providing for the reversion of the lands to the donor or his successors, if they are not used by the Government for forest purposes within a certain minimum period of time, as, for example, 10 years, or 20 years.

Certain landowners, while perhaps willing to sell marginal strips of their properties to the Government for forest purposes, may be deterred from so doing by the fear that if the shelterbelt program were modified or abandoned the Government might dispose of the land to persons who would use it for purposes incompatible with the best use of the vendor's remaining lands. Such a situation might be met by a provision that if the Government decided to restore the land to private ownership the vendor or his successors in interest would have a preference or prior right to purchase or enter the lands, subject to the conditions then prescribed by the Government; but existing law provides no authority for future commitments of such character, and it is improbable that deed of conveyance containing such a stipulation would be acceptable.

VALUATION

Land valuation is required as a basis for acquisition of lands for the Plains shelterbelt project. For field and farmstead shelterbelts it will be necessary to acquire varying degrees of control over a large number of small parcels. For other purposes included in the program land will be acquired in relatively large units. Each parcel will require individual bargaining, and negotiators must be prepared to bargain for the land with a definite knowledge of its worth and without the necessity of making a detailed and costly individual appraisal of each small tract.

CROP LAND

Various methods of evaluation for crop land have been considered and weighed in relation to conditions obtaining in the shelterbelt zone and the objectives of the shelterbelt project. If the true capital value of such land is to be obtained, the net income must be determined; and satisfactory cost data from which net income can be calculated are seldom available for small-farm operations. Evaluation on the basis of prices paid for land in the past is also unsatisfactory, because relatively few sales contracts show the prices actually paid; moreover, such contracts may be based on speculative prices that reflect conditions existent only at the time of the sale. The price paid in many such transactions is based on physical and economic relationships between individual tracts of land, or personal relationships between the parties at interest.

In short, the intrinsic worth of agricultural land, as distinguished from ordinary appraisal, must be measured by its productivity, and a method is required that will develop bargaining estimates that are related to productivity. If high values of land are closely associated with high productivity and low values with low productivity, it may be concluded that definitely appraised values are accurate in proportion as they reflect that relationship. It is realized, however, that no scheme of valuation will permit of a definite knowledge at any given time of all the factors affecting the value of the land. The private investor can only pay a price per acre for land, the average income from which may be expected, in a given period of years, to protect his investment and provide for a reasonable standard of living. The Federal Government should use a comparable basis in valuing land for the Plains shelterbelt project.

Average cash rent would appear to be the best measure of the productivity value of land. Data as to cash rentals are, however, extremely meager, since the common practice is to rent on a crop-share basis. Since cash rents cannot in most cases be correlated with values, the problem is one of correlation of the factors that produce rents, viz, value-productivity factors.

Although it is impossible to determine all productivity factors for land valuation on this project, the productivity method has been adopted since it correlates the average appraised value per acre with selected productivity factors which are both significant and determinable.

ALLOTMENT CONTROL CONTRACTS

As a result of the allotment control program of the Agricultural Adjustment Administration for corn-hog, wheat, and cotton production, detailed information as to the classification and productivity of land is obtainable for a large majority of the farms in the shelterbelt zone. These data are checked by local committees familiar with the agricultural economy of the locality. Comprehensive abstracts of this information for use in the shelterbelt project have been compiled on special forms.

The Federal farm-loan banks have appraised a vast number of farms for the purpose of granting loans. They determine the general level of land values in a community as a starting point, and by comparing each tract to be appraised with this basic determination of value arrive at the appraised worth of each farm.

In addition they determine the probable future income, based upon productivity and other factors, so as to assure themselves that the borrower will be able to retire the loan in the period for which it is granted. Basically, productivity and value are related to the so-called "100-percent index" parity for the period 1909–14. The final appraisal therefore is a fair value based upon reasonable expectation that the loan will be repaid. Abstracts of Federal farm-loan bank loan data, referring so far as possible to farms upon which classification and productivity data are also available, are used in determining the true indicative worth of the individual farms and in establishing a normal per-acre value (hereafter called "appraised value") for comparable groups of farm lands. (The above relates entirely to the Federal farm-loan bank loan and not to the so-called "Commissioner loan", which is the result of specific legislation to relieve farm distress.)

DEVELOPMENT OF METHOD

Before correlating value-productivity factors with the appraised values, it was necessary to segregate the land areas into zones within which the majority of land areas reflected a similarity of conditions. For this purpose, as well as to secure a more complete evaluation of productivity factors, vast amounts of miscellaneous data were obtained from the 1930 census reports, agricultural statisticians' reports over a period of years, State publications of specific studies, soil classifications by the Bureau of Chemistry and Soils and cooperating agencies, and other authoritative sources. These provided dependable information on noncultivable land, average yields of crops over any desired period of years, soils, and agricultural economy throughout the region, including small-grain farming, corn growing, livestock and range activity, and other forms of management, all of which information affected the establishment both of zones of value and of the value-productivity factors within zones as considered in final correlation.

With the aid of these data a practical zoning system has been set up by which lands are segregated in a numbered series within each State according to the principal elemental or physical factors which affect their value. The smallest subdivision considered in zoning is one county, although it is realized that the exact limits of a zone will not coincide with county lines and will have to be more closely delineated by examination on the ground as land is selected for planting.

With the zonal classification of a given body of land determined, it becomes possible to apply correlation formulas to the three factors that are sufficiently comprehensive and are pertinent to the problem of establishing intrinsic crop-land values for Government-acquisition purposes. These factors are appraised value, percentage of noncultivable land, and average yield.

Careful investigation of several formulas of correlation has led to the adoption of those given in the publication Correlation and Machine Calculation, by George W. Snedecor, of Iowa State College, and Henry A. Wallace, now Secretary of Agriculture. Land values thus determined by correlation of the essential factors have been subjected to comparison with known local data, such as bona fide sales, assessed valuation, census data, and lease-rental values. The results indicate that a satisfactory bargaining basis can be obtained through the use of these methods. The correlation coefficient as developed by zones is highly significant, and the limit of error of the correlation is suitable for the establishment of ranges in bargaining value.

APPLICATION OF METHOD

Land will be acquired through negotiation between the landowner and a representative of the United States Government. The representative will determine for each farm on which land is to be devoted to shelterbelt planting the average productivity in terms of the major crop and the average percentage of the farm in noncultivable land. He will do this by reference to the record of the allotment control contracts in the office of the county agricultural agent and by examination of the farm. To the productivity, in terms of bushels per acre of the major crop, he will apply a certain factor which pertains to the valuation zone in which the farm is situated; to the percentage of noncultivable land he will apply a certain other factor for that zone. The products he will then combine with a constant factor related to the appraised value for lands in that particular zone in order to arrive at a per-acre valuation of the tract in question. Each negotiator will be furnished with the factors, including the bargaining range, adopted for each zone.

The indicated value of the tract will be that determined by the method described above, modified by items of value pertaining specifically to the tract, such as fences, irrigation improvements, erosion damage, noxious weeds, and, on cultivable pasture land the cost of tillage. Values so determined and agreed upon will be used in outright purchases and will be stipulated in options of purchase included in leases.

NONCULTIVABLE PASTURE LAND

The Forest Service has already developed a system of evaluating range lands in the national forests that is applicable to noncultivable pasture land in the shelterbelt area. The unit of evaluation is the forage acre, which represents an ideal acre of pasture land fully stocked with palatable forage. The production value of any given tract can be expressed in terms of forage acres. M. L. Wilson, now Assistant Secretary of Agriculture, developed a similar system in which carrying capacity is expressed in terms of the number of livestock of a given class that a section of land would support for a given period, and the carrying capacity is related to the production of meat at any given price per pound. A correlation of the two systems affords a satisfactory basis for either purchase or lease of the land.

The land of higher value, the so-called "hard-soil" type, which is devoted to grazing, but which is potentially cultivable crop land may be valued as such, with deductions for the cost of cultivaton necessary to make it comparable to producing crop lands.

WOODLAND AND FARMSTEAD AREAS

There will be no occasion to acquire woodland or farmstead areas in connection with the Plains shelterbelt project, except as they may be included in larger areas to be purchased as units of land management. In such instances the acreage in woodland and farmstead areas will not be given separate consideration as such, but will be given a value based on its potential productive capacity or related by comparison to the value of the unit to which it belongs.

RENTAL VALUES

Although, as already stated, the general practice with regard to farm rentals in the shelterbelt zone is to lease land on a crop-share basis, somewhat extensive data have been obtained from investigation of cash rentals in each county of the zone. A comparison of these data with the average valuation of farm lands in the counties concerned indicates that the average cash rentals are 9 percent of the average value in North Dakota, 8 percent in South Dakota, 10 percent in Nebraska, 10 percent in Kansas, 8 percent in Oklahoma, and 9 percent in Texas. From this rental income, the owner pays taxes and specified upkeep of improvements. Since, however, the improvements on land acquired for shelterbelt planting will be maintained by the Government, the cash rentals should be reduced accordingly. It is therefore proposed to reduce the above percentages in each State by 1, so that the percentages of land value used to compute annual rentals for shelter-belt planting areas will be: North Dakota 8, South Dakota 7, Nebraska 9, Kansas 9, Oklahoma 7, and Texas 8.

Section 6.—PROSPECTIVE EFFECTS OF THE TREE-PLANTING PROGRAM

By Raphael Zon, *Director, Lake States Forest Experiment Station, Forest Service*

CONTENTS

The Plains shelterbelt project represents a national effort applied to the amelioration of regional conditions. The interest attaching to the undertaking from the national point of view is not solely whether annoying dust storms can be kept out of the East, but rather what returns in farm and range economy, in property and tax values, and in improved living conditions may be expected from the general readjustment of land use, of which shelterbelt planting is an early and striking phase. In evaluating the effects of shelterbelts, then, no narrow or sectional basis of appraisal can be taken into account; the necessary assumption is that benefits accruing to an interstate region that contributes vitally to the national economy accrue in like measure to the welfare of the Nation collectively.

EMERGENCY EMPLOYMENT

To begin with a matter of common necessity, it must be remembered that the Plains shelterbelt project received public support largely as a measure for the immediate relief of drought-stricken farmers in the prairie-plains region. The preparation of the planting sites, the fencing of the areas, the actual planting of the trees, and the future care and maintenance of the shelterbelts will require a large amount of local labor and can provide a considerable proportion of the cash income of many farm families in the shelterbelt zone for years to come. Much of the necessary work can be done in off seasons. The renting of farmers' machinery and, especially, the purchase and leasing of more than a million acres of land will provide a further flow of much-needed and productive income into this hard-pressed region.

Such benefits would, of course, flow from any other land-engineering project of similar scope, and the specific use value of the shelterbelt project must be judged by more objective standards.

EFFECT ON FIELD CROPS

Evidence of that value is not lacking. Thousands of examples have been reported from our Plains region in which crops have been benefited by plantations of trees. Similarly, there have been many reports to the effect that crops adjacent to shelterbelts have received no apparent benefit or may even have produced lower yields than those unprotected. On the basis of experience both in our own country and in Europe, we can generalize upon certain effects with reasonable accuracy.

The effect of shelter belts on field crops varies with the relative dryness of the season. In wet years any beneficial effect is at a minimum; the crops do not need such protection. In moderately dry years, such effects are at a maximum, and the effect of the shelterbelt may provide the margin between a partial crop in the protected zone and complete crop failure in the open plains.

The question of increased or decreased yields of grain, straw, and hay crops as affected by tree windbreaks needs further investigation, it is true; hearsay is not sufficient. Russian studies, mentioned in another section, have given some quantitative basis for expected effects of protective strips of trees. A study conducted in several of the Prairie and Plains States in 1908,[4] in which crops both protected and unprotected by shelterbelts were harvested and measured, showed increased yields for the protected crops in most cases. The fact, however, that the study was completed in a single season and dealt with various crops on many soils and with windbreaks of variable composition and condition disqualifies it as a final answer to the crop question.

What is now urgently needed is a wide-scale comparison of protected and unprotected fields with respect to their production of similar crops under otherwise similar conditions. The data can be collected, under all necessary scientific control, from existing farms throughout the shelterbelt zone. Analysis of the data would answer many practical questions of shelterbelt density, orientation, and the like, and would be of immense value in checking experience of the past and further adapting planting plans already in effect. In the meantime, valuable leads will be obtained by measuring physical factors and perhaps even the yields on small plots as affected by artificial

[4] Bates, C. G. windbreaks: their influence and value. U. S. Dept. Agr., Forest Serv. Bull. 86, 100 pp., illus. 1911.

A STUDY IN CONTRASTS

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FIGURE 6.—*A*, An unprotected schoolhouse on the open plains in South Dakota; *B*, A farm home protected by trees in the plains of Kansas. (See text, p. 35.)

windbreaks whose heights, densities, and orientation can be controlled.

On the basis of present knowledge, gained both in this country and abroad, of effects on wind velocity, evaporation, humidity of the air, and the like, it is possible to determine the proper spacing of shelterbelts to protect the whole territory between them. The present program of one shelterbelt per square mile, on the average, is merely the framework on which further developments may be based. Considering that the height of shelterbelts will be about 40 feet on the average, Forest Service studies have indicated that a single belt will extend some degree of protection to a distance of one-fifth mile. European data, based not on occasional windbreaks but on a succession of them at regular intervals, indicate that cumulative protection can be obtained if the belts are established at every one-third mile. Since the unit of land in the Plains region is the 40-acre tract, it will be convenient in the final development to make the interval between belts one-quarter mile, thereby insuring a high degree of protection for the entire area.

The point should be clearly made here that most of the advantages that accrue to the surroundings from the presence of a row or grove of trees can be traced either to the trees' checking of run-off or to their wind-stilling effect. Romantic expectations such as raising the water table or increasing the rainfall should not be entertained. The entire section, Shelterbelt Experience in Other Lands (pp. 59 to 76), forms an interesting commentary on the actualities of the case. The most remarkable effect, perhaps, is seen in the lowering of the evaporation rate in a sheltered area at one of the Russian experiment stations. Humidification of the air does apparently occur to a slight extent, but evaporation is checked in much more pronounced fashion, and the inference is strong that a lowering of wind velocity is the cause. The increased expectation of a fair crop yield in a dry year under shelterbelt influence may find part of its explanation on this same basis.

GARDENS AND ORCHARDS

Farmers in the Plains region are able to point out very distinct benefit to flower and vegetable gardens and somewhat less benefit to orchards, as a result of tree-belt protection. Gardens are often planted between two or inside of four rows of trees, which act as a snow trap in winter and release the accumulated moisture rather gradually in spring. The response of garden plants is marked, since they are heavy users of water—much more so than the cereals, which, as a group, represent one of nature's highest adaptations to wind and drying.

A high demand for water does not wholly characterize orchard trees, of which apricots and some varieties of apples can be set down as decidedly drought-resistant. Yet fruit trees in general show favorable reactions to shielding from dry winds. Protection against late spring frosts is also a large factor in fruit bearing. It may be said that benefit to orchards is to be expected if there is a cold storm, or a sudden cold snap accompanied by wind, such as is very common in the Plains region even after spring is well advanced. Planting too near the windbreak may result in root competition and loss of vigor of fruit trees.

PROTECTION OF FARMSTEADS

The value, both materially and personally, of tree planting about the home is attested by the high expenditure of time and money that has gone into the establishment of farmstead windbreaks throughout the Great Plains region. Except for the South, the settler's first wish is for shelter of his house, and next his barn, from the " cold ", by which is meant the driving cold of a penetrating wind. On this account a good windbreak can take an actual financial rating, for its protection can be translated into a substantial saving of fuel.

Far beyond this consideration is the invaluable benefit of an enjoyable home surrounding, not expressed in Federal appropriation acts but deeply implied in all their provisions that have made tree-planting stock cheaply available to farmers. The shelterbelt planting program does not specifically contemplate farmstead planting until some of the major lines have been established. But there is no doubt that living conditions will be enhanced in many neighborhoods through the general improvement of the countryside. Figure 6 illustrates the striking contrast between a neglected schoolhouse and a tree-sheltered farmstead, one slightly to the east and the other slightly to the west of the shelterbelt zone.

Enthusiastic farmers frequently state that they would not take a thousand dollars (or other considerable sum) for their groves. That such statements are something more than figments of the imagination is reflected by the fact that practical real-estate men add several hundred dollars to the value of a farm upon which thrifty groves of reasonable extent occur.

PROTECTION OF LIVESTOCK

A great benefit to the farmers' livestock will ensue upon establishment of the shelterbelts. Under many conditions the animals get along very comfortably with only the protection of a good windbreak. In connection with feed lots, the value of such shelter in terms of feed saving has been fully recognized by livestock feeders in Iowa, one of whom stated that his windbreak enabled him to save from $5 to $10 on the cost of feeding each steer.[5] Horses and cattle, particularly, are very sensitive to wind, and unless driven by hunger will rarely remain in an open pasture on a windy day when they can find any degree of protection. Protection from driving rain is equally welcome to stock, and in hot weather the shade of trees is eagerly sought.

These benefits are by no means inconsiderable items in the economy as well as the comfort of the farm, and they have long been appreciated in regions of less severe climate than the dry plains. The field shelterbelts cannot be opened to use by stock, but such use is not imperative to supply a necessary minimum of protection. Wherever one adjoins a pasture or a

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[5] SHERLOCK, C. C. THE ECONOMY OF WINDBREAKS: THE DOLLARS AND CENTS VALUE OF THE PROTECTION THEY AFFORD. Successful Farming 19 (2) : 53, 153, illus. 1920.

stock lot, a very slight addition to the main shelterbelt can be made where the farmer is willing to fence off a few square rods of his own land. Even here stock should be kept out of the actual planting, as stock damage has been shown to be a chief factor in killing out planted groves. (See A Survey of Past Plantings, pp. 39 to 47.)

CHECKING SOIL BLOWING

There is no doubt as to the adequacy of almost any type of windbreak to prevent soil blowing within the area in which its effects on wind movement is appreciable. Figure 7 is a striking illustration both of the efficacy of a windbreak in this respect and the condition with which it has to cope.

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FIGURE 7.—Outbuildings and trees partly covered by wind-blown soil in Tripp County, S. Dak., May 1934.

Even dead groves catch large quantities of blowing soil. The reasons for this are, (1) that it requires a wind of considerable velocity to effect any serious soil movement, and (2) that blowing soil almost certainly gathers intensity with travel, the movement of coarser particles at one point tending to abrade and loosen soil farther on; and the dead trees form sufficient obstacle to slow or halt such soil movement.

It is therefore of first importance to protect the points of weakness where soil blowing is most likely to start, if these be known. The importance of the shelterbelt lies in the fact that both the degree of reduction that is accomplished by an obstruction and the width of the area in which some reduction is felt are greater with a strong wind than with a moderate one. Since, also, the winds which cause soil blowing in a given locality are rather commonly from one direction, it follows that the zone of influence of a properly oriented shelterbelt is both more certain and more extensive as a preventive of soil blowing than as a factor to conserve moisture through all the variable conditions of a year or growing season.

It is not to be inferred, however, that shelterbelts will prevent dust storms, since many of them originate in the drier region to the west of the shelterbelt zone. However, the restoration of grass cover in the more westerly areas, along with strip cropping and shelterbelt planting in the present zone and eastward, will markedly reduce the possibility of frequent widespread dust storms.

BLOCK PLANTING ON SAND HILLS

The planting of solid blocks of trees on sand-hill areas has not been stressed nearly as much as the planting of shelterbelts around fields and farmsteads, yet it is a very important part of the contemplated program. Most sand-hill regions act as water reservoirs and feed many small streams. Although a good grass cover can afford real watershed protection, trees are capable of providing a more stable protective cover. In addition to preventing wind erosion of the area, it is possible that block planting over large areas may have some of the climatic effects attributed to forests. The deep-rooting trees are able to tap the subsoil moisture supply and make some of it available locally to the atmosphere through transpiration. This might conceivably have an effect in cooling adjacent regions and inducing more precipitation locally.

The conversion of sand hills covered with a sparse growth of grass to green forests has a very realistic value in relation to recreation. As has already been proved by the Nebraska sand-hill planting, Plains dwellers gather from near and far to enjoy these oases of trees. Various species of game birds and animals are provided shelter and protective cover, and their

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FIGURE 8.—Block plantations near Lookout Ranger Station, Nebraska National Forest, 1929. Such plantations, now extending over several thousand acres, demonstrate that under favorable local conditions forest planting can be a success even in a region occasionally beset by great droughts.

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FIGURE 9.—Part of a jack pine plantation about 25 years old in the Nebraska National Forest (sand-hill region), 1931. Forest conditions are evidenced by the good litter cover on the ground, the tall narrow crowns, and the dense stand.

numbers increase, adding further to the recreational interest. The protection given to game and insectivorous birds by tree planting in the Plains region, whether as block plantings or as shelterbelts, is an ameliorative feature that has long been recognized.

Figures 8 and 9 indicate how the appearance of the Nebraska sand hills has been changed by tree planting.

PLANTING ON "BREAKS" AND GULLIES

The "breaks", which represent high escarpments along the valleys of streams which cut through the high plains, are primarily areas of very active erosion, and are usually almost devoid of vegetation, except for occasional red cedars. These can be planted successfully only in connection with fairly comprehensive developments for controlling run-off which will, instead of passing from the high plain to the lowland, carrying great masses of soil in each rain, be so far as possible impounded above the breaks and allowed to seep away in such a manner as to subirrigate the slopes below.

The average gully, ravine, or draw is usually of an entirely different character from the raw, eroding breaks contiguous to the larger and deeper valleys. These smaller drains are characteristic of relatively flat country. They are usually moderately well sodded and eroding only in a normal degree except when overgrazed. They frequently contain scattered trees of such hardy species as elm, ash, hackberry, and boxelder. It is, therefore, but a step beyond natural processes to establish solid bodies of trees wherever such depressions occur and where the trees will receive some run-off. The primary purpose of such planting is to impound and conserve, in the soil, water which would run off to the adjacent streams during the more severe rains. The influence of this conservation will be felt in periods when rainfall is lacking. Moreover, the rural communities of the region need and will greatly appreciate groves of trees in such protected situations for local picnic grounds and park purposes.

WOOD PRODUCTS

Since the tree plantations in the Nebraska sand hills have reached sufficient size to require thinning, the trees removed have been sought eagerly as posts and fuel by local farmers and ranchers. A local supply of such material meets a very real demand, and the people account it a measurable benefit. With the increased block planting that is planned, such benefits will be available to a much larger number.

Although the main purpose of shelterbelt planting is protection from wind and storm, the value of the wood products which become available from thinnings and from removals as the groves mature cannot be overlooked. Indications are that acre for acre shelterbelts will produce as great a volume of wood as natural forest stands of similar age up to about 30 years, after which their production falls off.

The older windbreak plantings have provided many farmers with a considerable proportion of their needed fence-post material, and during the depression they have yielded a heavy toll of fuel as well. With the expansion of shelterbelt planting contemplated by the Plains shelterbelt project and the additional State and private activity which this is likely to stimulate, a much greater and more permanent supply of wood products will be available to the Plains farmer.

DISADVANTAGES CITED

The positive disadvantages of shelterbelts are so few and insignificant in their total effect as to call for only brief mention. It is obvious that in most cases the detriments arise from poorly planned use of trees, usually as to position.

In the present state of farm management, the greatest disadvantage of shelterbelts will be considered by many farmers to result from the breaking up of large fields into tracts in which large machines cannot be used economically or conveniently. This may be a serious item on a good many farms which have been highly mechanized.

A dense shelterbelt causes considerable stagnation of air on its leeward side, resulting in both higher temperatures during the day and lower temperatures at night. Although the effect is generally stimulating to growth, it may, during warm and dry periods, tend to accentuate conditions which are detrimental, despite the fact that the evaporation rate is somewhat decreased through the reduction in wind movement.

"Still" frosts are slightly encouraged, and while these are perhaps not as often injurious as freezing storms, especially those of late spring, it is generally found advisable for the protection of orchards and the more sensitive garden plants not to have a shelterbelt which too fully cuts off air movement near the ground.

When shelterbelts are placed too close, either to buildings or roads, the snow which drifts on the leeward side is often in a place where it causes a maximum of inconvenience. A shelterbelt which lets the snow through should be set farther back.

All tree rows, belts, or groves sap moisture to some extent from adjacent ground. The distance to which this sapping will be felt in the field, however, is usually not much greater than the spread of the branches of the outside trees. But in some cases, as with cottonwood on sandy soil, and Osage-orange on fine soils, the spread may be considerably greater. It is best to plow or at least disk the ground fairly close to the stems of the trees in the outside row, unless the shade density is such that weeds will be kept down. But it is also far better for the trees to permit them to use the soil and soil moisture for a certain distance, instead of seeding this strip to annual crops which will barely survive.

The disadvantages of block and erosion-control planting are even fewer. Such planting will not occupy any area which should be in cultivated crops, but rather, areas of low to medium value for grazing. Grazing has been permitted on the Nebraska plantations after they have reached 10 years in age. However, they are coniferous plantings, and other areas planted to hardwoods would probably have to remain closed to grazing longer. Even if the land must be given over entirely to tree growth, a greater public benefit will no doubt result from such use, considering the need for their establishment, at least to a certain moderate extent.

Section 7.—A SURVEY OF PAST PLANTINGS[6]

CONTENTS

In order to get a definite perspective of the possibilities of tree planting in the prairie-plains region, a study was made of the earlier plantations, particularly as regards the causes which contributed to their success or failure. Such a study should reinforce the scientific appraisal of the shelterbelt problem and give a practical view of the pitfalls which organized forestry proposes to avoid in solving it.

The study, requiring a rapid reconnaissance of existing plantations in a wide territory within which the shelterbelt zone was to be marked out, was conducted in the fall of 1934. Plantings in the region have been numerous in years past, and the survey was intended primarily as a check, under increased severity of the drought, of conditions already well known and studied. The results of a similar but more intensive investigation in North Dakota, recently published,[7] furnish much additional information that is applicable to the northern part of the shelterbelt zone in general.

In the short time available for this survey, it was of course impossible to examine all the plantations within the general region. In order to secure a representative sample, an east-west line through a part of each State was located on the basis of topography, soils, types of agriculture, and the amount of planting done in the past. This line was considered to be the center of a 2-mile-wide strip, within which observations were made of plantings (about 1,000 in all) of trees more than 10 years old. Certain deviations were made where the line paralleled the course of streams and where it traversed land devoted more to grazing than to crop production. The line also avoided all improved highways, because farm improvements, including windbreaks, are often better than the average along such thoroughfares. Figure 11 shows the location of the 2-mile-wide strip in each county of the six States in which the shelterbelt zone is located.

GENERAL DESCRIPTION OF PLANTINGS

In most cases the appearance of the shelterbelts reflected the hard conditions through which they had come, not only as a result of poor adaptation to climate, but also as a result of economic hardships affecting their ownership, management, and care. On the other hand, examples of healthy survival under difficulties were noted, and in the few cases where careful adaptation and management were controlling factors, the condition of the shelterbelts was on the whole satisfactory (fig. 10). The very promising situation existing at Mandan, N. Dak., a field station of the Bureau of Plant Industry, is noted under a separate heading below.

Two types of relatively recently planted shelterbelts were observed. In the Dakotas they often consist of belts five or six rows in width and usually located on the north and west sides of buildings. The other type is planted in two rows so as to create a snow trap. The two parallel rows of trees are separated by a space at least 100 feet wide which is sometimes occupied by an orchard or a garden plot.

In Oklahoma, few plantations are more than three rows wide, and in Texas the plantings often consist of only a single row. In general, the width of the shelterbelts has been too small to insure a favorable forest-cover condition.

One of the best features of the older tree claims (plantings under the terms of land settlement laid down in the Timber Culture Act of 1873) is that they usually have enough width to be in some degree effective in shading the ground and getting a forest-cover condition. In the planting of tree claims to obtain title to land, some farmers made a real effort to follow the letter of the law, and as a result there can be seen in the Great Plains region a considerable number of groves over 40 years of age which are still in good

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[6] This section is based on field data collected by parties under the direction of J. F. Kaylor, C. C. Starring, and C. P. Ditman, of the Lake States Forest Experiment Station, Forest Service.

[7] SCHOLZ, H. F. CAUSES OF DECADENCE IN THE OLD GROVES OF NORTH DAKOTA. U. S. Dept. Agr. Circ. 344, 37 pp., illus. 1935.

condition. These are usually about 10 acres in size, and their dimensions are 10 by 160 or 20 by 80 rods. They are invariably along section or quarter-section lines.

Such tree claims are still quite common in the Dakotas, Nebraska, and Kansas. They are conspicuous by their absence in Texas and Oklahoma. The latter State was admitted to the Union after all Federal legislation had been abolished which made possible the settlement and filing on land through the medium of tree planting. In Texas no tree-planting entries were possible because there was formerly no public domain (Federally owned land) in that State.

PLANTED AREA IN STATES AND COUNTIES; AVERAGE HEIGHTS AND PERCENTAGE OF SURVIVAL

General physical and climatic conditions were found to be largely accountable for the distribution of shelterbelts over the area. In the northern part, where winters are severe, a great many groves have been planted for the protection of homes as well as of livestock against snow and cold winds. In North Dakota the area occupied by planted groves was found to vary from 4.58 acres per square mile in eastern locations favorable for tree growth to 0.48 acre in the western part of the State where conditions are the most difficult. In all areas in which tree planting can be done with reasonable expectation of success, plantings average 2.56 acres per square mile. In South Dakota and Nebraska, where winters are also severe, the proportion of planted area is considerably larger.

In Kansas the proportion falls to 2.3 acres per square mile in the part best suited to tree growth, and to 0.31 acre per square mile in difficult parts. In Oklahoma and Texas, where winters are milder, settlers have not experienced the absolute necessity for protection that exists in the North, and the proportion of area planted for protection decreases toward the vanishing point. Table 8 shows the estimated proportion of the area of each State devoted to shelterbelts and similar plantings and the proportion of area so planted (by private effort) within the shelterbelt zone, as well as the approximate acreage planted in the zone. Figure 11 shows the estimated proportion of planted area in each county surveyed.

TABLE 8.—*Areas devoted to protective planting* [1]

State	Proportion of area in groves		Area of groves in shelterbelt zone
	Entire State [1]	Shelterbelt zone	
	Percent	*Percent*	*Acres*
North Dakota	0.250	0.303	38,800
South Dakota	.325	.560	71,680
Nebraska	.533	.609	77,952
Kansas	.300	.148	18,944
Oklahoma-Texas	(2)	.114	21,900
Total		.347	229,276

[1] Estimated from survey figures.
[2] Sample too small to give reasonable estimate.

The percentage survival of trees in plantings is shown according to States in table 9. This survival figure is the proportion of living trees to the total number of trees found in the groves when examined, and not on the number originally planted. The groves were divided into two groups, those under and those over 30 years of age. In most cases survival was better in the younger groves, a fact due to the longer time for the accumulation of dead trees in the older plantations and the greater experience behind the planting of the younger groves.

TABLE 9.—*Average survival of planted trees in States of the shelterbelt zone*

State	Average survival of trees		
	In groves under 30 years old	In groves over 30 years old	In all groves
	Percent	*Percent*	*Percent*
North Dakota	41.8	44.2	43.1
South Dakota	43.6	25.7	31.8
Nebraska	32.7	10.4	17.8
Oklahoma-Texas	25.9	34.2	28.4
Average	36.8	23.8	28.7

Among broad-leaved species the range of survival was, roughly, from 21 to 50 percent in young groves and from 17½ to 30 percent in groves of all ages, with green ash taking the lead in the one case and American elm leading by a slight margin in the other. Among the conifers, eastern red cedar far exceeds the broad-leaved group in its survival showing, which averaged 93.2 percent in all plantings examined. While the number of groves in which it appeared was relatively small, its rugged resistance recommends it for much wider use. Survivals of the more prevalent species, not subdivided as to State, are shown in table 10.

TABLE 10.—*Average survival of principal species examined in plantings*

Species	Groves in which occurring	Average survival		
		In groves under 30 years old	In groves over 30 years old	In all groves
	Number	*Percent*	*Percent*	*Percent*
Green ash	635	48.5	20.4	29.5
Cottonwood	459	34.0	24.5	27.1
Boxelder	456	36.1	20.2	25.2
Mulberry	403	25.6	12.9	17.4
American elm	223	38.0	20.1	30.2
Black locust	208	20.8	23.3	21.9
Catalpa	127	26.6	9.7	20.1
Eastern red cedar	93	94.9	92.4	93.2

The average heights of trees over 30 years in age of certain key species—those which usually give character to the groves—are as follows: Cottonwood, 50 feet; American elm, 27 feet; green ash, 26 feet; black locust, 26 feet; and eastern red cedar, 17 feet. These values represent a general average for the region, and will be markedly exceeded in some groves and not attained in others at the same age.

NORTHERN GREAT PLAINS FIELD STATION

The Northern Great Plains Field Station of the Bureau of Plant Industry, at Mandan, N. Dak., affords an excellent example of what can be done in the

SHELTERBELTS ADD COMFORT AND BEAUTY TO THE HOME

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FIGURE 10.—*A*, Farmstead near Madison, S. Dak., vastly improved by planting of hardwoods and conifers. Shelterbelts around the farmhouse protect buildings and livestock from winter's icy blasts. *B*, Cottonwoods make excellent growth in low areas; scene 14 miles east of Hoxie, Kans. Such protective forest strips add beauty to the landscape as well as value to the form property. (See text, p. 39.)

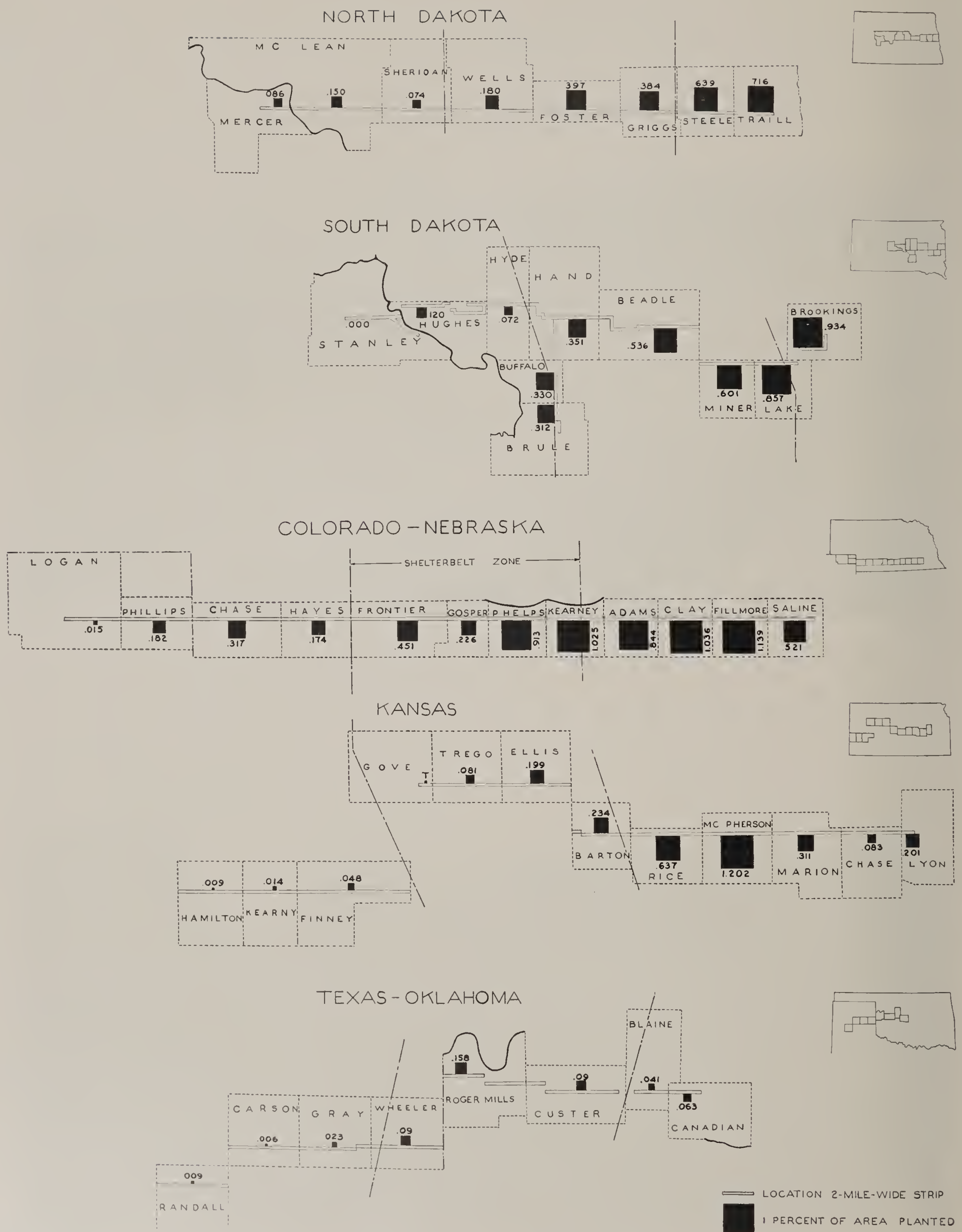

FIGURE 11.—Location of survey strips in States of the shelterbelt zone, together with percentages of area in forest plantings in counties sampled.

planting of shelterbelts. From 1916 to 1933 it has been instrumental in establishing on a cooperative basis with farmers in the western part of the Dakotas and in eastern Montana and Wyoming more than 2,700 demonstration shelterbelts. Despite the fact that this area lies west of the shelterbelt zone and has less favorable growing conditions, average survival for these plantings is over 70 percent.

In addition, the station laid out on its grounds at Mandan, from 1914 to 1920, approximately 100 test blocks of different types involving variations in species, spacing, cultivation, pruning, and mulching. These experimental plantings have been maintained under dry-land agricultural conditions and have demonstrated the value of reasonably close spacing. Figures 12 and 13 show two very fine test blocks.

ANALYSIS OF PRESENT SITUATION

If a serious picture of the condition of privately owned and planted shelterbelts has been drawn, it is mainly to focus attention on the factors that have brought the condition about, so that they may be allowed for or avoided in planned and organized action. They lie in the spheres of climate, occupancy, and technical management, and will be considered in order.

DROUGHT

Drought is undoubtedly of primary importance as a factor of damage and also as a test of the ability of individual species planted in shelterbelts to survive. During and after 1931, moisture conditions for plant life in the prairie-plains region became increasingly acute, and the summer of 1934 provided a devastating climax to the dry period.

Although considerable losses had been reported before 1931, the majority of the shelterbelts seemed to have held their own fairly well despite moisture shortage, sleet, rodents, grazing, and insects. But the parching winds and searing temperatures of the last 3 years proved to be more than many of the trees could withstand. In the Dakotas a feature of the general damage was that caused by the death of crown tips. A comparison of the survival figures obtained in the 1931 survey of North Dakota with the 1934 figures affords an estimate of the losses by drought during the interval. While the two surveys did not cover exactly the same area, the figures should be to some extent comparable. In the 1931 survey 293 plantings showed an average survival of 73.7 percent, whereas the survival for the groves examined in 1934 in North Dakota was only 43.1 percent. South of the Dakotas an even heavier toll of trees was taken by heat and drought. It should be remarked, however, that throughout the region the worst damage occurred where the soil was bare and packed hard by grazing stock. This compacting of the soil prevented the proper penetration of what little precipitation fell.

LATE FROSTS

Low temperatures as well as high must be taken into account when planning shelterbelt plantings. Late spring frosts are apt to injure undeveloped parts in lateral and terminal growing regions. Damage of this sort was caused in at least one instance encountered on the survey by a hard frost occurring in early April, which killed growing tips of mulberry, black locust, and honeylocust; the mulberry and black locust showed better recovery than the honeylocust.

Sleet, hail, and winds of cyclonic force are other climatic factors which have caused and will cause damage in the shelterbelt area and elsewhere. The best of planning can only allow for their occurrence, not try to forestall their effects.

OWNERSHIP OF LAND

Frequent change of ownership has militated generally against the proper care and upkeep of shelterbelts. Among the farms covered in the survey it is only the rare exception that has been in the continuous ownership of one man or his family. Often, where trees were planted and given good care originally, the sale of the farm meant a change in sentiment as well as in the person of the owner. The trees might be utilized for firewood or the grove turned into a stock pasture. Trees on farms operated by tenants are even more subject to bad treatment or neglect, through the indifference of the more or less transient occupants.

In some cases the national origin of settlers has been noted as a factor in the planting and care of shelterbelts. In sections originally settled by Germans and Scandinavians the greatest and most successful efforts in this direction were apparent.

A fortunate feature of tree planting under public auspices is that the undertaking carries at least the promise of permanent tenure and of uniform, continuing policy.

SELECTION OF PLANTING SITE

The first act of the homesteader was to locate a site for his house. Often the principal aim was to select a spot which afforded a view of the entire farm or ranch. After the house had been built, the need for protecting it from snow and wind became apparent, and if trees were planted they had to be planted where they would serve the need. Consequently, many groves and windbreaks were planted on soils which were either prohibitive or extremely difficult for tree growth. Other factors were also unfavorable on many sites. Often groves were situated on steep slopes where run-off of precipitation was rapid and where the trees were unduly exposed to the wind. In the relatively few cases in which the buildings were located in sheltered sites, the trees planted for protection survived well and proved to be a sound investment of the money and time required to establish them.

SELECTION OF SPECIES AND SEED SOURCE

Selection of species used for planting has decided the success or failure of the planting effort in cases without number. The earlier plantations show very little evidence of forethought in the selection of species. Apparently the species for planting were usually selected more as a matter of personal fancy than of adaptation to conditions. Newly introduced, fast-growing species were evidently in greater favor than the more drought-resistant, slower-growing native trees.

In many instances stock was purchased from nurseries at a considerable distance where conditions were very unlike those of the locality in which planting was

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FIGURE 12.—Test block of ponderosa pine, Northern Great Plains Field Station, Mandan, N. Dak.

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FIGURE 13.—Test block of blue spruce, Northern Great Plains Field Station, Mandan, N. Dak.

to be done. Often the seed from which the stock was grown was not of the same climatic region.

Naturally, such a hit-or-miss method resulted in the planting of a class of stock and of many species entirely unsuited to the region of prairie climate. The only existing evidence of many thousands of dollars spent in trying out these unadapted species and types is a disposition on the part of many farmers to consider tree planting a useless waste of money and effort.

Later, in communities where an active county agricultural agent had secured the cooperation of Federal and State forestry agencies, the composition of the groves was better. Demonstration plantings of suitable composition served to stimulate interest in local species. Shrubs and low-growing trees, however, were very seldom used, as their value for flanking taller growing shelterbelt trees has been realized only lately.

Choice of species in the future should be guided by the experience and advice of testing stations which have made a special study of species adaptation to shelterbelt conditions.

METHOD OF PLANTING

In some cases the experience of the farmers in regard to living plants guided them in properly planting and caring for the young trees. Usually, however, the small seedlings, when not supplied by a nursery, were pulled up and carried without any covering to the planting site. Often the plants were subjected to excessive drying, as when furrows had been opened long in advance of planting. Sometimes the seedlings were laid at an angle in a shallow furrow and covered by plowing a ridge of soil against them.

Naturally, such methods were not conducive to survival, and many of the trees succumbed early. When more painstaking methods were used the success was markedly greater. In the matter of planting, as in species selection, the cooperation of Federal and State agencies with the farmer through the county agent has been invaluable.

SPACING OF TREES

In the first plantations the density of planting was dictated by section 2 of the Timber Culture Act as amended in 1878, which required the planting of 2,700 trees per acre, equivalent to a spacing of about 4 by 4 feet. Frequent cultivations with a breaking plow destroyed large numbers of trees by exposing their roots. Many trees died from other causes, and the resultant spacing in the older plantings is now approximately 8 by 8 feet.

Where thinning was not practiced, some of the trees originally planted succumbed from crowding, as might be expected. This natural process has caused many planters of the present generation to believe that the original spacing was too close, and in recent plantings they have adopted a spacing of 8 by 8 feet. The change, which appears to be mainly an attempt to eliminate the need for artificial thinnings, is to be regretted. In widely spaced plantations the freer sweep of wind greatly reduces the opportunity for the accumulation of leaf litter and also increases the evaporation rate. Moreover, too wide spacing of trees permits too much sunlight to reach the soil and favors the increase of insect pests. The protective effect of the shelterbelt is decreased and its primary purpose thus in a measure defeated.

In the closely planted groves natural thinning alone is often sufficient to maintain a fairly normal growth rate. The earlier dense plantings that were observed showed a markedly good survival, fair forest-floor conditions where grazing had not been allowed, and a general tendency to retain a spacing closer than 12 by 12 feet at 50 or more years of age. The recent more widely spaced plantings show considerable loss through sun scald.

CULTIVATION

Cultivation is one of the most important factors in establishing shelterbelts. Many of the older plantings in the Plains region were given only 1 or 2 years of cultivation and then left to shift for themselves. Consequently competing weeds and grasses obtained an early foothold and aided very materially in causing poor growth or early death of the groves.

PROTECTION FROM LIVESTOCK

Unrestricted grazing was found to be one of the commonest causes of excessive mortality in both old and young shelterbelts. In some cases the groves were fenced at the time of establishment and the fences kept in good repair. In most of them, however, there has been grazing at some time or other during the life of the trees. Many of the groves have been open to the depredations and trampling of stock from the time they were planted, although others have been kept free of livestock until the past few years, when scarcity of regular feed and the necessity for shelter from the terrible heat forced the farmer to open his groves to the stock. Many of the fences have been allowed to go to pieces because of the farmer's preoccupation with crop production. But whatever explanation lies behind the fact of stock grazing, the effect remains the same, differing from farm to farm in degree only.

When cattle, sheep, hogs, horses, or even fowls are permitted to forage and bed in the groves, the soil is compacted in greater or less degree. The roots of the trees are exposed by the cutting and trampling action of the animals' hoofs. This leads eventually to the death of the trees, when hot winds or direct sunlight reach the exposed roots. In addition to the direct effect on the roots, compaction of the soil creates unfavorable conditions for moisture absorption. Sprouts, seedlings, and young trees, the lower branches of older trees, and all the smaller plants are ordinarily consumed by the grazing stock. Thus the accumulation of a normal leaf litter and moisture-conserving mulch becomes impossible.

Groves were observed where trees of small diameter and up to 15 or 20 feet tall had been "ridden down" by cattle in their efforts to reach young, tender branches and leaves. Places were found where sheep had stood on their hind legs and ripped off branches and bark. Severe damage by the scratching and roosting of large flocks of poultry was also plainly in evidence.

The destructive effects of grazing in farm woodlots have been studied and presented in a number of publications. Practically all of them point out that graz-

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FIGURE 14.—Remnant of a fairly extensive planting of green ash near Oakley, Kans. Only the trees growing next to the road ditch have survived the soil packing and other results of years of pasturing.

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FIGURE 15.—Excellent grove of green ash near Redfield, S. Dak., at about the center of the shelterbelt zone. The floor conditions here, unaffected by grazing until recently, illustrate conditions which are absolutely vital to the survival of plantations through drought periods. Original spacing, 3 by 3 feet; present spacing averages 6 by 6 feet at about 40 years of age.

ing causes lowered soil porosity, greater evaporation from the soil surface, continued loss of the normal leaf litter, complete lack of reproduction, and mechanical injury to the trees and their roots.

In Griggs County, N. Dak., an ungrazed plantation of green ash showed a survival of 70 percent, whereas in a comparable plantation which was moderately grazed the survival was reduced to 30 percent. Excellent forest-floor conditions existed in the ungrazed grove; there was a heavy layer of litter and leaf mold forming a water-holding blanket near the surface of the soil. Ground cover of young growth and shrubs aided in the collection and retention of snow. In contrast to this favorable condition, the grazed area showed many bare spots and openings without leaf litter or reproduction and was covered with a mat of sod competing with the trees.

Figure 14 shows the remnants of a grove which has been heavily pastured for many years. Only the trees near the road have been able to survive. Figure 15 shows a grove in which grazing has been permitted for only a short time. The differences are obvious. The inevitable conclusion from first-hand observations over the entire area is that grazing in areas planted to trees, especially on heavy soils, must be reduced to a minimum or entirely prohibited if the trees are to continue to grow and maintain themselves.

FIRE

Fire is still another factor which has a detrimental effect on tree growth in the shelterbelt zone. Residents of many communities recalled destructive fires which swept over the Plains in earlier times, and these are generally conceded to be accountable in part for the sparsity of natural tree growth in the region. In more recent times, fires have been started intentionally and often for the express purpose of removing tree growth which might be interfering with the owner's urge to put every acre into crop production. Careless burning of brush and weeds in garden plots has often injured or killed trees growing in the immediate vicinity.

Fire must be kept away from planted groves if they are to succeed.

CONCLUSION

In recent years plantings have improved considerably in species, composition, and the care they have received, owing mainly to the guidance and cooperation received by farmers from State and Federal agencies.

Summing up the results of shelter-belt plantings on the basis of the recent survey, some 230,000 acres appear to have been more or less successfully planted in the shelterbelt zone in the past 50 years. This figure does not include former plantings of which there is no present visible evidence. The average survival in the existing plantings is slightly less than 30 percent. Considering the poor care which characterized the establishment of some of these windbreaks, particularly the older ones, they have fared reasonably well. There are numerous tree claims from 40 to 50 years old over the entire shelterbelt zone from which much valuable information has been obtained as to the ultimate height and average age that individual species can be expected to attain under different conditions.

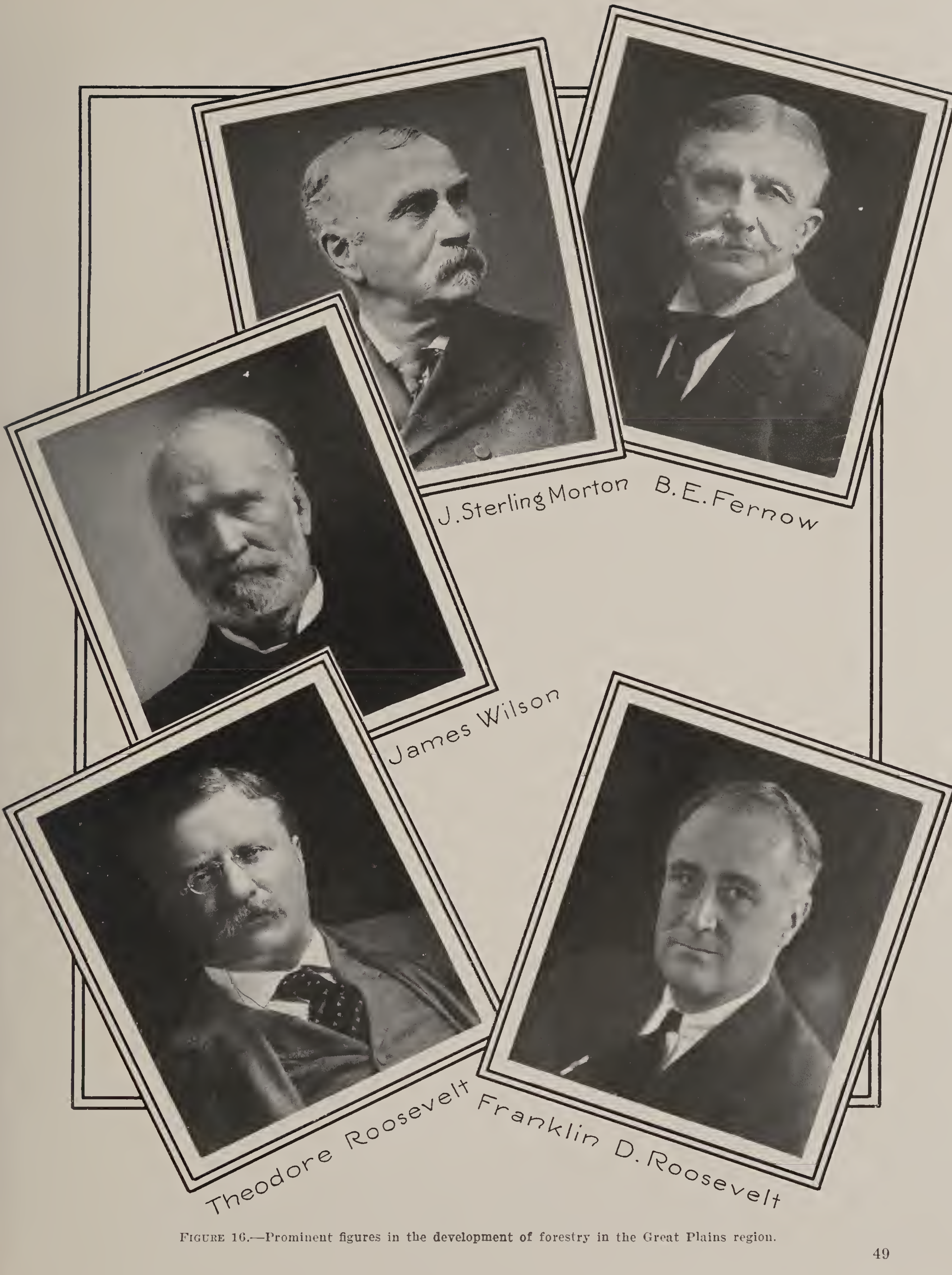

FIGURE 16.—Prominent figures in the development of forestry in the Great Plains region.

Section 8.—A REVIEW OF EARLY TREE-PLANTING ACTIVITIES IN THE PLAINS REGION

By John H. Hatton, *inspector, Plains Shelterbelt Project, Forest Service*

CONTENTS

Records of western exploration, beginning with the expedition of Lewis and Clark, contain detailed mention of tree species growing along the watercourses of the Plains which tallies in essential respects with the taxonomy of the region as it exists today. But the uplands of the Plains country have from prehistoric times been an essentially grassland rather than forest country. Currently accepted estimates place the total originally forested area of the Dakotas, Nebraska, and Kansas at about 3⅔ million acres, out of a total land area in those States of nearly 200 million acres.

Even before settlement by the whites, such wooded areas as were present had been subject to man-caused injury. The native timber had influenced the habitat of various early Indian tribes, who frequently set fires in order to deter the ingress of other tribes to favored hunting grounds.

When the white settlers came into this region, they first took up such lands as had accessible timber. With their advent came also extensive cattle grazing and more frequent prairie fires, both of which made further encroachments upon the native tree growth. The use of wood for fuel by river boats made another drain upon the natural wood supply, particularly cottonwood. Along the Missouri River extensive woodyards were established in the early days. Beginning in 1850, when the first river boat was put into operation on the Red River (of the North), a similar course of exploitation of native timber followed.

"All the native timber" in Nebraska was cut, according to a report in 1878, at the time of the building of the Union Pacific Railway, which was completed in 1869. The reference, no doubt, is to trees of usable size growing within a reasonable distance of the Platte River Valley.

Where destructive factors were eliminated, native timber reclaimed sections where it had been destroyed and, according to some opinion, even extended into other districts where it had not grown for centuries. But prairie fires continued to be a menace in some places both to native timber and planted groves. Before lands were generally plowed, prairie fires having wide scope frequently got beyond control and swept into or through planted groves, destroying or seriously impairing the growth of several years. Shelterbelt surveys made in 1934 and 1935 have brought to light the history of many plantings formerly existent but now completely effaced.

FEDERAL EFFORTS TO ENCOURAGE TREE PLANTING

As early as 1866, Joseph S. Wilson, Commissioner of the General Land Office, petitioned Congress to afforest the Plains in part. His message to Congress read:

> If one-third the surface of the Great Plains were covered with forest, there is every reason to believe the climate would be greatly improved, the value of the whole area as a grazing country wonderfully enhanced, the greater portion of the soil would be susceptible of a high degree of cultivation.

On March 3, 1873, Congress passed the Timber Culture Act. This has been the most conspicuous act in tree-planting history, either Federal or State. It provided for planting 40 acres on a timber-culture entry of one-quarter section, with trees not more than 12 feet apart each way. The act was amended in 1874 to permit entry of smaller tracts and requiring only a proportionate amount (one-fourth) of tree planting according to the acreage filed on. It was amended again in 1876, still retaining the 12-foot spacing, but permitting planting in four separate tracts and requiring replanting within a year of any trees, cuttings, or seeds which did not germinate or grow, or which were destroyed by grasshoppers.

A further amendment of the act in 1878 required that not less than 2,700 trees per acre be planted, which is equivalent to the requirement of 4- by 4-foot spacings. Provision was also made in this amendment that final certificates would be issued on a showing of 675 living and thrifty trees to each acre. Because the larger settlement booms occurred in the late seventies and the early eighties, most of the timber-entry planting was done under the 1878 provisions.

The Homestead Act went into effect May 20, 1862. Between that time and the passage of the Timber Culture Act a considerable number of settlers who came to the Plains States to establish permanent farm homes sought to improve their surroundings by planting groves and shelterbelts, and there are records of remarkably successful attempts at tree culture in some of the early-settled States. Tree planting on what might be termed a general scale, however, did not begin until shortly before the passage of the Timber Culture Act. While this act, repealed in 1891, cannot be said to have been generally successful, it did have the effect of further directing popular thought to tree culture as an important complement to Plains settlement. Commercial nurseries gradually adjusted themselves to provide additional and proper planting stock, and tree-planting thought pervaded the atmosphere more generally.

The Nebraska National Forest, established by proclamation on April 16, 1902, by President Theodore Roosevelt, constitutes the largest demonstration of sand-hill planting of conifers in the western country. The project was conceived through the success of a plantation of conifers established by the former Division of Forestry of the Department of Agriculture, in Holt County, Nebr., which is in the present shelterbelt zone. In 1891 some 20,000 seedlings were shipped in and planted on typical sand hills according to plans proposed by the then chief of the Division, B. E. Fernow. The species were ponderosa pine, jack pine, Scotch pine, and Austrian pine. Black locust, boxelder, hackberry, and black cherry were used as nurse trees.

The results of this planting led to a field examination of all the western Nebraska sand-hill area in 1901 and of the sand hills of southwestern Kansas in 1902. An area of 302,387 acres in Kansas was also proclaimed a national forest, the initial part of it in 1903, but for a number of reasons was discontinued as a national-forest project in 1915.

About 12,000 acres of coniferous forests have since been successfully established on the Nebraska area. A nursery [8] in the forest with an annual capacity of 2,500,000 trees has furnished the stock for a planting program now going forward on a scale of 1,000 to 1,200 acres annually. The capacity of the nursery is being greatly enlarged and its distribution and services extended to other projects.

The annual appropriation act for the Department of Agriculture passed on March 4, 1911, provided for furnishing trees from the nursery free of charge to settlers in the Sixth Congressional District of Nebraska, for which special homesteading privileges had been authorized by the Kincaid Act of April 28, 1904. Recently, the sixth congressional district was absorbed by the fifth, but the area covered by the original act remains the same. The provisions and purposes of the Kincaid Act have been largely absorbed by the Clarke-McNary Act.

In the 1913 appropriations for the Department of Agriculture, Congress included permission for the establishment by the Bureau of Plant Industry of the Northern Great Plains Field Station at Mandan, N. Dak., across the Missouri River from Bismarck, part of its activity to be the "growing, distributing, and experimenting with trees suitable to that region." Since the beginning of distribution in 1916, nearly 6,000,000 trees have been supplied to farms in parts of Montana, Wyoming, North Dakota, and South Dakota. The information resulting from these plantings will probably make the largest single contribution to the shelterbelt project because of the authentic records that have been kept on the behavior and successes of different species and methods of culture under different conditions, both at the station and in widely scattered field planting. This service is being supplemented by the Southern Great Plains Field Station at Woodward, Okla., and the Horticultural (or central Great Plains) Field Station at Cheyenne, Wyo.

On June 7, 1924, a milestone was erected in American forestry legislation. This was the passage of the Clarke-McNary Act, which provides for Federal and State cooperation with landowners in (1) the protection of forest land from fire, (2) the study of tax laws and the devising of tax laws designed to promote forest conservation, (3) the procurement and distribution of forest-tree seed and planting stock, (4) the establishing and renewing of wood lots, shelterbelts, and other forms of forest growth, and (5) the development and improvement of timbered and denuded forest land through acquisition and control by the Federal Government. Section 4 covers the distribution of seed and planting stock and has had a marked effect on the planting of shelterbelts and wood lots. For the distribution to be operative in any State it is required that the State make provisions to cooperate with the Government either through legislation or by designating an appropriate State department, such as the extension service, State forester's office, or conservation department, to perform the work under Federal inspection.

Results under the Federal acts have varied. Notwithstanding the strict provisions of the Timber Culture Act, it is well known that there were many cases of insincere or even fraudulent attempts at growing trees with the intent of getting title to free land; and it may be said, in general, that the existing stand of planted groves in the entire shelterbelt zone, estimated at 230,000 acres on the basis of recent observations, amounts to but a minute fraction of the 52,000,000 acres of the zone lying in the region subject to entry under the Timber Culture Act—a much smaller fraction than the extensive planting requirements of the law might have led one to expect.

But, in thousands of cases, the attempt to establish groves and shelterbelts was earnest, and repeated efforts were made until proper species and methods of culture were worked out. A large proportion of the settlers wanted trees, but the difficulties of growing them were many. Often nursery stock was bought comprising species that were neither hardy nor at all adaptable. The farmers in many cases had to profit by their own experience as tree growers, and valuable time was lost in the process. Since those earlier years, much attention has been given the subject of hardiness of species, and the pitfalls awaiting the early planters in this respect can now be avoided.

In many areas, where the planting spirit prevailed, groves sprang up and dotted the landscape, and many of them, living and thriving after 50 or 60 years, are in evidence today. These woodland monuments erected by the early settlers show the great possibilities that lie ahead of large-scale tree culture under a definite and sustained program of soil preparation, proper selection of species, provisions to hold the

[8] At Halsey, Nebr.; named the Bessey Nursery, in honor of the late Charles E. Bessey, of the University of Nebraska, through whose urging the initial steps were taken toward establishing the Nebraska National Forest.

snows, protection of the stand, and sustained cultivation and care until forest conditions shall have become established.

ARBOR DAY

Arbor Day originated in Nebraska and was first observed April 10, 1872. Since then it has come to have national and international significance. The plan was conceived and the name Arbor Day proposed by J. Sterling Morton, of Nebraska City, who was then a member of the State Board of Agriculture and later the third United States Secretary of Agriculture. According to Morton's History of Nebraska, a million trees were planted in Nebraska on that first Arbor Day. One man planted 10,000 cottonwood, soft maple, Lombardy poplar, boxelder, and yellow willow trees on his farm south of Lincoln.

On March 31, 1874, Governor Furnas, who himself had been an ardent supporter of afforestation, issued a proclamation designating Wednesday, April 8, as Arbor Day. This was the first official recognition of the event.

Each State now observes Arbor Day by Governor's proclamation or by law. It has become a school festival, which is observed not only in the United States but also far beyond its borders. Canada, Spain, Hawaii, Great Britain, Australia, the British West Indies, South Africa, New Zealand, France, Norway, Russia, Japan, and China, as well as the United States possessions now observe the occasion.

STATE EFFORTS

Each of the States through which the shelterbelt zone passes has encouraged tree planting by various means, both before and since the passage of the Timber Culture Act. Intelligent popular interest has also been wide-spread. Outstanding features of the movement will be outlined below under headings of the respective States.

NORTH DAKOTA

The area in native timber in North Dakota is said to be smaller than that in any other State in the Union.

There was little tree-planting activity in the State prior to the Timber Culture Act of 1873. In that year the Northern Pacific Railway was built to the Missouri River at Bismarck, and it was not until afterward that the influx of settlers reached the part of the State west of the Red River Valley.

North Dakota has a State forester designated by law. It also has a forest nursery established in 1913 at the School of Forestry at Bottineau. Both hardwood and coniferous trees are grown for distribution throughout the State, and work has been carried on in every county. The State has qualified for cooperation under the Clarke-McNary law. In addition, the State at one time offered a small bonus for planting and cultivating trees. Largely as a result of these activities, a distant horizon view now shows almost continuous plantations in some of the earlier-settled parts. Previous mention has been made of the important work of the Bureau of Plant Industry at the Mandan station.

Of special interest in North Dakota has been the tree-planting activity of the Great Northern Railway to prevent drifting of snow on the right-of-way. The work began in 1905. At the close of the season of 1909, 96,230 trees had been planted along 26.35 miles of main track between Grand Forks and Williston, at which time the percentage of trees living was reported as 81.5, as shown in the following figures, listed according to species and numbers planted:

	Percentage living
Ash (25,436)	79.6
Elm (18,371)	87.5
Southern cottonwood (16,684)	74.3
White willow (12,815)	76.3
Laurel willow (2,983)	86.7
Niobe willow (8,000)	85.0
Silver maple (3,697)	89.0
Silver poplar (2,000)	85.0
Boxelder (5,729)	89.3
Cottonwood (365)	86.6
Gray willow (150)	85.4
All species (96,230)	81.5

Detailed data on these plantings for years since 1909 are not at hand. Recent observations indicate, however, that the plantings for the most part are serving their purpose well.

According to estimates of F. E. Cobb, State shelterbelt director, there were planted in the North Dakota portion of the shelterbelt zone in the 10 or 12 years just prior to 1935 approximately 8 million trees, of which at least 60 percent have survived the drought and are growing.

SOUTH DAKOTA

In South Dakota a large part of land settlement occurred from 1870 to 1890, and records of tree planting prior to the Timber Culture Act are meager or of relatively small importance. Many plantings, mostly east of the Missouri River and within the central lowlands, were made under the terms of the Timber Culture Act, and many are still in evidence.

The State College of Agriculture at Brookings made extensive plantings in typical prairie sections on the east border of the State in 1885 and 1886. The trees were spaced 4 feet each way, too closely to grow to maturity without thinning. They suffered somewhat during the drought of 1893–94. In its more than 40 years of activity, the horticulture department of the State college at Brookings has made large contributions to successful tree culture by disseminating information on hardy species and methods of culture. The published reports of the South Dakota Horticultural Society record much of this information.

Forestry activities are, on the whole, of minor development in the State. No State nurseries exist. However, a State forest was created in the Black Hills by exchange of school lands for Federal lands, and recently the State has qualified for cooperation under the Clarke-McNary law.

On March 6, 1890, South Dakota passed a tree-planting bounty law, which provided that every person planting an acre or more of prairie land within 10 years after the passage of the act with not less than 900 per acre of any kind of forest trees and 100 or more of evergreens, and successfully growing and cultivating them for 3 years, would be entitled to receive for 10 years after the third season of such planting an annual bounty of $2 per acre for each acre of forest trees not to exceed 6 acres, and $1 for every 100 evergreens not to exceed 1,200.

Superseding the foregoing, a State law of 1920 provides for a bounty of $5 per acre, up to 10 acres, for a period of 10 years to any person " who, after the year 1920, shall have planted and successfully cultivated " not less than 150 trees per acre, with a showing of not less than 100 living trees per acre in any year for which the bounty is paid. A copy of the statute follows, as an example of such laws, which are more or less similar:

TREE BOUNTY

(From Compiled Laws of South Dakota, 1929)

SECTION 8045. *To Whom Paid.*—Any person who, after the year 1920, shall have planted and successfully cultivated the number of forest or fruit trees or shrubs prescribed by this article and who shall have complied with the provisions of this article, shall be entitled to a bounty of five dollars ($5.00) per acre, on not to exceed ten acres, each year for the period of ten years, to be paid by the board of county commissioners of the county in which such trees are located, out of the general fund of such county; provided that such person shall continue to comply with the provisions of this article.

SECTION 8046. *Application for Bounty.*—Any person desiring to secure such bounty shall file with the county auditor, on or before the first Monday in August, a correct plat designating the land upon which the trees are planted according to the United States government survey, together with an affidavit showing the number and varieties of trees planted, the date of planting and the cultivation of the same, corroborated by the affidavits of two freeholders residing in the vicinity.

SECTION 8047. *Number of Trees to the Acre.*—To secure such bounty there shall have been planted not less than one hundred and fifty trees to the acre, and there shall be not less than one hundred living trees per acre in any year for which such bounty is paid. Provided, that any trees or shrubbery planted after July 1st, 1927, may by resolution of the Board of County Commissioners passed at the first regular meeting of such board in January, of each year be required to be arranged and planted substantially as follows:

(a) Elms, ash, black walnut, boxelder, native cedars, Black Hills spruce, oak, cottonwood, willows, or other trees of like character not herein specifically mentioned, in rows forty feet apart and such trees twelve feet apart in each row.

(b) Russian olive and Caragana in rows thirty feet apart and such trees five feet apart in each row.

(c) Apple trees in rows forty feet apart and such trees forty feet apart in each row.

(d) Plum, pear, cherry, or other similar varieties not herein specifically mentioned, in rows thirty feet apart and such trees thirty feet apart in each row.

(e) Caragana, artisima, buckthorn, spiraea, common lilac, and other similar varieties of shrubs not herein specifically mentioned, in rows thirty feet apart and such plants one foot apart in each row.

(f) Lilac, snowball, and all other shrubs of a similar variety not herein specifically mentioned, in rows twenty feet apart and such plants five feet apart in each row.

NEBRASKA

Although Nebraska, the home of Arbor Day, has only about 3 percent of its area in native forests, it is credited with being the greatest tree-planting State in the Union.

The conservation and survey division of the University of Nebraska, which was established in 1921, includes a State forester. This organization has made a study of soils and climatic conditions in relation to tree growth and has promoted tree planting through its publications and in many other ways. There is also a State extension forester, who is on the staff of the State college of agriculture.

Veterans' organizations in Nebraska are active in their support of forestry. In 1933, the American Legion, with the assistance of the conservation division of the State university, conducted a tree-planting campaign, and in 1934 the Veterans of Foreign Wars began sponsoring a movement for a national arboretum near Nebraska City.

Congressman Luckey and Senator Burke have (in 1935) introduced identical bills into the Congress providing for the establishment of a forest experiment station for the Great Plains and Prairie States.

The State qualified early for cooperation in tree distribution under the Clarke-McNary Act, which is conducted by the agricultural extension service in cooperation with the Federal Government.

There is no State nursery, but tree-planting stock is obtained commercially and from the Forest Service nursery at Halsey (the Bessey Nursery) and distributed for planting windbreaks and wood lots at a cost to farmers of approximately $1 per hundred trees, or less in lots of more than 400 trees. In 1926, 34,000 trees were distributed to 105 farmers in 48 counties, and 53 percent of the trees lived. In 1927, 186,000 were supplied to 1,161 farmers in 92 counties; 700,000 were furnished in 1928 and a similar number in 1929. The activity has kept on increasing until, in 1934, the distribution was 1,125,000 trees.

Between Plattsmouth and Kearney the Burlington & Missouri Railroad in 1873 planted trees along 27 miles of cuts to prevent the snow from drifting into them.

Results of early plantings in most parts of the State were not altogether favorable because of improper selection of species and poor care. There was some planting in the prairies as early as 1854, but the greater part has been done since the early seventies, receiving its principal impetus from the establishment of Arbor Day in 1872 and the passage of the Timber Culture Act in 1873. By 1883 it was estimated that 250,000 acres had been planted. The early planters used such trees as cottonwood, ash, boxelder, locust, and catalpa, but relatively few pines and cedars. Fires and cattle damaged many of the groves, and few trees were irrigated.

The State gave aid to tree planters in 1869 by tax exemption up to $100 annually for 5 years if 1 or more acres were planted with trees spaced not more than 12 feet apart each way.

In 1894 the following list of trees was reported as having proved successful in the southwestern part of the State west of the one hundredth meridian:[9] Cottonwood, black locust, honeylocust, black walnut, catalpa, white ash, green ash, pine, red cedar, hackberry, silver maple, Russian mulberry.

The Nebraska College of Agriculture now issues a tree list in which the State is divided into five districts, each of which has particular requirements for tree growth. That part of the State lying west of the one hundredth meridian and wholly within the Great Plains area is designated district 5, for which the list of trees shows the following species as suitable: Honeylocust, American elm, green ash, black walnut, boxelder, cottonwood, Norway poplar, Black Hills spruce, Koster's blue spruce, blue spruce, jack pine, ponderosa pine, and Austrian pine.

[9] EGLESTON, N. H. REPORT ON FORESTRY (1884). v. 4, 421 pp., illus. U. S. Dept. Agr., Div. Forestry. 1884.

KANSAS

Kansas at one time maintained the lead as a tree-planting State but later lost it to Nebraska. About 2½ percent of the State area was originally in native forest, confined mostly to stream valleys and bluffs in the eastern part, and to ravines and watercourses farther west.

Prairie fires started by the Indians in tribal controversies were an early source of destruction to native timber, but as these were checked, timber grew again along the courses of the streams and protected ravines.

Before and during the Civil War, Kansas settlers realized that the natural wooded areas within the State were being depleted for fuel, houses, and railroad building, and many artificial plantings were made. Officials of the Kansas Pacific Railroad, apparently sensing a prospective shortage, made experimental plantings at three towns along their line in the fall of 1870 and in the spring of 1871, at elevations, respectively, of 1,186, 2,019, and 3,175 feet, all between the 98th and the 102d meridians.

An important historical publication on Kansas tree culture is the Second Report on Forestry of the Kansas State Horticultural Society (1880), which is based on answers to a questionnaire received from persons in a large number of counties. It gives information on species adaptable to low and high lands, desirable spacings, methods of culture, effect of trees on adjacent field crops, and the species, sizes, and locations of the oldest successful groves. Unfortunately, similar complete records for other States are not available.

Almost all the eastern counties of Kansas reported plantations successfully established in the years following the drought of 1860, and a few established in the late fifties. In counties farther west—McPherson, Mitchell, Reno, Saline, and Sedgewick—beginnings were made about 1870.

The above are some instances of tree planting antedating the Timber Culture Act. The planting sites were mostly on uplands, and no dissenting opinion was expressed as to the feasibility and desirability of spreading the gospel of tree planting on the Plains. All the correspondents stressed proper preparation of the soil and giving the trees the same culture as a crop of corn until the trees could shade the ground. Late seasonal cultivation was not advised. Those early experiences set forth principles that are considered as fundamentals in the inauguration of the present shelterbelt planting program. Had they been followed out consistently in early plantings, successes would have been much more numerous than have been recorded. With the rapid development of agriculture, however, there was an increasing tendency to neglect tree culture and concentrate on crops.

A few quotations from this historical report will illustrate how certain varieties are continually rediscovered. An Independence correspondent, after discussing the most important of the 60 native hardwoods of Kansas, wrote as follows:

> If those counties which are nearly or quite destitute of natural forests are to be settled by an agricultural people, in such numbers as to form a farming community, with farms sufficiently small to admit of having neighbors and schools, and all the advantages and pleasures that flow from social intercourse and country life in pleasant country homes, surrounded with shade trees, fruit trees and flowers, or even if those farms are to produce the common necessaries of life, then in connection with the preservation and increase of the timber already growing, the planting of artificial forests, in a systematic and extensive way, becomes a necessity. But the cultivation of forests will not be successful in a general way, until the Government and the people are fully awake to its importance, and until the business is conducted by intelligent and skillful men, whose foresight reaches beyond the mere present, and who are working to build up for themselves and their children pleasant and permanent homes. The mere adventurer seldom if ever does anything to benefit the locality where he chances to stop; he only destroys what there may be around him, and leaves more desolation behind him than he found.
>
> For wind-breaks, especially on division lines of farms, there can hardly be a better plan devised than to plant a double row of osage-orange, at the joint expense of the owners of the farms. Let a strip of land one rod wide be taken half from each farm, properly prepared, and two rows of osage-orange be set, with the plants a foot apart in the rows, which may be four feet apart. The land should be properly cultivated for a few years, and the young trees cut back, until the bottom of the hedge is sufficiently thick and strong, and then be allowed to grow at their will. They will soon form an impenetrable fence, and a very efficient wind-break. The rows will effectually support and protect each other, stop the snow, lessen the ill-effects of high winds, and form a safe and pleasant retreat for the birds.

The excellent advice of this contributor was well heeded in Kansas following 1880, but in the agricultural boom during and briefly following the World War the Osage-orange hedges, particularly, were heavily slaughtered. It may be questioned seriously whether this method of increasing the tillable area has paid, even up to the present.

Under the caption "Trees Successfully Grown in Kansas", the following interesting observations from Dickinson County, in the east-central part of the State, are found:

> *Honey locust.*—On account of rapidity of growth and value of timber for fuel, posts, furniture, etc., we regard this native tree as very valuable. The idea seems to be common that this tree, like the common black locust, is liable to sprout from the roots, and is also subject to attacks of the "borer." For the benefit of this quite numerous class, it will be well to state that both ideas have no foundation in fact. The seed ripens in September. Sow in spring, near corn-planting time. Before sowing, scald the seed severely, by pouring boiling water over them.
>
> *Elm* (*red and white*).—These two trees are beyond all question hardy, even in the most exposed positions. In rich soil they grow with great rapidity. They are, as far as our observation goes, entirely free from disease and insects. Grown thickly in artificial groves, they run up straight and tall. For isolated trees for shade, for avenues, or for group-planting for landscape effect, they are not excelled by any native tree. Michaux was right when he said that the "white elm was the most magnificent vegetable of the Temperate Zone." This special commendation of these two trees may be received with some doubt by those who have given the matter but little attention. We do not wish to convey the idea that exclusive plantations be made of any one tree. But example and fashion have too much influence in guiding tree planting. The soft maple, for instance, became, years ago, the popular tree for general planting all over the eastern portion of our State. Let us suppose that the elms had been the popular trees; how different would have been the face of the landscape there today! The seed of the elms ripen in May. Sow at once, in a moist, shady spot. Plant out the trees next spring, preserving the tap-root.
>
> *Evergreen trees.*—The number of these adapted to the climate of our State are not very numerous. The Scotch pine is easily transplanted, grows rapidly, and makes a strong, spreading tree. The Austrian pine is in every way a denser-growing and finer tree than the Scotch, and as a screen, is impenetrable to the wind. The red cedar is a tree of more moderate growth, but it is valuable in a shelterbelt. Avoid large trees of all of these three for transplanting. Choose sturdy growths one foot high, thrice transplanted. Plant

early in the spring, mulch when planted; continue mulching for years, and success is certain.

Trees discarded.—Ailanthus, *Catalpa bignonioides*, black and yellow locust, Lombardy poplar, larch, and white willow; evergreen trees—balsam fir, Norway spruce, white pine, and arborvitae.

Observations.—We observe in our journeyings throughout the state, that those settlers who planted shelterbelts and groves are fixtures on their farms, while those who never planted a tree have pulled up stakes and gone elsewhere, and others of the same class are still going. Home attractions are lacking.

We notice always that trees are an ample protection from the most violent storm. While a northwest blizzard is howling in frigid fury across the open prairie, piercing the many wrappings of humanity, it is pleasant to have the homestead safely anchored on the southeast side of a dense grove.

We observe that our domestic animals appreciate the shelter afforded by trees . . .

We notice everywhere throughout this broad commonwealth, that plantations of trees effectually protect the garden, the orchard and field crops. This question was settled most conclusively during the spring of 1880. Sleet-laden branches were snapped by the billows of the wind. The tender inflorescence was chilled to death. The garden planted by the careful housewife was swept bare by the drifting winds, and the cereals sown in the fields were whipped and ruined irretrievably; and all this and more, because good sturdy trunks and stout pliant branches were not put in the ground years before to wrestle with the mighty winds and wrest from them their destroying power. Give us timber belts every half mile, good solid hedges every eighty rods, and then the Kansas farmer can laugh at the impetuous cold of the northwestern storm.

The following observations concerning experimental plantings at Manhattan are pertinent, in the main, today:

Considering the poverty of the soil in which they stand, the black walnuts, catalpa, osage-orange and cottonwood have made exceptionally fine growth. The wisdom of close planting is here apparent. Trees in these plats, standing about one foot by four apart, have served as a protection to each other—shading the trunks, rendering them less liable to the attacks of boring insects, and retaining the moisture of the soil. The tendency to a low, spreading growth, which is found on less dense plantations, is here corrected; and the trees take instead an upright form, with smooth, straight trunks branching high. This is, of course, a consideration of great importance where trees are grown for timber.

It may be added that the excellent showing of close plantings at an early age was often not maintained, because of common mistaken sentiment against thinning. Such an operation is now recognized as absolutely necessary to maintain the health of stands, and its necessity is no argument for wide spacing at the outset, which subjects the young trees to all the rigors of complete exposure.

A report by the writer in August 1902 on the sand hill and adjacent section in southwestern Kansas, near the one hundred and first meridian, stated that tree planting was entirely practicable on the heavier soils, and that it was believed locally that conditions in the sand hills were even more favorable. The fact that all the trees then growing in southwestern Kansas had been planted within 25 years gave

large hopes for the future of forestry in that section of the state. Kinsley, Dodge City, and Garden City are veritable forests of trees, and water is 100 to 140 feet below the surface in parts of Dodge City. Unfortunately, little has been demonstrated in the sandhill formation.

The report outlined the differences in physical characters of the sand formation in the Kansas area and the western Nebraska areas, the former being much coarser in texture. Demonstrations later, by the Forest Service, in the Kansas sand hills proved discouraging and were discontinued in 1915. These soils proved less favorable for tree growth than the harder soils. Moisture near the surface was deficient, and young trees were unable to survive until they could get their roots down.

At that time the following tree species were noted in plantings in and about Garden City: Cottonwood and three other species of poplar (*Populus nigra*, *P. alba*, *P. balsamifera*), juniper, boxelder, sycamore, black locust, honeylocust, ailanthus, elm, Scotch pine, mountain-ash, plum, birch, catalpa, two species of ash, spruce, Swiss stone pine, and Russian-olive.

This was 22 years after the 1880 reports previously quoted, which recorded more easterly plantings. Again, in 1932, 30 years later still, Fred R. Johnson, of the Forest Service, Denver, made the following comments on a number of successful plantings near Dodge City and Goodland, Kans.:

Any doubt about the practicability of tree planting in western Kansas is removed, after seeing the foregoing groves. It is true that high-grade timber products are not secured, but that is not the main objective. Their protection value can scarcely be measured. It was of great interest to note that if trees are spaced close enough and the grove is large enough, forest conditions can eventually be secured and cultivation may be discontinued.

In this connection one planting 45 years old, near Goodland, was specifically cited.

The above observations for the southwest and northwest portions of the State are significant, because conditions there are considered less favorable, owing to excessive evaporation, than in most of the shelterbelt zone.

The first State forestry law in Kansas dates from 1887. This law allowed county commissioners to make some adjustment in taxes for tree planting, but practically no applications were made under it. A division of forestry was created in the State Agricultural College at Manhattan in 1909. There is also a State nursery at Hays.

Efforts at forestation in central and western Kansas since 1885 have resulted in a large number of good plantations, many poor ones, and, naturally, some failures due to variant ideas about tree planting and marked differences in conditions. There are enough successful plantations remaining to furnish lessons and encouragement for future planting under the shelterbelt program.

OKLAHOMA

Nearly 30 percent of the area of Oklahoma, confined mostly to the central and eastern parts, was originally in forest. Only the western one-third of Oklahoma, roughly between the 98th and 100th meridians, is in the Great Plains region, and much of this is covered by a scrubby growth of shin oak.

Oklahoma was peopled by Indians and was considered Indian Territory until 1889. The last tribes of plains Indians were moved into that territory in 1880. Prior to that time and following the Civil War, white cattlemen occupied a considerable part of the Oklahoma area, but white land settlement proper did not begin until 1889, when a clause attached to the Indian appropriation bill provided for the opening of "Old Oklahoma" or the "unassigned lands" to settlement. Oklahoma attained statehood in 1907.

Settlers, after the opening in 1889, planted considerable numbers of trees, most of which were black locust. Except on the bottom lands, however, they were largely killed out by borers.

In 1925 the legislature created a forestry commission. There are no forest-tax laws or tree-planting bounties. An interest in forestry, including the planting of trees and the reforestation of lands from which forests have been cut, is created and fostered in schools and colleges. Experimental and demonstrational tree planting was begun in the western part of the State in 1928, when five areas were planted under the supervision of the State forester.

TEXAS

It is estimated that about 18 percent of the gross area of Texas, mostly east of the 98th meridian, was originally in forests. This has been reduced to less than 10 percent of the gross area.

There are 4 State forests, totalling 6,293 acres, and 2 State nurseries with a combined capacity of 200,000 trees. There are no forest-taxation laws, but an effort is being made by the State forestry service and the Texas Forestry Association to have laws enacted that will encourage reforestation.

The public lands in Texas were owned by the State, and the Timber Culture Act did not apply to them. Despite lack of public aid, many plantings were made by the pioneers. Although most of them were neglected, there are isolated instances of success, even where groves were completely abandoned. On the High Plains of extreme western Texas, opened as wheat-farming territory more recently, tree planting has not been successful except with some degree of irrigation.

Experimental plantings in the Plains section have been at Dalhart, Amarillo, Lubbock, and Big Springs. At Dalhart, in 1908, the Forest Service directed the planting and furnished the stock. The species were ponderosa pine, black locust, American elm, green ash, Russian mulberry, Osage-orange, and red cedar. Catalpa was added later to replace ash. Russian mulberry, black locust, catalpa, and American elm, in the order named, showed the best survivals.

Section 9.—SHELTERBELT EXPERIENCE IN OTHER LANDS

By Paul O. Rudolf, *junior forester*, and S. R. Gevorkiantz, *silviculturist*, *Lake States Forest Experiment Station, Forest Service*

CONTENTS

No human activity so common and so wide-spread as the planting of trees for protective and ameliorative purposes can be adequately considered within the limitations of a hurried report. It is of compelling interest, however, to give some attention to available records of such foreign plantings as are in any wise comparable to our own shelterbelt project in scale, system, objectives, and conditions encountered. Sources of pertinent information in these respects are confined practically to plantings within the last half century in Canada, Denmark, Hungary, and, most notably, Russia. Salient aspects of these undertakings—their character, scope, and the results and findings thus far arrived at—are presented below, under headings of the respective countries.

CANADA

The prairie region of Canada, which occupies about 235,000 square miles, includes the southwest portion of Manitoba and the southern and central portions of Saskatchewan and Alberta (*32*).[10] In this region the soil, topography, and climate are sufficiently akin to those of the northern Great Plains area of the United States to offer similar inducements to shelterbelt planting, and the inhabitants, with governmental aid and encouragement, have done much work in developing planting methods and testing tree species.

The soil is generally fertile. Topographically, the area is level to slightly rolling. Elevations increase from about 800 feet above sea level on the east to 3,500 feet on the west.

The southern portion of Saskatchewan and the southeastern part of Alberta are characterized as semiarid. The rest of the area is slightly moister and is classed as subhumid (*41*). The average annual precipitation averages from 13 to 20 inches, decreasing from east to west; in dry years, it may be as low as 8 or 9 inches. Temperatures range from 100° F. (rarely) in the summer to −50° in the winter. From early November to early April the soil is frozen, with frost penetrating to depths of 7 or 8 feet (*32*). Average wind velocities are relatively high.

Thousands of early settlers in the prairie regions planted trees about their homesteads. Failures, however, were general, chiefly because of the use of unsuitable tree species and lack of experience in tree culture under rigorous conditions. This situation soon led the Dominion Government to establish experimental stations in the Prairie Provinces, and work was done which indicated certain species and technics with which successful tree planting could be accomplished on the prairie. In 1901 a system of cooperative planting was begun by the Dominion Forestry Branch, whereby farmers were supplied with planting stock free of charge on condition that they would carefully follow instructions in setting out, cultivating, and caring for the trees. Up to and including 1934, no less than 139,250,000 seedlings and cuttings had been distributed from the Government nurseries to some 54,000 farmers under this cooperative system, and the plantings have been generally successful.

SPECIES

Of the tree species native to the region, those most commonly occurring are aspen (*Populus tremuloides* Michx.), balsam poplar (*Populus balsamifera* L.), cottonwood (*Populus deltoides* Marsh.), boxelder (*Acer negundo* L.), green ash (*Fraxinus pennsylvanica lanceolata* (Burk.) Sarg.), and American elm (*Ulmus americana* L.). With the exception of cottonwood, all these reach their western limit approximately at the 108th meridian.

All the important native species and a number of exotics have been tested at the nursery station, Indian Head, Saskatchewan (*32*). Those distributed, however, are the ones that can be grown most cheaply and are best suited for the whole region. The species most commonly planted are, in order of frequency, boxelder, green ash, Siberian pea-tree (*Caragana arborescens* Lam.), Russian willows, various poplars, Scotch pine (*Pinus sylvestris* L.), and white spruce (*Picea glauca* (Moench.) Voss).

[10] Italic numbers in parentheses refer to titles in the bibliography at the end of this section, pp. 75–76.

PLANTING AND CULTIVATION

Where planted for the protection of farmsteads, shelterbelts usually consist of 5 to 7 rows of trees. The authorities do not recommend wider belts unless hedges are planted outside to act as snow traps and to prevent snow breakage within the groves. Shelterbelts for the protection of fields vary from one to four rows in width and are planted 600 to 1,200 feet apart laterally along the borders of the fields. Since the prevailing winds are chiefly from the west and northwest, the belts are usually oriented north and south (*32*).

Instructions require that the ground be thoroughly summer-fallowed the year before planting. During each of the first 3 or 4 years after planting the ground must be kept constantly cultivated and weeded. Trees are planted 4 feet apart both ways: consequently cultivation between rows is not ordinarily feasible after the fourth year, but in order to conserve all possible moisture and to prevent grass from encroaching from the sides, a strip of soil 10 to 15 feet wide along the outer edges is cultivated permanently (*32*).

The young stock is planted in furrows plowed in the previously prepared soil. Stock planted to date has consisted of approximately 98 percent hardwoods and 2 percent conifers. The hardwoods are planted usually as seedlings or cuttings and the conifers as transplants (2–2 years for pine and 3–3 years for spruce).

EFFECTS

No data are at hand indicating the relative extent of established shelterbelts in the region, but in no event can it be assumed that plantings, of whatever description, occupy as large a proportion of the area as that so occupied in the Dakotas or Nebraska. Conclusions as to generalized effects on climate, wheat production, and the like are therefore entirely unwarranted, nor are any sweeping claims current in such respect. The fact speaks for itself, however, that a satisfactory planting program is going forward in response to a broad demand from farm inhabitants, who consider that a good windbreak increases the value of their property, on the average, by $1,000. Reputable observers have noted clear instances during the recent dry years where fields on the leeward side of shelterbelts have produced grain crops, whereas those on the windward side had been entirely destroyed by soil blowing. Some of the older groves have already proved of considerable value as producers of fence posts obtained from thinnings.

DENMARK

Danish conditions are much more favorable for tree growth than are those in our Plains region. However, a brief description of Danish experience is included because shelterbelt technic has been highly developed in Denmark, and in its general features it is similar to that needed for successful shelterbelt planting anywhere.

In Jutland, the great low-lying peninsular part of Denmark that is exposed to the full sweep of winds from the North Sea, an area of once fertile agricultural soil has been gradually buried under drifting sand. In unprotected areas the wind destroys gardens, damages plants and buildings, dries out the soil, and whips off the grain in the fields (*7*). The Danes long ago undertook measures to combat this menace and have come to the conclusion that shelterbelts and hedges of trees and shrubs are the most satisfactory means for reducing high-wind velocities and their attendant damage.

SPECIES

The species used in Denmark are, of course, suited to a more humid climate than that of our shelterbelt zone. Those recommended are, of conifers, white spruce (*Picea glauca* (Moench.) Voss) and silver fir (*Abies alba* Mill.); of hardwoods, hawthorn (*Crataegus oxyacantha* L.), blackthorn (*Prunus spinosa* L.), mountain-ash (*Sorbus intermedia* Pers.), cherry (*Prunus padus* L. and *P. mirabilis* Hort.), syringa (*Syringa* sp.), willow (*Salix caprea* L. and *S. viminalis* L.), alder (*Alnus glutinosa* Gartn.), birch (*Betula* sp.), and poplar (*Populus* sp.). Others used to some extent are English elm (*Ulmus campestris* L.), English oak (*Quercus robur* L.), southern red oak (*Quercus rubra* L.), European beech (*Fagus sylvatica* L.), filbert (*Corylus avellana* L.), hornbeam (*Carpinus betulus* L.), hedge maple (*Acer campestre* L.), European elder (*Sambucus nigra* L.), Norway spruce (*Picea excelsa* Link.), and Sitka spruce (*Picea sitchensis* (Bong.) Carriere). All the species referred to are distinctively European, with the exception of white spruce, southern red oak, and Sitka spruce.

PLANTING AND CULTIVATION

Recommendations for planting specify thorough ground preparation, with complete turn-over of the soil to a depth of as much as 2 feet, in the fall; spring planting, with good stock and the use of very careful methods to promote natural root development; close spacing, ranging, according to the species, from 1 to 4 feet each way; and continuous and careful tending of the shelterbelts after planting. Danish practice favors relatively narrow shelterbelts, ranging from 2 rows of trees to 40 feet in width, distributed at intervals of 400 to 500 feet. For the wider belts, a three-storied stand is produced. Stands of mixed hardwoods and conifers are not recommended (*7*, *13*). Since the prevailing winds are westerly, the shelterbelts are made to extend north and south.

EFFECTS

Danish statements attribute to shelterbelts favorable effects upon air and soil temperatures, wind velocity, evaporation, relative humidity of air in local areas, and increases in agricultural yields up to 30 percent, for some crops (*7*, *13*, *18*, *5*). The distance to which shelterbelts extend protection is considered to be 10 to 12 times their height (*13*, *5*). Certain disadvantages in the use of shelterbelts are recognized, but the advantages are held to outweigh the disadvantages many times over.

HUNGARY

The Alfold, the Great Plain region of Hungary lying generally southeast of Budapest, embraces a vast area of dark and chestnut-colored soils known as the

"Pouszta", celebrated as a grazing and stock-breeding region. With the advance of farms and vineyards on these plains, the scarcity of tree growth has come to be felt keenly.

The climate of the Alfold is quite similar to that of the northeastern portions of our own prairie region. It is characterized as subhumid, microthermal (predominantly cool), and adequate as to precipitation (*42*). As a matter of fact, the precipitation is comparatively low, averaging 24.2 inches annually at Budapest. Strong and steady winds are characteristic of the region; annual monthly and daily temperatures vary strikingly, and the relative humidity is low (*18*).

The planting of shelterbelts for protection of orchards, vineyards, and cultivated fields has been common in the region for a considerable period, though what total area has been so planted is not known. Records show that in the vicinity of Szeged, in the extreme south, some 8,000 acres of groves and shelterbelts have been planted during the last 40 years (*18*).

A law promulgated in 1923 provided for a definite system of shelterbelt planting on the plains. It decreed that the Hungarian forest service should select areas to be planted to shelterbelts, should make all plans for such planting and for the future care of the stand, taking the wishes of the owner into consideration as far as possible, and should carry on shelterbelt research; that the owner should do the planting within a specified period according to forest service regulations and, in return, receive planting stock at nominal prices and enjoy reduced taxation on his land (*18*).

SPECIES

Hungarian foresters properly lay great stress on the adaptation of species to topography, locality, and soil. That the trees wanted for service in shelterbelts on the plains must show vigorous development and high survival value is reflected in the following list of preferred species:

Acacias, poplars, willows, Turkey oak (*Quercus cerris* L.), English oak (*Quercus robur* L.), hackberry, mulberries, hedge maple (*Acer campestre* L.), white birch (*Betula alba* L.), Scotch pine (*Pinus sylvestris* L.), and Austrian pine (*Pinus nigra* Arnold).

For hedges, the following are preferred: Osage-orange, honeylocust, hawthorn (*Crataegus oxyacantha* L.), blackthorn (*Prunus spinosa* L.), common privet (*Ligustrum vulgare* L.), tamarisk (*Tamarix gallica* L.), cornelian-cherry (*Cornus mas* L.), English elm (*Ulmus campestris* L.), mulberry, hedge maple (*Acer campestre* L.), lilac (*Syringa* sp.), and hornbeam (*Carpinus betula* L.).

PLANTING AND PLACEMENT OF SHELTERBELTS

The shelterbelts usually consist of 3 to 6 rows of trees planted in the ancient quincunx arrangement, that is, equally spaced in staggered rows, so that any group of five trees will be arranged like the "five" on dice. The belts are orientated at right angles to the direction of the most damaging winds, with intervals between them depending on the topography. If the slope is oblique to the direction of the prevailing wind, the belts are placed closer together than when the slope is parallel to the direction of the prevailing wind.

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EFFECTS

Many claims are made regarding the beneficial effects of these Hungarian shelterbelts, as that they reduce evaporation of soil moisture, promote dew formation, retain litter and snow, prevent deep freezing of soil, stabilize sandy soils, protect flowers, hasten the ripening of fruit, lessen vertical growth and decrease breakage of fruit trees, decrease premature fruit dropping, and reduce dust. Most, if not all, of these benefits, insofar as they are realized, can be attributed to a reduction of wind velocity. The belts are also of use in providing shelter for birds and furnishing some timber and fuel wood.

In November 1922, August 1923, and June 1925, careful and detailed measurements of wind velocities at various distances on all sides of a number of groves and shelterbelts were made in the Szeged-Királyhalma region and on the Nagyhortobagy Steppe at 41, 123, and 211 stations, respectively. The results of measurements at a height of 5.3 feet, with disturbing effects of ground humps and hillocks eliminated, present the following picture of wind behavior: As one approaches the stand from a distance of 66 to 263 feet (depending on the height and density of the stand) to the windward, the wind velocity begins to decrease. The decrease is continuous up to the edge of the stand, where a further slight but sharp decrease takes place. At a point within the stand the velocity decreases to a minimum—sometimes, in wide, dense stands, to zero—beyond which it increases slowly up to a point and then may remain constant until the leeward edge of the stand is reached. Here again the velocity decreases slightly but suddenly, and it continues to decrease up to a distance of 33 to 66 feet in the lee of the stand, where it reaches a second minimum. Thereafter it gradually increases until it regains its normal or general value, at a point from 10 to 30 times the height of the stand away. In the protected zone to leeward the velocity averages from 70 to 80 percent of normal. Practically no reduction in wind velocity is noted on the flanks of stands or toward their upper levels (*23*, *24*).

These measurements tend to bear out, to a degree, the claims made as to the benefits conferred by strip or shelterbelt planting. Other observations cited (*18*) are in substantial agreement in indicating that the distance to which shelterbelt effects extend is 15 to 20 times the height of the trees, although a further finding is made that the effect is not entirely dissipated until a distance of 50 times the height is reached. Whether this latter value applies to level or to sloping areas is not made clear. It is well known that groves on ridges are effective to a greater distance than those on the sides or bases of slopes (*51*).

Increased crop yields in protected fields have been noted near the town of Szeged. More specifically, data with reference to the effect of shelter belts on the production of strawberries have been recorded at the Rétfalu experiment station. Here two windbreaks of *Quercus cerris* L., about 23 feet high, protect a 0.25-acre field, in which the yields of strawberries were measured upon plots established at different distances from the shelterbelts during the seasons of 1920 to 1923 (*18*). The results, shown in table 11, indicate that the belts have a favorable effect not only on the total yield but also upon the early maturity of strawberries.

TABLE 11.—*Yield of strawberries at Rétfalu experiment station, Hungary*

Harvest	Distance from shelterbelt				
	20 feet	43 feet	59 feet	79 feet	98 feet
	Tons per acre	*Tons per acre*	*Tons per acre*	*Tons per acre*	*Tons per acre*
Annual average	4.062	3.750	3.390	2.945	2.095
Average, first 10 days of bearing	.847	.713	.402	.312	.268

Some detrimental effects of shelterbelts have also been noted under the conditions of the Hungarian Plains. Where shelterbelts are oriented east and west, a drying effect becomes evident in a zone extending some 26 to 33 feet on the south side, where sun exposure is greatest. The roots of the shelterbelt trees sap some moisture from the adjacent fields. It is stated that fruit trees growing near the belts produce small fruits of poor color, are less resistant to insect and disease attacks, and are more subject to damage by late frosts. Vines do poorly where they are shaded by the trees. To avoid these detrimental effects, the recommendation has been made that species resistant to solar radiation and dry conditions be planted on the south sides of the belts. To reduce the effects to the minimum, hay crops such as alfalfa, clover, or the like should be planted nearest the belts (*18*).

RUSSIA

Shelterbelt planting in Russia is largely confined to the Chernozem soil region of the steppes. The location and the great extent of these soils in Russia and Siberia can be visualized by referring to the map shown in figure 17. The steppes as a whole cover a broad zone centering approximately on the 50th parallel of latitude and extending for a quarter of its circuit around the world, from Poland and Rumania through the Ukraine, across the Volga River and the Ural Mountains into Siberia, and generally eastward to Manchuria. The region of Chernozem soils, which, in general, coincides with the zone most feasible for shelterbelt planting, occupies chiefly the northern, more humid portions of the steppes. Across central and southern Russia, through the Ukraine, and southeast far into the Caucasus, the Chernozem region has its greatest sweep in width, more than a thousand miles.

It is with the steppes of European rather than Asiatic Russia that this discussion is principally concerned, because it is there that shelterbelt planting and investigation have been most actively carried on. The region in question lies mostly between latitudes 48° and 54° in central Russia, extending from north of the Black Sea to north of the Caspian.

In many respects the Russian steppe bears a close resemblance to our prairie-plains region, as will be seen from the following brief description.

Its topography is essentially level to slightly rolling. The European portion is cut by numerous ravines, whereas the Siberian (Asiatic) portion is characteristically flatter.

It lies between a more humid, forested region (on the north) and more arid to semidesert regions (on the south). Climatically, it occupies a zone characterized in general as subhumid (prevailingly dry), microthermal to mesothermal (cool to moderate), and with adequate to deficient precipitation (*42*), corresponding in all three respects more or less closely to our Great Plains region. The climate is marked by sharp changes in temperatures, with cold winters and hot summers; a low and quite variable annual precipi-

FIGURE 17.—Chernozem soils of Russia and Siberia. (From Boleshaya Sovetskaya Entsiklopedia, v. 61, p. 330.)

tation ranging from 8 to 21 inches; sweeping desert winds (from the east), especially in winter and spring, which carry heated air with a relative humidity frequently as low as 10 percent; and high evaporation, usually greater than the annual precipitation. Severe dust storms occur periodically in the region, having been recorded as long ago as the sixteenth century (*45*) and as recently as 1934. The following precipitation-evaporation ratios help to explain the droughtiness of this region as compared with others: Forest region, 1.24; forest-steppe transition zone (oak steppe), 0.97; northern steppe, 0.63; southern steppe, 0.33. (The evaporation is that from a free-water surface.)

In the area where most shelterbelt investigations have been carried on, 11 weather stations from 48° 35′ to 54° 12′ north latitude and from 34° 35′ to 50° 10′ east longitude indicate an average annual temperature of 41.5° F. (ranging from 37.0° to 45.9°), and an average annual precipitation of 18.1 inches (ranging from 14.2 to 21.5 inches), with the lower values toward the southeast (*14*). From 9 to 12 inches of rainfall occur during the vegetative period, April to August, inclusive. Comparison of these various particulars with the climatic data of our shelterbelt area indicates essential similarities, although the temperatures in Russia correspond to those of the northern rather than to the southern part of our zone (see tables 12 and 13).

The typical soils in the portion of the steppes in which we are interested are the Chernozem soils. They cover a total area of 609 million acres, of which 338 million acres—an area more than four and a half times the size of the shelterbelt zone—are the European part. The Chernozem types are dark-brown to black in color and contain a high percentage of organic matter. As a result of the low precipitation, water does not penetrate them very deeply, and consequently concentrations of alkaline compounds and salts are formed at shallow depths, as in our Great Plains soils. These alkaline soil conditions are unfavorable to the growth of many tree species and more suited to grasses.

TABLE 12.—*Temperature and precipitation of the steppe region in Russia*

AVERAGE TEMPERATURE (° F.)

Station	Latitude north	Longitude east	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
Uliyanovsk [1]	54° 12′	48° 25′	7.3	9.8	20.5	26.7	56.4	63.2	67.9	63.2	51.9	38.7	25.2	12.9	37.0
Samara	53° 10′	50° 10′	7.8	9.3	20.5	40.4	58.0	65.9	70.7	67.2	54.7	40.9	26.3	14.0	39.6
Penza	53° 10′	45° 00′	10.3	11.3	21.2	39.0	56.8	64.3	68.3	65.8	53.0	40.7	26.9	16.5	39.5
Volsk	52° 50′	47° 30′	8.8	11.5	23.0	41.2	59.8	65.5	72.2	67.8	55.9	42.4	27.0	14.0	40.8
Tambov	52° 45′	42° 30′	10.7	14.9	22.4	39.9	57.7	64.8	68.8	65.3	54.2	42.3	28.6	18.0	40.6
Orel	52° 56′	36° 05′	13.7	16.0	24.0	39.1	56.6	63.3	67.9	64.8	54.2	42.7	28.4	18.6	40.8
Saratov	51° 30′	45° 55′	11.5	14.3	23.5	41.2	58.9	67.5	72.0	68.9	57.4	43.2	29.2	17.2	42.1
Voronezh	51° 40′	39° 10′	13.7	16.2	25.5	42.0	57.0	65.1	68.9	65.4	54.6	42.4	28.9	19.1	41.6
Kharkov	49° 58′	36° 11′	16.2	21.6	29.3	44.5	57.9	65.1	69.5	66.8	56.8	45.6	33.1	23.0	44.1
Poltava	49° 36′	34° 35′	17.5	20.3	29.6	44.5	59.3	65.7	69.7	68.7	57.9	46.7	33.0	23.3	44.7
Lugansk	48° 35′	39° 19′	17.1	19.8	30.1	46.7	60.8	68.1	72.8	70.9	59.7	47.1	34.4	23.6	45.9
Average															41.5

AVERAGE PRECIPITATION (INCHES)

Station	Latitude north	Longitude east	January	February	March	April	May	June	July	August	September	October	November	December	*Total annual*
Uliyanovsk	54° 12′	48° 25′	0.78	0.56	0.72	0.94	1.39	2.12	2.72	1.88	1.81	1.18	1.04	0.90	16.0
Samara	53° 10′	50° 10′	.91	.70	.67	.95	1.29	1.73	1.89	1.26	1.35	1.17	1.29	.98	14.2
Penza	53° 10′	45° 00′	1.20	1.20	.87	1.23	1.82	2.37	2.39	1.38	1.69	1.37	1.45	1.32	18.3
Volsk	52° 50′	47° 30′	1.58	1.51	1.09	1.44	1.63	1.76	2.09	1.42	1.96	1.68	1.98	1.78	19.9
Tambov	52° 45′	42° 30′	1.18	1.10	1.42	1.28	1.78	2.29	2.09	1.97	1.65	1.79	1.62	1.74	19.9
Orel	52° 56′	36° 05′	1.23	1.13	1.55	1.55	1.88	2.45	3.04	2.29	2.00	1.71	1.32	1.39	21.5
Saratov	51° 30′	45° 55′	.97	.93	.75	1.12	1.17	1.46	1.60	1.20	1.09	1.43	1.38	1.53	14.6
Voronezh	51° 40′	39° 10′	1.49	1.29	1.41	1.52	1.90	2.62	1.97	1.97	1.68	1.61	1.65	1.83	20.9
Kharkov	49° 58′	36° 11′	1.17	1.33	1.42	1.35	1.67	2.47	2.55	1.89	1.41	1.40	1.19	1.44	19.3
Poltava	49° 36′	34° 35′	.82	1.00	1.32	1.45	1.86	2.71	2.31	1.93	1.70	1.86	1.28	1.46	19.7
Lugansk	48° 35′	39° 19′	.83	.74	.94	1.13	1.76	2.02	1.95	1.38	1.11	1.15	1.24	1.06	15.3
Average															18.1

[1] No data are available on length of period upon which observations are based. It is probably safe to assume the data are averages for a period of at least 10 years, and probably longer.

TABLE 13.—*Temperature and precipitation at selected stations in the shelterbelt region*

AVERAGE TEMPERATURE (° F.)

Station	Years covered	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
	Number													
Towner, N. Dak	32	3.8	7.7	22.1	41.9	53.2	62.8	68.0	65.4	56.2	43.4	25.2	10.1	38.3
Steele, N. Dak	40	7.3	9.4	23.3	43.2	53.4	62.5	69.4	66.7	56.9	43.8	26.3	12.3	39.5
Ipswich, S. Dak	35	11.2	13.7	28.2	44.2	[1] 56.4	66.2	70.7	69.1	58.8	46.4	37.3	15.9	43.2
Tyndall, S. Dak	32	18.7	21.4	34.2	48.4	59.4	68.7	74.4	72.5	63.0	51.1	35.8	22.9	47.5
O'Neill, Nebr	31	20.4	23.3	34.4	48.5	58.8	68.1	74.6	72.4	64.1	51.5	35.3	24.4	48.0
McCook, Nebr	32	26.7	30.2	39.5	50.9	60.9	71.1	77.4	75.5	66.3	53.6	39.3	28.0	51.6
Oberlin, Kans	46	26.9	31.0	40.4	51.0	60.6	70.8	77.2	75.5	66.5	53.6	40.2	27.9	51.8
Coldwater, Kans	36	32.5	37.0	46.1	56.3	64.9	75.1	80.0	78.8	71.8	58.6	45.2	34.3	56.7
Woodward, Okla	33	35.4	39.3	48.3	58.4	67.0	76.6	81.5	80.5	72.9	59.7	47.9	36.5	58.7
Clarendon, Tex	27	38.2	42.3	50.1	58.5	66.8	76.2	80.5	79.5	72.0	60.1	48.9	38.3	59.3
Haskell, Tex	39	42.9	46.1	55.0	64.3	71.8	80.5	84.1	83.7	76.7	64.9	53.1	43.9	63.9
Average														50.8

[1] Ipswich records missing; Huron data substituted.

Table 13.—*Temperature and precipitation at selected stations in the shelterbelt region*—Continued

AVERAGE PRECIPITATION (INCHES)

Station	Years covered	January	February	March	April	May	June	July	August	September	October	November	December	Annual average
														Total annual
Towner, N. Dak	32	0.44	0.44	0.73	1.10	2.21	2.90	2.26	1.89	1.77	0.99	0.59	0.40	15.72
Steele, N. Dak	40	.46	.47	.81	1.19	2.58	3.50	2.90	2.37	1.45	1.07	.62	.55	17.97
Ipswich, S. Dak	37	.43	.48	.90	2.04	3.36	3.44	2.50	2.65	1.68	1.17	.50	.30	19.45
Tyndall, S. Dak	33	.41	.55	1.20	2.58	4.00	3.74	3.35	3.28	2.23	2.04	.82	.56	24.76
O'Neill, Nebr	32	.47	.62	1.31	3.05	3.16	3.84	2.50	2.79	2.25	1.27	.81	.65	22.72
McCook, Nebr	37	.29	.61	.78	2.04	2.90	3.29	3.10	2.65	1.74	1.29	.71	.52	19.92
Oberlin, Kans	46	.33	.75	1.09	2.67	2.97	3.04	3.36	2.99	1.85	1.32	.74	.66	21.77
Coldwater, Kans	36	.43	.77	1.11	2.01	3.80	3.63	2.86	2.66	2.64	1.76	1.22	.64	23.53
Woodward, Okla	33	.67	1.04	1.38	2.42	3.37	3.27	2.98	2.75	2.64	2.25	1.45	.88	25.10
Clarendon, Tex	28	.46	.74	1.12	2.29	3.52	3.40	2.50	2.89	3.23	2.66	1.15	.84	24.08
Haskell, Tex	42	.24	.41	.78	1.89	2.80	3.10	2.50	2.85	1.44	1.78	.74	.55	19.08
Average														21.35

Native tree growth occurs only along stream courses and in depressions and gullies. The following species of plants are commonly found in the steppe region:

COMMON NAME	BOTANICAL NAME
Trees:	
English Oak	*Quercus robur* L.
Apple	*Pyrus malus* L.
Common pear	*Pyrus communis* L.
Tartar maple	*Acer tataricum* L.
English elm	*Ulmus campestris* L.
Shrubs:	
Gorse	*Ulex europaeus* L.
Broom	*Cytisus biflorus* L'Herit.
Russian almond	*Prunus nana* Stokes
Dwarf cherry	*Prunus chamaecerasus* Jacq.
Grasses:	
Feathergrass	*Stipa pennata* L.
European porcupine grass	*Stipa capillata* L.
Junegrass	*Koeleria cristata* (L.) Pers.
Sheep fescue	*Festuca ovina* L.
Bulbous bluegrass	*Poa bulbosa* L.
Smooth bromegrass	*Bromus inermis* Leyss.

The following species are also present but somewhat less common:

COMMON NAME	BOTANICAL NAME
Trees:	
Norway maple	*Acer platanoides* L.
Hedge maple	*A. campestre* L.
European ash	*Fraxinus excelsior* L.
Winter linden	*Tilia cordata* Mill.
Elm	*Ulmus pedunculata* Fouger.
Scotch elm	*Ulmus glabra* Huds.
European aspen	*Populus tremula* L.
Hawthorn	*Crataegus oxyacantha monogyna* L.
European burningbush	*Euonymus europaeus* L.
European cranberrybush	*Viburnum opulus* L.
Wayfaring-tree	*V. lantana* L.
Shrubs:	
Lash tree	*Caragana frutex* Nutt.
Spiraea	*Spiraea crenifolia* C. A. Mey.
Broom	*Cytisus austriacus* L.
Blackthorn	*Prunus spinosa* L.
European buckthorn	*Rhamnus cathartica* L.
Spindletree	*Euonymus verrucosus* Scop.
Volga hazel	*Corylus avellana* L.
Sage	*Salvia nutans* L.
Herbs:	
Viper's bugloss	*Echium rubrum* Jacq.
Golden drop	*Onosma echiodes* L.
Quackgrass	*Agropyron repens* Beauv.
Meadow foxtail	*Alopecurus pratensis* L.
Meadow fescue	*Festuca elatior* L.
Sloughgrass	*Beckmannia erucaeformis* (L.) Host.
Timothy	*Phleum* sp.

In the European steppe, oak is the predominant tree species, but in the Siberian steppe birch takes this place.

The typical grasses mentioned in these lists represent both tall-grass and short-grass forms. Several of them have become naturalized in our own Plains region and serve to indicate further the similarity of this region with the Russian steppe.

No forest fauna are encountered on the steppes, but species of ground squirrel (*Spermophilus*), marmot or woodchuck (*Arctomys*), kangaroo rat (*Alactaga*), and mole rat (*Spalax*) are typical.

DEVELOPMENT OF THE SHELTERBELT PROGRAM

The outstanding interest which attaches to Russian experience with shelterbelts arises from the similarities of soil and climate to our own that have been noted, from the extensive character of a number of the plantings undertaken, and especially from the fact that planting programs and methods and the choice of species are guided by the scientific work of experiment stations.

Most of all, the Russian experience is significant in that past undertakings and accomplishments, carefully evaluated, have been made the basis of a publicly sponsored program for the planting, within the next few years, of a system of shelterbelts that compares in magnitude with our own undertaking and far exceeds any other project of similar character in history.

The first recorded planting of trees for shelterbelts in Russia was made in the early nineteenth century by German farmer immigrants who settled in the steppe region north of Crimea. A published account of these successful plantings appeared as long ago as 1833.

After that time no large-scale projects, aside from some railway plantings for snow stoppage, seem to have developed until about 1880, when windbreaks were established on a 2,700-acre farm in the Kherson district. These strips of trees, which still exist, were planted 105 feet wide and 700 to 1,370 feet apart, and occupied a total of about 215 acres. A study made in 1893 clearly indicated their favorable effect in reducing wind velocities and increasing soil moisture and agricultural yields (*10*). A planting nearly as large, but more thinly distributed, was made in 1886 on a 12,000-acre farm in steppe country southeast of the

Sea of Azov, the shallow northeastern arm of the Black Sea. The total length of the shelterbelts was 31 miles. They were 52 feet wide and were spaced from 1,650 to 3,300 feet apart.

The spectacular character and pleasing results of such plantings began to be widely noted as their number increased. The first governmental action in this field was taken in 1891, after a severe and general drought, when a commission for the forestation of the steppes was appointed. Nine objectives, reflecting the optimism which shelterbelt planting had engendered, were set before the commission. These were (1) protection of farms from wind, (2) aid in ripening grain, (3) decreasing evaporation, (4) more uniform distribution and retention of snow, (5) raising the water table, (6) decreasing the range of temperature fluctuations, (7) the attraction of rains, (8) raising the productivity of waste unused lands, and (9) the control of soil erosion and shifting sands.

Whatever marvels may have been expected, the most substantial results of the commissioners' work were the large and numerous experimental plantations which they established, at least six of which have been maintained more or less continuously as experiment stations.

The areas upon which study was first concentrated were known as the Kamennaya Steppe, Derkul, and Mariupol stations, all situated in a droughty district of south-central Russia from 150 to 300 miles north of the Sea of Azov. At each place a number of shelterbelts ranging in width from 66 to 263 feet were established at intervals ranging from 660 to 1,975 feet.

These plantings were followed in the years 1893 to 1895 by more ambitious and widely distributed undertakings in the old Provinces of Voronezh, Stavropol, Samara, Orenburg, and Saratov, where enormous windbreaks 1,960 feet wide and ranging in length from 1 to 4 miles were established on divides. Experimental shelterbelt plantings were made also at the Bezenchuk (near Samara) and Krasnokutsk stations, the Rostashi, Saratov, and Guselskii experimental farms, and the former Timashev estate in the Samara (central Volga) region. The above stations are indicated on the map (fig. 18), for convenient reference in the succeeding discussion.

Survivals of the commission's work, incomplete though they are, stand as a monument to the practical ideal of bringing forest benefits to a treeless region. Through succeeding neglect or abuse some of the larger plantings virtually disappeared; others, owing to unsound choice of species or poor arrangement, dwindled or barely held their own, as at Krasnokutsk; but those which, at Kamennaya Steppe, Mariupol, and elsewhere, were given a measure of care by competent

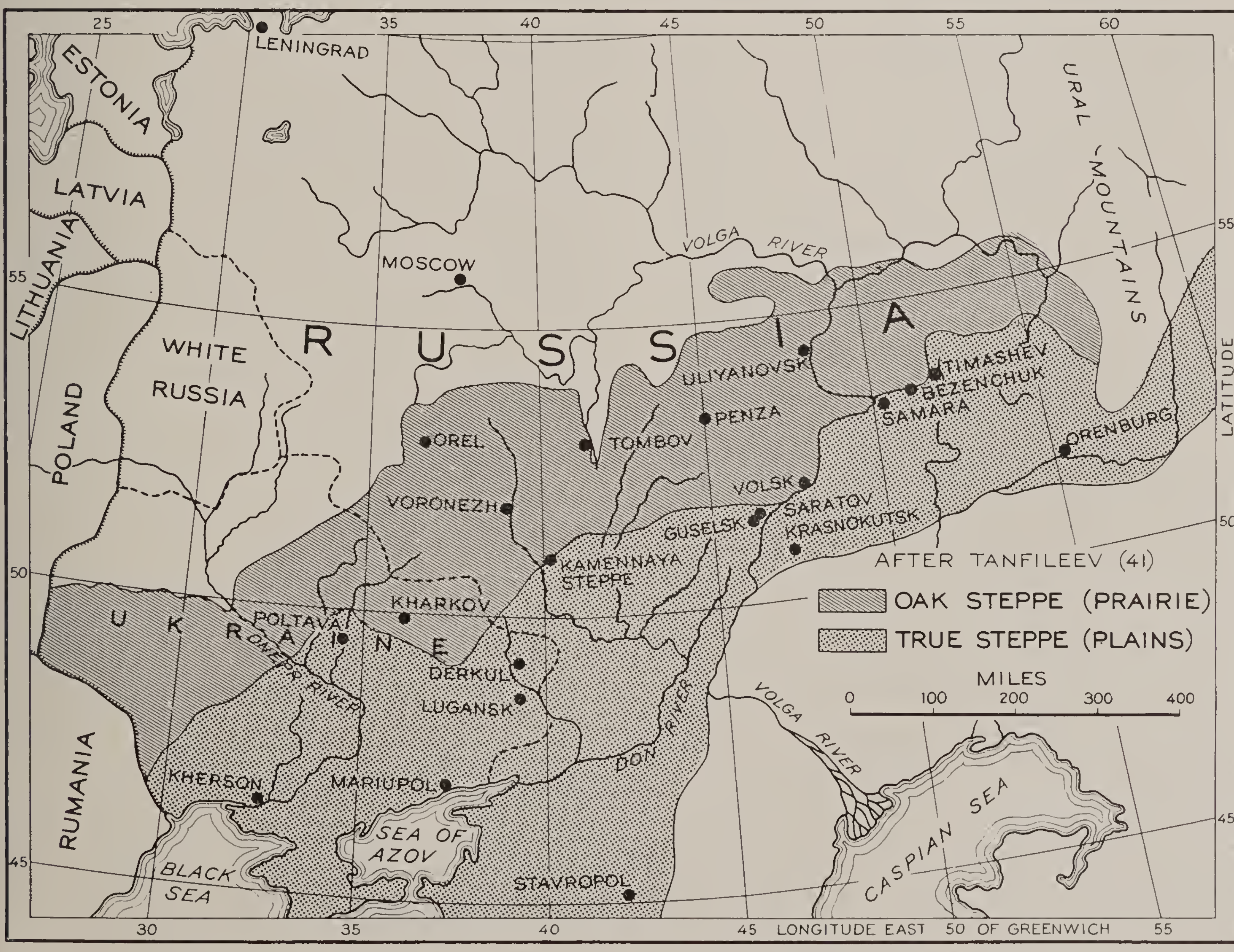

FIGURE 18.—Central Russian region in which most experimental shelterbelt plantings have been made.

staffs, have made satisfactory development and today form, altogether, one of the most remarkable features of the steppes.

A brief description of the Kamennaya Steppe station (fig. 19), which was the one first established by the Government and best maintained, and which has provided the basis for most of the conclusions as to shelterbelt effects, may be found of interest.

The experimental area includes some 2,500 acres, of which approximately 420 acres, or 17 percent, is occupied by shelterbelts. The shelterbelts themselves are oriented in various directions; some north and south, some east and west, some northeast and southwest, and otherwise. In some cases the belts are narrow, 66 feet in width; others are as wide as 328 feet. They are spaced at intervals ranging from 660 to 1,968 feet.

The strips of trees are composed of a variety of species. Some of them present a thrifty, well-kept appearance; others, because of the use of unsuitable

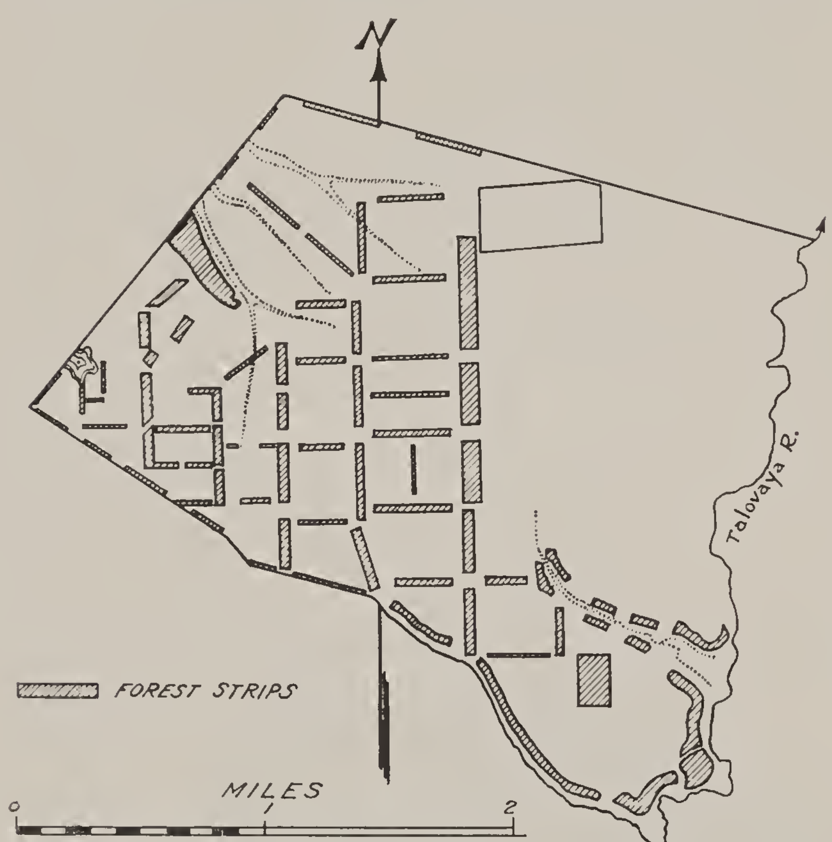

FIGURE 19.—Plat of experimental plantings at Kamennaya Steppe Station.

species or inimical mixtures, appear somewhat ragged and unkempt. Some of the best trees are over 60 feet in height and 8 inches in diameter at breast height (*39*).

Between the shelterbelts are fields in which such crops as wheat, rye, barley, oats, potatoes, alfalfa, and hay are raised, the yields of which are measured and compared with similar crops grown on adjacent fields in the open steppe.

Within the protected area there is a meteorological station at which measurements of physical factors are made and compared with those made at a similar station 1.3 miles distant in the open steppe (*2*).

Despite the fact that Russian writers since 1896 have repeatedly emphasized the desirability of continued shelterbelt planting on a wide scale, official interest took other directions during the early years of the twentieth century, both before and after the World War and the Russian Revolution. The severe famine of 1921, however, gave Soviet authorities new interest in any activity promising amelioration of conditions in the grain-producing regions, and shelterbelt planting activities were revived. The start was slow, and up to 1928 only some 5,000 acres of shelterbelts had been planted in the central and lower Volga regions, the only locations for which data were available (*53*). From 1929 to 1932, this total had been raised to about 35,000 acres, and the work is now being pushed vigorously. The objective for all Russia for 1932 was the establishing of approximately 99,000 acres of shelter belts, and for the second 5-year plan as a whole 865,000 acres. The latter figure, which is set up as a 5-year program, may be compared with the maximum of 1,282,000 acres proposed to be planted to field shelterbelts for our entire shelterbelt zone in a 10-year program.

SPECIES

On page 64 a list was given of common native tree and shrub species occurring on the Russian steppes. This list is of special interest in comparison with recent official recommendations (*12*) as to species which should be planted on different steppe soils, because of the high degree of reliance that is evidently placed on the native species, adapted by mass selection to the steppe environment. The recommendations are:

On Chernozem soils use *Quercus robur, Acer platanoides, Pyrus communis, Ulmus campestris, Robinia pseudoacacia, Gleditsia triacanthos, Fraxinus americana, Tilia cordata, Acer campestre, Fraxinus excelsior, Carpinus betula, Betula* sp., *Pyrus malus, Prunus spinosa, Acer tataricum,* and *Caragana arborescens*.

On Chestnut soils use *Quercus robur, Morus* sp., *Prunus armeniaca, Pyrus communis, Pyrus malus, Elaeagnus angustifolia, Toxylon pomiferum,* and *Acer tataricum*.

On soils with high salt content use *Quercus robur, Salix* sp., *Elaeagnus angustifolia,* and *Tamarix gallica*.

On Brown soils use *Pyrus eleagrifolia, Morus* sp., *Prunus armeniaca, Cotinus coggygria* Scop., and *Elaeagnus angustifolia*.

On sandy soils in the Chernozem type use *Pinus sylvestris, P. nigra pallasiana, P. nigra austriaca,* and *P. banksiana*.

Experience has, of course, shown great differences in success with the various species planted in shelterbelts. At the Kamennaya Steppe station plantings 30 to 35 years old showed survivals ranging from 28 to 73 percent, according to the species. The following remarks (*12, 35*) on the relative value of a number of widely used species, both native and introduced, are of interest as a commentary on the preceding lists, and more especially in comparison with the recommendations given in another section with respect to species suited to our somewhat similar shelterbelt zone conditions:

Oak (*Quercus robur* L.) is considered the key species in the European Russian steppe. It is drought resistant. As planting stock it does best when root-pruned and when the beds have been inoculated with the correct mycorrhiza. The tree is resistant to lateral suppression but cannot stand top suppression. It does best when planted in mixture with linden, maple, ash, and shrubs. The oak is the tree best able to withstand sodium and calcium sulphates, lime, and magnesia in the soil. It reproduces itself both by seed and by sprouting, but not very abundantly.

The ashes (*Fraxinus excelsior* L. and *F. americana* L.) develop well on leached soils where gypsum is absent and poorly on soils containing sodium sulphate and other salts. They require soils with available potassium. They demand moisture and do best when planted in depressions. The seed is collected in the fall, is planted in July, and germinates the following spring. The latter species reproduces itself quite abundantly by seed. *F. pennsylvanica* Marshall is planted in wet places.

The maples. *Acer platanoides* L. grows slower than oak except at an early age. It is frost-resistant but subject to considerable damage by rabbits. It is a prolific seeder. *A. campestre* L. and A. *tataricum* L. are useful as filler species in the southern steppes. The former does well on soils rich in lime and gypsum but poor in magnesia, and requires available potassium and phosphates. The latter does well on soils with high calcium, sodium, and magnesium sulphate contents. Both species reproduce by seed. *A. negundo* L. may be used to a limited extent in mixtures. It is a prolific seeder.

Linden (*Tilia cordata* Mill.) is useful as a second-story species, provided the stand is not too dense. It requires a fertile, moist soil and does best on the borders of strips. It develops a large root system but does not reproduce itself satisfactorily.

Birch (*Betula alba* L.) is a rapid-growing tree with the ability to survive on sod. It sprouts, but very weakly, and does not reproduce satisfactorily.

The elms (*Ulmus glabra* Huds., *U. pedunculata* Fouger., and *U. campestris* L.) all require fertile fresh soils and grow well in ravines and depressions. *U. campestris* does well on soils with high calcium and magnesium sulphate content, and requires available potassium and phosphates. The elms do not reproduce themselves satisfactorily.

The poplars (*Populus tremula* L., *P. nigra* L., *P. alba* L., *P. deltoides* Marsh., *P. maximowiezii* Henry, *P. balsamifera* L., and *P. laurifolia* Ledeb.) grow on any soil but do best on fresh, deep soils near streams. They should be planted more or less pure because of intolerance. Do not place near edge of strip.

Willows. *Salix alba* L. and *S. fragilis* L. are the best of the willows, the latter being the better of the two. They are similar to poplars in requirements.

Beech and hornbeam. *Fagus sylvatica* L. and *Carpinus betulus* L. can be grown in Crimea and the Caucasus although the latter species will not tolerate much lime.

Apple and pear. *Pyrus malus* L. and *P. communis* L. are very drought-resistant trees. The former does well on soils rich in lime and gypsum and sodium sulphate but poor in magnesium. The latter does well on soils with high calcium and magnesium sulphate contents.

Mountain-ash, cherries, apricot, and wild pear. *Sorbus aucuparia* L., which requires a soil rich in humus, *Prunus padus* L., which is subject to moth injury, *Prunus avium* L., *Prunus armeniaca* L., *Sorbus torminalis* Crantz., and *Pyrus eleagrifolia* Pall., are all slow-growing trees which are of use in forming a lower story.

Black locust (*Robinia pseudoacacia* L.) is a very intolerant tree; it cannot compete with weed growth in its early stages, is subject to frost injury, and is recommended for use only in small quantities in the interiors of shelter belts in the southern steppes. It does well on soils with high calcium and magnesium sulphate contents and requires available potassium and phosphate. It does best on sandy soils.

Honeylocust (*Gleditsia triacanthos* L.) is good for hedge planting because of its spiny character. It is drought-resistant and can withstand calcium, sodium, and magnesium sulphates, but is susceptible to frost injury. It is useful for planting in the southern steppes. It requires soils with available potassium and phosphate.

Ailanthus or tree of heaven (*Ailanthus altissima* (Mill.) Swingle) is susceptible to frost injury. It sprouts very freely, however, and is recommended for planting on chestnut-colored soils, particularly in mixture with black locust and honey locust.

Black walnut (*Juglans nigra* L.) is injured by frost and is recommended for planting in the southern steppes only.

The mulberries (*Morus alba* L., *M. nigra* L., and *M. rubra* L.) are resistant to both drought and frost.

Osage-orange (*Toxylon pomiferum* Raf.) is a good hedge species for the southern steppes.

Hackberry (*Celtis occidentalis* L.) is a good tree for the southern steppe region.

Eastern red cedar (*Juniperus virginiana* L.) can be grown in pure stands and is recommended as a good tree for the Ukraine region.

Conifers other than red cedar are not generally recommended, but Scotch pine (*Pinus sylvestris* L.), Crimean pine (*P. nigra pallasiana* Schneid.), Austrian pine (*P. nigra austriaca* Schneid.), and jack pine (*P. banksiana* Lamb.), are of some value on sandy soils in the Chernozem type. Siberian larch (*Larix sibirica* Ledeb.) is used on fertile fresh soils with some success.

Among the shrubs, the Siberian pea-tree (*Caragana arborescens* Lamb.) is the outstanding one for general use. It does well on soils rich in lime and gypsum but poor in magnesium and on those with high sodium sulphate content, and requires available potassium and phosphates. *C. frutex* Nutt., is listed as the shrub best able to withstand lime and magnesium, sodium, and calcium sulphates. The caraganas reproduce themselves by seed.

Filbert (*Corylus avellana* L.) does well on a variety of soils but is a light-demanding species.

The hawthorns (*Crataegus oxyacantha* L., *C. sanguinea* Pall.) are all useful as hedge shrubs. They require clay soils for satisfactory development. They are, however, subject to insect damage.

Wayfaring-tree (*Viburnum lantana* L.) is a useful shrub where considerable amounts of moisture are available.

Tamarisk (*Tamarix gallica* L.) is useful on salty soils.

Common privet (*Ligustrum vulgare* L.) makes a good hedge shrub and has the additional advantage of being repellent to cattle.

Dogwood (*Cornus sanguinea* L.) is a good shrub on fresh soils.

European elder (*Sambucus nigra* L.) is a good weed combatant and reproduces itself satisfactorily by seed.

The following species all make good hedge shrubs:

COMMON NAME	BOTANICAL NAME
Tartar honeysuckle	*Lonicera tatarica* L.
Russian-olive	*Elaeagnus angustifolia* L.
European shadblow	*Amelanchier vulgaris* Moench.
Sea-buckthorn	*Hippophae rhamnoides* L.
Blackthorn	*Prunus spinosa* L.
Ninebark	*Opulaster opulifolius* (L.) Kuntz.
Willowleaf spiraea	*Spiraea salicifolia* L.
Dogbrier	*Rosa canina* L.
Rose	*R. villosa.*
Austrian brier rose	*R. eglanteria* L.
Japanese rose	*R. japonica* Waitz.
Scotch rose	*R. spinosissima* L.
Lilac	*Syringa* sp.

Data as to the growth habits of different tree species in the Russian shelterbelts are scanty. From the growth of oak at the Mariupol station it has been concluded that up to 20 years the development is similar to that in natural stands but thereafter decreases so that at the age of 30 years it has fallen one site class (*39*). Table 14 shows the height growth of three species at the Mariupol station and the Vladimir Range (*39*).

TABLE 14.—*Total height of shelterbelt trees at various ages at the Mariupol station and the Vladimir Range*

Species	Locality	Height at age of— 3 years	6 years	9 years	12 years	15 years	18 years	21 years	24 years	27 years	30 years
		Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*
Oak	Mariupol	5	10	15	20	25	29	33	36	39	-----
Do	Vladimir	3	7	11	15	18	21	23	27	31	-----
Ash	Mariupol	6	9	17	21	25	28	31	35	-----	-----
Do	Vladimir	4	9	13	17	21	23	27	30	-----	-----
Elm	Mariupol	5	11	16	20	21	27	29	31	33	36
Do	Vladimir	6	12	17	21	21	26	28	37	-----	-----

Table 15 shows the growth in diameter and height of several species at the Kamennaya Steppe station; no age data are given, but it is assumed that the average is about 35 years.

TABLE 15.—*Size of shelterbelt trees at Kamennaya Steppe station*

Species	Diameter		Height	
	Maximum	Minimum	Maximum	Minimum
	Inches	*Inches*	*Feet*	*Feet*
Birch	8.1	6.2	62	53
Boxelder	7.0	3.9	42	36
European ash	4.6	2.6	49	20
Oak	5.2	3.1	39	31
Maple	5.6	2.8	44	27
White ash	3.9	2.6	43	33
Linden	5.4	2.2	43	26
Pear	4.7	3.5	34	28
Apple	6.1	3.8	33	18

Russian plans for research have included the establishment of a series of regional tree naturalization stations. Thus far only one such station, established in 1924 in the steppe region, has materialized. Its object is the study of the biological, silvicultural, protective, and decorative qualities of foreign forest trees and the selection of varieties valuable for purposes of prairie planting. It is fully described in recent literature (*44*).

PLANTING, STRUCTURE, AND CARE OF SHELTERBELTS

The following paragraphs constitute a digest of the more recent Russian recommendations for shelterbelt planting.

In the first place, the planting of shelterbelts is considered economically justifiable only in regions (*39*) where the precipitation-evaporation ratio is less than unity and only on Chernozem, loess, or sandy soils. On the lighter colored soils trees cannot be established, ordinarily, without irrigation.

The primary system of shelterbelts should be placed along the edges of gullies, ravines, streams, and permanent roads. A secondary system should be placed along the borders of permanent fields. Finally, this skeleton system should be supplemented by a net of geometrically arranged shelterbelts. Any areas unsuitable for agriculture (sandy areas, slopes, etc.) should be planted to trees (*39*). In very level areas the whole system of shelterbelts may be geometrically arranged. In such cases, the main belts should be oriented at right angles to the direction of the most destructive winds. Lateral shelterbelts should be placed at right angles to the direction of the main belts. In general, the strips should occupy the minimum amount of agricultural land consistent with their maximum beneficial effects (*33*). This is considered to be from 5 to 8 percent of the total area involved.

Conferences of shelterbelt workers held since 1929 have issued recommendations which vary somewhat with the region represented. In general, the distance between shelterbelts is greater in the northern areas than in the drier southern regions. The maximum recommended distances are 3,280 and 1,640 feet (*39*) in the two extremes. The latter distance, however, is considered the maximum at which there is a cumulative wind-quieting effect. A conference in the Ukraine (*12*) recommended that shelterbelts be placed closer together than the average interval on the windward side of the area, with possibly greater intervals to the leeward.

The grain authorities in March 1930 made the following recommendations (*12*): (1) The optimum spacing (considered 100 percent efficient) between main belts is 1,640 feet (0.31 miles). The length between breaks (left in the main belt at junctions with laterals to permit desirable air movement) is also 1,640 feet. (2) Seventy-percent efficiency is obtained by a spacing of 3,280 feet (0.62 miles) between both main and lateral belts. (3) If the spacing is more than 1.3 miles, the efficiency is probably only 25 to 30 percent.

After the locations of the shelterbelts have been determined, the next step is the preparation of the site for planting. It is recommended (*12*) that wherever possible the site selected be one upon which cereals have been grown for several years, on account of the deep plowing required. Where such sites are not available, the area should be plowed to a depth of at least 11 inches in the fall (assuming spring planting). In the spring, when the soil is just dry enough to be worked, it should be harrowed three or four times, all weeds removed, and planting rows marked out (*39*). Spring planting, as soon as the soil is free of frost, is preferred to fall planting because of the greater soil moisture and less danger of frost-heaving. Owing, however, to the heavy spring demand for farm labor, planting often must be postponed to the fall.

Well-developed stock, not too large, is recommended; 2–1 transplants are often used, and the desirability of normal root development is recognized. In this connection one authority recommends the planting of acorns along with each oak plant so as to assure the development of plants with natural root systems (*39*). Great care is taken to keep the roots of planting stock moist.

The most common method of planting, and the cheapest, is the slit method using a dibble, whereby two men are able to plant 1,000 to 1,500 trees per 8-hour day. Recent investigations, however, have shown that trees planted by this method suffer from root compression, with ill effects that do not appear until several years later. Although much better planting can be done with a special soil auger, by means of which a cylindrical hole about 6 inches in diameter is bored into the soil, a two-man crew can plant only 700 trees per day by this method, for which reason it also was discontinued. A third system, which best combines quality and quantity of planting, is the "square-hole with spade" method, and this is preferred to all others where hand labor is to be used; the necessity of firm packing of the soil about the roots is stressed. Since, however, the Government is undertaking planting on a very large scale, the development of suitable machinery for planting is strongly advised (*39*).

The consensus of recommendations as to spacing within the belt is for rather dense planting averaging 4,050 plants per acre, half of which are to be of shrub species (*12, 39*). This is considered about the best density when both early closing of the canopy and the abundance of later thinnings are considered.

Rows are spaced from 4.1 to 4.6 feet apart and the plants from 1.6 to 2.6 feet apart in the rows. Shrubs in the marginal rows bordering on open fields should be planted more closely, 1.3 to 1.6 feet apart. Close spacing of stock permits more rapid crown closure but makes for a greater drain on soil moisture. As many as 8,400 plants per acre are sometimes planted in the northern, more humid part of the shelter belt (*12*). The initial cost of less dense planting is, of course, lower. The moister the region, the closer the spacing that may be practical. Dense rows of spiny or prickly shrubs are planted along the edges of the shelterbelts to keep out livestock (*38*).

Recommendations as to the best widths of strip vary somewhat, but the generally established minima are 50 feet for main belts and 33 feet for lateral belts, with greater widths preferred (*12*). Certain proponents of narrow, more open shelterbelts apparently regard them only as physical obstacles to wind forces and not as living stands of trees (*21*).

Considerable attention has been given to the structure of shelterbelts. Three general schemes have been used (*12*, *33*) (fig. 20):

(1) The tree type, in which there is a principal species (usually oak) with a second story composed of other slower growing species. The several variations of this method are distinguished chiefly by the different species and mixtures of species used in the second story.

(2) The shrub type, in which the second story is composed of shrub species only.

(3) The mixed type, in which the lower stories are composed of both short and slow-growing trees and shrubs. This type usually consists of three fairly distinct stories. Agreement is quite general that the mixed type, although the most expensive, is the most desirable one (*12*, *33*). It is regarded as best fulfilling the desiderata of protecting the soil under the groves from insolation, decreasing dangers of insect and disease attacks, providing proper training of the principal species, and making possible arrangements to reduce future necessary thinnings to a minimum (*16*). This method provides a shelterbelt which is rooflike in cross section.

Species with far-spreading root systems and wide crowns should be kept away from the edges of the belts so as not to encroach on the fields (*39*).

One authority recommends the use of the tree type of shelterbelt under the more favorable climatic conditions (*16*).

Evidence points to the necessity for exercising considerable care as regards mixing species. At the Kamennaya Steppe station, for instance, in 30- to 35-year-old shelterbelts, both oak and ash showed higher survivals when mixed with linden, maple, and shrubs than when mixed with birch, boxelder, and elms (*33*).

If too many intolerant species are used, the entrance of weeds and formation of sod are not prevented. Some species, notably birch, produce very little litter (*33*).

After shelterbelts have been planted, they require constant care and attention if they are to be successful. During the first 4 years the most important tasks are protection against livestock, weeding, and cultivating. According to the weather, soil and cover, plantations should be cultivated and weeded 4 or 5 times the first year, 3 or 4 times the second year, 2 or 3 times the third year, and 1 or 2 times the fourth year (*39*). First-year losses often run from 10 to 30 percent and are made good by replanting in the spring of the second year. Cultivation between rows is best done by machine cultivators and that between plants by hand hoeing, continuing until such time as the crown canopy has closed. Such care is recognized as expensive, but absolutely necessary.

About the sixth year the first thinning is made, if shrubs have been planted. Shrubs alone are cut at this thinning. They will sprout, and about 6 years later they should again be removed. About the fifteenth or sixteenth year the selective removal of secondary tree species is begun, always favoring the principal species (usually oak). At the end of 20 to 25 years a pole stand is produced, with an upper story of oak and a few other species, a second story of slower growing trees, and third story of brush. After the twentieth year, if slow growth and depleted soil moisture demand it, further cautious thinnings may be made, leaving a final stand of 400 to 600 trees per acre. Good 33-year-old stands containing 1,600 trees per acre are found at the Mariupol station. If symptoms of a serious depletion of soil moisture become evident, the whole grove may be clear cut in order to utilize the wood (*39*).

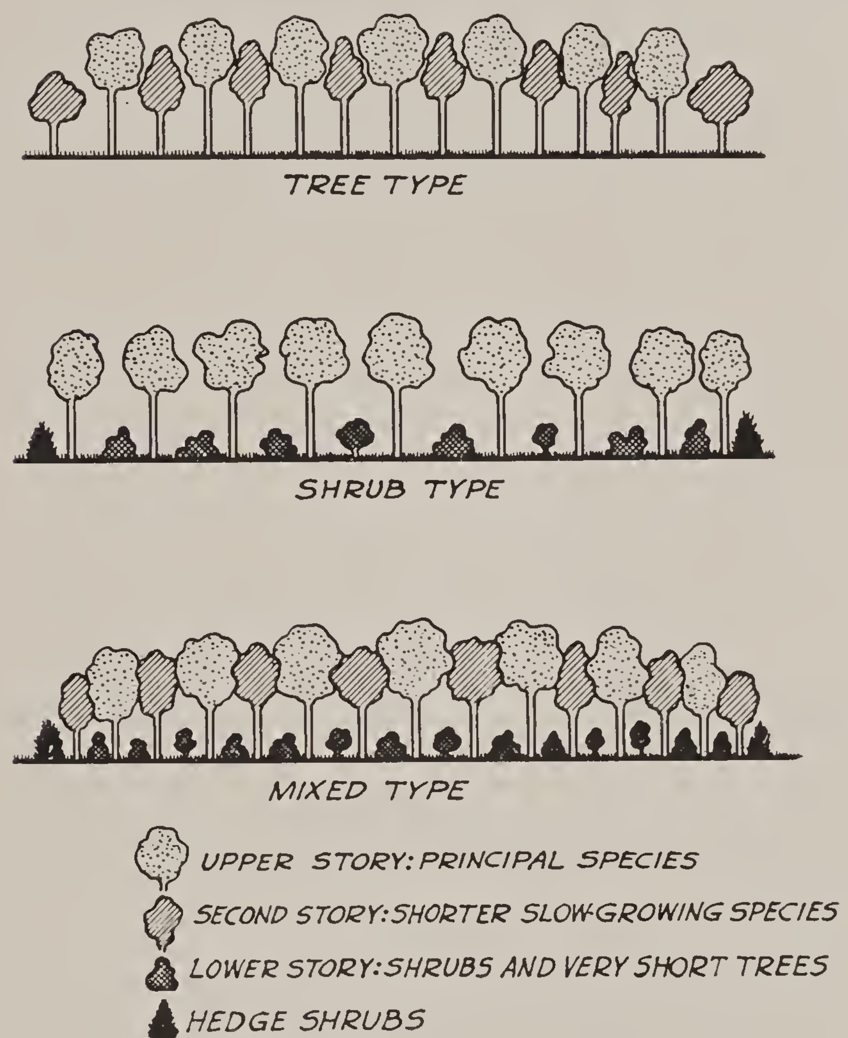

FIGURE 20.—Three methods of shelterbelt construction as used in Russia.

The cost per acre of establishing shelterbelts under conditions prevailing in Russia, and at the present rate of currency exchange, is reckoned at about $75. The cost is distributed by items as follows: Planting, 34 percent; replanting fail spots, 7 percent; stock (4,050 plants per acre), 48 percent; and subsequent care, 11 percent.

Regeneration of shelterbelts will probably come through combinations of planting and natural reproduction. Some species reproduce themselves under shelterbelt conditions by seeding or sprouting; others may die out.

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EFFECTS [11]

Considering the seriousness with which the Russians have undertaken the task of protective planting on the steppes, it would naturally be supposed that their past experience with such plantings had been, on the whole, favorable. Such a conclusion seems further warranted by the technical records at hand. Without entering upon any unknown grounds of mass opinion or public policy, it will be sufficient in the following discussion to review rather briefly the meterological and experimental findings that lie in the background of the present unparalleled developments.

Many of the citations will necessarily refer to the work and records of the Kamennaya Steppe experiment station, one of the three established in 1893, and the one where the longest and most complete series of shelterbelt observations of all kinds has been made.

WIND VELOCITY

Probably the most obvious and certainly the most important effect of shelterbelts, especially on the wide, dry, and dusty Russian steppes, is their action in breaking the force of winds; their other principal

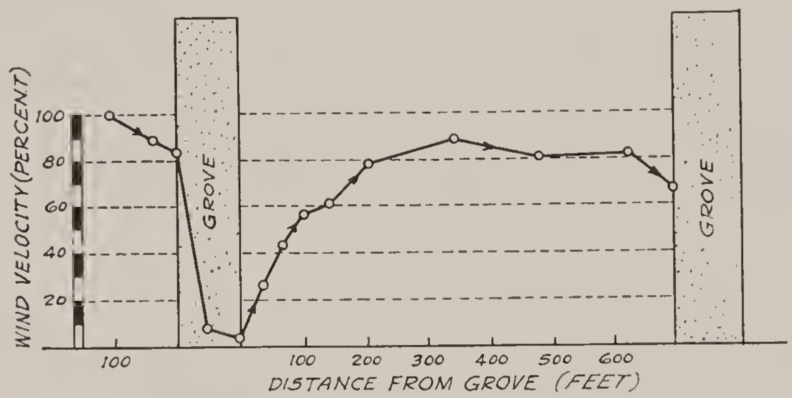

FIGURE 21.—Wind velocity at 4 feet above ground as affected by shelterbelt at Kamennaya Steppe station; velocity of 27 miles per hour taken as 100 percent.

effects are directly or indirectly dependent upon this.

One of the first investigations (*2*) of the effect of shelterbelts on wind velocity was made at the Kamennaya Steppe station in 1898. At that time the plantations were only 5 years old and averaged 8 feet in height. Even at that stage it was concluded that the strips were slowing down the wind somewhat. The question was restudied at this station 4 years later (*6*) for a group of shelterbelts ranging from 70 to 140 feet in width. Heights by that time were 12 to 22 feet. It was concluded that the shelterbelts reduced the wind velocity for a distance of 210 to 560 feet to the leeward, beyond which distance the velocity increased, until at a point about 140 feet to windward of the next strip, it became even greater than in the open steppe. The leeward distance to which the protective effect extended was found to vary (within the above limits) with the "free" velocity of the wind and the height and width of the shelterbelt. Figure 21 illustrates the results of one set of these measurements.

[11] There is a considerable body of Russian literature dealing with shelterbelt effects. A good deal of it, however, is rather general in nature and often quotes results derived chiefly from other sources. In this report all material has been reviewed critically. In all possible cases the original source of information has been consulted and, unless otherwise indicated, only such statements as seemed to be substantiated by satisfactory data are included.

Height is generally agreed to be a dominant factor in the distance to which protection is extended by shelterbelts. Various investigators place the effective distance of a single shelterbelt as ranging from 10 to 30 times the height of the trees (*22*, *24*, *51*) and a figure of 20 times the height is rather commonly accepted (*50*, *39*, *21*, *18*). Measurements made at the Mariupol station led to a more elaborate formula wherein the effective distance is placed at two and one-half times the square of the height of the belt when the meter is the unit of measure (*21*).

For shelterbelts on the crests of slopes, the effective distance is increased, and for those on the sides or bases of slopes it is decreased (*51*). Investigators seem to be unanimous in concluding that while shelterbelts affect the velocity of wind, they do not greatly change its direction.

The decrease in wind velocity due to shelterbelts is important in reducing soil-blowing. Their effect in breaking up dust clouds has been specifically noted (*45*). Since the blowing of soils in dry winters and the consequent destruction of sown crops of winter grains is one of the greatest perils of agriculture in the steppe region, great value is attached to shelterbelts in reducing such action (*39*).

Some years ago a meteorological study of shelter belt effectiveness was made at Kharkov Agricultural School Farm in the Ukraine. Mean monthly wind velocities were compared for the 15-year period before shelterbelts were planted with those for the succeeding 15-year period after planting (table 16). Considering the short time of the shelterbelts' growth, the figures are striking in their showing that for the second period there was a marked reduction in mean wind velocities for each month of the year, and that the annual mean velocity was reduced by 29 percent.

TABLE 16.—*Mean monthly wind velocities in miles per hour, Kharkov*

Period	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual average
First, 1887–1902	10.7	11.4	10.9	10.9	10.9	7.4	6.5	6.3	6.5	8.7	9.6	8.7	9.0
Second, 1902–17	6.9	7.4	7.6	6.9	5.8	5.1	4.9	4.7	5.8	6.5	7.4	7.2	6.4

TEMPERATURE

Temperature records at the Kamennaya Steppe station for the 7-year period 1918–24, indicate a slight tendency toward a cooler average summer temperature and a warmer average winter temperature in the area protected by the shelterbelts, but the differences are so small (less than 1° F.) that little significance can be accorded them. It is maintained by one writer that frosts are more severe in areas protected by shelterbelts than on the open steppes (*51*).

PRECIPITATION

Much uncertainty unfortunately attaches to the Kamennaya Steppe precipitation records, which are the only figures available for present consideration. No question is of more intense interest to everybody than whether or not shelterbelts can increase rainfall, but this is a question which must be left open here.

The data (*12*), recorded for the years 1918–24, actually indicate an average difference in precipitation in favor of the shelterbelt area, as compared with the open steppe, of 2.19 inches per year, or nearly 15 percent—17.3 inches as against 15.11. Critics have pointed out, however, that although five rain gages were used the measurements were made at two stations only, and that the differences are no greater than might possibly be accounted for by some difference in exposure of the gages (*51*). If this is not the explanation, the consistently higher figures for the shelterbelt area, year by year, denote a trend of great significance.

The records further show a higher average monthly precipitation in the protected area for all months except June and July. The differences are greater for the cold months than for the warm months, the period October–March showing a balance of 1.79 inches in favor of the protected area as against an April–September favorable balance of only 0.40 inch. These figures, if accepted, suggest that the largest differences are to be expected in periods of snowfall.

WATER RETENTION

One of the most positive and generally admitted effects of shelterbelts, and probably the one earliest obtainable, in the life of the stand, is that of moisture retention. This is accomplished chiefly by the catching of snow in drifts alongside and through the belts, as well as by a more uniform distribution of snow over the wind-sheltered fields. In a plains area without protection, most of the snow is blown into natural depressions and comparatively little is left on the fields where it is most needed.

The earliest measurements of water-retention effects were made at the Kamennaya Steppe station in the winters of 1901–2 and 1902–3, when the shelterbelts were only 3 to 9 years of age and 5 to 10 feet in height (*25*).

Typical snow-accumulation profiles for wide and narrow belts are shown in figure 22. The study demonstrated that even such young shelterbelts were effective in accumulating snow; that snow was 17 to 41 days later in melting in the groves than at near or more remote distances in the open; that the total amount of snowfall retained in the open protected area was only 6 percent less than that actually registered by the rain gage; and that in the spring a definite movement of water occurred from the melting drifts toward the fields.

At the Mariupol station, during the winter of 1927–28, winter wheat on the open steppe was frozen out and produced no yield, but the fields protected by shelterbelts were covered by snow and yielded at harvest 0.557 ton per acre (*15*). Like results are reported at other stations.

By investigations conducted on a number of experimental areas, it has been learned that while such factors as the width, density, composition, and orientation of shelterbelts all more or less affect snow accumulation, the effect of the shelterbelt is, in general, positive and beneficial. At the Rostashi station it was shown that the amount of available moisture furnished by melting snow in the spring averages 60 percent greater in the area protected by shelterbelts than on the adjacent open steppe (*39*).

On the other hand, deep drifts of snow near the shelterbelt sometimes have a detrimental effect on crops. Melting off later than the shallower accumulations farther out, they give the crop a later start and prevent early cultivation (*21*, *29*, *50*). This condition has been noted during cool springs at both the Krasnokutsk and Saratov stations (*21*).

SOIL MOISTURE

At the same early stage of development of the Kamennaya Steppe shelterbelts as noted under the preceding heading, the moisture content of the soil was determined at several depths ranging from 4 inches to 13 feet, both within and without the shelterbelts (*25*). It was found that the maximum moisture content of the soil occurred in April and the minimum

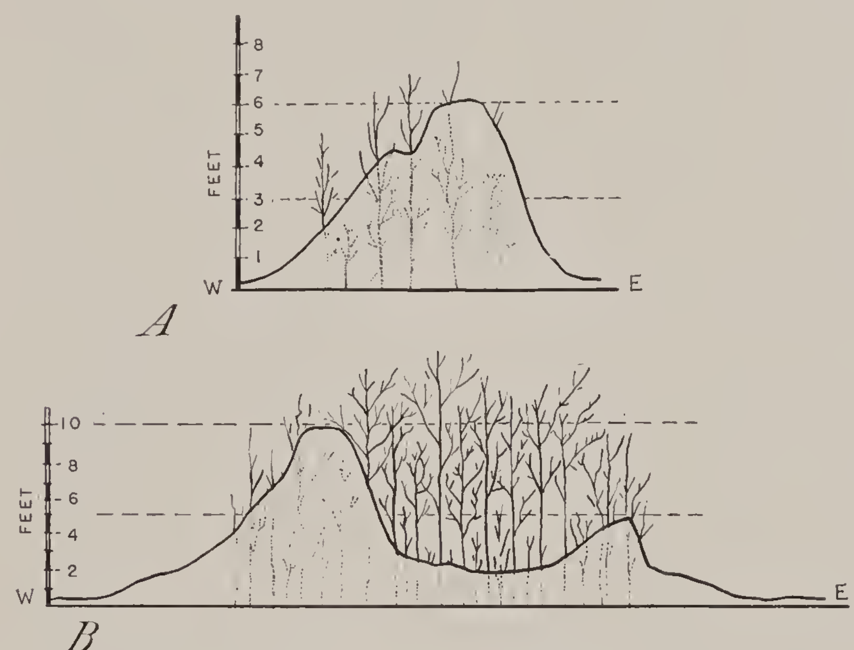

FIGURE 22.—Typical profiles of snow accumulation by shelterbelts, Kamennaya Steppe station: *A*, Kamennaya Steppe strip no. 15, 70 feet wide, planted 1895; snowdrift measured in March 1902. *B*, Kamennaya Steppe strip no. 6, 210 feet wide, planted 1894; snowdrift measured in March 1903.

in July; that in April the higher moisture content of the soil under the shelterbelts, as compared with the open steppe, extended down to a depth of 20 inches, there being no difference between the two conditions below that depth; that in July the upper soil layers under the shelterbelts were slightly moister than those in the open, while the lower layers were slightly drier; and that groves only 6 to 8 years old act to increase the soil moisture content up to a distance of 69.5 feet on the outside.

As long ago as 1890 careful soil-moisture determinations were made on the 2,700-acre estate in the Kherson district that had been shelterbelt planted in 1880. Samples were taken at several depths down to 3.3 feet at localities within the shelterbelts, in fields protected by them, and on the open steppe. The soil-moisture percentage showed irregular variations, but the average was definitely higher for the protected fields (*10*). Average moisture content of the 3.3-foot section on the steppe was 12.12 percent of the weight of dry soil; in fields protected by north-south shelterbelts, 12.91; in fields protected by east-west shelterbelts, 13.85. (The last percentage may be questioned on account of one exceptionally large reading at the deepest level.)

Although shelterbelts thus appear to improve soil-moisture conditions in the areas protected by them, they often have a reverse effect on the zone immediately adjacent, of a width roughly equal to the height of the belt, where the tree roots sap the moisture (*21*, *29*, *51*). This effect is found to be reduced by a proper choice of species in the border rows (*29*) and by ditching (as at the Saratov experimental farm) and by cultivating along the edges of the belts (*21*, *29*).

HUMIDITY AND EVAPORATION

Since the rate of moisture loss from soils, plant tissue, and organic materials in general is augmented at all temperatures by a low relative humidity of the atmosphere, any effect that tree plantings about fields may have in raising the air-humidity level is of great importance to the farmer. The weight of evidence from Russia is to the effect that shelterbelts do increase the humidity to a somewhat minor extent and decrease evaporation to a much larger extent.

Observations at the Kamennaya Steppe station indicate a slightly higher relative humidity for the areas between shelterbelts about 1,500 feet apart, as compared with the open steppe (*12*). The difference in average relative humidity for the period April to September during the years 1918 to 1922 varied from 0.5 percent to 4.5 percent, and the mean humidity during the whole 5 years for the protected area was 69.3 percent, as against 66.7 percent for the steppe—a favorable difference of 2.6 percent. That the shelterbelts were especially useful in mitigating extremes of low humidity is shown by favorable differences of 4 to 8 percent between average monthly lows for the same two locations over the same 5-year period. The beneficial effect of the shelterbelts appears to be most pronounced at the time of hot, drying east winds (*21*).

One observer, who took records (*6*) at the Kamennaya station when the shelterbelts were younger and more open, made the rather odd finding that in the majority of cases the relative humidity of the air in the area of reduced wind velocity was lower than that of the air in the open, before it reached the strip.

Even more telling than humidity measurements, however, are records of the greatly reduced rate of evaporation. The figures at the Kamennaya Steppe station (*12*) indicate a reduction of 30 percent in evaporation for the whole 7-year period 1918–24, on the areas protected by shelterbelts. During the growing season, April to September, when 90 percent of the drying takes place, shelterbelt effectiveness is also at its height. The records further indicate a change in precipitation-evaporation ratio from 46.5 percent in the open to 76.5 percent in the protected area.

Table 17 shows the monthly average evaporation for the period under consideration.

TABLE 17.—*Monthly average evaporation, 1918–24, at Kamennaya Steppe station*

Month	Evaporation		Month	Evaporation	
	Between strips	In the open		Between strips	In the open
	Inches	*Inches*		*Inches*	*Inches*
January	0.16	0.19	August	4.08	5.68
February	.09	.10	September	2.79	4.24
March	.40	.56	October	1.41	1.96
April	2.19	3.02	November	.39	.47
May	4.24	6.05	December	.12	.16
June	3.48	5.15			
July	3.31	4.94	Total	22.66	32.52

SOIL BUILDING

Investigations made recently at the Kamennaya Steppe station (*43*) indicate an increased depth of humus at distances between 35 and 1,050 feet from the shelterbelts. Closer to the belts the humus depth decreases, and leaching extends down to a greater depth, tending to change the typical prairie soil to a forest soil. On the open steppe the average depth of humus was found to be 24.8 inches, at a distance of 700 to 1,050 feet from shelterbelts to be 26.2 inches, and at a distance of 35 to 350 feet from them to be about 28 inches. The average percentages of humus, on the basis of dry soil weight was also determined. From the open steppe to 35 feet from the shelterbelt the change of humus content increased progressively from 6.10 to 7.08 percent.

The origin of the increase in humus thickness—about 12 percent at its maximum—is not explained. It is too much to suppose that it was formed by the decomposition of plant remains in situ, since it would be a matter of centuries to produce the extra depths by this process. It is more likely that the deposits were formed by the shelterbelt's ability to catch blowing topsoil, causing it to accumulate on a small scale in the same manner as snowdrifts. An investigation of an oak grove in the Crimea planted 200 years ago also showed an increased depth of humus in the vicinity which might very plausibly have been due to the influence of the grove alone (*22*).

At the Mariupol station a deepened humus layer was found in the area protected by shelterbelts (*39*), a condition attributed to "better moisture conditions." No tendency toward a change to forest soil under the shelterbelts was observed, the difference being explained by the greater clay and lime content of the Mariupol soils as compared with those of Kamennaya Steppe.

AGRICULTURAL YIELDS

Information as to the effect of shelterbelts on yields of agricultural crops is available from several experimental stations established in steppe areas. Rather uniformly, the data point to large and significant increases in yields from shelterbelt protected areas as compared to yields from lands exposed to the full rigors of the steppe, although grain crops may occasionally show the opposite trend. While the grains are largely benefited by protection in extreme seasons, they sometimes yield less in a normal season in the presence of shelterbelts. Table 18 presents a good cross section of the significant crop data that are available.

TABLE 18.—*Effect of shelterbelt protection on crop yields at Russian stations*

Station and crop	Year or years	Yield per acre			
		On fields protected by shelterbelts	On open steppe	Increase on protected fields	
		Tons	*Tons*	*Tons*	*Percent*
Kamennaya Steppe:[1]					
Winter rye:					
Grain	1914	0.774	0.597	0.177	29.6
Straw		2.208	1.335	.873	65.4
Grain	1918	.587	.548	.039	7.1
Straw		1.390	2.404	[2](1.014)	[2] (42.2)
Grain	[3] 1921	.388	.101	.287	284.2
Straw		.716	.247	.469	189.9
Grain	[4] 1922	.756	.635	.121	19.1
Straw		2.085	1.630	.455	27.9
Grain	1923	.414	.254	.160	63.0
Straw		1.137	.826	.311	37.7
Grain	1924	.490	.337	.153	45.4
Straw		1.535	1.088	.447	41.1
Grain	1925	.556	.550	.006	1.1
Straw		1.005	.881	.124	14.1
Grain	1926	.957	.782	.175	22.4
Straw		2.233	1.706	.527	30.9
Grain	1927	.784	.846	[2] (.062)	[2] (7.3)
Straw		1.759	1.878	[2] (.119)	[2] (6.3)
Grain	1928	.593	.812	[2] (.219)	[2] (27.0)
Straw		1.888	1.968	[2] (.080)	[2] (4.1)
Grain	1929	.882	.725	.157	21.7
Straw		2.056	1.504	.552	36.7
Grain	1930	.732	.566	.166	29.3
Straw		1.392	1.162	.230	19.8
Average:					
Grain		.659	.563	.096	17.1
Straw		1.617	1.386	.231	16.7
Oats:					
Grain	1914	.474	.417	.057	13.7
Straw		.915	1.679	[2] (.764)	[2] (45.5)
Grain	1918	.301	.401	[2] (.100)	[2] (24.9)
Straw		1.100	1.260	[2] (.160)	[2] (12.7)
Grain	1920	.327	.194	.133	68.6
Straw		.886	.562	.324	57.7
Grain	[3] 1921	.468	.187	.281	150.3
Straw		.729	.287	.442	154.0
Grain	[4] 1922	1.064	.763	.301	39.4
Straw		1.667	1.432	.235	16.4
Grain	1925	.868	.988	[2] (.120)	[2] (12.1)
Straw		1.346	1.331	.015	1.1
Grain	1926	.401	.700	[2] (.299)	[2] (42.7)
Straw		.590	.948	[2] (.358)	[2] (37.8)
Grain	1927	.367	.494	[2] (.127)	[2] (25.7)
Straw		1.189	1.322	[2] (.133)	[2] (10.1)
Grain	1928	.828	.859	[2] (.031)	[2] (3.6)
Straw		1.305	1.505	[2] (.200)	[2] (13.3)
Grain	1929	.454	.548	[2] (.094)	[2] (17.2)
Straw		1.380	1.113	.267	24.0
Grain	1930	.790	.606	.184	30.4
Straw		1.060	.775	.285	36.8
Average:					
Grain		.577	.559	.018	3.2
Straw		1.106	1.110	[2] (.004)	[2] (0.4)
Alfalfa	1919	1.243	.497	.746	150.1
Do	1920	1.325	.414	.911	220.0
Do	1921	1.077	.290	.787	271.4
Average		1.215	.400	.815	203.8
Bromegrass	1919	.746	.497	.249	50.1
Do	1920	.746	.414	.332	80.2
Do	1921	.828	.249	.579	232.5
Average		.773	.387	.386	99.7
Saratov:					
Spring wheat	1918–22	.623	.375	.248	66.1
Winter rye	1918–23	.963	.701	.262	37.4
Saratov—Continued.					
Sunflower	1918–22	.674	.350	.324	92.6
Potatoes	1920–22	4.110	2.418	1.692	70.0
Alfalfa	1918–22	2.094	.992	1.102	111.1
Mariupol:					
Winter wheat	1926–29	.692	.393	.299	76.1
Barley	1926–30	.615	.412	.203	49.3
West Siberian:					
Rye	1915–22 (3 years)			.367	
Wheat	1919–22 (2 years)			.406	
Krasnokutsk:					
Grasses (1 year)	1914–17 (1 year)	.505	.429	.076	17.7
Grasses (2 years)	1914–22 (6 years)	1.045	.860	.185	21.5
Grasses (3 years)	1914–21 (6 years)	1.076	.699	.377	53.9
Grasses (4 years)	1914–22 (6 years)	.880	.538	.342	63.6
Winter rye	1914–22 (7 years)	.529	.476	.053	11.1
Winter wheat	1914–28 (4 years)	.474	.252	.222	88.1
Wheat [5]	1914–28 (8 years)	.323	.233	.090	38.6
Do.[6]	1914–28 (7 years)	.256	.229	.027	11.8
Do.[7]	1914–18 (4 years)	.355	.364	[2] (.009)	[2] (2.5)
Barley [8]	4 years	.959	.748	.211	28.2
Rostashi: [9]					
Winter wheat:					
Grain	5 years	.580	.502	.078	15.5
Straw		1.383	1.191	.192	16.1
Rye: [10]					
Grain		.577	.479	.098	20.4
Straw		1.422	1.243	.199	15.9
Oats: [11]					
Grain	1929–31	.618	.577	.041	7.1
Straw	1929–30	.828	.830	[2] (.002)	[2] (0.24)
Spring wheat:					
Grain	5 years	.517	.489	.028	5.7
Straw	4 years	.939	.914	.025	2.7
Sunflower	1929–30	.330	.299	.031	10.4
Fodder beets:					
Roots	2 years	6.618	5.489	1.129	20.6
Leaves		1.216	.955	.261	27.3
Potatoes	1930–31	4.150	2.436	1.714	70.4
Hay [12]	1931–32	.835	.620	.215	34.7
Do.[13]	1929–30	.537	.468	.069	14.7
Guselskii:					
Winter wheat	1930–31	.454	.370	.084	22.7
Spring wheat		.514	.497	.017	3.4
Lentils		.684	.434	.250	57.6
Hay [13]		.862	.394	.468	118.8
Oats		.599	.675	[2] (.076)	[2] (11.3)
Barley		.771	.659	.112	17.0
Sunflower		.461	.388	.073	18.8

[1] Crop yields at this station are average for 238 acres between shelter belts and 270 acres on open steppe.
[2] Decrease.
[3] Dry year.
[4] Wet year.
[5] Bieloturka variety.
[6] Russak variety.
[7] Khvinka variety.
[8] Sown with alfalfa.
[9] Data for protected field refer to entire area enclosed by shelterbelts; data for "open steppe" based on yield at center (least protected portion) of protected field.
[10] Yelisseyeff variety.
[11] Pobieda variety.
[12] Mixture of oats and *Vicia sativa*.
[13] *Bromus* sp.

It will be seen from the table that, at the Kamennaya Steppe station, the beneficial effect of the shelterbelts on both grain and straw production was much more pronounced in 1921, a dry year, than in 1922, a wet year, if the differences in yield are reckoned on a percentage basis. This important trend may be regarded as typical.

Other conclusions derived from experience at the Kamennaya Steppe station (*12*) are that shelterbelts are especially beneficial during the dry winds of spring and during the period of heading of grain, that the yield of native steppe plants is highest near the shelterbelts and decreases away from them, and that (as shown in table 19) the yield of oats increases up to a distance of 130 to 200 feet from the strip and then decreases, while the maximum yield of rye and of hay is found nearest the strips (*12*, *21*, *37*). Similar data have been collected at the Saratov and West Siberian experiment stations and the Timashev experimental farm (*21*).

TABLE 19.—*Yield of hay and grain in tons per acre at Kamennaya Steppe station*

Distance from shelterbelt (feet)	Hay	Rye	Oats
	Tons per acre	*Tons per acre*	*Tons per acre*
0 to 66	1.170	0.477	0.441
66 to 132	.964	.414	.508
132 to 198	.792	.414	.575
198 to 264	.750	.352	.513
264 to 330	.692	.338	.475
330 to 396	.656	.330	.475

The greatly increased yields shown at the Saratov station (table 18) (*37*) are attributed largely to the better moisture conditions produced through snow accumulation by the shelterbelts (*39*). At Krasnokutsk the considerable increase of yield recorded within the sheltered area was attained despite the fact that the shelterbelts had suffered neglect and were not considered to have been of the best construction originally.

Perhaps the most interesting bearing that the tabulated figures have on farming conditions in the United States is seen when the grain crops are converted from tons per acre to our more familiar bushels per acre. The striking fact then emerges that in the very poor years these Russian farm crops in dry steppe regions, when planted and cultivated under shelterbelt protection, increased from about 1¾ to about 8½ bushels per acre in the case of wheat, from 11⅔ to 29¼ in the case of oats, and from 3⅔ to 12 in the case of rye.

In relation to all the foregoing, the occasionally reported undesirable effects of shelterbelts appear considerably less important. It has been stated, however, that the plants in the protected areas are more susceptible to diseases and are less able to withstand strong winds, torrential rains, and hailstorms than those in the open, and that there is a tendency toward greater development of weeds in the protected fields (*21*).

The effect of shelterbelts upon Russian agricultural practices was a factor little recognized until, in recent years, the formation of large collective farms, with the attendant greatly increased use of machinery, brought up new problems to be considered in locating and orienting shelterbelts. The only point thus far clearly developed has been the need for spacing the belts so as to leave ample working areas. The zonal experiment station at Omsk, Siberia, has advised the use of rectangular working units about 1,650 by 6,600 feet in dimensions, with the long axis at right angles to the direction of the prevailing winds (*15*). This accords fully with recommendations of the grain authorities already cited.

EFFECT ON LIVING CONDITIONS

No reports are available as to the degree of use of the shelterbelts allowed to local residents or as to their opinions regarding the general value of shelterbelts to the community. The only information relating to living conditions is the statement of one authority (*29*) that shelterbelts contribute to the general health of the inhabitants of neighboring industrial villages through their effect in reducing the dust and obnoxious gas content of the air.

CONCLUSION

Of the four systems of shelterbelt practice abroad which have been reviewed in the foregoing, the Russian system seems to be the most nearly applicable, in scale and conditions encountered, to the present shelterbelt undertaking in the United States. The Russian program and its results thus far have therefore been the most closely examined, and the many similarities of natural conditions there and here have been pointed out.

While it is not the purpose of the writers to recommend any blind following of foreign methods, American foresters will do well to consider very seriously Russian experience and practice in regard to the layout of shelterbelt areas, dimensions and spacing of units, density of planting, and species composition of shelterbelts. Also, the preparation of sites for planting and the general silviculture of shelterbelts as practiced in Russia have such sound and specific bearings on our situation that they could be transferred almost bodily.

As regards species, a fact of high significance that has been noted, especially under the rigorous conditions of Canada, Russia, and Hungary, is the prime reliance placed by foresters on trees native to the several regions as the "shock troops" of the shelterbelt line. On the other hand, a number of workable associations of species, native and foreign to given regions, have been pointed out. The Russians have used some of our native species successfully in shelterbelt planting, and we have found certain Russian species, such as caragana and Russian-olive, to be very useful components of our shelterbelts. Other promising foreign species should be given thorough tests for suitability in our plains. In the matter of species mixtures, Russian experience sounds a note of caution. It has been demonstrated that individual species react quite differently in various mixtures with other species that are seemingly well adapted to such association, which fact warns us to proceed carefully in producing artificial mixtures.

As to the good effects of the shelterbelt on its surroundings, one convincing proof is that shelterbelt planting is an established and increasing custom which is bringing its satisfactions not only to Americans but to other peoples, near and far. Other evidence of a scientific nature presented in this review, from the Kamennaya Steppe records and elsewhere, tend to establish that confidence. However explained, the observations of wind velocity, humidity, evaporation, soil moisture, soil fertility, and even precipitation, point with truly remarkable accord to the shelterbelt's practical ameliorative value.

From the research point of view, there are two points which may be noted from foreign experience. One is the desirability of regional stations for thoroughly testing out promising species, both native and exotic; the other is the need for a comprehensive program for the investigation of shelterbelt effects which, with full recognition of the laws of proper sampling, will settle moot questions in the meteorological category, clearly define the agricultural bearings of the subject, and establish a firmer scientific foundation for shelterbelt undertakings in North America.

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Section 10.—ECONOMIC AND SOCIAL ASPECTS OF AGRICULTURE IN THE PLAINS REGION

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CONTENTS

The first white men to penetrate the Plains region of North America labeled it a desert. This conception of the Plains persisted in the reports of explorers and travelers and in the minds of eastern writers up to the time of the Civil War.

The slow demise of the desert concept in the eastern part of the United States must in part be explained in the light of the traditional environment of the early colonists and their forebears. The colonists came from a humid, forested Europe and settled in a humid, forested America. In the traditional way land was cleared and planted to crops. By common consent it was held that only forested regions of the world were fertile and suitable for agricultural purposes. Geographical textbooks explaining the virtues of prairie lands for agricultural purposes did not exist. In fact it was never even suspected that such lands had much value. Thus when the pioneers first moved westward they sought wooded lands for farming. Records show that the early settlers in Illinois and Iowa sought the wooded flood plains first for their homesteads. Here the trees were cleared with great effort to provide farming land. Only by accident was it discovered that the prairie land and the interstream area was equally if not more productive. This ideology was largely responsible for the eastern suspicion of the prairie country, much of which they considered a desert.

In line with such a concept, we need but to consider the Oregon migration in the forties. In this instance several thousand families extended the American frontier nearly 2,000 miles in one migration. They traveled an almost impossible distance and endured untold difficulties in moving from one forested section to another forested section. A distressingly large percentage of these immigrants succumbed on their journey because of hardships and Indian massacres. It is doubtful that these people would have made this migration if they had suspected the fertility of the prairie in Iowa and eastern Nebraska.

The myth of the American desert did not explode suddenly. Only locally and in restricted places did it give way. The garrisons at forts located to protect overland travel to the Pacific discovered that crops could be successfully raised in the less humid sections. Travelers, stranded on their way to the west coast, established themselves on the Plains and found the region suited to agriculture. But as late as 1859 Horace Greeley described the plains of western Kansas, over which he took a journey, as the "acme of barrenness and desolation." "This sand", he wrote, "seems to be as fine as Sahara can boast." He also left the seemingly contradictory slogan: "Young man, go west and grow up with the country."

PLAINS SETTLEMENT

The "desert" myth did at last disappear, so far as it attached to the Plains area, and modern observation even indicates that settlement, with strong governmental encouragement, overstepped the westward limits of safety, so far as the homesteading type of agriculture was concerned.

The pioneers who arrived in the sixties and seventies generally obtained land east of the ninety-eighth meridian, where rainfall was sufficient to produce fair crops, and even at the time of the Civil War the fringe of settlement had reached the Missouri River in its north-and-south extension, where the land was found highly productive. Such success on what had been called a desert led them to suspect that they were transforming an arid region into a humid region. Thus the theory of the migration of rainfall was conceived and soon received wide-spread acceptance. The rather wet years in the late seventies and early eighties lent much encouragement to this contention. Prominent scientists, publicists, and clergymen accepted and encouraged this belief. Samuel Aughey, of the University of Nebraska, was perhaps the most prominent scientist to give dignity to the theory. In 1880 he wrote in his book, entitled "The Physical Geography and Geology of Nebraska", that increased rainfall resulted from cultivating the sod land of the prairie. Another prominent Nebraskan, C. D. Wilber, who subscribed to the same theory, said that all deserts in the world existed because of the neglect of man. The plow and cultivated crops could change all that, according to his belief and writings.

The Homestead Act was passed May 20, 1862, providing for the entry of 160 acres by citizens and those who had declared their intentions to become citizens. An entry fee of $14 and 5 years' residence were required to "prove up" and obtain patent. The Homestead Act furnished the prime impetus to what may be called a mass movement of westward settlement. The Timber Culture Act of 1873, which added its momentum to the drive, is discussed elsewhere (pp. 51 to 52).

The Desert Land Act, passed in 1877, was the first significant change in the Homestead Act as applied to the Plains, recognizing, at least by name, that there was an arid element in western geography. It applied to the Territories of the Dakotas, Montana, Wyoming, New Mexico, and all States and Territories to the west of them. In 1893 it was also applied to Colorado. It allowed title to 640 acres per applicant, contemplating that the land should be irrigated.

In 1909 Congress passed the Enlarged Homestead Act, sometimes referred to as the "Dry Farming Act", which made it possible for settlers in 9 different States and Territories to secure 320 acres as a homestead. The act stipulated that one-fourth of the land was to be cultivated. This was found in many cases not to conform to physical conditions or the best use of the lands.

The Enlarged Homestead Act of 1909, the Stock Raising Act of 1916, and the Kincaid Act applying to western Nebraska recognized the transitional nature of the Plains as between a strictly agricultural status and more extensive forms of use. The Taylor Act of 1934, providing for Government regulation of the remaining public domain, finally recognized the difficulty of prescribing homestead acreages as a basis of land use on the more arid plains, as well as the need for the regulation of such use in the interests of the western grazing industry.

There was a phase of early homesteading known as commutation, which encouraged speculation in land. The commutation clause of the Homestead Act provided for issuing patents on the basis of 14 months' residence and after the payment of $1.25 per acre. With 6 months allowed to establish residence after filing, only 8 months of actual residence was necessary, and this could be adjusted to avoid residence during the severe months of winter by those who did not plan on settling permanently, or who were unable, at first, to construct comfortable homes. A number of early settlers took advantage of this clause after making their regular 5-year homestead entries. Meantime, many of them also took "tree claims." By this means, together with "preemption" or outright purchase of a quarter section at a nominal price, some acquired a total of 480 acres under the three forms of acquisition.

Early in the present century, as homestead lands became more scarce, and land more valuable, the commutation clause was used more extensively and often in land speculation. Veritable armies of people of small means who had lived previous to 1898 without thought of land now took advantage of their homestead opportunities—some earnestly, hoping to provide security against old age, but many speculatively, either on their own account or under inducement by other interested parties. A few years previous to 1898 deeded lands could be had for the cost of carrying the homestead to patent. By 1904 the average selling price for quarter sections in the Minot land district in North Dakota reached $1,922, and in the Devils Lake district, $1,706. These conditions were influenced by liberal opportunities to obtain loans on lands. In towns throughout the areas being newly settled numerous operators promoted real estate and real estate loans. Eastern capital came in freely. This provided a good market for the homesteader who wished to sell to someone who could not or had previously exercised his homestead right, or to a neighbor to enlarge his holdings.

Between 1898 and 1904, 11,778,000 acres were acquired in homesteads in North Dakota and 3,577,000 acres in South Dakota. Less than 35 percent of the entries made in the short space of 6 years were occupied either by original or subsequent owners. Less than 45 percent, under the most liberal allowances for necessity or adversity, had fulfilled the objects of the commutation clause, which was intended to aid the homemaker.

While the standard farm unit of 160 acres still persists in certain sections, in others the size is more frequently 320, 480, or 640 acres. Agriculturally, the region is new, and adjustments are still under way. Each dry period serves to eliminate some of the least securely attached farmers. Their lands tend to be taken over by others who remain, and the size of the typical farm in the West has been increased to several times the original homestead unit.

A study of transfers during the boom period has shown that 78 percent of them occurred within 1 year and 95 percent within 2 years after final proofs were made. Loans reached figures as high as $1,500 per quarter section, whereas before 1898 it was difficult to obtain $300 or $400.

This settlement boom, which extended into new frontiers in eastern Montana, Colorado, and other sections, was the last one of large proportions. As far as settlement was concerned, the erstwhile "American Desert" had been conquered. What happened later to the homesteader, to invested capital, to lending agencies, and to the progressive pioneer spirit of many good citizens is a much larger and more serious chapter in Plains history, which conditions of the past decade have made apparent to all and needs no commentary here.

POPULATION

In the large area now comprising the States of North Dakota, South Dakota, Nebraska, Kansas, Colorado, Oklahoma, and Texas—across portions of which the shelterbelt zone will extend—about 10 percent of the population was of foreign birth at the time of the 1870 census. Of these about 40 percent were of German origin and about 35 percent were from Great Britain. Other countries represented in decreasing numbers were Canada, Sweden, France, Bohemia, Austria, Norway, Switzerland, Denmark, Poland, Netherlands, Italy, Belgium, Hungary, Russia, and Asiatic countries. By 1880 the proportion of foreign-born residents had increased to about 23 percent of the total population, in the counties located wholly or partially within the zone area. The proportionate increase was nearly twice as great in the Dakotas as in the other States.

From 1880 to 1890 the proportion of foreign-born residents decreased, until in the latter year it constituted about 19 percent of the population. Here also, the northern States had the greater proportion of foreign-born, the proportion in North Dakota actually increasing by 10 percent.

Land-settlement programs played a large part in determining the nationality of the Plains settlers. There was a heavy migration from the older settled States by rail or over land, but also an effective advertising campaign was carried to the northern European countries by railroads seeking to sell land and settle farmers in territory served by the roads.

Railway agencies were very active in attracting settlers to North Dakota. They had a large amount of granted lands to dispose of. One road maintained a general European agency in London, with branches in Liverpool, Germany, Netherlands, and the Scandanavian countries, for the distribution of propaganda and the sale of their lands. In 1883 the company was maintaining 124 agencies in Norway, Sweden, Denmark, Netherlands, Switzerland, and Germany. Land was advertised in 200 Canadian and American newspapers, in 68 German papers, and in 32 Scandanavian-American papers.

The Dakota territorial government in 1870 was also active. An office of commissioner of immigration was created. It was abandoned in 1877 but reestablished in 1885. Newspapers were very active in settlement propaganda. Some were printed in Norwegian. The trains were run principally by night through what were called the "poverty-stricken areas of Minnesota" and by day from Fargo to Bismarck, to keep immigrants interested only in the country in which their settlement was desired.

Immigration from Europe increased enormously during the early eighties. The size of land holdings compared with those at home was a revelation to immigrants. Settlers wrote back to relatives telling of remarkable opportunities in America with 160 acres "free or next to nothing."

IMPORTANCE OF AGRICULTURE IN THE PLAINS

The Plains region is our greatest wheat-producing section. More than half the Nation's spring wheat is produced in the two Dakotas. About half the winter wheat is grown in the Plains States, and nearly all the hard red winter wheat is produced in southern Nebraska, Kansas, the western half of Oklahoma, and the Texas Panhandle. The shelterbelt zone passes through the central part of the great wheat-producing region. East of the zone in North Dakota, Kansas, and Oklahoma lie the important areas of concentrated wheat production, in which yields are reasonably certain. West of the zone in these States and in Texas and Nebraska lie the areas in which wheat is grown on a large scale on mechanized farms, but in which droughts are common and the yields are uncertain.

Corn is less important than wheat. Although the tier of States which include the shelterbelt zone produces nearly one-fourth of the United States corn crop, most of it is grown east of the zone. West of the zone, except in limited areas, corn is unimportant.

Barley and flax are relatively important crops in North Dakota and South Dakota. These two States produce one-fourth the barley and more than one-half the flaxseed grown in the United States.

Livestock is important, and previous to the recent severe droughts numbers of livestock had been consistently increasing in the shelterbelt area. In sections too rough for cultivation, cattle are produced on native grass. In sections producing corn or barley, hog numbers were increasing, and, particularly in the northern area, sheep were important.

CHARACTERISTICS OF FARMING IN THE AREA

The nature of the systems of farming and the characteristics of the people in the region are a product of the Great Plains environment. In the shelterbelt zone, as well as in the higher and drier sections to the west, farmers in working out an adjustment to the natural conditions have developed a system of farming unlike that followed in the humid sections to the east. The influencing factors are climate, soil, and topography. In a region of characteristically uncertain and variable rainfall, moisture is the essential element limiting crop production. Temperature, wind velocity, and the accompanying high rate of evaporation tend to intensify the situation created by a shortage of moisture. Differences in temperature and in the length of the growing season affect the adaptation of crops in different latitudes of the zone. Consequently there are wide differences in the farming systems and in the crops grown, but deficient rainfall is a probability in all sections, and the consequences of drought lend a similarity to the farm organizations throughout. Within local areas differences in topography and the nature of the soil may determine certain lines of production. In others, distance to market may limit the kinds of products.

The variability and the seasonal distribution of rainfall exert a dominant influence on the agriculture of the shelterbelt zone, although here the effect is less pronounced than on the extensive reaches of the Plains to the west. In a region such as the Panhandle country of Texas, where the annual rainfall seldom equals the normal rainfall of the humid farming sections in the eastern parts of the United States, the moisture supply is usually close to the minimum for crop production. If the normal precipitation of about 20 inches is considered, along with the high temperature and a variability which gives less than 15 inches of rain in 20 percent of the years, the uncertainty of crop production is apparent. Lack of sufficient moisture during the fall months to start and carry the wheat crop through the winter, or lack of moisture in the spring to grow and produce the crop, may lead to failure. In the northern Plains, with a lower evaporation, crop production can be and is carried on under conditions of lower annual precipitation, but here also moisture is deficient in a high proportion of the years. Under such conditions the farmer, over a period of years, can expect a few bumper crops, several fair-to-good crops, a number of crops that pay little more than the cost of harvest, and some seasons in which crops do not grow at all. It is in these years of failure that the Plains farmer either sacrifices his livestock or maintains them at heavy expense on purchased feed, the productivity of the soil suffers from wind erosion, and the profits of past good years may be wiped out.

The greatest spring-wheat producing area of the United States centers in the shelterbelt zone in North Dakota. This is an area of specialized wheat and small-grain farms. Approximately half the cultivated land is normally seeded to wheat grown in combination with other spring-seeded crops such as barley, oats, and flax. Corn, if grown at all, provides a badly needed cultivated crop. It is usually cut for roughage rather than harvested for grain. The other adapted crops, being subject to the same seasonal influences as wheat, permit some diversification but add little to the possibility of avoiding crop failures. The most important hay crop is wild hay. Before the feed shortage of the recent droughty years forced liquidation of livestock, sheep, stock cattle, milk cows, and hogs were becoming more important as a source of farm income. It seemed desirable, during a period of livestock prices that were high relative to the prices of grain, to turn more to feed crops and livestock and to carry reserves of feed as insurance against dry years.

In South Dakota, with a longer growing season, farmers in the shelterbelt zone had shifted from a one-crop system of farming based on wheat to a system of general farming, in which wheat remained the most important single crop, but in which corn and feed grains replaced a large part of the former wheat acreage. Livestock, particularly hogs, were an important part of the farm business, although wheat was and is still the favored cash crop.

Corn is a more important crop than wheat in the general-farming sections of South Dakota and Nebraska, which represent the transition area between the centers of wheat and corn production. Yields average lower than in the Corn Belt proper, and crop production is less certain; but the livestock enterprises, cattle and hogs, resemble more closely the Corn Belt system than the Wheat Belt system of farming. In Nebraska the shelterbelt zone includes in its western portion an area which forms a transition zone between the sand hills and the farming country to the east and south. The land too sandy for cultivation is a hay and livestock section. Hay and pasture land may constitute as much as 60 percent of the area near the sand hills, although cultivated crops predominate in the portions nearer the farming sections. As the land is too sandy and too subject to blowing for wheat, corn is the major cultivated crop.

Where the shelterbelt zone crosses Kansas, no other crop approaches wheat in importance. For the most part, the area is level or rolling, with heavy, fertile soil which lends itself readily to wheat production with large equipment. Here the system of farming approaches most nearly a one-crop system. As the usual equipment enables 1 man to farm an acreage 2 or 3 times as great as could be handled even 15 years ago, the tendency is to increase the size of the farms and to operate on a large scale. Since, however, the size of farm was established during a period of horsepower farming, when agriculture was centered around the acreage that could be homesteaded, the farms are smaller than in the one-crop areas of western Kansas and the Panhandle of Texas. Yields average higher and are more reliable than in the western areas, corn and grain sorghums are more important as a regular part of the farm business, and livestock, particularly where rough land makes pasture available, is important.

Some diversification or replacement of wheat with feed crops is possible, but in this area, as in the northern sections of the shelterbelt zone, the farm program must aim to conserve moisture and to minimize the extent of soil blowing. Clean cultivation and the timeliness of field work play a large part in successful crop production. The shallow sandy soils, which intersperse the areas of heavy soil and extend in some cases from southwestern Nebraska to Texas, have proved to be the safest forage-crop land in the area. Corn or grain sorghums, used largely for cattle feeding, are the common crops.

In the southern extremity of the shelterbelt zone the Great Plains environment has given rise to a system of cotton production on a large scale. On the level to rolling land, in a climate which permits field work during most of the crop season, cotton is planted and cultivated with multiple-row equipment. Such equipment, used on large acreages, reduces the labor requirements of growing the crop. In some cases the stripper has replaced hand picking. Acre yields are not high and are variable, but little fertilizer is used, and here the tendency is for cotton acreage to continue its expansion.

In general, the climate of the Plains has placed on the farmer a limitation as to the types of crops that he can grow successfully. He operates on a relatively large acreage with the use of mechanical power and large units of equipment. Returns are highly variable from year to year, and moisture rather than fertility conservation is the primary consideration. On the lighter soils some crop cover is necessary to prevent wind erosion, and during long-continued periods of drought, when seeded crops do not germinate or grow and crop cover cannot be maintained, serious damage may follow.

In reality, the uncertainty of crop yields and fluctuations in prices make farming in the area a highly speculative undertaking. The hope of obtaining at some time a good yield and a high price carries the operator through discouraging periods of crop failure. Adverse periods have in the past eliminated those who could not adapt themselves to conditions, and those who remain continue to stake their own time and capital on an increased acreage against the hazards of climate, knowing that a series of good yields will compensate for the losses incurred during the years of failure.

As the farming business is highly commercialized, a large part of the costs of operating the farm must be met in cash. In addition to the farmers' own labor, some additional help must be hired. Fuel and oil for the tractor and repairs to equipment represent a cash outlay. These expenses, labor hire, and machinery operating costs made up 40 percent of the cost, other than the farmers' own labor, of operating farms in a wheat section in southwest Kansas. An allowance for replacement of machinery made up 25 percent more. If the operator is an owner he must pay the taxes on his farm or allow them to become delinquent. If the farm is mortgaged, interest and payments on the principal must be met. Consequently a dry year leaves him with little reduction in expenses. If feed for livestock and seed must be purchased, the expense may even be increased. The farm returns nothing for his labor, and, at the best, living expenses must be reduced and debts allowed to accumulate. On the other hand, a happy combination of yields and favorable prices provides funds for meeting expenses, reducing debts, replacing equipment, and improving living conditions. Too frequently the prosperity of a few years recalls the belief that the climate is changing or leads the farmer to think that at last he has learned the method of controlling the natural environment. The losses of the poor years are forgotten, and new indebtedness is taken on to enlarge the size of the farm and to provide equipment to operate the increased acreage.

SOCIAL SERVICES AND COMMUNITY LIFE

The different States in recent years have given special study to community questions. In 1927 (before the depression) such a study, by the rural sociological department of South Dakota State College, of typical east-central South Dakota conditions, showed that 87 percent of the farmers and their families were well satisfied with the farm as a home and as a mode of living. Very little dissatisfaction was registered against any of the community services, such as the church, school, library, and local government. Also the local marketing, credit, and trading facilities were fairly satisfactory to most farmers. The farmer's chief concern seemed to be his apparent economic inequalities as compared with capital and labor. As evidence of this he pointed to low labor income, mortgage foreclosures, and increased taxation. For the past few years many farmers have looked to State and Federal legislation as a means of obtaining economic relief, although feeling at the same time that farm relief is a group problem whose solution must come through group organization and action. In general, the farmers and their wives indicated that they would undertake farming if starting over again, and they were encouraging their children to remain on the farm.

On the other hand, a study of high-school education of farm boys and girls in South Dakota in 1930 showed that three-fourths of the farm pupils attending high school did not return to the farms, although vocational training in agriculture and home economics seemed to be an influence favoring their return. Many farmers' children had to patronize some other district as tuition pupils at an average cost of $110.61 for the school year—a total tuition bill for the rural districts of over $1,000,000. It was concluded, however, that it would not pay to build up a separate high-school system, but that it would be wise for agriculture to throw in its lot with the townspeople.

The North Dakota Agricultural Experiment Station in a bulletin by E. A. Wilson (1928) on the social organizations and agencies in that State, shows that the State is well provided with religious agencies from the standpoint of number of churches, but there was lack of efficient organization. Organizations and agencies designed to provide recreation and social life were many and varied, but most of them were located or centered in the towns and cities. Relatively few farmers participated in the activities of social clubs and societies, although patronizing extensively moving picture-shows and pool and dance halls. Library service was available to very few people. The author concludes that "if farm children are to remain on the land, farming must not only be profitable but life on the farm must be satisfying."

A bulletin published in January 1928, on rural changes in western North Dakota showed that almost 70 percent of the farm residences were good to fair, but very few had modern conveniences. Compared with areas in the eastern part of the State, which had been settled twice as long, there were fewer good farmsteads and fewer home and cultural conveniences; but this is a condition typical of newly-settled areas. More girls than boys continue their education beyond the grades. A larger proportion of boys than girls remain on the farm after finishing school. Counties in which the nationality of the farmers is predominantly German or Russian showed smaller decreases in the number of farms than other counties. Of the farm operators who left the farms from 1920 to 1926, inclusive, 40 percent left for economic reasons, and financial difficulties were responsible for the departure of three-fourths of these.

Almost three-fourths of present operators attended church, as compared to 60 percent of former operators. Nationality, which is closely related to church denominations, is a more influential factor in churchgoing than distances to church. Relatively few farmers, and a less proportion of farmers' wives, belong to lodges or other social organizations located in towns. They are more inclined to affiliate with rural social organizations. Social organizations for the young people, other than boys' and girls' 4-H clubs, are few in number. More than 90 percent of the farm operators queried in this North Dakota study said they "liked their community." Community clubs are most numerous in the counties which have had county extension agents for the longest periods.

Social services and community life vary by nationalities and for other local or regional reasons; but the observations in the Dakotas are doubtless more or less typical in these times of rapid transport and communication and the somewhat centralized direction and assistance by both the Federal and the State government in agricultural, community, and other rural affairs. There is no longer enforced isolation among rural populations. These things have tended toward common thinking, related viewpoints, and similar social customs.

HIGHWAYS

In the shelterbelt zone there are nearly 6,000 miles of all-weather surfaced roads of all types. In addition many miles of graded and maintained earth roads can be used for the major portion of each year. No point within the entire zone is more than 20 miles distant from at least one improved roadway which can be traveled at all times of the year. Whereas it was formerly customary for a large percentage of automobiles to be stored during the winter months, year-round travel by automobile throughout the area is now commonplace.

PHYSICAL HANDICAPS OF THE REGION

Drought and winds, hail, cloudbursts, occasional extreme cold, and their influences on agrarian pursuits contribute the principal physical handicaps to present-day agriculture of the plains. The farmer, even with improved defenses from these attacks, must pit himself against all their uncertainties, any one of which may completely upset his calculations. They have placed the farmer in much of the Plains area in a position of "gambling with nature" that pales the operator on the board of trade.

Of late years, with the subduing of the soil and the removal of root fibers and other soil-binding material, wind and gully erosion are removing untold millions in capital values. A shortage of domestic and stock water is a large handicap over broad areas, although considerable relief has been obtained by the sinking of deep wells. Drought exerts very direct effects on water resources through the lowering of water tables and the drying up of erstwhile adequate wells and other sources of supply. About 1,000 sandhill lakes in Nebraska dried down to or near their beds in 1934, and the larger areas become shallower and smaller. Livestock suffered more from lack of water in some critical areas than from pasture shortage. Many marshes, lakes, and streams went dry. Municipal water supplies had to be extended and many new irrigation wells made. The worst local feature of the prolonged drought was exhaustion of drinking-water supplies. Droughts serve to make people water-minded and less wasteful of water from whatever source. Some of the States have attempted to regulate improvident uses of artesian flows.

LAND USE

There is little question that large areas of land in the entire plains region have been abused. To prevent wind and water erosion, some land should be kept permanently in sod. The report of the National Resources Board traces to the manner of disposing of the land many present abuses of land. To survive as a farmer, one may be forced to accept the short-time exploitative point of view. Even the farmer who wishes to adopt a system which will eliminate erosion or loss of soil fertility may find the conservative way of farming impractical. For this reason controlled land use appears unavoidable. Land subject to loss from blowing may be protected, by shelterbelts, and different cultural methods, or restored to natural cover. Some land unsuited to cultivation, but which was plowed for the sake of 1 or 2 crops, could well be used as pasture land to achieve that balance between cash crops, permanent grass, and livestock production which will add to the stability of agriculture in what is now an area of speculative farming.

Section 11.—CLIMATIC CHARACTERISTICS OF THE PLAINS REGION [12]

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CONTENTS

From the standpoint of practical importance, the items of greatest interest in the climate of the Plains are the persistent, rather high wind movement; the low precipitation in the northwest sector farthest removed from the Gulf supply; the high frequency of droughts in the section of southwest Kansas most directly in the path of southwest winds; and the extreme temperatures which occur everywhere when moisture is lacking at midsummer.

Except in affecting locally the wind movement, the ways in which shelterbelt planting or more extensive planting in blocks can affect climate appear to be somewhat remote, and possibly not as important as direct water-conservation measures. Each can play its part, however, in any well-rounded program for the amelioration of the climatic conditions of the Plains.

In treating the subject constructively, it is hardly sufficient to say that the climatic conditions of the Plains are such and such. It is necessary to develop a sufficient understanding of matters to indicate how far the local climatic factors can be changed by any "developments" which might be undertaken by man, such as the change from grassland to farming conditions which has already taken place, and the extensive tree-planting and water-conservation measures which are proposed for the future. Hence the various phases of the subject are discussed, not in the order of their immediate importance, but to develop logical cause-and-effect relationships. Little space is given in this discussion to the bare facts of climate, which may be read from the accompanying maps (figs. 23 to 35).

WIND DIRECTIONS AND VELOCITIES

The well-known windiness of the Plains is probably due in a small measure to local factors causing wind (this may be a considerable factor during the summer period, when storms are largely bred locally), but more largely to the unbroken topography and lack of impediments on the surface, giving the wind a free sweep. The average wind velocity over most of the region [13] is from 10 to 12 miles per hour, but is above 12 miles in eastern North Dakota and eastward to Lake Superior, in a small area around Valentine, Nebr., and over a large area on and adjacent to the Texas High Plains.

These average velocities are in excess of those prevailing in most other sections of the United States, although an area bordering the Great Lakes and a considerable area in Nevada and southern Idaho show velocities of 10 miles per hour, or slightly more. Nearly one-third of the country has average velocities of 5 to 8 miles per hour, while a similarly large area averages 8 to 10.

The prevailing direction of the wind over most of the area is from the northwest in the winter and south or southeast in the summer. At no point in the region is the southwest wind an important factor as indicated by duration, yet over most of the area southwest winds occur at intervals and are usually very damaging because of their dryness and the heating which results therefrom. The rather frequent occurrence of such winds in South Dakota suggests a local origin, perhaps in the heavy, arid clay soils which prevail west of the Missouri River.

In the lower western Gulf region there is a large area extending to southeastern New Mexico and as far north as Wichita, Kans., in which, even during the winter, the winds continue prevailingly from the south (figs. 23 and 24).[14] While this condition affects only the southern extremity of the shelterbelt zone,

[12] Due acknowledgment is made to the U. S. Weather Bureau not only for the general use of their data herein but for special help given by J. B. Kincer of the central office in the preparation of certain maps and to the section directors of all of the States involved for very fine cooperation in making unpublished material available for the compilations. Credit for the compilations and maps made at the Lake States Forest Experiment Station belongs almost entirely to W. E. Barnes, junior forester, acting under the writer's direction.

[13] These general statements are based on the map shown on p. 34, Atlas of American Agriculture II, B (Washington, 1928).

[14] Beginning in 1918, various Weather Bureau first-order stations have successively taken up the compilation of the wind-direction and velocity data on an hourly basis, tabulating under one of the eight directions, which happens to prevail during each hour, the whole number of miles of wind in that hour. Although the periods for which such information is available are not uniform throughout, this is not thought to be important if the record for at least 10 years is employed.

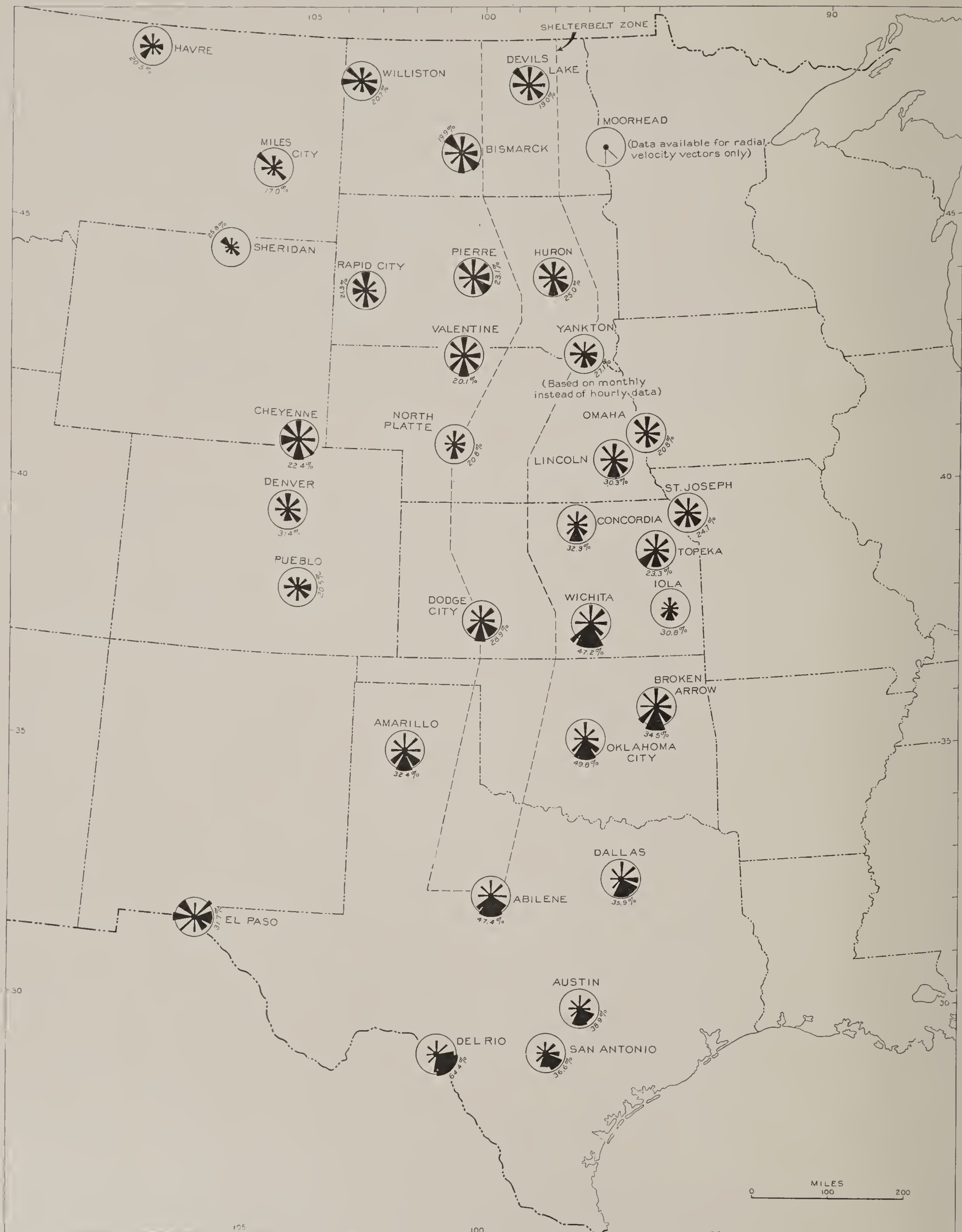

FIGURE 23.—Wind directions and velocities for the 3 summer months. Proportion of time from each direction shown by width of wedgelike petals of each "wind rose" and average velocity by the length of the wedge; the radius of circle denotes 10 miles per hour.

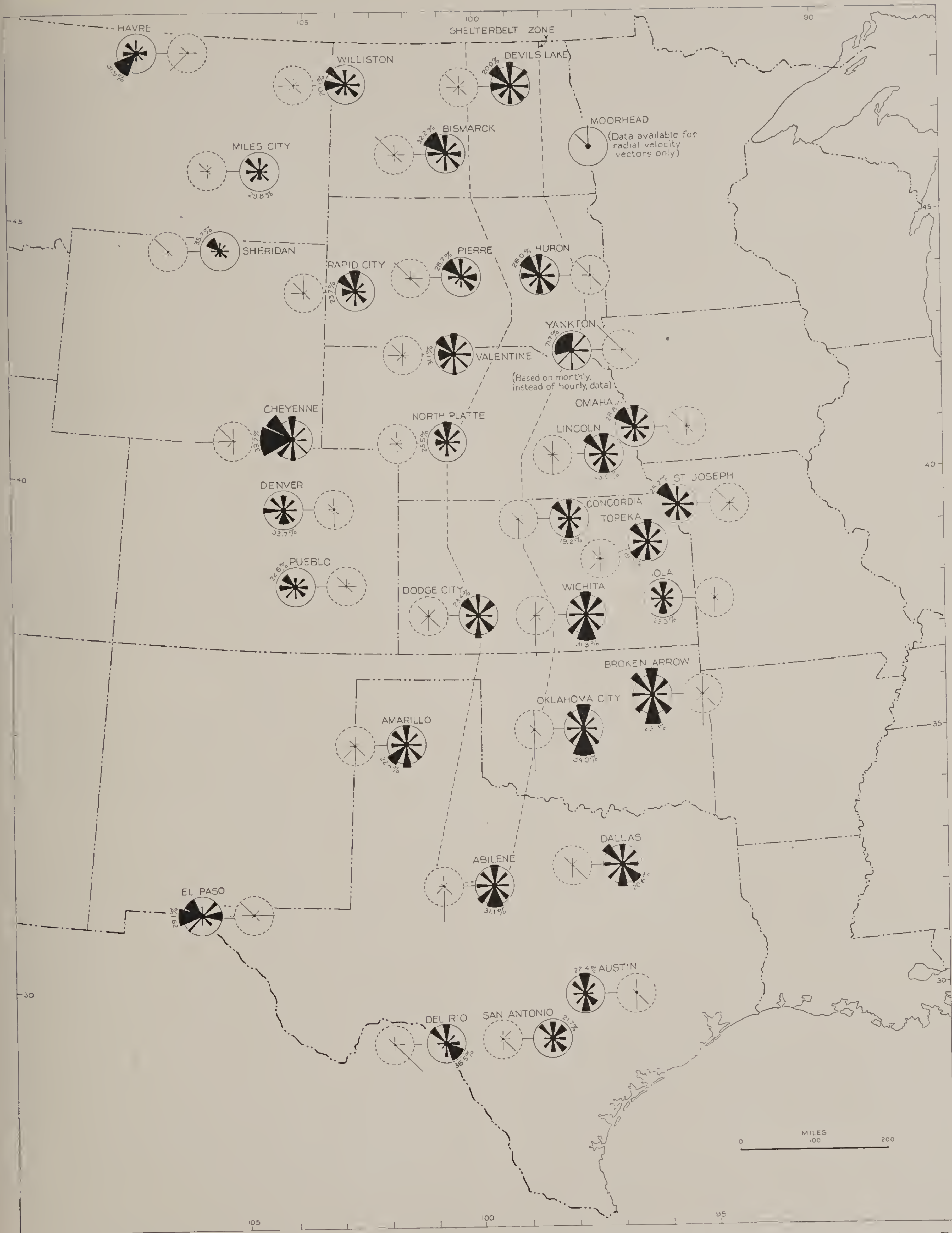

FIGURE 24.—Wind directions and velocities for the 6 months November to April, and total movement for the year from each direction. Proportionate time and velocity from each direction for winter period shown by width and length, respectively, of wedgelike sectors of "roses," radius of circle denoting 10 miles per hour. Total movement for the year from each direction shown by length of radial lines in secondary "roses," radius of circle representing 20,000 miles

it is worth keeping in mind that the effect of northern blasts is felt only intermittently and that, when these do occur, the change from the usually mild winter conditions is very marked and often severely damaging to trees and other living things.

FORCES CONTROLLING WIND DIRECTION

In the central United States, the winter winds are the prevailing westerlies; i. e., a general west-to-east air movement characteristic of most of the North Temperate Zone, together with a southerly movement from the cooler land area to the warmer waters of the Caribbean region, apparently strongly influenced by the proximity of the warm Gulf Stream in the southeast quadrant. During this season, however, the regular southeasterly movement is frequently interrupted by the passage of "cyclonic storms" or low-pressure areas which, with the westerlies, move in from the north Pacific region, dip somewhat to the south, then move out of the United States in a northeasterly direction. Again, the center of low pressure may move across the central portion of the Plains, or well to the south.

Frequently these whirling masses of air, forming a large vortex with low atmospheric pressure, move across the United States with great regularity, drawing the air to them from all directions. Occasionally the centers of low pressure are diverted here and there, so that the regular movement is seriously disturbed.

When such low-pressure areas move across the northern United States, they bring well toward the northern border, warm moist air from the Gulf, which, coming in contact with colder and drier air drawn from Arctic regions, is elevated, and its moisture largely precipitated.

Even with this frequent disturbance and opportunity for mixing and elevation of warm, moist air currents, the winter precipitation of the western basin area remains surprisingly low, but is a somewhat more important factor in the total precipitation of the southern section than of the northern. Low precipitation at this season results from a smaller capacity of the atmosphere to evaporate and pick up moisture from the Gulf region, and also from the less steady and persistent air movement from the Gulf to the land during the winter. Describing it in another way, the dry air from the west and north at this season intrudes itself much more strongly upon the entire scene.

ANTICYCLONIC WINDS OF WINTER

For this reason, while cyclonic storms frequently interrupt the westerlies for several days at a time, one of the outstanding features of the winter season is the strength of these westerlies in the wake of the passage of a low-pressure area. It is not uncommon, in the low-precipitation zone near the base of the Rockies, to see the scant snow which has fallen, carried away by these so-called anticyclonic winds without having opportunity to moisten the soil at all. Following this, if high velocities persist, comes complete drying of the soil, dust storms, and serious soil erosion, these phenomena being more common as winter advances into spring without the expected spring precipitation.

One can see here that the preservation of soil moisture at that period, when the winter forces—not generally conducive to precipitation—are having their last "whirl", may represent an important and crucial point in the entire moisture regime. Certainly it is apparent that in those seasons when the winter forces of dryness hold sway unduly late, the immediate effect upon soils and fall-sown crops is not only crucial but in many instances fatal. Assuming that protection can be afforded which will materially reduce the drying power of the augmented westerlies during the winter, it would seem that the retention, in the western zone, of soil moisture to be evaporated later, will make spring rains more beneficial.

Believing that this is a critical point, if only from the standpoint of the certain, direct, localized benefit from protection, it is recommended that special stress should be laid on shelterbelt orientation to protect the soil from these early season winds quite as much as from the obviously desiccating hot south winds of summer.

SUMMER WINDS AND LOCAL STORMS

Wind directions during the summer are, in the main, much more moderate in velocity than those of winter.

The commanding force determining direction of wind during the summer months (the months June to August are segregated in our calculations because in the northern region only these months show a definite reversal of the conditions which prevail most of the year) is the higher temperature and lower pressure which prevail over the continent as compared with the oceanic areas on all sides.

Air enters the entire Mississippi Basin from a southerly or southeasterly direction at this season, spreading fanlike to the northwest, north, and northeast. So far as the western sector is concerned, the westward drift is plainly due to the fact that the lowest pressure generally persists at this period over the region of the Great Basin.

At this season, it may be said that the entire continental area is setting up its local convectional currents. These, set up as a result of local inequalities of heating—to a slight extent small cyclonic swirls—take the place of the larger cyclonic movements, which either fail entirely to develop over the Pacific, or, coming inland by aid of the weakened westerlies, encounter so many disturbances over the land that their identity is lost. These local convections, while largely responsible for precipitation or the lack of it, have little effect on the prevailing wind. At the same time, some of the most violent and destructive winds of short duration are commonly connected with the actual storm periods. To illustrate, on the Plains thunderstorms may begin to develop before midafternoon, the cloud formations increasing in size until late afternoon, and very often moving eastward perceptibly. Their "breaking" late in the afternoon is almost invariably accompanied by a squall from the west, which persists, perhaps only for a few minutes, until the rain is well under way or the center of disturbance has passed and spent itself without rain.

INFLUENCE OF SURFACE CONDITIONS ON LOCAL CONVECTION

The movement of the wind toward areas of low pressure cannot, of course, be stopped or even checked by any condition on the surface. If man were to erect barriers, or windbreaks, which completely stopped wind movement close to the ground, and if other conditions remained the same (which of course they would not), it could only result in the movement occurring at a slightly higher level. On the other hand, one might say that the development of low-pressure areas is dependent upon many conditions, some of which have been and will be modified by man's actions, although possibly the effect of such modification is imponderable in comparison with the major forces which have their origin in the existing, yet variable, composition of the entire solar system.

SHELTERBELT ORIENTATION

From the standpoint of shelterbelt orientation, with prevailing winds "quartering", it is often difficult to state whether the axis may best be in one direction or another. But because east winds are themselves generally harmless, and both north and south winds are frequently quite damaging, there is a tendency everywhere, except possibly in North Dakota, to ignore west winds despite their frequent occurrence during storms, and as "anticyclones", and to believe that shelterbelts having their axes east-west can accomplish the greater degree of protection. Whether this is an entirely correct assumption remains to be shown by a more detailed analysis of wind values and of their effect on local evaporation than is possible at this time.

PRECIPITATION

SOURCE

The entire Plains region, being cut off from Pacific moisture by the mountains on the west, and enclosed on the north by a cold area in which relatively little evaporation can occur no matter how extensive the lakes and ice fields, is dependent to a large degree on moisture from the Gulf region to replace that which has been lost. It is largely this dependence upon one source and upon winds from one direction which is responsible for the small quantities received in the most distant northern and western portions of the Plains, for great variability in the precipitation in the southwest part of the area, and for the frequent occurrence of droughty periods. It is also this factor, together with the southerly course taken by some cyclonic storms during the winter, which accounts for the extremely low winter precipitation in the North, with the ratio of winter moisture to the annual amount tending to increase southward.

The high Rockies, which, together with the coastal mountains, draw from the westerly winds essentially all moisture which has been evaporated over the Pacific, stand as a barrier against entry of much rain from that direction, and winds coming down from the mountains to the western Plains are usually dry, warmed by their descent and likely to be very desiccating.

Winds from the North, no matter how great the moisture available in the Arctic regions, can carry only an amount of moisture limited by their temperature, and when this temperature is below freezing the absolute moisture which they carry is trifling.[15] Arctic air in running south into a drier region is not likely to add to its moisture as rapidly as its temperature increases. Upon becoming involved with much warmer and moister air from the South in the cyclonic "mixing bowl", some of the moisture of Arctic air may be precipitated, but it is insignificant in comparison with the amount that may be brought from a warmer oceanic area.

East winds, in the Plains region, are usually felt for a short time just before a storm and it is common knowledge that they always feel cold and moist. Insofar as such winds are truly from the land areas farther east (and the Great Lakes) which are much better watered than the Plains, east winds may be returning a portion of the moisture which has previously been carried out of the Plains region by the drying west winds. Actually, however, the wind seldom blows long from the East, and even when it does it represents, in part at least, the air from the South which has already become involved in the counterclockwise swirl of the cyclone.

Thus, for new supplies of moisture, the Plains region is dependent very largely on winds from the Gulf, and the more distant portion of the region is dependent upon the chance that, long before the winds from the Gulf have reached it, they will have encountered disturbing conditions causing most of the moisture to be precipitated. Hence the rather steady decrease in amount of precipitation from the Gulf outward, particularly in a northwesterly direction.

The high western rim of the Plains, i. e., the Rockies, receive much more moisture than adjacent Plains areas, and this is almost wholly from the Gulf, the cooling of air currents as they rise over the mountains being sufficient to cause much of it. The mountain ranges adjacent to the Plains benefit greatly from the southwestern low which is responsible for a summer rainy season which begins, usually July 10 to 15, at about the same time that the rainfall of the northern Plains drops off markedly. This "rainy season" is hardly noticeable beyond southern Wyoming and is most sharply defined in southern Colorado, New Mexico, and Arizona.

In short then, the winds from the Gulf, normally give to the western part of the Plains at midsummer a little better chance than they would have if only dry south winds were driven over this section, as sometimes occurs. The Gulf winds are fairly well laden with moisture; but, with the Plains very hot, there is generally no inducement to precipitate such moisture until the air currents strike the high and much cooler mountain ranges.

There is some slight compensation for this in the fact that the excess rainfall in the mountains flows through the Plains giving the driest portions the only permanent streams which they possess, with the marked exceptions of the Cimarron and Republican

[15] For example, theoretically complete saturation at 0° F. has become only 21 percent relative humidity if, in moving southward, the air current has become warmed to 32° without change in moisture content. If the current saturated at 0° meets and mixes with a current saturated at 40°, the mixture will be saturated at about 20°. The prevailing opinion now appears to be that the warm air is more likely to flow up over the cold air and that precipitation results from elevation and cooling of the former more largely than as a result of mixing.

Rivers. A great deal of this water is used for irrigation, in Nebraska and Kansas, for example. The question deserves careful study, whether at least the flood water from some of the more southerly streams could not be more fully stored and utilized in the Plains for improving agricultural conditions.

ANNUAL AMOUNTS OF PRECIPITATION

The average or "normal" amounts of precipitation referred to in this discussion, unless otherwise specified, are the averages for the period of approximately 40 years, from 1895 to 1934, inclusive. The purpose in adopting this period was to include, as nearly as possible, a complete "cycle" from the end of the last great depression of precipitation in the Plains region to the end of the current depression. However, 40 years is a fair basis for comparing different parts of the region and is about the longest that can be employed for any large number of stations. Even for this period it is necessary to extrapolate parts of the records, which has been done, for stations with less than 40-year records (but in no case less than 15), by comparing such stations during their period of record with 2 or 3 stations surrounding them, and assuming that the same ratio existed between these stations and the incomplete one during the period when the latter had no record.

The average annual precipitation of 55 to 60 inches in the central portion of the Gulf "arch" decreases up the Mississippi Valley to about 33 inches in southwestern Wisconsin and does not increase with closer approach to the Great Lakes (fig. 25). A rainfall very much less on the west shore of the Gulf of Mexico, amounting to only about 26 inches at the mouth of the Rio Grande, increases slightly to the northward owing to a fairly high plateau south of the Colorado River, but, continuing further along the 98th meridian, remains at about 30 inches until northern Oklahoma is reached, then decreases with fair regularity to 18 inches at the Canadian border. The lower Rio Grande Valley and the plains of northern Mexico east of the central plateau are regions no better watered than many parts of our own Plains. On the 100th meridian the annual rainfall is only 20 inches at the Rio Grande, increases slightly over the Edwards Plateau of lower Texas, then decreases rather regularly to less than 16 inches at the Canadian border. The smallest amounts, generally around 14 inches, are found on the smooth but very gently rising plains between the 100th meridian and the foot of the Rockies, with an extreme low of about 12 inches recorded at Pueblo, Colo., in the Arkansas Valley just at the base of the mountains.

"TURN-OVER" MOISTURE V. REPLENISHMENT FROM THE GULF

If we are to have a proper understanding of the moisture-supply problems of the Plains, the importance of "turn-over" moisture must be realized. This idea has been developed elaborately by Zon.[16]

If the wind blew persistently off the Gulf of Mexico to the north and northwest, and if all of the moisture carried from the Gulf and the Caribbean were precipitated along the first 100 miles of the Gulf coast, a very considerable area would have very heavy rain. Of this amount a large proportion, probably two-thirds, would flow back to the Gulf because, with moist Gulf winds always blowing, the evaporating power of the air is or would be very low indeed. There would thus be only about one-third of the total which, being picked up at times when the air was not saturated, might be reprecipitated later or carried farther inland, where it could water a similar 100-mile zone much less abundantly than the first zone was watered. It is probable, from the facts known, that very little would flow from the second zone back to the Gulf, and, the atmosphere being drier than in the coastal belt, the evaporation of this moisture after it fell would be much more complete and prompt.

This is what is implied by "turn-over moisture", and the process plays a very important part in watering an interior region. The coastal conditions are, of course, not exactly as stated, although there is a cooled belt in the central Gulf sector which receives a 60-inch precipitation and returns a very large part of it to the sea. There are, however, no sharply demarked zones and, fortunately, there is no sharp elevation along the Gulf coast to cause a strong concentration of precipitation there, else the interior would receive much less than it does. While large quantities are dropped near the Gulf simply because very little disturbance is required to cause precipitation, it is nevertheless true that much of the original moisture is carried farther inland, and at times, without doubt, to the outermost limits of the Plains region. The point to which it is directly carried at any time depends, primarily, upon the latitude through which cyclonic storms pass.

Stated briefly, the Gulf moisture is carried, directly or indirectly, to all parts of the Mississippi Basin, to the crest of the Rockies, and to the Arctic regions. There is a fairly steady northward movement and very little return from the extreme northern areas to lower latitudes because of the impossibility of rapid evaporation at low temperatures. There is also, during the winter, a more or less general and steady movement of vapor from west to east, but there is also, for brief periods, considerable return from eastern sections of the Basin to the drier west. When it is observed that the entire average return to the oceans through the Mississippi, Hudson Bay, and St. Lawrence drainages, does not exceed 7 inches per annum, while the average precipitation of this entire area is evidently in excess of 30 inches, it becomes evident that for large continental areas as much as three-fourths or four-fifths of the total precipitation must be turn-over or reevaporated moisture.[17] Brückner[18] estimated this at 78 percent of the total for continental areas as a whole.

While, then, it may in any instance be very difficult to determine where evaporated moisture will go, or from what direction a given area may receive moisture, it is evident that any possible increase in the atmospheric-moisture supply held within the Plains

[16] ZON, RAPHAEL. THE RELATION OF FORESTS IN THE ATLANTIC PLAIN TO THE HUMIDITY OF THE CENTRAL STATES AND PRAIRIE REGION. Soc. Amer. Foresters Proc. 8 (2): 139–153. 1913. Also pub. in Science (n. s.) 38: 63–75. 1913.

[17] It is impossible to estimate this closely for any particular area on the basis of the return to the sea through streams. For example, most of the shelterbelt zone yields only 1 to 2 inches per annum in this form, but the southern region yields a steady flow of atmospheric moisture to the north, and the northern region loses a great deal to the east, so that both sections must have "replenishment" in a larger measure than is indicated by stream flow.

[18] BRÜCKNER, E. KLIMASCHWANKUNGEN SEIT 1700. 324 pp., illus. Wien and Olmütz. 1890.

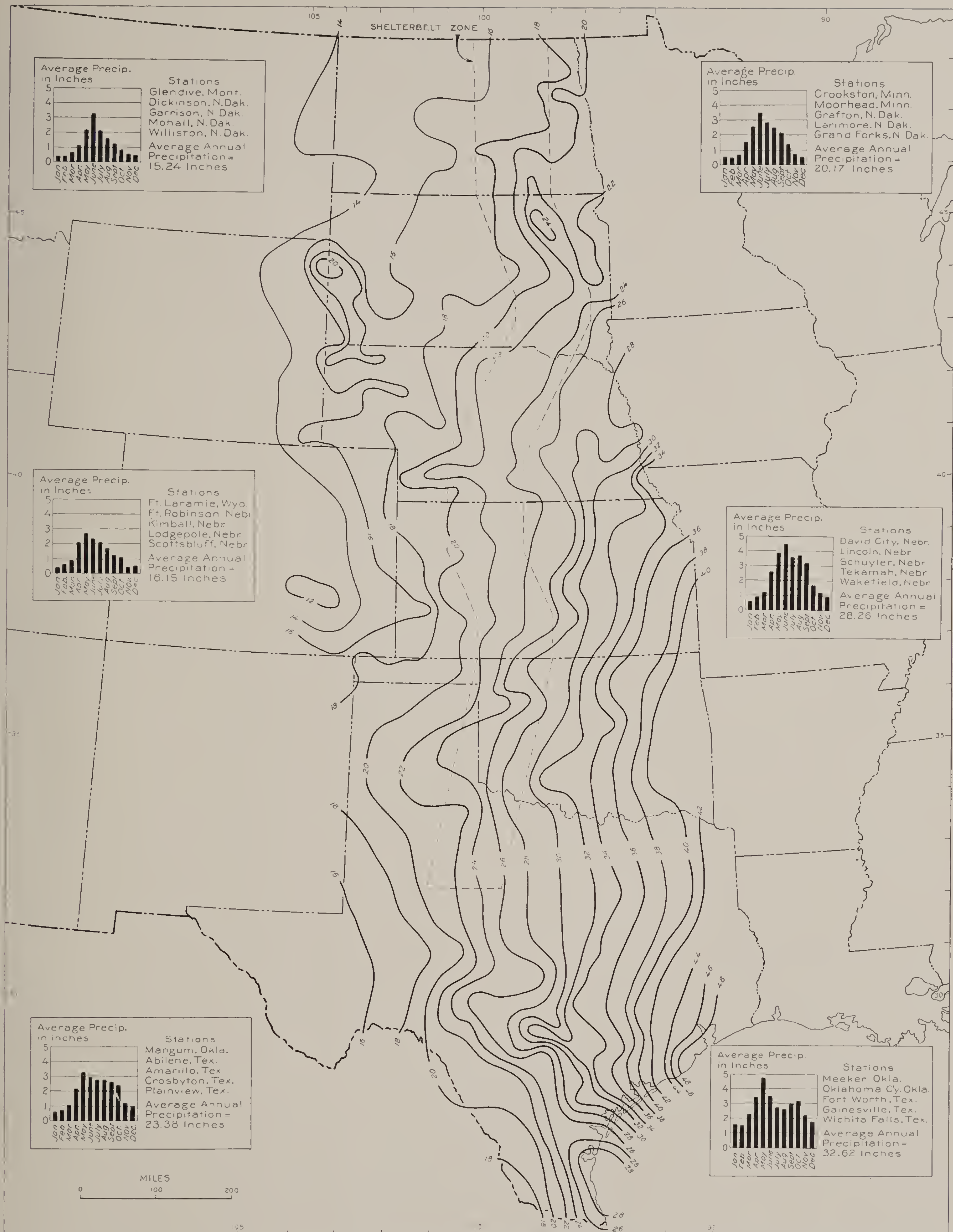

FIGURE 25.—Average annual precipitation in inches for the 40-year period 1895–1934, together with typical monthly distribution charts for various parts of the region.

region cannot fail to be reflected by an increase, in some slight degree, at least, of precipitation in or near the region. Primarily, a change in this direction can be accomplished only by preventing the return to the sea of that portion of the rainfall which now reaches the streams, but a slight change in the time or season of precipitation may be effected by any factor which tends to delay evaporation of moisture from the soil.

EFFECT OF TOPOGRAPHY, SOIL, VEGETATION, ETC., ON LOCAL PRECIPITATION

Increase in precipitation is noted wherever there is any appreciable elevation, as on the High Plains of the Texas Panhandle, where, at an elevation of about 3,000 feet, there is an increase of 5 to 6 inches annually above what might be expected on an even plain. In the Black Hills of South Dakota, elevations slightly above 5,000 feet induce an excess of nearly 8 inches (the long-term records do not show so much as this, but there have been observations which show that nearly 25 inches fall on the western rim of the Black Hills); and even an added elevation of scarcely more than 200 feet between the Republican and Platte Rivers in Nebraska gives an increase of about 3 inches per annum. Another irregularity is the excess in the upper James River Valley in South Dakota, which may be induced by the Missouri Escarpment, having an elevation of 200 to 300 feet near the boundary between North Dakota and South Dakota, and lying immediately west of the valley where the increase is recorded.

If these effects of elevation are pronounced, the shortage of moisture falling in, or close to, some of the larger valleys is also notable and is significant in indicating that the areas of highest evaporation do not necessarily receive the benefits thereof. The Plains, where dissected by the valleys of the large eastward-flowing streams, in a notable number of instances receive more rainfall than the valley stations in the same longitude.

It is probably the wide and shallow Cheyenne River Valley, draining from the Black Hills to the Missouri River in a direction slightly north of east, and the extension of extremely flat land in the same direction east of the Missouri, which accounts for the droughty conditions through central South Dakota. An excess of precipitation in the upper James River Valley, as just mentioned, may to a slight extent "rob" the territory farther west. The observation stations in this area are so scattered that the effect may be more localized in the Cheyenne Valley than the precipitation and drought maps would suggest.

The diversion or "pulling" eastward of the isohyetal lines across the Platte Valley is fairly evident almost to Grand Island on the east. West of North Platte it apparently becomes combined with an eastward pull exercised by the sand hills which lie north of the Platte and which may have an influence similar to that of a valley, as will be apparent when the cause of any such influence is described.

The Arkansas River, more definitely set between short-grass plains throughout western Kansas, shows a similar pull on the lines, with the most marked effect at the west boundary of the State, but noticeable to the vicinity of Wichita. Again, in the Great Bend section of this river, the depression is thrown to one side in the decidedly sandy, subirrigated flats which center in Pratt County.

The Canadian River apparently has a similar effect from the Texas line eastward. In a line from Arnett to Kingfisher, however, the depression is distinctly north of the Canadian Valley, and it is notable that a considerable part of this territory is the sandy shin oak land. Probably this is a combined effect of the Canadian, North Canadian, and Cimarron Rivers which, east of Arnett, are all within a distance of 50 miles.

The Red River shows no marked tendency. Where it passes through the High Plains of the Texas Panhandle in rather narrow canyons, the precipitation is plainly "pulled" westward by the elevation of the short-grass plains, much more strongly than by any contrary pull of the conditions along the narrow valley or valleys.

Thus, if it be conceded that the records are now long and detailed enough to prove such a point, it is apparent that certain conditions of the "hard" plains tend to make them better watered (i. e., receiving greater precipitation) than the valleys or tall-grass sandy land in the same longitudes, in both of which the vegetation draws upon deep moisture and which, therefore, are likely during drought periods to be transpiring moisture to the atmosphere much longer than the short-grass land.

Several explanations of this phenomenon are possible:

1. The first inclination will be to ascribe the higher precipitation of the hard plains areas to their altitude. This, together with lower summer temperatures, may be the most reasonable explanation in the case of the Texas high plains, which rise abruptly enough and to a sufficient height above the land to the east and south, to have a noticeable effect. It is hardly the explanation where the plains between stream valleys are essentially flat and scarcely more than 100 feet higher than the valley bottoms.

2. The harder lands, by reason of their capacity to hold more water in the surface layers of the soil, evaporate and transpire it more quickly after rains than do the "soft" or sandy lands. They thereby produce a quicker local turn-over of the moisture. We might, to use a concrete illustration, say that the moisture supply of a given area of hard land is evaporated and reprecipitated in the same locality 5 times per year as against 4 times for a locality in which the moisture sinks deeper into the soil and is brought up and evaporated more slowly through the aid of plants. Finnell[19] estimates that on heavy soils in this region, as represented by experiments at Goodwell, Okla., only 19.8 percent of total rainfall on the average gets into the subsoil available for plant use, while 64 percent evaporates very quickly following both effective rains and those which wet only the surface.

While it is believed that this quick evaporation from the hard lands of the Plains is an important factor in increasing the total precipitation, it is well to point out that the chance of reevaporated moisture falling in the exact locality from which it was derived is remote indeed. Such importance as this factor possesses is, probably, covered in the following paragraphs.

3. If elevation and quicker turn-over are factors in the situation, there is still another worthy of consideration. River valleys which are subirrigated, or artificially irrigated, and to a lesser extent sandy areas in which the rainfall alone wets the soil to a considerable depth, through the more constant activity of vegetation, in reasonably calm weather tend to keep the air immediately above them cooled, relatively to the short-grass plains on either side and the frequently bare, eroding slopes of the valleys. Thus there tends to be a downdraft of air, at least during the day, which is in no sense conducive to precipitation in the valleys. The air thus cooled

[19] FINNELL, H. H. THE UTILIZATION OF MOISTURE ON THE HEAVY SOILS OF THE SOUTHERN GREAT PLAINS. Okla. Agr. Expt. Sta. Bull. 190, 24 pp. 1929.

and more or less laden with moisture in the valleys is pushed out on either side, where it is again warmed on the more bare valley walls, and on to the already dry plain, where a warm ascending current is being developed under the heat of the sun. Thus, with any focus for such a formation, such as a slight promontory or a bare area with very rapid radiation, we might expect rain clouds to develop over the plain areas, though the moisture of the air was being derived largely from moister valleys or tall grass areas nearby. It is a well-known fact that thunderstorms, often of the most violent character, develop on sultry days; that is, on days when there is no definite wind movement and when, therefore, local convectional currents may develop without interference in a locally heated focus where the rapid ascent of the moist air definitely begins.

If the plain between valleys is assumed to rise to a definite ridge, we would expect the focus for ascending air currents to be here, because such a ridge would naturally have the scantiest vegetation and would radiate heat most rapidly during the day. A focus might, almost as well, develop over a dried-up lake bed or any other distinctly bare area, the elevation of the ground having little to do with the matter. It is not the elevation of mountain peaks which makes them foci for convectional currents, but their bare rock surfaces.

Apparently, then, an area which dissipates its moisture most rapidly and subjects itself to the greatest extremes of heat and aridity may actually receive heavier rainfall than an adjoining area which retains and uses its moisture more conservatively. This apparently, is a severe blow to the theory that shelterbelt planting may increase local rainfall. The opposite effect seems a possibility. The importance of the theory is sufficient to justify a careful examination at this point, while the natural facts are clearly in mind.

If, for example, there is planting of trees along a valley or on a sandy plain where it is known there is sufficient subsoil moisture to maintain the trees in an active condition even during dry weather, it is possible that the rate of transpiration in the valley, and the total contribution of a given area of valley land to the moisture of the atmosphere, might be slightly increased, especially at a time when early season crops have matured and fields are largely bare. *No material increase* from such a planting is, however, to be expected if the trees, through checking wind, tend appreciably to reduce the rate of evaporation from the fields adjoining them. Therefore it is not seen that the trees can make of the valley area a much greater source of moisture than it would otherwise be.

As an alternative proposition, let it be supposed that planting be more largely concentrated on the hard ground of the Plains. Some of the rainfall received here commonly runs off and a large part of that which goes into the ground is held close to the surface and is quickly evaporated without benefiting vegetation, but it may be assumed that the areas planted to trees, through better rainfall reception and through reduction of direct evaporation, will obtain and store enough water to carry the trees through any ordinary dry season in an active condition. What then will happen? During dry periods the tree-covered areas will add a small amount of moisture to the air about them. It is not believed that small bodies of trees will directly have any important net effect on air temperatures in their immediate vicinity. While, on a calm day, they may appreciably cool the air which makes contact with them, it is also undeniable that air stagnation on their leeward sides tends to produce higher midday temperatures. This contrast may, in itself, tend to set up convection in a small way, a desirable thing, particularly in puncturing the blanket of hot air which frequently lies over the Plains until temperature differences become so great as to cause an upheaval. Such regular circulation, by mixing the air strata, may have a much greater effect on ground temperatures than the cooling effect of the trees.

However, it is fairly evident that both this minor and ineffective mixing, and the mechanical barriers to circulation along the ground may tend to reduce the flow toward effective foci of convection and reduce the chances for thunderstorms. In any event, these are likely to be at some distance from the planted area.

Since even a fallow field is moister than unbroken shortgrass sod after a short period of drying, it would seem that something similar to this is what may already have happened as a result of extensive cultivation in the Plains region—the creation of many cool, moist spots alternating too frequently with dry sod areas. This will be further discussed in connection with cyclic variations in precipitation.

VARIABILITY IN PRECIPITATION; DROUGHTS

While the average amount of precipitation received in various parts of the Plains reflects distance from the Gulf source and to some extent the effect of elevation, it is only when the fluctuations in amount are considered that the source of most of the moisture difficulties and the immediate cause of the droughts can be understood. While many measures of the variability in precipitation might be employed [20] the measure here taken is the number of occurrences, in the 40-year period just ended, of droughts of a length of 4 months, longer and shorter periods being given values in geometric proportion. In any such group of months, each must show less than 60 percent of the normal monthly precipitation for that station, based on the average for the same 40-year period. Emphasis is thus placed on the variation, and not on the absolute amount of rainfall.

The most striking features of the map (fig. 26) showing this frequency are that (1) the lowest number of droughts is not found on the Gulf coast, but somewhat inland; (2) a low number of 18, along the eastern border of the area treated, occurs northward in the general vicinity of the 94th meridian from lower western Louisiana to northeastern Kansas, increasing northward to about 20; (3) the number increases rapidly westward along the Gulf coast, as soon as one passes out of the zone in which a south wind may be expected to bring moisture directly from the Gulf. The high number for Brenham, Tex., 37, is found by the direct mathematical method not to be

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[20] A purely mathematical basis for measuring variability, such as the standard deviation in the amount for individual months, seasons, or years, probably has some advantages over any such arbitrary method as here employed. For a number of stations representative of the extremes of variability in this region the standard deviations in monthly and yearly precipitation have been computed, together with an index of variability (*I*) obtained by dividing the sum of the standard deviations for the 12 months by the total annual precipitation. This, it is evident, gives a weighted average for the entire year, in which the unit for calculation is still the month. The great variation in winter precipitation in most places is reduced in significance by the small amount occurring in winter, which is as it should be if proper emphasis is to be placed on the effect of variations during the growing season. Except for a few stations in the western Gulf regions which have had one or more exceptionally long droughts and hence are given a high rating in terms of 4-month droughts, there is a satisfactory correlation between the results of the two methods. The method of segregating the periods which have precipitation below the fixed standard, however, has the decided advantage of giving value to the length and continuity of droughts, which the statistical method does not recognize in any degree.

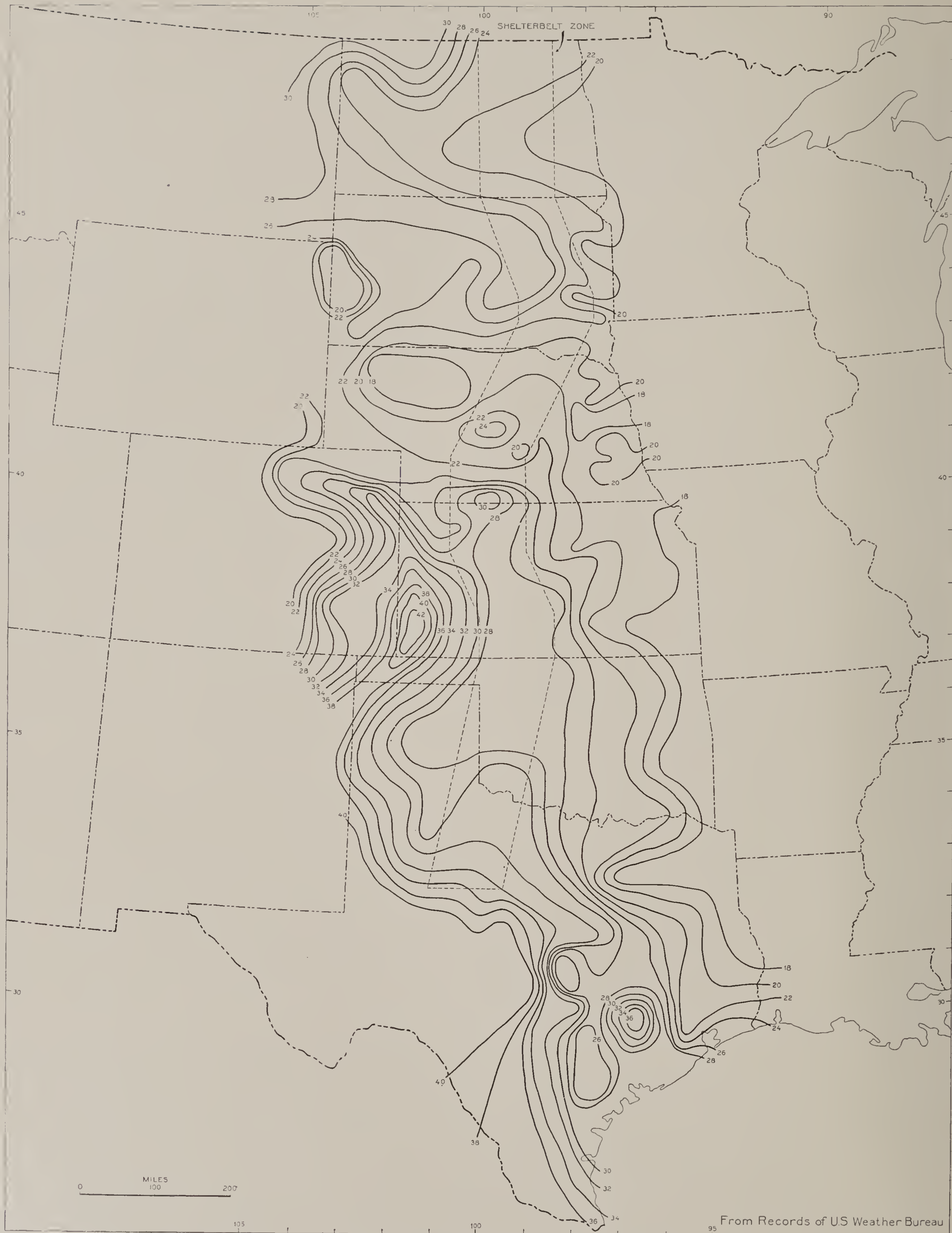


FIGURE 26.—Number of 4-months droughts in the 40 years 1895–1934, or their equivalent in effect, computed in geometric proportion to their length.

significant, being rendered abnormal by a single drought of 15 months' duration in 1924–25. Corpus Christi likewise shows a distorted number due to one drought of 17 months, but at this position the actual variability is quite high. It is interesting to observe that where the normal precipitation is 36 inches per annum, as in the lower Colorado and Brazos Valleys, there may be as many as 25 drought periods in 40 years, and at Austin, Tex. (34 inches annual), the number 32 seems to have high significance. It is thus evident that local topography is probably very important and that portions of this area are watered only when there are southeast winds directly from the Gulf. If the wind holds from a more westerly origin, precipitation is likely to fail. It is desired to emphasize this point, because it exemplifies a condition which prevails throughout the western part of the Plains; namely, that winds which originate west of the Gulf of Mexico bring nothing but dryness.

In the central portion of the Texas-Mexican border it is seen that a nearly maximum number of 40 drought periods has occurred, even this region of low precipitation being quite dependent on easterly or southeasterly winds from the Gulf. Further west, El Paso, with 42 drought periods in 40 years, represents a low point in an essentially enclosed desertlike basin.

The next focus for variability in precipitation is southwestern Kansas.[21] Noting that the High Plains of Texas have a lower drought frequency than might be expected in their longitude and position, and also that the frequency is low in all of the mountain area and even in the lesser elevations of northeastern New Mexico, the droughty spot in southwest Kansas is not difficult to explain. The comparatively low normal precipitation of this area contiguous to the Arkansas Valley helps in an understanding of its occurrence. Evidently, it is so shut off by higher land to the south, and even to the southeast, by the extension of the High Plains, that it receives precipitation only under the most favorable conditions. If, rarely, a south or southwesterly wind might be moisture bearing, such moisture would be precipiated on either the High Plains to the south or the New Mexico mountains farther west, also, an open lane is provided for desert winds from the Pecos Valley to reach this area. This focus is so marked and so important to much land to the north as to suggest the need and desirability for extensive water impoundment in the upper reaches of the Cimarron and North Canadian Rivers.

From this center,[22] droughty alleys are to be noted extending to the north-northeast as far as southern Nebraska, and also to the northwest over the hard plains to Akron and Fort Morgan, Colo.

Between these two dry alleys is an area in northwest Kansas which is scarcely higher than the surrounding territory but noticeably dissected by the headwaters of several streams. Here the rougher topography seems to have some ability to induce precipitation locally and occasionally to end a drought period. Where dependent on only 1 or 2 stations, such a local showing may be, however, due to some fortuitous circumstance in the record.

It has been noted that the large area of sand hills in Nebraska (20,000 square miles) does not seem to attract any unusual precipitation by reason of its roughness, but on the contrary, in its southwestern sector at least, appears to have a tendency similar to that of a valley. The fact that scattered records for the sand-hill region imply a lower drought frequency[23] than any area in the Plains in this longitude indicates that this region is capable in a large measure of "creating" its own moisture supply by conserving it. That disappointing phenomenon of the Plains proper, the local thunderstorm which appears but does not materialize, is far less frequently known in this area, where nature created a natural reservoir and man has not been able to drain it. That superheating from sandy surfaces during the hours of sunlight may assist in producing effective local convection cannot be denied. This may be judged better after noting the temperature conditions of the sandhills.

There is noted again in South Dakota the intrusion into the central portion of the State of the droughty conditions which are also expressed in the low annual rainfall. Here, apparently, exist conditions which are almost the exact antithesis of those of the sand hills. In the heavy soils and rolling topography of South Dakota west of the Missouri River, run-off bears a very high ratio to precipitation. This is most true of the White River Badlands, but hardly less so of the bare bluffs of the wide Cheyenne Valley. The failure of moisture to penetrate deeply the clay soils is mainly responsible for the quick dissipation of the rainfall received. Excessive heating in dry weather results. Further, when only moderately moist winds reach this very flat section, there is no topographic relief to assist in precipitating the moisture. From the position of this dry belt, it would seem to be related in some way to the heavy precipitation of the Black Hills, which mountain mass is responsible for convectional storms. An explanation of such an effect upon the adjacent Plains region cannot be offered when one considers that the moisture-bearing winds do not come from the west.

DROUGHT YEARS

Another basis for considering variability of precipitation or frequency of droughts is by use of the annual total amounts. Since a low moisture condition for an entire year is more serious in its practical effects than one of only 4 months, it is probable that a rainfall of less than 75 percent of normal may mean about the same thing as less than 60 percent for the shorter period. The showing made on this basis (fig. 27), however, is only in very rough agreement with the showing on the basis of 4-month droughts, the effects being less definitely localized, probably because of the use of fewer stations in this year-long calculation. Points which are again emphasized are: High drought frequency in the southwestern part of the Plains region, this area being separated from the Kansas area by one of greater uniformity of precipitation in the Panhandle of Oklahoma and in extreme

[21] While Ulysses, Kans., is the high point as regards the arbitrary measure of drought frequency used, its index of variability, 0.808, is not as high as that of several points along the Arkansas Valley to the west—the peak of 0.855 being reached near La Junta, Colo. In general aspects, however, the mathematical basis of measurement confirms the arbitrary measure chosen and shows dry "prongs" to the northeast and northwest of Ulysses.

[22] This is notably the area in which severe drought persisted longest in the spring of 1935.

[23] Hay Springs, near the northwestern edge of the sand hills, has a lower index of variability (0.593) than any station along the eastern edge of the area considered in this study.

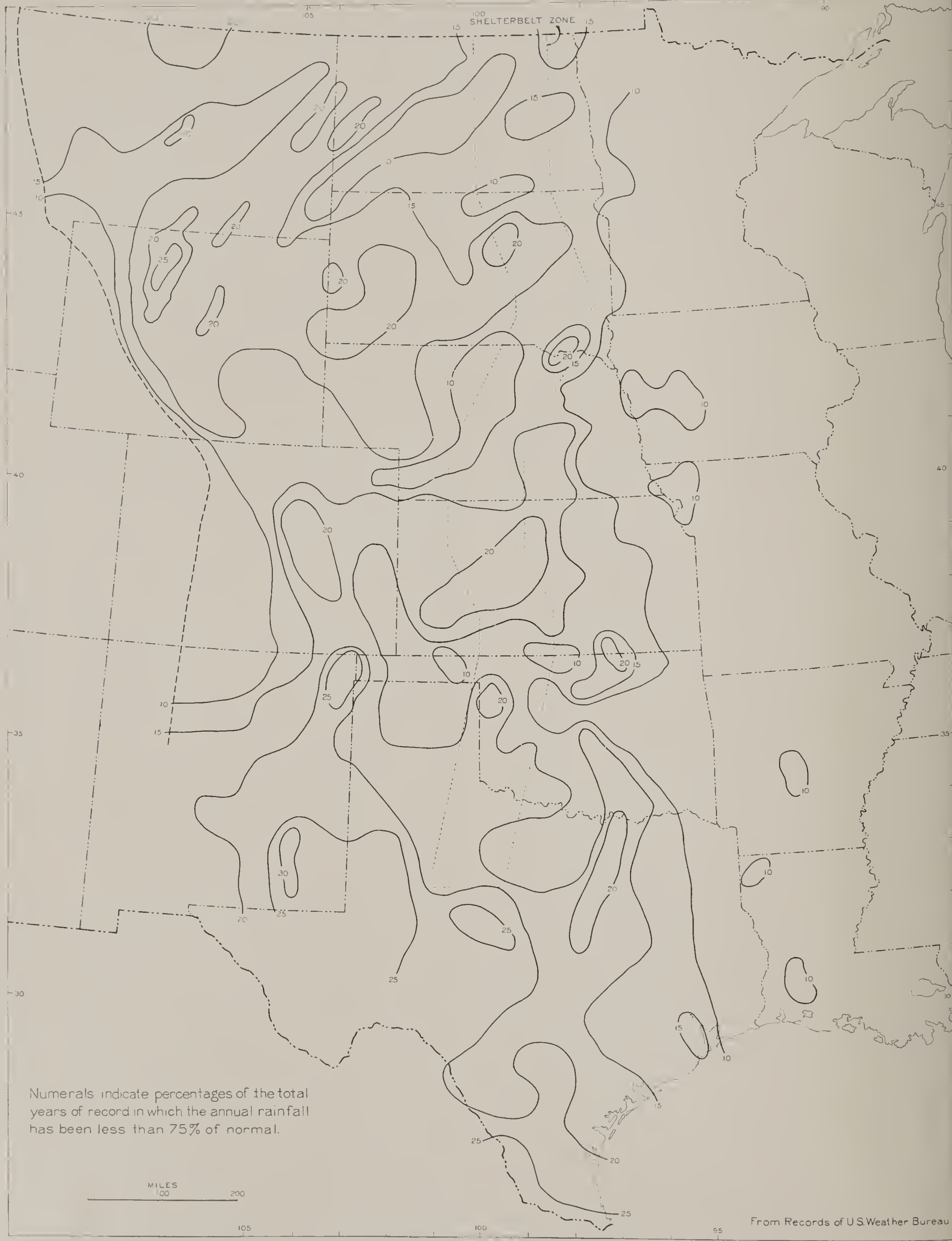
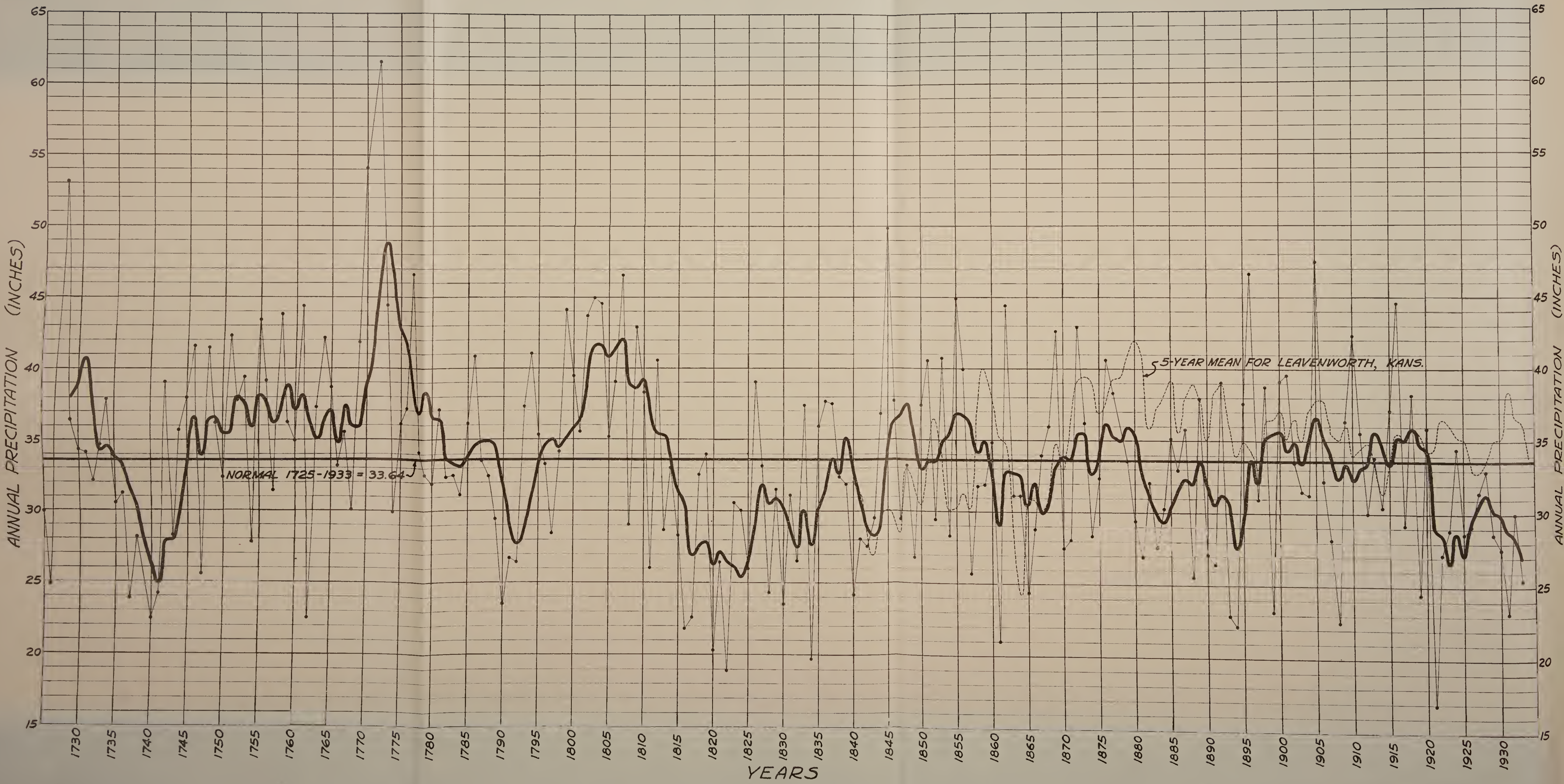


FIGURE 27.—Drought frequency as shown by precentage of full calendar years having less than 75 percent of normal precipitation.



145405—35. (Face p. 95.)

FIGURE 28.—Two-hundred-and-nine-year precipitation record for Padua, Italy, based on 5-year means, including 4 years preceding the date entered; similar curve for Leavenworth, Kans., superimposed. Dots indicate current precipitation (Padua).

southwestern Kansas; very favorable conditions in the eastern portion of the Nebraska sand-hill area and to the northeast and southwest of it; fairly high drought frequency east of the Black Hills of South Dakota; important favorable areas extending across North Dakota and also between the Missouri and Yellowstone Rivers in Montana. All of these points are suggestive of great possibilities for localizing the danger spots for agriculture as well as for tree planting, especially as longer weather records are obtained and the methods of analysis are carefully studied as to their practical meaning.

For other maps based upon still different approaches to the matter of drought, but usually bringing out the same more important characteristics of the region, the reader is referred to pages 8 and 40 of the Atlas of American Agriculture, II, A, 1922.

CYCLIC VARIATIONS AND GENERAL CHANGES IN RAINFALL

While the preceding discussion has been concerned with the changes in precipitation from year to year, or with a comparison of corresponding months in different years, it is well known that there are wet and dry cycles, or successive periods of considerable duration in which the rainfall may be almost continuously superabundant or deficient by comparison with the longest averages. It is the occurrence of protracted droughts which, periodically, raises a serious question as to the feasibility of agriculture in the western Plains region.

On no question is there greater divergence of professional opinion than on that of the causes of these wide variations. The lay mind can grasp and understand the theory of Humphrey's that, since the polar ice is gradually melting and receding and the polar climate becoming warmer, there may result less circulation of the atmosphere between the polar and tropical regions. But it is not so easy to grasp why in the course of such a change there should be violent, relatively temporary fluctuations. The thought that the intensity of the sun's heat might vary, through fairly regular sun-spot cycles, by as much as 2 or 3 percent, has given rise to hope that other variations in the climate of the earth might be understood, but Brückner[24] has pointed out that in Europe either wet or dry cycles may coincide with the periods when the heat of the sun has been most intense. Elsewhere, considerable doubt has been expressed as to whether variations in rainfall are, properly speaking, periodic at all.

Brückner, who examined all possible sources of information in Europe, some of which anticipated by centuries the accurate recording of meteorological phenomena, but which also included a few rainfall records starting about 1700, showed that there has been a fairly regular sequence of rainfall cycles averaging about 35 years in length from trough to trough or peak to peak. The individual lengths vary considerably, however, and there are minor cycles within the major changes which may, at times, make it difficult to recognize a major peak or trough, especially where the evidence is not of a very exact character.

Of the long records in Europe readily available that for Padua, Italy,[25] which has been kept at the university since 1725, is probably a fair sample. Padua, in latitude 45° north, corresponding to that of central South Dakota, is on the low Venetian plain at the head of the Adriatic Sea, surrounded by mountains forming a semicircle to the north. Presumably it is at times cut off from moisture from the Mediterranean by the mountains of the main peninsula of Italy. Also, beyond the Mediterranean lie the deserts of Africa and, without doubt, winds from the south sometimes fail to gather sufficient moisture to offset the desert influences. There are, because of topography, various spots almost on the shores of the Mediterranean which at times are very arid, and any impression should be dispelled that the Mediterranean region as a whole receives regular and abundant rainfall.

The record for Padua, as represented in figure 28, is of interest in showing, during the 209 years, five complete rainfall cycles with an average length of 35 years, and during the entire period a gradual decrease in the amplitude of the extremes. At the same time, the average amount has declined, so that the 209-year mean of 33.58 inches has been attained in only 44 years since 1812. Considering 35-year progressive means (since that is a period in which both high and low extremes may generally be reached), and dating by means of the eighteenth year in any group of 35 years, the progressive means reached a high point of 38.24 inches in 1761, which has not been approached even remotely since that time. The extreme low of 29.89 inches as a 35-year average centers upon 1827, and since then the highest average attained has been 34.34 inches in 1861. The last year for which such an average may be computed, 1916, shows the position as 31.75 inches.

Since 1921, which was also the approximate beginning of the current drought in the northern Plains region, a surprising number of dry years have occurred, only 1924 being above normal.

Although it would be too much to expect that conditions which caused a shortage of precipitation for one year or a series of years, in our Mississippi Basin, should be felt around the world or even throughout the North Temperate Zone, there are times at which a remarkable parallelism exists between this record for a European station and the record for Leavenworth, Kans. This must bring a realization that the causes which produce the wide swings in precipitation are in no sense local, although it does occasionally happen that a restricted locality may for several years at a time be subjected to greater extremes than other localities nearby. An occurrence of this kind must be ascribed entirely to "chance" variations. The study of standard deviations shows the possibilities of abnormality in any individual record to be very great.

The longest records available in the United States which are sufficiently close to the Plains region to reflect even remotely the conditions which are encountered in the region under discussion are those for St. Paul and Minneapolis, Minn., beginning in 1837; for Leavenworth, Kans., beginning in 1836; and for Manhattan, Kans., beginning in 1858. A partial early record for Fort Scott, Kans., 1843–52, is of value only in showing that the all-time low of 15.94 inches for Leavenworth in 1843 represents either an error in recording or an extremely local condition, for Fort Scott, approximately 100 miles farther south,

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[24] Loc. cit. (see footnote 18, p. 88).
[25] For the year-to-year record, see Monthly Weather Review, October 1923, p. 515, and July 1934, p. 250.

had in that year 3 inches more than its average of 41 inches.

The earliest portions of these American records may be subject to question because of the vicissitudes under which they were made, in Army camps, and also because the equipment available for catching precipitation was not so satisfactory at that time as now, and less was understood as to the conditions necessary to obtain full catches in gages of any kind. Since the errors of precipitation records in a great majority of cases arise from failure to catch or hold in the gage the full amount which falls, and since this applies particularly to snowfall, examination has been made of the Twin Cities (St. Paul and Minneapolis) record, comparing the first 20 years with the last 20 (fig. 29). The mean annual amounts for these two periods happen to be almost exactly the same, slightly over 25 inches per annum. Of the respective amounts, 18.7 percent was recorded during the snowfall months of November to March in the earlier period, and 24.4 percent during the corresponding months of the past 20 years. This cannot be taken as proof that there was failure fully to record snowfall in the early days, but is strongly suggestive of such a tendency. If the figures were accepted at face value, assuming that there had been no actual change in the seasonal distribution, the early annual amounts would have to be increased by about 1.75 inches to make up the apparent deficit in snow measurement.

Using the single record which was available before 1866 and the combined records for St. Paul and Minneapolis since that time (which tends to level out discrepancies between the two points, in one case a difference of 10 inches in the annual totals), it is found that the 98-year average through 1934 is 27.21 inches, 0.04 inches more than the normal of 1895–1934. It was 27.41±0.59 inches during the first 49 years, and during the last 49 years 27.01±0.49 inches. In statistical terms, such a decrease is not in any sense significant. In fact, if there were added to the average for the first period practically the entire amount of the error of measurement described above as a possibility, or if, for example, the first average were considered to be 29 inches against the more recent average of 27.01 inches, the difference between the two periods would still not be significant. Altogether, it must be said that in this record there is not the slightest proof of a permanent tendency either up or down.

We may recognize, in this entire record, droughts or troughs of precipitation culminating in 1843, 1856, 1864, 1880, 1891, 1914, and 1934 or later, on the basis of the 5-year means, which is possibly as short a period as can have much significance in creating a deficiency, at least from the standpoint of tree growth. Of these seven depressions, 1856, 1891, and 1934 are probably to be considered the ends of long cycles.

On the basis of 35-year averages, the high point of the entire record, 28.78 inches, centers upon the year 1882, and the lowest average, 26.93 inches, is for the first 35 years, centering upon 1854. This is slightly lower than the average for the period which comes up to 1934. Since the record in 1837 began upon a very low scale, it seems altogether probable that a century ago there was being experienced a drought of greater severity than any since known, although here, again, it is necessary to keep in mind the possible deficiency of the early measurements. Such a deep depression would correspond to the low in the Padua record centering on the year 1827.

The record for Leavenworth (fig. 29) is in some respects very different from that for the Twin Cities. The principal differences are the much greater depression at Leavenworth (5-year means) than at the Twin Cities in 1854, and the great build-up to 1880, when the Twin City precipitation was suffering a considerable decline. Likewise, the high of 1869 in the Twin Cities is represented by a minor peak at Leavenworth somewhat below the general average.

The only striking point of similarity in the two records is the gradual build-up from the beginning to about 1860, after which both records show many more years above the normal line than below. This phenomenon is more striking in the Leavenworth record than in that for the Twin Cities, however, which has given rise to the belief held by many that the precipitation for the southern portion of the Great Plains is definitely increasing.

But, if the two halves of this period be compared, as was done before, it is found that there has been practically no difference, and certainly no significant difference, in the average amounts of precipitation. The period 1836–85 shows an average of 34.38±0.89 inches, the period from 1886 to 1934, 35.18±0.57 inches.

The 35-year moving means started at an extreme low of 32.23 inches for the period centering upon 1853 and rose, with only slight recessions, to peaks of 36.52 inches in 1873, 37.38 in 1882, and 37.73 in 1887. Since the last date the recession has been almost as steady, and since 1900 the average has at no time been above 36 inches. It was 34.95 inches for the last 35 years of record. Thus the all-time high, on this basis, came just 5 years after the corresponding high point in the Twin City record, while on the basis of 5-year means the times are 1880 and 1869, respectively.

The comparison of the record for Leavenworth with that for Manhattan, Kans., 100 miles west and more nearly approaching arid conditions, shows much the same timing of droughts and wet periods, although Manhattan experienced a series of quite dry years, 1917 to 1921, in which conditions at Leavenworth were practically normal. Even the slight differences in the 5-year means for these two stations, and the much more marked differences in trends of the successive years, serves to show how completely unreliable for the drawing of any general conclusions the record of a single station must be.

The first 37 years of the Manhattan record (fig. 29), including the low year 1894, averaged about 2 inches less per annum than the second period of 40 years, which is a fairly complete cycle. Again, however, the difference between these two periods is not sufficient to be certainly indicative of a trend in one direction. If the division is made so as to include 49 years in the second period to correspond with the Twin Cities and Leavenworth, the average is only 0.94 inch higher in the last period.

FLUCTUATION OF RAINFALL IN REGIONAL SUBDIVISIONS

In order to eliminate discrepancies which are certain to occur in the record of any single station, to obtain a fair basis for comparing the severity of the present drought with the preceding major depression, and to illustrate the fact that frequently one small

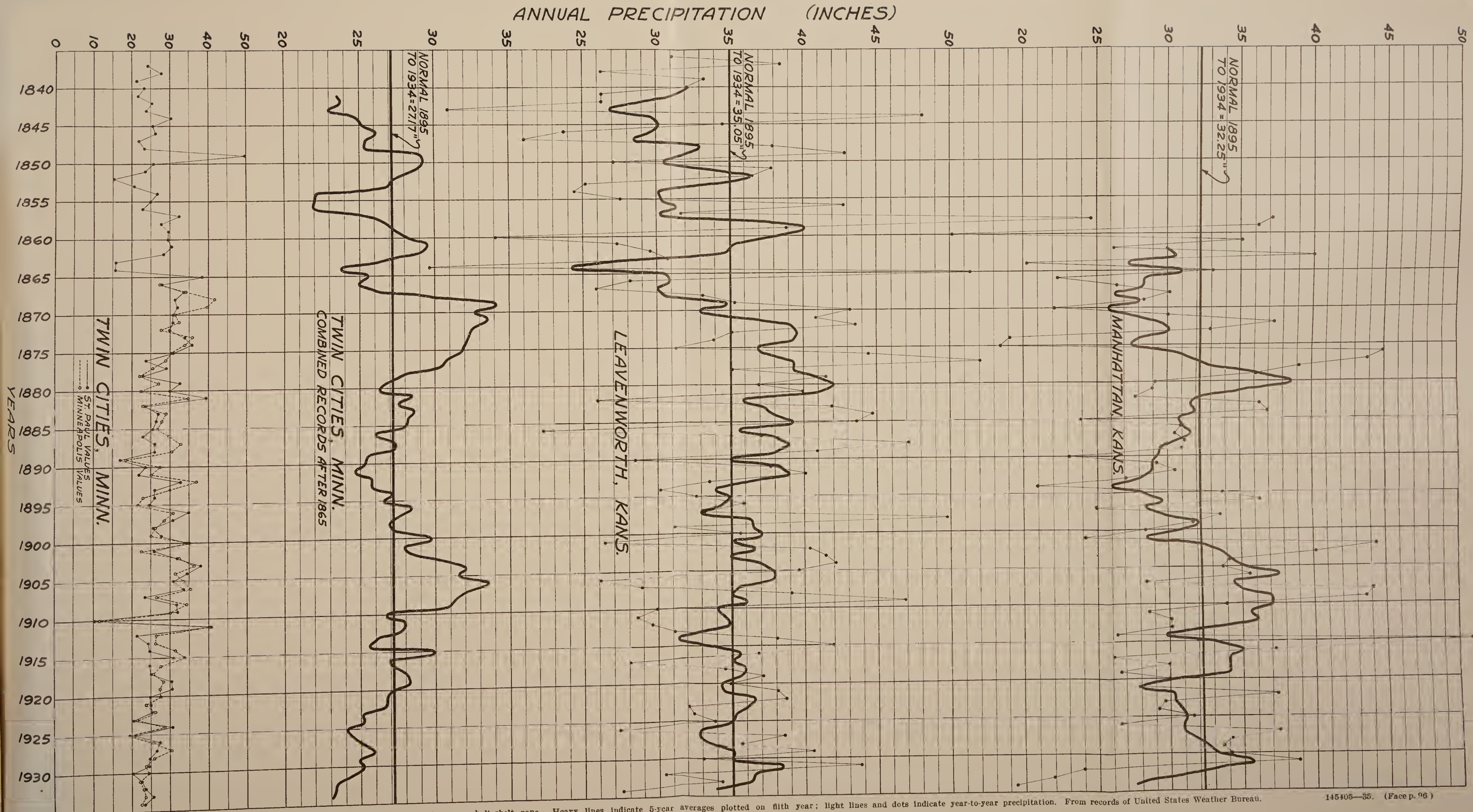

FIGURE 29.—Long-term rainfall records at stations near shelterbelt zone. Heavy lines indicate 5-year averages plotted on fifth year; light lines and dots indicate year-to-year precipitation. From records of United States Weather Bureau.

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section of the Plains region is affected by much more severe drought than other portions, group averages for 5 latitudinal zones east and 5 west of the shelterbelt zone have been computed for the past 50 years. It was at first hoped to include about 10 stations in each group, but in some groups it was found impossible to obtain so many without covering too great a range of longitudes. Consequently, the smallest group contains only 4 stations, the others from 7 to 10. In each group, except the western portion of the Oklahoma-Texas area, the records for some of the stations begin as early as 1885, but the full complement of stations does not become available until 1890–92. Consequently it must be understood that the beginning of each record is not accurate, being built up on the later established ratio of precipitation at a few stations to that of the entire group, a ratio by no means constant from year to year.

Figure 30 shows the annual averages in each group, which are considerably less variable than annual amounts for single stations. In order to develop facts which are shown only by the moving means for 5- and 10-year periods, a summary is offered in the paragraphs below. It should be borne in mind that in referring to the means for 5 and for 10 years, there always is implied the period leading up to and including the year mentioned. The normals referred to are averages for the period 1895–1934 as used throughout this report.

Eastern North Dakota and Minnesota.—Normal for 8 stations, 20.38 inches; highest, 27.02 inches, 1905. Current low, 14.72 inches; lower in 1917 (11.57 inches), 1910, and 1889. Last 5 years, 16.26 inches; has not approached this depth previously. Last 10 years, 18.14 inches; lowest. Since 1917 the averages have all been below normal except 10 years to 1928.

Western North Dakota and Montana.—Normal for 10 stations, 15.27 inches; highest, 20.66 inches, 1927. Current low, 8.12 inches; previous low, 10.27 inches in 1917. Last 5 years, 12.52 inches; previous low was 12.91 inches to 1921. Last 10 years, 13.98 inches; lower to 1926, 13.93 inches. Since 1919 only four of the 10-year averages have been up to normal.

Eastern South Dakota and Minnesota.—Normal for 10 stations, 23.91 inches; highest, 32.06 inches, 1908. Current low, 17.12 inches (1933). Lower in 1914 and 1894. Last 5 years, 19.11 inches. Previous low was 20.38 inches to 1891. Last 10 years, 20.58 inches. Previous low was 21.61 inches to 1895. All averages 1925 and later below normal.

Western South Dakota and Wyoming.—Normal for 7 stations, 18.91 inches; highest, 27.50 inches, 1915. Current low, 11.82 inches. Previous low was 13.70 inches in 1910. Last 5 years, 15.49 inches. Previous low was 16.38 inches to 1913. Nearly as low in 1898. Last 10 years, 17.28 inches. Equalled for 10 years ended 1902. Only since 1932 have 10-year means been below normal.

Eastern Nebraska.—Normal for 10 stations, 26.04 inches; highest, 37.21 inches, 1902. Current low, 15.02 inches. Previous low, 16.33 inches in 1894. Last 5 years, 22.91 inches. Previous low, 23.61 inches to 1914. Last 10 years, 23.34 inches. Previous low, 24.56 inches to 1901. All 10-year means since 1925 have been below normal.

Western Nebraska and Colorado.—Normal for 9 stations, 18.73 inches; highest, 25.28 inches, 1905. Current low, 12.10 inches. Lower in 1894. Last 5 years, 16.80 inches. Lower to 1914 and 1897–96. Last 10 years, 18.14 inches. 18.15 inches to 1919. Eight years between 1895 and 1903 showed 10-year averages lower than these. Did not drop below normal in present movement until 1933.

Eastern Kansas.—Normal for 10 stations, 29.64 inches; highest, 42.95 inches, 1915. Current low, 22.35 inches. Previous lows, 22.76 inches 1910, 22.82 inches 1893. Last 5 years, 26.11 inches. Lower to 1914. Last 10 years, 29.24 inches. Not significant because of high 1927–29. Averages were much lower to 1895, 1919, and 1925, with many others lower than 29.29 inches.

The long records for Manhattan (included in these averages) and Leavenworth do not entirely agree with this composite record, but the differences are not important. The Manhattan record shows the current conditions (5-year averages) exceeded by droughts of 1864 and 1875. At Leavenworth the conditions were worse in 1843, 1854, and 1864, but the extreme severity of the 1843 drought seems questionable or very local in character when the Fort Scott record is compared.

Western Kansas and Colorado.—Normal for 10 stations, 18.34 inches; highest, 27.54 inches, 1923. 1915 and 1891 also good. Current low, 10.05 inches. Previous low, 11.60 inches in 1894. Last 5 years, 16.27 inches. Lower to 1914 and 1896. Last 10 years, 17.25 inches. Lower to 1919, 1917, and 1894–98. Only the last 2 years of recent drought have 10-year means below normal.

Eastern Texas-Oklahoma.—Normal for 8 stations, 34.83 inches; highest, 47.69 inches, 1905. Current low, 27.67 inches. Lower in 1917, 1910, 1909, 1901, 1896, and 1886. Last 5 years, 33.95 inches. Lower, 31.47 inches, to 1897 and 30.28 inches to 1913. Last 10 years, 35.11 inches. Only one 10-year mean since 1920 has been below normal. The lowest values are 32.17 to 1918 and 32.40 inches to 1902, but on 10-year basis this region practically has no droughts.

Western Texas-Oklahoma.—Normal for 4 stations, 22.74 inches; highest, 37.18 inches, 1923. Current low, 15.13 inches. Lowest, 13.08 inches, in 1910. Also lower 1917. Last 5 years, 20.16 inches. Lower 1912 and 1891–96, lowest, 17.54 inches, to 1893. Last 10 years, 21.87 inches. Lower 8 periods to 1903, also 1910–12, 1916–19. Nine out of last 12 averages are above normal.

Widely separated stations show somewhat the same cyclic trends in precipitation but varying in degree, and, even in regions not widely separated, the years in which extremes of a movement are reached may vary considerably. Such discrepancies appear even when moving means or cumulative amounts for a period of years are employed, so that graphs for neighboring areas are often dissimilar in their timing and amplitude. In short, even in drought periods or periods of excess, local variations, wholly unaccountable, play a large part in shaping the records.

Nearly every section of the Plains regions has experienced drier years than 1934 and drier 5- and 10-year periods than that ended in 1934.

The early portions of the Twin Cities and Leavenworth records, taken in conjunction with the Padua record, indicate the possibility of drought conditions about 1825–40 much worse than anything shown since settlement of the Plains. Explorers about this time might have had better reason than we realize for describing the Plains as the "Great American Desert."

While there has been no significant change in the mean amounts of precipitation in areas adjacent to the Plains in the second as compared with the first half of the past century, this does not prove that a slight change in one direction or the other may not be under way. The fact, however, that the apparent change is in opposite directions, downward in the north and upward in the southern portion of the area studied, again detracts from the significance of any change whatever.

If there has been any change which is significant and apparent in all the long records consulted in this connection, it is a decrease in amplitude of the variations from year to year and from period to period. If this is not sufficiently apparent from figures 29 and 30, it is readily proved by the smaller standard deviations and probable errors in the later periods of the two 100-year records which have been

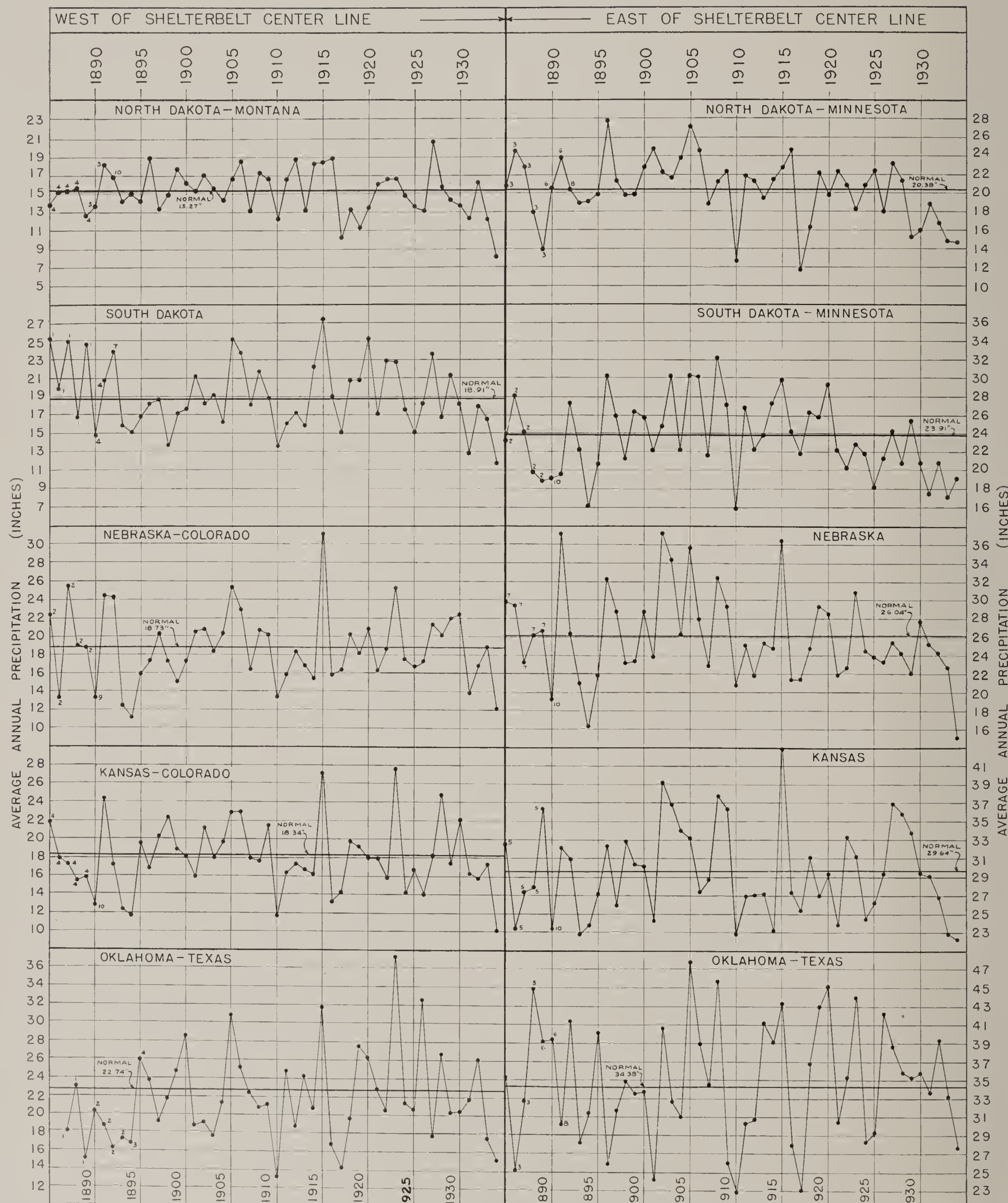

FIGURE 30.—Precipitation in 10 divisions of the Plains region during the last 50 years; averages for groups of stations. Numbers opposite points indicate number of stations reporting, until full number in each division is reached; early data adjusted as explained in text. From records of United States Weather Bureau.

presented. Thus in the case of the Twin Cities record, the amplitude, as shown by standard deviations, was about 20 percent greater in the first period, and in the case of the Leavenworth record about 57 percent greater. A similar, rather steady decline can be shown by 50-year periods through the entire length of the Padua record.

There is a possibility that such a change as this, toward a more even distribution of precipitation in point of time, may be related to changed conditions on the earth's surface, although no such contention can be conclusively proved because there is no manner in which possible changes in cosmic conditions can be eliminated from consideration. However, the following possible reasons for a steadying of the rainfall of the Plains region are offered for whatever they may be worth—possibly only to suggest a line of investigation by which some more certain proof of the importance of surface conditions may be obtained.

1. The importance of moisture turn-over within any continental area has already been stressed. From this standpoint, quick evaporation of any moisture which falls is a factor tending to increase the total rainfall. Thus it is obvious that for the Plains region as a whole, if all rainfall ran back to the sea, or if all of it were held in the soil, or in ponds or lakes without evaporation, the precipitation would shortly be down to possibly one-fourth of what it now is, and certain areas more or less shut off from Gulf winds probably would receive little or none.

2. At the same time, it is evident that quick evaporation must serve to emphasize the differences between wet and dry periods. No argument is needed to show that, if a given part of a region does not conserve or retain any of its moisture, and if replenishment from the Gulf source is temporarily witheld, there is little possibility even of local thunder-showers.

3. It is believed that the fine soils of the flat Plains region were, in their native state, peculiarly susceptible to quick loss of a very large part of the rain which fell upon them. Even with normal or more than normal amounts of rainfall, storage in the soil during the winter and spring did not penetrate beyond a depth of 2 or 3 feet, and with the advent of the growing season this stored supply was quickly used up by the short-grass cover which typically had completed its growth cycle by June. Thunder-showers of the hot summer months would rarely wet the soil more than a few inches and would be rapidly dissipated back to the atmosphere. If excessive amounts fell in such showers, absorption into the soil was slow, resulting in a good deal of run-off which might be quickly lost from the region, or which went into small ponds on the plain. These, typically, dried up quickly and were dry during much the greater part of the warm season.

4. Cultivation of an increasing acreage during the last half of the nineteenth century, with a final large increase during the World War period, modified these conditions considerably. It may be granted that the raising of grain crops on the land fully utilizes all moisture which could be accumulated, yet under cultivation there was considerably more opportunity for accumulation than in the unbroken prairie soils under sod. In ordinary farming practice, there is better opportunity for absorption and also better protection from direct drying of the soil, both while the crop is growing and after it is harvested. The stubble is a considerable aid to moisture retention throughout the long period when some accumulation is possible. Fall plowing also permits good absorption and good protection merely by roughening the surface, as compared with a smooth, short grass cover. Invariably a field which is being used will show in the fall, winter, or early spring, moisture penetration to greater depth than a sod area of the same soil. Moreover, in any farming region there is invariably a percentage of the land fallowed each year unintentionally or with the direct purpose of storing moisture. In short, there is at all times a considerably higher level of storage moisture under agriculture than under natural Plains conditions. Probably the growing of winter wheat is less conducive to storage than the usual line of summer crops and, in fact, it is possible that with a living crop on the land through the winter there is less storage than there would be otherwise at this season. It is possible that winter wheat in the South has increased the rate of winter turn-over of moisture and since, at that season, winds are much less persistently from the south than is the case in summer, this turn-over may have resulted mainly in a local increase in precipitation. So far as this is the case, it does not imply a shortage of moisture at other seasons. Some such difference as this may explain a present apparent difference between the northern and southern portions of the Plains region.

5. In short, then, although this is purely inference from known facts and cannot be proved as regards the meteorological results, it appears that cultivation of the land means a greater degree of conservation of the moisture supply through longer retention in the soil, less total turn-over and consequently fewer turn-overs in any given period, and decreased total rainfall—but, because of more moisture held in reserve, less liability to great extremes of drought and abundance.

That a similar change in the character of the precipitation graph is apparent in one European record,[26] which has been discussed, does not imply that the same set of changes have affected this record, nor that the settlement of North America has exerted an influence on European conditions during the past century. In the case of Padua, three distinct modifications of the surrounding territory had occurred by about 1900 which might have affected the local atmospheric moisture supply, although not necessarily all in the same direction. These were: Improvement of the Nile irrigation system from 1861 to a recent date, which has kept the acreage irrigated more uniform despite variations in the regimen of the Nile; reforestation in the Karst region to the east, beginning in 1842, which by 1909 had greatly improved the cover conditions on more than 400,000 acres; and drainage of about 600,000 acres in the River Po region prior to 1900, doubtless augumented by some drainage in other parts of the Venetian plain. It is, of course, a different story from the settlement of the Plains in the United States.

Insofar as these appearances of an effect of agricultural development in slightly stabilizing the rainfall of the Plains may be accepted as at all logical or likely, they suggest the possibility of further stabilization and avoidance of moisture extremes through further and more intensive agricultural development, through successful storage, both in the soil and in ponds and lakes, of some proportion of the rainfall which, under existing conditions, is entirely lost to the region through run-off, and through the planting of trees. The ability of forested areas to absorb and to store temporarily in the soil almost unlimited quantities of rain, as well as to protect some adjacent areas from rapid evaporation is beyond dispute.

RELATIVE HUMIDITY AND EVAPORATION

The map (fig. 31) shows the mean relative humidity for the Plains region throughout the year, together with the more important records available for warm-season evaporation, in inches, from the free-water surface of a pan. This map was prepared from data recorded by various agencies, as indicated. It relates to the 15-year period 1917–31, except as noted in small figures within station symbols.

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[26] Brückner suggests a tendency for the world precipitation to go to somewhat greater extremes toward the end of the period included in his studies, but this tendency was in large measure due to the introduction in the nineteenth century of records of stations in North America, where the periodic variation of rainfall is wider than in most of continental Europe.

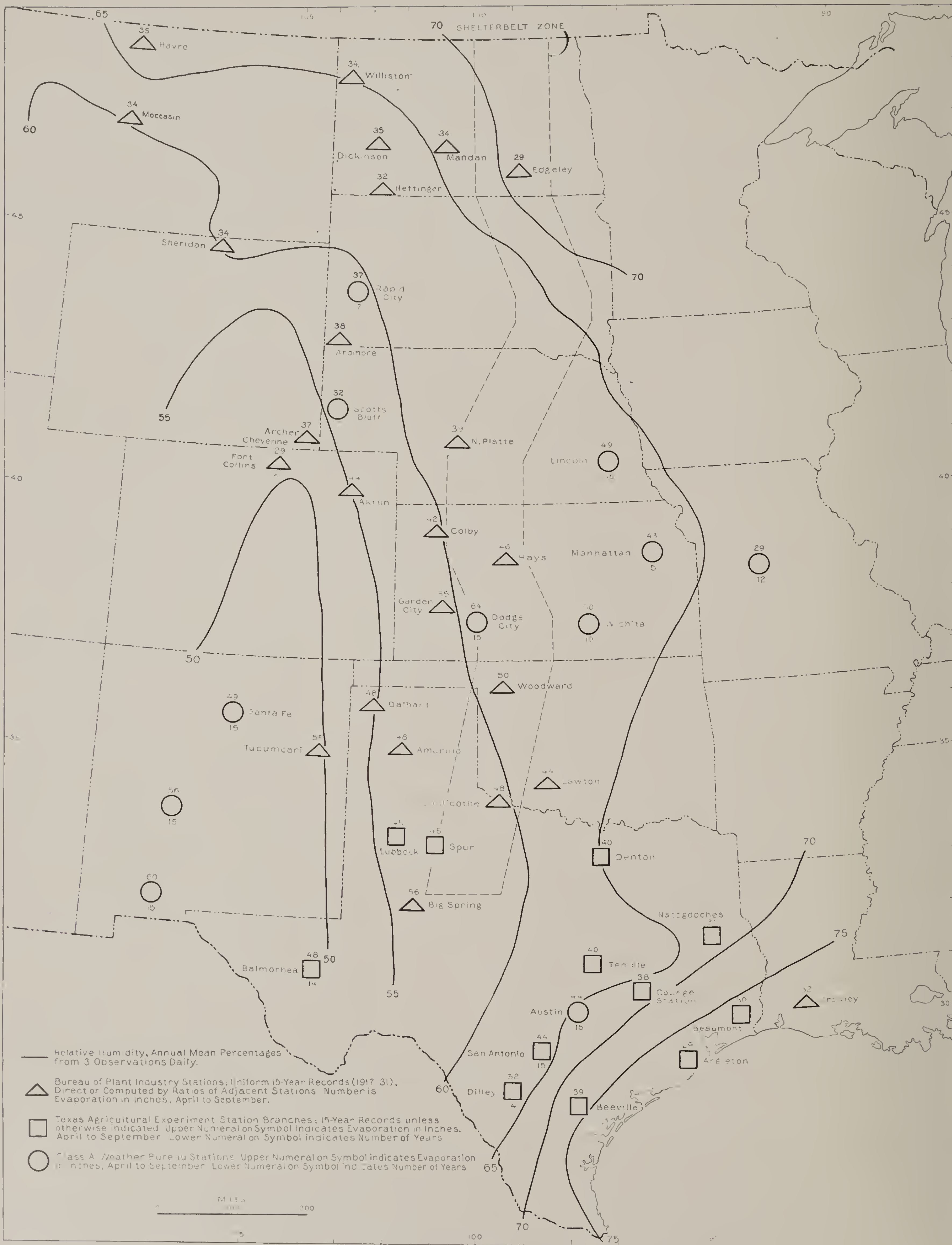

FIGURE 31.—Mean relative humidity (percent) and amount of warm-season evaporation at individual stations (inches).

The outstanding feature of the lines indicating equal relative humidities is their general parallelism with the Rocky Mountain Range. Although each line dips back to the south within the mountain area because of the low temperatures prevailing there, in any latitude the lowest relative humidity is found at the base of the mountains, and an increasing degree of moistness is attained quite regularly to the eastward. This fact is, of course, intimately related to that dryness of the westerly winds which has already been noted, and which is a factor of such importance in causing the loss of the moisture which finds its way to the western edge of the Plains.

Rate of evaporation reflects temperature, relative humidity of the atmosphere, and the prevailing rate of wind movement. Thus, while the relative humidity as calculated is based on the capacity of the atmosphere for moisture at the prevailing temperature, it does not follow that with the same relative humidity the unsatisfied capacity, sometimes described as the vapor deficit, remains the same for different temperatures. Indeed, with a mean summer temperature in the South of about 85° F., and in the North of 65° F., the capacity of the atmosphere for additional moisture at any given relative humidity is about twice as great in the South as in the North. Notwithstanding this fact, in such a case as that of Austin, Tex., or of Williston, N. Dak., both on the line of 65-percent relative humidity, such a relation does not hold in the actual evaporation figures; here the relatively high evaporation in the North is due at least in part to greater wind movement, which for the 3 summer months averages 7.8 miles per hour at Williston as compared with 7.3 miles per hour at Austin. When the driest west winds occur at Williston, moreover, the greatest velocities are recorded. But it must be remembered that the evaporation figures here considered apply to the warm season only.

A much greater difference between northern and southern latitudes is observed when the entire year is considered, for in the north the winter evaporation is practically nil, while in the south it continues at an important rate. Thus, for Austin, the average for 17 years [27] shows only 68 percent of the evaporation occurring from April to September. Spur and Balmorhea, Tex., with 66 to 70 inches total free-water evaporation annually, show about the same percentage in the same months. Lubbock, with greater altitude and lower temperatures, has 72 percent of its total in the summer. The same percentage has been assumed for Big Spring, with only a summer record, making it slightly higher in annual total than Dilley, where the summer percentage is only 68. The annual allowance for Big Spring is probably not enough, considering that it is apparently warmer in the winter than Lubbock. The 4 years 1929–32 at Dilley were below average, so that its annual total should doubtless be about 80 inches also.

While evaporation through the winter has rarely been measured in the north, and is not feasible where pans are employed, a single year's record (1934) from the Forest Service evaporimeter at Denbigh, N. Dak., showed 87 percent of the total occurring in the months April to September. We need, then, allow a total evaporation for Williston of only 39 inches per annum, at which figure a true comparison is afforded with the annual average of 65 inches at Austin, Tex.

EFFECTIVE PRECIPITATION AS LIMITED BY EVAPORATION TRENDS

The preceding discussion of humidity and evaporation values merely serves to emphasize the great difference in effectiveness of precipitation in different parts of the region, based upon the much greater tendency toward quick loss of moisture from the soil under the high temperatures of the south and the greater absolute dryness of the west.

Within the narrow longitudinal range of the shelterbelt zone, it has been observed that on favorable, not too heavy soils a normal annual precipitation of 15 inches at the Canadian border seems to be about as effective in fostering tree growth as 22 inches annually in the latitude of the southern boundary of Oklahoma. This does not in any case imply an absolute limit to tree growth, but only a limit to what may be considered effective growth as regards height, density, and vigor. Moreover, tree growth is not limited by precipitation in irrigated valleys or those in which the water table is naturally maintained at a high level; this is also true of some very favorable sandy soils west of the zone limits.

Obviously, the normal precipitation, considered either alone or as its effectiveness is modified by evaporation, cannot be a satisfactory measure of the suitability of a locality for sustained crop yield or for tree growth, without taking into consideration also the frequency and degree of variations from the normal level. It is for this reason that considerable space has been given to a discussion of the frequent short droughts and of the longer changes in precipitation. But when all has been said and done with the present available physical facts, it is still fanciful to expect that the basis is available for saying that at one point crops will succeed and trees will survive through the longer climatic cycles, while at another point either or both will succumb. There is no means of measuring the persistence of human endeavor except through long experience, and in the borderland there is as yet no accurate means for determining, except by observation after the occurrence, whether trees have the capacity to survive a certain combination of physical conditions.

In consequence of the large number of variables involved, any attempt to solve the problem of the "limit of feasible agriculture and tree growth" by formula in lieu of observation or experience is obviously fraught with dangers and weakness. The results may have general value but can rarely be expected to fit the individual or very local situation. Moreover, in the words of Russell [28]:

> A climatic boundary is not a precise line * * *. It is an attempt to approximate central position within a zone of change. In regions of great hypsometric (altitudinal) contrast, such zones will often be quite narrow and climatic boundaries * * * fairly precise, but in a flat country such is not the case.

[27] Data quoted in this paragraph are from Tex. Agr. Expt. Sta. Bull. 484, Rate of Water Evaporation in Texas, 1933, in which complete records for 20 stations are given. Records of stations credited on the map as State branch stations are taken from this source, mostly for the 15-year period 1917–31.

[28] RUSSELL, R. J. DRY CLIMATES OF THE UNITED STATES. I. CLIMATIC MAP; II. FREQUENCY OF DRY AND DESERT YEARS 1901–1920. Calif. Univ. Pubs., Geogr. 5: 1–41, 245–274, illus. 1932.

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Both Russell and Thornthwaite [29] have attempted to classify various sections of the United States on the basis of precipitation-evaporation balances and frequency of dry years. Russell's work is confined to arid and semiarid regions. In his general map (1931) a line has been drawn on the basis of climatic records correlated with soil and vegetation conditions practically corresponding to the boundary between the shelterbelt zone and the short-grass Plains. This is defined as the eastern limit of the cold-steppe region from North Dakota to southern Kansas and of the warm-steppe region south of that latitude, both having climates characterized by precipitation shortage during the winter. Although the definition of different climates is based upon a relationship between rainfall and temperature, with a consideration of the seasonal distribution of rainfall, it is not necessary to go into the matter more fully here.

Russell's second work involves a consideration of essentially the same data, but instead of defining climatic zones by means of the average precipitation and temperature for a period of about 20 years for each station, he has considered each year on its own showing. The line, to the west of which more than 10 out of 20 years have shown a dry or steppe climate, does not correspond exactly to line for mean values, west of which the same type of conditions prevail. Some slight difference is to be expected in the results of the two methods of calculation and, in this case, it is not at all important. Consequently, there has been reproduced in figure 32 the line *A* on which, during the period 1901–20, just half of the years had steppe climatic conditions.

The method employed by Thornthwaite to determine the degree of aridity of climates and of individual years in the records of a large number of stations is also based upon a formula employing precipitation and temperature, after calculating from a number of precipitation, evaporation, and temperature records the functional variation of evaporation with temperature.

The result of computations from his formula is the setting up of precipitation-evaporation quotients for months, and indices for years by addition of the quotients. The arbitrary divisions of climates selected by Thornthwaite are given the following numerical limits in terms of the final index values:

Humid forest	64 to 127.
Subhumid grassland	32 to 63.
(Below 48, dry subhumid, short-grass)	
Semiarid steppe	16 to 31.
Arid desert	Less than 16.

It was found desirable to distinguish between climatic zones on the basis of the character of the seasonal distribution of moisture, but since the entire region with which we are concerned is considered to be relatively deficient in precipitation at all seasons, it is not necessary to make any such distinction in the data to be considered. However, a division between the temperature efficiency of the northern and southern Plains regions is made in northern Kansas.

The data as prepared by Professor Thornthwaite specifically for this report and brought up through 1933 in order to include the recent dry years, together with Russell's critical line and the empirical precipitation limit (corrected only for temperature as indicated by latitude) are shown together for purposes of direct comparison in figure 32.

Five of Thornthwaite's lines, representing respectively from 8 to 12 years of semiarid climate, or 33 to 50 percent of the years from 1910 to 1933, are shown because it is felt that either the higher or lower of these values might be misleading if taken to define closely the limits of what may be called effective tree growth. By means of any of these lines, however, it is possible to obtain the location of what, under this classification, are considered to be equally effective moisture conditions at different latitudes—differing, of course, from north to south in length and warmth of the growing season. If the *F* line, west of which the average conditions must be considered distinctly semiarid, be employed for comparison with the directly obtained rainfall limit, the outstanding difference in location and trends are: (1) The former does not start so far west in North Dakota but elsewhere maintains about the same position; (2) in South Dakota the *F* line does not bow so far east in the center of the State (the *B* line, it will be noted, shows this flexure to the east much more strongly); (3) in Nebraska it bows much farther to the west under the influence of comparatively low temperatures on the high plain west of the sand hills; (4) the *F* line eliminates more of northwestern Kansas but practically the same area at the southern edge; (5) it does not make as wide a sweep to the west on the High Plains of Texas. The differences in Nebraska and northern Kansas are probably all in favor of the *F* line, which is to say that this method of computation brings out clearly the advantages of slight variability in the precipitation in and adjacent to the Nebraska sand hills and the converse, very high variability in northwestern Kansas.

To some extent, the differences between the two lines may be due to the *F* line representing only the last 24 years of precipitation record, while the other represents 40 years and introduces relatively somewhat higher precipitation values in the North.

This is of course also true in comparing the *A* line with any of the others. On the whole, although giving different results, all of these lines are valuable, and principally so as they bring out rather marked differences within comparatively narrow latitudinal ranges. For the extreme latitudinal range of 15° to 16°, any such method may easily be greatly in error, at least with regard to the possibilities for any particular type of vegetation. As a matter of fact, the same types of vegetation do not exist in the North and the South.

TEMPERATURES AND THEIR SIGNIFICANCE [30]

Temperature factors are here mainly of interest in their relation to the moisture supply. The annual mean temperature varies quite regularly from about 70° F. in lower Texas to 36°–38° at the Canadian border. The northern Plains near the northeast limit of the shelterbelt zone have the lowest midwinter average

[29] THORNTHWAITE, C. W. THE CLIMATES OF NORTH AMERICA ACCORDING TO A NEW CLASSIFICATION. Geogr. Rev. 21 (4): 633–655, illus. 1931. Dr. Thornthwaite has personally aided in the present study.

[30] Since records which go back to 1875 indicate a rather general rise in temperatures almost steadily from the earliest to most recent years, all quantitative data used in this discussion are averages for the period 1904–33, unless otherwise stated. This period gives a sufficient number of records for the necessary mapping and comparison of localities.

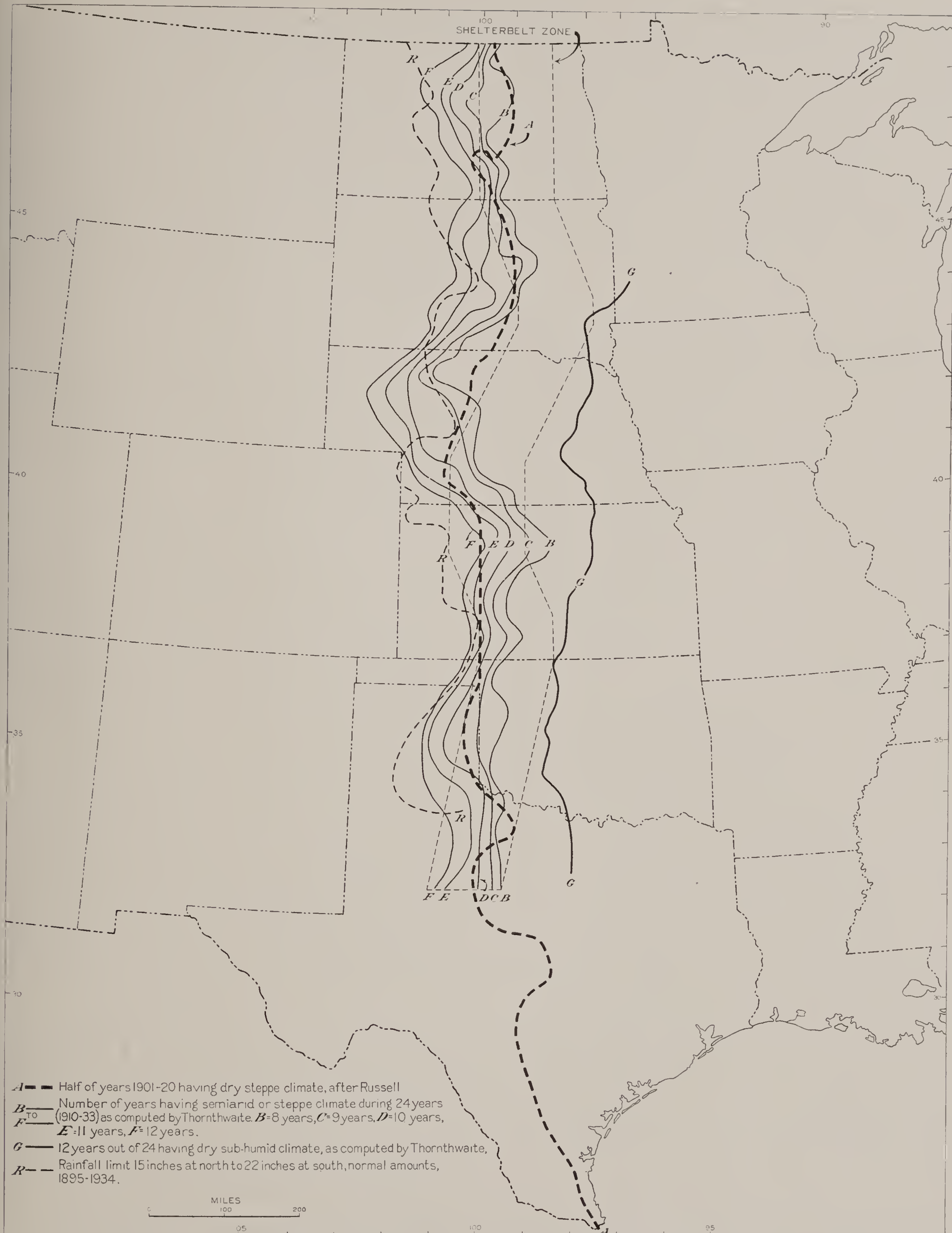

FIGURE 32.—Lines of equal moisture efficiency by various standards.

and minimum temperatures prevailing in any part of the United States, the latter reaching −10° for January. The southern Plains, especially near the mouth of the Rio Grande, have July average maximum temperatures above 100°, exceeded only a few degrees by those occurring in the desert areas of California and Arizona. The area in which the 95° maxima occur regularly in July extends nearly to the south-central boundary of Kansas, 90° well into southern Nebraska, and 85° reaches to northeastern South Dakota and southwestern North Dakota. Only a small area at the north end of the zone has July maxima normally below 80°.

TEMPERATURE VARIATIONS

WARM AND COLD WAVES

Among the most striking features of the Plains is the frequency of sharp changes in temperature in the spring and fall. While bareness and rapid radiation are factors, it is probably the speed with which warm or cold winds can traverse the area that gives rise to these frequent drops or rises in short periods. The average number of cold waves per year is slightly less than the number of warm waves, but the difference is not great enough to warrant separating them. Except for a few points along the base of the Rockies especially liable to Chinook effects, the most frequent changes (nearly 12 per year) of 45° or more occur in the center of the treeless Plains area and, perhaps significantly, close to the Nebraska sand hills, where quick radiation may permit either rapid rises or sudden cooling. The number of stations referred to in preparing the map of temperature changes (fig. 33) is not sufficient to bring out many local variations which might have some bearing on tree and orchard planting.

Judging from the average maximum daily ranges, as tabulated by monthly periods for a considerable number of stations in the northern portion of the shelterbelt zone, the spring and fall periods are about equally liable to marked changes in temperature, with the midsummer period least changeable and the end of the year also fairly free from wide fluctuations. In North Dakota only June and July are much below average, with May, August, and September decidedly changeable, a fact indicating the shortness of the safe growing season. In South Dakota, June, July, and August are fairly safe, and the most critical months are April and October. In Texas the first 4 months of the year are most variable, with March leading, but there is a slight increase from a low period of variability in August to the end of the year.

From these facts, it is seen that the sharp temperature changes of the portion of the Plains in which our interest mainly lies are rather distinct from those felt at the eastern base of the Rockies resulting from "Chinook" winds. These warm winds are probably most frequent from January to March at most points, and frequently occur when the general temperatures have been quite low and the ground is frozen.

ANNUAL MEAN TEMPERATURES

Mean temperatures of about 65° F. for the entire year prevail across Texas at about the latitude of southern New Mexico (fig. 34). The direction of all of the lines up to about 48° showing a tendency to reach higher latitudes to the east suggests the effect of the Gulf or tropical warmth in the central Mississippi Valley and of a cooling effect of the mountains on the west. The effect of proximity to the Gulf is not only to modify extremes of temperature but generally to raise the temperature.

North of about the 40th parallel the situation is changed. At the east end all northern temperature lines tend to be pushed south by the cooling effect of the Great Lakes, which absorb much of the energy of the sun and express it in the form of evaporation. During the winter the winds from much farther north generally have a strong sweep to the east, and their effect is less felt near the mountains, or is partly obliterated by warm descending winds from the mountains.

MEAN MINIMUM TEMPERATURES (JANUARY)

The means of the January daily minima are of more interest in connection with a general climatic study than in connection with this discussion, since the temperatures during the coldest month of the year, even in the mildest portion of the region, are not conducive to a high rate of evaporation or important losses of moisture.

The isotherms of low temperature take about the same directions as the mean temperatures for the year, those farthest north having the steepest dip to the southeast. The general parallelism which exists between the isotherm of January minima and of mean annual temperatures indicates clearly that the latter are most strongly influenced by winter conditions and only slightly by the variable highs of summer. The "port of entry" for the most extreme cold is seen to be in northeast North Dakota and adjacent Minnesota, the north end of the Red River Valley of the North being prevailingly the coldest place in the United States during the winter.

The 15° isotherm, after dipping well to the southwest, strikes near the base of the Rockies in southern Colorado and extends to the north at least as far as Casper, Wyo. This illustrates the previous statement as to a winter-moderating effect from the mountains, felt at their eastern base, a situation exactly contrary to most popular conceptions. This is by no means due to warmth in the mountains, but to increasing pressure on the air, which is pushed down the eastern slope under the prevailing westerly winds.

The mean temperatures in January average about 15° higher than the average of the daily minima, the range varying slightly from place to place.

MEAN SUMMER TEMPERATURES

In order not to be misled as to the origin of summer heat which is sometimes thought to be wafted northward by the winds prevailing at that season, it is well to mention the mean temperatures of summer and of July before discussing the maxima. July is the hottest month throughout the Plains, with August norally 1° to 2° cooler and June from 5° to 8° cooler.

A map of mean summer temperatures for the period 1895–1914 [31] shows only a small, narrow band along

[31] See Atlas of American Agriculture II, B (Washington, 1928). The averages for this period are likely to be somewhat lower than those for the period employed in the accompanying maps, since there has been a slight general increase in temperatures in recent years.

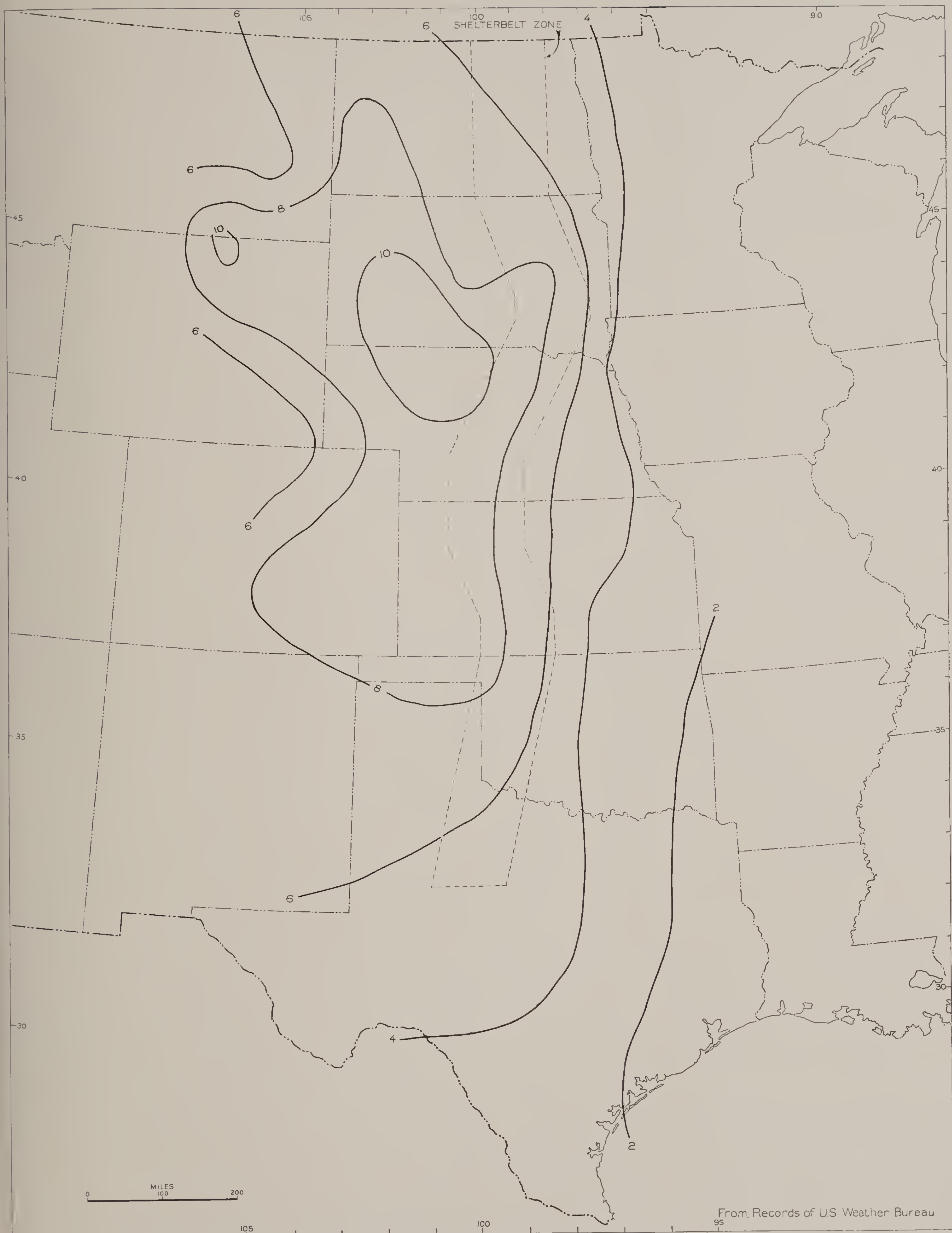

FIGURE 33.—Average annual number of temperature changes exceeding 45° F. within 24 hours, 1898–1933.

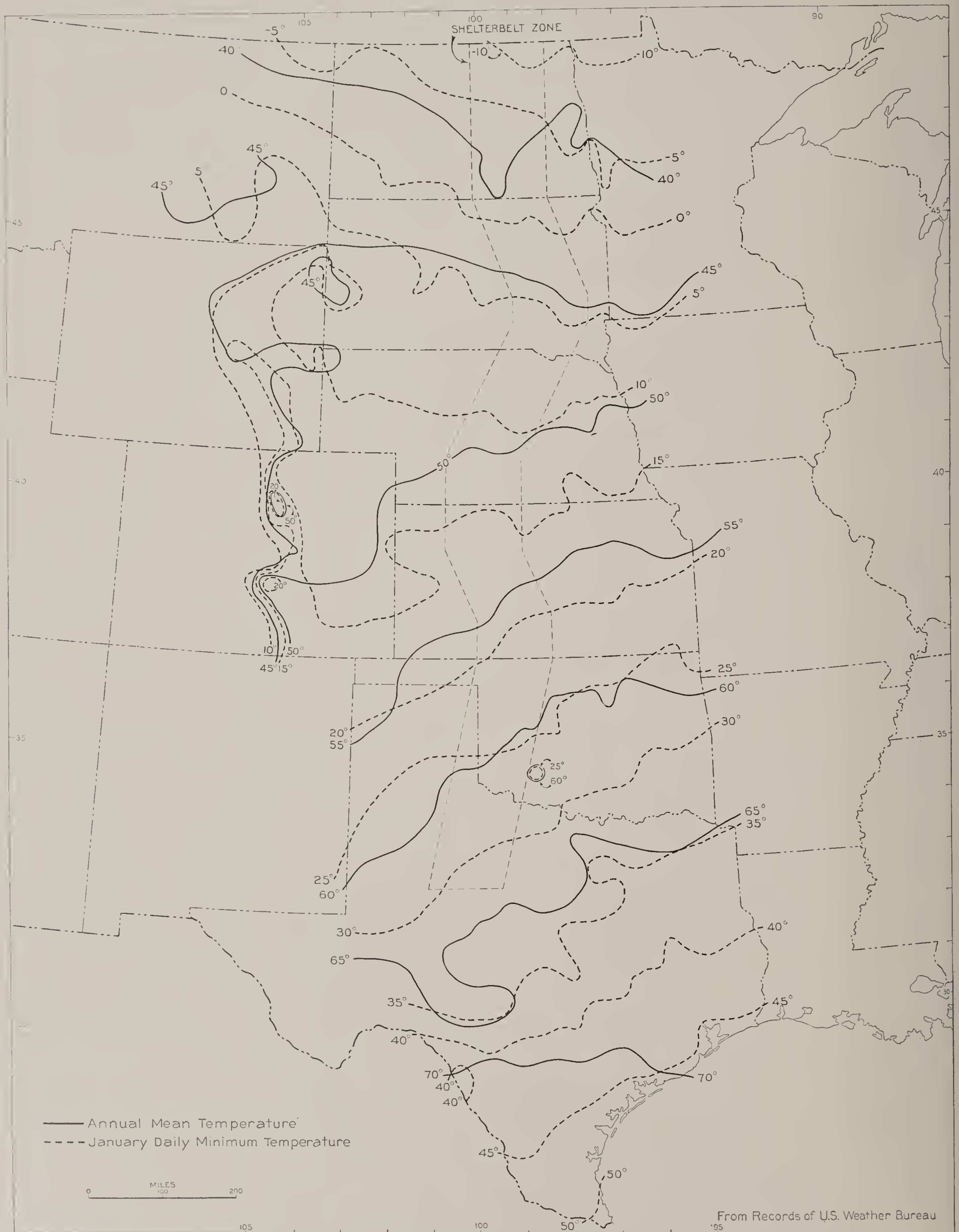

FIGURE 34.—Annual mean temperatures and January mean daily minima, 1904–33, or shorter records adjusted to the period.

the lower Rio Grande having an average as high as 85° F. The entire Gulf coast region, however, has temperatures above 80°, the width of this band being considerably greater in Texas and Louisiana than eastward, where elevations are encountered not far from the Gulf. It is generally true that even slight elevations give lower temperatures than are dictated by the latitude.

Centrally, the isotherm of 75° F. keeps a rather uniform distance from the Gulf (at about the latitude of St. Joseph and Terre Haute), but bows sharply southward along the eastern base of the Rockies and western base of the Appalachians.

Individual maps of mean temperatures for June, July, and August [32] show similar characteristics, and in no case is there a hint of lower mean temperatures along the coast than slightly farther inland. From these facts and what will be shown in the following paragraphs, it may be inferred that, despite some lag in the warming of the waters of the Gulf, the air blown inland day and night at this season (when the winds are quite persistently from the south) is not appreciably cooling, although its temperature is probably much less variable, at different times, than the air over the land. There is, on the other hand, in the lower Rio Grande section of Texas and in the lowlands near the east coast of adjacent Mexico,[33] an area from which some dry, hot air may be carried northward by winds. It is apparent, however, that the temperatures of summer days must be largely generated locally.

MEAN MAXIMUM JULY TEMPERATURES

In the mean maximum temperatures of midsummer are found the most significant relations to the dryness of the Plains, since several months of warm weather have, when this season is reached, largely dissipated the reserves of moisture accumulated during the winter. With precipitation falling off markedly after June, a greater degree of drought generally prevails in August than in July, despite the fact that temperatures are then very slightly lower. The maxima of July have therefore been selected for special study. Isotherms for this phase of temperature distribution are shown in figure 35.

Along that portion of the westerly Gulf coast which is mapped, the proximity of the water keeps the daily maxima down to 90° F. or slightly less, not more than 6° to 8° above the mean temperature of the period. Thence for a considerable distance inland the temperatures increase, despite higher latitude. On the 94th meridian, the increase is about 7.5° in daily maxima northward from the coast before any decrease due to latitude appears. The increase is somewhat greater, about 9°, northwestward from the locality of Galveston before there is any decrease.

Except for the area along the Rio Grande, whose high mean temperature has already been noted and whose maxima reach 100° F., the highest maximum temperatures are recorded in the Colorado and Brazos River Valleys of Texas, where a few points normally reach 98.5° for the average day in July. This warm zone is quite obviously cut off from the even warmer zone of the Rio Grande by the slight elevation of the plateau which lies between (maximum 94° or less), so that it seems extremely improbable that the heat developed at one point is really carried any appreciable distance northward.

The 96° isotherm, after making a long detour nearly to the southeast corner of New Mexico, swings back eastward and northward to southwestern Oklahoma, then returns southward entirely on the west side of the Gulf.

The 94° isotherm extends from southeastern New Mexico nearly north to southern Kansas, thence southward and eastward probably as far as Alabama before looping back more or less parallel with the coast line to the mouth of the Rio Grande.

The marked projection northward, in the vicinity of the 100th meridian, of all lines for this midsummer period, representing both mean and maximum temperatures, is rather clearly due to the increasing dryness inland and to the west, which means that a smaller proportion of the sun's heat is expended in evaporating the moisture which has reached the ground. That similar temperature conditions may, however, be produced with more abundant rainfall, by low elevation and restricted circulation of air in valleys, is shown by the fact that a similar projection of the isotherms for summer mean temperatures develops in the Mississippi Valley east of the Ozarks. On the west edge of the Plains, higher elevations and the coolness of the Rockies plainly limits the temperature of the poorly watered lower lands adjacent.

The 92° isotherm is found to reach an extreme latitude almost corresponding to the southern boundary of Nebraska, near its center. The 90° and 88° isotherms crowd in closely at this longitude. There is, apparently, an influence here causing cooling somewhat more sharply than the latitudinal ascent. The fact is of sufficient importance in relation to the subject of Plains tree planting to merit closer examination. The sand hills are recognized as being a natural reservoir for moisture, which the Plains in their natural condition are not but which they might become, to some extent, by careful conservation of moisture and protection through tree planting. The sand hills, through the deep-rooted vegetation, steadily return a certain amount of water to the atmosphere when the surrounding Plains are essentially dry and their vegetation practically dead.

Coolness of the midsummer nights in the sand hills is well known and is supposed to result in part from the fact that partial reflection of the sun's heat and rapid radiation of that which is absorbed, limited largely to the surface soil layer, leaves less heat to be radiated at night. With this prima facie evidence of quicker radiation, it might be expected that midday temperatures would be higher than elsewhere in corresponding latitudes and the maxima perhaps reached earlier in the day.

The average gradient (negative) of the July maximum temperatures is approximately 1° F. for each degree of latitude, from 35° north to 49° north. Near the 100th meridian, however, a decrease of 4° occurs (between the 92° and 88° isotherms) in 2° of latitude. From this point north there is no essential drop in temperature for the next 3° of latitude, and in fact

[32] Loc. cit. (footnote 31). These isotherms are too far apart to show whether slightly cooler temperatures occur along the coast.
[33] HENRY, A. J. HERNANDEZ ON THE TEMPERATURE OF MEXICO. Monthly Weather Rev. 51: 497–509, illus. 1923. [Abstract.]

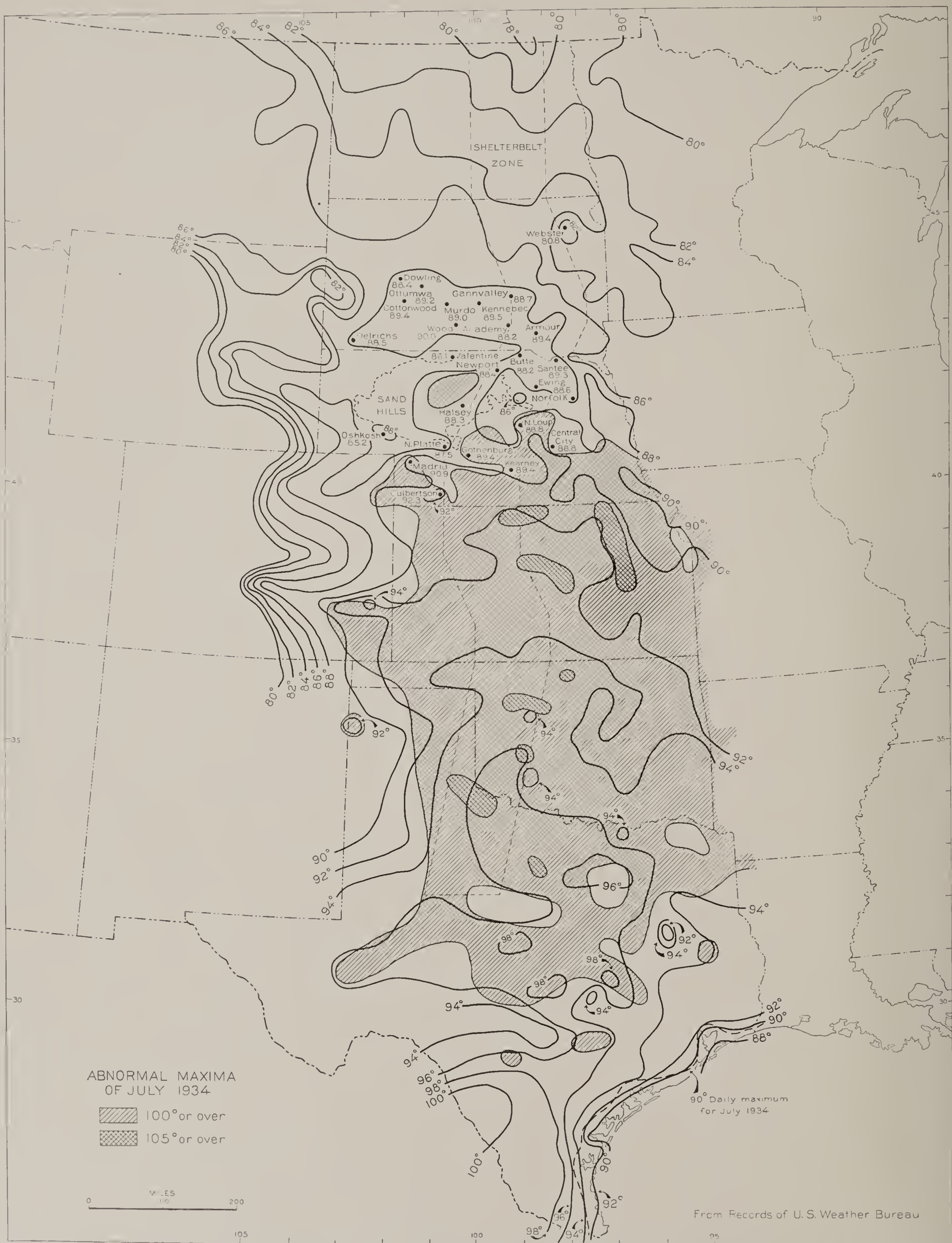

FIGURE 35.—Average maximum temperatures of July for the 30 years 1904–33, or shorter records adjusted to the period, and drought maxima of July 1934.

the highest temperatures of the entire area occur in the northern part, as indicated by individual station readings. Here is a latitudinal inversion of temperatures which must be the result of radically different surface conditions.

Through the center of the Nebraska area, which is apparently cooled by the sand-hill influence, there is an alley defined by the 88° isotherm in which temperatures somewhat above 88° F. prevail. This is the highest, roughest portion of the sand hills, an important receiving area in the vast reservoir, but one in which, because of the depth of the water table (frequently as much as 100 feet below the tops of the dunes), there can be relatively little dissemination of the stored moisture. The alley is thus kept open to the northeast, forming a junction with the hotter territory of South Dakota in that part of Nebraska in which heavy clay soils occur and which includes also a considerable portion of the Elkhorn Valley, above Norfolk, in which there is seepage from the sand-hill section. It is apparently through this alley, if at all, that South Dakota may be said to "receive heat from Nebraska", borne in upon southwest winds. In fact, one can almost visualize the alley as a continuation of the belt of high drought frequency extending from southwestern Kansas (figs. 26 and 27).

The remainder of the sand-hill section is vastly different, not only because it is not in the path of particularly dry southwestern winds but also because it has better moisture conditions. The northwest portion, although high in elevation, contains numerous lakes and considerable areas with high water tables. The area to the east and southeast is one in which most of the accumulated water of the sand-hill section appears in streams, moistening extensive fertile valleys of the Loup River system.

The high-temperature area of South Dakota, west of the Missouri River, is plainly the concomitant of the true Badlands topography on the upper reaches of the White and Cheyenne Rivers and the only slightly less bare soils which prevail on the bluffs throughout the length of these wide and deep valleys. Since the soil throughout is prevailingly one of heavy clay, even the rolling lands between the valleys express an arid condition during a considerable part of the year.

The relatively high temperatures occurring in the North Platte Valley of western Nebraska and eastern Wyoming are again expressive of the effects of bare soils occurring in a rapidly eroding area commonly designated as "Badlands." It is interesting to observe that the irrigation of this valley floor is entirely insufficient to overcome the intense heat of the bare areas which surround it.

The Nebraska sand-hill planting, centered at Halsey, is in the path of the dry southwest winds which plow their way through to South Dakota. Unfortunately, because of the height of the dunes in this section, the trees have a minimum moisture supply and can exert only a minimum effect on local temperatures. If areas at both the northern and southern edges of the sand hills, where ground water is much closer to the surface, could be similarly developed, possibly a slightly greater effect could be produced. The plan which has been put forward in connection with the shelterbelt project, to develop numerous relatively small areas in the sand hills, has everything to recommend it, provided these tracts are located where they will be served by abundant moisture supplies, as in the case of the canyons of the southeast sector.

Shelterbelt planting in this same important path can have an effect insofar as it makes use of water which would otherwise be lost to the region through run-off. Thus, northern and northwestern Kansas, although particularly difficult for upland tree planting because of the extreme heat conditions and drought frequency which have here been described, is a considerably dissected region and offers innumerable opportunities for planting along gulches and, with very minor engineering works, for storage of water in the soil. Such country as that in which the recent Republican River flood occurred could be vastly improved by water-conservation and planting work.

1934 DROUGHT TEMPERATURES

Under ordinary drought conditions plants fail to grow, and may die, solely on account of the gradual exhaustion of moisture within reach of their roots. When at midsummer, however, rain is long withheld and the ground surface becomes so dry that there can be no general evaporation, the solar energy received is almost wholly expended in raising the temperature of the soil and thence of the air in contact with it. This heating may rise to such a pitch that plants are directly killed by the high temperature even when their roots are able to obtain some moisture. In 1 or 2 days of excessive heat crops may be killed, and even the leaves of trees may shrivel.

The exceedingly high temperatures of the Plains region which often occur in dry summers are hardly to be thought of as "coming from the south" to any appreciable extent. There was an almost unbroken hot spell from June 20 to August 18, 1934. In July maximum temperatures in excess of 100° F. were felt daily as far north as central Nebraska, and at various points in Kansas, Oklahoma, and the Ozark section the average daily maxima for the month were 105° or more. These special conditions are shown by the hatched areas on the map (fig. 35). A strong tendency for the greatest heat to be observed farther east than normal was probably the result of unusual moisture deficiency in Missouri and even in some areas east of the Mississippi River.

As usual, the area of these excessive temperatures is found to be entirely separate from the hot area on the Rio Grande, which was scarcely as warm as the normal. The 90° isotherm along the Gulf coast was practically normal in position, but 95° temperatures crowded closer to the coast than usual, despite higher-than-average wind velocity from the Gulf. In some cases the velocity of the south wind was nearly doubled. The wind direction at several Texas stations had less of an easterly origin than usual, although exceptions occurred. Perhaps the most important change from normal was a greater dryness of the air as it entered the southern Plains region.

The greatest excesses over normal July maxima, 13°, were felt in northern Kansas, where temperatures of 105° F. were registered. Near the Canadian line the excesses were of about 5°.

Aside from the general extension northward of the excessive temperatures, which are rarely encountered except in desert regions, the outstanding feature of the 1934 record was the occurrence in the center of the Nebraska sand-hill area of temperatures in excess of anything recorded elsewhere in Nebraska. This confirms the theory derived from the normal July maxima, namely, that the high dunes of this sector have little or no opportunity to evaporate their deeply stored ground water through the draft of vegetation. Consequently real drought conditions can occur here much more markedly than in the surrounding seepage zones.

It is evident from the examination of 1934 conditions that daily maximum temperatures are controlled very closely by the degree of dryness attained locally, and *not* by the bringing in of heat as such, from the south or elsewhere.

On the other hand, there is a relationship between drought on the Plains and the normal heat and dryness of the Rio Grande area and perhaps other desert-like areas to the southwest which, although somewhat indirect, cannot be entirely overlooked. When, because of general air-pressure conditions which are abnormal for the season, summer winds do not swing northward and westward from the Gulf but rather blow from relatively arid regions of the south or southwest, their temperature and extreme dryness at the outset have something to do with extending the area of arid conditions. High temperatures arise in their path when they have sapped the lands to the north and northeast of such upper soil moisture as they possessed.

In physical terms, the principals of drought alleviation herein set forth and explained may be summarized thus: (1) The significance of hot winds in summer lies much more in their capacity to increase evaporation than to increase directly the temperature of the locality; (2) and in consequence of the above, it is certain that the storage of moisture, either in the soil or in reservoirs, through the agency of tree planting and of auxiliary works which insure the collection and storage of run-off water, will help to mitigate other distressing phenomena of droughts.

Section 12.—SOIL AND FOREST RELATIONSHIPS OF THE SHELTER BELTZONE

By F. A. Hayes, *senior soil scientist, Division of Soil Survey, Bureau of Chemistry and Soils,* and J. H. Stoeckeler, *junior forester, Lake States Forest Experiment Station, Forest Service*

CONTENTS

What is the nature of the soils of the shelterbelt zone, and what types of tree growth, native or introduced, do the different soils now support? The answer to these questions will supply, to a very significant degree, the working data of afforestation projects in the area, on whatever scale they may be undertaken.

With a knowledge of the presence or absence of trees, with observation of the success or failure of previous plantings in thousands of localities, the soil map and the climatic data take on new meaning to the forester, offering definite guidance to the selection of vast acreages favorable to new growth.

To obtain the needed correlation between soil and forest types, a rapid survey was conducted in the entire region for which nationally sponsored tree shelterbelts were proposed.

The results of many years of work by the Bureau of Chemistry and Soils and the agencies of the several States were available in the form of either detailed county soil maps or soil-reconnaissance surveys over a considerable part of the area, and these were very fortunately supplemented by the reconnaissance soil erosion survey made by the Soil Conservation Service in the summer of 1934; consequently the main task was to make as thorough a canvass of the territory as possible in strictly limited time, carefully correlating soil-type classifications, observing kinds and conditions of tree growth, and referring each group of trees to its proper place on the soil map.

Field work included a study of the various tree and shrub species now planted or growing naturally in the region, particular attention being given to their age, height, vigor, and rooting habits in the various soils. In the 2 months allotted to the survey, 3 parties, traveling by automobile in the northern, central, and southern sections respectively, observed a total of about 10,000 plots or groups of trees within an area generally more than 100 miles wide extending from the Canadian boundary of North Dakota to Lubbock, Tex. Soil types were examined and many soil samples taken. With the assistance of farmers, 126 designated trees and shrubs were trenched and their root systems examined.

The data thus assembled may be considered fairly and definitely indicative of natural conditions broadly governing tree growth in the shelterbelt zone. The results of the survey are shown in simplified form in the maps (figs. 38, 39, and 40).

Prevailing soil types are indicated on these maps by numbers placed within the respective soil boundaries, and upon the areas thus defined various crosshatchings are used to indicate the feasibility of growing trees on the different soil groups. The classification of the soils with respect to tree growth should not, however, be interpreted too literally on too small an area. The zone area amounts to tens of thousands of square miles and considerable variations of soil quality may be found within an area of one soil type as shown on the map. The variations may be favorable or unfavorable to tree growth. The purpose of the present mapping is, in short, to help to visualize general soil conditions. For actual planting, more detailed maps must be used to guide the work according to the actual site and the service to be rendered.

Within these limitations, the maps face us with certain broad realities.

(1) They indicate that tree belts cannot be created in any geometric pattern of uninterrupted, equidistantly spaced lines, but will have to be arranged more in accord with the dictates and habits of nature.

(2) The distribution of the soils, confirmed by observation of long-established plantings, indicates that successful tree growing can be expected over large areas throughout the zone. By "successful" tree growing is meant the reasonably easy establishment of groves of trees whose average life will be between 30 and 60 years and whose ultimate average height will range between 25 and 40 feet.

Estimates based on field conditions in the 115,000 square miles of the entire shelterbelt zone place the favorable, difficult, and unfavorable soils at 56, 39, and 4 percent, respectively. In the 56 percent of the soils considered as favorable are included from 30 to 40 percent of those shown on the map as difficult. Certain soil types or groups, particularly loamy soils in the eastern half of the shelterbelt zone, receive enough

SOIL TYPES INDICATE SHELTERBELT POSSIBILITIES

FIGURE 36.—Rough morainic pasture land on Williams stony loam. Such land is unsuited to shelterbelt planting. Walworth County, S. Dak. (See text, p. 127.)

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FIGURE 37.—The Colby soils are among the most drought resistant of the finer textured upland soils. Most species of trees do well on this type of soil in localities where the moisture snoply is favorable. Typical undissected phase of Colby silt-loam soil in western Kansas, with green ash windbreak in background, 4 miles east of Goodland, Kans. (See text, p. 142.)

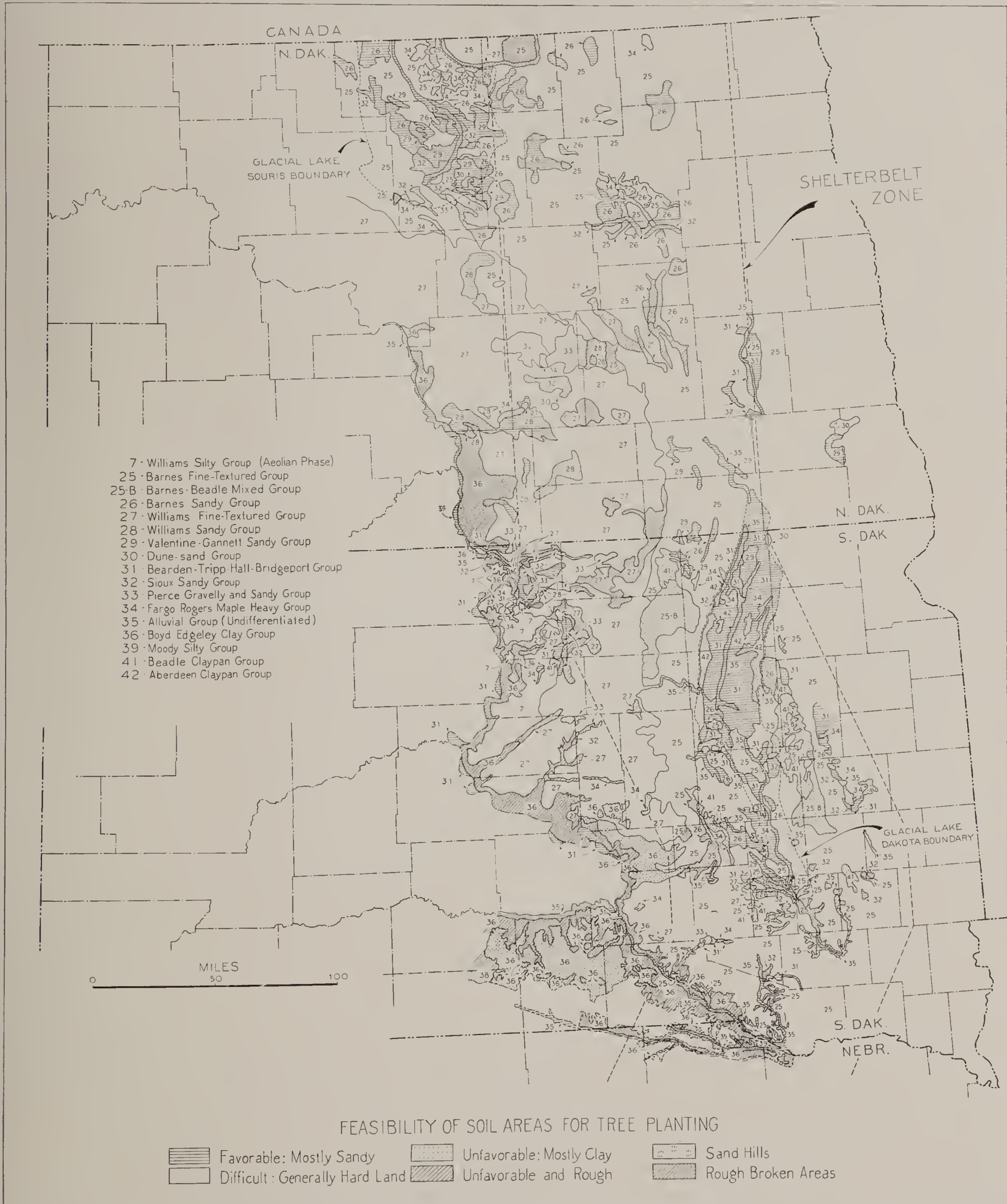

FIGURE 38.—Soil groups of the shelterbelt zone, northern section.

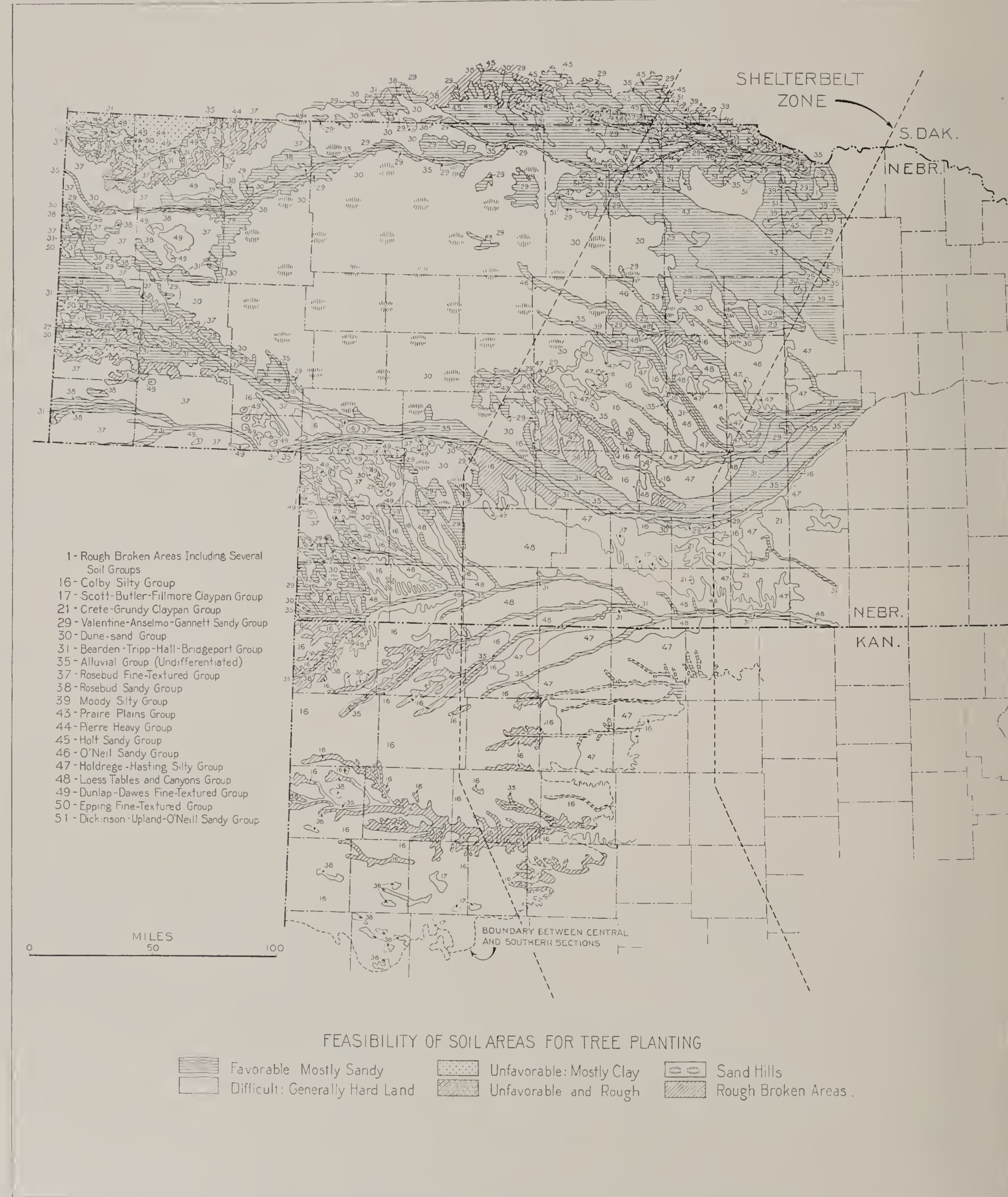

FIGURE 39.—Soil groups of the shelterbelt zone, central section.

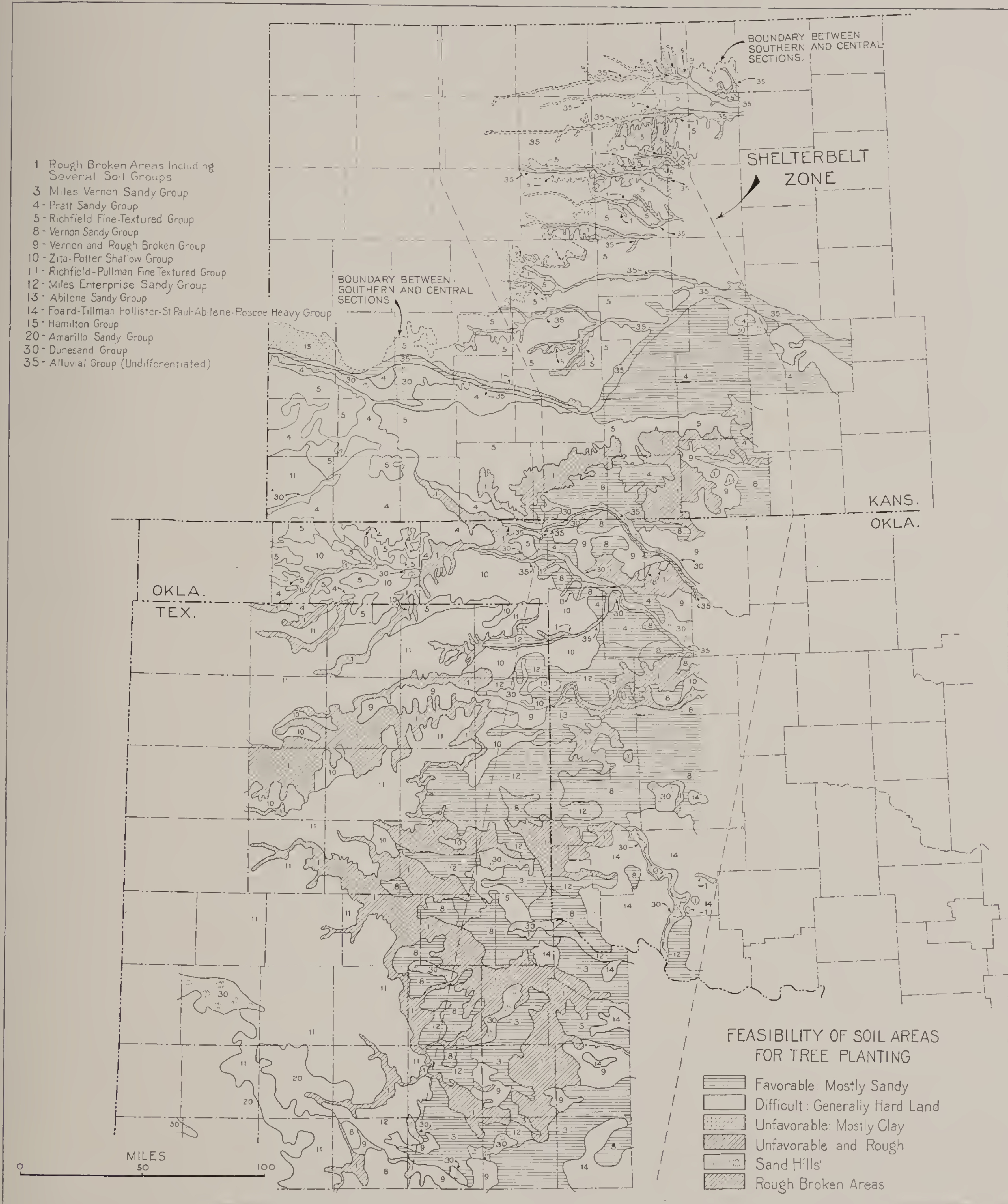

FIGURE 40.—Soil groups of the shelterbelt zone, southern section.

precipitation to characterize them as favorable, but they grade off to the westward into the difficult class so gradually that it is not considered feasible to indicate their extent by definite crosshatchings on the map.

(3) Since the establishment of shelterbelts is a much more limited and selective project than the afforestation of an entire region, it is reasonable to suppose that the forester can change a considerable part of the difficult area to a favorable category and so successfully plant such sites by proper choice of species, careful ground preparation, listing, terracing, impounding water by dams, and by other water-conserving measures which are entirly practicable to undertake.

(4) The last and most important fact for our consideration is that the zone as shown on the map coincides with the area often referred to as the "bread basket of the Nation." The soil and topography of the area as a whole lend themselves admirably to the large-scale production of wheat, and much of the area is being so used. If this area is to be retained in a productive condition and its soils safeguarded against destructive wind erosion, shelterbelt planting, especially on certain critical soil types, seems at least a partial answer to the problem.

Among these critical types are sandy loam soils with sandy or gravelly subsoils. Such soils are much more subject to severe injury by wind erosion in a short time than other soil types, but at the same time they are among the most favorable in the Great Plains for tree planting; and it is entirely logical that the planting effort should be concentrated first and most intensively on them.

GENERAL DESCRIPTION OF THE SOILS

OUTLINE OF SOIL DEVELOPMENT

Geologic formations, through weathering, produce the parent materials of soils. The parent materials, largely inorganic, constitute the bulk of the soil complex and determine initially, and to a greater or less degree permanently, its physical characteristics.

From given parent materials soils have developed through processes involving the operation of climatic factors, the growth and decomposition of organic materials, the formation of new chemical compounds, the progressive disintegration and modification of less-resistant parent materials, the translocation of materials in the soil section, and the formation of a more or less layered profile.

The stage of development attained by the soil of a given region depends broadly on the climate and vegetation, but is influenced locally by the topographic and drainage conditions and by the resistance of parent materials. Soils which have developed for the longest periods under good drainage, without abnormal erosion, from parent materials easily affected by soil-forming processes are the most deeply and fully developed, and are commonly known as "mature soils." All of them in a given climatic, geologic, and vegetative region have the same number of well-developed layers or horizons, which occur in a definite order or succession and which differ from one another in one or more easily discernible features such as lime content, texture, structure, and compaction.

Most of the extensive soils of the shelterbelt zone are mature or are approaching maturity of development, although there are both large and small areas within the zone where development is regarded as immature on account of recent deposition as in bottom lands, or because of abnormal erosion, poor drainage, recent glacial action, or the resistant character of parent materials.[34]

To obtain the most general picture of the soils of the shelterbelt zone from the point of view of their origin and present development, it is convenient to block them out roughly under the three territorial sections of the zone—northern, central, and southern.

NORTHERN SECTION

The width of the shelterbelt zone as now delimited is everywhere 100 miles, measured along parallels of latitude. Its northern section is contained entirely in the States of North Dakota and South Dakota except for a minor overlap into Nebraska.

The soils over the greater part of this section, outside the alluvial river basins, have developed from highly calcareous glacial drift. A large proportion of them have been put under cultivation. They are friable (capable of being crumbled by the fingers) and, on the whole, are darker and more limy than any other upland soils within the zone. Most of them contain some pebbles and glacial boulders, and a few are composed largely of such materials.

Areas of wind-blown sandy soils with light-colored surface layers and low lime content occur in several places. The northern section also includes areas in which the soils have developed from heavy Cretaceous shales and are dense throughout. In addition there are numerous small basins in which standing water has produced heavy soils, and a few rather large areas in which alkali associated with periodically poor drainage has produced claypan soils.

CENTRAL SECTION

The central section of the shelterbelt zone adjoins the northern section at or near the north boundary of Nebraska and extends southwest through that State and thence south into north-central Kansas.

The greater part of the central section is covered by a level or gently sloping mantle of loess—a light-gray, limy, and floury silt, most of which has been deposited in the course of ages by winds blowing from a westerly direction. This material is very uniform in texture and color throughout the area of its distribution. From it soils have developed which owe their differences largely to variations in the luxuriance of the grass cover under which they have formed and in the amount of water to which they have been subjected. Most of them are friable, but a few have developed heavy claypan layers. They include the most productive upland soils of the section, and the greater part of the area occupied by them is under cultivation.

Much of the remainder of the central section is occupied by a large intruding area of the sand hills of north-central and southwest Nebraska. Derived largely from the disintegration of Tertiary sandstones but partly from late Pleistocene deposits, the sand over most of this area in times past has been whipped by the wind into the typical sand-hill topography. In the smoother areas and in poorly drained pockets and swales, the sandy soils have accumulated sufficient

[34] Not all immature soils are necessarily unfavorable to plant growth, as will be noted later in the case of important sandy areas.

organic matter to have dark topsoils. Most of the land in the sand hills is used for grazing purposes or hay production.

North and east of the sand hills lies a considerable body of sandy and gravelly upland soils closely intermingled. These have accumulated much organic matter. The sandy soils, however, have the thicker topsoils and better moisture-holding capacity, and are more favorable to crop production. More than 50 percent of the gravelly soils are used only for grazing.

SOUTHERN SECTION

The southern section of the zone extends from north-central Kansas through western Oklahoma and the eastern part of the Texas Panhandle, and ends at about latitude 32°30′ in northwest Texas. Most of the soils in this section have developed from parent materials which in the northern and central sections are absent, deeply buried, or present only as local outcrops.

A somewhat prominent feature of the southwestern Kansas area, which appears in the Oklahoma portion to a less extent, is the High Plains on which the soils have developed from fine-textured Tertiary and Quaternary materials containing considerable proportions of clay. Here the soils are deeply developed and are somewhat heavy, especially in their subsoil layers. They intrude into the shelterbelt zone on southeastward extensions of the extremely flat formation known further west as the " Llano Estacado " or " Staked Plains."

In Kansas and Oklahoma the soils of the High Plains have a wide range in textural features. Those formed from the most finely divided deposits have silty, brownish topsoils overlying lighter brown or yellowish silty clay subsoils. Those over the sandier deposits have developed into light-brown sandy soils with subsoils ranging from yellow or reddish-brown sandy loam to sandy clay loam. On the escarpment or breaks bordering the smooth High Plains, the soils are on rather severely eroded Tertiary deposits and have thin, poorly developed topsoil and subsoil layers.

East and south of the escarpment lies the rolling plain, forming the main portion of the shelterbelt zone in Oklahoma and Texas and a considerable portion in southern Kansas. It is occupied largely by red beds locally capped with Tertiary and Quaternary remnants. It has a great variety of soils, most of which are reddish and moderately to extremely sandy. In southwestern Oklahoma, however, some of the smoother lying soils on the rolling plain have dark silt loam or clay loam surface layers which are underlain by heavier subsoils. The latter, in places, are of claypan character.

In the extreme southern part of the zone, sandy material of reddish color thinly mantles fine-textured Tertiary deposits of the high plains formation, and here distinctly red or reddish-brown sandy soils are common.

PREVAILING FEATURES

None of the factors which contribute toward soil development is uniform throughout the proposed shelterbelt area. The semiarid climate and especially the grass vegetation have, however, given the soils of the area as a whole two outstanding features, namely, dark topsoils containing a greater or less proportion of black decomposed organic material, and a zone of calcification or lime enrichment at a comparatively shallow depth in their subsoils, marking in a general way the lower limit of water percolation from the surface. These features are present in varying degrees in the soils of 85 percent or more of the area.

DARK TOPSOILS

The darkest topsoils occupy situations where the grass growth is or has been luxuriant, where vegetal decay is relatively rapid, and where the topography favors accumulation of the decayed residue. In the shelterbelt zone such conditions occur in restricted areas such as bottom lands and terraces and in wet pockets on sandy land. On a larger scale they occur on the well-drained uplands across the northern end of the zone and along its eastern edge through Nebraska and the Dakotas, where the precipitation has been sufficient to support a dominantly tall-grass vegetation. The extensive root systems of the tall grasses, upon decaying, produce large amounts of black carbonaceous material which becomes intimately mixed with the mineral-soil constituents. This material, except in spots where erosion by wind or water has been especially severe, has imparted a very dark brown or almost black color to the topsoils, forming what are known as Chernozem (black soil) after nomenclature originally used in Russia. The color averages darkest in the Dakotas, as already noted.

Elsewhere throughout the shelterbelt zone the grass growth is less luxuriant. Tall grasses occur along the eastern edge of the zone in Kansas, Oklahoma, and Texas, but owing to their bunch habit of growth they do not supply as much carbonaceous material as the grasses farther north. Consequently the intensity of darkness in the topsoil layers here is less pronounced, the soils being designated generally as chestnut colored.

Westward across the zone, tall grasses gradually disappear, except on sandy lands or in unusually moist situations, and most of the soils have developed under a short-grass cover. Vegetal decay is relatively slow and incomplete, and the topsoils are lighter in color than those developed under the tall bunch-grass cover. The color may range from chestnut brown to reddish brown or even, in the extreme south, to red, the more reddish colors being imparted mainly by the parent Red-Bed formations.

ZONE OF LIME ENRICHMENT

The zone of lime enrichment is a product of the vegetation, climate, and parent soil material. Practically all the geological formations from which the soils of the shelterbelt area have developed contain lime. The roots of the grass plants bring the calcium and other basic compounds within reach to the surface horizons. Upon decay of the grass, these compounds are released and carried downward by moisture. Thus the topmost soil layers are gradually cleared of lime. But where precipitation is insufficient to penetrate the soil deeply, the soluble compounds are leached to a comparatively shallow level, where they are reprecipitated and gradually accumulate to a maximum concentration. Thus there is built up, under a topsoil practically free of lime, a layer of higher lime content than occurs elsewhere in the entire soil profile.

A zone of lime enrichment is not usually present in the more sandy soils of the region nor in the alluvial soils along drainage ways. Neither is it present in some of the soils occupying undrained upland basins where the moisture, accumulating from both precipitation and run-off, is sufficient to remove the lime to the water table.

In most of the soils, the depth or shallowness of the lime zone is a reliable indicator of the abundance or scarcity of the precipitation and of its ability to support trees and vegetative growth in general. This rule does not hold, however, over the greater part of the glaciated country in the Dakotas, where the lime lies nearer to the surface of the ground than the amount of precipitation would seem to warrant. This condition is ascribed to the lateness of the glacial epoch, insufficient time having yet elapsed for the precipitation to remove the lime from the upper part of the unusually calcareous parent material.

SAND AND GRAVEL SOILS

Aside from the dark color of topsoils and the layer of lime enrichment, which occur fairly generally throughout the zone, other soil features such as texture and degree of friability or compaction are far from uniform. They vary from place to place, according to the character of the parent material and the topographic and drainage conditions. Where the parent soil materials are coarse siliceous deposits, which are extremely resistant to weathering, most of the soils are of a sandy or gravelly nature. Within the zone boundaries, large areas of sandy soils exist, particularly in the glacial Lake Dakota Basin of South Dakota, in the sand hills of Nebraska, in southwest Kansas, and in the Panhandle sections of Texas and Oklahoma. Narrow strips of extremely sandy soils, usually associated with strips of finer textured soils, are common on the first bottoms and terraces of streams.

Owing to their resistant nature, few of the materials of high sand content have made much progress toward soil development. While they have generally accumulated more or less organic matter, the greater part are light colored, even at the surface, and show little change downward either in color or texture. Unless protected by adequate vegetative cover, they are subject to destructive wind erosion.

Nevertheless, the sandy soils of the zone as a whole rate high in the scale of vegetative capacity. Their greatest asset is their rapid absorbing power, which permits a higher percentage of retention from available precipitation, deeper penetration, lower wilting coefficient, and more even distribution of absorbed moisture than is the case in fine-textured soils.

The largest areas of gravelly soils are those occurring north and east of the main sand-hill body in Nebraska and on hills, knobs, and ridges in parts of North Dakota and South Dakota. Terrace areas having coarse gravelly soils occur in several of the lake depressions and stream valleys of the Dakotas.

Gravelly soils, being more stable than sandy soils, have accumulated more organic matter. As a rule, they have rather dark colored but thin topsoils. Some of them, especially on the terraces, have zones of lime enrichment. They take up moisture at least as rapidly as sandy soils, but pass much of it to the under drainage, especially in localities where the surface soil is thin. These soils, except where the water table is shallow, are usually droughty.

"HEAVY" SOILS

A considerable area of very heavy soils developed from shale occurs north and south of the Dakota-Nebraska line within the shelterbelt zone. They have dark, clayey surface layers underlain by subsoils composed of dense clay. All of them have high moisture-holding powers but absorb water very slowly, losing much of the precipitation as run-off. During seasons of frequent rainfall such soils may be very productive, but in dry periods the topsoil moisture evaporates, the clay shrinks and cracks, and they become extremely droughty.

The soils of the High Plains of southwestern Kansas that have developed from the more finely divided Tertiary deposits are fairly heavy, and they probably absorb moisture only slowly. Yet they are not compact and are easily penetrated by roots.

Rather extensive areas of heavy soils developed from bedrock clays and shales of Permian and Triassic age occur in the Oklahoma and Texas portions of the shelterbelt zone. These soils have slightly lighter colored surface layers than those in Nebraska and the Dakotas, but have similar moisture relationships.

Heavy soils in lake beds and basins, some underlain by claypans, occupy small scattered bodies over nearly all parts of the shelterbelt zone. They are of little agricultural value, owing to their clayey nature and poor underdrainage. Locally they may be alkaline, especially in the Dakotas.

Soils in which salts have contributed to the development of claypans are found at a number of places, particularly in South Dakota and Nebraska, but they comprise only a small part of the zone. They have been formed through the action of sodium carbonate, which, under certain chemical and moisture conditions, replaces the flocculating calcium and magnesium salts and destroys the granular structure of the soil. The finer soil particles become mobile and are easily carried down by percolating water into the upper part of the subsoil, which they increase in thickness and density. In a few cases the sodium salts have caused the development of typical Solonetz soils, which mark a definite stage in the evolution of true alkali soils. These are characterized by dark and extremely dense claypans which break into prisms and vertical round-topped columns, the tops of which may be covered with a light-colored layer of loose siliceous material.

SOILS OF INTERMEDIATE TEXTURE

Between the extremes represented by sand and gravel on the one hand and clay on the other, the soils of the shelterbelt zone present a wide range in textural features and in the degree of compaction which they have attained, but over the greater part of the zone they are neither extremely sandy nor extremely clayey.

In the glaciated section of the Dakotas most of the upland soils, although more or less stony, range in texture from silt loam to fine sandy loam and are friable. The subsoils are only slightly heavier than the topsoils. The soils developed from loess, which occupy most of the uplands in southern Nebraska and northwest Kansas, are composed largely of silt (intermediate in fineness between sand and clay), and with few exceptions, are friable. They have rapid moisture-absorbing capacities, ranking almost as high in this respect as soils of a considerably more sandy nature, but they are more subject to water erosion than sandy soils, and along drainage ways the parent loess is exposed in numerous places.

The soils of the rolling plains of Texas, Oklahoma, and southern Kansas, while predominantly sandy, usually contain sufficient clay to hold the sand grains loosely. They have rapid moisture-absorbing capacities but erode easily.

SOIL AND TREE RELATIONSHIPS

The general aspect of the region in which the shelterbelt zone lies is that of a level to gently rolling plain devoid of native trees except along stream courses and in a few other favored localities. The landscape is, however, dotted here and there with shelterbelts and other farmstead tree plantings. These planted trees are growing with varying degrees of vigor on all but a few of the soil types found in the zone. Aside from a few species which show special soil adaptations, the vigor and the percentage of survival of trees throughout the well-drained uplands and terraces increases with the sand content of the soils and decreases with the clay content. This phenomenon is related to the available moisture supply in the sandy and clayey soils at all times, and especially during droughts.

The precipitation within the shelterbelt zone, although moderate, is probably everywhere sufficient to maintain tree growth if all, or even the greater part of it, were made available to the tree roots. Its effectiveness, however, in supplying soil moisture is rather low over most of the area occupied by fine-textured soils, especially in the western part of the zone, where the precipitation is lowest, and in the southern part, where evaporation is highest.

The relative ineffectiveness of the precipitation on the fine-textured soils is not due to any lack of water-holding capacity of such soils. Investigations have shown that a 6-foot column of silty or clay loam soil is able to carry more than twice as much water available to plants than an equal column of coarse sandy soil.[35, 36] The decreased effectiveness of the finer textured soils under precipitation conditions encountered in the shelterbelt zone is to be attributed to their slow rate (rather than total potential volume) of moisture absorption, to the resulting relatively large run-off, to the retention of water mostly in the upper soil layers, and to the high wilting coefficient of the soil. That the first two characteristics mentioned reduce the effectiveness of the precipitation for vegetative growth is obvious. The third may favor some farm crops but is definitely unfavorable to trees, in a region of moderate precipitation, because it keeps much of the absorbed moisture near the surface of the ground, where evaporation is greatest and where the moisture is not available to the deeper tree roots.

The fourth characteristic relates to the amount of moisture retained by the soil at the time plants wilt beyond recovery. This is residual moisture which is unavailable, or too slowly available to sustain life. The amount is influenced somewhat by the character of the vegetation and also by atmospheric conditions, but it is controlled largely by the texture of the soil. It is small in the sandy soils, frequently as low as 4 percent, whereas in some of the fine-textured soils it may amount to more than 15 percent and in exceptional cases be as high as 30 percent. Although most of this unavailable moisture is a permanent soil feature, a certain amount of it, in the topsoil, is subject to evaporation, and the part so lost must be replaced by precipitation before any moisture can become available to plants. Thus the effectiveness of light showers is likely to be much less on fine-textured than on sandy soils; in fact, a rainfall of less than one-half inch is of little benefit to vegetation on any of the fine-textured soils of the shelterbelt zone, unless it comes while the surface is still moist from a preceding rain. Below depths of 2 or 3 feet these soils never attain their field-carrying capacity, except possibly in years of highest precipitation.

The relative ineffectiveness of such soils in taking up precipitation and making it steadily available for plant growth is confirmed by such investigations as have been made to correlate precipitation and soil moisture in soils of the shelter-belt zone. In three series of studies which are of record, conducted on fine-textured crop soils in Oklahoma,[37] Nebraska,[38 39] and North Dakota,[40] it was found that the average proportion of annual precipitation stored in the soil and made available to plants ranged from 18 to 25.9 percent, with an exceptional low at one station of 14.2 percent. By reference to Weather Bureau precipitation records for the various stations it appears that the amount of water thus stored ranged from 3 to 4.7 inches.

Most of the preceding figures apply to points west of the shelterbelt zone, where the precipitation, and consequently the moisture actually absorbed by the soils, is lower than within the zone. Since it may be reasonably assumed, however, that the ratio between precipitation and moisture absorbed by similar soils remains fairly constant in a given latitude within the particular region, the data become significant in determining the probable effectiveness of the precipitation on the fine-textured soils in different parts of the zone.

As elsewhere indicated, the mean annual precipitation within the shelterbelt zone ranges from about 16 to about 28 inches. If 25 percent of this, which is not an unreasonable allowance, can be absorbed by the fine-textured soils, the effective moisture carried by such soils amounts to 7 inches per annum under the higher precipitation. Under the lower one it is 4 inches, and over the zone as a whole it averages 5.4 inches per annum.

The question naturally arises, Are these amounts of moisture sufficient to sustain vigorous tree growth, especially after the moisture stored in the deeper

[35] KING, F. H. SOIL MANAGEMENT. 311 pp., illus. New York. 1914.

[36] BURR, W. W., and RUSSELL, J. C. REPORT OF CERTAIN INVESTIGATIONS ON THE CENTRAL NEBRASKA SUPPLEMENTAL IRRIGATION PROJECT. Nebr. Dept. Pub. Works, Ann. Rept. 15: 199–240, illus. 1923–24.

[37] FINNELL, H. H. THE UTILIZATION OF MOISTURE ON THE HEAVY SOILS OF THE SOUTHERN GREAT PLAINS. Okla. Agr. Expt. Sta. Bull. 190, 24 pp. 1929.

[38] BURR, W. W. THE STORAGE AND USE OF SOIL MOISTURE. Nebr. Agr. Expt. Sta. Research Bull. 5, 88 pp., illus. 1914.

[39] ZOOK, L. L. DRY LAND CROP PRODUCTION AT THE NORTH PLATTE EXPERIMENTAL SUBSTATION. Nebr. Agr. Expt. Sta. Bull. 279, 49 pp., illus. 1933.

[40] THYSELL, J. C., MCKINSTRY, H. C., TOWLE, R. S., and OGAARD, A. J. DRY FARMING INVESTIGATIONS IN WESTERN NORTH DAKOTA. N. Dak. Agr. Col. Bull. 110: 159–207, illus. 1915.

layers during some past rainfall cycle has been exhausted? This question, in the light of present information, cannot be answered. It can only be stated that the condition of the older trees, over much of the uplands occupied by fine-textured soils, indicates a severe moisture deficiency.

Drought has greatly affected a large percentage of the planted stand, particularly in the western part of the zone, where a very large percentage of the trees in many of the groves are dead or dying. The mortality has been greatest on the more clayey and least on the more silty types of the fine-textured soils.

It must be admitted, however, that few of these trees received adequate care after planting and that many of them are of species not best suited to their present soil and climatic environments. Fire, disease, insect pests, rodents, hail, and sleet have taken a heavy toll. Under good management, involving careful selection of trees and planting sites, proper precautions against damage, and the conservation of moisture through tillage, mulching, or through surface obstructions designed to utilize the run-off, the mortality can undoubtedly be lowered materially.

Most of the trees now growing on fine-textured upland soils within the zone seem to make fairly good growth during early life. Later, usually within a period of 20 years, growth, particularly in height, practically ceases. Whether the growth decline coincides with exhaustion of a previously stored subsoil moisture supply has not been determined for trees within the shelterbelt zone. Data indicating that such moisture has been exhausted in orchards in parts of southeastern Nebraska have been recently obtained by the horticulture department of the University of Nebraska.[41]

During droughts, trees on the finer-textured soils in the shelterbelt zone must depend almost entirely upon deeply stored moisture, usually of very small amount. Showers or light rains afford little benefit to these trees, aside from temporarily reducing the transpiration loss, because they do not appreciably replenish the soil-moisture supply. If the drought, which usually is accompanied by hot desiccating winds, is sufficiently prolonged, the trees on the finer soils rapidly reduce the supply of soil moisture to a point where it will no longer support them.

On sandy soils very few of the natural or planted species have succumbed to drought. This is true despite the fact that such soils are unable to store as much moisture as fine-textured types, that they occur in a region where the precipitation is not usually frequent, and that the water received during any single storm seldom exceeds the field-carrying capacity of a 6-foot section. But since a higher proportion of the stored moisture is available to plants during the intervals between replenishments, a closer balance is maintained than is usually supposed, and the under drainage loss is not great except in extremely coarse soil.

In sandy soils the moisture is evenly distributed to greater depths than in fine-textured soils, which encourages the development of deeper and wider root systems. Sandy soils permit little water to be lost by surface run-off and evaporation. In contrast to fine-textured soils their available moisture supply is appreciably replenished by light rains, even during droughts. These favorable factors enable them to supply a higher percentage of the total precipitation to the trees than is supplied by the heavier soils.

The only soils in the shelterbelt zone on which apparently little attempt has been made to grow trees occur on coarse gravel knobs and hills and in numerous poorly drained basins.

The gravelly soils occupy small areas, chiefly in the Dakotas. Their moisture content is too low to support more than a scant cover of short grasses and cacti.

The basin soils occur in poorly drained lake beds within the glaciated section of the Dakotas and in small undrained depressions on the more nearly level uplands and terraces throughout the remainder of the zone. They are periodically covered with water, sometimes for several weeks. These soils are composed largely of clay, which shrinks and cracks badly when the water evaporates. No trees seem able to adapt themselves consistently to this wide range in moisture conditions.

Alkaline areas occupy less than 1 percent of the land in the shelterbelt area. They occur chiefly in basin-like depressions and in claypan soils of the Dakotas. None of them are well suited to tree growth.

OBSERVATIONS OF TREE ROOTS

The root systems of 126 trees and shrubs occurring in the shelterbelt zone, 84 on fine-textured and 42 on sandy soils, were examined during the progress of the survey. They were studied from trenches or pits sunk close alongside the tree, 6 to 10 feet long, wide enough only for ample working room, and usually as deep as the deepest root exposed but seldom deeper than 10 feet. Where roots penetrated to an unusual depth, excavations were extended by means of augers, and the maximum root depth was roughly determined from fragments in the borings.

The roots were undermined on the pit wall nearest the tree by means of iron bars and ice picks. Their average spread was estimated or was determined by means of trenches which followed one of the main horizontal roots. Drawings or photographs were made of the exposed part of the root system, although in the drawings no attempt was made to indicate the more fibrous portions.

Data were also obtained on the location, history, species, age, height, diameter, vigor, class, spacing, and dominance of the tree; the soil profile was described, and notes were taken concerning drainage conditions, topography, and the depth of the ground water. The soil was sampled by horizons for later study.

For present purposes, the point of chief interest is the depth of root penetration in the different soils. It was assumed at the beginning that the larger, older, and more drought-resistant trees would be found supported by a deeper root system than trees of the opposite description. Field observations indicate that this assumption is usually correct. Except in areas where the ground water lies high, the shallow-rooted trees of the shelterbelt zone are more subject to serious injury or death during periods of deficient precipitation. Many of the deeper rooted trees, however, were subject to considerable injury during the recent great drought, especially the older ones growing on fine-textured upland soils.

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[41] WIGGANS, C. C. THE EFFECT OF ORCHARDS ON SUBSOIL MOISTURE. Nebr. State Hort. Soc. Rept. 1935. (In press.)

The data obtained seem to warrant the following general conclusions concerning the rooting habits of trees in soils of the shelterbelt zone.

1. Rooting is invariably deeper in sandy than in fine-textured soils in all localities where the water table is beyond the reach of tree roots.
2. Among the fine-textured upland soils, rooting is deeper in those developed from loess than in those developed from other geologic formations, that is, in the loess-derived soils of Nebraska and northwestern Kansas.
3. Rooting is shallowest in the fine-textured drift-derived soils of the Dakotas.
4. Rooting in the fine-textured soils of southwestern Kansas and the Texas Panhandle is intermediate in depth between that in the northern section (Dakotas) and the central section (Nebraska-Kansas) of the shelterbelt zone.
5. The roots of most trees are more numerous above the zone of lime enrichment, that is, within the upper 2 or 3 feet of the soil section where such factors as moisture, aeration, nutrients, temperature, and soil organisms are most favorable for growth.

DEPTH OF ROOTING OF INDIVIDUAL SPECIES

In addition to the above general observations, it was found that some species have a tendency to be shallow-rooted while others invariably showed strong, deep-penetrating root systems. The following list, based on the observation of 84 root systems of trees growing on fine-textured soils, indicates the relative rooting depths of the respective species under the condition regarded as critical. The other 42 trees, growing on sandy soils, were generally deeper rooted. The trees studied were usually between 20 and 40 years of age.

CLASSIFICATION OF TREES WITH RESPECT TO ROOTING DEPTH

Deep-rooted (10 to 20 feet in depth):
- Ponderosa pine [1]
- Hackberry [2]
- Honeylocust [1]
- Bur oak [1]
- Mulberry [1]
- Osage-orange [1]

Intermediate (5 to 10 feet in depth):
- Green ash [1]
- American elm [2]
- Red cedar
- Russian-olive
- Caragana
- Boxelder
- Black locust [1]

Shallow-rooted (1 to 5 feet in depth):
- Jack pine
- Scotch pine [2]
- Norway spruce
- White willow
- Cottonwood [2]
- Catalpa

The species listed in the first and second groups, although more or less injured recently by a moisture deficiency, have survived the long drought much better than those listed in the third group. Most of the species of the latter group are not well suited to shelterbelt planting on fine-textured soils having low water tables. In general, they are relatively fast-growing species which require an abundance of moisture in the upper soil layers and are subject to early injury during periods of low precipitation. Trees of the first two groups, having deep or intermediate root systems, are not so soon affected by drought, especially if any deep soil moisture is available. It was also observed that trees of the same species were more likely to have a strongly developed taproot on the sandier soil.

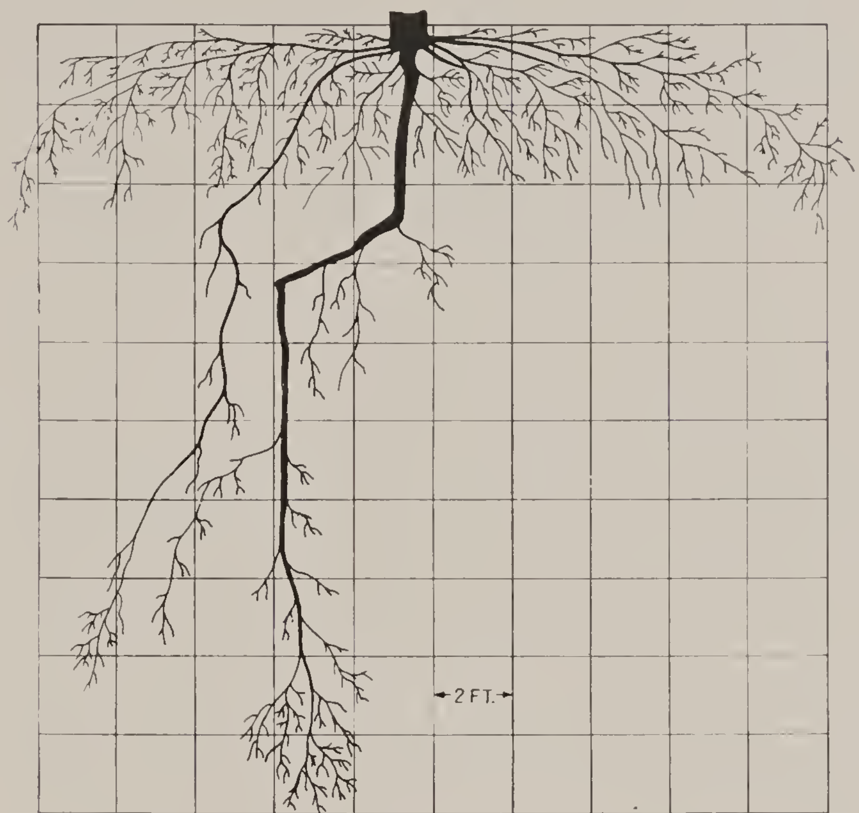

FIGURE 41.—Root system of 30-year-old native open-grown American elm in dune sand, McHenry County, N. Dak. Height of tree, 17 feet; diameter breast high, 6.3 inches; vigor, fair; care received during growth, none. Topography, strongly rolling; subsoil, fine sand; zone of lime enrichment, absent; depth of water table, 20 feet.

There is apparently little difference in the drought resistance of species in the deep-rooted and intermediate groups. The latter includes some species which, owing to their slow growth rate, use the subsoil moisture very slowly and are as drought resistant as most of those in the first group. Observations indicate that the slower-growing trees of the shelterbelt zone have the greater life span.

VARIATIONS OF ROOT HABITS IN DIFFERENT SOIL TYPES

Although most species have a mode of rooting which is inherent, many of them show remarkable variations

FIGURE 42.—Root system of 50-year-old native dominant American elm in Lamoure clay loam, McHenry County, N. Dak. Height of tree, 45 feet; diameter breast high, 11.8 inches; vigor, fair; care received during growth, none. Topography, level; subsoil, silty clay loam; zone of lime enrichment, 2.5 to 3.5 feet; depth of water table, about 15 feet.

in their rooting habits, even within a limited area, depending on the texture of the soil, which, in turn, influences the moisture supply. Figures 41 and 42, which are drawings of the root systems of native (not planted) trees, are given as illustrations. Figure 41 represents the roots of a 30-year-old American elm growing on a small sand dune. The taproot, which is 20 feet long, extends to the water table. Figure 42

[1] Usually strongly taprooted.
[2] Occasionally strongly taprooted.

illustrates the root system of a 50-year-old tree of the same species growing on a heavy silty clay soil in the bottom land. It has little taproot, and the maximum depth of any root as exposed in the pit is about 6 feet.

Roots of the same tree may react differently at various depths where pronounced changes occur in the physical composition of the soil. Figure 43 illustrates the root system of a planted 40-year-old American elm growing on a sandy soil in which two thin clay layers occur at depths of 3 and 4.2 feet, respectively. These

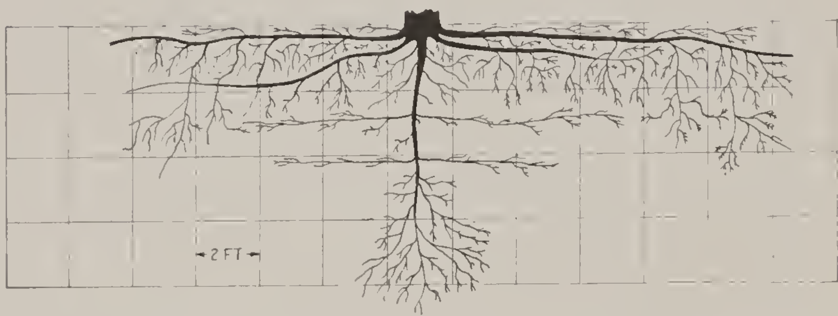

FIGURE 43.—Root system of 40-year-old codominant American elm (planted in windbreak) in Sioux sandy loam, McHenry County, N. Dak. Height of tree, 40 feet; diameter, breast high, 9.4 inches; vigor, poor; care received during growth, fair. Topography, almost level; subsoil ranges from coarse sand to gravel; two thin clay layers (average thickness about 3 inches) at depths of 3.0 and 4.2 feet; zone of lime enrichment, not definite, some traces of lime at a depth of 4 feet; depth of water table, 10 feet.

layers temporarily check the downward movement of soil moisture, and strong laterals from the taproot have extended over them radially for distances of 4 to 6 feet.

Generally, the trees observed on upland soils of high clay content, especially on claypan soils, were distinctly inferior in height, vigor, and longevity to trees on more friable soils in the same climatic region. This difference is probably due to some extent to poorer aeration in the heavier soils, in addition to their slower water-absorbing characteristic. In claypan soils the situation is extremely unfavorable. The "pans" lie at depths of 1 to 2 feet and are 6 to 16 inches thick. They undoubtedly interfere seriously with percolation, keeping most of the absorbed moisture in the upper soil layers, where it speedily evaporates.

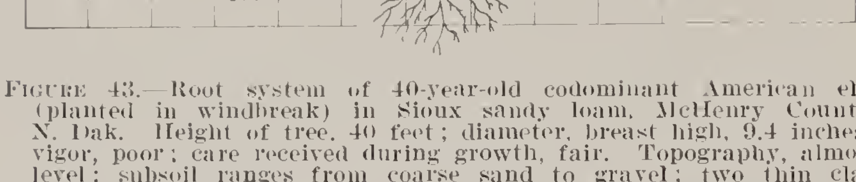

FIGURE 44.—Root system of 46-year-old open-growth green ash (planted in windbreak) in Beadle silt loam (a claypan soil), Beadle County, S. Dak. Height of tree, 23 feet; diameter, breast high, 4.7 inches; vigor, poor; care received during growth, poor; land used as pasture for the last 20 years. Topography, almost level; subsoil, claypan at 0.6 to 2 feet, a dense tight clay; from 2 to 4 feet soil is clay loam, below 4 feet, silty clay; zone of lime enrichment, 2 to 4 feet; depth of water table, 30 to 40 feet.

As a rule, the trees examined on clayey and claypan soils were little if any shallower in their rooting habit than those on fine-textured associated soils of more friable character. An occasional tree, however, showed a decided aversion to deep-rooting in clayey soils, especially where a claypan was well developed. Figure 44 shows how the taproot of a 46-year-old green ash turned horizontally and stayed above the claypan, which was between depths of 0.6 and 2.0 feet. Doubtless a higher moisture supply above than within the claypan influenced the behavior of this root.

Figure 45 reveals the superficial character of the root system of a 38-year-old green ash growing in the clayey soil of a depression known locally as a "buffalo wallow." The tree was only 15 feet high. The soils in these depressions are particularly unfavorable to tree growth because of poor aeration and a wide periodic fluctuation of moisture, ranging from inundation to extreme dryness. Moreover, some of the basin soils are very alkaline.

Before starting the root study, it was thought that the layer of lime accumulation or lime zone which has been described might inhibit the root growth of certain species because of its concentration of carbonates. The assumption was based partly on observations of several forest nurseries and of a few plantings on the Great Plains in which some seedlings become chlorotic and died. Death was attributed in most cases to an excess of carbonates and alkalis, which were thought to have toxic effects. However, none of the native or introduced trees which are best adapted to Plains planting seem to be seriously affected by the zone of lime accumulation in the soils. This zone in some fine-textured soils of the Dakotas contains 8 percent or more of calcium carbonate, but even in those soils the roots of most of the hardier native or near-native tree species and shrubs examined

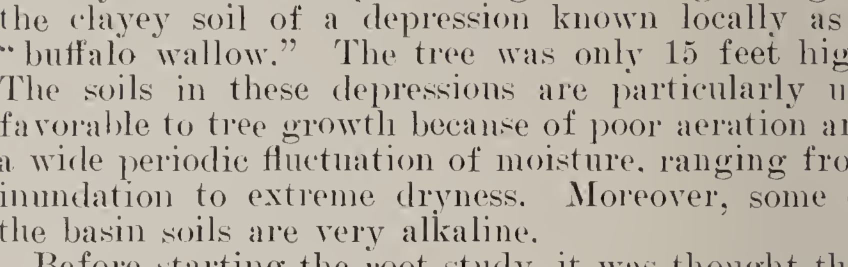

FIGURE 45.—Root system of 38-year-old codominant green ash, planted in windbreak in Fargo silty clay loam (undrained basin), Hyde County, S. Dak. Height of tree, 15 feet; diameter, breast high, 3.9 inches; vigor, poor; care received during growth, poor—grove has been used by livestock for the last 14 years. Topography, slightly rolling, 1.5 percent slope; subsoil, silty clay; zone of lime enrichment, 2.8 to 4.3 feet; depth of water table, probably 8 or 10 feet.

penetrated the limy layer quite readily. Such species, through long-continued adjustment, have probably become adapted to soils of relatively high lime content. In this connection it is logical to assume that seed from local sources should be used for planting in the shelterbelt zone.

Although the limy layer does not in itself inhibit root development of trees now growing on the Plains, it marks, except in some of the drift-derived soils, the average depth of moisture penetration. In other words, it marks the average depth to which the precipitation is effective in supplying soil moisture. For this reason the layer may appear to have influenced the root development of some trees, especially in localities where the precipitation has not penetrated below the top of the lime zone for several seasons.

Figure 46 illustrates the root system of a 32-year-old green ash that had grown on an upland loam soil in North Dakota. The taproot penetrated to, and then extended along, the top of the lime zone. The tree itself, near death, had been cut down. It had been surrounded by weeds and grasses, the roots of which assisted in absorbing any downward-moving water before it penetrated the lime zone. Had the land around the tree been tilled to prevent grass and weed competition, to promote deeper moisture penetration, and to conserve the moisture absorbed, it is highly probable that the taproot would have penetrated the lime zone and that the tree would have survived. Summer-fallowing the year before planting and the maintenance of either a dust or vegetative mulch until the trees have extended their roots well into the subsoil are essential, especially on the finer-textured soils of the Plains.

Figure 47 represents the root system of a 25-year-old American elm on an upland soil in North Dakota. The taproot of this tree turned horizontally when it reached the lime zone but later penetrated the zone gradually and also sent down a vertical branch in line with its original perpendicular course. The abnormal behavior of this taproot seems to indicate that the lime zone was too dry to allow root penetration during the early life of the tree but received more moisture at a later period.

FIGURE 46.—Root system of 32-year-old green ash, planted in windbreak in Barnes sandy loam, McHenry County, N. Dak. Height unknown, tree having been cut several years ago; diameter, 6.5 inches at 1½ feet aboveground; stump is sprouting with moderate vigor; care received during growth, fair at time of establishment, none later. Topography, almost level, 0.5 percent slope; subsoil, very fine sandy loam grading into a silt loam at 4.1 feet; zone of lime enrichment, from 2.7 to 3.4 feet; depth of water table, 30 feet.

In figure 48, from a drawing of a 50-year-old bur oak root system, the taproot is seen to have developed in somewhat the same manner as that of the tree previously described. It is entirely possible that, with good care, a tree planted in a cycle of subnormal precipitation might find enough moisture to maintain life but would remain shallow-rooted until the seasons became more favorable.

Observations show that on encountering the water table the main roots usually end abruptly and send out numerous short, fibrous laterals just above the water line. Figure 49 is from a drawing of the root system of a vigorous 38-year-old cottonwood tree which illustrates this condition. An abundant moisture supply obviated the necessity of a wide-spreading root system.

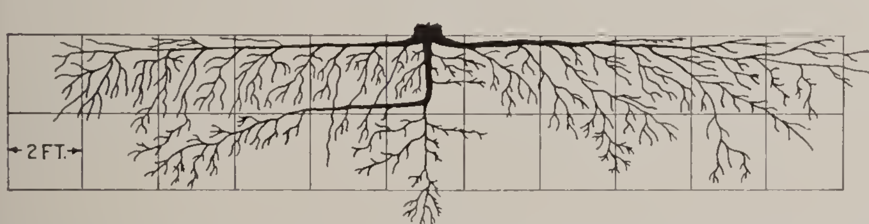

FIGURE 47.—Root system of 25-year-old dominant American elm, planted in windbreak in Barnes fine sandy loam, McHenry County, N. Dak. Height of tree, 26 feet; diameter breast high, 6.2 inches; vigor, fair; care received during growth, fairly good. Topography, slightly rolling; subsoil, clay loam to silty clay loam; zone of lime enrichment, 1.8 to 2.4 feet; depth of water table, 45 feet.

OTHER FACTORS THAT INFLUENCE ROOT HABITS OF TREES AND SHRUBS

Among other factors which appear to have influenced the root development of planted trees are the following:

METHOD OF PLANTING

Trees planted with ample room to place their roots in a normal position make the fastest initial growth and have the best chance of survival. Root systems which had been crowded into small holes and into narrow opening or slits in the ground could, in many instances, especially in fine-textured soils, be readily recognized by their abnormal development.

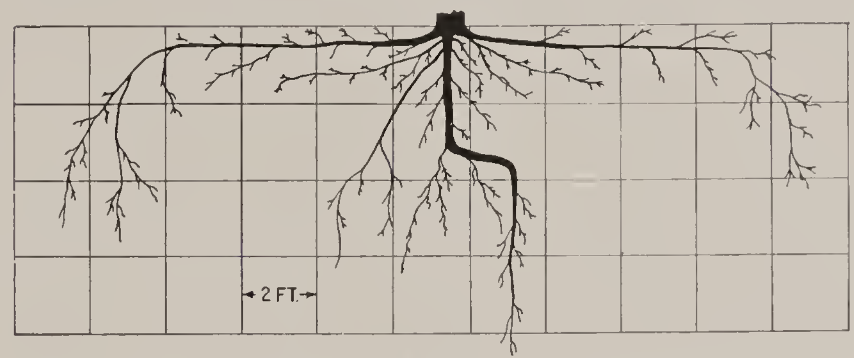

FIGURE 48.—Root system of 50-year-old native codominant bur oak in Lamoure clay loam, McHenry County, N. Dak. Height of tree, 40 feet; diameter breast high, 5.6 inches; vigor, fair; care received during growth, none. Topography, level; subsoil, silty clay loam; zone of lime enrichment, 2.5 to 3.5 feet; depth of water table, about 15 feet.

AGE OF STOCK

A small tree usually withstands transplanting better than a larger one, and its roots are more likely to develop naturally. The more numerous and longer roots of older plants are apt to be cramped into abnormal positions during planting. Extremely small stock, however, is probably not desirable for Plains planting, because very short root systems are more subject to injury when the surface soil becomes dry.

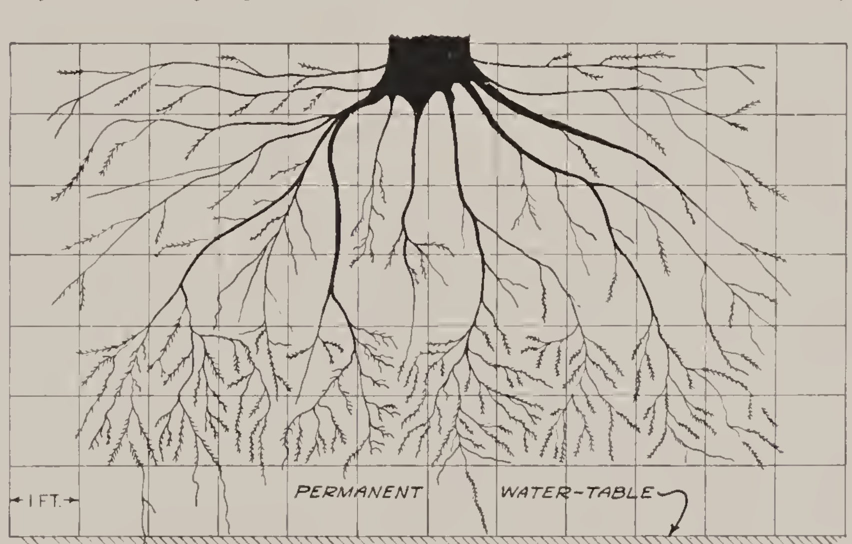

FIGURE 49.—Root system of 38-year-old codominant cottonwood, planted in windbreak in Sioux sandy loam (sandy subsoil phase), McHenry County, N. Dak. Height of tree, 70 feet; diameter breast high, 10.6 inches; vigor, good; care received during growth, fair. Topography, slight slope, 1 percent; subsoil, coarse sand; zone of lime enrichment, 2.0 to 3.0 feet; depth of water table, 7.0 feet.

SPACING OF TREES

Closely spaced trees have less lateral root spread than those which are more widely spaced. On the other hand, they have also less crown spread and less leaf surface, factors which reduce the transpiration loss and which must be taken into account in shelterbelt plantings and investigations relating thereto.

TOPOGRAPHY

Trees on rolling or undulating areas of fine-textured soils usually have shallower root systems than those on similar soils of nearly level areas. This difference is probably due to the relative effectiveness of the precipitation in the two localities. The rolling land is more subject to run-off and is not moistened as deeply as the smoother land; consequently there is less stimulus to deep rooting.

CLASS (DOMINANCE IN STAND)

Suppressed and intermediate trees in a stand usually have shallower and less spreading root systems than vigorous dominant and codominant individuals.

DESCRIPTION OF MAJOR SOIL GROUPS

The principal soil types of the shelterbelt zone will now be briefly described by groups which accord with the numbering and locations shown on the maps (figs. 38, 39, and 40). Within each group the soils are fairly uniform in their major features and are about equally well suited to trees. Some of the less extensive soils classed within a given group may differ considerably from those giving character to the group. Several such cases are described which could not be mapped separately on the scale used in this survey. The maps indicate the general characteristics of soils both within and extending for various distances east and west of the shelterbelt zone, the map for the central section being the most extensive. In many cases the descriptions refer to sites which happen to lie well outside the present zone, but which are of interest in relation both to conditions in the zone and to plantings that may be undertaken in the future.

SOILS OF THE NORTHERN SECTION

The following counties in the northern section have been covered in detailed soil surveys and the maps published by the Bureau of Chemistry and Soils: Bottineau, McHenry, Lamoure, Dickey, and parts of Ramsey, Foster, and Stutsman Counties, N. Dak.; and Walworth, Hyde, Douglas, and Brown Counties, S. Dak. A reconnaissance soil map made by the same Bureau covers the western tier of counties within the section across North Dakota and areas adjacent to the zone within Lyman, Gregory, and Tripp Counties, S. Dak. The remainder of the northern section is included within the area covered by reconnaissance soil erosion maps [42] made by the Soil Conservation Service during the past year. Free use has been made of all available soil and erosion maps in compiling the present one. Certain soil combinations and separations not shown on the original maps have been made in order to bring out the relationships between soils and trees. The reconnaissance soil maps of western North Dakota and South Dakota and the detail maps covering parts of Ramsey, Foster, and Stutsman Counties, N. Dak., were made prior to 1910. Some of the soil correlations shown on them are not recognized on the present map, which is made to conform to more recent developments in soil classification.

The following groups of soils are recognized and mapped in the northern section (fig. 38):

	Number on map
Barnes fine-textured soil group Includes Barnes loam, silt loam, clay, clay loam, silty clay loam, and very fine sandy loam.	25
Barnes and Beadle mixed soil group Includes mixture of Barnes and Beadle silt loams.	25B
Barnes sandy soil group Includes Barnes fine sandy loam, sandy loam, and loamy sand.	26
Williams fine-textured soil group Includes Williams loam, silt loam, clay loam, silty clay loam, and very fine sandy loam.	27
Williams sandy soil group Includes Williams fine sandy loam, sandy loam, and loamy sand.	28
Williams silty soil group (aeolian phase) Includes silty soils along Missouri River in northern South Dakota.	7
Moody silty soil group Includes Moody silt loam.	39
Bearden, Tripp, Hall, and Bridgeport soil group Only the Bearden and Tripp soils of this group occur in the northern section.	31
Boyd and Edgeley clay soil group Includes Boyd and Edgeley clay, clay loam, silty clay loam, and loam.	36
Beadle claypan soil group Includes Beadle silt loam and silty clay loam.	41
Aberdeen claypan soil group Includes Aberdeen silt loam, silty clay loam, clay loam, and clay.	42
Fargo, Rogers, and Maple heavy soil group Includes silt loam, silty clay loam, clay loam, and clay types of these soils.	34
Pierce gravelly and sandy soil group Includes Pierce loams, fine sandy loams, and gravelly loams.	33
Sioux sandy soil group Includes Sioux loamy sand, loam, fine sandy loam, and sandy loam.	32
Valentine and Gannett sandy soil group Includes the sand, loamy sand, and fine sandy loam types of these soils.	29
Dunesand group Includes hilly wind-blown sands.	30
Alluvial soils (undifferentiated)	35

Summarized data pertaining to the groups listed above are given in table 20.

[42] Without these maps, which were kindly furnished by H. H. Bennett, Director, Soil Conservation Service, U. S. Department of Agriculture, it would have been impossible to complete the present map when needed.

TABLE 20.—*General characteristics of soils of the northern section of the Shelterbelt Zone* (*North Dakota and South Dakota*)

Soil	Approximate percentage of area in States of northern section	Physiography and drainage	Native vegetation	Approximate (minimum) depth of water table in feet
Aberdeen [1]	S. Dak., 0.77	Nearly level terraces; underdrainage restricted.	Short and mixed grasses	15 to 100.
Barnes (fine-textured types) [2]	N. Dak., 54.00 S. Dak., 54.50	Nearly level to strongly rolling well-drained upland.	Tall and mixed grasses	40 to 100.
Barnes (sandy types) [2]	N. Dak., 4.70 S. Dak., 2.97	Undulating to strongly rolling well-drained upland.	Tall grasses	40 to 100.
Beadle [1]	S. Dak., 4.00	Nearly level uplands; underdrainage restricted.	Short and mixed grasses	40 to 100.
Bearden [2]	N. Dak., 0.65 S. Dak., 8.94	Nearly level well-drained terraces	Tall, mixed, and short grasses	15 to 50.
Boyd [2]	N. Dak., (3) S. Dak., 0.30	Nearly level to hilly upland; surface drainage good to excessive, underdrainage slow.	Short grasses	90.
Cass [2]	N. Dak., 0.40 S. Dak., 2.00	Nearly level bottom lands; drainage variable.	Tall grasses; trees and shrubs	5 to 20.

[1] Principal occurrence in South Dakota.
[2] Principal occurrence in North Dakota and South Dakota.
[3] Not stated.

TABLE 20.—*General characteristics of soils of the northern section of the Shelterbelt Zone (North Dakota and South Dakota)*—Continued

Soil	Approximate percentage of area in States of northern section	Physiography and drainage	Native vegetation	Approximate (minimum) depth of water table in feet
Dickinson [2]	N. Dak., 1.00 S. Dak., 0.30	Nearly level to rolling upland; underdrainage good.	Tall grasses	15 to 60.
Dunesand [2]	N. Dak., 0.30 S. Dak., (3)	Rolling to hilly upland; underdrainage good to excessive.	Tall grasses and yucca	20 to 60.
Edgeley [2]	N. Dak., (3) S. Dak., 0.04	Nearly level to strongly rolling upland; underdrainage restricted.	Tall, mixed, and short grasses	90.
Fargo [2]	N. Dak., 4.00 S. Dak., 3.00	Glacial lake basins and river terraces; poor surface and underdrainage.	Alkali grasses and wheatgrasses; cattail and sedges.	15 to 100.
Gannett [2]	N. Dak., 0.30 S. Dak., (3)	Poorly drained sand-hill basins	Coarse marsh grasses, cattail, and sedges.	0 to 15.
Holt [1]	S. Dak., 0.50	Rolling to hilly; good to excessively drained upland.	Tall, mixed, and short grasses	40 to 100.
Lamoure [2]	N. Dak., 0.27 S. Dak., 1.02	Nearly level bottom lands; drainage variable	Tall grasses; trees and shrubs	5 to 20.
Maple [2]	N. Dak., 0.50 S. Dak., 0.40	do	Alkali grasses and wheatgrasses; cattail and sedges.	5 to 40.
Moody [1]	S. Dak., 0.45	Nearly level to hilly; well to excessively drained upland.	Tall and mixed grasses	50 to 100.
O'Neill (upland phase) [1]	S. Dak., 0.28	Nearly level to rolling upland; good surface but excessive underdrainage.	Tall and mixed grasses; cactus and yucca.	20 to 100.
Orman (dark-colored phase) [2]	N. Dak., (3) S. Dak., 0.10	Nearly level terraces; good surface but poor underdrainage.	Short and mixed grasses	15 to 100.
Pierce [2]	N. Dak., 1.00 S. Dak., 0.53	Strongly rolling to hilly upland; underdrainage excessive.	Sparse cover of mixed and short grasses; yucca.	50 to 100.
Rogers [2]	N. Dak., 0.80 S. Dak., 0.40	Glacial lake basins; poor surface and underdrainage.	Little or no vegetation	0 to 50.
Rosebud (fine-textured types) [1]	(3)	Nearly level to hilly; well to excessively drained upland.	Short grasses	50 to 100.
Rosebud (sandy types) [1]	(3)	Nearly level to strongly rolling well-drained upland.	Short and mixed grasses	50 to 100.
Rough broken land [2]	N. Dak., 8.00 S. Dak., 6.00	Hilly upland	Tall, mixed, and short grasses	30 to 100.
Sarpy [2]	N. Dak., 0.03 S. Dak., 0.04	Nearly level bottom lands; drainage variable	Tall grasses; trees and shrubs	5 to 15.
Sioux [2]	N. Dak., 3.00 S. Dak., 0.64	Nearly level to undulating terraces; underdrainage excessive.	Tall grasses	15 to 50.
Tripp [2]	N. Dak., 0.12 S. Dak., 0.20	Nearly level well-drained terraces	Short grasses	30 to 100.
Valentine [2]	N. Dak., 3.78 S. Dak., 0.33	Nearly level to hummocky uplands; underdrainage good to excessive.	Tall grasses; yucca	15 to 60.
Williams (fine-textured types) [2]	N. Dak., 16.22 S. Dak., 11.97	Nearly level to strongly rolling well-drained upland.	Short and mixed grasses	90.
Williams (sandy types) [2]	N. Dak., 0.93 S. Dak., 0.30	Undulating to strongly rolling well-drained upland.	Tall and mixed grasses	50 to 100.
Williams (silty types—aeolian phase).[1]	S. Dak., 0.02	Nearly level to strongly undulating well-drained upland.	Short and mixed grasses	50 to 100.

Soil	Upper portion of soil profile	Lower portion of soil profile	Parent material	General feasibility for trees
Aberdeen [1]	Very dark grayish brown to black; friable to moderately compact, loamy to clayey, 7 to 14 inches thick.	Brown to black claypan underlain by friable grayish-brown silty clay loam; 22 to 30 inches thick.	Silts and clays	Difficult to unsuited.
Barnes (fine-textured types) [2]	Very dark grayish brown to black; friable, coherent, loamy to clayey, 7 to 12 inches thick.	Friable dark-brown to light grayish-brown silty clay loam, 18 to 30 inches thick.	Glacial drift	Fair to difficult.
Barnes (sandy types) [2]	Very dark grayish brown to black; friable, coherent to moderately loose, sandy, 7 to 14 inches thick.	Friable dark brown to light grayish-brown; very fine sandy loam to loamy sand, 20 to 30 inches thick.	do	Fair to good.
Beadle [1]	Very dark grayish brown to black; friable to moderately compact, loamy to clayey, 6 to 13 inches thick.	Brown to black claypan underlain by friable light grayish-brown silty clay loam; 20 to 30 inches thick.	do	Difficult to unsuited.
Bearden [2]	Very dark to dark grayish brown; friable, loamy, 8 to 14 inches thick.	Friable dark-brown to grayish-brown silt to fine sandy loam; 18 to 30 inches thick.	Silt and silt-sand mixtures.	Good.
Boyd [2]	Very dark grayish brown to black; compact, clayey, 4 to 8 inches thick.	Compact grayish yellow to grayish-blue clay, 6 to 15 inches thick.	Pierre shale	Difficult to unsuited.
Cass [2]	Very dark grayish brown to black; coherent to moderately loose, friable, loamy to sandy, 6 to 10 inches thick.	Incoherent grayish-brown sand or sand and gravel mixtures, 8 to 14 inches thick.	Recent sands and gravels.	Good.
Dickinson [2]	Dark to very dark grayish brown; coherent to moderately loose, friable, loamy to sandy, 8 to 18 inches thick.	Brown to grayish-brown incoherent sand, noncalcareous, 16 to 30 inches thick.	Sands	Good.
Dunesand [2]	Light grayish brown incoherent sand, ½ to 2 inches thick.	Yellowish loose sand	do	Fair.
Edgeley [2]	Very dark grayish brown; friable to moderately compact, loamy to clayey, 5 to 12 inches thick.	Compact grayish-yellow to grayish-blue clay or gravelly clay, 12 to 18 inches thick.	Shale or reworked shale and drift.	Difficult to unsuited.
Fargo [2]	Black; friable to moderately compact, loamy to clayey, 6 to 14 inches thick.	Grayish-brown to black; compact clay to silty clay loam, 18 to 24 inches thick.	Silts and clays	Unsuited.
Gannett [2]	Very dark grayish brown to black; friable, coherent, loamy to sandy, 8 to 20 inches thick.	Light grayish-brown; incoherent sand with thin clay layers in places; 12 to 20 inches thick.	Sands	Good for a few species only.
Holt [1]	Very dark grayish brown to black; friable, coherent to moderately loose, loamy to sandy, 8 to 14 inches thick.	Brown to light grayish brown; friable; loam to fine sandy loam, 10 to 20 inches thick.	Tertiary sandstone	Fair to good.
Lamoure [2]	Very dark grayish brown to black; friable to moderately compact, loamy to clayey, locally alkaline; 8 to 18 inches thick.	Dark grayish brown to gray; moderately compact clay to silty clay loam, 12 to 30 inches thick.	Recent silts and clays	Good.
Maple [2]	Very dark grayish brown; friable to moderately compact, loamy to clayey, usually alkaline; 6 to 16 inches thick.	Grayish brown to light grayish yellow; clay or sand and clay mixture, moderately compact, 10 to 18 inches thick.	do	Unsuited.
Moody [1]	Very dark grayish brown; friable, coherent, loamy, 7 to 16 inches thick.	Brown to light grayish yellow; friable silt loam, 14 to 36 inches thick.	Gray loess (Peorian?)	Good.
O'Neill (upland phase) [1]	Very dark grayish brown; friable, coherent to moderately loose, loamy to gravelly, 6 to 10 inches thick.	Brown to grayish brown; incoherent mixture of sand and gravel; noncalcareous, 10 to 30 inches thick.	Sand and gravel	Difficult.

[1] Principal occurrence in South Dakota.
[2] Principal occurrence in North Dakota and South Dakota.
[3] Not stated.

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TABLE 20.—*General characteristics of soils of the northern section of the Shelterbelt Zone (North Dakota and South Dakota)*—Continued

Soil	Upper portion of soil profile	Lower portion of soil profile	Parent material	General feasibility for trees
Orman (dark-colored phase) [2]	Very dark grayish brown; compact, clayey, 8 to 14 inches thick.	Compact grayish-yellow to grayish-blue clay, 8 to 24 inches thick.	Clays and shales	Fair to good.
Pierce [2]	Dark grayish brown; friable to moderately loose, loamy to gravelly, 2 to 12 inches thick.	Brown to grayish brown; incoherent mixture of sand and gravel, 8 to 12 inches thick.	Coarse sands and gravels.	Unsuited.
Rogers [2]	Grayish brown; friable to moderately compact, loamy to clayey, alkaline; 7 to 12 inches thick.	Gray to light grayish yellow; clay to silty clay; compact, 12 to 18 inches thick.	Silts and clays	Do.
Rosebud (fine-textured types) [1]	Dark grayish brown; friable, coherent, loamy, 8 to 14 inches thick.	Light brown to light grayish brown; silt loam to very fine sandy loam, 12 to 30 inches thick.	Tertiary sandstone	Difficult.
Rosebud (sandy types) [1]	Dark grayish brown; friable, coherent to moderately loose, sandy, 10 to 16 inches thick.	Light grayish brown; friable; fine sandy loam to loamy fine sand, 12 to 30 inches thick.	do	Fair.
Rough broken land [2]	(3)	(3)	Variable	Variable.
Sarpy [2]	Grayish brown; friable, usually incoherent and sandy, ½ to 8 inches thick.	Light gray; incoherent sand or sand and gravel mixture, 6 to 12 inches thick.	Recent sands and gravels.	Good.
Sioux [2]	Very dark grayish brown to black; friable, coherent to moderately loose, loamy to sandy, 10 to 14 inches thick.	Grayish brown; incoherent sand or sand and gravel mixture, 10 to 24 inches thick.	Coarse sands and gravels.	Fair to good.
Tripp [2]	Dark grayish brown; friable, coherent, loamy, 8 to 14 inches thick.	Light grayish brown; friable; silt loam to very fine sandy loam, 18 to 30 inches thick.	Silts	Do.
Valentine [2]	Grayish brown; loamy to sandy, usually incoherent, 2 to 7 inches thick.	Light grayish-brown incoherent sand, 12 to 20 inches thick.	Sands	Do.
Williams (fine-textured types) [2]	Dark grayish brown; friable, coherent, loamy, 4 to 10 inches thick.	Light brown to light grayish brown friable silty clay loam, 10 to 16 inches thick.	Glacial drift	Difficult.
Williams (sandy types) [2]	Dark grayish brown; friable, coherent to moderately loose, sandy, 5 to 10 inches thick.	Light brown to light grayish brown; friable; very fine sandy loam to loamy sand, 14 to 18 inches thick.	do	Fair to good.
Williams (silty types—aeolian phase) [1]	Dark grayish brown; friable, coherent, loamy, 8 to 14 inches thick.	Very light grayish-brown friable silt loam, 18 to 24 inches thick.	Silts	Fair.

[1] Principal occurrence in South Dakota.
[2] Principal occurrence in North Dakota and South Dakota.
[3] Not stated.

BARNES FINE-TEXTURED SOIL GROUP

The soils of the Barnes fine-textured soil group (fig. 50) are among the most extensive in the northern section. Their topsoils include a variety of textures but range mostly between silt loams and loams, there being no large areas in which they are sandy. The subsoils are composed largely of silt or silty clay. The entire soil is friable. These soils have developed under tall, sod-forming grasses. They have accumulated large amounts of black, well-decomposed grass remains, and are almost black to depths ranging from 7 to 12 inches. The subsoils are brown in the upper part and almost white in the lower. They have a well-developed zone of lime enrichment which lies at depths ranging from 12 to 24 inches and often contains as much as 8 percent of calcium carbonate. These soils have developed from unconsolidated, light-colored limy drift which usually lies at a depth of about 40 inches. The drift is extremely variable in texture but generally contains considerable amounts of coarse material, including gravel and boulders of various sizes, mixed with the more abundant silt and clay constituents.

The surface ranges from nearly level to hilly, the rougher areas occurring along the lines of glacial moraines where part of the land is too rough or too stony for cultivation. Surface and underdrainage is everywhere good. Some sheet erosion occurs on the steeper slopes where unprotected by vegetation.

The soils of this group have high moisture-holding power and where not too rough or stony for cultivation, are the most productive farming soils of the uplands. The water table, except in local areas, lies at depths exceeding 50 feet.

Nearly all trees commonly planted in the uplands of the Dakotas occur in one locality or another on the fine-textured Barnes soils. Most of the trees, however, root shallower, are a little more stunted and have a higher mortality than trees on the sandier Barnes soils. Cottonwood, willow, and boxelder show the highest mortality. Practically all of the golden willows have succumbed to drought on the soils of this group, especially in localities where the topsoils are shallow. Few of the cottonwood and boxelder more than 30 years old are alive.

Among the trees which seem to do best on the fine-textured Barnes soils are green ash, hackberry, Russian-olive, caragana, dwarf Asiatic elm, choke cherry, cedar, wild plum, and buckthorn.

In the Turtle Mountain section of Bottineau and Rolette Counties, N. D., the soils of this group are supporting thrifty stands of bur oak, aspen, American elm, paper birch, green ash, and willow trees. The heavy growth here is probably due to unusually favorable moisture conditions rather than to any feature of the soils.

BARNES SANDY SOIL GROUP

The soils of the Barnes sandy soil group (figs. 51 and 52) occur in close association with those of the Barnes fine-textured group, from which they differ only in that their topsoils and subsoils are more sandy. Most of them contain sufficient silt and clay mixed with the sand to give the soil material good "body" and high water-holding powers. They have developed from sandy glacial deposits and are much less extensive than the soils of the Barnes fine-textured group. In places they can be distinguished from the Valentine soils only by their higher lime content.

Most trees commonly planted in the uplands throughout the Dakotas do well on these soils.

WILLIAMS FINE-TEXTURED SOIL GROUP

The soils of the fine-textured Williams group (fig. 53) are characterized by dark-brown silty or loamy topsoils, 4 to 10 inches thick, and buff or almost white silty clay subsoils which rest at depths of 18 to 24 inches on unweathered limy drift. These soils occur on well-drained, undulating to hilly uplands and are friable throughout. They are distinguished from the fine-textured Barnes soils by their slightly thinner and lighter colored surface layers and by the shallower depths of their entire soil section. They occupy most of the western part of the shelterbelt zone in the Dakotas, where they support mixed short and tall grasses.

Owing to their rather fine texture and to the low precipitation of the region in which they occur, these soils are low in moisture. They are not as well suited for trees as the finer textured soils farther east or the sandy upland soils in either the eastern or western parts of the northern shelterbelt section. A large percentage of the trees planted on them have died during the recent prolonged drought. Exceptionally drought-resistant species such as caragana, green ash, hackberry, Russian-olive, choke cherry, and cedar, although rather stunted, have survived fairly well.

WILLIAMS SANDY SOIL GROUP

Soils mapped with the Williams sandy soil group are more sandy in both topsoil and subsoil than those of the Williams fine-textured group but are otherwise very similar to those soils and occur in close association with them. They resemble the sandy Barnes soils except that they have slightly thinner and lighter colored topsoils.

These soils are among the better tree soils of the uplands in the western part of the shelterbelt zone. Trees growing on them are not quite so thrifty as those on the sandy Barnes soils farther east, owing to a decrease in the precipitation westward, but are usually more thrifty than those on any of the fine-textured soils of either the Barnes or Williams groups. Few of the hardier native or planted trees have succumbed to the drought on the soils of this group (figs. 36 and 54).

WILLIAMS SILTY SOIL GROUP (AEOLIAN PHASE)

The soils of the Williams silty soil group occupy a few large areas east of Missouri River in South Dakota. They have developed from light-colored loess or floury silt which thinly covers the glacial drift. The topsoils are brown to dark brown, and the subsoils, which are very limy, are light grayish yellow or almost white. The soils and parent material are friable.

These soils, except for the slightly lighter color of their topsoils, are identical with the friable loess-derived soils of southwestern Nebraska. In common with most soils developed from loess in the shelterbelt zone, they absorb water rather rapidly and have high moisture-holding capacities. They are more moist or drought resistant than any of those in the Williams fine-textured group and are more deeply penetrated by roots. Trees growing on them have survived the drought remarkably well, considering the low precipitation. Even cottonwood, which is poorly suited for most of the fine-textured upland soils in the western half of the zone, shows fairly good growth and survival. Ash, red cedar, ponderosa pine, Russian-olive, caragana, choke cherry, and honeylocust are all doing well on them.

MOODY SILTY SOIL GROUP

Soils belonging to the Moody silty soil group occupy only a few small bodies in the southern part of the northern section. They are described in connection with the central section, where they occur more extensively.

BEARDEN, TRIPP, HALL, AND BRIDGEPORT SOIL GROUP

Only the Bearden and Tripp soils of this group occur in the northern section, where they occupy outwash flats and benches within the glaciated area. These soils are among the most productive farming soils in the Dakotas. They have thick topsoils which

FIGURE 50.—Profile of one of the fine-textured Barnes soils of Dickey County, N. Dak. This soil differs from the Williams soil chiefly in that it has a darker topsoil; it has developed under a higher rainfall. Most trees do well on the soils of this group.

in the Bearden are very dark, often almost black, and in the Tripp are dark brown or chestnut brown in color. The topsoils have a wide textural range, but few of them contain sufficient amounts of coarse material to be droughty or of clay to prevent rapid water absorption. The subsoils are light colored and very limy. They range in texture from silts to fine sandy loams. These soils are friable throughout and have high moisture-holding powers. All of them have good surface and underdrainage. The water table lies within shallow depths in places.

For establishing successful groves, the soils of this group are among the best in the Dakotas. Fifty-year-old green ash trees, in good groves, have attained a maximum height of 70 and an average of 55 feet.

F296016

Figure 51.—Barnes fine sandy loam on an extensive flat area 4 miles east of Forestburg, S. Dak., underlain by water table at no great depth. Excellent shelterbelts, chiefly of cottonwood, occur frequently over this flat. Field in foreground left fallow in 1934 and protected from blowing by weed growth (Russian thistles). Compare with figure 52.

F296017

Figure 52.—Barnes fine sandy loam, under exactly the same conditions as shown in figure 51, illustrating the urgent need for shelterbelt planting on all such sandy soils in the Plains to protect them from complete destruction by wind. Dunes or drifts of soil from 1 to 3 feet in depth, such as seen in the foreground, are collected by the presence of a few weeds.

Most trees on these soils are vigorous and have survived the severe drought remarkably well.

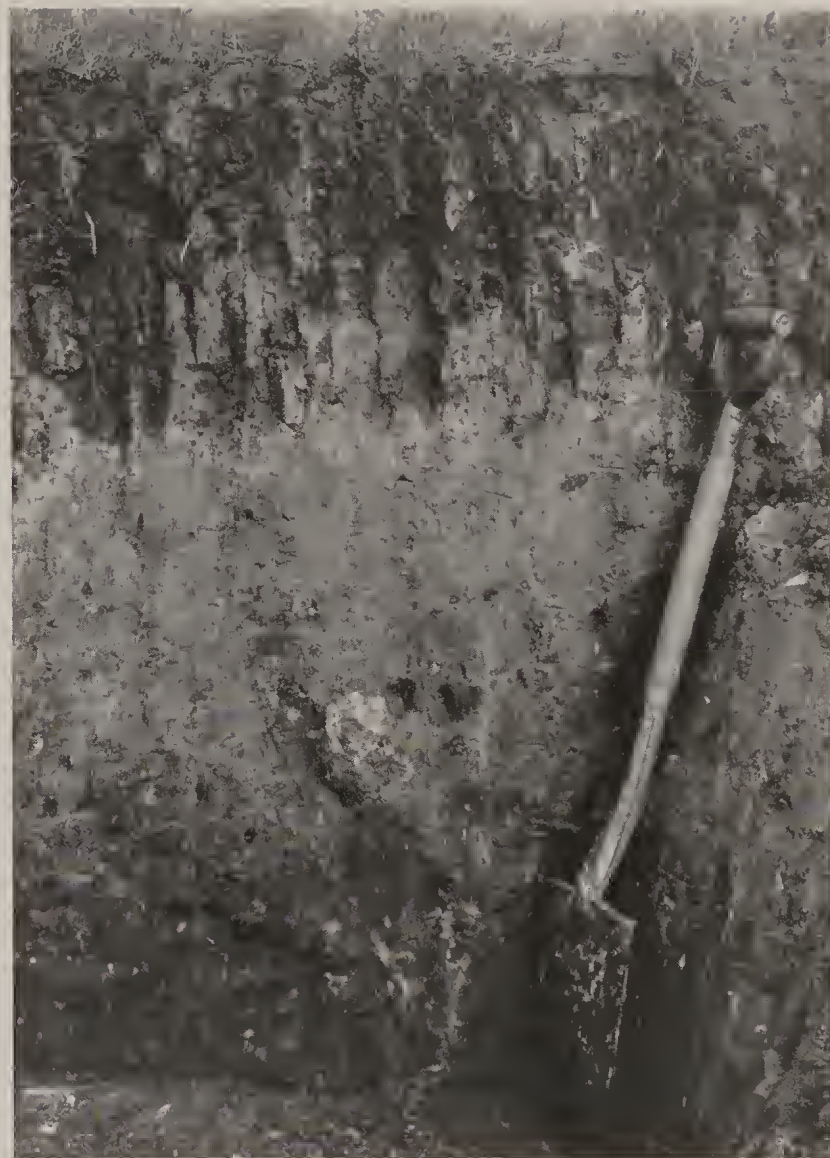
BOYD AND EDGELEY CLAY SOIL GROUP

The Boyd and Edgeley group (figs. 55 and 56), includes soils which have developed from dense bluish and grayish Pierre shales or from mixtures of drift and shale in which the latter material predominates. The largest developments within or near the shelterbelt zone are on the rolling uplands in Lyman, Gregory, and Tripp Counties, S. Dak., and in the Missouri River breaks. The soils occur locally in some of the northern Nebraska counties.

The topsoils are very dark brown or almost black except where erosion has been unusually severe. They range in texture from clays to loams and are rather shallow, as the dense clay does not lend itself readily to weathering. The subsoils, which lie at depths ranging from 6 to 14 inches, are composed mainly of clay and are extremely compact. The unweathered shale usually is within a 3-foot depth, even on the smoother areas. It outcrops in all eroded situations. The soils are often limy at the surface.

The Boyd and Edgeley soils probably have higher water-holding capacities than any of the other soils in the northern section, but owing to their extremely clayey nature absorb moisture very slowly. Most of the precipitation falling on them evaporates or runs off the land before it can be utilized by plants. In years of high and frequent rainfall these soils are very productive. In dry years the clay, of which they are so largely composed, becomes extremely dry, shrinks, and cracks, and leaves the soils very droughty.

Only a few groves, consisting mostly of green ash or honeylocust and scattered American elm, Russian-olive, and red cedar trees, were observed on these



F259492

FIGURE 53.—Profile of one of the fine-textured Williams soils, developed under rather arid conditions within the Altamont Moraine territory in western Wells County, N. Dak. The zone of lime concentration, with numerous small concretions, is plainly visible. Such soils must be planted to exceptionally drought-resistant shelterbelt species.

FIGURE 54.—Williams stony loam on Altamont Moraine south of Goldwin, N. Dak. This soil is rather porous. The shrubbery, buckbrush, and silverberry in foreground indicates that it is probably suited to trees.

F289977

FIGURE 55.—Boyd clay loam on the slightly dissected Missouri Plateau about 30 miles west of Pierre, S. Dak. The soil is locally known as "black gumbo", and the native sod here is largely grama grass. Shelterbelt establishment on this soil type will be exceedingly difficult because of the slow rate at which water is absorbed.

F289979

FIGURE 56.—Rough type of Boyd clay loam, derived from the Pierre shale, at the mouth of White River a few miles south of Chamberlain, S. Dak. Such land is included in rough broken areas on the map (figs. 38–40).

soils. Most of the trees are short and scrubby and in some of the groves 70 to 90 percent of them are dead. Red cedar and Russian-olive seem to have withstood the drought much better than the others. Dwarf Asiatic elm and caragana would probably do well, although neither species was observed. Considering the heavy nature and droughty character of these soils, shelterbelt planting on a large scale should not be attempted on them.

Associated with the Boyd and Edgeley soils but not located on the map are a few narrow terrace developments of Orman soils. These have developed from water-transported Pierre shale and are almost identical in all soil features to the Boyd, but owing to their lower topographic position are not quite as droughty. In places they support scattered native ash, hackberry, American elm, cottonwood, boxelder, and red cedar trees, which seem to have withstood the drought fairly well.

BEADLE CLAYPAN SOIL GROUP

Beadle silt loam occupies the greater part of the Beadle claypan soil group. It is found in nearly level undissected upland situations within areas of fine-textured Barnes soils. The most uniform bodies are in Beadle, Spink, Clark, and a few other counties of South Dakota. They are designated on the map by the number 41. Less uniform bodies, namely those in which the soil occupies numerous small patches within areas of Barnes soils are designated by the symbol (25B).

Beadle silt loam differs from the soils of the Barnes fine-textured group chiefly in that it has a much heavier and more compact upper subsoil layer. The topsoil, which is composed largely of silt, is friable and very dark brown or almost black. It rests at an average depth of 10 inches upon very dark brown, dense clay ranging in thickness from 4 to 12 inches. The dense layer, which is a true claypan, is underlain by friable limy and often alkaline silty clay. The silty clay is light-colored but is more or less splotched with rusty-brown stains indicating poor drainage. It contains gypsum in places.

Areas of this soil are not well suited to trees, probably owing to poor aeration beneath the claypan layer. Most of the trees observed are dead or dying, and practically all of them are shorter and less vigorous than on adjacent soil types. Even such hardy trees as green ash show serious decadence on Beadle soil after 25 to 30 years, whereas the same species remain quite vigorous for 40 to 50 years on the more friable associated soils. On the basis of present knowledge, it does not seem advisable to plant extensively on the Beadle soil.

ABERDEEN CLAYPAN SOIL GROUP

The Aberdeen claypan soil group as mapped includes the silt loam and silty clay loam types of the Aberdeen soils, which are chiefly in the dry bed of glacial Lake Dakota. These soils are identical in all features with the Beadle soils but occupy terrace positions, whereas the Beadle is on the uplands. They have almost black topsoils and dense claypan upper subsoils which overlie friable limy silt or silty clay.

Although the soils of this group have a claypan, they do not seem to be as inimical to trees as Beadle soil. Hurried field observations indicate that a few trees can be grown on them with moderate success, but that the choice of suitable species will be rather limited. In South Dakota the soils are supporting a few fairly good windbreaks of green ash, caragana, boxelder, and Russian-olive. The longevity and height of most trees on the Aberdeen soils are intermediate between those of trees on the Beadle and Barnes soils. Green ash in well-tended groves remains vigorous for about 50 years, but the trees average only about 30 to 35 feet in height at that age. Cottonwood makes good initial growth on the Aberdeen but becomes decadent when about 30 years old.

FARGO, ROGERS, AND MAPLE HEAVY SOIL GROUP

The soils of the Fargo, Rogers, and Maple heavy soil group occupy numerous poorly drained basins within areas of the finer textured upland and terrace soils in the Dakotas. Only the largest developments within the shelterbelt zone are shown on the map. These soils are periodically covered with water, often for several weeks. They are composed largely of clay to depths exceeding 3 or 4 feet. When the water evaporates from the basins the clay dries, shrinks, and cracks badly, and the soils become extremely droughty.

FIGURE 57.—Rogers clay loam in partially dry lake bed, north of Turtle Lake, McLean County, N. Dak. The Rogers soils are highly alkaline. The soil around the margin of the water in the background is covered with white alkali, chiefly $CaSO_4$.

Fargo soils occupy most of the basins. They have deep, almost black topsoils composed largely of silt or clay. The subsoils are gray, very dark brown, or splotched gray and brown, and are very heavy although not true claypans. The soils are limy below a depth of 2 or 3 feet and in numerous places are calcareous at the surface. They seldom contain injurious amounts of alkali.

The Maple soils resemble the Fargo in most features but have thinner topsoils and lighter, often almost white, subsoils. They are alkaline. The Rogers soils have light-colored topsoils and are very alkaline. They occupy only a few of the basins (fig. 57).

Practically none of the soils of this group is suited to trees. Patches of the Fargo soils support plantings of cottonwood, green ash, caragana, and boxelder in localities where the moisture supply is unusually favorable, but the soils of the group as a whole are treeless. The Rogers soils support practically no vegetation.

PIERCE GRAVELLY AND SANDY SOIL GROUP

Pierce gravelly and sandy soils occur in widely scattered and usually small areas throughout the glaciated parts of the Dakotas. Only the larger areas are shown on the accompanying map.

FIGURE 58.—Profile of Pierce gravelly loam; Kidder County, N. Dak. The Pierce soils differ from the Sioux chiefly in that they have thinner topsoils. They occur in the uplands, whereas the Sioux occupy terraces, and are very droughty.

These soils occupy gravel-covered knobs and ridges. They have thin though fairly dark-colored topsoils ranging in texture from loams to coarse gravelly loams. The subsoils in most places are composed of large and small water-worn stones mixed with an abundance of fine gravel and coarse sand but locally may consist almost entirely of sand (fig. 58).

Owing to their high-gravel content, the soils of this group, as a whole, have very low moisture-holding powers and are unable to support satisfactory trees. The few localities in which the subsoils are sandy are fairly well suited to some of the hardier trees and shrubs.

SIOUX SANDY SOIL GROUP

The soils of the Sioux sandy soil group (figs. 59 and 60) are on the more sandy or gravelly outwash flats and benches within the glaciated part of the Dakotas. They have dark and often rather thick topsoils, which range widely in texture but usually contain more sand or gravel than fine material. The subsoils may consist of sand, gravel, or a mixture of the two. They are very limy. The water table is at shallow depths in many places.

These soils, as a whole, are well suited to trees. Cottonwoods thrive where the water table is within 10 feet of the surface, often attaining a height of 60 or 70 feet in about 30 years. The only localities where trees do poorly are those in which the subsoil and substratum consist of coarse, dry gravel to great depths.

VALENTINE AND GANNETT SANDY SOIL GROUP

The Valentine and Gannett soils occur in extremely sandy areas having a strongly rolling or choppy surface (fig. 61). Usually the water table is within a depth of 10 feet. The largest developments of these soils, in the northern section, are in the Lake Souris Basin of Bottineau and McHenry Counties, N. Dak., and just outside the basin to the southeast. The Valentine soils, which occupy the higher and better-drained situations, are the more extensive. They have accumulated only small amounts of organic matter and have thin, brownish topsoils. The Gannett soils are in low, poorly drained pockets and swales where the grass growth is most luxuriant and decay is relatively rapid. Their topsoils are deep and almost black.

FIGURE 59.—Profile of Sioux fine sandy loam; Kidder County, N. Dak. The Sioux soils have dark topsoils underlain by porous gravelly and limy subsoils. They are droughty except where underlain by high water tables.

The subsoil in both Valentine and Gannett types usually consists of gray, incoherent fine to medium sand, which in the former is very low in lime and in the latter is highly calcareous. Some of the Gannett soils contain thin clay layers and are water-logged a part of each year. Locally they may be alkaline.

These soils support a natural growth of aspen and willow, and in several places planted groves of cottonwood. The Valentine soils are well suited to a variety of trees in addition to those mentioned, including hackberry, boxelder, Russian-olive, American elm, choke cherry, wild plum, red cedar, and ponderosa pine.

The Gannett soils are a little too moist during average years for most tree species except cottonwood and willow.

DUNE-SAND GROUP

There are numerous small bodies of dune sand in the northern section, but few, if any, are sufficiently large to warrant showing on a map of the scale used in this survey. One of these is in the extreme northeast corner of Brown County, S. Dak. Most of the bodies not shown on the map are associated with areas of Valentine soils. A few lie within sandy Barnes soil areas, as in the vicinity of Forestburg and Mound City, S. Dak., and south of Bergen, N. Dak.

Dune sand includes areas in which the wind has piled loose sand into high hills and ridges. The material differs from Valentine soils only in that it has a rougher surface and less topsoil. It is composed of gray, fine to medium sand from the surface downward. At present a negligible part of the dune sand is subject to active wind erosion because its native grass cover is good. The material is not calcareous.

Dune sand seems to have an adequate available moisture supply and is remarkably drought-resistant considering its loose, open structure. It supports in many places a natural growth of choke cherry, hackberry, boxelder, American elm, bur oak, and aspen (fig. 62).

ALLUVIAL SOILS UNDIFFERENTIATED

The undifferentiated alluvial soils have developed from sediments recently washed from the uplands and deposited on the flood plains along streams. They consist chiefly of various types of Lamoure soils, but include small amounts of Cass and Sarpy soils.

The Lamoure soils have formed from the finer textured sediments. They have deep, almost black topsoils, ranging in texture from clay loams to fine sandy loams. The subsoils, which consist largely of silt or a mixture of silt and clay, are light-colored and very limy. They frequently contain rusty brown splotches and streaks caused by imperfect drainage.

The Cass and Sarpy soils have developed from the coarser stream sediments and have sandy or gravelly subsoils. The Cass soils have accumulated considerable amounts of organic matter and have developed dark topsoils. The Sarpy soils are light-colored from the surface downward.

All the soils mapped with this group are subirrigated, the water table frequently lying within 6 or 8 feet of the ground surface. They are well suited to most trees commonly grown in the Dakotas. Native

FIGURE 60.—Field of Sioux sandy loam, showing accumulations of wind-blown sand around clumps of sandgrass. This field, about 10 miles southwest of Towner, N. Dak., has been practically ruined by wind erosion. Trees do poorly in localities where subsoil and substratum consist of coarse gravel to great depths.

F 250035

FIGURE 61.—Valentine fine sand with a more or less general natural cover of aspen; Richland County, N. Dak. The Valentine soils differ from dune sand chiefly in topography—they are not hilly. These soils often support small patches of natural tree growth.

F250000

FIGURE 62.—Dune sand within the basin of old Lake Souris, McHenry County, N. Dak., bearing a natural forest of bur oak, elm, and hackberry. This illustrates the much more favorable conditions for forest and shelterbelt planting on sand in the northern portion of the shelterbelt zone as compared with the southern portion, where light sands become very droughty.

forests composed largely of boxelder, willow, and cottonwood occur on many of them.

ROUGH BROKEN AREAS

Areas of rough, broken land in the different soil groups are indicated on the soil map by diagonal cross-hatching. There is considerable variation in the relief within these areas, especially in those occupied by soils of the Boyd (fig. 55) and Edgeley group just east of the Missouri River in Hughes County, S. Dak., and in Emmons and Burleigh Counties, N. Dak. Here much of the land adjoining the river breaks is rolling, but since it is occupied by soils which are relatively poor for trees, it is included in this survey with rough and broken land. Aside from these rolling areas, the rough, broken land mapped in the northern section consists mainly of boulder-covered morainic hills and ridges within areas of the Barnes and Williams soils (figs. 51–54), and of severely eroded areas in stream valleys. More of the morainic areas might have been mapped as rough, so far as their usefulness for cultivation is concerned.

Except for local patches and part of the rolling areas previously mentioned, the rough, broken land is used for grazing purposes. It is practically devoid of trees, although clumps of choke cherry, green ash, buffaloberry, red haw, and wild plum occur locally in pockets on the Pierre slopes along the Missouri River.

SOILS OF THE CENTRAL SECTION

Most of the central section of the proposed shelterbelt zone was mapped prior to 1912 in reconnaissance soil surveys [43] that include the western parts of South Dakota, Nebraska, and Kansas. Practically all of the Nebraska counties within the section are mapped in detailed soil surveys.[43] In addition, the section as a whole is covered by reconnaisance soil-erosion surveys [44] made during the past year. Data from each of these surveys were used in compiling the present map of the central section, and because of their availability and the very pertinent soil facts that they record, this map has been extended far beyond the shelterbelt zone in Nebraska and Kansas. As in the northern section, soil combinations and correlations not appearing on the original maps have been made on the present draft.

The following groups of soils are shown on the map of the central section (fig. 39):

	Number on map
Rosebud fine-textured soil group Includes Rosebud silt loam, very fine sandy loam, and loam.	37
Rosebud sandy soil group Includes Rosebud fine sandy loam and loamy sand.	38
Holt sandy soil group Includes Holt sandy loam, fine sandy loam, gravelly sandy loam, and loamy sand.	45
Dunlap and Dawes fine-textured soil group Includes all textures of these soils.	49
Epping fine-textured soil group Includes all textures of these soils.	50
Pierre heavy soil group Includes all textures of Pierre and Orman soils.	44
Dickinson and upland O'Neill sandy soil group Includes all textures of these soils.	51
O'Neill sandy soil group Includes sandy soils on terraces.	46
Prairie-Plains soil group Includes intricate mixture of Cass and Valentine soils and dune sand.	43
Bearden, Tripp, Hall, and Bridgeport soil group Includes friable fine-textured soils on terraces.	31
Holdrege and Hastings silty soil group Includes all textures of Holdrege and Hastings soils.	47
Colby silty soil group Includes all textures of these soils.	16
Crete and Grundy claypan soil group Includes all textures of these soils.	21
Scott claypan soil group Includes Scott, Butler, and Fillmore soils.	17
Moody silty soil group Includes all textures of these soils.	39
Soils of loess tables and canyons Include Colby, Holdrege, and Hastings soils intimately associated with their eroded phases.	48
Dune-sand group Includes dune sand and small bodies of Valentine and Gannett soils.	30
Valentine, Anselmo, and Gannett sandy soil group Includes all textures of these soils.	29
Alluvial soils (undifferentiated)	35

Summarized data pertaining to the above groups are given in table 21.

ROSEBUD FINE-TEXTURED SOIL GROUP

Areas in which the soils are composed chiefly of Rosebud silt loam, very fine sandy loam, or loam types are included in the Rosebud fine-textured soil group.

These soils have developed from loosely cemented and very limy sandstone of Tertiary age. They are most extensive in northwestern Nebraska, where they cover the greater part of the nearly level to gently rolling and higher lying uplands. They also occupy rather large areas in several of the southwestern counties of Nebraska. All of them have formed under a short-grass cover.

The topsoils are brown to dark brown, range in thickness from 7 to 10 inches, and are composed largely of silt or mixtures of silt and the finer grades of sand. The subsoils are light grayish yellow and very limy. They consist mainly of silt, although they frequently contain enough sand to give them a gritty feel. The entire soil section is friable.

The fine-textured Rosebud soils have good water-holding powers but do not absorb as much of the precipitation as soils with a higher sand content. In dry years crops growing on them usually suffer more from drought than those growing on the more sandy Rosebud soils.

[43] Bureau of Chemistry and Soils.
[44] Soil Conservation Service.

TABLE 21.—*General characteristics of soils of the central section of the Shelterbelt Zone (Nebraska and Kansas)*

Soil type	Approximate percentage of area in States of central section	Physiography and drainage	Native vegetation	Approximate (minimum) depth of water table
				Feet
Albion (fine-textured types) [1]	Kansas, 0.20	Undulating to rolling well-drained upland	Tall and mixed grasses	40–100
Albion (sandy types) [1]	Kansas, 0.10	do	Tall grasses	40–100
Arkansas [2]	Kansas, 4.00	Nearly level to undulating bottom lands; surface drainage variable.	Tall grasses; trees and shrubs	5–50
Boyd [3]	Nebraska, 0.70	Nearly level to hilly upland; surface drainage good to excessive, underdrainage slow.	Short grasses	90
Bremer [3]	[4]	Nearly level low terrace, well drained	Tall grasses; trees and shrubs	20–50
Bridgeport-Mitchell [5]	Nebraska, 0.50	Nearly level well-drained terrace or gradual colluvial slopes.	Short and bunch grasses	20–75
Canyon [6]	[4]	Rolling to hilly excessively drained upland	Short and bunch grasses, yucca	50–100
Cass [7]	Nebraska, 8.50 Kansas, 2.00	Nearly level bottom land; drainage variable	Tall grasses, trees, and shrubs	5–15
Castleton [2]	Kansas, 0.02	Nearly level to undulating upland, surface drainage good, underdrainage slow.	Short and mixed grasses	50–100
Cheyenne [5]	[4]	Nearly level terrace; excessive underdrainage	Short and bunch grasses; yucca, cactus	15–60
Colby [7]	Nebraska, 19.80 Kansas, 16.12	Nearly level to hilly and broken surface; drainage good to excessive.	Short and bunch grasses	50–100
Crete [7]	Nebraska, 0.30 Kansas, [4]	Nearly level to undulating upland; surface drainage fair, underdrainage slow.	Short and mixed grasses	50–100
Dawes [5]	[4]	Nearly level to undulating upland; surface drainage fair to good, underdrainage slow.	Short grasses	100
Dickinson [8]	Nebraska, 4.00	Nearly level to rolling upland; underdrainage good	Tall grasses	15–60
Dunesand [7]	Nebraska, 14.40 Kansas, 1.08	Rolling to hilly upland; underdrainage good to excessive	Tall and bunch grasses; yucca	20–60
Dunlap [9]	[4]	Nearly level upland; surface drainage good, underdrainage slow.	Short grasses	100
Englewood (fine-textured types) [2]	Kansas, 0.50	Nearly level to gently rolling well-drained upland	Tall and mixed grasses	50–100
Englewood (sandy types) [2]	Kansas, 0.80	Undulating to gently rolling well-drained upland	Tall grasses	50–100
Epping [10]	[4]	Steeply sloping to hilly, well to excessively drained upland.	Short grasses	50–100
Ewing [11]	Nebraska, 0.10	Level to undulating uplands; surface drainage good, underdrainage slow.	Tall and mixed grasses	100
Gannett [3]	Nebraska, 0.10	Poorly drained sand hill basins	Coarse marsh grasses; cattail sedges	0–15
Greensburg [2]	Kansas, 7.00	Nearly level to rolling well-drained upland	Tall, mixed, and short grasses	30–100
Hall [7]	Nebraska, 4.40 Kansas [4]	Nearly level well-drained terraces	do	15–50
Holdredge [7]	Nebraska, 16.10 Kansas, 8.92	Nearly level to rolling well-drained upland	Mixed and short grasses	50–100
Holt [8]	Nebraska, 0.50	Undulating to hilly, well to excessively drained upland	Tall, mixed, and short grasses	40–100
Keith [12]	Nebraska, 4.00	Nearly level to rolling well-drained upland	Short grasses	50–100
Lamoure [7]	Nebraska, 2.10 Kansas, 0.18	Nearly level bottom lands; drainage variable	Tall grasses; trees and shrubs	5–20
Laurel [7]	Nebraska, 0.10 Kansas, 0.80	do	do	5–15
Lincoln [1]	Kansas, 0.20	do	do	5–15
Miller [1]	[4]	do	do	5–15
Minatare [5]	[4]	do	Wheatgrasses and alkali grasses; trees and shrubs.	5–15
Moody [11]	Nebraska, 3.80	Nearly level to hilly, well to excessively drained upland.	Tall and mixed grasses	50–100
O'Neill [3]	Nebraska, 1.00	Nearly level to undulating terrace; underdrainage good to excessive.	Tall and mixed grasses; cactus, yucca	10–50
O'Neill (upland phase) [11]	Nebraska, 1.90	Nearly level to rolling upland; good surface drainage but excessive underdrainage.	do	20–100
Orman [13]	Nebraska, 0.02	Nearly level terrace; good surface drainage but slow underdrainage.	Short grasses	15–100
Pierre [13]	[4]	Undulating to hilly upland; surface drainage good to excessive, underdrainage slow.	do	100
Plainfield-Sparta [3]	Nebraska, 0.16	Nearly level to uudulating terrace; underdrainage good to excessive.	Sparse tall grasses; cactus, yucca	20–60
Pratt (fine-textured types) [1]	Kansas, 0.10	Nearly level to rolling well-drained upland	Tall, bunch, and short grasses	5–30
Pratt (sandy types) [1]	Kansas, 13.24	Nearly level to dunelike upland; underdrainage good to excessive.	Tall and bunch grasses	5–30
Richfield (fine-textured types) [1]	Kansas, 20.70	Nearly level to rolling well-drained upland	Bunch and short grasses	30–100
Richfield (sandy types) [1]	Kansas, 3.00	do	Tall grasses	30–100
Rosebud-Sidney (fine-textured types) [5]	[4]	Nearly level to rolling, well to excessively drained upland	Short grasses	50–100
Rosebud-Sidney (sandy types) [5]	Nebraska, 0.09	Nearly level to rolling well-drained upland	Short and mixed grasses	30–100
Rough broken land [14]	Nebraska, 5.70 Kansas, 15.16	Severely eroded upland	Bunch, mixed, and short grasses	30–100
Sarpy [7]	Nebraska, 0.50 Kansas, 0.50	Nearly level bottom lands; drainage variable	Tall grasses; trees and shrubs	5–15
Scott-Butler-Fillmore [7]	Nebraska, 0.20 Kansas, 0.10	Poorly drained hard-land basins	Variable, depending on moisture supply.	50–100
Sioux [13]	[4]	Nearly level terraces; underdrainage excessive	Tall grasses	15–50
Sogn [7]	Nebraska, 0.40 Kansas, 0.50	Steeply sloping to hilly excessively drained upland	Chiefly short and bunch grasses	50–100
Summit [2]	[4]	Nearly level to hilly, well to excessively drained upland	Tall and mixed grasses	50–100
Tripp-Yale [5]	[4]	Nearly level well-drained terraces	Short grasses	20–75
Valentine [13]	Nebraska, 10.63	Nearly level to hummocky uplands; underdrainage good to excessive.	Tall and bunch grasses	10–40
Vernon (fine-textured types) [1]	Kansas, 1.00	Rolling to rough and broken upland; drainage good to excessive.	Tall, bunch, and short grasses	100
Vernon (sandy types) [1]	Kansas, 3.78	Rolling to hilly well-drained upland	Tall grasses	60–100

Footnotes at end of table.

TABLE 21.—*General characteristics of soils of the central section of the Shelterbelt Zone (Nebraska and Kansas)*—Continued

Soil type	Upper portion of soil profile	Lower portion of soil profile	Parent material	General feasibility for trees
Albion (fine-textured types) [1]	Dark brown to very dark brown; friable, loamy, 10 to 14 inches thick.	Reddish brown to brownish red; loamy to clayey; contains abundance of coarse sand and gravel; 20 to 30 inches thick.	Tertiary silts and clays	Good.
Albion (sandy types) [1]	Dark brown; friable, loamy to sandy, 8 to 14 inches thick.	Red to reddish brown; incoherent sand to friable sandy clay, 20 to 36 inches thick.	Tertiary sands and gravel.	Do.
Arkansas [2]	Brown to dark brown; friable; texture and drainage variable; 8 to 12 inches thick.	Light brown to yellowish brown; loamy to sandy or gravelly, 12 to 20 inches thick.	Recent silt and silt-sand mixtures.	Do.
Boyd [3]	Very dark grayish brown to black; compact, clayey, 4 to 8 inches thick.	Grayish yellow to grayish blue compact clay, 6 to 15 inches thick.	Pierre shale	Difficult to unsuited.
Bremer [3]	Very dark grayish brown to black; friable, loamy to clayey, 8 to 12 inches thick.	Grayish brown to very dark grayish brown; moderately compact, silty to clayey, 20 to 30 inches thick.	Silts and clays	Good.
Bridgeport-Mitchell [5]	Dark grayish brown; friable, loamy to sandy, 6 to 10 inches thick.	Very light grayish brown; friable, loamy to moderately sandy, 20 to 30 inches thick.	Silts and silt-sand mixtures.	Fair to difficult.
Canyon [6]	Grayish brown; friable, loamy to gravelly, 2 to 7 inches thick.	Light grayish brown; friable, stony and gravelly, 2 to 12 inches thick.	Tertiary gravel and bedrock.	Difficult.
Cass [7]	Very dark grayish brown to black; coherent to moderately loose, friable, loamy to sandy, 6 to 10 inches thick.	Incoherent grayish brown sand or sand-and-gravel mixtures, 8 to 14 inches thick.	Recent sands and gravel.	Good.
Castleton [2]	Dark brown to grayish brown; friable, loamy, 8 to 12 inches thick.	Gray clay mixed with shaly limestone, friable, 10 to 15 inches thick.	Shaly limestone	Fair to difficult.
Cheyenne [5]	Grayish brown; moderately loose to incoherent, loamy to gravelly, 4 to 8 inches thick.	Light grayish brown incoherent mixture of coarse sand and gravel, 12 to 18 inches thick.	Sands and gravel	Do.
Colby [7]	Dark grayish brown to grayish brown; friable, loamy to silty, 2 to 8 inches thick.	Very light grayish brown; friable, silty, 10 to 15 inches thick.	Peorian loess	Do.
Crete [7]	Very dark grayish brown; friable, loamy to silty, 12 to 20 inches thick.	Grayish-brown to brown compact claypan over very light grayish-brown friable silt; 18 to 40 inches thick.	do	Do.
Dawes [5]	Dark grayish brown; friable, loamy, 10 to 15 inches thick.	Very dark grayish-brown thin claypan over very light grayish brown friable silt or silt-sand mixture; 12 to 18 inches thick.	Tertiary silts and clays.	Difficult.
Dickinson [8]	Dark to very dark grayish brown; coherent to moderately loose, friable, loamy to sandy, 8 to 18 inches thick.	Brown to grayish brown incoherent sand, noncalcareous, 16 to 30 inches thick.	Sand	Good
Dunesand [7]	Light grayish brown incoherent sand, ½ to 2 inches thick.	Incoherent sand	do	Fair.
Dunlap [9]	Dark grayish brown; friable, loamy to silty, 10 to 18 inches thick.	Grayish brown moderately compact silty clay over very light grayish brown friable silt; 10 to 36 inches thick.	Tertiary sandstone	Difficult.
Englewood (fine-textured types) [2].	Dark brown to brown; friable, loamy, 16 to 20 inches thick.	Brown to reddish brown; loamy, 10 to 15 inches thick.	Triassic and Permian "Red Beds."	Fair to good.
Englewood (sandy types) [2]	Light reddish brown; coherent to moderately loose, sandy to loamy, 12 to 16 inches thick.	Very light reddish brown; moderately loose to incoherent, sandy, 15 to 24 inches thick.	do	Good.
Epping [10]	Grayish brown; friable, loamy to silty, 4 to 10 inches thick.	Very light gray; friable, silty to clayey, 6 to 16 inches thick.	Brule clay	Difficult to unsuited.
Ewing [11]	Very dark grayish brown; friable, loamy, 12 to 18 inches thick.	Grayish-brown moderately compact sandy clay over light grayish brown incoherent sand-gravel mixture; 14 to 30 inches thick.	Pleistocene gravel and clay.	Fair to difficult.
Gannett [3]	Very dark grayish brown to black; friable, coherent, loamy to sandy, 8 to 24 inches thick.	Light grayish brown incoherent sand with thin clay layers in places; 12 to 20 inches thick.	Sand	Good for a few species only.
Greensburg [2]	Very dark grayish brown; friable, 15 to 18 inches thick.	Grayish-brown to light grayish brown friable silt, 20 to 24 inches thick.	Limestone	Fair to difficult.
Hall [7]	Very dark grayish brown; friable, loamy to silty, 16 to 20 inches thick.	Grayish brown; friable, loamy to silty, 16 to 40 inches thick.	Silts and clays	Good.
Holdredge [7]	Very dark grayish brown; friable, loamy to silty, 16 to 18 inches thick.	Grayish brown; friable, loamy to silty, 24 to 40 inches thick.	Peorian loess	Fair to difficult.
Holt [8]	Very dark grayish brown to black; coherent to moderately loose, loamy to sandy, 8 to 14 inches thick.	Brown to light grayish brown; friable, loam to fine sandy loam, 10 to 20 inches thick.	Tertiary sandstone	Fair to good.
Keith [12]	Dark grayish brown; friable, loamy to silty, 10 to 14 inches thick.	Light grayish brown; friable, silty, 15 to 40 inches thick.	Peorian loess	Fair to difficult.
Lamoure [7]	Very dark grayish brown to black; friable to moderately compact, loamy to clayey, locally alkaline; 8 to 18 inches thick.	Dark grayish brown to gray, moderately compact clay to silty loam clay, 12 to 30 inches thick.	Recent silts and clays	Good.
Laurel [7]	Dark grayish brown; friable, loamy to silty, 6 to 12 inches thick.	Light grayish brown; friable, loamy to silty, 12 to 36 inches thick.	Recent silts and silt-sand mixtures.	Do.
Lincoln [1]	Brown; coherent to moderately loose, loamy to sandy, 10 to 15 inches thick.	Light grayish brown; moderately loose to incoherent, sandy, 24 to 30 inches thick.	Recent sands and silt-sand mixtures.	Do.
Miller [1]	Dark chocolate red; friable to moderately compact; texture and thickness variable.	Chocolate red; moderately compact, loamy to clayey, 20 to 30 inches thick.	Recent silt-sand-clay mixtures.	Do.
Minatare [5]	Dark grayish brown; friable to moderately compact, loamy to clayey, locally alkaline, 8 to 14 inches thick.	Gray, with rusty brown and green mottlings; moderately compact, clayey, 10 to 30 inches thick.	Recent silts and clays	Good to unsuited.
Moody [11]	Very dark grayish brown; friable, coherent, loamy, 7 to 16 inches thick.	Brown to light grayish yellow friable silt loam, 14 to 36 inches thick.	Gray loess (Peorian?)	Good.
O'Neill [8]	Very dark grayish brown; moderately loose to incoherent, 10 to 18 inches thick.	Grayish brown incoherent sand or sand-gravel mixture, 12 to 24 inches thick.	Sands and gravels	Fair to good.
O'Neill (upland phase) [11]	Very dark grayish brown; friable, coherent to moderately loose, loamy to gravelly, 6 to 10 inches thick.	Brown to grayish brown incoherent mixture of sand and gravel, noncalcareous, 10 to 30 inches thick.	do	Difficult.
Orman [13]	Dark grayish brown; compact, clayey, 8 to 14 inches thick.	Grayish yellow to grayish blue compact clay, 8 to 15 inches thick.	Clays and shales	Do.
Pierre [13]	Dark grayish brown; compact, clayey, 4 to 8 inches thick.	Grayish yellow to grayish blue compact clay, 4 to 10 inches thick.	Pierre shale	Difficult to unsuited.
Plainfield-Sparta [3]	Light grayish brown; loose to incoherent, loamy to sandy, 4 to 10 inches thick.	Very light grayish brown incoherent sand, 12 to 20 inches thick.	Sands and gravels	Good.
Pratt (fine-textured types) [1]	Brown; coherent, friable, loamy, 10 to 14 inches thick.	Light brown to pale reddish brown; friable, loamy to sandy, 10 to 20 inches thick.	Tertiary silts and clays.	Fair to difficult.
Pratt (sandy types) [1]	Brown; loose to moderately coherent, loamy to sandy, 10 to 18 inches thick.	Light grayish brown with reddish tinge; moderately loose to incoherent, sandy, 18 to 24 inches thick.	Tertiary sands and gravels.	Good.
Richfield (fine-textured types) [1]	Brown to dark brown; friable, loamy to clayey, 10 to 18 inches thick.	Dark-brown to brown crumbly clay to clay loam, 18 to 40 inches thick.	Tertiary silts and clays.	Fair to difficult.
Richfield (sandy types) [1]	Brown; coherent to moderately loose, loamy to sandy, 10 to 18 inches thick.	Light brown to brown; friable, loamy to sandy, 18 to 40 inches thick.	Tertiary sands and gravels.	Fair to good.

Footnotes at end of table.

TABLE 21.—*General characteristics of soils of the central section of the Shelterbelt Zone (Nebraska and Kansas)*—Continued

Soil type	Upper portion of soil profile	Lower portion of soil profile	Parent material	General feasibility for trees
Rosebud-Sidney (fine-textured types).[5]	Dark grayish brown; friable, loamy, 8 to 16 inches thick.	Light grayish brown; friable, loamy to silty, 14 to 24 inches thick.	Tertiary sandstone	Difficult.
Rosebud-Sidney (sandy types)[5]	Dark grayish brown; moderately loose to incoherent, 10 to 16 inches thick.	Light grayish brown; friable, loamy to sandy, 14 to 20 inches thick.	do	Fair to good.
Rough broken land [14]	(4)	(4)	Variable	Variable.
Sarpy [7]	Grayish brown; friable, usually incoherent and sandy, ½ to 8 inches thick.	Light-gray incoherent sand or sand-and-gravel mixture, 6 to 12 inches thick.	Recent sands and gravels.	Good.
Scott-Butler-Fillmore [7]	Dark grayish brown to black; friable to moderately compact, loamy to clayey, 4 to 18 inches thick.	Light bluish-gray, compact claypan, 24 to 40 inches thick.	Silts and clays	Unsuited.
Sioux [13]	Very dark grayish brown to black; friable, coherent to moderately loose, loamy to sandy, 10 to 14 inches thick.	Grayish-brown incoherent sand, locally mixed with gravel, 10 to 24 inches thick.	Sands and gravels	Fair to good.
Sogn [7]	Dark grayish brown to grayish brown; friable, loamy, 2 to 6 inches thick.	Grayish brown to light grayish brown; friable, stony, 4 to 16 inches thick.	Limestone	Fair to difficult.
Summit [2]	Black; silty to clayey, friable, 10 to 14 inches thick.	Very dark grayish-brown to black moderately compact clay, underlain by yellowish to light grayish brown friable clay; 20 to 36 inches thick.	do	Good.
Tripp-Yale [3]	Dark grayish brown; friable, coherent, loamy, 8 to 14 inches thick.	Light grayish brown, friable in Tripp, moderately compact in Yale; silt loam to very fine sandy loam, 18 to 20 inches thick.	Silts and clays	Fair to good.
Valentine [13]	Grayish brown; loamy to sandy, usually incoherent, 2 to 7 inches thick.	Light grayish-brown incoherent sand, noncalcareous, 12 to 30 inches thick.	Sand	Good.
Vernon (fine-textured types)[1]	Red to reddish brown; friable, loamy to clayey, 2 to 10 inches thick.	Red; friable loamy to sandy clay, 10 to 14 inches thick.	Triassic and Permian "Red Beds."	Fair to difficult.
Vernon (sandy types)[1]	Red to reddish brown; coherent to moderately loose, loamy to sandy, 6 to 14 inches thick.	Rod; moderately loose to incoherent, sandy, 12 to 20 inches thick.	do	Good.

1 Principal occurrence in Kansas and Oklahoma.
2 Principal occurrence in Kansas.
3 Principal occurrence in Nebraska.
4 Not stated.
5 Principal occurrence in western Nebraska.
6 Principal occurrence in western Nebraska and Kansas.
7 Principal occurrence in Nebraska and Kansas.
8 Principal occurrence in northern Nebraska.
9 Principal occurrence in northwestern Nebraska.
10 Principal occurrence in northwestern Nebraska and southwestern South Dakota.
11 Principal occurrence in northeastern Nebraska.
12 Principal occurrence in southwestern Nebraska.
13 Principal occurrence in Nebraska and South Dakota.
14 Principal occurrence in Nebraska, Kansas, and Oklahoma.

Only a few plantings of green ash, caragana, American elm, and boxelder were observed on these soils. Few of the trees exceed 20 feet in height, although many of them are more than 40 years old. A large percentage of them are dead or dying. The soils of this group are of doubtful value for shelterbelt planting on any large scale.

ROSEBUD SANDY SOIL GROUP

Most of the soils of the Rosebud sandy soil group surround or adjoin areas of Valentine soils and dune sand. The largest developments are in western Nebraska and northwestern Kansas. The topsoils consist of brown fine sandy loams to loamy fine sands. The subsoils, which are very light colored and highly calcareous, usually contain less sand and more silt than the topsoils. They rest at depths of 2 or 3 feet upon the soft limy sandstone from which the soils have developed. The high sand content of these soils is due in many places to admixtures of wind-blown sand from Valentine soils and dune-sand areas. In some of the soils of this group the surface layers are so sandy that they become unstable if the protective vegetation is destroyed.

Although occurring in a rather dry region, these soils are able to absorb practically all the precipitation. Their subsoils have high moisture-holding power, and most of the moisture absorbed is available to the vegetation. Even light rains are able to replenish the moisture supply appreciably, thus enabling the native grasses to remain green much longer during droughts than on the finer Rosebud soils.

The soils of this group are superior to the fine-textured Rosebud soils for trees. Scattered plantings of American elm, green ash, ponderosa pine, and honeylocust are making fairly good growth. Most of the trees are vigorous. Russian-olive and red cedar, although not observed on these soils, are probably well suited to them. All species would undoubtedly be more difficult to establish, especially during dry years, and would make slower growth here than on sandy soils farther east. Carefully selected species should survive well, however, provided they are given reasonable care.

HOLT SANDY SOIL GROUP

The soils of the Holt sandy soil group (fig. 63) are identical in texture with those of the Rosebud sandy soil group and in common with those soils have developed from loosely cemented calcareous sandstone. They lie farther east, however, in a region of higher rainfall and more luxuriant grass growth and have developed deeper and darker surface layers. All of them have highly calcareous subsoils.

These soils absorb moisture rapidly, have high water-holding capacities, and are well adapted to a variety of trees and shrubs, including honeylocust, red cedar, ponderosa pine, American elm, Russian-olive, green ash, choke cherry, and wild plum.

DUNLAP AND DAWES FINE-TEXTURED SOIL GROUP

The Dunlap and Dawes fine-textured soils occur in large and small bodies within areas of Rosebud soils throughout western Nebraska. They usually are in nearly level situations on the higher lying parts of the uplands, although the Dawes may be on long gradual slopes. Their topsoils are friable, are brown to dark brown, and are 10 to 14 inches thick. They range from silt loams to fine sandy loams, the silty textures predominating. The upper subsoils consist of moderately heavy, brown to very dark brown silty clay loam, 8 to 24 inches or more in thickness; those in the Dawes are thinner but darker and denser than those in the Dunlap and usually have a thin grayish subsurface layer which is not present in the Dunlap. The lower subsoils are composed of floury light-colored and limy silt, which rests on parent limy sandstone or on mixtures of sand and clay at a depth of 4 or 5 feet.

FIGURE 63.—Profile of one of the finer textured Holt soils, Holt very fine sandy loam; Brown County, Nebr. The Holt soils differ from the Rosebud chiefly in that they have darker colored topsoils. They have developed from limy Tertiary sandstones. These soils are well adapted to a wide variety of trees and shrubs.

These soils have high water-holding capacities, but owing to their rather heavy character are unable to absorb much moisture from the light precipitation. Even during seasons of normal percipitation water does not often penetrate beyond the base of the upper subsoil layer. In dry years the topsoils are seldom wetted for their entire depth.

A few groves and scattered trees, chiefly ash, have been planted on some of the soils of this group. The majority of the trees observed are surviving fairly well, but all of them are short and scrubby.

EPPING FINE-TEXTURED SOIL GROUP

The Epping fine-textured soil group (fig. 64) occupies a few large areas in northwestern Nebraska. The soils are immature. Their topsoils are gray to light grayish brown and range between silt loams and fine sandy loams, the finer textures predominating. They seldom exceed 6 or 8 inches in thickness and usually rest directly upon the parent material, a pale flesh-colored or white clay belonging to the white river beds of Tertiary age.

Nearly all the Epping soils are rather steeply sloping. In numerous places the parent material is exposed and in local spots has been eroded into a badland topography.

The soils absorb moisture too slowly to support good vegetative growth in this region. They permit excessive water loss through run-off and remain rather droughty even during seasons of normal precipitation. Practically the entire area occupied by them is in pasture land. They are unsuited to trees, except very hardy and drought-resistant species, such as red cedar.

PIERRE HEAVY SOIL GROUP

This Pierre heavy soil group includes the Pierre and Orman soils of northwestern Nebraska. The soils have developed from the heavy Pierre shale formation and are similar in subsoil features to those of the Boyd and Edgeley clay soil group farther east but have lighter colored, thinner, and more limy topsoils.

The Pierre soils are on undulating to rolling uplands, whereas the Orman occupy narrow broken strips on stream terraces. The two are similar in profile features.

The topsoils consist of light-brown or grayish-brown clay or clay loam which rests on dense subsoil clay, usually within a 6-inch depth. The parent shale seldom lies more than 2 feet beneath the ground surface in the Pierre soils, but the substratum beneath the Orman consists of water-transported clays which may be several feet thick. The soils of this group are very limy from the surface downward and somewhat alkaline.

Owing to their high clay content, the Pierre and Orman soils absorb the precipitation very slowly and, in the rather dry region of their occurrence, are droughty. They support a sparse cover of bluestem and grama grasses. The Pierre soils are practically treeless. Narrow broken strips of native vegetation, including ash, cottonwood, American elm, hackberry, and boxelder, occur on the Orman soils, especially along drainage ways, where the subsoil drainage is good.

DICKINSON AND UPLAND O'NEILL SANDY SOIL GROUP

The Dickinson and upland O'Neill sandy soil group as mapped includes areas of nearly level to gently rolling uplands on which Dickinson and upland O'Neill soils are so intricately mixed that the individual bodies of each cannot be indicated legibly on the map. The soil mixture occupies rather large areas in the northeastern part of the central section, chiefly in Holt, Rock, Brown, and Keyapaha Counties, Nebr.

The upland O'Neill and the Dickinson soils are similar in that both have very dark topsoils and noncalcareous subsoils. Otherwise they differ greatly. The former are composed largely of gravel or mixtures of coarse sand and gravel and have rather shallow topsoils, whereas the latter consist mainly of fine or medium sands and have deep topsoils. These soils are about equally extensive in most of the areas where the group is mapped.

They absorb practically all precipitation as rapidly as it falls, but the Dickinson soils have higher moisture-holding powers and, as a whole, are more drought-resistant than the upland O'Neill, especially for crops. On the Dickinson soils most tree species commonly grown on the uplands of northern Nebraska do well, including green ash, hackberry, American elm, dwarf Asiatic elm, honeylocust, Russian-olive, choke cherry, mulberry, red cedar, and ponderosa pine.

Trees are difficult to establish on the upland O'Neill soils, and during the first few years many of them die owing to the droughty nature of the subsoil. As the roots extend downward, however, they are able to reach a ground-water moisture supply in some places. In general, the trees on the upland O'Neill soils are not as vigorous as those on the Dickinson soils, and the species which can be used successfully are more limited.

O'NEILL SANDY SOIL GROUP

The O'Neill sandy soil group includes all the sandy soils of the terraces in the central section that are in bodies of sufficient size to be indicated on the map. The group consists chiefly of the O'Neill, although it includes small patches of Sparta and Plainfield soils.

The O'Neill soils are characterized by deep, dark-colored topsoils ranging in texture from fine sandy loams to loamy sands. Their subsoils are composed largely of sand but contain considerable gravel in places. These soils are practically lime free. The Sparta and Plainfield soils, which are much alike, differ from the O'Neill only in having lighter colored and thinner topsoils.

The soils of this group have nearly level to gently undulating surfaces and are well drained. In places where gravel is especially abundant the underdrainage is excessive, and the soils are rather droughty, especially for farm crops. All of the sandy soils of the terraces, however, are favorably situated to receive run-off from higher levels, which gives them a greater moisture supply than occurs in upland soils of comparable texture. In many places they are subirrigated at depths within the reach of tree roots.

The group as a whole is well suited to a variety of trees and shrubs, including American elm, green ash, hackberry, honeylocust, boxelder, black walnut, Russian-olive, mulberry, choke cherry, wild plum, and red cedar. Cottonwood makes excellent height growth where the water table is within 10 or 12 feet of the surface.

FIGURE 64.—One of the few areas of uneroded Epping soils, showing the light color of topsoil; Banner County, Nebr. The Epping soils are normally unsuited to the growth of any but highly drought-resistant trees.

PRAIRIE-PLAINS SOIL GROUP

The prairie plains of northeast Nebraska are occupied by an intricate mixture of sandy soils. Cass soils are the most extensive, but the area includes numerous small bodies of Valentine and Dickinson soils and dune sand.

The large prairie-plains area has many of the features of sandy bottom lands but is much larger than would seem possible were it formed by its present drainage system. A few permanently flowing streams occur in it, but they are small. Seepage from the vast sand-hill region to the west maintains the water table constantly within a depth of 4 or 5 feet in the Cass soils, and during the spring the water rises sufficiently to produce marshy spots. The other soils of the group have good surface and underdrainage, but the water table, except in dune sand, is nearly everywhere within a 20-foot depth. In the eastern part of the area the Cass soils are fairly continuous, covering in places entire townships within which the local relief seldom exceeds 5 feet. Westward these soils follow an intricate system of narrow lowland strips surrounding slightly elevated bodies of Dickinson and Valentine soils, or high hills and ridges of dune sand.

The soils of this group are extremely sandy from the surface downward. The Cass and Dickinson types have accumulated an abundance of organic matter and have thick, dark topsoils. Dune sand and the Valentine soils are low in organic matter and rather light colored even at the surface.

Planted groves and trees are more numerous in the prairie-plains area of Nebraska than in any other area of equal size in the proposed shelterbelt zone. Cottonwood trees comprise the bulk of the plantings, most of which are on the Cass soils. Numerous plantings are on the Valentine and Dickinson soils, however, and a few are on dune sand. On the Cass soils, cottonwood attains an average height of 60 to 80 feet in 30 or 40 years. Some of the green ash trees growing on these soils are 60 feet high. Willows thrive in many places. Russian mulberry, red cedar, American elm, Russian-olive, honeylocust, and choke cherry do well on most soils of the group. Catalpa is good, particularly on the heavier soils. Volunteer seedlings of red cedar are found in several localities.

BEARDEN, TRIPP, HALL, AND BRIDGEPORT SOILS GROUP

All soils of the Bearden, Tripp, Hall, and Bridgeport soils group are in the central section. The Bearden and Tripp, which occur also in the northern section, have been previously described. Since all soils of the group are fairly similar in their features and adaptabilities to trees, only those characteristics which apply to the group as a whole will be mentioned here.

The soils are on nearly level to gently undulating and well-drained terraces along the larger streams. They are characterized by clayey to loamy topsoils, which are underlain by light-colored, silty to moderately clayey and very limy subsoils. The entire soil section is friable and is easily penetrated by moisture, air, and roots.

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FIGURE 65.—Winter view of an extremely flat, undissected area of Holdrege silt loam a few miles east and north of Holdrege, Nebr. For several miles in each direction this flat is interrupted only by about one drainageway per mile, not exceeding 8 feet in depth and not interfering with cultivation. Occasional undrained depressions occur in which the soil is more clayey and is classed as "Scott."

Owing to their terrace position, these soils receive some water in the form of run-off from higher levels and are usually better supplied with moisture than the upland soils of the region. They include some of the most productive general farming soils of the central section. Practically the whole area occupied by them is under cultivation. A large part of it is irrigated. In places the water table is within a depth of 15 feet.

Many kinds of trees are growing successfully on these soils. Green ash, American elm, cottonwood, boxelder, honeylocust, hackberry, Russian-olive, choke cherry, and red cedar usually give good results. Dwarf Asiatic elm, catalpa, black locust, black walnut, bur oak, coffeetree, ponderosa pine, Austrian pine, Russian mulberry, Osage-orange, caragana, lilac, and wild plum have all been observed growing and surviving well.

HOLDREGE AND HASTINGS SILTY SOIL GROUP

The soils of the Holdrege and Hastings group have been developed on the thick loess mantle which is such a pronounced feature of the central section. They extend for almost the whole width of the zone in southern Nebraska and northern Kansas where they occupy nearly level to gently rolling and well-drained upland situations (fig. 65).

The topsoils range from 10 to 18 inches thick, have accumulated large amounts of well-decayed organic material, and are very dark (fig. 66). The subsoils are brown in the upper part and light gray in the lower. They are very limy below depths of 3 or 4 feet. The entire soil section is composed largely of silt. The Holdrege soils are friable throughout. The subsoils of the Hastings are slightly compact in the upper part but are easily penetrated by moisture, air, and roots.

FIGURE 66.—Profile of Holdrege silt loam, Gosper County, Nebr. This soil has a thick dark-colored topsoil and is friable to great depths.

The Hastings and Holdrege soils have high moisture-holding powers but are unable to absorb as much of the precipitation as more sandy soils. Moreover, the absorbed moisture is held higher in the soil section than it is in sandy soils and is subject to greater evaporation loss. In the eastern part of the shelterbelt zone these soils receive enough rainfall to give them an adequate moisture supply except during the most prolonged droughts, but in the western part their available moisture is too low for good tree growth.

Most of the tree species and shrubs common to the uplands of central Nebraska are growing on the soils of this group, including honeylocust, American elm, green ash, mulberry, Osage-orange, hackberry, dwarf Asiatic elm, Russian-olive, lilac, wild plum, choke cherry, and red cedar. The trees are more vigorous in the eastern than in the western part of the zone, but few of them attain a height of 40 feet on any of the Holdrege or Hastings soils.

COLBY SILTY SOIL GROUP

The Colby soils as mapped in this survey occur in both the eastern and western parts of the central section. In recent surveys of Nebraska some of these soils are designated as "Keith." In the western part of their distribution, the Colby soils occur on the smooth loess-mantled plain of southwest Nebraska and northwest Kansas (fig. 37). Here they have developed in a region of light rainfall under a short-grass vegetation and in the absence of severe erosion. They resemble the Holdrege soils except that they have thinner and lighter colored topsoils and are more limy (fig. 67). In the eastern part of the shelterbelt zone, the soils mapped in this survey as Colby include areas in which Holdrege and Hastings soils have been so thinned and lightened by erosion in their surface layers that the resultant soil is essentially similar to the true Colby farther west. These areas have a strongly rolling to hilly surface but are not sufficiently broken to be classed as rough land.

The Colby soils do not differ essentially in their moisture-absorbing and holding capacities from the Holdrege and Hastings soils. They are among the most drought-resistant of the finer textured upland soils in the shelterbelt zone, but they are less resistant to drought than some of the sandier soils.

Most trees commonly grown on the uplands of central Kansas and Nebraska are making good growth on Colby soils in the eastern part of the zone. In the western part, only the most drought-resistant species are surviving. Few of the planted ash, honeylocust, or black locust growing on the western Colby soils exceed 20 feet in height, regardless of their age. There are practically no native trees growing on these soils in either the eastern or western parts of the zone. Much of the green ash and black locust on the Colby and associated soils of Nebraska and Kansas has suffered severely from borers.

CRETE AND GRUNDY CLAYPAN SOIL GROUP

Crete soils, which in some of the older county surveys were correlated as Grundy, extend into the shelterbelt zone in south-central Nebraska. These soils have developed on nearly level areas of the loessial uplands under a precipitation sufficient to support mixed tall and short grasses.

The topsoils, which extend to depths of 14 to 16 inches, are composed of friable silt intimately mixed with an abundance of black organic matter which gives them a very dark color. They overlie a brownish claypan 12 to 20 inches thick. The remainder of the section consists of loose, floury, and highly calcareous silt which rests on the parent loess at depths of 4 or 5 feet.

The claypan has developed largely from clay carried into the subsoils by percolating waters. "Alkali" salts may have contributed to its development; none of the Crete soils, however, is now alkaline.

Although the soils of this group are underlain by claypan, they receive enough precipitation to give them a favorable moisture supply except during the most severe droughts. They do not seem to be particularly inimical to tree growth. Fairly good groves of honeylocust, American elm, mulberry, red cedar, green ash, Osage-orange, and ponderosa pine were observed on them in south-central Nebraska. It is possible that the claypan may be unfavorable to some species. No definite conclusion has as yet been drawn in this regard.

SCOTT CLAYPAN GROUP

Scattered throughout the finer textured and more nearly level upland soils in the central section are shallow basins or depressions occupied by claypan soils. They are comprised chiefly of the Scott claypan group but include correlated bodies of the Butler and Fillmore soils.

The basins, which are locally known as "buffalo wallows" or "lagoons", seldom exceed 500 acres and generally occupy less than 10 acres. There is usually one or more of them in each square mile throughout the uplands. Only the largest ones, as in Scott County, Kans., and Phelps County, Nebr., are shown on the map.

The Scott soils have thin, dark surface layers underlain by extremely dense, dark-gray claypans, ranging from about 18 inches to 4 feet or more in thickness. The Butler and Fillmore soils differ from the Scott mainly in that they have thicker topsoils and slightly thinner and darker claypans.

The claypans of the Scott, Butler, and Fillmore soils are almost impervious to water, and the basins in which they occur are occupied by shallow ponds for several weeks after rains. When the water evaporates the soils become extremely dry and shrink and crack badly. Most of the depressed areas are used for pasture land.

The soils of this group as a whole are unsuited to trees, owing largely to the wide range of moisture conditions to which they are subjected. In a few places green ash was observed growing on Butler soil, which occupies the shallower basins and has the thinner claypan.

MOODY SILTY SOIL GROUP

Moody soils are developed on the loess-mantled uplands in the northeastern part of the central section and occupy a few areas in the southern part of the northern section. They have nearly level to strongly rolling surfaces and are everywhere well drained.

These soils are somewhat similar to the loessal Holdrege soils of south-central Nebraska and northern Kansas but differ from them in having slightly thinner surface layers and more limy subsoils. Their outstanding feature, and the one which serves to distinguish them from all other loess-derived soils is a subsoil zone which is unusually rich in small lime concretions.

The Moody soils have high moisture-holding powers and are friable throughout. They are in a region where the precipitation is sufficient to give them a good moisture supply. All of them are well suited for the trees and shrubs mentioned in connection with the Holdrege group.

SOILS OF LOESS TABLES AND CANYONS

The group of loess table and canyon soils is mapped to include the soils of areas in which the smooth loess plains are dissected by erosion into a series of long, narrow, and flat-topped divides separated by steep-sided valleys or canyons (figs. 68 and 69). Few of the divides exceed 3 miles in width, and most of them are much narrower. They are occupied almost entirely by the silty Colby, Holdrege, and Hastings soils, all of which have been described. The canyons vary in width from a few rods to about a quarter of a mile. Many of them have flat floors on which the soils are rather dark, but unweathered loess is exposed on all of the slopes leading to the divides.

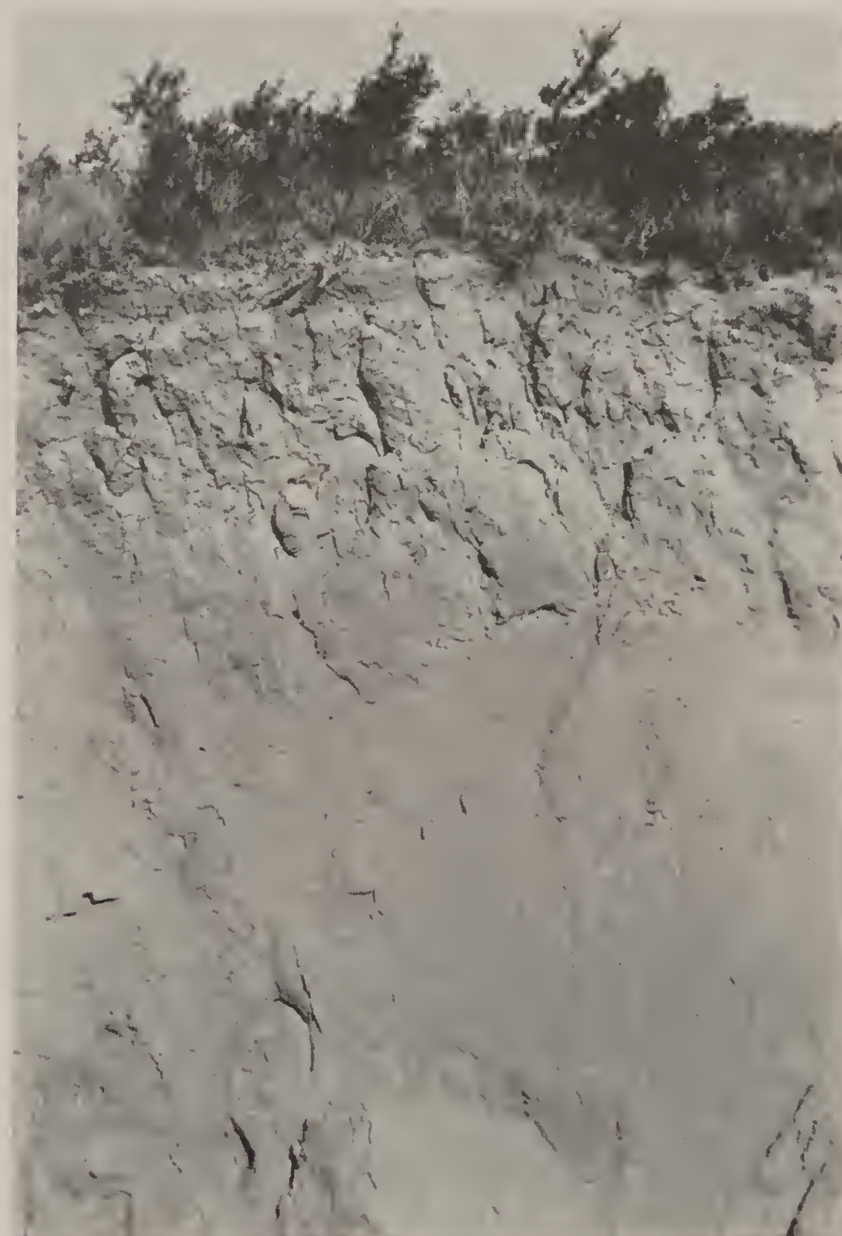

FIGURE 67.—Profile of Colby silt loam, Rawlins County, Kans. This soil differs from Holdrege in that it has a lighter colored topsoil. It has developed under rather arid conditions.

None of the soils within areas belonging to this group is inimical to trees, although some of the areas lie in a region where the precipitation is too low to support any except the most drought-resistant species.

Hackberry, honeylocust, Russian-olive, dwarf Asiatic elm, American elm, mulberry, lilac, choke cherry, and red cedar have, with good care, given fair results in the western areas of this soil group. Green ash also does fairly well but is more or less subject to borer damage. Throughout their eastern distribution the

FIGURE 68.—Eroded but rather gently sloping phase of Colby silt loam, Frontier County, Nebr. A wide variety of trees is suited for forest shelterbelt planting on the Colby silt-loam soils.

FIGURE 69.—Characteristic topography of the loess tables and canyons, Frontier County, Nebr. Even this deep erosion may not go to the bottom of the loess deposit from which the Colby silt-loam soil is developed.

soils of the loess tables and canyons are suited to all species mentioned in connection with the Holdrege and Hastings silty soil group.

DUNE-SAND GROUP

Areas belonging to the dune-sand group are mapped in the northern, central, and southern sections of the shelterbelt zone. The largest areas are in the central section, where they occupy several thousand square miles in the sand-hill regions of north-central and southwestern Nebraska.

Dune sand is not a soil. It occurs as a succession of sand hills and ridges, some of which rise 100 feet above their surroundings. Valleys, pockets, and swales are of frequent occurrence. The wetter of these are occupied by Gannett and the drier by Valentine soils, neither of which is in bodies of sufficient size to be shown on a small map.

The Forest Service has planted thousands of acres of ponderosa and jack pine in the Nebraska sand hills. Red cedar has also been planted and is increasing in favor. These species are growing well, although the pine is considerably handicapped by tip-moth injury. Some planted hardwoods, chiefly cottonwood and willow, thrive on the Gannett and Valentine soils where the water table is at shallow depths.

VALENTINE, ANSELMO, GANNETT SANDY SOIL GROUP

The soils of the Valentine, Anselmo, and Gannett group cover a large total area in the central section, where they occur as numerous bodies and strips within and around the edges of the sand hills. Most of the bodies are small. Only the larger ones are shown on the map.

The Valentine, Anselmo, and Gannett soils are composed largely of sand. The first two, which are the more extensive, occupy undulating to rolling well-drained areas. They have accumulated only small amounts of organic matter and have rather thin topsoils of brown or light-brown color. The subsoils are gray, those in the Valentine consisting almost entirely of loose sand, whereas the Anselmo subsoils contain sufficient silt to give them good body. The Gannett soils are in poorly drained pockets or basins throughout the sand hills. They have developed under conditions favorable to rapid vegetal growth and decay and have thick, almost black topsoils. Their subsoils are usually composed of loose gray sand but in local areas may contain a thin clay layer. Some of the Gannett soils are rather alkaline, especially in the western part of Nebraska.

The soils of this group, as a whole, are well suited to trees. Red cedar, ponderosa pine, mulberry, green ash, and cottonwood are surviving well on many of the farmsteads within Valentine soil areas. Scattered willow and cottonwood trees grow naturally within and around the edges of some of the Gannett soil bodies, which are generally too alkaline for pines. The Anselmo soils seem well adapted to honeylocust, American elm, boxelder, Russian-olive, choke cherry, mulberry, red cedar, and ponderosa pine.

ALLUVIAL SOILS UNDIFFERENTIATED

The alluvial soils of the central section comprise soils of the first bottom on flood plains along streams. Only the wider developments are shown on the map. These include various types of the Lamoure, Laurel, Minatare, Cass, and Sarpy soils. The first three named have developed from fine-textured stream sediments and have silty or clayey profiles. The Cass and Sarpy soils have developed over sandy or gravelly sediments. Aside from the Minatare and Sarpy, which are rather light-colored even at the surface, all soils of this group have accumulated an abundance of black humic material and have very dark topsoils. Locally the flood-plain soils may be alkaline.

The alluvial soils of the central section are well adapted to a variety of trees except in spots where alkali is sufficiently abundant to be injurious. Cottonwood, hackberry, willow, green ash, catalpa, black walnut, American elm, honeylocust, black locust, mulberry, Russian-olive, Osage-orange, red cedar, and several other trees do well on these soils. Coffeetree, sycamore, and silver maple occur in places.

ROUGH BROKEN AREAS

Rough broken land comprises several areas in the central section. They are indicated by diagonal crosshatching on the map. Those composed of soils belonging to the same group are further indicated by the group number. Those composed of a mixture of soils belonging to several groups are indicated by the number (1).

Practically all of the rough broken land shown on the map of the central section is too rough or stony for farming. That in northwestern Nebraska includes Pine Ridge, Wildcat Range, and areas of extremely broken and stony land on the valley slopes along the Platte and Republican Rivers. In these localities erosion has exposed and deeply carved the basal Tertiary sandstone formation. Throughout the remainder of the section most of the rough broken areas are occupied by severely eroded loess, although some of them include Tertiary material.

Trees grow naturally in many of the rough broken areas. In the canyons of western Nebraska native American elm, hackberry, green ash, boxelder, cottonwood, red cedar, choke cherry, and wild plum occur in several places. In parts of Sheridan, Dawes, and Sioux Counties, Nebr., considerable areas of broken land are occupied by a natural growth of ponderosa pine. Red cedar, aspen, mountain-ash, dwarf maple, and narrowleaf cottonwood occur locally in Sioux County.

SOILS OF THE SOUTHERN SECTION

Most of the southern section of the shelterbelt zone has been covered by reconnaissance soil surveys,[45] including those of western Kansas and the Panhandle section of Texas, which were made in 1910, and a similar survey [45] of northwest Texas made in 1919. The Oklahoma portion of the southern section has had no reconnaissance surveys, although a detailed soil survey [45] of Roger Mills County was made in 1914. Detailed soil surveys [45] of a few Texas and Oklahoma counties within the southern section have been made during the past few years but as yet these are unpublished. The Oklahoma and Texas parts of the zone that had not been covered by soil surveys were mapped

[45] Bureau of Chemistry and Soils.

in a rapid reconnaissance [46] and the boundaries of the general soil groups determined during the present survey.

Each of the soil group areas shown on the map of the southern section includes a number of soils. In most of the areas the more extensive soils are similar in their broader characteristics and their adaptabilities for trees. Some of the areas are mapped entirely on the basis of their rugged surface features and may include a number of soils having widely divergent characteristics. The soil names used in this section are taken from recent correlations and in many instances differ from those used in the original surveys.

The following soil groups are recognized and shown on the map covering the southern section of the shelterbelt zone (fig. 40).

	Number on map
Richfield and Pullman fine-textured soil group Includes silty clay loam types of these soils and small areas of Potter and Zita soils. Also includes Amarillo silty clay loam as mapped in the 1910 reconnaissance soil survey of the Panhandle section of Texas.	11
Richfield fine-textured soil group Includes Richfield silt loam, Greensburg silty clay loam and silt loam, Summit silt loam and silty clay loam, and small areas of Potter soils.	5
Zita and Potter shallow soil group Includes Zita and Potter loams and fine sandy loams and small areas of rough broken land.	10
Hamilton soil group Includes Hamilton silt loam and silty clay loam.	15
Amarillo sandy soil group Composed chiefly of Amarillo fine sandy loam.	20
Pratt sandy soil group Includes Pratt fine sandy loam, loamy fine sand, loamy sand, gravelly sandy loam, and coarse sandy loam, Richfield sands and sandy loams, and small bodies of Enterprise fine sand. Also includes some sandy Albion soils as mapped in Reno County, Kans.	4
Miles sandy soil group Includes Miles fine sand and fine sandy loam, small bodies of Abilene, Enterprise, and Vernon sandy soils, and dune sand.	12
Abilene sandy soil group Includes Abilene fine sands and fine sandy loams, also some bodies of Miles and Vernon sandy soils.	13
Vernon sandy soil group Includes Vernon, Mutual [47], and Woodward [47] fine and very fine sandy loams and Vernon clay loam.	8
Miles-Vernon sandy soil group	3
Foard, Tillman, Hollister, St. Paul, Abilene, and Roscoe heavy soil group Includes silt loam, clay loam, and silty clay loam types of these soils.	14
Alluvial soils undifferentiated	35
Vernon soils and rough broken areas Includes areas in which rough broken land and tillable areas of Vernon soils are so intricately associated that they cannot be separately indicated on a small map.	9
Dune-sand group Consists chiefly of Enterprise sand (dune phase).	30

Summarized data pertaining to the above groups are given in table 22.

RICHFIELD AND PULLMAN FINE-TEXTURED SOIL GROUP

The Richfield and Pullman fine-textured soil group consists almost entirely of Richfield and Pullman silty clay loam soils but includes also small areas of Potter and Zita clay loams and loams.

The Richfield silty clay loam consists of brown or dark brown silt loam overlying very dark brown moderately heavy, silty clay or clay. The material below a depth of 3 or 4 feet is highly calcareous and merges gradually downward into grayish-yellow marl, from which the soil has developed.

[46] This reconnaissance and the descriptions of the soil groups were prepared by W. T. Carter, inspector, southwestern district, Soil Survey Division, Bureau of Chemistry and Soils.

[47] Tentative correlations.

TABLE 22.—*General characteristics of soils of the southern section of the Shelterbelt Zone (Texas and Oklahoma)*

Soil	Principal occurrence	Approximate percentage of area in States of southern section	Physiography and drainage	Native vegetation	Approximate minimum depth of water table
					Feet
Abilene (fine-textured types)	Rolling plains of Texas and Oklahoma.	Oklahoma, 10.00; Texas, 6.00.	Nearly level to undulating well-drained upland.	Short grasses	100
Abilene (sandy types)	do	Oklahoma, 2.04; Texas, 0.57.	Nearly level to rolling well-drained upland.	Bunch, short, and mixed grasses; mesquite, shin oak, shrubs.	100
Amarillo (fine-textured types)	High plains of southern Panhandle of Texas.	(1)	Undulating to rolling well-drained upland.	Short grasses and smaller bunch grasses.	100
Amarillo (sandy types)	do	(1)	Rolling to hummocky well-drained upland.	Bunch, short, and mixed grasses; mesquite, catclaw, shrubs.	100
Calumet	Rolling plains of Texas and Oklahoma.	(1)	Nearly level terrace; surface drainage and under-drainage slow.	Short and salt grasses	50–100
Enterprise (dune phase)	Chiefly rolling plains of Texas and Okahoma.	Oklahoma, 7.65; Texas, 3.71.	Hilly; underdrainage good to excessive.	Bunch grasses; shin oak, sand sage, yucca.	15–50
Foard	Rolling plains of Texas and Oklahoma	Oklahoma, 5.00; Texas, 3.00.	Nearly level upland; slow surface drainage and underdrainage.	Short grasses	100
Hollister	do	Oklahoma, 2.26; Texas, 1.65.	Nearly level to undulating upland; slow surface drainage and underdrainage.	do	100
Lincoln	Texas and Oklahoma	Oklahoma, 2.00; Texas, 0.01.	Nearly level bottom lands; drainage variable.	Tall grasses; trees and shrubs	5–15
Miles Enterprise (sandy types)	Rolling plains of Texas and Oklahoma.	Oklahoma, 8.59; Texas, 28.58.	Rolling to strongly rolling, well-drained upland.	Bunch, short, and mixed grasses; shin oak, sand sage.	50-100
Miller	Texas and Oklahoma	Oklahoma, 1.00; Texas, 0.01.	Nearly level bottom lands; drainage variable.	Tall grasses; trees and shrubs	5–15
Mutual [2]	Rolling plains of Texas and Oklahoma.	Oklahoma, 7.00; Texas, 1.40.	Nearly level to undulating well-drained upland.	Bunch and short grasses	100
Potter	High plains and margins in Texas and Oklahoma.	Oklahoma, 3.00; Texas, 1.50.	Rolling to steeply sloping upland; surface drainage excessive.	Bunch, short, and mixed grasses	100
Pratt	Oklahoma and Kansas	Oklahoma, 3.96	Nearly level to hummocky or dune-like upland; underdrainage good.	do	5–130
Pullman	High plains of Texas, Oklahoma, and Kansas.	Oklahoma; [1] Texas, 0.15.	Nearly level to gently undulating uplands; surface drainage good to slow.	Short grasses	30–100

[1] Not stated.
[2] Provisional correlation.

TABLE 22.—*General characteristics of soils of the southern section of the Shelterbelt Zone (Texas and Oklahoma)*—Continued.

Soil	Principal occurrence	Approximate percentage of area in States of southern section	Physiography and drainage	Native vegetation	Approximate minimum depth of water table
					Feet
Randall	High plains of Texas and Oklahoma.	Oklahoma;[1] Texas, 0.02.	Poorly drained hard land basins	Short grasses	100
Richfield (fine-textured types)	High plains of Texas, Oklahoma, and Kansas.	Oklahoma, 0.05; Texas.[1]	Nearly level or slightly depressed to gently rolling lands; surface drainage good to slow.	Bunch and short grasses	30–100
Rough broken land	Texas and Oklahoma	Oklahoma, 15.72; Texas, 21.22.	Severely eroded upland	Bunch and short grasses; some shrubs.	30–100
Spur	Texas	Texas, 0.02	Nearly level bottom lands; drainage variable.	Tall grasses; trees and shrubs	5–150
St. Paul	Rolling plains of Texas and Oklahoma.	Oklahoma;[1] Texas, 1.00.	Undulating to rolling well-drained upland.	Short grasses	100
Summit	Rolling plains of Oklahoma and Kansas.	[1]	Nearly level to hilly, well to excessively drained upland.	Tall and mixed grasses	50–100
Tillman	Rolling plains of Texas and Oklahoma.	Oklahoma, 4.00; Texas, 2.00.	Undulating to rolling upland; slow underdrainage.	Short grasses	100
Vernon	Rolling plains of Texas, Oklahoma, and Kansas.	Oklahoma, 19.81; Texas, 28.00.	Rolling to hilly, well to excessively drained upland.	Bunch and short grasses	100
Woodward [2]	Rolling plains of Oklahoma and Kansas.	Oklahoma, 6.00	Nearly level to undulating well-drained upland.	do	100
Yahola	Texas and Oklahoma	Oklahoma, 0.59; Texas, 0.01.	Nearly level bottom lands; drainage variable.	Tall grasses; trees and shrubs	5–115
Zita	High plains and margins in Texas and Oklahoma.	Oklahoma, 1.93; Texas, 0.55.	Undulating to rolling upland; surface drainage good to excessive.	Bunch and short grasses	100

Soil	Upper portion of soil profile	Lower portion of soil profile	Parent material	General feasibility for trees
Abilene (fine-textured types)	Brown to chocolate brown; friable, loamy to sandy, 8 to 14 inches thick.	Brown to pale reddish brown; friable, loamy to clayey, 20 to 30 inches thick.	Tertiary and Quaternary silts and clays.	Fair to difficult.
Abilene (sandy types)	Brown to chocolate brown; coherent to moderately loose, sandy, 10 to 16 inches thick.	Yellowish to pale reddish brown; friable, loamy to sandy, 22 to 36 inches thick.	Tertiary and Quaternary sands.	Fair to good.
Amarillo (fine-textured types)	Chocolate to reddish brown; friable, loamy to clayey, 4 to 10 inches thick.	Red; crumbly, clayey, 10 to 20 inches thick.	Tertiary and Quaternary silts and clays.	Difficult.
Amarillo (sandy types)	Reddish brown; friable to moderately loose, loamy to clayey, 10 to 18 inches thick.	Red or reddish brown; friable sandy clay, 15 to 25 inches thick.	Tertiary and Quaternary sands.	Fair to difficult.
Calumet	Light brown; moderately compact, silty to clayey, 4 to 10 inches thick.	Brown to very dark brown; dense clay (claypan), 15 to 25 inches thick.	Reworked silts and clays	Difficult to unsuited.
Enterprise (dune phase)	Light-brown incoherent sand, ½ to 5 inches thick.	Yellowish brown or reddish yellow incoherent sand, 10 to 15 inches thick.	Wind-blown sand	Fair to difficult.
Foard	Dark to very dark brown compact clay, 6 to 8 inches thick.	Very dark brown to nearly black dense clay (claypan), 20 to 25 inches thick.	Permian and Triassic "Red Beds."	Difficult.
Hollister	Dark brown; friable, silty to loamy, 8 to 10 inches thick.	Dark brown, compact semiclaypan, 25 to 30 inches thick.	do	Fair to difficult.
Lincoln	Brown; coherent to moderately loose, loamy to sandy, 10 to 15 inches thick.	Light gray brown; moderately loose to coherent, sandy, 24 to 30 inches thick.	Recent sands and sand-silt mixtures.	Good.
Miles Enterprise (sandy types)	Grayish brown to reddish brown; coherent to moderately loose, loamy to sandy, 10 to 15 inches thick.	Red to reddish brown; friable sandy clay, 25 to 40 inches thick.	Tertiary and Quaternary sands and sandy clays.	Do.
Miller	Dark chocolate red; friable to moderately compact; texture and thickness variable.	Chocolate red; moderately compact, loamy to sandy, 20 to 30 inches thick.	Recent "Red Beds" sediments.	Do.
Mutual [2]	Brown; friable, loamy to sandy, 10 to 16 inches thick.	Dark brown; friable, clayey, 16 to 40 inches thick.	Permian and Triassic "Red Beds."	Do.
Potter	Brown to grayish brown; friable, loamy to clayey, 4 to 8 inches thick.	Grayish brown to light yellowish brown; friable, clayey, 6 to 12 inches thick.	Tertiary silts and clays	Difficult.
Pratt	Brown; loose to moderately coherent, loamy to sandy, 10 to 18 inches thick.	Light brown to reddish or yellowish brown; friable, loamy to sandy, 18 to 24 inches thick.	Tertiary and Quaternary sands and gravels.	Fair to good.
Pullman	Brown; friable, loamy to clayey, 10 to 18 inches thick	Dark brown to brown crumbly clay over reddish-brown crumbly clay; 18 to 40 inches thick.	Tertiary silts and clays	Difficult.
Randall	Dark brown to black compact clay, 4 to 10 inches thick.	Gray to bluish-gray dense clay (claypan), 30 to 48 inches thick.	Silts and clays (lacustrine)	Unsuited.
Richfield (fine-textured types)	Brown to dark brown; friable, loamy to clayey, 10 to 18 inches thick.	Dark brown to brown crumbly clay to clay loam, 18 to 40 inches thick.	Tertiary silts and clays	Fair to difficult.
Rough broken land	[1]	[1]	Variable	Variable.
Spur	Light brown to dark, chocolate brown: friable; texture and thickness variable.	Light brown to light chocolate brown; friable; texture and thickness variable.	Recent sand, silt, and clay sediments.	Good.
St. Paul	Brown; friable, silty to clayey, 10 to 14 inches thick.	Brown; moderately compact, clayey, 35 to 40 inches thick.	Permian and Triassic clays and sandy clays.	Fair to good.
Summit	Black; silty to clayey, friable, 10 to 14 inches thick.	Very dark grayish-brown to black moderately compact clay, underlain by yellowish-brown friable clay; 20 to 36 inches thick.	Limestone	Good.
Tillman	Brown; friable, silty to loamy, 8 to 12 inches thick.	Reddish brown; moderately compact, clayey, 30 to 35 inches thick.	Permian and Triassic clays and sandy clays ("Red Beds").	Fair to difficult.
Vernon	Red to reddish brown; friable, loamy to sandy, 2 to 10 inches thick.	Red; friable, loamy to sandy clay, 10 to 14 inches thick.	do	Good to difficult.
Woodward [2]	Red to reddish brown; friable, loamy to sandy, 8 to 12 inches thick.	Red to brown red; loamy, 14 to 20 inches thick.	do	Good.
Yahola	Chocolate red to red; friable, loamy to sandy; thickness variable.	Red; moderately loose to incoherent, sandy, 20 to 30 inches thick.	Recent "Red Beds" sediments.	Do.
Zita	Brown; friable, loamy to sandy, 7 to 12 inches thick.	Brown to yellowish brown; friable, clayey, 12 to 18 inches thick.	Tertiary silts and clays	Fair to difficult.

[1] Not stated.
[2] Provisional correlation.

The Pullman silty clay loam differs from the corresponding texture of the Richfield soil chiefly in that it has a slightly lighter colored topsoil (fig. 70). Both soils are developed on nearly level surfaces, but the Richfield usually occupies the almost dead-level or slightly depressed situations, while the Pullman, in most places, has sufficient slope to permit water to run off slowly.

This soil group covers most of the smooth High Plains of the Texas Panhandle, the Richfield occurring more extensively north of Canadian River and in the eastern part of the High Plains south of that stream (fig. 71).

The water table throughout most of the area lies at depths ranging from 100 to 300 feet, though in some localities of the Texas portion water can be obtained at depths of 30 to 70 feet.

FIGURE 70.—Profile of Pullman silty clay loam, showing a thick topsoil and a well-developed zone of lime accumulation, Potter County, Tex. This soil is heavy but not compact.

Many small depressions or lake beds are within the areas mapped with this soil group. These contain water, often for several weeks, after heavy rains, but are dry most of the year. They are occupied by Randall clay, a dark-gray, dense formation several feet deep which has been thoroughly leached of its lime.

The Pullman and Richfield silty clay loams have high moisture-holding powers, and their smooth surfaces favor the collection and retention of water. They are in a region, however, where much of the precipitation falling on fine-textured soils evaporates before it can penetrate deeply and is rather ineffective in supplying the soils with sufficient moisture for good tree growth.

Few trees are making vigorous growth on the soils of this group. The species which seem to be surviving best are red cedar, desert-willow, lilac, tamarisk, Russian-olive, dwarf Asiatic elm, honeylocust, and hackberry. Few of these trees, except where artificially watered, exceed 20 feet in height, and most of them are lower. It is doubtful that extensive tree planting on the soils of this group will be successful, and the shelterbelt zone has been so delimited as to avoid them for the most part.

RICHFIELD FINE-TEXTURED SOIL GROUP

The Richfield fine-textured soil group, which consists chiefly of Richfield silt loam, comprises most of the High Plains occurring within the shelterbelt zone in southwest Kansas and northwest Oklahoma. The group includes large areas of soils classed on the reconnaissance soil map of western Kansas as Greensburg and Summit silt loams and silty clay loams. From examination it appears that there is insufficient difference between them and true Richfield silt loam to warrant a separation for the present purpose.

The topsoil of Richfield silt loam is dark-brown, mellow silt loam about 10 inches thick. The upper subsoil is light-brown, moderately heavy clay loam which grades at a depth of about 26 inches into grayish-brown calcareous silty clay loam. The parent material is soft brownish-yellow marl. It is highly calcareous and lies within a depth of about 4 feet. The entire soil section is friable. The water table is 100 to 300 feet deep.

The surface of the Richfield silt loam ranges from nearly level to very gently rolling. All of the soil has adequate surface and underdrainage.

This group, as mapped, extends almost across the shelterbelt zone in southern Kansas and entirely across it in central Kansas. The soil has a high moisture-holding capacity but in the western part of its range is unable to absorb enough of the rather low precipitation to support good tree growth. In the eastern part of the zone it is fairly well adapted to dwarf Asiatic and American elm, hackberry, red cedar, Russian-olive, mulberry, lilac, and tamarisk, although practically none of these trees has made good height growth. Many black locust and green ash trees have been planted on this soil, but most of them have been injured by borers, especially in the western part of the zone.

ZITA AND POTTER SHALLOW SOIL GROUP

The Zita and Potter shallow soil group is composed mainly of loams and fine sandy loams. It also includes small scattered areas of rough broken land.

The Zita and Potter soils are developed on unconsolidated marl-like beds of the High Plains, under conditions of rather severe sheet erosion. They occupy gentle to fairly steep slopes within areas of the Richfield and Pullman soils and occur also on the escarpment leading down from the High Plains to the Rolling Plains on the east. Most of the areas shown on the map are in northern Texas and northwestern Oklahoma.

The Potter soils have thin top soils ranging in color from brown to grayish brown and in texture from loam to sandy loam. The subsoils are lighter in color than the topsoils. They usually consist of clay loam or loam but in many places are composed of gray chalky marl which has been little modified by weathering. Numerous outcrops of marl are characteristic.

The Zita soils differ from the Potter only in that they are a little better developed. They have slightly thicker topsoils and subsoils and occupy less steeply sloping surfaces.

The soils of this group are not well suited to trees, owing largely to unfavorable moisture conditions. Much of the precipitation is lost as run-off before it can penetrate the ground. Some of the smoother areas of the Zita soils have about the same tree adaptations as the Richfield and Pullman soils, but the more eroded areas are of little value for shelterbelt planting.

upland soils. These possibilities are not encouraging, however, on account of the scanty rainfall of the section.

The topsoil is red or reddish-brown fine sandy loam, 10 or 15 inches deep. This grades below into friable red fine sandy clay or fine sandy loam, which becomes highly calcareous at an average depth of 3 feet. The subsoil rests on Plains marl.

PRATT SANDY SOIL GROUP

The soils of the Pratt sandy soil group occupy large areas in southern Kansas and northwestern Oklahoma and are locally developed in the northern part of the

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Figure 71.—A typical stretch of Richfield silt loam, which, with the closely related Pullman soil, characterizes the surface of the slightly undulating High Plains of the western Texas Panhandle, a small portion of Oklahoma, and southwestern Kansas. This view, showing closely grazed buffalo grass sod, was taken 8 miles south of Dodge City, Kans.

HAMILTON SOIL GROUP

The soils of the Hamilton group have no relation to the shelterbelt zone as it now exists. They occupy an upland area north of the Arkansas River in the extreme western part of Kansas. They appear to bear only scrubby tree growth and are considered unsuited to shelterbelt planting.

AMARILLO SANDY SOIL GROUP

The Amarillo sandy soil group is occupied chiefly by Amarillo fine sandy loam, which occurs on the High Plains of Texas considerably west of the extreme southern part of the shelterbelt zone. The soil lies adjacent to the heavier Pullman and Richfield soils. Should shelterbelt planting later be attempted on the High Plains of Texas, the soils of this group have better possibilities than any other of the finer textured

Texas Panhandle. They have developed from sandy materials, the greater part of which were probably produced through the weathering of sandy Tertiary formations—although in some areas of the Pratt soils they came from sandy shales of the "Red Beds." In most places the parent material has been so mixed and reassorted by the wind that it is impossible to make any definite statement in regard to its origin.

The Pratt soils as mapped in this survey are variable, but nearly all of them are sandy. The topsoils in most places have accumulated rather large amounts of organic matter and are brown or grayish brown. They range in texture from fine sandy loams to sands, the loamy sands predominating. The subsoils are composed largely of loose sand but may locally contain considerable amounts of clay. They are light brown or reddish brown. Some of them are calcareous.

The surface features of the Pratt soils have been produced largely by wind, which has whipped the loose sands into low rounded hummocks and ridges, creating a gently rolling or billowy topography. Locally, the surface, especially that of the coarser textured types, is somewhat dunelike.

The soils of this group absorb practically all of the precipitation and, considering their sandy character, have high moisture-holding powers. Those in southwestern Kansas do not receive enough moisture to insure satisfactory growth of any except the most drought-resistant trees and shrubs. Those in the shelterbelt zone, however, not only offer good chances of growth and survival to drought-resistant species but also are fairly favorable to such trees as boxelder, cottonwood, ponderosa and Austrian pine, wild cherry, tamarisk, silver maple, black walnut, coffeetree, sycamore, and catalpa. The last four species mentioned seem much better adapted to the finer- than to the coarser-textured soils of the group.

MILES-ENTERPRISE SANDY SOIL GROUP

The Miles sandy soil group includes soils characterized by grayish-brown loose sand or fine sandy loam topsoils and friable red sand-clay subsoils. The topsoils range from a few inches to about a foot in thickness. The subsoils are usually calcareous.

These soils have developed from water-laid sandy clays which thinly cap the "Red Beds" in places and which are probably of Tertiary or Quaternary age. They have undulating to hilly surfaces. Their topsoils, being composed largely of loose sand, rapidly absorb the precipitation, and the sandy clay subsoils permit little or no moisture to be lost in the underdrainage. Included with this group are some areas of Enterprise soils. These differ from the Miles chiefly in that their subsoils contain less clay, are less coherent, and have a lower lime content.

The soils of this group are very drought-resistant. All of them are well suited to trees. Much of the land occupied by them now supports thick growths of low shin oak. Hackberry, American and dwarf Asiatic elms, honeylocust, catalpa, soapberry, red cedar, mulberry, Osage-orange, lilac, and desert-willow are all showing favorable growth. The following species are less extensively grown but seem to give fair results: Black locust, silver maple, coffeetree, sycamore, apricot, gum elastic, black walnut, little walnut, Austrian pine, Arizona cypress, Russian-olive, ponderosa pine, wild plum, wild cherry, and redbud.

ABILENE SANDY SOIL GROUP

The Abilene sandy soil group as mapped consists chiefly of sandy types of the Abilene soils, which occupy only a small area in the shelterbelt zone. Most of these soils are in Roger Mills County, Okla., where they were correlated as Richfield soils in an earlier survey. They have developed from Tertiary or Quaternary deposits which locally cover the "Red Beds."

The Abilene soils are characterized by grayish-brown sandy or loamy topsoils and yellowish-brown sandy clay subsoils. They resemble the Miles soils in topographic, drainage, and textural features but differ from them in subsoil color.

The soils of this group have rapid water-absorbing and high moisture-holding capacities. They are very drought-resistant and are well adapted to a variety of trees, including most of the species mentioned in connection with the soils of the Miles sandy soil group. Much of the area occupied by the Abilene soils is now covered by a rather thick growth of shinoak.

VERNON SANDY SOIL GROUP

The Vernon sandy soil group comprises a number of red and reddish-brown soils, largely of sandy texture, on the rolling "Red Bed" plains of western Oklahoma and the eastern part of the Texas Panhandle. These soils have developed from reddish-colored sandy shales or sandy clays. The group as provisionally correlated includes three principal soils, namely, Vernon, Woodward, and Mutual.

The Vernon soils are composed largely of fine or very fine sandy loam but locally contain considerable clay. They have no well-developed topsoil and subsoil layers. The sandy shales or sandy clays of the "Red Beds" from which they are forming are, in many places, within a depth of 2 or 3 feet. The Vernon soils are calcareous even at the surface, and have a bright-red or reddish-brown color. The topography, as a whole, ranges from gently rolling to hilly. These soils are very erosive and include numerous small areas in which the "Red Beds" have been deeply carved.

The Woodward soils are similar to Vernon but occupy smoother areas, have slightly thicker and darker topsoils, and are a little more deeply developed. Their subsoils are red and very limy.

The Mutual soils are on the more nearly level-lying areas of the rolling "Red Bed" plains and have well-developed profiles. Their topsoils are brown and are underlain by thick, friable clay loam or loam subsoils of reddish-brown color. Lime occurs at a depth of several feet.

The soils of this group are well enough watered in the shelterbelt area to support a variety of tree growth. Native growths of shin oak and mesquite occur on them in places. On the more level-lying areas, the following species have been planted and are growing with reasonable vigor: Honeylocust, Osage-orange, green ash, hackberry, dwarf Asiatic elm, soapberry, Russian-olive, desert-willow, redbud, red cedar, Arizona cypress, apricot, and wild plum.

MILES-VERNON SANDY SOIL GROUP

The Miles-Vernon sandy soil group occupies areas in which sandy Miles and Vernon soils are so intimately mixed that separations are impracticable on a small map. Within these areas the parent soils materials consist of patchy remnants of Tertiary and Quaternary sandy clays which cap the "Red Bed" formations in numerous places. Practically all of the areas are in the north Texas portion of the shelter-belt zone. The individual soils are similar to those in other groups with which they are associated (figs. 72 and 73).

FOARD, TILLMAN, HOLLISTER, ST. PAUL, ABILENE, AND ROSCOE HEAVY SOIL GROUP

The group of Foard, Tillman, Hollister, St. Paul, Abilene, and Roscoe heavy soils cover a large area in southwestern Oklahoma and occur locally in the northwestern part of that State. They are found in nearly level to rolling situations on the "Red Bed" plains. The soils have moderately heavy silt loam or clay loam surface layers underlain in most places by heavy clay subsoils which vary in their physical features. All soils of this group have developed mainly from "Red Bed" materials and have highly calcareous subsoils.

The Foard soils have nearly level surfaces. They have light-brown to dark-brown silty clay loam topsoils underlain by brown dense claypan upper subsoils.

The Tillman soils are on undulating surfaces. They have brown topsoils and reddish-brown, heavy but not claypan subsoils.

Hollister soils are dark brown in the upper layers and have dark-colored semiclaypan subsoils, ranking between the Foard and Tillman in claypan tendencies.

St. Paul soils have uniformly rich-brown surface layers overlying brown, thick subsoils which are only moderately compact.

as in the northern and central sections. It comprises areas of steeply sloping lands or breaks which are so severely eroded that they are of no value for farming except in local patches. Large developments occur on the escarpments bordering the High Plains areas in Texas, where erosion has cut through thick Tertiary deposits and has greatly dissected the underlying "Red Beds." Large developments also occur on the rolling "Red Bed" plains in western Oklahoma.

Considerable areas of these breaks can be advantageously planted to conserve run-off and prevent erosion. Red cedars grow naturally in many places.

ALLUVIAL SOILS UNDIFFERENTIATED

The soils of the first bottoms or flood plains occupy narrow strips in the southern section. Only the wider developments are indicated on the map, and the width of these is perhaps exaggerated in many places.

FIGURE 72.—Miles loamy sand (cotton field in foreground) showing the shin oak cover which prevails more or less on this soil in western Oklahoma and the eastern portion of the Texas Panhandle. Location 7 miles north of Ramsdell, Wheeler County, Tex.

The Abilene soils belonging to this group are much heavier than those of the Abilene sandy group. Here they differ from the St. Paul soils chiefly in origin; the Abilene is developed on materials from Tertiary or Quaternary deposits, whereas the St. Paul are formed largely on older formations.

Roscoe soils have black or very dark-brown topsoils overlying moderately compact dark-gray or brown subsoils. They differ from the Foard soils chiefly in that their subsoils are less compact.

Although the soils of this group have high clay content and slow moisture-absorbing powers, they lie in a region where the precipitation is sufficiently abundant to offset the latter disadvantage in large degree, especially on the less clayey members. Time did not permit a study of the trees on these soils.

ROUGH BROKEN AREAS

Rough broken land is extensive in the southern section and is indicated on the map in the same manner

The widest strips of alluvium are along the Arkansas River, where they are occupied chiefly by the friable, fine-textured Laurel soils. The sandy brown soils of the narrow bottom lands in the rolling "Red Bed" plains are classed as Lincoln soils. Some of these soils along the Cimarron River and the north fork of Canadian River contain alkali. Red alluvial soils occur in narrow strips along streams passing through "Red Bed" formations on the Rolling Plains. Those composed largely of silts and clays are classed as Miller, while those of a sandy character are correlated as Yahola soils. Narrow strips of Spur soils, having chocolate-brown topsoils and slightly lighter colored subsoils, occur along some of the drainage ways in the High Plains. The Spur soils vary little in texture from the surface downward.

Practically all the soils in the bottom lands of the southern section are well adapted to trees. Most of them are underlain by a water table within the reach of tree roots. Cottonwood, hackberry, and American elm grow naturally and attain considerable size on these soils. Native willows, soapberry, gum elastic, walnut, mulberry, and wild plum also occur. Among the planted trees and shrubs, dwarf Asiatic elm, honeylocust, catalpa, black locust, coffeetree, ailanthus, apricot, red cedar, Russian-olive, lilac, desert-willow, and redbud are well adapted to most of these soils.

VERNON SOILS AND ROUGH BROKEN AREAS

The group of Vernon soils and rough broken areas includes areas in which the Vernon and Potter soils and rough broken land occur in such small and intricately associated bodies that separations are not practical in a reconnaissance survey.

The Vernon soils, chiefly Vernon fine sandy loam, cover the greater part of the area included in the group. They are found on rolling to hilly land and are associated with Potter fine sandy loam, especially in localities where the "Red Beds" are capped by thin Tertiary remnants. Narrow strips and small, irregular-shaped bodies of rough broken land occur where erosion has deeply carved the Tertiary and "Red Bed" deposits.

The species listed as giving the best results on the soils of the Miles group are equally well adapted to the sandier Vernon soils of this group. Planting of drought-resistant trees can be done advantageously even on the Potter soils and rough broken land, especially as a water-conservation and erosion-control measure.

DUNE-SAND GROUP

Dune sand in the southern section is usually browner than that in the northern and central sections and generally has a reddish tinge not present in the more northern dune sand. It is classed in detailed soil surveys as Enterprise fine sand, dune phase. Aside from color, the material is almost identical with that of the Nebraska sand hills. The surface features are similar to those in the more northern sand-hill areas.

Dune sand covers several rather large areas in the southern section. Most of it is on the rolling "Red Bed" plains near the Red River-Panhandle angle of Texas and Oklahoma. Although very dunelike, it is protected from blowing in most places by a sparse cover of grasses. Practically all of it is included in grazing land. No shelterbelt planting is contemplated on this material, although in places extensive forest planting would be a possibility.

FIGURE 73.—View of the fine sandy phase of Vernon soil of the Rolling Plains of western Oklahoma in Harper County. The less droughty character of these soils, as compared with the Richfield of the High Plains (fig. 71) may be noted here.

ACKNOWLEDGMENTS

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The writers are indebted to G. E. Condra, director of the conservation and survey division of the University of Nebraska, for providing the survey headquarters with office, drafting, and library accommodations, and for making available the assistance of L. A. Brown, E. H. Tyner, and B. J. Abashkin in the preparation of data.

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North Dakota.—Bottineau, McHenry, Lamoure, and Dickey Counties, Cando area, Jamestown area; reconnaissance soil survey of western North Dakota.

South Dakota.—Walworth, Hyde, Douglas, Beadle, and Brown Counties; reconnaissance soil survey of western South Dakota.

Nebraska.—Sioux, Dawes, Sheridan, Box Butte, Scotts Bluff, Banner, Morrill, Garden, Kimball, Cheyenne, Deuel, Keith, Perkins, Lincoln, Chase, Dundy, Hitchcock, Red Willow, Furnas, Harlan, Franklin, Webster, Adams, Kearney, Phelps, Dawson, Buffalo, Hall, Howard, Custer, Nance, Boone, Madison, Pierce, and Antelope Counties; Frontier County (field work in progress); surveys, completed but not published, of Hayes, Gosper, Sherman, Valley, Greeley, Wheeler, Garfield, Loup, Holt, Rock, Brown, Keyapaha, Boyd, and Knox Counties.

Kansas—Reno County; reconnaissance soil survey of southwestern Kansas.

Oklahoma.—Roger Mills, Texas, Kiowa, Tillman, Greer, and Woodward Counties; Washita County (field work in progress).

Texas.—Potter, Dickens, and Lubbock Counties; Randall and Wheeler Counties (not yet published); reconnaissance soil surveys of Panhandle region of Texas and of northwest Texas.

Other maps consulted were the following:

Land classification map of the central Great Plains, 1931, cooperation Department of the Interior with Department of Agriculture.

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Nebraska land classification surveys, Nebraska Conservation and Survey Division, Lincoln (not published).

Section 13.—NATIVE VEGETATION OF THE REGION

By J. M. Aikman, *botanist, Lakes States Forest Experiment Station, Forest Service*

CONTENTS

THE GRASSLAND

Before the advent of the plow, grasses prevailed throughout the central portion of North America, with all other vegetative types as minor associates. The displacement of much of the grass in favor of field crops that has since occurred has not altered the essential character of the region.

The grassland formation of the central United States extends westward to the Rocky Mountains from a line running through central Minnesota and Iowa, along the eastern boundary of Kansas, and southward to the Gulf of Mexico.

This extensive plant community may be divided throughout its length from north to south into two almost equal-sized units, corresponding to its naturally dominant types—the prairie on the east, and the short-grass plains on the west. The two important factors which seem to account for this division are simply the amount of precipitation (rain and snowfall), and the proportion of this moisture that is left available to vegetation as against losses through evaporation, run-off, and colloidal adsorption or binding of moisture by the soil. The tall or prairie grasses require a combination of these two factors (such as occurs to the eastward) which makes for a relatively high available moisture content in the soil for a relatively long time through spring and summer; whereas the short grasses are adapted to the more difficult moisture situation that exists to the west.

There is, of course, no definite dividing line between the two plant communities, but rather a north-south zone upon which precipitation, decreasing generally from east to west, occurs in just the requisite marginal amounts to insure the growth of both tall and short grasses in association or mixture; this association of plants may occur as a commingling of individuals or of limited tracts or patches, as determined by local variations of soil.

The boundaries of this mixed-prairie zone, like those of all such natural groupings, are irregular. Within its confines the soils vary from clay or silt through a series of loams to pure sand, either fine or coarse, with the silt or loams predominating; but its western border is deeply enfolded by extensions of the more continuous heavy western soils—the typically or exclusively short-grass country. The map (fig. 76) plainly shows this feature. Its eastern border is somewhat more regular, because soil differences are to some extent equalized as climatic factors become more favorable.

The determination of the general boundaries of the mixed prairie zone was an important factor in the final location of the shelterbelt zone, which was to be placed far enough west to protect areas of predominantly agricultural land, and yet not too far to insure success in growing trees. While there is a higher percentage of farm land in areas farther east, the mixed prairie zone represents the westward extent, in the central region, of land which may be considered predominantly actual or potential farm land—even though a satisfactory land-use program might reduce to some extent the present farm acreage. At the same time, the presence of well-established tall grasses in the native grassland cover indicates a depth of water penetration much more favorable for the growth of shelterbelts than the shallow depth of water penetration in the short-grass plains bordering the mixed prairie on the west.

The shelterbelt zone boundaries as now delimited have been superposed on the grassland map (fig. 76). Their generally close correlation with the mixed prairie zone is evident.

THE TRUE PRAIRIE

Because of the narrowness of the mixed prairie zone in several places, portions of the prairie fall within the shelterbelt zone. While these are true prairie sites, the sparse habit of growth of their grasses is more or less similar to the typical bunch-grass habit of tall-grass components of the mixed prairie.

In the present discussion only this western border of the prairie, included in the shelter-belt area, is considered. The chief prairie dominants along this border in North Dakota and the northern half of South Dakota are slender wheatgrass, *Agropyron*

DEMONSTRATED SHELTERBELT POSSIBILITIES

F 298265

FIGURE 74.—No apparent encouragement to tree growth in this sandhill section of Nebraska, but a type of site proved by actual experiment to be well suited for forest planting. These low, stabilized sand hills are covered, somewhat sparsely, with prairie grasses, prairie beardgrass. and porcupine grass. Near Rose, Nebr., in northern Loup County. (See text, p. 162.)

F 295446

FIGURE 75.—An illustration of tree-growing possibilities in the shelterbelt zone. White spruce and ponderosa pine growing without irrigation at the Northern Great Plains Field Station, Mandan, N. Dak.; height, 24 to 30 feet. (See text, p. 162.)

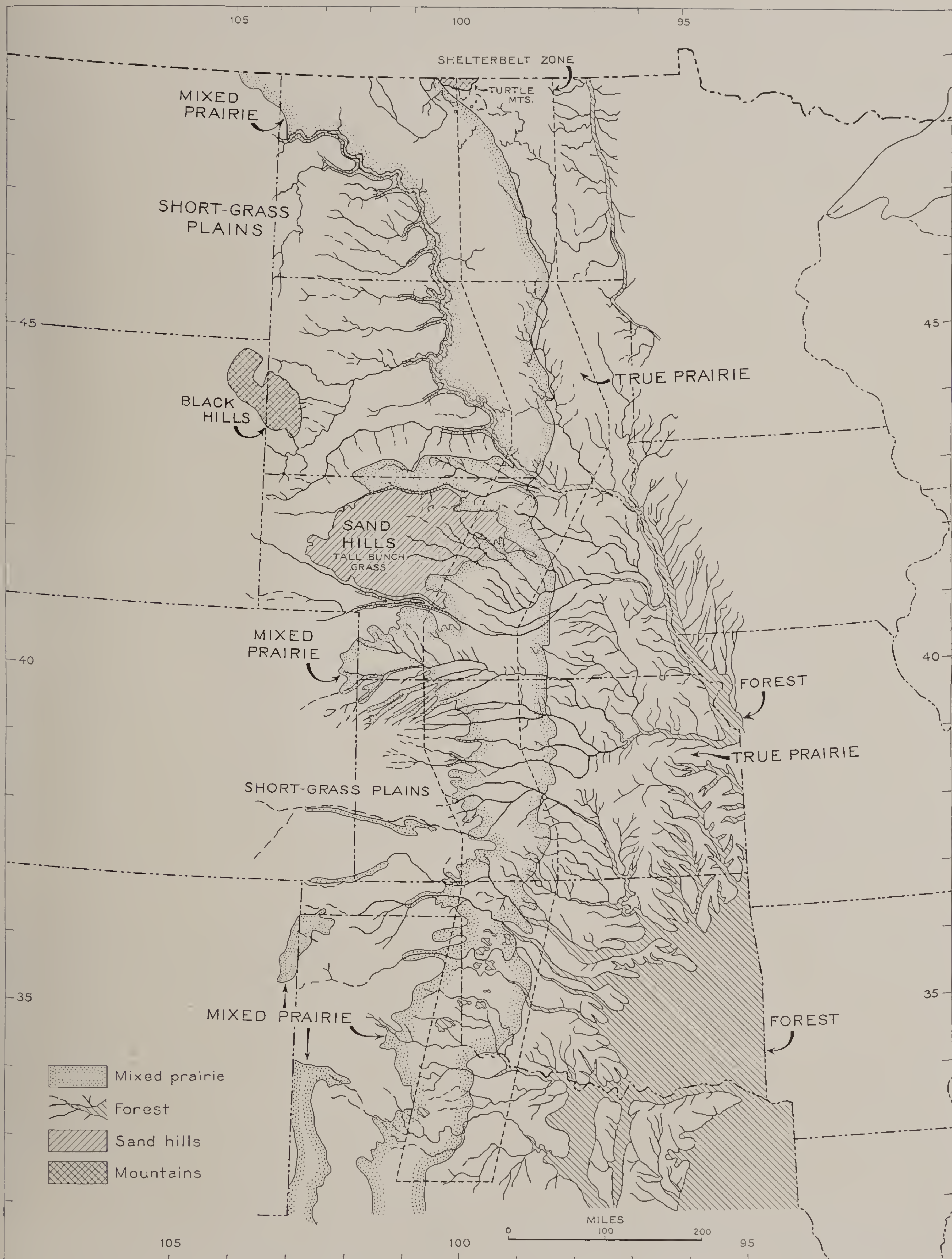

FIGURE 76.—Principal vegetative zones of the prairie-plains region.

pauciflorum (Schwein.) Hitchc., (with some bluestem, *A. smithii* Rydb., invading from the southwest) and porcupine grass, *Stipa spartea* Trin., (with needle-and-thread, *Stipa comata* Trin and Rupr., invading from the west). Other species, the first of which in some places assumes a role of dominance, are prairie beardgrass, *Andropogon scoparius* Michx.; side-oats grama, *Bouteloua curtipendula* (Michx.) Torr.; junegrass, *Koeleria cristata* (L.) Pers.; prairie dropseed, *Sporobolus heterolepis* Gray; and bluejoint turkeyfoot, *Andropogon furcatus* Muhl. This cover of grasses uses all of the available moisture of the soil by the middle of the summer, in the more favorable years making a later growth; but differs from the grassland types farther east in being often limited by drought. The growing season is of sufficient length, however, to insure a permanent tall-grass cover of sufficient density to prevent the invasion of short grasses. Although the soil is chiefly of a heavy type, a yearly rainfall of 18 to 22 inches, with a low rate of evaporation, insures survival of the tall grasses, and also of adapted trees if competition of native vegetation is removed.

The chief dominants of that portion of the prairie from central South Dakota to northeastern Nebraska which is included in the shelterbelt zone are prairie beardgrass and porcupine grass (with needle-and-thread invading from the west). Wheatgrass and bluestem may be dominant in certain localities. Prairie beardgrass occupies the most favorable sites and bluestem the least favorable. Important subdominants are side-oats grama, prairie dropseed, junegrass, and bluejoint turkeyfoot.[49]

The annual rainfall for this region ranges from 22 to 26 inches. The northern part of the region in east central South Dakota, with a rainfall of only 22 inches and with an increase in evaporation over that of the North Dakota section, is less favorable to the growth of prairie grasses than the other included prairie areas. These conditions are further accentuated by the presence of some heavy, unfavorable soils.

In the discontinuous narrow strip of prairie occurring in the shelterbelt zone in southern Kansas and Oklahoma, prairie beardgrass is the chief dominant. Another of the silver beardgrasses, *Andropogon saccharoides* Swartz, is a codominant. Other important species of the true prairie are bluestem and a longleaf grass, *Sporobolus asper* (Michx.) Kunth.

The tall prairie grasses, porcupine grass and junegrass, are here found, in scattered bunches, only in the most mature and well-established portions of the prairie. On deep sandy soil bluejoint turkeyfoot, *Andropogon furcatus* Muhl., and turkeyfoot, *A. hallii* Hack, are important. The annual rainfall of the prairie here is 26 to 28 inches. If correction for increased evaporation in the south is made by subtracting 6 inches from these figures, they still compare favorably with the rainfall of 18 inches for the western border of the prairie in northern North Dakota. Here, as elsewhere in this strip, there is sufficient moisture to insure survival of true prairie grasses and of properly adapted trees, although after midsummer there is usually a deficiency of moisture for continued growth.

THE MIXED PRAIRIE

The western boundary of the mixed prairie may be described as a line (fig. 76) east of which sufficient rain falls and penetrates the soil to wet it periodically to a depth varying from 24 to 30 inches. Plants whose roots penetrate the soil to a depth of 24 inches or more obtain moisture for sustained growth for a period of at least 2½ months each year, even in drought years. The presence of a permanent tall-grass population is thus insured. The space between these bunches of prairie grasses is occupied by short grasses. On typical upland soil west of the area thus defined, a periodic shortage of water even at a depth of 18 inches precludes the maintenance of a definite permanent tall-grass population within the short-grass cover.

The eastern boundary of the mixed prairie is a line west of which prairie grasses, which assume a bunch-grass habit because of a shortage of available soil moisture, no longer entirely dominate the area but share dominance with short grasses which become permanently established. There are, however, several isolated areas of heavy impervious soil, as those east of the Missouri River in North Dakota and South Dakota from Bismarck to Chamberlain, and those in southern Gosper, Phelps, Kearney, and Adams Counties and in northern Harlan and Franklin Counties in Nebraska, where almost no permanent establishment of the true prairie-grass components of the mixed prairie occurs; their absence in the eastern part of these areas may, to some extent, be attributed to severe grazing.

The depth of penetration of roots in the mixed prairie zone would seem to insure the establishment in the more favorable soils of tree species especially adapted to xeric conditions. Most of the trees within shelterbelts in this zone have been able to extend their roots to a considerably greater depth than 30 inches, especially under conditions which, in the regular addition of duff to the soil and the collection of additional snow by the trees and shrubs, to any extent simulate forest conditions.

THE SHORT-GRASS PLAINS

To the west of the area just described lie the vast plains of the short-grass country. The adaptation of the short grasses to the heavy soils and light precipitation of this region (and to similar soils in the mixed prairie region) is quite definite. In the heavy, fine-textured soils, percolation of moisture is slow and limited in depth, and there is a high percentage of run-off, especially of the heavier rains, so that for months or years the subsoil may remain dry. The short grasses make fullest use of the topsoil moisture. Their root systems, fibrous and shallow, almost completely cover the area, taking up the small amount of available water in a limited time, and their season's growth and reproductive processes are completed in a few weeks.

The most important dominant of the entire short-grass plains community (association) (fig. 76) is blue grama, *Bouteloua gracilis* (H. B. K.) Lag. In the central and eatsern part of the Plains, from southern South Dakota southward, buffalo grass, *Buchloe*

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[48] Nomenclature of the grasses follows HITCHCOCK, A. S.: MANUAL OF THE GRASSES OF THE UNITED STATES. U. S. Dept. Agr. Misc. Pub. 200, 1040 pp., illus. 1935.

[49] WEAVER, J. E., and FITZPATRICK, T. J. THE PRAIRIE. Ecological Monog. 4: 111–295. 1934.

dactyloides (Nutt.) Engelm., is associated with blue grama. In well-developed short-grass plains, the cover is short and has the smooth appearance of a closely grazed pasture.[50] Taller grasses, as three-awn, *Aristida* sp., and herbs are more abundant on the eastern border of the Plains, but even here the role of the tall-grass constituents, because of the shallowness of moisture penetration, is not important and permanent enough for the community to be considered mixed prairie. Because of the complete occupation of the top few inches of soil by the fine, fibrous roots of the blue grama and buffalo grass, these grasses are shown to be the true dominants of the community.

NATIVE TREE AND SHRUB COMMUNITIES OF THE SHELTERBELT ZONE

Within the shelterbelt zone native trees and shrubs are found growing in considerable numbers, despite plants in the grassland formation as it occurs in one State (Kansas) is shown in figure 77.

SPECIES AND VARIETIES

In a preliminary survey of 11 weeks' duration in the summer and fall of 1934, collections of many plants were made at 115 separate stations, chiefly within the shelterbelt zone, but also in areas adjacent to the zone along both the eastern and western boundaries, and in many other locations. It is proposed that the collected specimens will be mounted and lodged in a permanent collection. For the present, this collection is to be maintained at the Lake States Forest Experiment Station at St. Paul, Minn.

Table 23 is a list of the species and varieties of trees and shrubs of the shelterbelt zone, which may be considered complete except in the minor respects to be noted later. It includes 141 species and varieties.

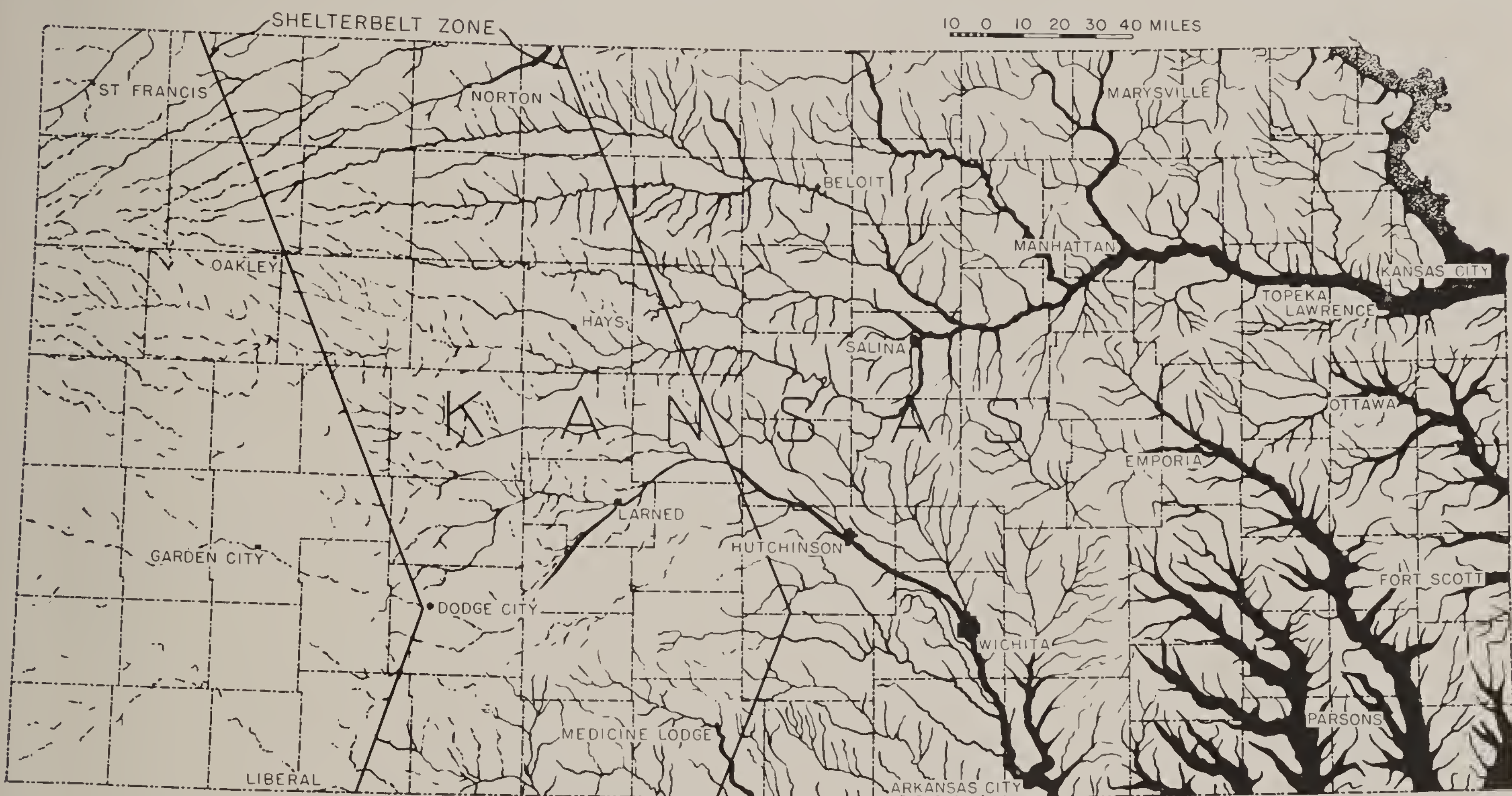

FIGURE 77.—Typical distribution of trees and shrubs bordering stream courses in the grassland formation (Kansas).

the disadvantages of a typically grassland climate. Their presence, bordering stream courses and dry runs, in ravines and in potholes, may be attributed to the protection afforded against excessive evaporation as well as to the additional water supply available in these situations. Such forested areas forecast the general advance of woodland should the climate become wetter, and they suggest the entire feasibility of shelterbelt growing under proper methods of species selection, site preparation, and water conservation such as are contemplated.

Irregular topography is the chief factor affecting reduction of the evaporating stress of the atmosphere, although the presence of the trees and shrubs themselves affects the rate of evaporation in the immediate vicinity and lessens the net moisture demand per individual. A typical distribution of these woody

The list was compiled from the collections of trees and shrubs in the herbaria of the State colleges and universities of the States in which the shelterbelt zone is located and from the collection list of the author. All specific and varietal names were included except those concerning which there is considerable controversy.

Nomenclature of tree species is after Sudworth's Check List of the Forest Trees of the United States. The scientific names of trees not included in this list and of the shrubs were determined by the author after an examination of the specimens and existing lists of specimens prepared by workers in the several States. General keys used in this examination were Gray's Manual of Botany, seventh edition, Rydberg's Flora of the Prairie and Plains, and Coulter and Nelson's New Manual of Rocky Mountain Botany. In each case the name of the authority is included in order that synonyms may be determined. The common

[50] SHANTZ, H. L. THE NATURAL VEGETATION OF THE GREAT PLAINS REGION. Ann. Assoc. Amer. Geogr. 13: 81–107. 1923.

names are from the above sources, but in case of conflict the author selected the common name which seemed to be in most general use.

It was attempted, by the removal of specimens from one herbarium to another for comparison, to make the classification of species uniform for the composite list. Specimens which had been identified by authorities in different groups were given especial attention in this comparison. In some instances the specimens in a herbarium were reclassified by the author and the results tabulated under the new name decided upon. Assistance was obtained from the curators of the several herbaria in this evaluation and comparison, but the author must take full responsibility for the final results.

Data of distribution in the shelterbelt zone by States are included in the table. A species or variety is checked for a given State if it occurs at any place within the shelterbelt zone in that State. Table 23 may be used as a reference list for all scientific and common names of trees and shrubs occurring hereinafter.

TABLE 23.—*Native trees and shrubs of the Shelterbelt Zone*

[x implies that the species occurs in the State indicated]

No.	Scientific name	Common name	Mapped	Distribution in Shelterbelt Zone					
				North Dakota	South Dakota	Nebraska	Kansas	Oklahoma	Texas
1	Pinus ponderosa Laws	Ponderosa pine	x			x			
2	Juniperus communis L	Dwarf juniper	x	x	x	x			
3	J. horizontalis Moench	Creeping juniper		x	x				
4	J. pinchotii Sudw	Redberry juniper	x						x
5	J. scopulorum Sarg	Rocky mountain red cedar	x			x			
6	J. virginiana L	Eastern red cedar	x	x	x	x	x	x	x
7	Smilax hispida Muhl	Bristly greenbrier			x	x	x	x	
8	Salix amygdaloides Anders	Peachleaf willow	x	x	x	x	x	x	x
9	S. bebbiana Sarg	Beak willow		x	x	x			
10	S. candida Fluegge	Hoary willow		x	x				
11	S. mackenzieana Barr	Diamond willow	x	x	x	x	x		
12	S. discolor Muhl	Pussy willow		x	x				
13	S. exigua Nutt	Sandbar willow					x	x	x
14	S. humilis Marsh	Prairie willow				x	x		
15	S. longifolia Muhl	Sandbar willow	x	x	x	x	x	x	x
16	S. lucida Muhl	Shiny willow		x	x	x			
17	S. lutea Nutt	Yellow willow			x				
18	S. nigra Marsh	Black willow			x	x	x	x	x
19	Populus acuminata Rydb	Lanceleaf cottonwood			x	x			x
20	P. augustifolia James	Narrowleaf cottonwood			x	x			x
21	P. balsamifera L	Balsam poplar		x	x	x			x
22	P. deltoides virginiana (Cast.) Sudw	Southern cottonwood	x	x	x	x	x	x	x
23	P. sargentii Dode	Cottonwood	x	x	x	x	x	x	x
24	P. tremuloides Michx	Aspen	x	x	x	x			
25	Juglans nigra L	Black walnut	x		x	x	x	x	
26	J. rupestris Engelm	Little walnut	x					x	x
27	Hicoria pecan (Marsh.) Britt	Pecan	x					x	
28	Ostrya virginiana (Mill.) K. Koch	Hop-hornbeam	x	x	x	x			
29	Betula fontinalis Sarg	Red birch		x					
30	B. papyrifera Marsh	Paper birch	x	x	x	x			
31	Corylus americana Walt	American hazelnut	x	x	x	x			
32	C. rostrata Ait	Beaked hazelnut		x	x				
33	Quercus havardii Rydb	Havard oak	x					x	x
34	Quercus macrocarpa Michx	Bur oak	x	x	x	x	x	x	x
35	Q. marilandica Muench	Blackjack oak	x					x	x
36	Q. mohriana Rydb	Shin oak	x					x	x
37	Q. muhlenbergii Engelm	Chinquapin oak	x				x	x	x
38	Q. stellata Wang	Post oak	x					x	x
39	Q. stellata parviloba Sarg	do	x					x	x
40	Ulmus americana L	American elm	x	x	x	x	x	x	x
41	U. fulva Michx	Slippery elm	x	x	x	x	x		
42	Celtis laevigata Willd	Sugarberry	x	(1)	(1)	(1)	(1)	(1)	(1)
43	C. occidentalis L	Hackberry	x	x	x	x	x	x	
44	C. occidentalis crassifolia (LaM.) Gray	do		x?	x?	x?	x?	x?	x?
45	C. reticulata Torr	Paloblanco	x				x	x	x
46	C. reticulata vestita Sarg	do	x				x	x	x
47	Morus rubra L	Red mulberry	x				x	x	x
48	Toxylon pomiferum Raf	Osage-orange	x					x	
49	Clematis ligusticifolia Nutt	Western virgins-bower		x	x	x	x	x	x
50	C. virginiana L	Virgins-bower		x	x	x			
51	Menispermum canadense L	Common moonseed		x	x	x	x		
52	Odostemon aquifolium Rydb	Oregon hollygrape			x	x			x
53	Cocculus carolinus (L.) DC	Carolina snailseed					x	x	
54	Ribes aureum Pursh	Slender golden currant	x	x	x	x	x	x	x
55	R. americanum Mill	American black currant	x	x	x	x	x		
56	R. inebrians Lindl	Squaw currant			x	x			
57	R. odoratum Wendl	Golden currant	x	x	x	x	x	x	x
58	Grossularia missouriensis (Nutt.) Cov. and Britt.	Missouri gooseberry		x	x	x	x		
59	G. setosa (Lindl.) Cov. and Britt	Redshoot gooseberry	x	x	x	x			
60	Platanus occidentalis L	Sycamore	x	(2)	(2)	(2)	(2)	(2)	(2)
61	Opulaster intermedius Rydb	Ninebark	x	x	x	x			
62	Spiraea alba DuRoi	Meadow spirea		x	x				
63	Cercocarpus parvifolius Nutt	Valley-mahogany					x	x	x
64	Rubus argutus Link	Highbush blackberry					x	x	
65	R. idaeus aculeatissimus (C. A. Mey.) R and T.	Wild red raspberry	x	x	x	x			
66	R. occidentalis L	Common blackcap	x	x	x	x	x		
67	Rosa acicularis Lindl	Prickly rose		x	x	x			
68	R. arkansana Porter	Arkansas rose				x	x		
69	R. blanda Ait	Meadow rose		x	x				
70	R. fendleri Crep	Fendler rose			x	x			
71	R. macounii Greene	Macoun rose			x	x			
72	R. pratincola Greene	Wild prairie rose	x	x	x	x	x	x	
73	Amelanchier alnifolia Nutt	Alder-leaved serviceberry		x	x	x			
74	A. humilis Wieg	Low shadblow	x	x	x	x			

[1] South and east of Shelterbelt Zone.
[2] East of Shelterbelt Zone.

TABLE 23.—*Native trees and shrubs of the Shelterbelt Zone*—Continued

No.	Scientific name	Common name	Mapped	Distribution in Shelterbelt Zone					
				North Dakota	South Dakota	Nebraska	Kansas	Oklahoma	Texas
75	*Crataegus occidentalis* Britt	Spike hawthorn	x	x	x	x			
76	*C. chrysocarpa* Ashe	Hawthorn		x	x				
77	*Prunus americana* Marsh	Wild plum	x	x	x	x	x	x	
78	*P. angustifolia* Marsh	Chickasaw plum	x				x	x	x
79	*P. angustifolia watsoni* Waugh	Sand plum	x				x	x	x
80	*P. besseyi* Bailey	Bessey cherry		x	x	x	x		
81	*P. pennsylvanica* L	Pin cherry		x	x				
82	*P. virginiana* L	Choke cherry	x	x	x	x	x	x	x
83	*P. virginiana melanocarpa* (A. Nels.) Sarg	Western choke cherry	x	x	x	x	x	x	x
84	*Prosopis juliflora glandulosa* (Torr.) Cook	Honey mesquite	x				x	x	x
85	*Gleditsia triacanthos* L	Honeylocust	x		x	x	x		
86	*Gymnocladus dioicus* (L.) Koch	Coffeetree				x	x	x	
87	*Cercis canadensis* L	Redbud						x	
88	*Amorpha canescens* Pursh	Leadplant	x	x	x	x	x	x	x
89	*A. fruticosa angustifolia* Pursh	False indigo		x	x	x	x	x	
90	*A. nana* Nutt	Dwarf indigobush		x	x	x			
91	*Xanthoxylum americanum* Mill	Common prickly-ash	x	x	x	x	x		
92	*Ptelea trifoliata* L	Hoptree	x				x	x	x
93	*Rhus glabra* L	Smooth sumac	x	x	x	x	x	x	x
94	*R. nortonii* (Greene) Rydb	Western skunk brush	x			x	x	x	x
95	*R. trilobata* Nutt	Lemonade sumac	x	x	x	x	x	x	x
96	*Toxicodendron rydbergii* (Small) Greene	Western poison-ivy	x	x	x	x	x		
97	*T. radicans* (L.) Kuntz	Poison-ivy	x	x	x	x	x	x	x
98	*Celastrus scandens* L	American bittersweet		x	x	x	x	x	
99	*Euonymus atropurpureus* Jacq	Wahoo			x	x	x		
100	*Acer negundo* L	Boxelder	x	x	x	x	x	x	x
101	*A. negundo violaceum* Kirch	do	x	x	x	x	x	x	x
102	*Sapindus drummondii* H. and A	Western soapberry	x				x	x	x
103	*Ceanothus ovatus* Deaf	Inland Jersey-tea			x	x	x	x	x
104	*C. ovatus pubescens* T. and G	do			x	x	x	x	x
105	*Zizyphus obtusifolia* Gray	Texas jujube						x	x
106	*Vitis cinerea* Engelm	Sweet winter grape	x					x	
107	*V. doaniana* Munson	Doan grape						x	
108	*V. longii* Prince	Long's grape	x				x	x	x
109	*V. rupestris* Scheele	Sand grape						x	
110	*V. vulpina* L	Riverbank grape	x	x	x	x	x	x	x
111	*Parthenocissus quinquefolia* Planch	Virginia creeper	x	x	x	x	x	x	x
112	*P. vitacea* Hitchc	Thicket creeper	x	x	x	x	x		x
113	*Tilia glabra* Vent	Basswood	x	x	x	x	x		
114	*Shepherdia argentea* Nutt	Silver buffaloberry	x	x	x	x	x	x	x
115	*S. canadensis* Nutt	Russet buffaloberry		x	x				
116	*Cornus amomum* Mill	Silky dogwood		x	x	x			
117	*C. asperifolia* Michx	Roughleaf dogwood	x		x	x	x	x	x
118	*C. baileyi* Coult. and Evans	Bailey dogwood		x	x				
119	*C. candidissima* Small	Dogwood		x	x				
120	*C. instolonea* A. Nels	do	x	x	x	x	x		
121	*C. interior* Rydb	do				x			
122	*C. stolonifera* Michx	Red-osier dogwood	x	x	x	x			
123	*Diospyros virginiana* L	Persimmon	x					x	x
124	*Bumelia lanuginosa* (Michx.) Pers	Gum elastic	x					x	x
125	*Fraxinus campestris* Britt	Prairie ash	x	x	x	x	x	x	x
126	*F. pennsylvanica lanceolata* (Borkh.) Sarg	Green ash	x	x	x	x	x	x	
127	*Forestiera acuminata* Poir	Texas adelia		x	x			x	x
128	*Cephalanthus occidentalis* L	Buttonbush	x				x	x	x
129	*Sambucus canadensis* L	American elder	x		x	x	x	x	x
130	*Viburnum lentago* L	Nannyberry	x	x	x	x			
131	*V. trilobum* Marsh	American cranberrybush		x	x				
132	*Symphoricarpos occidentalis* Hook	Western snowberry	x	x	x	x	x		
133	*S. orbiculatus* Moench	Coralberry	x			x	x	x	x
134	*Chrysothamnus graveolens* (Nutt.) Greene	Rabbit brush		x	x	x			
135	*C. howardii* (Parry) Greene	do				x			
136	*C. pulchellus* (Gray) Greene	do						x	
137	*Gutierrezia sarothrae* (Pursh.) Britt. and Rus	Broom snakeweed		x		x	x	x	x
138	*Artemisia filifolia* Torr	Sand sagebrush		x			x	x	x
139	*A. tridentata* Nutt	do		x	x	x	x	x	x
140	*Baccharis salicina* T. and G	Willow baccharis					x	x	x
141	*Elaeagnus argentea* Pursh	Silverberry	x	x					

This list of 141 trees and shrubs, compiled from the collections studied, does not include all species and varieties that have been reported for the zone area. Such a list has, however, been compiled; it contains 173 names. Some of the names included in the manuals as of plants occurring in the area are names of varieties which are not recognized in the above list; other names are of plants of very sparse or doubtful occurrence; a few, doubtless, are of plants which may be added to the above list after a more careful survey has been made, for which purpose a collecting trip was definitely planned for the spring and summer of 1935.

DISTRIBUTION OF IMPORTANT SPECIES AND SUBTYPES

The origin of the species of trees and shrubs found within the area may be traced easily. More than half of them are constituents of two divisions of the deciduous forest formation of eastern United States, namely, the central hardwoods and the southern hardwoods. Their invasion into the zone has followed up the main streams and tributaries from the east. The other important movement of species has been eastward from the Rocky Mountain forest formation through the central and the southern Rocky Mountain forests.

Maps showing the extent of the entire grassland distribution of the 71 trees and shrubs of most common occurrence in the shelterbelt zone have been prepared. These maps are based on distribution data and collections obtained in the 1934 preliminary botanical survey of the shelterbelt area, the findings of which were compared with published and unpublished reports on distribution made by several investigators in the area and further checked by a study of the collection points of specimens in the herbaria of State colleges and universities of the States in which the shelterbelt zone occurs.

There are four trees which occur throughout the entire area—sandbar willow, cottonwood, boxelder, and choke cherry. In mapping cottonwood, no distinction was made between *Populus deltoides virginiana* (Cast.) Sudw. and *P. sargentii* Dode. Boxelder, *Acer negundo* L., and the western variety, *A. negundo violaceum* Kirch., were mapped together, as were choke cherry, *Prunus virginiana* L., and western choke cherry, *P. virginiana melanocarpa* (A. Nels.) Sarg. Since no two investigators seem to agree as to the proper distinction between the eastern and western forms of each of these three trees, it is found impossible to map separate distributions for any of the forms with any degree of satisfaction. Separation of the two species of golden currant, *Ribes aureum* Pursh. and *R. odoratum* Wendl., is easier, but the overlapping of the distribution of the two species and their similar habitat requirements make it advisable to combine their distribution.

One shrub, the golden currant, one shrubby vine, poison-ivy, and one vine, the riverbank grape, are distributed over the entire zone.

Almost complete for the entire area are the distributions of six trees—eastern red cedar, peachleaf willow, American elm, hackberry, green ash and prairie ash combined, and the wild plum. The northeastward extent of the first, the southward extent of the second, the westward extent of the next two, and the southwestward extent of the last two are so indefinite that their distribution over the area might well be considered complete. Green ash and its westward form, the prairie ash, because of difficulty of separation, have been mapped as one species.

RELATIVE ECOLOGICAL IMPORTANCE OF SPECIES

A chart has been prepared representing graphically the occurrence and the ecological value of species of native trees and shrubs in the shelterbelt zone (fig. 78). Each of the strips running crosswise of the page represents the shelterbelt zone, with divisions showing the portion of the zone in the several States. The whole chart, and consequently each strip, is oriented geographically: Top, east; left side, north. Absence of a species from any portion of the belt is designated by a blank space, and its presence, together with its relative importance ecologically, is indicated by one of four different hatchings in the proper space. Thus each strip is a species-ecology map in miniature.

A species is given the highest rating (indicated by double crosshatching) if it is found in sufficient abundance to influence the habitat value of the site in which it occurs, provided that the type of site in which it is found is common throughout the area designated. In general, those species which occur in a wider variety of sites, if at all abundant in the average site, rank higher than those which are more specific in habitat requirements. Greater abundance of a species in sites of a particular type may, however, compensate to some extent for its lack of distribution in different types of sites, and vice versa. Shrubs and trees have been represented separately in the chart.

Of the 73 trees and shrubs considered of ecological importance within the shelterbelt area and included in the chart, 40 are found in the belt in North Dakota, 43 in South Dakota, 49 in Nebraska, 41 in Kansas, and 50 in Oklahoma and Texas. The westward extension of nine species of southern trees and shrubs into the zone region only as far as the Oklahoma and Texas portion accounts for the increased number in those States. Favorable conditions presented by the sandhill section probably account for the fact that species extend from all directions into Nebraska, giving it the second highest number. Species from northern Nebraska continue along the Missouri River into southern South Dakota.

Computation of results in terms of number of species entirely covering the shelterbelt zone in the five State divisions of the belt gives the following figures: North Dakota, 34 species; South Dakota, 34; Nebraska, 36; Kansas, 28; and Oklahoma and Texas 30. Of these species, those having the highest rating ecologically in the respective divisions appear in the following number: North Dakota, 23; South Dakota, 17; Nebraska, 11; Kansas, 11; and Oklahoma and Texas, 16. These data give emphasis to the fact, not usually recognized, that forest communities in the northern part of the shelterbelt area have fewer casual species and a greater number of important representative species than have those in the southern part of the area.

COMPOSITION OF TREE AND SHRUB COMMUNITIES

Despite wide variation from north to south in the climatic conditions of the shelterbelt zone, the native tree and shrub communities in the northern, central, and southern divisions of the region are surprisingly uniform in general appearance.

This uniformity would seem to be attributable to the fact that there is no wide variation from north to south in the balance between available soil water and loss of water by evaporation. The presence of one narrow plant-life form, the mixed prairie, throughout the entire region gives special emphasis to this uniformity of balance. That there is, however, a quite definite change in balance from east to west is evidenced by the difference in general appearance of tree and shrub communities within this short distance of approximately 100 miles. The most apparent change in such communities from north to south is change in species rather than in any important change in life form, whereas a lessening in abundance and vigor of growth in a number of species is noted as one crosses the zone westward. Figures 74 and 75 and figures 79 to 94 were not selected with this effect particularly in view, but they indicate the main aspects of tree and shrub development in the region. Figures 79, 80, 91, and 92 fairly well present conditions in its westward reaches.

The native forest communities within the shelterbelt area may be divided into two types: The hydrophytic type, immediately bordering water, as along permanent or intermittent streams or in pockets containing surplus water, and the upper flood-plain and upland type, farther removed from free water.

THE HYDROPHYTIC TYPE

Hydrophytic plant communities, occurring as noted above, more or less resemble the lower flood-plain communities of the eastern United States. They are more uniform as to species and general character throughout the area than are those of the other type. In all parts of the area, the borders of streams which have

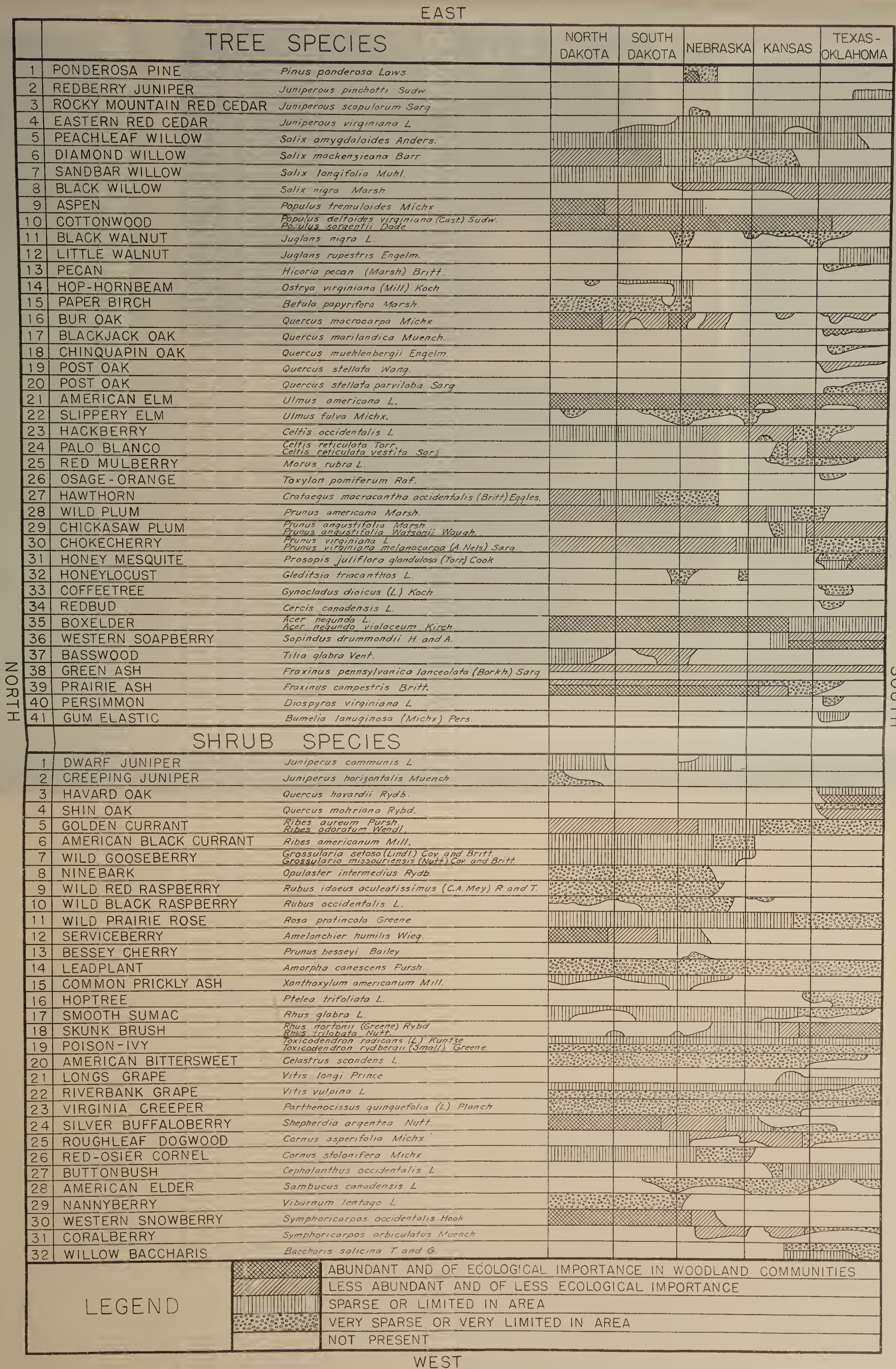

FIGURE 78.—Ecological value of species and varieties of trees and shrubs in native woodland communities in the shelterbelt zone.

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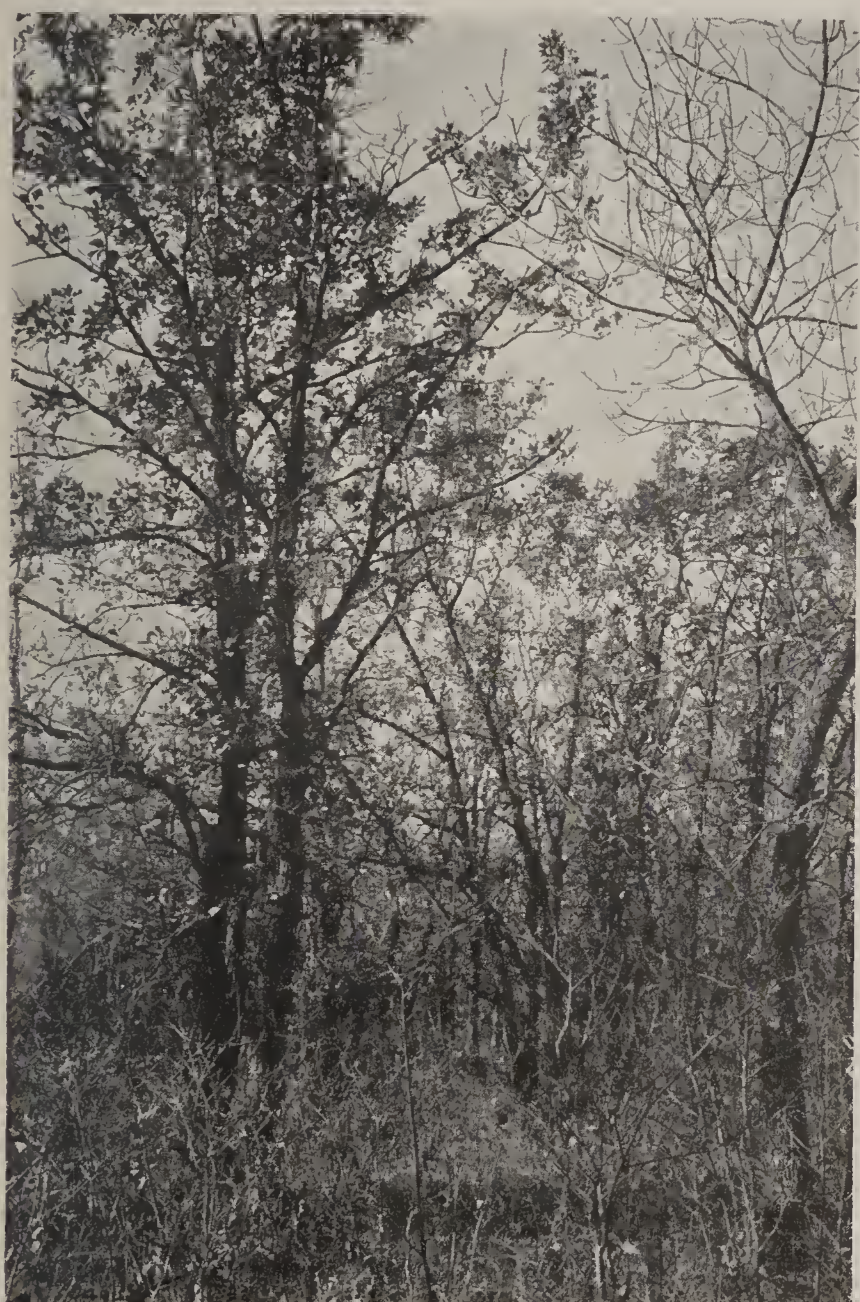
an abundance of water for at least a few months of the year are more or less completely lined with a mixture of sandbar willow, black willow, peachleaf willow, diamond willow, cottonwood, false-indigo, boxelder, and, in the South, buttonbush. On sandy borders of larger streams from southern Kansas southward, *Tamarix gallica*, an early escape, and the willow baccharis, a tall, alkali-tolerant shrub, are important members of the communities. To the westward, as permanent water supply becomes more of a rarity, the stand becomes more open, until at last, along a thousand small, intermittent tributaries, hydrophytic communities made up of widely spaced willow, cottonwood, and boxelder constitute the only forested areas.

There is little in this ultimate sparse and irregular grouping of trees to suggest typical forest conditions.



F295443

FIGURE 79.—Bur oak-prairie ash association on gentle slope on the south border of Devils Lake, N. Dak. The stand averages 300 trees per acre, 22 to 30 feet in height, and 3 to 8 inches in diameter breast high. The dominants of the dense undergrowth are choke cherry, serviceberry, and American plum. Other tall shrub associates are nannyberry, hawthorn, silverberry, and buffaloberry. Low shrubs growing in this cover and extending beyond the tall shrubs and trees are gooseberry, wild red raspberry, smooth sumac, western snowberry, and wild prairie rose.

Shade, quantity of duff, and protection afforded associate plants are at a minimum. Many of such groups are of recent origin, having developed only since the cessation of periodic prairie fires.

THE UPPER FLOOD-PLAIN AND UPLAND TYPE

Tree and shrub communities of the upland type are found on the upper flood plains of streams and on the bordering slopes. They may be of only occasional

F295470

FIGURE 80.—An isolated prairie ash, showing rough bark and generally stunted habit of growth under dry-land conditions. The slope borders a small intermittent stream 7 miles south of Mandan, N. Dak.

occurrence, as along the more shallow valleys, or may be continuous, as along deep valleys. Most of the valleys and slopes in the more easterly part of the shelterbelt zone afford sufficient protection for forest communities of this type.

The communities are made up of a few species of eastern upland and upper flood-plain trees which are adapted to growth in drier situations. With these species are associated a few species from the West. In composition and structure the communities vary, according to the protection of the site, percentage of available soil water, age, and stage of successional development, from sparse, poorly developed groups having 200 or fewer small trees per acre, with associated shrubs, to well-developed stands of as many as 900 mature trees per acre. In the latter case there is usually sufficient duff to form a rich soil, and only a sparse growth of the more tolerant shrubs. In less

F295445

FIGURE 81.—Association of prairie ash, American elm, Rocky Mountain red cedar, and boxelder on protected portions of the upper flood plain and on protected slopes bordering the Little Missouri River, 15 miles south of Watford City, N. Dak. These restricted communities contain 80 to 100 large trees per acre and 400 to 800 small trees, with ash predominating. A well-developed second story of wild plum, serviceberry, buffaloberry, dogwood, skunk brush, wild prairie rose, and creeping juniper also occurs.

F295465

FIGURE 82.—Comparison of prairie ash (right and left) and boxelder (center) under upland shelterbelt conditions. The ash is 15 feet high and 2 to 4 inches in diameter breast high. The boxelder has been cut back to live growth after severe drought injury. Northern Great Plains Field Station, Mandan, N. Dak.

favorable sites or on grazed sites there may be no duff but an undercover of grass or, where grass is absent, a dense growth of less tolerant shrubs.

This type differs so greatly in species for different parts of the area that it must be described as it occurs in the north, central, and south divisions of the zone. The chief difference evident in proceeding from the eastern border of the zone westward is a reduction in number of species and in size of trees and shrubs, and a less frequent ocurrence of sites suitable for the development of the type. The change from north to south is a change in important species.

THE NORTHERN DIVISION

In North Dakota and the northern half of South Dakota, the important species of the upland type on the eastern border of the shelterbelt area are green ash, American elm, and bur oak. The three species grow well together, forming an association on upper flood plains and on protected slopes, where basswood is also of frequent occurrence. These communities take on a forestlike aspect, with plentiful shade, sufficient duff, and protection to associate plants. In the more favorable sites, 400 to 800 trees per acre, of diameter breast high averaging 8 inches and a height of 20 to 45 feet, may ocur. Associate trees are the hackberry and slippery elm. Openings in the stand are often occupied by aspen and boxelder and, occasionally, by paper birch.

Species of small trees and shrubs within and bordering the stand are choke cherry, western choke cherry, wild plum, silverberry, buffaloberry, common prickly ash, serviceberry, golden currant, American black currant, Missouri gooseberry, and dwarf juniper. More xeric shrubs forming a zone between this type and the grassland are western snowberry, smooth sumac, wild prairie rose, and leadplant. Less favorable sites, as upland ravines and pockets, may contain most of these shrub species with no trees or with the young trees developing in the cover of shrubs. Especially in North Dakota, extensive areas on the more protected slopes are covered with western snowberry, some serviceberry, silverberry, buffaloberry, and choke cherry.

F295460

FIGURE 83.—Green ash-American elm association on the upper flood plain of Snake Creek, a tributary of the James River about 3 miles south of Ashton, S. Dak. A $\frac{1}{10}$-acre plot contains 18 elm and 30 ash trees of a height of 30 to 40 feet and diameter breast high of 6 to 12 inches.

F295458

FIGURE 84.—A specimen of green ash 25.5 feet in height and 6.3 inches in diameter breast high, growing in a sparse stand in the same general upland location shown in figure 89. The man is picking ash seeds.

The most important change in type as we proceed westward is the dropping out of basswood, slippery elm, and common prickly-ash, the reduction in the size of the trees, and the increasing importance of shrubs in the sites, especially silverberry, buffaloberry, choke cherry, serviceberry, and western snowberry. Within the glaciated region in central North Dakota

F295456

FIGURE 85.—Prairie ash trees 15 to 18 feet in height and 4 to 5 inches in diameter breast high, growing in sparse stands on the upper flood plain of the Keyapaha River in southern South Dakota.

F298268

FIGURE 86.—Mixed prairie on sandy loam, located 20 miles north of Wray, Colo., but typical of several sandy loam areas within the shelterbelt zone. Prairie grass dominants are prairie beardgrass, porcupine grass, side-oats grama, and three-awn. The chief short-grass dominant is blue grama, *Bouteloua gracilis*. Yucca is an indicator of deep-seated moisture.

F298263

FIGURE 87.—A favorable site for shelterbelts within the zone. Dissected loess area in central Nebraska, 23 miles west of Albion. Western snowberry in protected pockets (in curve of road) and a well-developed shelterbelt in the background.

F298271

FIGURE 88.—Forest community of above-average development near the eastern side of the shelterbelt zone along the Medicine Lodge River, 4.2 miles west of Medicine Lodge, Kans. The dominants on the upper flood plain and on the upland are American elm, green ash, black walnut, and paloblanco, and on the lower flood plain are cottonwood and boxelder.

FIGURE 89.—A sparse stand of blackjack oak, with an occasional gum elastic tree, on sandy land bordering the North Canadian River on the eastern border of the shelterbelt area, near Seiling, Okla.

F298272

FIGURE 90.—Marginal forest community of limited extent on the Cimarron River at New Liberty, Okla. The trees are paloblanco (hackberry) and the shrubs are skunk brush and sand plum.

are a large number of potholes and poorly drained depressions, which are occupied by stands of aspen with some diamond and other willows.

One of the outstanding characteristics of this northern Dakota area is the persistence of prairie ash westward and towards the ends of ravines and in pockets. American elm is an accompanying species of slightly less importance in the stands.

THE CENTRAL DIVISION

The central division of the shelterbelt zone, lying in southern South Dakota and in Nebraska and extending to central Kansas, differs distinctly from the northern and southern divisions in composition of the tree and shrub communities of the upland type.

The center of distribution of trees in this division of the zone occurs in Nebraska, in the section around the sand hills and that bordering the Republican River and its tributaries. The important species of the upper flood plain and the upland are bur oak, American elm, and green ash (including prairie ash), the three species being of about equal abundance except toward the southern extreme of the area, where bur oak drops out. In forestlike aspect these communities are, in general, better developed than those in the westward reaches of the northern division. Associate trees, in most of the division, are hackberry, slippery elm, and eastern red cedar, with basswood, black walnut, honeylocust, coffeetree, and Rocky Mountain red cedar present, chiefly along the Niobrara and Republican Rivers. Occasional aspen and paper birch occur in openings only in South Dakota and northern Nebraska.

Species of small trees, and shrubs, seem to have at least as important a role in contact with the tree communities and on protected slopes and in depressions as in the northern division. Additional species of shrubs present in most of the area are roughleaf dogwood, American elder, and coralberry. Smooth sumac is much more important here in its invasion of the grassland, and serviceberry is less important. Of the entire division, the flatland of the second and third northern tiers of counties in Kansas seems to be the least favorable for the growth of trees and shrubs of this type.

Basswood, slippery elm, and common prickly-ash drop out toward the west, as in the northern division. Three shrubs—smooth sumac, roughleaf dogwood, and American elder—drop out westward, and serviceberry and common prickly-ash southwestward. Skunk brush is found in the western part of the division and not in the eastern, and coralberry replaces western snowberry in the undergrowth of sparse upland trees and in communities bordering trees and taller shrubs.

THE SOUTHERN DIVISION

The upper flood plain and upland vegetation of the southern division of the shelterbelt zone, from central Kansas to Lubbock, Tex., differs greatly in species from that of the other two divisions. For the entire eastern part of the division, the two most important and generally distributed trees are the paloblanco and the American elm. The paloblanco species is *Celtis reticulata* Torr., with the variety *C. reticulata vestita* Sarg. more important in the northern and western parts of its range and persisting in less favorable sites elsewhere.

These species are the dominant trees on the upper flood plain, on well-developed upland sites, and in protected pockets and ravines in otherwise unfavorable situations, as those bordering the Cimarron and Canadian Rivers and their tributaries. Of the two, the elm dominates the more mature and extensive woodland communities, whereas the paloblanco (hackberry) dominates upland communities in the early stages of tree development, being often the only species present.

The western soapberry, a persistent, drought- and alkali-resistant tree, is often codominant with paloblanco in early stages of tree development on less-favorable sites. In the eastern half of the area it is of less importance, because there forest communities have reached a higher stage of development. In the western half of the area, because tree growth is chiefly confined to poorly developed groups in ravines, pockets, and other protected sites, the soapberry and the paloblanco may be considered the two most important trees. Of the two, soapberry appears to be the pioneer in sites which are definitely alkaline, and the paloblanco in less alkaline sites.

Associated with the dominants in most of the division, although usually rare in occurrence, are eastern red cedar, little walnut, bur oak, post oak, and blackjack oak. Honey mesquite is distributed over the region, chiefly in Texas, from the (southern) Canadian River southward. It forms a very sparse stand in the typical mixed prairie (associated with sagebrush) and also in some parts of the plains area. It is found with the soapberry and paloblanco along streams and in pockets.

The following trees are associated with the elm and paloblanco in the northeastern portion of the division: Green ash, black walnut, hackberry, and wild plum. None of them are abundant enough to be considered of even local dominance. Gum elastic, occurring in the central-eastern part, is a component of the woodland vegetation, although it usually appears as an occasional tree rather than in close stands. Its foliage, which persists until early winter, makes it conspicuous in the woodland cover in late summer and fall. The coffeetree and persimmon are only of local occurrence in the division.

The following small trees, shrubs, and vines are quite abundant within the elm-hackberry stands, and in places in the division they form dense borders for the trees; in many canyons and pockets they form thickets which are excellent seed beds for tree species; Sand plum, the small-lobed variety of post oak, two species of shin oak, choke cherry, golden currant, hoptree, riverbank grape, Long's grape, coralberry, western skunk brush, smooth sumac, and wild rose. The sand plum and western skunk brush may be considered the dominants of these shrubby communities, the other species being either sparse over the entire range or of local occurrence.

In the entire division, oaks cover limited areas of sandy soils. Low sandy hills bordering streams in the eastern part are completely covered by blackjack oak for a distance of 1 to 4 or 5 miles back from the river. Post oak occurs in the slightly less sandy sites in these communities and forms small, sparse groups in favorable sites along the eastern border of the zone, as well as more and more isolated groups in pockets

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FIGURE 91.—Western soapberry on rough broken land bordering an intermittent stream west of the shelterbelt zone. 8 miles south of Borger, Tex. The trees are 10 to 25 feet high and 4 to 8 inches in diameter breast high. Most of the showy transparent yellow fruits remain on the tree during winter.

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FIGURE 92.—Occasional cottonwood trees, 25 to 40 feet in height and 12 to 36 inches in diameter breast high, and groups of paloblanco trees, 10 to 25 feet tall and 5 to 12 inches in diameter breast high, associated with western soapberry; 8 miles south of Borger, Tex.

and ravines to the westward. Varieties of post oak, of which the small-lobed variety and Palmer's variety seem to be the most common, together with two definitely recognized species of shin oak, occur on sandy land in the area southwestward from Woodward, Okla.

ADAPTATION OF NATIVE TREES AND SHRUBS TO SHELTERBELT PLANTING

As we have now seen, the shelterbelt zone is, except for those areas more or less closely bordering streams and lakes, essentially a mixed prairie region, with portions of residual prairie distributed along most of its eastern border. Although growth conditions in the zone as a whole, originally covered with grasses, are more unfavorable than in its limited forested area, it is equally true that the progeny of tree and shrub species bordering streams or occupying the adjacent slopes and uplands are better adapted to planting in the area than are tree and shrub species grown under conditions widely removed and different from those of the planting sites. This principle is stated with particular reference to native American species, since the present discussion is not concerned with exotics. A few of the latter, from sites comparable to our shelterbelt area, have been successfully introduced; these and others deserve thorough test as to their adaptability and importance to major shelterbelt developments.

REACTION OF TREES AND SHRUBS TO DRY CONDITIONS; ECOTYPES

The trees and shrubs native to the area are more drought-resistant than representatives of the same species growing under more favorable moisture conditions, chiefly farther east. This is self-evident from their mere presence under more xeric conditions; it is also fully attested by morphological modifications generally recognized as of drought-resistant significance, which are present in these western forms.

According to the principle of Klebs, the course of plant development is determined by internal conditions, but these internal conditions may be significantly altered by external factors. When plant development has thus been, indirectly, altered by environment (ecological) conditions of sufficient effect to change the appearance of the plant, the new form may be recognized as an ecotype.

It seems to be well established by experimental evidence that changes that have occurred in the ecotype are not permanent, and that the plant or its progeny will revert to original form when replaced in the original environment. The important consideration is, however, that plants so modified have taken on structural differences and also a different physiological behavior.

Abundant water, sufficient nutrient materials from the soil, and carbon dioxide, oxygen, and light, as well as moderate temperature, are necessary for what is usually considered normal plant growth. Under typical forest conditions in the eastern part of the United States, none of these factors is lacking except light for certain of the understory plants, and the balance attained is, on the whole, favorable.

A reduction in water supply is the most important difference between the environment of the mixed prairie and the forested areas farther east. Lack of water has its effect on the first stage of growth (cell division) of the tree or shrub, but since only small quantities of water are required for this stage, the reduction in cell division is not great except in years of extreme drought.

It is in the second stage of growth that the water supply is most important, because abundant water, with attendant manufacture of small quantities of food (sugars) is required for the enlargement of the newly divided, plastic-walled cells at the tips of roots and stems and in the cambial region at which growth in girth appears. It is in this stage of growth, therefore, that lack of water in the soil shows important effects in the general stunting of trees and shrubs. Often a severe drought year will result in a great reduction in and even a total absence of this second stage of growth. The severity of the great drought of 1934 was not sufficient, however, to reduce cell enlargement to any unusual extent in the better adapted trees of the mixed-prairie region.

The maturing and differentiation of enlarged cells in the third period of growth is especially dependent upon the supply of sugars manufactured by the plant. Reduction of the water supply usually causes a shortening of the second period of growth in favor of the differentiation stage, as does also an increase in temperature. This is the reaction which usually causes the stunting effect noticed above. Under very severe drought conditions there may be insufficient moisture for production of the sugars required for complete differentiation, but the usual reaction is the hastening of differentiation, especially of the flowers and fruits, and a consequent reduction in growth of the other parts of the plant.

Under the average precipitation conditions of the shelterbelt area, even the favorable soils have insufficient moisture for optimum growth of trees, but sufficient moisture for their continued growth and fruiting; in other words, the food-making process of the tree is not reduced below the minimum necessary to its life. Sugars which, under more favorable moisture conditions, would be used in growth accumulate and serve as the stimulus and the materials for differentiation. Cuticle and cork show more pronounced development, cell walls are thickened, fibers and conducting elements are more abundant in the new tissues; resins, gums, and the like accumulate, the cells become more resistant to drying and cold, and flowering and fruiting occur more regularly. Under these conditions of differentiation, induced by a moderate or average shortage of water, organic materials which normally accumulate in the aboveground parts and, with a sufficient water supply, promote top growth, move to the roots and stimulate root development. This increase in the ratio of roots to aboveground parts, which is characteristic of dry-land trees and shrubs, insures water absorption from larger soil areas and consequently a greater chance of permanent establishment.

CHARACTERISTICS OF TREES GROWING UNDER XERIC CONDITIONS

Because of their apparent adaptability to environmental conditions in some such manner as above described, native green ash trees were given particular study in the 1934 field survey. Ash "stations", at which special investigations and collections were made,

FIGURE 93.—Shin oaks invading sparse tall-grass prairie on sandy soil, 8 miles west of Wellington, Tex.

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FIGURE 94.—Gravelly floor of Palo Duro Canyon, beyond the western border of the shelterbelt zone, 14 miles east of Canyon, Tex. The chief woody plants are honey mesquite, redberry juniper, eastern red cedar, paloblanco, and lemonade sumac, growing with species of cactus and short grasses.

were located throughout the northern and central zone area.

Comparison of the eastern with the western forms is complicated by the recognition of the prairie ash by some authorities as a separate species, *Fraxinus campestris* Britt. and by others a variety, or simply an ecotype. Additional study is necessary before even an approximately satisfactory classification of the western green ashes can be made in this respect, and a careful investigation of the variation in structural and physiological response of the ash trees of the region is now in progress under the author's direction. Through study of twig characters (pubescence, leaf scars, bundle scars, and buds) and of leaf and fruit characters, an attempt is being made to separate the group into different forms on a morphological basis. A physiological study of the seedlings and of the parent trees is also being made to determine the possibility of making a division on the basis of physiological behavior. If these two attempts are successful, it may be found possible to separate the group into one or more ecotypes, and to select by morphological criteria those best adapted physiologically to survive.

The most apparent silvical variation of the green and prairie ashes, including both *Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg. and *F. campestris*, from observations at selected stations in order from east to west is reduction in size, as demonstrated by the following average measurements of mature trees:

	Height of tree (feet)	Diameter, breast high (inches)
Emmetsburg (northern Iowa)	57	17.9
Grand Forks, N. Dak	44	11.7
Devils Lake, N. Dak	25	5.2
Williston, N. Dak	20.5	3.9

In general, an ecotype or special form of an eastern tree which has become established in or beyond the shelterbelt area shows several characteristic differences from its original in addition to those of size. These results, verified by observation and data from several sources, would seem to arise from the series of reactions of the tree to dry conditions which have been previously discussed. They may be summarized as follows:

Increase in:
- Crown spread—slight.
- Ratio of girth to height.
- Ratio of twig diameter to length.
- Thickness of bark.
- Pubescence of twigs and leaves.
- Thickness of leaves (with thickening of cuticle).
- Production of resins, gums, alkaloids.
- Thickness of woody and fibrous elements.
- Regularity of flowering and fruiting.
- Ratio of root growth to crown growth.
- Fibrous development of root system.
- Extent of root system.

Reduction in:
- Height.
- Girth.
- Rate of growth.
- Length of nodes.
- In amount of food made, but not in rate.

Again referring to the green ash of the shelterbelt zone, modifications closely paralleling the above and thoroughly integrated into an adapted form whose habitat requirements accord more closely with those of the prairie grasses than do those of eastern ash are recognized in it. A typical prairie ash tree of the kind in question is shown in figure 80. In general, this western form of the green ash is a more compact and drought-resistant tree than its eastern congener. The particular tree shown has a height of about 20 feet, a crown round in outline rather than elongate, a rough appearance resembling the bur oak, shortened internodes, pubescent twigs, and shorter, thicker, more compact leaves. The girth is much reduced as compared to that of the eastern form, but the ratio of girth to height is increased.

The physiological activities of the tree have also become modified toward true drought resistance in the increased rate of food making when water relations are favorable and in the adaptability to quick change in response to lack of water during dry seasons.

Mass selection for drought-resistance has probably operated in a manner somewhat as follows: A tree, as the ash or elm or bur oak, which became established in a ravine at the edge of the shelterbelt area in a given year, bore a few hundred or a few thousand fruits. Of this number a small percentage fell, were blown, or were carried by birds or rodents into favorable situations, where the seed germinated. Severe conditions of various kinds accounted for the death of most of the seedlings, but the inheritance of various unit characters for survival, such as vigor, effective root system, thick bark, and the like, contributed to the establishment of a few of them and to the successful development of a still smaller number.

Those that developed had, in a higher degree than the others, the characteristics necessary for germination and establishment in an unfavorable habitat. A higher percentage of progeny of this generation would have those characteristics necessary for survival than progeny of the original parent tree had. Repetition of this process of mass selection through many generations would reasonably account for the development in the region of large numbers of trees representing ecotypes of eastern species.

THE ADAPTATION OF TREES AND SHRUBS TO ALKALI

According to Marbut, there is present in the entire shelterbelt area, on some horizon of the soil section, a zone of alkaline salt accumulation, chiefly calcium carbonate. The zone of accumulation, because of the decreased depth of water penetration, is nearer the surface as one proceeds westward. The presence of such a zone would indicate that all trees and shrubs of the area are to some extent alkali-resistant as compared to forms of the same species growing in the east, and the closeness with which the roots of a given plant can approach the zone of carbonate accumulation may be taken as a rough measure of that resistance.

The series of reactions of such plants to a gradual increase in alkalinity or salinity of the soil solution is to some extent comparable to the reactions to dry conditions, but the alkali response is more complex because of the great variety of the chemical reactions involved. The response also differs according to the quantity of each compound in the soil solution; very weak solutions of many alkalis increase the rate of water absorption, whereas the presence of any considerable quantity of alkali salts in the soil solution results in a decrease in the rate of water absorption and in the injury and inhibited development of root hairs and roots of the plant. In the case of neutral salts, the rate of absorption may be decreased only because of the lowered diffusion-gradient of water into the plant as concentration of the soil solution increases.

The degree of modification of trees and shrubs of the area toward alkali resistance is an important factor in their adaptability to shelterbelt conditions. The more definite adaptation of several species, as the willow baccharis, western soapberry, and honey mesquite, in this respect makes possible their planting and growth in moderately alkaline areas. Thereafter, by stages of plant succession, the alkaline sites may be slowly modified and made more favorable with deeper penetration of roots and resultant leaching of alkali salts.

Section 14.—GROUND-WATER CONDITIONS OF THE SHELTERBELT ZONE

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CONTENTS

The amount of ground water within the shelterbelt zone, not including the soil and subsoil moisture, is far greater than that of the surface water, and considerably greater than the volume of an annual rainfall. It has important economic relations in supplying well water, subirrigation water, and springs.

In some places where the ground water is shallow, it contributes directly to the growth of plants. There are in the shelterbelt zone a number of such areas, often sandy in character, whose boundaries are shown on the accompanying water-region maps which accompany the report. A knowledge of the location of areas in which the water table lies at depths of 5 to 20 feet is invaluable, because such localities offer the best possibilities in the shelterbelt zone for tree planting, from the point of view of growth and longevity. Such localities probably occupy, altogether, some 5 or 6 percent of the total area of the zone. It is entirely reasonable to assume that in these same areas in drought years, recently established plantations could be irrigated by systems of temporary wells and portable power pumps.

Over the remainder of the area the water table is beyond the reach of tree roots, but information as to the depth, quantity, and quality of the water is of interest especially in deciding the location of forest nurseries. A plentiful source of good water at a practical depth is an important factor in influencing the cost of production of the nursery stock. The quality of the water is of prime importance because a water of high mineral content will eventually destroy the usefulness of the soil for nursery production.

The following description of ground-water conditions in the shelterbelt zone is accompanied by areal geologic maps, geologic cross sections, and State water-region maps. The principal facts considered are the geologic occurrence of ground water, its source of replenishment, accessibility, quality, and quantity.

The data presented come from the writer's investigations and experience and from conference with the following State geologists: H. E. Simpson, North Dakota; E. P. Rothrock, South Dakota; R. C. Moore, Kansas; C. N. Gould, Oklahoma; and E. H. Sellards, Texas.

GROUND-WATER RELATIONS

The source of ground water in this area is precipitation, local and distant. Part of the run-off of rain and snowfall is trapped in porous soil, porous mantle rock, and along the out-crop areas of porous bedrock formations. The water so trapped is in slow motion by percolation downward and laterally through the contained beds from its source or sources of replenishment to places where it is lost by evaporation, transpiration, leakage, or through wells.

Some close-textured soils, as shales in the hilly lands, pass much of the rainfall at once to surface run-off, whereas the thick, open-textured, sandy formations, whether flat or rough, absorb the maximum of rainfall and pass it to ground storage, from which it later emerges through the deeper drainage ways. Certain porous bedrock formations which dip for long distances beneath impervious beds carry water under pressure (artesian).

The close relation that exists between the rainfall, ground-water intake, surface run-off, and subsurface drainage should not be overlooked. The ground water recharged from rainfall in shallow, porous formations lying upon impervious platforms in dissected areas contributes ultimately to surface run-off as streams, which, during their high stages, pass water into alluvial land storage. This reservoir of alluvial water becomes comparatively static, but its return flow to the streams during their low stages, as during dry years and drought, has a stabilizing effect on their discharge.

The sandy uplands of the shelterbelt zone absorb and store a considerable part of the rainfall as ground water, from which the subsurface drainage to the valleys and streams heading in them is comparatively uniform. Similarly, the less sandy lands having a vegetative cover of prairie or forest pass relatively large amounts of the rainfall to ground storage but with little or no underflow. Vegetative cover retards the erosion and release of sediment from the uplands. It also furthers the absorption of ground water and stabilizes the local run-off and the discharge of streams. In other words, the cover stores some water, retards the surface run-off, and passes relatively large amounts of water to ground storage, from which the movement to the surface is very slow and uniform as compared with the direct surface run-off. It may not, however, increase the total long-time run-off of an area. Only the form, stabilization, and beneficial use of this run-off are affected by such cover. In contrast to the conditions just noted, the hilly, shaly lands without a protective cover develop a minimum of ground-water storage, have little underflow to streams, and shed the rainfall as erratic surface run-off.

Geological conditions vary greatly in the shelterbelt zone (fig. 95). In places the land is deeply covered with loose mantle rock, such as alluvium, glacial drift, sand and gravel wash, loess, or dune sand. There are also large areas in the zone where bedrock of shale, chalk rock, limestone, or sandstone is at the surface and extends downward for many feet. The nature and occurrence of the geological formations influence the behavior of ground water. They also influence the mineralization of the water and the volume and condition of its storage.

Open-textured mantle rock absorbs and stores relatively large amounts of the rainfall, and its water becomes medium hard to hard. Shale and chalk rock formations carry little available ground water, and it is usually of poor quality. In contrast, the sands, gravels, and sandstone are the principal water-carrying formations of the belt, and certain persistent limestones that are porous and jointed contain hard water.

Places exist within the shelterbelt zone which are practically without ground water except at great depth, and there are other places with abundant water of good quality at various depths. This section outlines both the favorable and unfavorable ground-water conditions in the shelterbelt zone and explains them on a geologic basis.

WATER-BEARING HORIZONS

Ground-water survey is closely related to stratigraphic and areal geology. Its purpose, in the beginning, is to determine and describe the occurrences of water by geologic horizons, so as to assist in locating, developing, and improving water supplies. The leading aquifers (ground-water horizons) in the shelterbelt zone, as a whole, are as follows:

1. Alluvial bottom lands.
2. Sand and gravel deposits in, between, and otherwise associated with the till sheets (glacial deposits).
3. Sand and gravel deposits bordering drift deposits, as in central Nebraska.
4. Sand and gravel formations of Tertiary age, known as the "Ogallala and Fort Union formations."
5. Sandy layers in the Fox Hills formation (Cretaceous) of North Dakota and South Dakota.
6. The Dakota group of sandstones, which underlie extensive areas. These are at the base of the Cretaceous in North Dakota, South Dakota, Nebraska, and a considerable part of Kansas.
7. Certain Permian and Pennsylvanian sandstones and limestones in Oklahoma and Texas.
8. Various bedrock horizons too deep to be tapped for use by the shelterbelt project.

NOTE.—Except the Dakota sandstones and the sandy beds of the Laramie and Fox Hills, practically none of the Cretaceous formations in the shelterbelt zone yield ground water. These non-water-bearing formations are the Graneros shale, Carlile shale, Niobrara chalk, and Pierre shale, all widely distributed and quite thick. At places in Nebraska and Kansas, however, the massive basal part of the Niobrara does afford some well water and springs. The Brule clay at the base of the Tertiary in small areas of the shelterbelt zone in South Dakota and Nebraska carries a little water, and large areas of the red beds of Oklahoma contain small amounts of available water.

The distribution of the water-bearing and non-water-bearing formations of the shelterbelt zone is shown by the accompanying areal geologic maps and cross sections and is explained in connection with the discussion of the water regions of the States.

GROUND-WATER REGIONS

During the past few years some attempt has been made to delimit and describe the ground-water resources by natural regions or provinces. Thus far, however, no uniform basis has been agreed upon among water geologists for the description, correlation, and naming of these regions, many of which cross State lines. Most of the ground-water regions now recognized were delimited and named from surface features of the land rather than from the geological conditions. Others were described with reference to the nature and occurrence of the water, whether scant, abundant, shallow, deep, artesian, soft, alkaline, hard, or highly mineralized, and some were named from their geographic position. It seems, therefore, that there is need for the revision of the nomenclature relating to water regions. In the following discussion the water region names now in use are recognized, but with some revision due to correlation that must be made between the States.

The ground-water conditions are now described regionally by States.

NORTH DAKOTA

The late A. G. Leonard,[51] Simpson,[52] and others have described the geology and ground waters of North Dakota, and their reports have supplied most of the data herein compiled. The conditions are mapped in cross section no. 1, figure 95, and figures 96 and 97. The geologic column is described in table 24.

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[51] In Geology and Natural Resources of North Dakota. See Bibliography at end of section.

[52] In Geology and Ground-water Resources of North Dakota. See Bibliography at end of section.

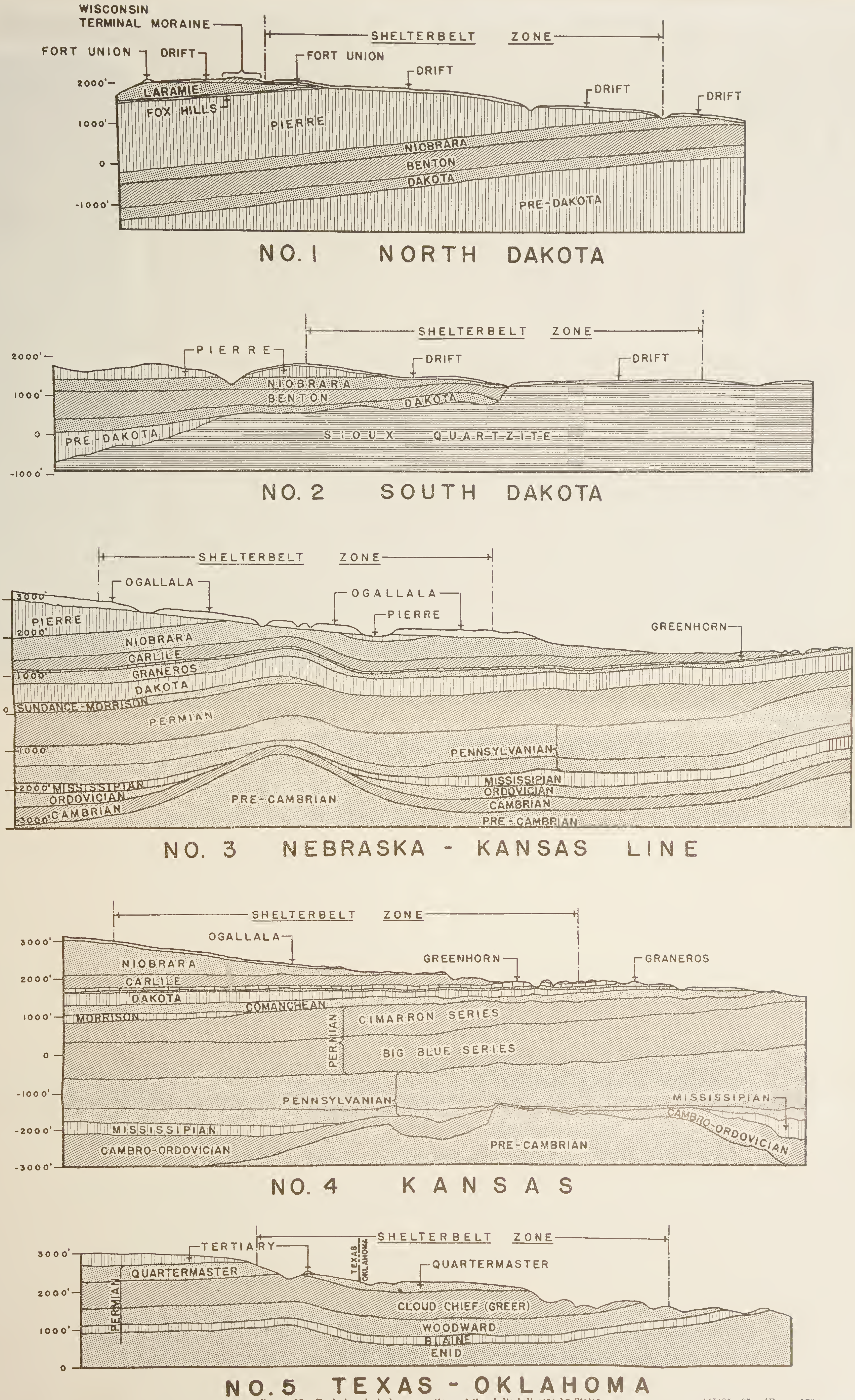

FIGURE 95.—Typical geological cross sections of the shelterbelt zone by States.

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TABLE 24.—*Geologic column in the shelterbelt zone of North Dakota*

Age	Name of formation	Thickness	Lithologic character
		Feet	
Recent and Pleistocene.	Alluvium	1-250	Silt, sand, gravel.
Do	Lake silt	1-100	Silt and some sand.
Do	Till and associated deposits.	10-450	Till; clay with sand, gravel and boulders; coarse morainic materials; outwash deposits.
Eocene and Tertiary.	Fort Union formation.	1,200 but less where eroded.	Beds of light-colored clays, friable sandstones and lignite.
Tertiary (?) / Cretaceous (?)	Lance formation	Maximum where not removed by erosion about 900.	Gray sandstone, clay, and lignite beds.
Cretaceous	Fox Hills formation	125 or less	Soft massive yellow to gray sandstone.
Do	Pierre shale formation.	300-1,100	Largely dark-gray shale.
Do	Niobara formation	About 270	Light-gray shaly chalk.
Do	Benton shales, equivalent of Carlile, Greenhorn, and Graneros.	About 500-600	Dark-colored shales; the Greenhorn limestone not reported.
Do	Dakota group	400-500	Friable sandstones; and shales.
Jurassic	Probably absent.		
Triassic	Probably absent.		
Paleozoic	Reached in few wells; not differentiated.		

SURFACE FEATURES

The following description is by Leonard:

In traveling from east to west across the State one crosses three plains rising one above another. The lowest of those is the broad Red River Valley, with an elevation of from 800 to 1,000 feet above sea level. . .

The remarkably level plain known as the Red River Valley stretches along the eastern border of the State and extends from 30 to 40 miles west of the river. Near the southern end, at Wahpeton, the valley has an elevation of 965 feet; at Fargo it is 905 feet; at Grand Forks, 830 feet; and at Pembina, near the Canadian line, 789 feet above sea level, the slope toward the north being only about one foot to the mile. . .

West of the Red River Valley, and lying between that and the Missouri Plateau, is a plain intermediate in elevation between the surface on either side. Since it is everywhere covered with glacial drift, it may be called the Drift Plain, though the drift-covered portion of North Dakota is not confined to this plain, and the deposits of the ice sheet are also found on the Missouri Plateau. . .

Bordering the Drift Plain on the west is an escarpment even more prominent than that forming its eastern margin. This escarpment marks the eastern edge of the Missouri Plateau, which stretches westward to the Rocky Mountains. . .

The surface features of North Dakota have been formed by various processes, but in general they have originated in one of three ways, namely, (1) through the agency of continental glaciers or ice sheets, (2) through the erosion of streams and running water, and (3) through the agency of lakes. There are thus three types or kinds of land surface within the State which differ widely in origin and are strikingly unlike in general appearance. These are the level lacustrine plains of the Red River Valley and the Mouse River region in Bottineau and McHenry counties; the wide stretching, gently rolling to rough Drift Plain with its innumerable lakes, its comparatively few rivers and imperfect drainage, occupying nearly two-thirds of the State; and the plateau area. . .

Both the Red River Valley and the Mouse River[53] district are old lake plains or the bottoms of former lakes. The sediment carried into these was spread far and wide over the floor of the lakes to form the remarkably level lacustrine plains of Lake Agassiz and Lake Souris. The broad depression of the Red River Valley, which during the Glacial Period was occupied by Lake Agassiz, was eroded to a depth of 800 to 900 feet in the Cretaceous and older rocks of eastern North Dakota and adjoining parts of Minnesota by a large northward-flowing river. Later, during the Glacial Period and before the advent of Lake Agassiz, this old valley was filled to a depth of 200 to 300 feet and over with drift left by the continental ice sheet when it invaded the region. The old valley floor is thus deeply buried beneath this mantle of glacial debris, and is only reached in deep wells which have penetrated the drift and entered the underlying bedrock, the latter being in many places granite. Lake Agassiz was formed through the damming of this ancient northward-sloping valley by the ice sheet which covered the country to the north and formed a thick ice barrier to the north and northeast, while higher land held in its waters on the other sides of the basin. During the time the lake was in existence, sediment carried in by rivers was spread over the bottom to a depth of 20 to 50 feet, covering the drift in most places. . .

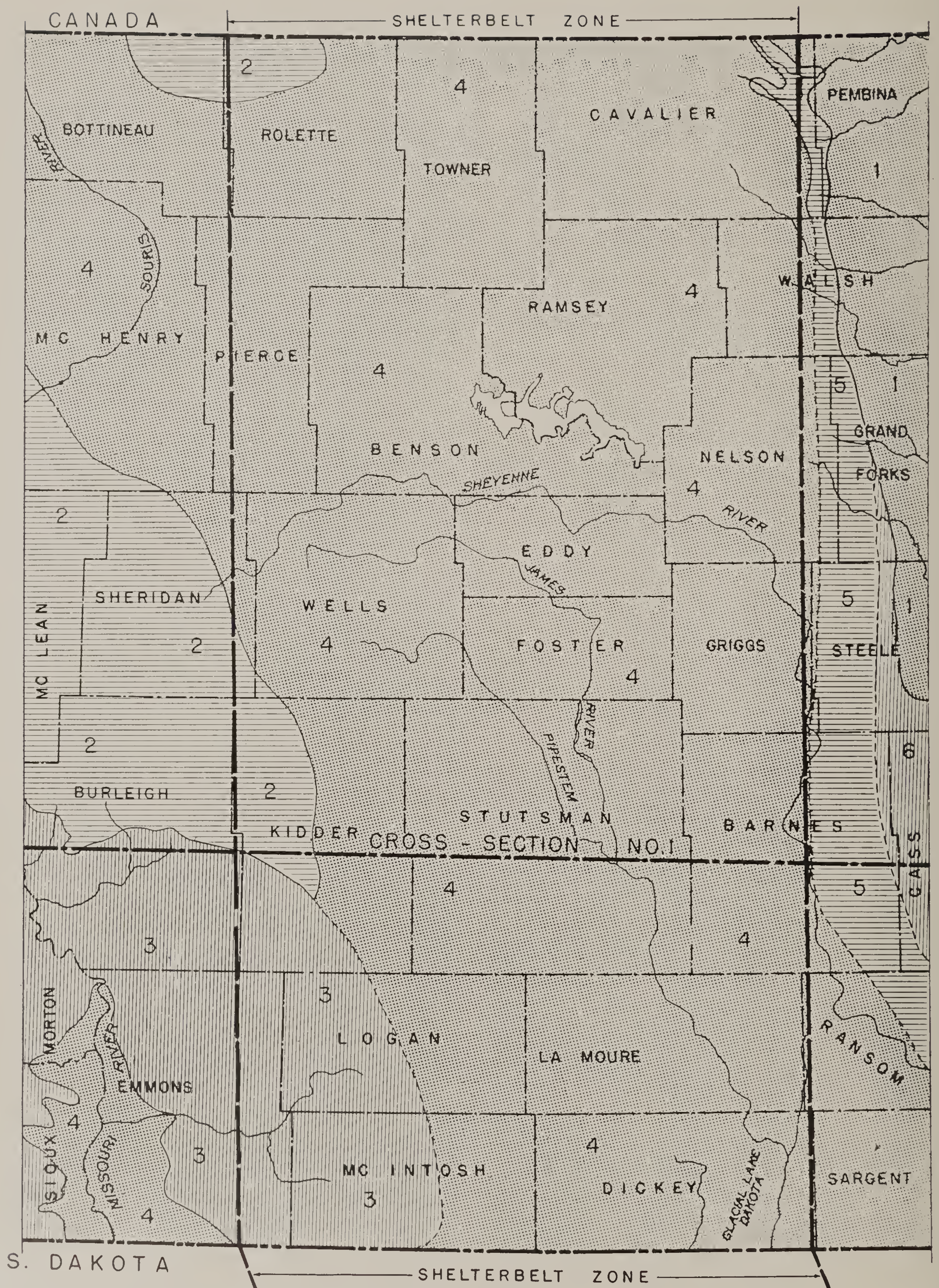
Gravel and sand beaches were built up by the waves about the shores of Lake Agassiz, and the rivers entering the lake carried sediment which accumulated to form deltas. The best-developed beach ridges, which commonly rise 10 to 20 feet above the adjoining surface on the side toward the former lake, vary in width from 10 to 30 rods and are composed of gravel inter-stratified with sand. The development of these beaches varies greatly from place to place, depending apparently upon the abundance and character of the materials within reach of the waves.

Three deltas were formed in that portion of the lake included within North Dakota. The largest, that of the Sheyenne River, lies mostly in Richland and Ramsey counties, covering an area of not far from 800 square miles. The sand has been heaped by the wind into dunes, and a large tract of the delta is covered by these sandhills. The Pembina River formed a delta having an average thickness of 150 feet, and Larimore is built on another such deposit which extends from McCanna south to Mayville and Portland. The stream which formed this latter delta is no longer in existence.

The surface features of the Drift Plain are due to the irregular and uneven deposition of drift, which is heaped up more in some places than in others, so that its surface is gently rolling to rough. It thus presents a marked contrast to the erosional topography of the region west of the Missouri River, and to the level areas of the lacustrine plains. The ice sheet which invaded North Dakota from a center of movement west of Hudson Bay has been by far the most important factor in moulding the surface areas of over two-thirds of the State. Even the lacustrine plains are indirectly the result of the ice invasion, since the lakes which formed them had their origin in the blocking of the drainage by the glacier. The preglacial surface had undergone great erosion during the long Tertiary period, so that it was doubtless quite uneven and rough and cut by many stream valleys, probably resembling somewhat the area west of the Missouri River as it appears today. The ice sheet modified all this and tended to level the region by wearing down the hills and ridges and filling the valleys with glacial debris. As it withdrew it left behind the heavy mantle of drift which conceals from view the preglacial surface. The drift is commonly from 150 to 300 feet thick. It is this deposit which has determined largely the surface features of the Drift Plain.

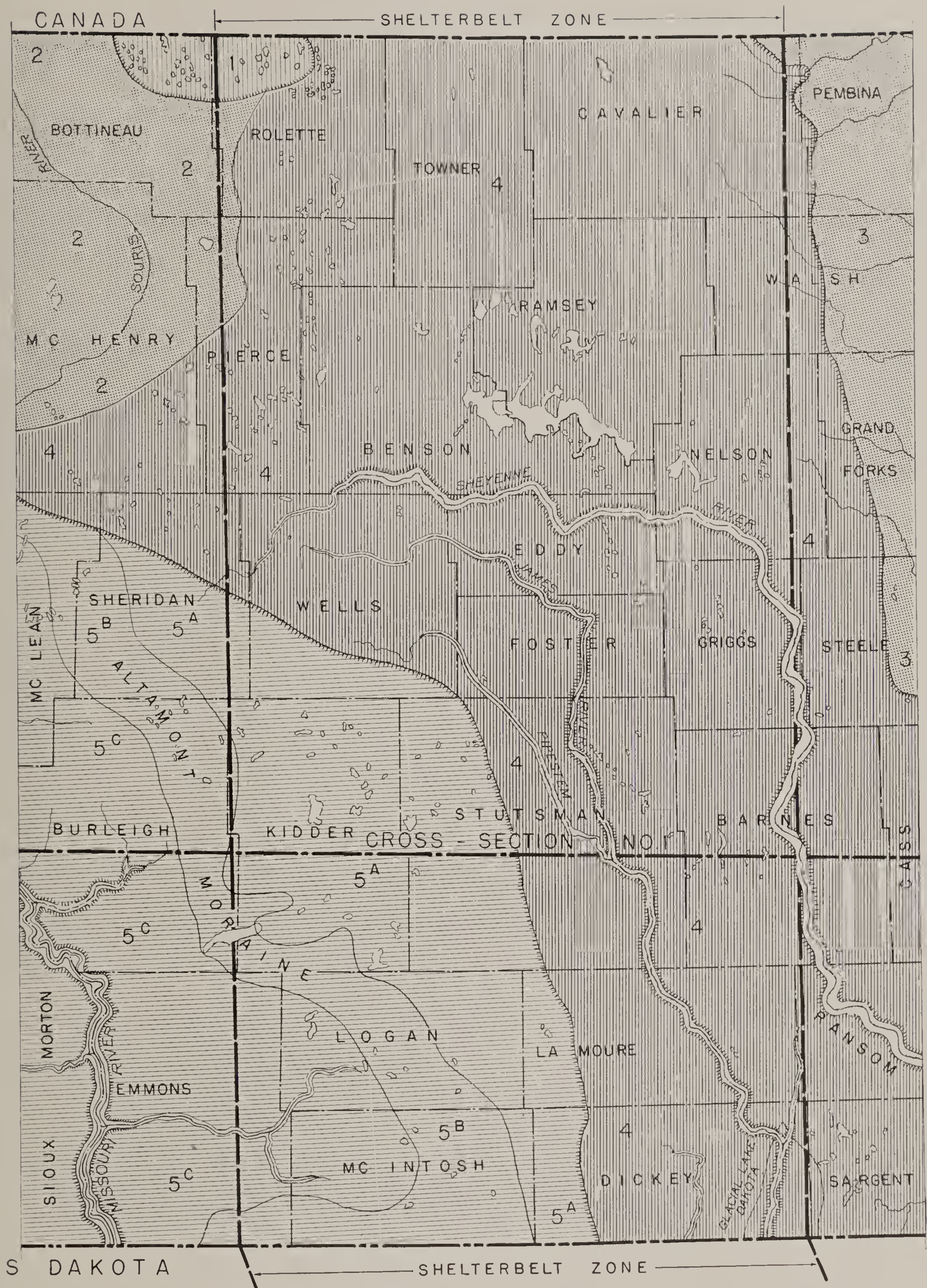
During its recession the ice sheet halted again and again and thus built a series of moraines. Some of these halts were brief and resulting moraines poorly defined; others were of much longer duration, as shown by the great amount of material deposited and the large size of the hills and ridges. By far the best developed of these morainic belts is the Altamont moraine, marking the limit reached by the Wisconsin ice sheet. * * * It stretches across the State from northwest to southeast and extends without interruption for many hundreds of miles. This remarkably well developed moraine forms a very rough belt of massive hills and ridges which

[53] The Mouse River District is the Souris River Basin.



LEGEND: 1 UNDERLAIN BY CRETACEOUS AND OLDER ROCKS
2 FORT UNION
3 LANCE
4 FOX HILLS AND PIERRE
5 NIOBRARA
6 BENTON

FIGURE 96.—Geological bedrock map of shelterbelt zone in North Dakota.



LEGEND:

1 TURTLE MOUNTAINS
2 SOURIS RIVER BASIN
3 RED RIVER VALLEY
4 DRIFT PLAIN
5 MISSOURI PLATEAU

FIGURE 97.—Ground-water regions of shelterbelt zone in North Dakota.

in places has a width of 20 miles and over and throughout most of its extent in North Dakota probably averages at least 12 to 15 miles in width. Many of the hollows and undrained depressions which occur in such large numbers among the hills are occupied by lakes, ponds, and marshes. But while lakes are more numerous in the morainic areas they are also common elsewhere on the Drift Plain. They are in fact very characteristic of the Drift Plain as a whole, dotting the surface by the score and hundred and adding beauty and variety to the landscape. The largest is Devils Lake, which owes its existence to the partial filling with glacial drift of an old river valley and its tributaries. the unfilled portion of the valley being occupied by the lake.

The small number of rivers is another notable feature of the Drift Plain. Besides the Missouri River, which may be considered as forming the western boundary of the drift-covered plain, the Mouse, James, and Sheyenne are the only streams of any importance, and even these have few tributaries. There are entire counties, such as Kidder, Logan, and McIntosh, which are without a single river. This scarcity of streams and abundance of lakes indicates a young land surface on which rivers have not yet had time to erode valleys and whose lakes have not been drained or filled. * * *

So recent is it geologically since the last ice sheet withdrew from North Dakota, and since Lake Agassiz and Lake Souris were drained, that the surface of the Drift Plain and the lake beds have been but slightly affected by erosion and are still much as they were left at the close of the Glacial Period.

As has already been pointed out, much of the Missouri Plateau, or that portion lying east of the river, is covered by a thick deposit of glacial drift and thus has the topography of a drift plain. * * *

AREAL BEDROCK MAP

The map (fig. 96) shows what bedrock formations lie immediately below the mantle rock, i. e., where they would appear at the surface in the shelterbelt zone if the mantling beds were removed. The Fox Hills, Pierre, and Niobrara formations outcrop at few places in the zone, and the Fort Union and Lance outcrop more prominently.

It should be observed in this connection that the area (4) designated as Fox Hills-Pierre has been delimited largely from well logs. Undoubtedly the Pierre is the topmost bedrock formation in most of this occurrence, especially to the east and south, but without much doubt it is thinly covered by lower beds of the Fox Hills at places to the west and north, as evidenced by the logs of wells and the quality of well water obtained.

GROUND-WATER HORIZONS

Much of the ground-water supply of North Dakota is obtained by shallow wells in the mantle rock, in the alluvial, lacustrine, and drift deposits. The water-bearing horizons in the bedrock are in the Fort Union, Lance, Fox Hills, and Dakota formations. Those of the older formations lie too deep for economic production.

LOWERING THE WATER TABLE

Evidently the water table stood high in the shelterbelt zone in the mantle rock deposits when the last glacier (Wisconsin) retreated from North Dakota, but it has since lowered in the areas adjacent to the main valleys, owing to their erosion. It also has fluctuated upward and downward in response to seasonal evaporation and rainfall and to periods of wet and dry years. The retreat of the ice dam from the Red River and from the Souris River Basin caused lowering of ponded lakes in these areas, followed by a drop of the ground-water level, first in the border lands and later in the beds of the basins that had been occupied by the lakes.

The water level still stands relatively near the surface in most of the shelterbelt zone of North Dakota, approximately where it may be expected to remain in response to replenishment from rainfall, the slow depletion by underdrainage, and the poorly established surface drainage.

REPLENISHMENT OF GROUND WATER IN THE BEDROCK FORMATION

Although the mantle rock of North Dakota generally rests upon an eroded, impervious bedrock platform, there are local zones of replenishment extending into the bedrock horizons. The drift cover on the Fort Union and Lance formations loses some water by percolation and through joints to the Fort Union and Lance formations, and some of the underflow in the lower sands and gravels of the drift and alluvial deposits passes into the impervious horizons of the Fort Union, Lance, and Fox Hills formations and moves along the dip to greater depths.

The intake of the Dakota group, according to most geologists, is thought to be along the flanks of the Black Hills and other mountains to the west, yet there are some who maintain that this source of replenishment is not accountable for all the water in the Dakota sandstones, in the broad areas east of the mountains. The dissenters point to certain areas in which the replenishment is plainly local and to certain other places where it is largely from along the flanks of old high lands east of the broad Dakota basin, as the Sioux Falls " high " and the Laurentian Highlands. It seems, therefore, that the water of the Dakota sandstones in North Dakota may come in considerable part from the east side of the basin rather than from the more distant sources to the west.

SPRING WATER

The leakage of ground water from the shallow aquifers lying above the impervious beds in the rock escarpments and along the deeper valleys of the shelterbelt zone develops numerous springs. Some of the springs issuing from small catchment areas are reduced during droughts, even to no discharge. Others are permanent.

ARTESIAN WELLS

According to Leonard, there are 6,000 or more artesian wells in North Dakota, and apparently most of them are in the shelterbelt zone. The artesian wells within the zone range between 100 and 1,800 feet in depth. The shallower ones, in small drift basins, have weak flows. Those tapping the Fort Union and Lance formations are 200 to 400 feet or more in depth, and those of the Fox Hills still deeper.

The water in the Dakota sandstones at first, second, or third horizons is under heavy hydrostatic pressure and gives strong flows. Its depth ranges from about 400 feet along the east border of the zone to 1,800 feet or more along the west border, where it is not economically feasible to drill wells to reach it.

According to Dr. Simpson, the hydrostatic pressure of the Dakota waters in North Dakota has been greatly reduced as a result of the number of wells that have been drilled to them and the wastage of water from such wells. The State has enacted legislation for the control of artesian wells and has assigned the duty of enforcing the terms of the act to the State Geological Survey.

GROUND-WATER REGIONS

The ground-water regions, according to Leonard and Simpson, coincide quite closely with the topographic provinces, and are here described under the names Turtle Mountains, Souris River Basin, Red River Valley, Drift Plain, and Missouri Plateau. Their distribution in the shelterbelt zone of North Dakota is shown by figure 97.

TURTLE MOUNTAINS

The Fort Union formation caps this region. It is overlain by drift which stores the rainfall as ground water, some of which percolates into the sandy beds below and leaks out over impervious layers in the escarpment as springs, making small live streams. This region, being sparsely settled, has few wells, most of which are shallow and reach only the drift. The water is medium hard.

According to Simpson, the Turtle Mountains formerly were thickly wooded and the springs there were stronger than they have been since much of the forest was removed. If such deduction is correct, here is a good example of the relation of forest cover to ground-water storage and the indirect run-off. At any rate, this is an ideal region for reforestation and the demonstration of what changes may result from it.

SOURIS RIVER BASIN

The Souris River Basin lies to the west and southwest of the Turtle Mountains and extends only a short distance into the shelterbelt zone. Its shallow water-supply conditions are similar to those of the Red River Valley, which is described later. The deeper waters here are similar to those along the west border of the Drift Plain.

RED RIVER VALLEY

This and the following descriptions of ground-water regions are quoted from Simpson (Water-Supply Paper 598):

> In the Red River Valley water is obtained from shallow wells in the beach and delta deposits and in the lake silt and from deeper wells in the Wisconsin drift and the sedimentary bedrock beneath. Much of the water in the sandy layers of the drift and the bedrock is under sufficient artesian pressure to produce flows in wells of moderate depths. The lake silt supplies some shallow wells with a small amount of water, much of which is "alkaline", and the sandy beaches and deltas on the western margin yield to shallow wells some of the best water in the State. The deeper artesian waters are generally highly mineralized, especially those that come from the bedrock.
>
> *Drift Plain.*—In the Drift Prairie water is obtained from the alluvium in the valleys, from the glacial drift, and from the underlying rock. The drift is so thick that it is the most generally utilized formation in the State. The sand and gravel at the base of the drift, immediately above the shale, form a common source of supply.
>
> The deposits of sand and gravel under the broad floors of the principal valleys, particularly those of the Sheyenne and the James, yield ample supplies for cities of several thousand people. The waters are commonly obtained by wells fitted with drive points and strainers. Many wells penetrate the shale that underlies the drift and draw from the few sandy layers found in it a moderate supply of slightly mineralized water.
>
> In the southern parts of this province many wells are drilled to the Dakota sandstone and obtain strong flows of higher mineral character. The area of artesian flow of this sandstone constitutes an important subdivision of the Drift Prairie province and occupies all of its southern and central portion.
>
> *Missouri Plateau.*—In the glaciated part of the Missouri Plateau the water is commonly obtained from the drift, as in the Drift Prairie province. In the nonglaciated part the water is obtained from the alluvium of the valleys, the residual soils that cover the surface to considerable depths on the uplands, and the layers of lignite and sandstone in the upper part of the bedrock. In some of the larger valleys shallow wells draw an abundance of good water from the alluvial gravel and sand. These materials were largely washed out from the front of the Wisconsin ice sheet when it occupied its most advanced position along the Altamont moraine. In this region springs from the lignite and other outcropping rocks of the valley sides are so numerous that they greatly decrease the number of wells necessary. All the deeper wells enter the bedrock sandstone and lignite, and some that are located in the deeper valleys yield weak flows.

SOUTH DAKOTA

Refer to figures 98 and 99; cross section no. 2, figure 95.

SURFACE FEATURES

The altitude of the shelterbelt zone in South Dakota ranges between 1,250 feet on the Missouri River bottom land to about 2,050 feet in the northwest part, giving a relief of about 800 feet.

Most of the belt is essentially a plain mantled with drift deposits—smooth to hilly—and trenched by the Missouri, James, and other valleys, bordering which the bedrock formations are exposed, forming rough lands. All of the belt in this State has been glaciated, much of it two or more times.

The surface drainage generally is better developed than in North Dakota but is of the same general type, with moraines, gravelly terraces, and lake basins resulting from glaciation. The glacial Lake Dakota basin (2^2, fig. 99) is the largest and best-defined upland plain. Some of the basins and abandoned drainage ways are occupied by lakes, most of which are intermittent.

TOPOGRAPHIC REGIONS

The topographic regions of the shelterbelt zone in South Dakota are the Missouri Plateau, which is poorly defined; the Drift Plain; the Sioux Falls area; and the Missouri River lowland.

STRUCTURAL CONDITIONS

The bedrock formations of this zone in South Dakota lie nearly level in much of their occurrence, modified by a low westward dip and by steeper inclines bordering the Sioux Falls high against which the Dakota beds thin out. The higher Cretaceous formations, if ever deposited on the Sioux Falls high, have been eroded away.

Apparently there has been some uplift of the bedrock in a northwest-southeast trend in the area northwest of the western end of the Sioux Falls high. This probably accounts for the high position of the Niobrara formation here.

The cross section (fig. 95), after Darton, passing through the Sioux Falls high and westward, shows

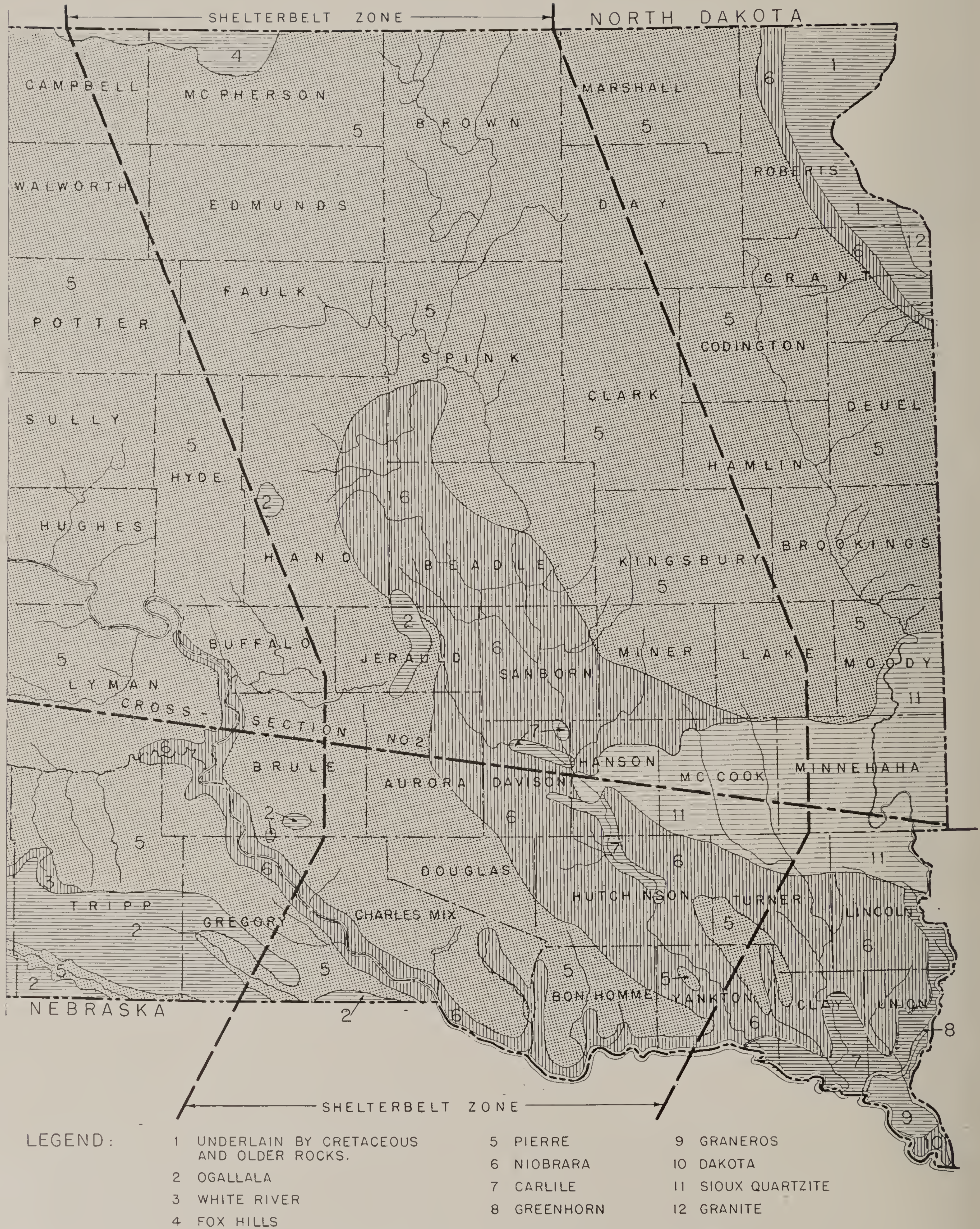


FIGURE 98.—Geological bedrock map of shelterbelt zone in South Dakota.

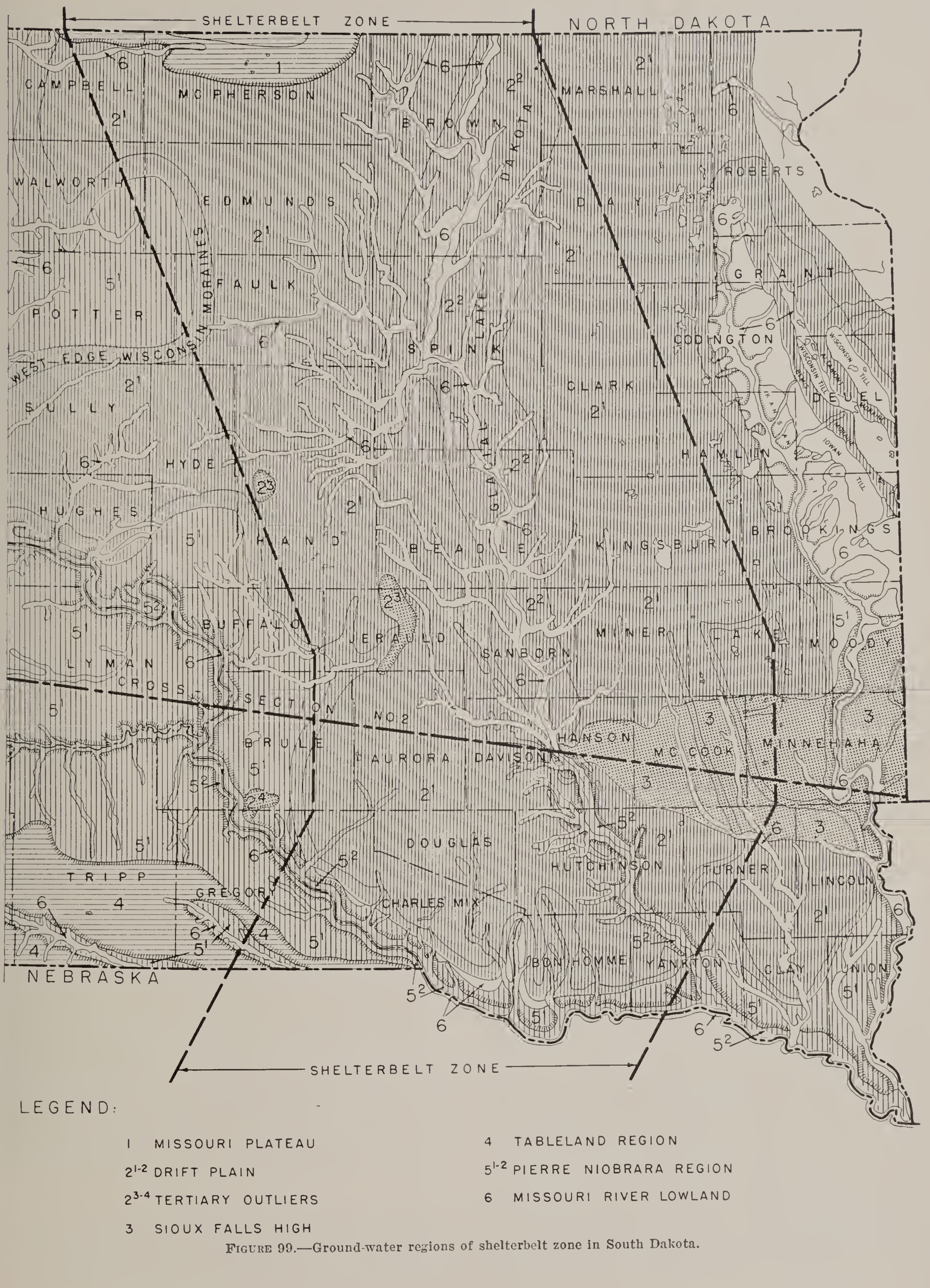


FIGURE 99.—Ground-water regions of shelterbelt zone in South Dakota.

the geological sequence of formations in that part of the shelterbelt zone. The geologic column is given in table 25.

TABLE 25.—*Geologic column of the shelterbelt zone, South Dakota*

Age	Name of formation	Thickness	Lithologic character
		Feet	
Recent and Pleistocene.	Alluvium	0–100	Silt, sand, gravel.
	Loess	0–20	Largely silt.
	Drift deposits	0–300	Till, silt, sand, gravel, boulders.
Pliocene	Ogallala	0–100	Sandstone, silt, sand, gravel.
Cretaceous	Fox Hills	40	Shale, sandstone, coal seams.
	Pierre	0–700	Dark-gray shale.
	Niobrara	200–250	Shaly chalk above; sandy lime or limy sandstone at base.
	Carlile	[1] 200	Dark shale, some sandstone.
	Greenhorn	24	Thin limestone and shales; thins out northeastward.
	Dakota group	0–400	Sandstones and shales, some coal.
Marked unconformity on older formations.			
Paleozoic	Probably under portions of zone.		
Pre-Cambrian	Sioux	0–500	Quartzite and sandstone.

[1] About.

BEDROCK MAP

Figure 98 shows where and what bedrock formations would appear at the surface in the shelterbelt zone of South Dakota, if the drift, lacustrine, and alluvial deposits were removed. Data used in the compilation of this map were obtained from the South Dakota Geological Survey, Todd's Bulletin 158, United States Geological Survey, Darton's Water Supply Paper 227, United States Geological Survey, Geologic Atlases 96, 99, 100, United States Geological Survey, and other sources. The map also shows the distribution of the bedrock formations in areas adjacent to the shelterbelt zone.

GROUND-WATER HORIZONS

Ground-water horizons are in (1) the alluvium, (2) drift and associated deposits, (3) Ogallala formation, (4) Fox Hills formation, (5) Niobrara formation, basal portion, (6) Greenhorn limestone, (7) Dakota sandstones, (8) Sioux formation (quartzite).

The water-supply reports on South Dakota refer to ground-water horizons at the top and near the base of the Carlile. This study of the water horizons in northern Nebraska, however, shows quite conclusively that the Fort Hayes base of the Niobrara there is quite sandy and an aquifer of some importance, and also that the Greenhorn produces water in some wells. It seems, therefore, that these horizons may persist to and through the South Dakota section, and that they may be correlative with the upper and lower Carlile horizons of Darton and others.

ARTESIAN WATER

Water under pressure occurs immediately beneath the drift deposits, in small areas; in the sandy basal member of the Niobrara, more generally; in the Greenhorn at some points; and in the Dakota throughout the zone, except at upper parts of the Sioux Falls high. The flowing wells in the drift are shallow, yielding medium-hard water. Those reaching the basal Niobrara and the Greenhorn are considerably deeper, yielding soft to medium-hard water. The Dakota wells range from about 250 to 1,000 feet in depth, and their water is quite highly mineralized but usually potable.

SPRING WATER

The springs in the shelterbelt zone of South Dakota are numerous, but most of them are affected by heavy rainfalls and drought. They occur largely on the sides of valleys, where water is released from the drift deposits along the contact with impervious shales, and at the borders of the tableland outliers.

GROUND-WATER REGIONS

The six ground-water regions in the shelterbelt zone of South Dakota are the poorly defined Missouri Plateau, the Drift Plain, the Sioux Falls region, the Pierre-Niobrara region, the tableland region, and the Missouri River lowland region (fig. 99).

MISSOURI PLATEAU

The Missouri Plateau, as noted above, is well shown at places in North Dakota, but its occurrence in South Dakota is limited and poorly defined, i. e., not well set off from the Drift Plain. Evidently, however, there is a small area of the Fox Hills in the northwestern part of the shelterbelt zone in this State. It is mantled generally with drift, from which water percolates to the sands below. The water in the drift is drawn upon through shallow wells, and the deeper water of the Fox Hills is tapped by a few deeper wells which produce hard or alkaline water (not very desirable for drinking).

The region is underlain by the Pierre shale and the regular succession of Cretaceous formations down to and including the Dakota, which is quite deep.

DRIFT PLAIN

The drift plain presents about the same features here as in North Dakota, but has been trenched more by rivers, with resulting greater leakage from the shallow waters. Its broad interstream areas are modified by moraines and depressional areas, of which the fossil Lake Dakota basin is the largest. There are also extensive alluvial lands in the James Valley and its tributaries and in certain interglacial valleys that are filled or nearly filled with coarse sediments.

The writer is in doubt regarding just what glaciations and deglaciations were enacted here. Todd [54] maps the Altamont and other moraines of this belt and seems to infer that the narrow strip of drift south of his Altamont moraine may be the Kansan. Then, in an area not far east of this belt, Leverett and Sardeson [55] map the Altamont moraine, also the Wisconsin, Iowan, and Kansan drifts. Their Altamont moraine seems to correlate with the Altamont of Todd.

[54] In The Moraines of Southeastern South Dakota and Their Attendant Deposits; see Bibliography at end of section.
[55] In Quaternary Geology of Minnesota and Parts of Adjacent States; see Bibliography at end of section.

A personal study of the drift sheets in Nebraska just south of the shelterbelt zone of South Dakota has shown that both the Nebraskan and Kansan tills occur there, the first named being the thicker and separated from the latter by sands and gravels of Aftonian age. It seems, therefore, that both the Nebraskan and Kansan ice sheets must have advanced over at least part of the shelterbelt zone in South Dakota, and that their tills probably were deposited there and should be found there now unless they have been removed by erosion.

The Kansan till sheet is high in the uplands in the eastern part of the shelterbelt zone of Nebraska, where it has been eroded through locally and entirely removed in places. This means that if erosion has been as active north of the river, all the Kansan till may have been eroded away there and its former western border effaced eastward beyond the shelterbelt zone. In this event, the Nebraskan may be Todd's old drift located just south of the Altamont moraine in the shelterbelt of South Dakota, and it may or may not be the Kansan in the area mapped by Leverett and Sardeson. At any rate, the Nebraskan invasion probably crossed South Dakota as far westward as west of Yankton.

Finally, although it is generally supposed that all the drift back of the Altamont moraine, as mapped by Todd, is the Wisconsin, it is believed that the Kansan or the Nebraskan or both of these, and probably the Iowan, may occur beneath the Wisconsin at places in that area. The occurrence, age, and correlation of the drift deposits in this part of South Dakota will require close study in all of the area between Iowa, Minnesota, and Montana. Such an investigation, if made, should be of the kind that has been made the past few years by Leverett and Sardeson in Minnesota and southeastern South Dakota, by Kay in Iowa, and by Alden in northeastern Montana.

Unfortunately the drift deposits in the shelterbelt zone of South Dakota and North Dakota are too little known to give the necessary guidance in ground-water investigation, but it can be said that the drift mantle in these States is quite thick, that it consists of several forms of accumulation and types of sediment, and that it occurs generally except where it has been removed by erosion.

The drift is the principal water horizon in the Drift Plain region of South Dakota. Its wells are driven, dug, bored, or drilled. There are also many deeper wells in this section, reaching the base of the Niobrara, the Greenhorn, or, more generally, the Dakota.

The depth of the Dakota sandstone wells increases with distance from the flanks of the Sioux Falls high, and also westward and northwestward across the region. Thousands of artesian wells have been drilled here.

There are a few disconnected areas of tablelands in the western part of the Drift Plain region, as at the Bijou Hills, where they are capped by firm Ogallala sandstone and underlain by silt, sand, and some gravel. Their ground water is of good quality.

SIOUX FALLS HIGH

There are some outcrops of the Sioux quartzite in this region, hence the name. The surface of the region is further modified by deposits of drift and alluvium. The water supply is drawn from the mantle rock deposits and also from the Sioux quartzite at depths of 150 to 300 feet. Water in this hard bedrock occurs principally in fissures and cracks, and at places in the voids of the rock. The water is of good quality.

PIERRE-NIOBRARA REGION

The Pierre-Niobrara part of the shelterbelt zone of South Dakota and Nebraska consists of bluffs, hills, and small plains developed on the Pierre and Niobrara formations. It is broken into disconnected areas or subregions which collectively are the southeastward extensions of the large Pierre Plains region lying west of the shelterbelt zone in South Dakota. The occurrence of this general region in South Dakota is shown by 5^1 and 5^2 in figure 99. The ground-water conditions in it are described under the heading of Nebraska.

TABLELAND REGION

Along the west border of the shelterbelt zone at the boundary between South Dakota and Nebraska are tablelands in which the ground water is of better quality than that found in the Missouri Plateau in the northern part of South Dakota. It occurs in the sands and gravels of the Ogallala formation, small outliers of which are found in the Bijou Hills and similar elevations east of the Missouri. The ground-water conditions in the areas capped by the Ogallala in the shelterbelt zone of South Dakota and Nebraska are further discussed under the Nebraska heading.

MISSOURI RIVER LOWLAND

The Missouri River lowland lies along the Nebraska-South Dakota line. It is comparatively narrow here, but much broader farther east. The ground water here occurs in the deep alluvial lands along the river and in the bedrock horizons. There are a number of flowing wells in this part of the region, some of which are allowed to waste the water. The alluvial water, though potable, is not very desirable for drinking, and that of the Dakota sandstones is quite heavily mineralized.

NEBRASKA

Refer to figures 100 to 103; cross section no. 3, figure 95.

Of the 14 ground-water regions in Nebraska, 9 extend into the shelterbelt zone and are known by topographic names as follows: Missouri River Lowlands, Northern Tablelands, Pierre-Niobrara region, Sand-hill region, Loess-Drift Hills, Loess Hills, Platte River Lowland, Loess Plain, and the Republican Valley region. Physiographically the Northern Tablelands are comparable to the Turtle Mountains and the Missouri Plateau. The Missouri Lowlands are common to South Dakota, Iowa, Nebraska, and some other States. The Pierre-Niobrara region is best developed west of the shelterbelt zone and is quite well shown in Nebraska; the Loess-Drift Hills region is a continuation of the Drift Plain of the Dakotas, but in Nebraska it is more eroded and is capped with two loess formations.

Except in two regions, the shelterbelt zone in Nebraska is deeply mantled with alluvium, dune sand.

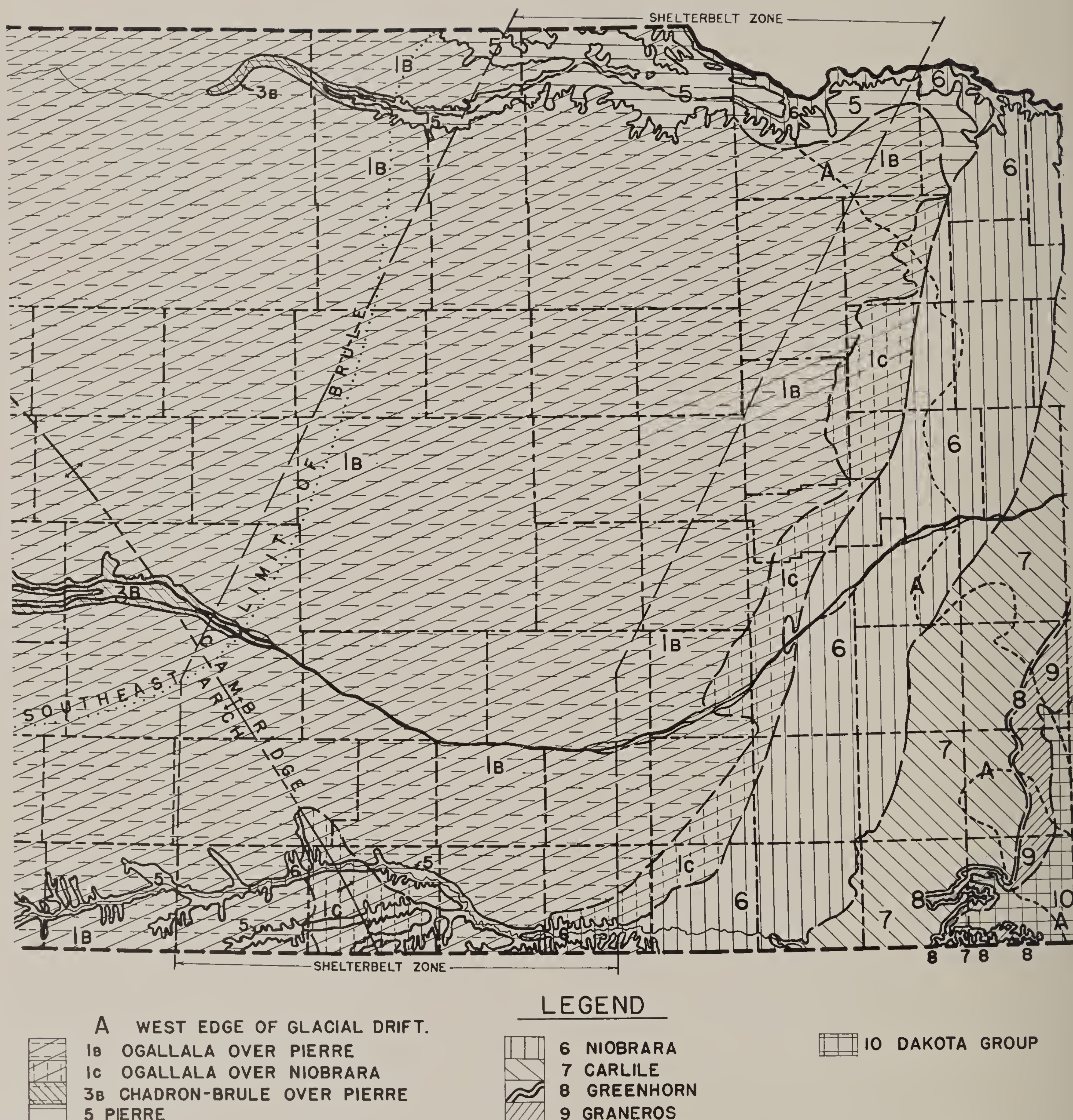


FIGURE 100.—Geological bedrock map of shelterbelt zone in Nebraska.

LEGEND:

1^{1-4} NORTHERN TABLELANDS

1^{5} PIERRE-NIOBRARA REGION

2^{1-4} SAND-HILL REGION

3 LOESS-DRIFT HILL REGION

4 LOESS HILL REGION

5 PLATTE RIVER LOWLANDS

6 LOESS PLAIN REGION

7 WESTERN LOESS REGION

8^{1-2} REPUBLICAN VALLEY REGION

FIGURE 101.—Ground-water regions of shelterbelt zone in Nebraska.

loess, or thick sheets of fluvio-glacial sands and gravels, and, in a small area, by glacial drift. Parts of it are underlain at or near the surface by loosely consolidated Tertiary deposits.

The impervious bedrock platform on which the water-bearing mantle-rock formations rest is largely shales and chalk rock, and the zone is underlain at a greater depth by the well-known sandstones of the Dakota group, in which the artesian-water pressure is sufficient to cause a flow in wells located along certain bottom lands. There are places on the slope lands

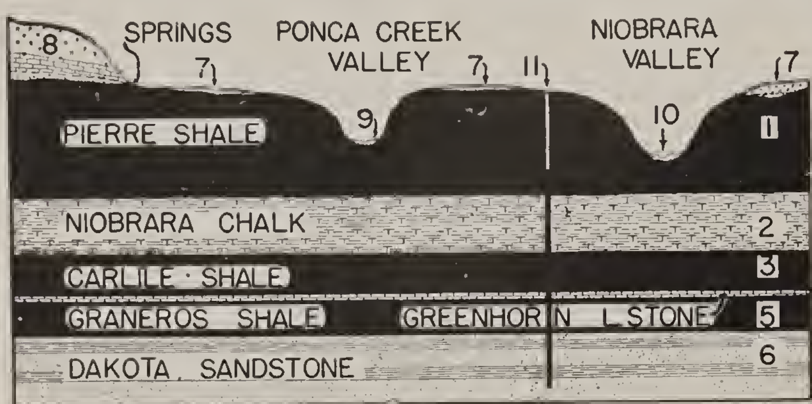


FIGURE 102.—Cross section of eastern Boyd County and the Niobrara Valley, showing the geological formations and the water horizons. The region is underlain by the Pierre shale and other shaly and chalky formations, and quite deeply by the Dakota sandstone. There is no available water in the shales and chalk. The areas where the shale is at the surface carry little or no well water. The sandy, silty surface formations to the north (8) absorb considerable rainfall and store it above the impervious shale. This condition affords well water and springs. The thin surface sand (7) stores small amounts of rainfall from which limited water supplies are obtained during wet years, but the water is depleted by underdrainage, evaporation, and use during dry years. The run-off from the uplands stores water in the alluvial bottom lands (9 and 10), which are the most dependable sources of well water, except where the alluvium is thin and its water is not recharged during drought. However, the Niobrara alluvium is supplied quite uniformly by water coming from the sand hills. The last resort in obtaining water on the shaly land of the area represented by this cross section, and at similar points farther east, is to make deep wells to the Dakota sandstone, from which, owing to artesian pressure, the water is lifted near the surface, as shown by the well at (11).

bordering the valleys in the Pierre-Niobrara region and the Republican Valley region where the impervious bedrock is exposed and where there is little or no ground-water storage. Aside from these places, there is an abundance of ground water in the zone, usually of good quality. The geologic column is given in table 26.

TABLE 26.—*Geologic column in the shelterbelt zone of Nebraska*

Age	Name of formation	Thickness	Lithologic character
		Feet	
Recent and Pleistocene.	Alluvium	0–90	Silt, clay, dust, sand, and gravel.
	Dune sand	0–150	Dune sand and wind-blown dust, silt, and clay.
	Peorian loess	0–200	
	Loveland loess:		
	Loess phase	0–135	Red eolian silt, clay, and fine sand.
	Valley phase	0–35	Red sand and silt, some fine gravel.
	Upland formation	5–35	Greenish-gray silt and clay—gumbotil.
	Kansan gumbotil	0–3	
	Grand Island sand and gravel.	40–100	Sand and gravel; boulder clay.
	Kansan till	0–100	
	Fullerton formation	20–85	Silt and clay (Fullerton); sand and gravel, and gumbotil.
	Intertill sand and gravel.	0–50	
	Nebraskan gumbotil	0–6	
	Holdrege formation:	50–100	
	Nebraskan till	0–100	Sand and gravel; boulder clay.
	David City formation.	30	Sand and gravel.

Erosional unconformity on bedrock formations.

TABLE 26.—*Geologic column in the shelterbelt zone of Nebraska*—Continued

Age	Name of formation	Thickness	Lithologic character
		Feet	
Pliocene	Ogallala	0–127	Sand, sandstone, gravel, and clay.
Cretaceous	Pierre shale	0–700	Dark-gray shale, some bentonite seams.
	Niobrara chalk	280–510	Gray chalk; sandy lime at base.
	Carlile shale	155–280	Dark shale, concretions.
	Greenhorn limestone	25–40	Thin limes and shales.
	Graneros shale	80–90	Dark shale, sandy at base.
	Dakota group	400–600	Sandstone, shales; thin coals.

Pre-Cretaceous (many formations, but not tapped for water in shelterbelt zone in Nebraska).

GROUND-WATER REGIONS

A review of the ground-water conditions of the various regions of the shelterbelt zone in Nebraska follows. The numbered locations refer to figure 101.

NORTHERN TABLELANDS (1^1–1^4)

These are the high uplands principally in Boyd and Holt Counties, and as noted before, they extend into South Dakota (subregion 5). They are erosional remnants of a former large tableland, formed on the Ogalalla beds of Tertiary age, which rest upon Brule clay to the west and upon the Pierre shale to the east. Much of the rainfall here passes to ground-water storage, from which springs issue along the deeper drainage ways at the contact with the impervious bedrock platform.

The wells of this general region range between 75 and 100 feet or more in depth. Their water is medium

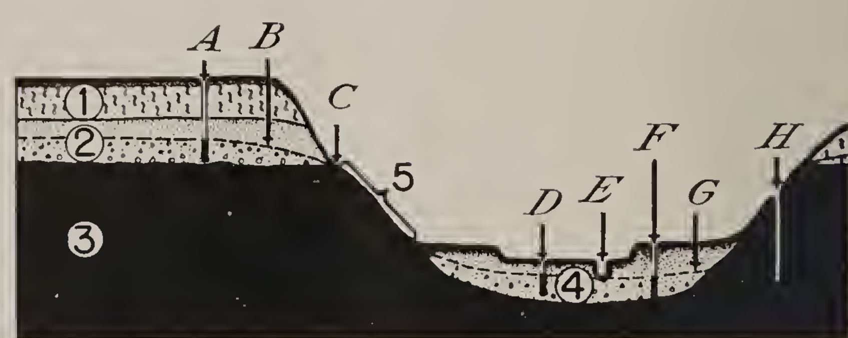


FIGURE 103.—Cross section of the Republican Valley in Webster County. Note the dry, shaly land belts along the valley sides (5) on shale (3). Observe the location of the thick, upland sands and gravels (2) in which there is a strong underflow from the Platte Valley with the water table at *B*. There is water-bearing alluvial land in the Republican Valley (4). The dependable water supplies here during drought are obtained from the underflow along the Republican and from the sands that are recharged from the Platte Valley. Elsewhere in the area of the cross section there is little water except that found in the Dakota sandstone at a depth of 400 feet or more on the valley floor and at greater depths in the uplands. The location of the river is at *E*; a bottom-land well is at *D* and a terrace well at *F*, whereas a dry well is in the shaly land at *H*. The water-table level is shown by *G*.

hard and potable. The only weak wells are those located near the edge of the tablelands adjacent to the shaly lands, where little water remains in storage, owing to leakage.

PIERRE-NIOBRARA REGION (1^5)

The Pierre-Niobrara region occupies central Boyd County and narrow belts along the Keyapaha, Niobrara, and Missouri Valleys. It is a continuation southward of subregion 4^1 and 4^2 of South Dakota. The surface—flat, rolling, hilly, or rough—was largely developed on the Pierre shale and Niobrara chalk. Direct surface run-off is relatively high, except from small areas of sandy land along the valleys and small, scattered tracts on the uplands.

Much of this region is not well supplied with shallow ground water and suffers from drought. Use is made of the springs issuing from the tablelands bordering the region. Shallow wells tap the storage in alluvial and other sandy areas. The creeks and rivers are sources of supply. Surface run-off is ponded at many places, mainly for stock water. The last recourse for a ground-water supply is the Dakota sandstone, at depths varying from about 400 feet on the Missouri River bottom land at the east border of the zone to 1,000 feet or more on the uplands westward. Several artesian wells have been drilled in the Missouri and Ponca Creek Valleys, and deeper wells in which there is no flow have been drilled on the upland.

The water from the Dakota is potable but considerably mineralized. That from the local areas of sandy land is suited for drinking purposes.

SANDHILL REGION (2^1–2^4)

The sand hills of the shelterbelt area were formed by wind, principally of materials from the fluvio-glacial and Ogallala formations. They mantle to various depths the lower zones of the formations from which they were derived and are deeply underlain by impervious beds. Since they are open-textured, most of the rainfall becomes ground water, with underflow to the Niobrara, Elkhorn, Loup, and other rivers. The water table is high, being exposed in the basins and valleys as marshes and lakes. In places where the water table is at or near the surface, it is lowered by evaporation, transpiration, and natural and artificial drainage. It is elevated by underflow from the extensive storage grounds, and by local rainfalls.

There is a vast amount of water in the sand hill region, usually of good quality and soft to medium-hard. Its mineralization runs 60 to 100 parts per million. Some of the lakes and lake basins are heavily alkalinized, but deeper beneath them is good potable water. Well water can generally be obtained at shallow depths in the region, most wells being driven. Windmills are largely used for pumping.

The drought of the past few years did not cause much lowering of the water table in this region, although there was a drop of 2 to 4 feet in some valleys, causing many of the lakes to lower and disappear. The rivers that head in the sand hills showed no marked reduction in discharge, but their discharges were reduced somewhat in their courses outside the region, owing mainly to excessive evaporation and to transpiration.

The prairie-plains (2^2) subregion of the sand hills is a nearly flat prairie land, dotted with few sand hills proper. Much of its soil is sandy, and the water table is shallow. This area, like the hay flats in the sand hills proper, is favorable for forestation.

The sand hills constitute Nebraska's most important water-storage ground. The main ground-water problems here relate to the regulation of artificial drainage and the prevention of the wastage of artesian water. There are many flowing wells in the shelterbelt zone of the sand hill region with depths of 80 feet or more. They tap horizons in the Pleistocène and Tertiary formations.

LOESS-DRIFT HILL REGION (3)

The Loess-Drift Hill region occupies much of northeastern Nebraska, extending a short distance into the shelterbelt zone, in Knox County. The region is characterized by the presence of two sheets of glacial drift, known as the Nebraskan (lower) and the Kansan (upper). They are composed of till, some sand, and boulders. They carry only small quantities of available water, but are separated at many points by the Aftonian sands and gravels, which supply well water at places where the storage is not lost through drainage to the valleys. Locally, there are irregular and often discontinuous deposits of sand and gravel below the Nebraskan drift. This horizon also affords some well water in parts of the region.

In the shelterbelt zone the sands and gravels next below the Nebraskan drift are irregular in occurrence; the Nebraskan sheet is well defined; the Aftonian is quite thick, and the Kansan has been largely eroded, becoming thin to the west. Water occurs in the Aftonian where drainage and drought have not depleted it, and some water is found in the subglacial sands and gravels, which rest upon the eroded Cretaceous formations.

In places where sufficient water is not found in the sands associated with the drift sheets, wells are located on alluvial lands, if possible. Where there are no alluvial lands and the sands mentioned above are dry or absent, deep wells are sunk to the Dakota beds, at depths ranging between 400 feet and about 800 feet, the depth increasing with surface elevation westward and with the dip of the Dakota in that direction. It should be noted in this connection that the Niobrara formation in this distribution contains some potable water in its basal member, which is known as the " Fort Hayes limestone ", and that several wells tap this horizon, making it unnecessary to drill through the Carlile, Greenhorn, and Graneros formations to the Dakota beds.

The water in the alluvial and glacial sands is medium hard, and that of the Dakota in this part of the Loess-Drift region is not too highly mineralized for drinking.

LOESS HILL REGION (4)

The surface of the Loess Hill region is occupied by hills and small upland plains developed on the Ogallala formation, Pleistocene sands, and the Peorian and Loveland loesses. It is trenched from northwest to southeast by the Elkhorn Valley and branches of the Loup River and is further modified by numerous small drainage ways tributary to the major valleys. The loess mantle is thick and not very pervious. It rests upon fluvio-glacial formations (Grand Island and Holdrege) in much of that part of the region which lies in the shelterbelt zone, and upon the Ogallala formation at the west border of the zone. The large valleys are intrenched through the loess deposits and for some distance into the Pleistocene and Tertiary formations, which rest uncomformably upon the impervious Cretaceous floor.

Much of the rainfall of this region becomes direct run-off because of the deep, close-textured mantle rock. This condition causes soil erosion and gullying. Some of the run-off is absorbed by the sandy lands of the valley floors. Generally, however, the ground water of this region is replenished directly by underflow and indirectly by surface discharge coming from the sand-hill region. The direction of underflow is for the most part southeastward through Pleistocene and Ogallala deposits. Its movement is differential, being greatest in old buried channels.

The water table in the uplands is quite deep and not directly affected by drought. In the bottom lands, where the water table is shallow, there is some response to drought. The loss of water by evaporation and transpiration causes the discharge of these rivers to dwindle to some extent during summer.

The thickness of the water-filled zone above the impervious floor in this region varies from about 50 feet to more than 250 feet, averaging 125 feet or more. The ground water is medium hard and uniformly of good quality. Tubular wells are installed on the uplands and at places in the lowlands, where driven wells are common. Windmills are used generally.

PLATTE RIVER LOWLANDS (5)

The well-defined Platte River lowlands consist of first bottoms, terraces, and colluvial slopes. Water storage is in recent alluvium, the Grand Island and Holdrege formations, and the Ogallala formation, all underlain by an impervium platform of Brule clay to the west and Pierre shale and Niobrara chalk farther east. There is a vast storage in this region, in sands and gravels extending from near the surface to depths of 80 to 290 feet.

Much of the ground water of the middle course of the Platte Valley within the shelterbelt zone is in the Grand Island and Holdrege sands and at places in the Ogallala formation. It is replenished from rainfall and in part by underflow from the regions northwest, and also by the return flow and normal discharge of the North Platte and South Platte Valleys.

Much well water is used in the middle course of the Platte Valley for irrigation. This use of water tends to lower the water table at places during the irrigation season. Elsewhere, and generally in the region, the water level is lowered somewhat by plant growth and evaporation. Some water is lost by underflow southeastward to and through the Loess Plain region. Apparently, as shown by observations at many wells, the water table in the Platte Valley was lowered only a few feet during the recent drought. So long as there is rainfall and the other sources of replenishment continue in season, the water-bearing beds of this region may be expected to recharge as in the past. Much of the region is well suited to forest growing, as evidenced by results that have been obtained. Trees seem to grow best on the sandy soils where the water table fluctuates least and is not too deep.

LOESS PLAIN REGION (6)

The Loess Plain region extends about half-way across the shelterbelt zone, entering from the east. It is a flat upland thickly mantled with loess deposits and underlain by the Grand Island and Holdrege sands and gravels in a thickness of 100 to 200 feet. The latter deposits rest upon the Ogallala formation to the west and upon the Pierre and Niobrara farther east. The Holdrege and Grand Island formations are important aquifers. They carry underflow southeastward to the Republican and Blue Rivers.

Except in a few small sandy areas, the ground-water replenishment from rainfall is comparatively small. The marked feature here is the underflow from the Platte Valley to the Big Blue, Little Blue, and Republican Valleys. This insures a dependable well-water supply in this belt at a depth of 125 feet or more. The wells here are of the tubular type and, except in lifting water for towns, windmills are used generally. The water is medium hard and of good quality.

WESTERN LOESS REGION (7)

The ground-water conditions in the Western Loess region are similar to those of the Loess Hill region, except that the Holdrege and Grand Island sands are absent at most points, and the storage is largely in the Ogallala formation. The surface of the region is developed on the Peorian and Loveland loesses and, locally, on the Ogallala formation. It is composed of small plains cut by numerous canyons. The main streams are permanent, owing to the water they receive from the sand-hill areas to the north and northwest.

The underflow in this region is southeastward in the Ogallala sands and gravels, which rest upon the uneven surface of the Pierre shale and, locally, upon the Niobrara, as along the Cambridge Arch. Except in the valleys, the wells are 100 feet to 300 feet in depth and are tubular. Windmills are used generally. Strong wells prevail, and the water is soft to medium hard and of good quality.

REPUBLICAN VALLEY REGION (8)

The ground-water conditions of the Republican Valley region are complicated. The Republican River and its tributaries have eroded through the upland water-bearing formations and into the Pierre shale and Niobrara chalk, exposing them in the valley sides. This condition causes the leakage of ground water from the aquifers of the uplands to the alluvial bottom lands, as in the Pierre-Niobrara region. There is practically no water in the Pierre slopes of this region and very little surface water where the Niobrara outcrops. The areas on these formations are dry zones. The Pleistocene sands are thin in parts of the region, especially south of the Republican, where underdrainage is great and the wells go dry during drought, whereas north of the valley, where there is underflow from the Loess Plain, the well-water supply is not affected much by drought. Farther west in the Republican Valley region, that is, on divides between the tributaries south of the river, there are narrow belts of water storage in the Ogallala formation at points back from the valley sides. The alluvial land along the Republican River is not very thick, but it usually carries water up to the level of the river, which lowered to a dry bed during the late drought. Locally, where there is most intake from the north, the alluvial water level in the Republican Valley held to near the normal stage.

Fortunately, the Republican Valley region is traversed by a river which is fed by small live streams, as Buffalo Creek, Rock Creek, Frenchman River, Red Willow Creek, and Medicine Creek, all of which head in sandy land, and by certain creeks farther east which head in the underflow from the Platte. Without the influence of these sandy upland aquifers the alluvial recharge would not be very dependable during drought. Fortunately, also, regions 6 and 7 drain ground water to this region as spring-fed streams, which develop storage in the alluvial bottom lands. Figure 102 shows the water conditions along the Republican Valley east of the shelterbelt zone.

Unfortunately the Dakota sands are quite deep in much of the Republican Valley region, the depth ranging from about 400 feet on the east to 2,000 feet or more at the Colorado line. The water of the Dakota here, though potable at some places, is too heavily mineralized with soda and salt at others for domestic use. A well drilled at Beaver City in 1934 reached the Dakota water at a depth of about 1,100 feet. This water is used for the municipal supply.

KANSAS

Refer to figure 104, and cross section no. 4, figure 95.

The ground-water conditions in the shelterbelt zone of Kansas are quite unlike those that prevail in Nebraska. Except in the Arkansas River lowland, there is much less mantle rock storage than in Nebraska, and relatively more wells are drilled to the bedrock horizons.

SURFACE FEATURES

The surface of the zone in Kansas consists of upland plains separated by low northeast-southwest-trending escarpments and cut across by river valleys leading eastward. Traversing the belt from Barber County northwestward (fig. 104) one finds in succession the escarpment (1) at the north border of the Cimarron "Red Beds", the smooth to rolling Arkansas River lowlands (5^2), a belt of Dakota sandstone hills (3), a narrow, steep slope on the Graneros shale (2E), which is capped by the Greenhorn limestone (2D), a wide rolling to hilly plain on the Carlile (2C), an escarpment and a plain on the Niobrara (2B), an escarpment on the outcrop of the Ogallala, and a tableland on the Ogallala (1) thinly mantled with loess. The belted occurrence of the surface features of the land is clearly shown.

STRUCTURAL CONDITIONS

The subsurface outlines in figure 104 and table 27 show formations that persist with uniform thickness. These formations lie in regular sequence with a low dip westward and northwestward, modified by minor faulting and some folding in the area designated as the Cambridge or Barton Arch, which includes several small anticlines.

There are unconformities at different horizons in the geologic section, notably at the base of the Cretaceous and lower. The variable thickness of the Dakota is due to the uneven floor upon which it was deposited and to the amount of erosion it has endured on its outcrop.

It should be recognized here that the Cretaceous formations rest one upon another in regular succession westward, each having little variation in thickness throughout the shelterbelt zone. This means that the Niobrara at 2B is underlain in order by the Carlile, Greenhorn, Graneros, and Dakota, and that this succession holds throughout the zone. Similarly, a well drilled on 2C would pass through such thickness of the Carlile as has not been eroded and would penetrate the Greenhorn, Graneros, Dakota, and the yet older beds in the order and thickness in which they occur. This brief statement shows how geologists are able to determine the depth to a bedrock water horizon in an area where the beds are uniform in sequence and thickness.

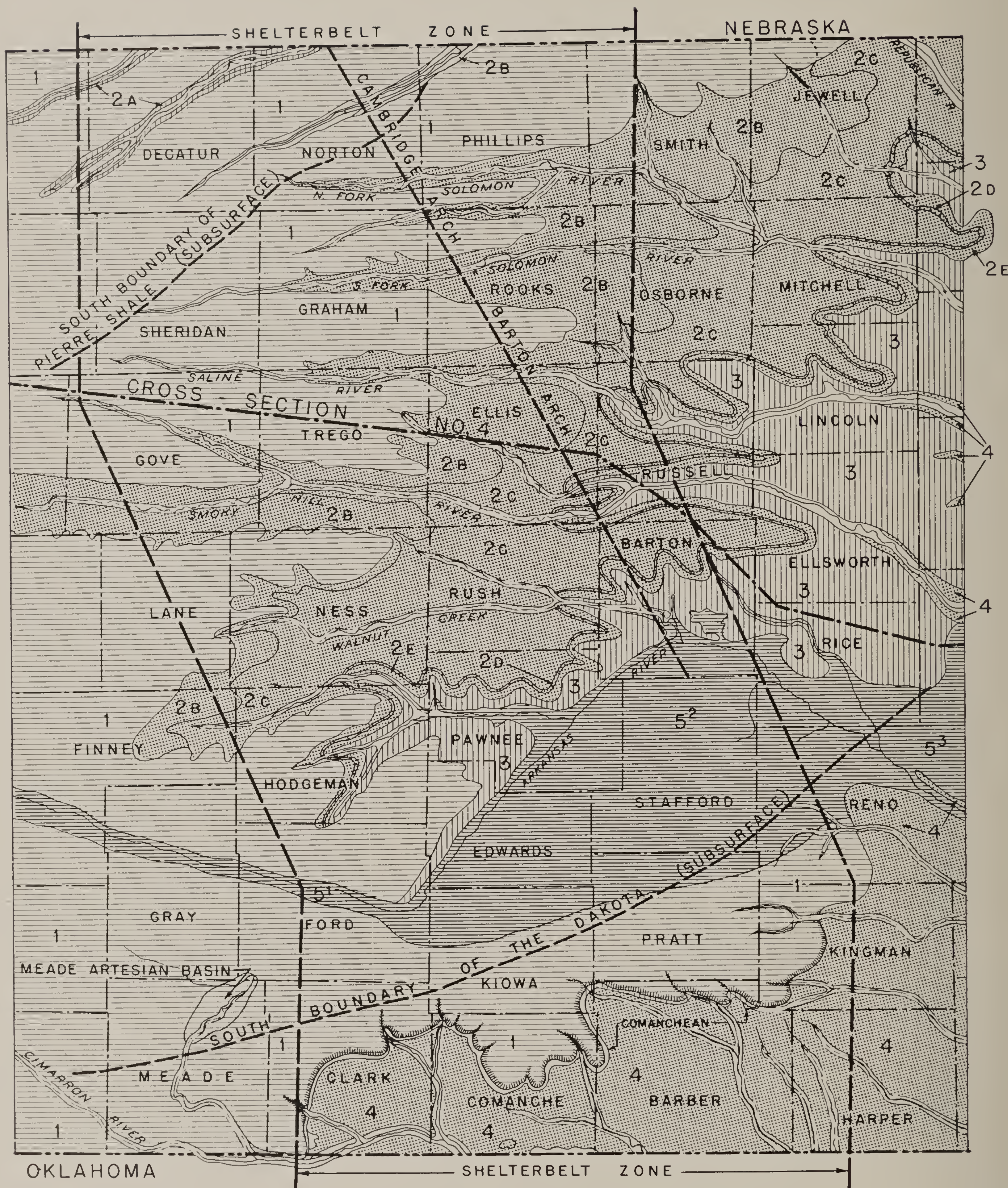
TABLE 27.—*Geologic column in the shelterbelt zone of Kansas*

Age	Name of formation	Thickness	Lithologic character
		Feet	
Recent and Pleistocene.	Alluvium	0–60	Silt, sand, gravel.
	Dune sand (very local)	0–50	Fine sand.
	Peorian loess (northwest).	0–30	Largely silt.
	Loveland loess (northwest).	0–10	Silt, clay, fine sand.
	Grand Island and Holdrege formations (locally at north end of zone).	0–30	Sand and gravel.
Pliocene	Ogallala formation	0–80	Sand, limy sandstone, gravel.
Cretaceous	Pierre shale (thickens westward).	0–200	Dark-gray shale.
	Niobrara (thickens westward).	400–530	Shaly chalk; massive sandy lime at base.
	Carlile	190	Dark shales.
	Greenhorn	30–45	Thin limes and shales.
	Graneros (thickens northward).	80	Dark shale, sandy at base.
	Dakota group	300–450	Sandstones and shales.
(?) Probably correlative with basal Dakota.	Comanche	150	Largely shale; Cheyenne sandstone at base.
Unconformity			
Cimarron Permian	Several formations	800–900	Red shales, sandstones, gypsum.
Big Blue Permian	Various formations	1,000	Not drilled for water in shelterbelt zone.

GROUND-WATER HORIZONS

The ground-water horizons of Kansas, named downward in order of their age, are (1) the alluvium, (2) Pleistocene sands, (3) Ogallala, (4) Fort Hayes limestone at the base of the Niobrara, (5) Greenhorn limestone, (6) Dakota sandstones, (7) sandstones at the base of the Comanche, (8) sandstones in the Permian "Red Beds." In much of the shelterbelt zone no water is tapped below the Dakota.

The basal Niobrara and the Greenhorn yield water in few wells but are sources of some spring water in their outcrop areas. The alluvial and Tertiary waters generally are medium hard to hard and desirable for drinking; locally the shallow, alluvial water is alkaline or saline; that obtained from the Niobrara carries lime and some magnesium sulphate, but is usable; the Dakota water coming from a thin sandstone above a mottled shale is saline, but elsewhere in this group of sandstones the volume of water is large and the quality is not so objectionable. The three formations carrying the most dependable water in the zone are the alluvial lands, the Ogallala, and the Dakota. The shaly lands have little and it is of poor quality.



LEGEND:

1 TABLELANDS

2A PIERRE REGION

2B-E NIOBRARA-BENTON REGION

3 DAKOTA OUTCROP REGION

4 "RED BEDS" REGION

5^{1-2-3} ARKANSAS RIVER LOWLANDS

FIGURE 104.—Ground-water regions of shelterbelt zone in Kansas.

GROUND-WATER REGIONS

As indicated in figure 104 the ground-water regions are the tablelands (1), Niobrara-Benton region (2B, 2C, 2D, 2E), Dakota Outcrop region (3), "Red Beds" region (4), and the Arkansas River Lowlands (5^1, 5^2, 5^3). These regions have been delimited with reference to the quality, quantity, accessibility, and condition of occurrence of their ground-water supplies.

TABLELAND REGION (1)

Here, as in the northern tableland region of Nebraska, the Ogallala formation rests upon an impervious floor. It overlaps in succession, from northwest to southeast, the Pierre, Niobrara, Carlile, Greenhorn, Graneros, Dakota, and Comanche formations. The rainfall builds up storage in its open-textured zones and establishes a water level sloping eastward and southeastward and, locally, to the valleys that have been eroded to the Cretaceous rocks. The wells are largely of the tubular type, and the water supply at most places is adequate for farms and towns.

The valleys shown by 2A and 2B are tributaries of the Republican. Like most other tributaries in the Republican Valley region, they have dry zones along their borders. The Pierre shale underlies the valleys at 2A, and the Niobrara the valleys at 2B. Water from the alluvial horizons is sought at these places.

Some groves on the smooth tablelands of this region are in fair condition, but others have failed, owing in part to lack of protection. There are small, scattered areas of brush growth and trees on the rough escarpment lands.

NIOBRARA-BENTON REGION (2B, 2C, 2D, 2E)

Much of the surface of the Niobrara-Benton region is occupied by the Niobrara and Benton formations, which carry little potable water. The surface-water supply generally is inadequate except in the better developed alluvial lands and in the Dakota sandstones, which lie at a depth ranging from 125 feet or more along the eastern border of the region to a maximum of about 800 feet northwestward. Fortunately there is sufficient pressure in the Dakota horizons to force the water upward to considerable heights in the wells. The deep wells here are of the cased type.

As noted before, some wells in this region draw upon the Fort Hayes and Greenhorn horizons, but in places where these fail and there is no alluvial supply, it is necessary to drill to the Dakota or to pond the surface run-off.

Except on the outcrops of the Fort Hayes and Greenhorn limestone, on the slope land of the Graneros, and on the alluvial valley floors, there is little natural growth of brush or trees in this region. The percentage of survival of trees planted on the smoother upland formed on the Carlile and Niobrara formations has been low.

DAKOTA OUTCROP REGION (3)

The Dakota beds crop out in large areas east of and across the shelterbelt zone. They absorb most of the rainfall, building up local storage from which springs issue and which is tapped successfully by wells of moderate depth. One zone near the middle of the Dakota releases saline water, which, by accumulation on the adjacent lower lands, develops salt flats and marshes of considerable areas in the aggregate. Most of these areas, however, are located east of the shelterbelt zone.

It is quite possible that the underflow in the Dakota from intake in the Rocky Mountain region reaches the shelterbelt zone in Kansas and Nebraska but does not extend through the Cambridge Arch, at least generally, and that a considerable amount of the Dakota replenishment east of this arch may come from the outcrop within and east of the shelterbelt zone. Just how generally the underflow from the west is blocked in the arch is not known, yet some of the wells drilled on this arch are dry in the Dakota, which lies high in the structure. This explains why the location of the arch is shown on the map.

The soil and water conditions generally in the Dakota outcrop region seem to be favorable to afforestation with trees adapted to the conditions. This conclusion is evidenced by the small areas of natural forest located on the steeper slopes, in ravines, and along the drainage ways.

"RED BED" REGION (4)

At the south end of the zone in Kansas is an area of scant ground-water supply. It is rolling, hilly, or rough, and was developed on the Comanche shales and the Permian "Red Beds." Some water leaks out of a sandstone (Cheyenne) exposed at the north edge of the region, making springs and small streams, and some water occurs in the thin sandstones of the "Red Beds." Generally, however, the water supply is a problem here. The best well water occurs in the alluvial areas at shallow depths and locally in the sandstone at depths of 100 feet or more. At the latter depths some of the water carries salts of calcium and magnesium. A considerable amount of surface run-off is ponded in the region.

Ravines and the escarpment generally at the north border of this region, as well as the alluvial and upland sandy lands elsewhere, seem to be favorable areas for tree growing.

ARKANSAS RIVER LOWLANDS (5)

The Arkansas River Lowlands is the outstanding ground-water region in Kansas. The land is comparatively flat, consisting of the first bottoms along the river and bordered by low terraces, south of which is a plain covered with areas of loamy soil and small tracts of low sand hills. The bedrock is largely Ogallala, Dakota, and Cimarron, deeply underlain with "Red Bed" formations. An enormous storage is built up here from the local rainfall and from the river. The water table is at a depth of 3 to 20 feet in the lowest, poorly drained land, and deeper in the higher areas, where its depth is 50 to 80 feet. Except in the small alkaline and saline areas the water is both potable and suited to irrigation. The wells are driven or drilled, and their flow is usually strong. Few wells are drilled to the Dakota.

This region resembles the prairie-Plains areas and part of the Platte River Lowland of Nebraska. Like in the regions just named, the soil and ground-water conditions are very favorable to tree planting.

OKLAHOMA-TEXAS

Refer to figure 105, and cross section no. 5, figure 95.

The shelterbelt zone in Oklahoma and Texas crosses the "Red Bed" country, bordering the High Plains territory on the west and extending across the lower Permian and upper Pennsylvanian outcrop area on the southeast. The Wichita uplift, in which very old formations are exposed, is the dominant structural feature. The geologic column is given in table 28.

Table 28.—*Geologic column in the shelterbelt zone of Oklahoma and Texas*

Age	Name of formation	Thickness	Lithologic character
		Feet	
Recent and Pleistocene.	Alluvium; Terrace deposits and dune sand.	2–30+; 0–100±	Silt, sand, and gravel. Sand and gravel.
Tertiary (late)	"Mortar beds"	100–300	Clay, sand, gravel.
Triassic	Dockum group	115–1,000	Varicolored shales, some sandstones and conglomerates.
Permian	Quartermaster	300±	Soft red sandstones, sandy clays, and shales.
	Cloud Chief (Greer) [1]	150–300	Gypsum, red clays, shales, and sandstones.
	Woodward [1]	300±	Red shales, sandstones, and dolomites.
	Blaine [1]	75–200	Red shales, gypsum, thin dolomites.
	Enid [1]	1,200–1,500	Brick-red clay shales with some red and whitish sandstone.
Cambro-Ordovician	Arbuckle		Limestone.
Pre-Cambrian	Wichita Mountain.		Gabbro, granite, porphry and granite.

[1] In Texas the Cloud Chief, Woodward, Blaine, and upper Enid are included in the Double Mountain group (undivided), consisting of red and gray or blue shales and sandstones with dolomites and gypsum, 1,500–2,000 feet thick; the lower Enid is called the Clear Fork group and consists of shale, sandstone, dolomites, and some gypsum, 1,200 feet in thickness.

GROUND-WATER HORIZONS

The surficial deposits of the shelterbelt zone in Oklahoma and Texas which yield ground water are the alluvium of the stream valleys and the dune sand and terrace deposits. Bedrock horizons which are important water sources include the Tertiary sands and gravels; sandstone beds in the Dockum group of Triassic age, and the Quartermaster, Woodward, and Enid formations of Permian age; the limestones of Cambro-Ordovician age; and the pre-Cambrian granite. The Cambro-Ordovician and pre-Cambrian rocks are near the surface only in the vicinity of the Wichita Mountains.

GROUND-WATER REGIONS

The shelterbelt zone in Oklahoma and Texas crosses three main regions, namely, (1) the Tertiary, (2) the "Red Beds," and (3) the Wichita uplift. It includes also groups of scattered areas, namely, (4) the alluvium, terrace, and dune sand areas and (5) the saline flats. No attempt is made here to differentiate the older Permian and the upper Pennsylvanian beds as regions and subregions. Location numbers in the following paragraphs refer to those marked on the map (fig. 105).

TERTIARY REGION (1)

The Tertiary regions consist of clay, sand, and gravel. The rocks appear to be correlative with the Ogallala formation of Kansas and Nebraska. The ground-water conditions are similar to those in the Tertiary region of Kansas. In general, there is a good supply of water at depths of 100 feet or more.

"RED BED" REGIONS (2^1–2^5)

The "Red Bed" region, as shown on the map, includes five subregions, as follows:

Subregion 2^1 is formed on the Dockum group and the Quartermaster formation. The Dockum group is Triassic in age and consists of varicolored shales, with some interbedded sandstones and conglomerates. It overlies the Quartermaster formation unconformably. The Quartermaster formation is made up of soft red sandstones, sandy clays, and shales, and is late Permian (Cimarron) in age. The water from both these horizons is of good quality but often limited in quantity.

Subregion 2^2, developed on the Cloud Chief or Greer formation, generally yields bad water. The Cloud Chief formation is a series of gypsums, red clays, shales, and sandstones. It is also Cimarron in age.

Subregion 2^3, on the Woodward formation, consisting of red shales, sandstones, and dolomites, carries good water. The Woodward formation is Permian in age and equivalent to a part of the Cimarron.

Subregion 2^4, on the Blaine formation, which contains thick beds of gypsum interbedded with red shales and thin dolomites, yields hard water. It is also of Permian (Cimarron) age.

Subregion 2^5, developed on the red clay shales and sandstones of the Enid formation, has good water with the exception of areas affected by leakage from the overlying Blaine formation. The Enid formation is Permian in age.

The Cloud Chief, Woodward, Blaine, and Enid formations have not been mapped in Texas but are included in the Double Mountain group. It has, therefore, been impossible to trace the various subregions across the State line, although zones similar to those in Oklahoma are known to exist.

The ground water of the "Red Beds" region encountered at shallow depths is generally fair to good; that found at considerable depths is often unsuitable for drinking.

WICHITA UPLIFT REGION (3)

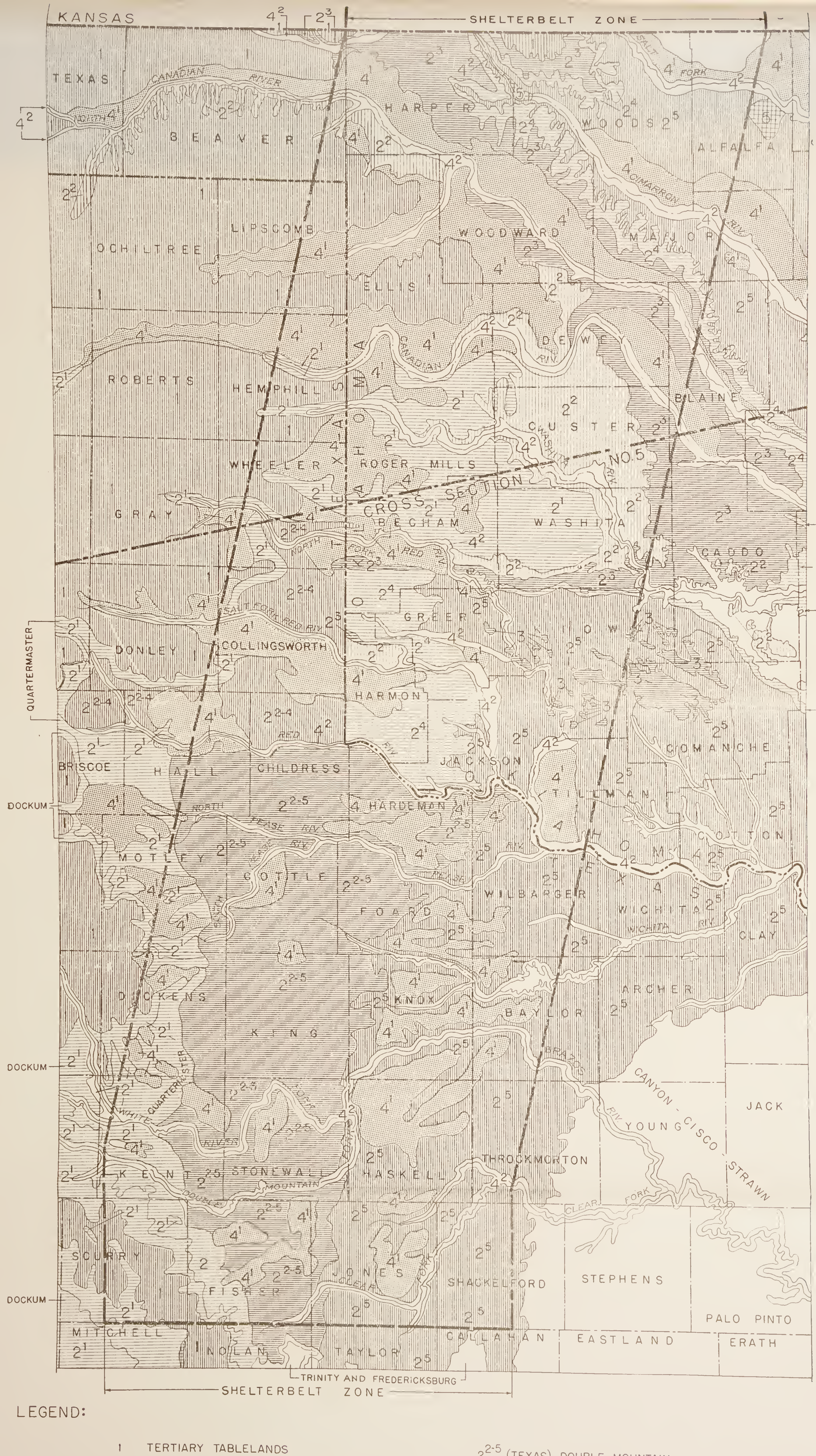
The Wichita Mountains are formed on ancient rocks, as granite, gabbro, and very old limestone. They are flanked by the "Red Bed" formations. The ground water of the granite is said to be soft, and springs are abundant. Water from the heavy lime beds is hard. All told, there is a good water supply in this region.

ALLUVIUM AND DUNE-SAND AREAS (4)

The alluvium and dune-sand areas are in or along the largest valleys of the shelterbelt zone. Generally, they carry a fair grade of water except where there are leakages of highly mineralized water from the overlying gypsiferous and saliferous zones. Most of the water is shallow and soft, medium-hard, or hard.

SALINE AREAS (5)

Salt leakages from the gypsiferous and saliferous upland formations (Cloud Chief or Greer and Blaine) accumulates in flat areas in some of the valleys of the shelterbelt zone in Oklahoma and Texas. These areas are nearly barren.



LEGEND:

1	TERTIARY TABLELANDS	$2^{2\text{-}5}$	(TEXAS) DOUBLE MOUNTAIN
2^1	DOCKUM QUARTERMASTER SUBREGION	2^5	(TEXAS) CLEAR FORK-WICHITA
2^2	CLOUD CHIEF SUBREGION	3	WICHITA MOUNTAINS
2^3	WOODWARD SUBREGION	4^1	DUNE, SAND AND TERRACES
2^4	BLAINE SUBREGION	4^2	ALLUVIUM
2^5	(OKLAHOMA) ENID SUBREGION	5	SALT FLATS

FIGURE 105.—Ground-water regions of shelterbelt zone in Oklahoma and Texas.

145405—35. (Face p. 191)

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APPENDIX

COMMON AND SCIENTIFIC NAMES OF SPECIES REFERRED TO IN THE TEXT

[The species recommended for use in shelterbelt plantings in the Plains region are indicated by asterisks]

COMMON NAME	SCIENTIFIC NAME
Adelia, Texas (swamp privet)	*Forestiera acuminata* Poir.
*Ailanthus (tree-of-heaven)	*Ailanthus altissima* (Mill.) Swingle.
Alder, European	*Alnus glutinosa* Gartn.
Almond, Russian	*Prunus nana* Stokes.
Apple	*Pyrus malus* L.
*Apricot	*Prunus* sp.
Apricot, common	*Prunus armeniaca* L.
Arborvitae, Chinese. (See Oriental arborvitae.)	
*Arborvitae, oriental (Chinese arborvitae)	*Thuja orientalis* L.
Ash, European	*Fraxinus excelsior* L.
Ash, green	*Fraxinus pennsylvanica lanceolata* (Borkh.) Sarg.
*Ash, prairie	*Fraxinus campestris* Britt.
Ash, red	*Fraxinus pennsylvanica* Marsh.
Ash, wafer. (See Hoptree.)	
Ash, white	*Fraxinus americana* L.
Aspen	*Populus tremuloides* Michx.
Aspen, European	*Populus tremula* L.
Baccharis, willow (groundsel tree)	*Baccharis salicina* T. and G.
Basswood	*Tilia glabra* Vent.
Beardgrass, prairie (little bluestem)	*Andropogon scoparius* Michx.
Beardgrass, silver	*Andropogon saccharoides* Swartz.
Beech, European	*Fagus sylvatica* L.
Birch, European white	*Betula alba* L.
Birch, mountain. (See Red birch.)	
Birch, paper	*Betula papyrifera* Marsh.
Birch, red (mountain birch)	*Betula fontinalis* Sarg.
Bittersweet, American	*Celastrus scandens* L.
Blackberry, highbush	*Rubus argutus* Link.
Blackcap, common (wild black raspberry)	*Rubus occidentalis* L.
Blackthorn	*Prunus spinosa* L.
Bluegrass, bulbous	*Poa bulbosa* L.
Bluestem (western wheatgrass)	*Agropyron smithii* Rydb.
Bluestem, big. (See Turkeyfoot.)	
Bluestem, big. (See Bluejoint turkeyfoot.)	
Bluestem, little. (See Prairie beardgrass.)	
Boxelder	*Acer negundo* L.
Do	*Acer negundo violaceum* Kirch.
Bromegrass, smooth	*Bromus inermis* Leyss.
Broom	*Cytisus austriacus* L.
Broom	*Cytisus biflorus* L'Herit.
Buckthorn, common (European buckthorn)	*Rhamnus cathartica* L.
Buckthorn, European. (See Common buckthorn.)	
Buckthorn, Texas. (See Texas jujube.)	
Buffaloberry, russet (bullberry)	*Shepherdia canadensis* Nutt.
*Buffaloberry, silver	*Shepherdia argentea* Nutt.
Buffalo grass	*Buchloë dactyloides* (Nutt.) Engelm.
Bullberry. (See Russet buffaloberry.)	
Burningbush. (See Wahoo.)	
Burningbush, European (spindle tree)	*Euonymus europaeus* L.
Buttonbush	*Cephalanthus occidentalis* L.
Caragana. (See Pea-shrub.)	
Catalpa, common	*Catalpa bignonioides* Walter.
*Catalpa, hardy	*Catalpa speciosa* Warder.
Catclaw	*Acacia greggii* Gray.
*Cedar, eastern red	*Juniperus virginiana* L.
*Cedar, Rocky Mountain red	*Juniperus scopulorum* Sarg.
Cherry	*Prunus mirabilis* Hort.
Cherry, Bessey (western sand cherry)	*Prunus besseyi* Bailey.
Cherry, black	*Prunus serotina* Ehrh.
*Cherry, choke	*Prunus virginiana* L.
Cherry, dwarf	*Prunus chamaecerasus* Jacq.
Cherry, European bird	*Prunus padus* L.
Cherry, pin	*Prunus pennsylvanica* L.
*Cherry, western choke	*Prunus virginiana melanocarpa* (A. Nels.) Sarg.
Cherry, western sand. (See Bessey cherry.)	
Chittimwood. (See Gum elastic.)	
*Coffeetree	*Gymnocladus dioicus* (L.) Koch.
*Coralberry	*Symphoricarpos orbiculatus* Moench.
Cornel, silky. (See Silky dogwood.)	

COMMON NAME	SCIENTIFIC NAME
Cornelian-cherry (dogwood)	*Cornus mas* L.
Cottonwood	*Populus sargentii* Dode.
Cottonwood, eastern	*Populus deltoides* Marsh.
Cottonwood, lanceleaf	*Populus acuminata* Rydb.
Cottonwood, narrowleaf	*Populus angustifolia* James.
Cottonwood, southern (Carolina poplar)	*Populus deltoides virginiana* (Cast.) Sudw.
Cranberry, highbush. (See American cranberrybush.)	
Cranberrybush, American (highbush cranberry)	*Viburnum trilobum* Marsh.
Cranberrybush, European	*Viburnum opulus* L.
Currant, American black (wild black currant)	*Ribes americanum* Mill.
Currant, flowering. (See Golden currant.)	
Currant, flowering. (See Slender golden currant.)	
Currant, golden (flowering currant)	*Ribes odoratum* Wendl.
*Currant, slender golden (flowering currant)	*Ribes aureum* Pursh.
Currant, squaw (wild currant)	*Ribes inebrians* Lindl.
Currant, wild. (See Squaw currant.)	
Currant, wild black. (See American black currant.)	
*Cypress, Arizona	*Cupressus arizonica* Greene.
*Desert-willow (desert flowering willow)	*Chilopsis linearis* (Cavanilles) D. C.
Dogbrier (rose)	*Rosa canina* L.
Dogwood	*Cornus femina* Mill.
Dogwood	*Cornus instolonea* A. Nels.
Dogwood	*Cornus interior* Peters.
Dogwood. (See Cornelian-cherry.)	
Dogwood, Bailey	*Cornus baileyi* Coult. and Evans.
Dogwood, bloodtwig	*Cornus sanguinea* L.
Dogwood, gray	*Cornus racemosa* Lam.
Dogwood, red-osier	*Cornus stolonifera* Michx.
*Dogwood, roughleaf	*Cornus asperifolia* Michx.
Dogwood, silky (silky cornel)	*Cornus amomum* Mill.
Dropseed, longleaf	*Sporobolus asper* (Michx.) Kunth.
Dropseed, prairie	*Sporobolus heterolepis* Gray.
*Elder, American	*Sambucus canadensis* L.
Elder, European	*Sambucus nigra* L.
Elm	*Ulmus pedunculata* Foug.
*Elm, American (white elm)	*Ulmus americana* L.
*Elm, Chinese	*Ulmus parvifolia* Jacq.
Elm, Chinese. (See Dwarf Asiatic elm.)	
*Elm, dwarf Asiatic (Chinese elm)	*Ulmus pumila* L.
*Elm, English	*Ulmus campestris* L.
Elm, red. (See Slippery elm.)	
Elm, Scotch	*Ulmus glabra* Huds.
Elm, slippery (red elm)	*Ulmus fulva* Michx.
Elm, white. (See American elm.)	
False-indigo	*Amorpha fruticosa angustifolia* Pursh.
Feathergrass	*Stipa pennata* L.
Fescue, meadow	*Festuca elatior* L.
Fescue, sheep	*Festuca ovina* L.
Filbert (hazel; Volga hazel)	*Corylus avellana* L.
Fir, balsam	*Abies balsamea* (L.) Mill.
*Fir, Douglas	*Pseudotsuga taxifolia* (La M.) Britt.
Fir, silver	*Abies alba* Mill.
Foxtail, meadow	*Alopecurus pratensis* L.
Golden drop	*Onosma echiodes* L.
Gooseberry, common wild. (See Missouri gooseberry.)	
Gooseberry, Missouri (common wild gooseberry)	*Grossularia missouriensis* (Nutt.) Cov. and Britt.
Gooseberry, redshoot (western wild gooseberry)	*Grossularia setosa* (Lindl.) Cov. and Britt.
Gooseberry, western wild. (See Redshoot gooseberry.)	
Gorse, common	*Ulex europaeus* L.
Grama, blue	*Bouteloua gracilis* (H. B. K.) Lag.
Grama, side-oats	*Bouteloua curtipendula* (Michx.) Torr.
Grape, doan (wild grape)	*Vitis doaniana* Muns.
Grape, early wild. (See Riverbank grape.)	
Grape, Long's (shrubby grape)	*Vitis longii* Prince.
Grape, Oregon. (See Oregon hollygrape.)	
Grape, riverbank (early wild grape)	*Vitis vulpina* L.
Grape, sand (wild grape)	*Vitis rupestris* Scheele.
Grape, shrubby. (See Long's grape.)	
Grape, sweet winter	*Vitis cinerea* Engelm.
Grape, wild. (See Doan grape.)	
Grape, wild. (See Sand grape.)	
Greenbrier, bristly	*Smilax hispida* Muhl.
Groundsel tree. (See Willow baccharis.)	
*Gum elastic (chittimwood)	*Bumelia lanuginosa* (Michx.) Pers.
Gutierrezia. (See Broom snakeweed.)	
*Hackberry	*Celtis occidentalis* L.
*Hackberry	*Celtis occidentalis crassifolia* (La M.) Gray.
Hackberry. (See Paloblanco.)	
Haw, black. (See Nannyberry.)	
Haw, red. (See Washington thorn.)	
Hawthorn	*Crataegus chrysocarpa* Ashe.
Hawthorn, spike	*Crataegus occidentalis* Britt.
Hawthorn, English	*Crataegus oxyacantha* L.
Hawthorn	*Crataegus oxyacantha monogyna* L.

COMMON NAME	SCIENTIFIC NAME
Hawthorn	*Crataegus sanguinea* Pall.
Hazel. (See Filbert.)	
Hazel, Volga. (See Filbert.)	
Hazelnut, American	*Corylus americana* Walt.
Hazelnut, beaked	*Corylus rostrata* Ait.
Hollygrape, Oregon (Oregon grape)	*Odostemon aquifolium* Rydb.
*Honeylocust	*Gleditsia triacanthos* L.
*Honeysuckle, tatarian	*Lonicera tatarica* L.
Hop-hornbeam	*Ostrya virginiana* (Mill.) K. Koch.
Hoptree (wafer ash)	*Ptelea trifoliata* L.
Hornbeam, European	*Carpinus betulus* L.
Indigo, false. (See False-indigo.)	
Indigobush, dwarf (smooth leadplant)	*Amorpha nana* Nutt.
Jersey-tea, inland (New Jersey tea)	*Ceanothus ovatus* Deaf.
Jersey-tea, inland (New Jersey tea)	*Ceanothus ovatus pubescens* T. and C.
Jersey-tea, New. (See Inland Jersey-tea.)	
Jujube, Texas (Texas buckthorn)	*Zizyphus obtusifolia* Gray.
Junegrass	*Koeleria cristata* (L.) Pers.
Juniper, creeping (horizontal juniper)	*Juniperus horizontalis* Moench.
Juniper, dwarf	*Juniperus communis* L.
Juniper, horizontal. (See Creeping juniper.)	
*Juniper, one-seed	*Juniperus monosperma* (Engelm.) Sarg.
*Juniper, redberry	*Juniperus pinchotii* Sudw.
Larch, Siberian	*Larix sibirica* Ledeb.
Lash tree. (See Russian pea-shrub.)	
Leadplant	*Amorpha canescens* Pursh.
Leadplant, smooth. (See Dwarf indigobush.)	
*Lilac (syringa)	*Syringa* sp.
Linden, littleleaf European	*Tilia cordata* Mill.
*Locust, black	*Robinia pseudoacacia* L.
Mahogany, mountain. (See Valley-mahogany.)	
Maple, dwarf (mountain maple)	*Acer glabrum* Torr.
Maple, field. (See Hedge maple.)	
Maple, hedge (field maple)	*Acer campestre* L.
Maple, mountain. (See Dwarf maple.)	
Maple, Norway	*Acer platanoides* L.
Maple, silver (soft maple)	*Acer saccharinum* L.
Maple, soft. (See Silver maple.)	
Maple, tartar. (See Tatarian maple.)	
Maple, tatarian (Tartar maple)	*Acer tataricum* L.
Mazzard	*Prunus avium* L.
Mesquite, honey	*Prosopis juliflora glandulosa* (Torr.) Cook.
Moonseed, common	*Menispermum canadense* L.
Mountain-ash	*Sorbus intermedia* Pers.
Mountain-ash	*Sorbus torminalis* Crantz.
Mountain-ash, European	*Sorbus aucuparia* L.
Mulberry, black	*Morus nigra* L.
*Mulberry, red	*Morus rubra* L.
*Mulberry, Russian	*Morus alba tatarica* (L.) Loudon.
Mulberry, white	*Morus alba* L.
*Nannyberry (blackhaw)	*Viburnum lentago* L.
Needle-and-thread (western needlegrass)	*Stipa comata* Trin. and Rupr.
Needlegrass. (See Porcupine grass.)	
Needlegrass, western. (See Needle-and-thread.)	
Ninebark	*Opulaster intermedius* Rydb.
Ninebark, common (spiraea)	*Opulaster opulifolius* (L.) Kuntz.
Oak, blackjack	*Quercus marilandica* Muench.
*Oak, bur	*Quercus macrocarpa* Michx.
Oak, chinquapin	*Quercus muehlenbergii* Engelm.
Oak, English	*Quercus robur* L.
Oak, European turkey	*Quercus cerris* L.
Oak, havard (shin oak)	*Quercus havardii* Rydb.
*Oak, post	*Quercus stellata* Wang.
Oak, post	*Quercus stellata parviloba* Sarg.
Oak, shin	*Quercus mohriana* Rydb.
Oak, shin. (See Havard oak.)	
Oak, southern red	*Quercus rubra* L.
*Osage-orange	*Toxylon pomiferum* Raf.
Osier, common (willow)	*Salix viminalis* L.
Paloblanco (hackberry)	*Celtis reticulata* Torr.
Paloblanco (hackberry)	*Celtis reticulata vestita* Sarg.
Pea-shrub, Russian (lash tree)	*Caragana frutex* Nutt.
*Pea-tree, Siberian	*Caragana arborescens* Lam.
Pear, common	*Pyrus communis* L.
Pear, oleaster	*Pyrus eleagrifolia* Pall.
*Pecan	*Hicoria pecan* (Marsh.) Britt.
Persimmon	*Diospyros virginiana* L.
*Pine, Austrian	*Pinus nigra austriaca* Schneid.
Pine, Cembra. (See Swiss stone pine.)	
Pine, Crimean	*Pinus nigra pallasiana* Schneid.
Pine, jack	*Pinus banksiana* Lamb.
*Pine, limber	*Pinus flexilis* James.
Pine, northern white	*Pinus strobus* L.

COMMON NAME	SCIENTIFIC NAME
*Pine, ponderosa (western yellow pine)	*Pinus ponderosa* Laws.
*Pine, Scotch	*Pinus sylvestris* L.
Pine, Swiss stone	*Pinus cembra* L.
Pine, western yellow. (See Ponderosa pine.)	
*Pistache, Texas	*Pistacia texana* Swingle.
*Plum, chickasaw	*Prunus angustifolia* Marsh.
*Plum, sand (western chickasaw plum)	*Prunus angustifolia watsoni* Waugh.
Plum, western chickasaw. (See Sand plum.)	
*Plum, wild	*Prunus americana* Marsh.
Poison-ivy	*Toxicodendron radicans* (L.) Kuntz.
Poison-ivy, western	*Toxicodendron rydbergii* (Small) Greene.
Poplar	*Populus laurifolia* Ledeb.
Poplar, balsam	*Populus balsamifera* L.
Poplar, black	*Populus nigra* L.
Poplar, Carolina. (See Southern cottonwood.)	
Poplar, Carolina (hybrid) (Norway poplar)	*Populus eugenei* Hort. ex Dode.
Poplar, gray (silver poplar)	*Populus alba canescens* (Smith) Loudon.
Poplar, lombardy	*Populus nigra italica* Du Roi.
Poplar, Mongolian	*Populus maximowiczii* Henry.
Poplar, Norway. (See Carolina poplar (hybrid).)	
Poplar, silver. (See Gray poplar.)	
Poplar, white	*Populus alba* L.
Porcupine grass (needlegrass)	*Stipa spartea* Trin.
Porcupine grass, European	*Stipa capillata* L.
Prickly-ash, common	*Xanthoxylum americanum* Mill.
Privet, common. (See European privet.)	
Privet, European (common privet)	*Ligustrum vulgare* L.
Privet, swamp. (See Texas adelia.)	
Quackgrass	*Agropyron repens* Beauv.
Rabbitbrush	*Chrysothamnus graveolens* (Nutt.) Greene.
Rabbitbrush	*Chrysothamnus howardii* (Parry) Greene.
Rabbitbrush	*Chrysothamnus pulchellus* (Gray) Greene.
Raspberry, wild black. (See Common blackcap.)	
Raspberry, wild red	*Rubus idaeus aculeatissimus* (C. A. Mey) R. and T.
*Redbud	*Cercis canadensis* L.
Rose	*Rosa villosa* L.
Rose. (See Dogbrier.)	
Rose, Arkansas	*Rosa arkansana* Porter.
Rose, Austrian brier	*Rosa eglanteria* L.
Rose, Fendler (wild rose)	*Rosa fendleri* Crep.
Rose, Japanese	*Rosa japonica* Waitz.
Rose, Macoun (wild rose)	*Rosa macounii* Greene.
Rose, meadow (wild rose)	*Rosa blanda* Ait.
Rose, prickly (wild rose)	*Rosa acicularis* Lindl.
Rose, Scotch	*Rosa spinosissima* L.
Rose, wild. (See Fendler rose.)	
Rose, wild. (See Macoun rose.)	
Rose, wild. (See Meadow rose.)	
Rose, wild. (See Prickly rose.)	
Rose, wild prairie	*Rosa pratincola* Greene.
*Russian-olive	*Elaeagnus angustifolia* L.
Sage	*Salvia nutans* L.
Sagebrush	*Artemisia tridentata* Nutt.
Sagebrush, sand	*Artemisia filifolia* Torr.
Sea-buckthorn, common	*Hippophae rhamnoides* L.
*Serviceberry	*Amelanchier canadensis* (L.) Medicus.
Serviceberry. (See European shadblow.)	
Serviceberry. (See Low shadblow.)	
Serviceberry, alder-leaved	*Amelanchier alnifolia* Nutt.
Shadblow, European (serviceberry)	*Amelanchier vulgaris* Moench.
Shadblow, low (serviceberry)	*Amelanchier humilis* Wieg.
Silverberry	*Elaeagnus argentea* Pursh.
Sloughgrass	*Beckmannia erucaeformis* (L.) Host.
Skunk brush. (See Lemonade sumac.)	
Skunk brush, western	*Rhus nortonii* (Greene) Rydb.
Smoketree, common	*Cotinus coggygrea* Scop.
Snailseed, Carolina	*Cocculus carolinus* (L.) D. C.
Snakeweed, broom (gutierrezia)	*Gutierrezia sarothrae* (Pursh.) Britt. and Rus.
Snowball, common	*Viburnum opulus roseum* L.
*Snowberry, western (wolfberry)	*Symphoricarpos occidentalis* Hook.
*Soapberry, western	*Sapindus drummondii* H. and A.
Spindle tree	*Euonymus verrucosus* Scop.
Spindle tree. (See European burningbush.)	
Spiraea, snow	*Spiraea crenata* L.
Spiraea. (See Common ninebark.)	
Spiraea, meadow	*Spiraea alba* DuRoi.
Spiraea, willowleaf	*Spiraea salicifolia* L.
Spruce, Black Hills. (See Western white spruce.)	
*Spruce, blue	*Picea pungens* Engelm.
Spruce, Koster's blue	*Picea pungens* var. *glauca Kosteri* Hort.
Spruce, Norway	*Picea excelsa* Link.
Spruce, Sitka	*Picea sitchensis* (Bong.) Carriere.
Spruce, western white (Black Hills spruce)	*Picea glauca albertiana* (S. Brown) Rehd.
Spruce, white	*Picea glauca* (Moench) Voss.

COMMON NAME	SCIENTIFIC NAME
Sugarberry	*Celtis laevigata* Willd.
*Sumac, lemonade (skunk brush)	*Rhus trilobata* Nutt.
*Sumac, smooth	*Rhus glabra* L.
*Sycamore	*Platanus occidentalis* L.
Syringa. (See Lilac.)	
*Tamarisk	*Tamarix gallica* L.
Thicket creeper (Virginia creeper)	*Parthenocissus vitacea* Hitchc.
*Thorn, Washington (red haw)	*Crataegus phaenopyrum* (L.) Medicus.
Three-awn grass (wire grass)	*Aristida* sp.
Timothy	*Phleum* sp.
Tree-of-heaven. (See Ailanthus.)	
Turkeyfoot (big bluestem)	*Andropogon hallii* Hack.
Turkeyfoot, bluejoint (big bluestem)	*Andropogon furcatus* Muhl.
Valley-mahogany (mountain mahogany)	*Cercocarpus montanus* Raf.
Valley-mahogany	*Cercocarpus parvifolius* Nutt.
Viper's bugloss	*Echium rubrum* Jacq.
Virginia creeper	*Parthenocissus quinquefolia* Planch.
Virginia creeper. (See Thicket creeper.)	
Virgins-bower	*Clematis virginiana* L.
Virgins-bower, western	*Clematis ligusticifolia* Nutt.
Wayfaring-tree	*Viburnum lantana* L.
Wahoo (burning bush)	*Euonymus atropurpureus* Jacq.
*Walnut, black	*Juglans nigra* L.
*Walnut, little	*Juglans rupestris* Engelm.
Wheatgrass, slender	*Agropyron pauciflorum* (Schwein.) Hitchc.
Wheatgrass, western. (See Bluestem.)	
Willow. (See Common osier.)	
Willow, beak	*Salix bebbiana* Sarg.
Willow, black	*Salix nigra* Marsh.
Willow, brittle	*Salix fragilis* L.
Willow, desert flowering. (See Desertwillow.)	
Willow, diamond	*Salix mackenziana* Barr.
*Willow, European white	*Salix alba* L.
Willow, goat	*Salix caprea* L.
*Willow, golden	*Salix alba vitellina* Stokes.
Willow, gray	*Salix cinerea* L.
Willow, hoary	*Salix candida* Fluegge.
*Willow, laurel	*Salix pentandra* L.
Willow, peachleaf	*Salix amygdaloides* Anders.
Willow, prairie	*Salix humilis* Marsh.
Willow, pussy	*Salix discolor* Muhl.
Willow, sandbar (silky sandbar willow)	*Salix exigua* Nutt.
Willow, sandbar	*Salix longifolia* Muhl.
Willow, shiny	*Salix lucida* Muhl.
Willow, silky sandbar. (See Sandbar willow.)	
Willow, yellow	*Salix lutea* Nutt.
Wire grass. (See Three-awn grass.)	
Wolf-berry. (See Western snowberry.)	
Yucca	*Yucca* sp.