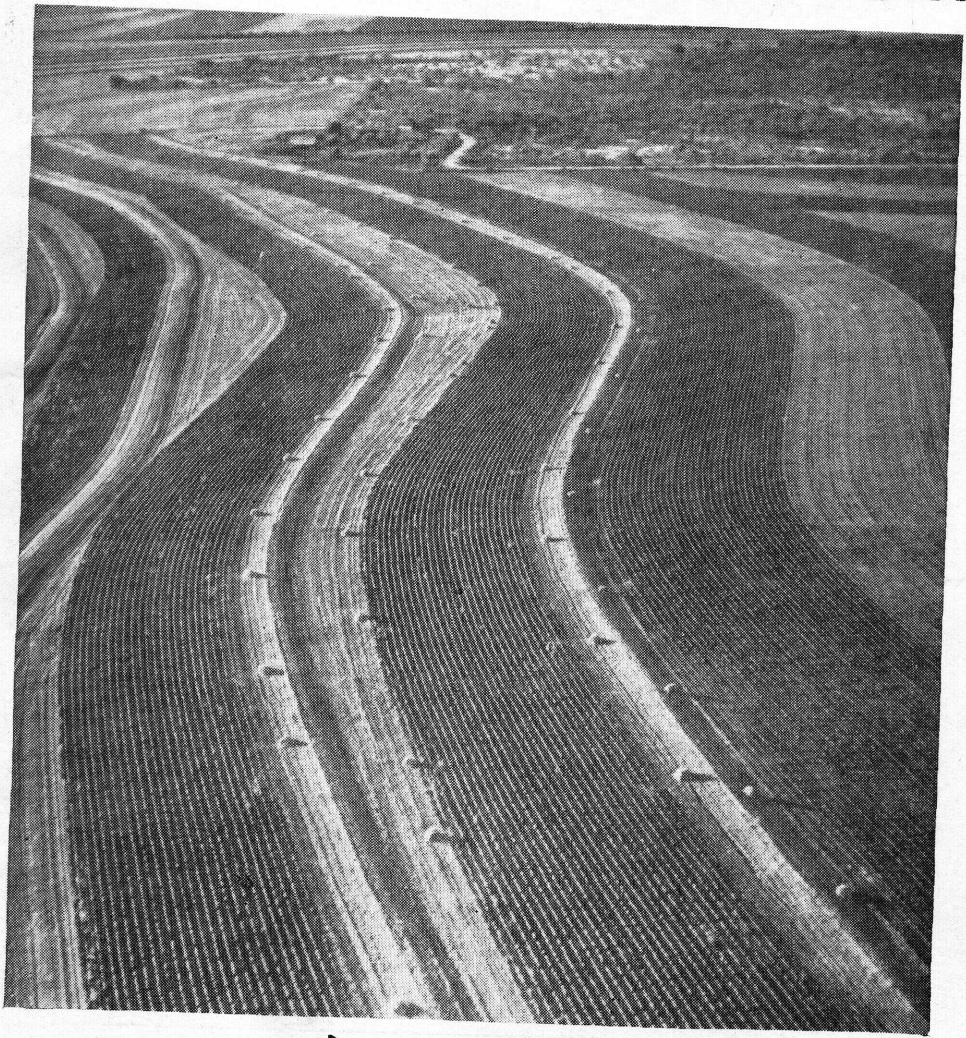
(Revised)

TERRACING for SOIL and WATER CONSERVATION



FARMERS' BULLETIN No. 1789
U. S. DEPARTMENT OF AGRICULTURE

IN THE PRODUCTION of farm crops and livestock, American farmers are confronted with the problem of conserving soil and rainfall on sloping lands. The importance of this problem has been overlooked in the past, and the continual loss of fertile topsoil by erosion has already rendered useless large areas of good farm land for profitable cropping. Additional areas are being abandoned each year. Farmers must adopt soil-conserving practices on erodible slopes before a permanently successful type of agriculture can be established.

Early American farmers introduced the use of hillside ditches to combat soil erosion. The ditches themselves proved inadequate, but the principle of controlling erosion by systematically intercepting surface runoff on sloping lands has led to the use of farm terracing. The development of terracing as recommended today has required years of use, extensive field observations and experimentation, and many modifications from time to time in construction procedure. When terraces are properly used and constructed and adequately supported by approved cropping and tillage practices they provide one of the most effective erosion-control measures applicable to cultivated lands. When improperly constructed or not coordinated with proper land use practices they often accelerate rather than retard soil losses.

This bulletin has been revised in order to give its readers the benefit of the most up-to-date information on terrace construction and maintenance in coordination with other recommeded soil-conservation practices. The information it contains is based on the terracing work of the Soil Conservation Service in every important agricultural region of the United States.

This bulletin supersedes Farmers' Bulletin 1669, Farm Terracing.

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TERRACING FOR SOIL AND WATER CONSERVATION

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INTRODUCTION

PROGRESS OF TERRACING

For centuries agriculturists of other countries have used terraces effectively to combat soil erosion and facilitate tillage practices on sloping land. More than 4,000 years ago the Incas terraced their steep hillsides, and over 2,000 years ago the present practice of terracing rice fields in the Philippine Islands was begun by the natives. That terraces are widely distributed is indicated by the terrace vineyards of Europe, the terraced fields of the Orient, and the more recent terracing of wheatfields in Australia. These terraces are raised level benches supported on one or more sides by walls of masonry or sloping banks of turf and exemplify the true meaning of the word.

In the United States the term "terrace" has become identified with a hillside channel or ridge constructed for the purpose of controlling the flow of surface water. The true terrace, or bench terrace, as it is commonly known, is used only in limited areas where necessary to cultivate excessively steep slopes.

[1] Revised by T. B. Chambers, Chief, Engineering Division. It contains the information gained during 5 years of terracing work carried on by the Soil Conservation Service since the publication of the earlier edition. Former members of the Division, particularly Hans G. Jepson and G. E. Ryerson, assisted the author, who also used information from former studies made by C. E. Ramser and M. L. Nichols.

During the latter part of the eighteenth century and the beginning of the nineteenth century, farmers in the Southern States began to use ditches and furrows across the slopes of cultivated fields to intercept runoff and retard erosion. This practice was probably introduced by some of the early immigrants from Europe. The term "terrace" in connection with this practice appears to have been used in this country as early as 1847. Some of the principles used in installing these early hillside ditches were correct, but the effectiveness of the measures themselves was usually counteracted by inaccurate installations and lack of supporting practices. The evolution from these early hillside ditches to the modern agricultural terrace has been slow and gradual and is the result of the efforts of many people.

A few of the earlier installations had such refinements as wide ridges and variable grades and spacing according to the rate of rainfall and degree of slope, but in general farmers were slow to adopt these improvements. Although the old-type hillside ditches or terraces very frequently failed, they were sufficiently successful to induce farmers to continue their use, year after year.

Apparently the first major improvement widely followed was made by P. H. Mangum of North Carolina, who in 1885 introduced the wide-base terrace permitting tillage operations to be conducted over the entire structure. Before the introduction of the wide-base terrace, the narrow-ridge terrace had been used. These narrow ridges could not be cultivated and were allowed to grow to grass and briars. This, together with inadequate control practices between ridges, gradually led to the development of bench terraces on many fields of the Southern States.

It was not until terracing received attention from the State agricultural colleges and the United States Department of Agriculture that systematic studies and extensive progress in terrace construction were made. Preliminary studies were undertaken by the Department in 1903. Definite investigations of the use of terraces to combat soil erosion were begun in 1915 by C. E. Ramser of the Office of Experiment Stations. The report of his findings was published in 1917. The State experiment stations of Alabama, Texas, and Oklahoma started some of the earlier experimental work on terracing soon after the publication of this report. Other State experiment stations also made local studies.

The Extension Service and State extension agricultural engineers and county agents have devoted much time to educational work on terracing, including field demonstrations and assistance to farmers in constructing their terraces.

Between 1929 and 1934, 10 Federal experimental erosion farms were established in cooperation with the States, in accordance with an act of Congress. These farms are in regions representing wide differences in soil, climate, and farming practices. Experimental study of the capacity of terraces, their effectiveness, design, spacing, construction, and maintenance, and their relation to soils and cropping practices and to the operation of machinery is conducted on these farms. These soil-erosion experimental farms were transferred to the Soil Conservation Service in 1935.

Since then the Soil Conservation Service cooperating with State experiment stations and extension services has assisted in demonstrating the use of terraces for erosion control and water conservation in practically every part of the United States where they are needed. Wherever row crops are grown on sloping land will be found terraced fields.

SOIL EROSION

Unless controlled, the undermining action of erosion will at no distant date make large areas of cultivated land in the United States valueless for agricultural use. Millions of acres of once-fertile farm land have already been eroded beyond immediate repair. It has been estimated that the rate of plant-food removal by erosion is about 21

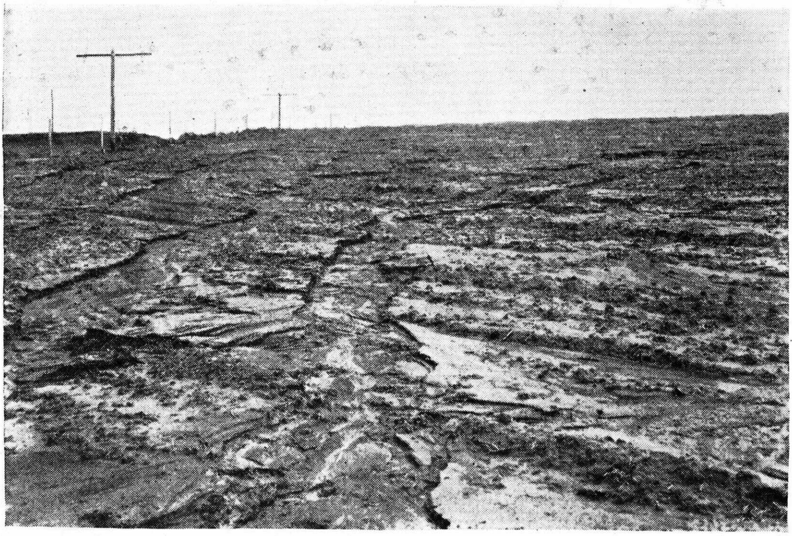

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FIGURE 1.—Severe sheet erosion on moderately sloping cultivated land.

times greater than the rate of removal by agricultural crops. This loss by erosion does not include losses through silt damage to bottom lands, water reservoirs, and irrigation channels.

The two main classes of water erosion are sheet erosion and gully erosion. Sheet erosion is the removal of surface soil in fairly uniform layers or sheets; gully erosion the removal of soil at points of excessive water concentration, where relatively deep ditches are cut into the surface. As a rule, gullies follow sheet erosion, but they may appear without being preceded by sheet erosion, and sheet erosion may occasionally continue indefinitely without the formation of gullies. It may not be as spectacular as gully erosion, but its effects are generally much more harmful. Figure 1 shows a field on which sheet erosion has taken its toll. The intermediate stage between severe sheet erosion and gully erosion is shown in figure 2, and a gullied

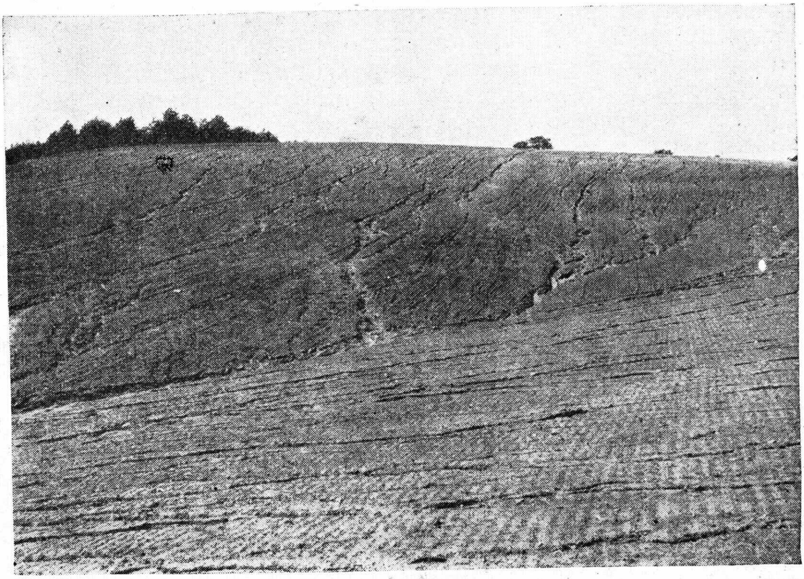

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FIGURE 2.—Sheet erosion that has developed into the fingering or shoestring stage of gully erosion.

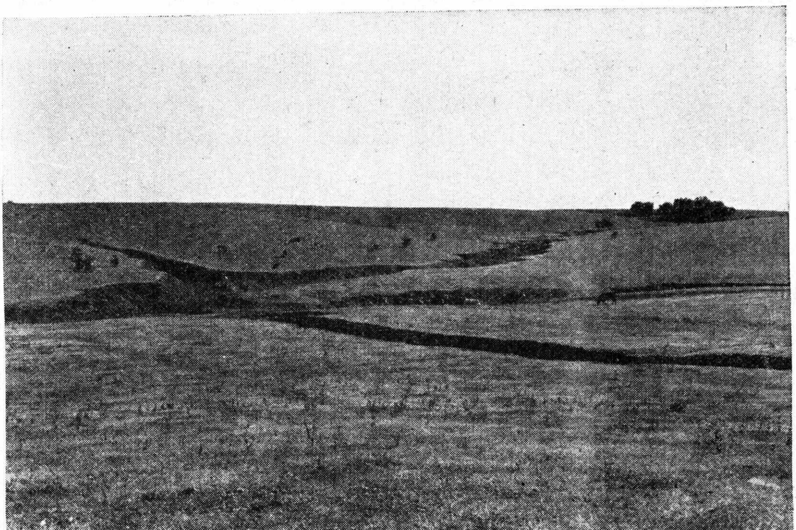

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FIGURE 3.—Once gully erosion has advanced to this stage, it practically prohibits cultivation of a field and greatly reduces its value for any agricultural use.

field in figure 3. Such gullying is a considerable obstacle to regular farming operations and may necessitate abandonment of the field.

Terracing is a valuable preventive of both types of water erosion and, as a conserver of moisture, it indirectly aids in the control of wind erosion also. Terraces form intercepting channels that break long slopes into short segments and thereby provide low-velocity surface drainage, which materially reduces the amount of topsoil that can be carried down the slope or from the field by surface runoff. When placed on the contour, terraces retain much more of the runoff on the field, and so conserve water.

TERRACING IN AN EROSION-CONTROL PROGRAM

The basic factor that must be recognized in the application of erosion-control measures is the proper utilization of the land. The use of land in accordance with its capabilities is a guide in considering what areas or fields are to be terraced.

Land capability is dependent primarily on four factors: (1) Quality of the soil, (2) slope, (3) erosion, (4) climate. An analysis of these factors will indicate whether or not the field in question is adaptable to cultivated crops in either short or long rotations.

Land used for cultivated crops should be terraced where runoff and erosion cannot be controlled by use of vegetation or tillage practices in the proposed cropping rotation. Land unsuited for cultivated crops should not be terraced except in special cases. For instance, where land has been depleted by misuse, terraces may be desirable to assist in the establishment of a permanent vegetation. In such places terraces are used as a temporary measure and may be constructed to standards below those required for a permanent system. Experience indicates that terracing on land not suited to cultivation usually results in expensive failures. The original cost and subsequent maintenance is high, owing to steep slopes, erosion, or unsatisfactory working conditions of the soil. The high cost of construction and maintenance coupled with the unusually low yields in cultivated crops would indicate that a less intensive use, such as for pasture, meadow, or woods, would result in greater net income.

TERRACING AND AGRONOMIC CONTROL MEASURES

Terracing cannot be economically justified on cropland that can be protected by less expensive conservation measures. Agronomic measures, such as contour tillage, crop rotations, and strip cropping, are all that is needed on many sloping areas. These agronomic measures alone may furnish enough protection where rainfall intensities are low and the soil absorbs the rainfall rapidly, where the soils are erosion resistant and the slopes gentle, and where profitable rotations can be introduced that will provide an erosion-resistant cover during a large part of the rotation cycle, particularly during the rainy seasons. But where erodible soil, long slopes, and high rainfall intensities prevail and where short rotations must be followed to provide a profitable farm income, the agronomic control measures may give only partial control. They must then be reinforced with terracing, which is a mechanical control measure, before adequate protection from erosion can be assured.

Terraces should always be supplemented with the best possible cropping practices because terraces in themselves do not improve soil fertility. They do, however, save fertile topsoil and retain costly seed and applications of lime and fertilizer. These facts justify the expectation that terraced fields will produce better crop yields over several years than unterraced fields, which may rapidly become less productive because of erosion losses (fig. 4).

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FIGURE 4.—When terraces are properly constructed and supplemented with suitable tillage practices, good farm crops can be produced without excessive soil loss.

TERRACING EXPERIMENTS AT THE SOIL AND WATER CONSERVATION EXPERIMENT STATIONS

Comparison of the amount of soil moved by erosion from similar terraced and unterraced areas on the soil and water conservation experiment stations of the Soil Conservation Service indicates the effectiveness of control by terracing under various soil and climatic conditions. It should be recognized, however, that under the experimental technique that was used at the stations the two measurements are not precisely comparable. It is difficult to select even adjacent areas that are exactly the same in all respects. Before final conclusions can be developed it will be necessary to make some adjustments in the experimental procedure and to secure data that cover a longer period and also a larger variety of soil and climatic conditions, crops, and cropping practices.

The runoff measurements given in figure 5 indicate surface runoff, and the soil-loss measurements from the terraced areas measure

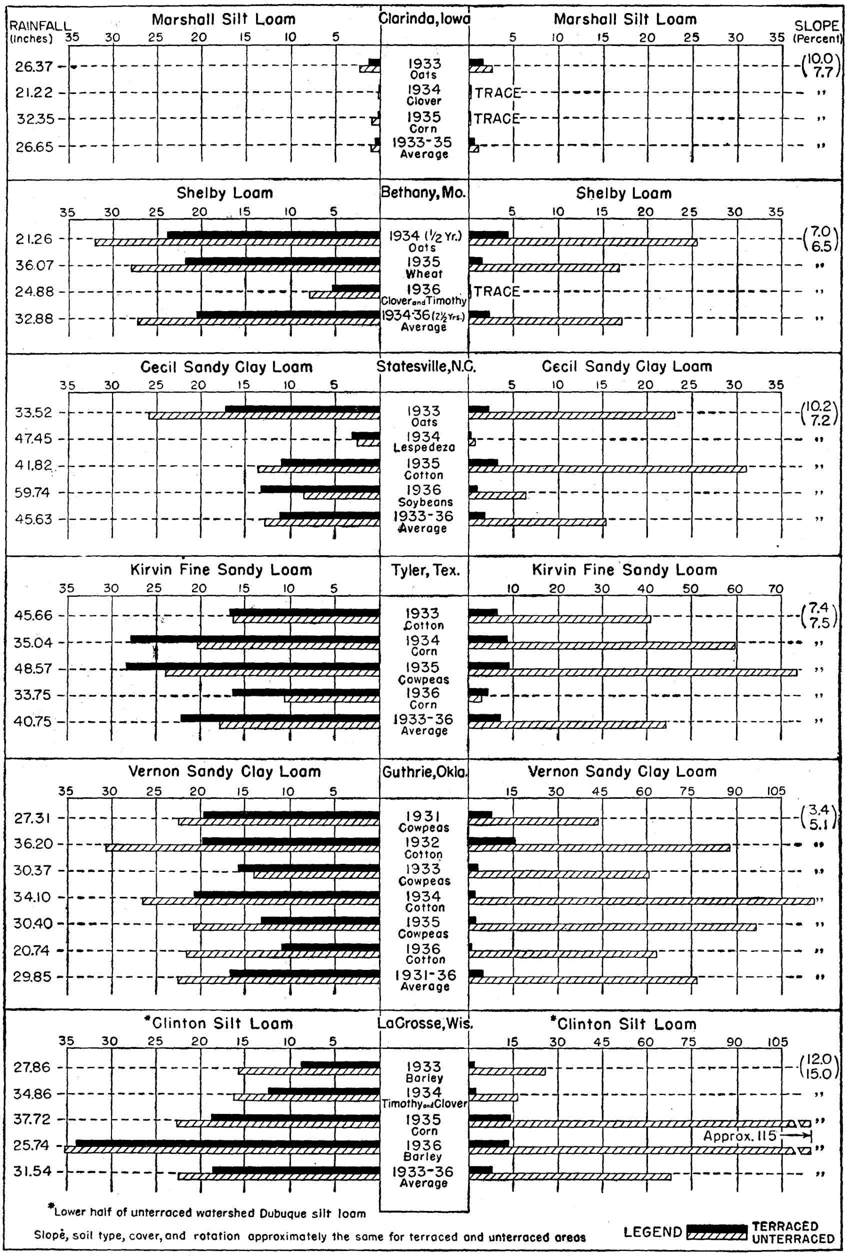

FIGURE 5.—Runoff and soil loss in runoff from field plots on six of the soil and water conservation experiment stations. The terraces were supported by crop rotation and contour tillage, which were also used on the unterraced areas. Except at the Bethany and Clarinda stations the waterways in the unterraced areas were inadequately protected. The higher soil losses reported for the terraced areas at Guthrie during 1931–32 resulted from inadequate outlet protection.

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only the soil in runoff at the end of the terrace channel and do not account for soil lost as silt deposited in the terrace channels and gradually worked over the ridge during maintenance operations. It is thought, however, that this soil loss is small if proper tillage, cropping, and maintenance practices are followed. Some of the unterraced experimental watersheds had completely or partly protected waterways which may have held some of the eroded soil from the field. On others the gullying produced by unprotected or inadequately protected waterways probably contributed to the higher soil-loss measurements secured from these areas.

An analysis of the experimental information now available indicates that soil loss on the small, terraced areas has invariably been less than on the unterraced areas, except on the more pervious soil types. The greatest difference usually resulted when rains of high intensities occurred during critical crop periods. The experiments indicate that terraces have been more valuable as conservers of soil than of rainfall. The rate of runoff from the terraced areas has usually been less than that from the the unterraced areas, but the total annual runoff from the terraced areas has not been consistently less than that from the unterraced. It is believed that a more appreciable and consistent reduction in both the amount and rate of runoff will be secured where level terraces can be used—and practically all of the rainfall can be retained where level terraces with closed ends are applicable.

The disturbance of the soil during terrace construction may temporarily reduce crop yields where the topsoil in comparatively shallow, but usually this loss will be compensated for within a few years after construction. With proper cropping and soil-improvement practices the yields on the terraced areas can invariably be increased until they are back to or above normal, whereas the yields on the unprotected area will usually continue to decline as additional fertility and topsoil is washed away year after year. Observations also indicate that terraces pay the greatest proportional returns when used as conservers of soil soon after it is first put into cultivation and the lowest returns when used in an attempt to reclaim cultivated lands already stripped of the topsoil and disfigured with gullies.

HYDRAULICS OF TERRACE DESIGN

Rainfall coming at a high rate is likely to induce considerable surface runoff, which will accumulate in depressions and flow down the slopes. When runoff attains a velocity of about 2 to 3 or more feet per second it is usually capable of loosening and transporting topsoil from unprotected fields. Velocities of even less than this frequently cause erosion on some of the finer clays and sands. At the top of a slope the quantity of runoff is usually small and the movement slow—without power to do much damage. But as the water flows down the slope its volume and velocity increase, and it gains increasing momentum and power to tear away soil particles.

Terraces must intercept the surface runoff before it attains sufficient velocity to erode the soil to any important extent. They must carry the surplus rainfall from the field at nonerosive velocities and deliver it to stabilized waterways. This is accomplished by placing a series of terraces across the slope, the first one being located near enough to the drainage divide to intercept all the runoff from the contributing area above before it attains excessive erosive power or a volume that will exceed the capacity of the terrace channel. Each succeeding terrace down the slope is located in a similar manner. The surface slope and the rate and velocity of runoff are therefore the first factors to be considered in the design of a terrace system.

SURFACE SLOPE

On long, steep slopes the velocity and erosive power of runoff are greater than on short, gentle slopes. Terraces are, in effect, a means of decreasing erosion by making slopes shorter. If they are to serve this purpose most effectively, spacing of the terraces must vary according to the slope. That is, the steeper the slope the shorter must be the distance between terraces. Each terrace must intercept the runoff from above before its erosive power has become great enough to carry away the soil. In designing a system of terraces, therefore, it is valuable to know how great an increase in velocity and erosive power can be expected as the degree of slope increases. The full significance of slope in terrace design is not appreciated until its effect on the rate, the velocity, and the erosive power of runoff is realized.

For example, if the slope of a field is such as to produce a runoff velocity of 2 feet per second, theoretically that slope would have to be only 4 times as great to produce a runoff velocity of 4 feet per second. Yet at 4 feet per second the power of the water to erode or tear away soil is 4 times greater than it is at 2 feet per second. The carrying capacity of water has an even greater proportionate increase. At 4 feet per second the runoff water can carry almost 32 times the quantity of material of given size that it is capable of carrying at 2 feet per second. If the slope is increased sufficiently to produce a velocity of 8 feet per second the erosive power would be increased 16 times and the transporting power 1,024 times.

Velocity increases not only with the steepness of slope, but with the length of slope. The speed with which water flows downhill is not constant but increases at a certain rate until it reaches the maximum velocity possible under the conditions on a particular field. The amount of runoff also increases as water travels down the slope owing to the increase in the contributing drainage area. This accumulation of water increases the velocity even more because as the volume of runoff increases, the water tends gradually to concentrate in deep, narrow channels and so moves at a higher rate than it would if evenly spread over the surface of the field.

These facts make it plain that much soil will be lost on steep unprotected slopes unless the flow of water down these slopes is checked. The velocity and the consequent erosive power of the runoff can be checked by decreasing the length of slope. A series of terraces across a field does just this, for the length of slope on a terraced field is only as great as the distance from terrace to terrace.

RATE OF RUNOFF

In computing the required channel capacities, the rate at which runoff will be discharged from the watershed is more significant than the total amount discharged from any particular rain, unless it is planned to store or retain all of the excess rainfall on the watershed. The rate of runoff from a drainage area is influenced by rainfall characteristics and watershed characteristics. The rainfall characteristics are intensity, duration, and frequency. The watershed characteristics that influence the rate of runoff are configuration, size and shape of the drainage area, degree and length of slopes, soil type, physical condition, and vegetal cover. The relative influence of these characteristics of rainfall and watersheds is discussed elsewhere in this bulletin.

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FIGURE 6.—Overtopping, caused by improper design, construction, or maintenance of terraces, damages both field and terrace.

Average rates of runoff cannot be used as a safe basis for computing required channel capacities because the terrace would overtop and fail during each storm that produced runoff rates higher than the average. The maximum runoff rates for which the terrace spacing and channel capacity must be designed are likely to occur when rains of high intensities fall on saturated or frozen soil and during periods when fields may be devoid of vegetation. Charts are given in United States Department of Agriculture Miscellaneous Publication 204, Rainfall Intensity-Frequency Data,[2] from which can be determined the maximum rates of rainfall that are likely to occur in different localities during periods of 2, 5, 10, 25, and 100 years. Ordinarily a terrace is designed to take care of runoff from rains of

[2] Out of print, but may be consulted in libraries.

the maximum intensity that is likely to occur during a 5- to 10-year period. Designing for runoff from rains of the maximum intensity likely to occur during a shorter period would result in frequent overtopping and consequent heavy repair costs, and designing for runoff from rains of an intensity that is not likely to occur more frequently than once in 15 or 25 years would involve excessive construction costs. It is conceded that during parts of the year when rates of runoff from fields are below average the full capacity of terraces designed for storm recurrence intervals of 5 to 10 years will probably not be utilized. However, terraces that cannot carry the higher rates of runoff will fail at the very time when they are most needed to retard soil loss (fig. 6).

The capacity in cubic feet per second of any water channel is computed by multiplying the cross-sectional area in square feet by the computed channel velocity in feet per second. For example, a channel with a depth of 2 feet, a width of 6 feet, and a velocity of 1½ feet per second will carry $2 \times 6 \times 1\frac{1}{2} = 18$ cubic feet per second. In determining the size of channel to construct it is usually considered good practice to make it slightly larger than the computed requirements because of the uncertainty of runoff values and the difficulty of maintaining exact field construction specifications through all periods of the year.

VELOCITIES IN TERRACE CHANNELS

Terrace channels of ample capacity must be constructed so as to transport water at nonerosive velocities; otherwise much soil may be carried from the channel with the runoff and serious gullying may develop. The velocity in a terrace channel increases not only as the slope of the channel increases, but as the average water depth (approximately the hydraulic radius) increases and as the surface resistance (coefficient of roughness) decreases.

Under field conditions the roughness of the channel surface is established by soil, tillage, and crop conditions and cannot be varied for the purpose of controlling velocity. The velocity, therefore, can be controlled by adjusting only the gradient and the average depth of water in the channel.

The maximum channel gradient that can be satisfactorily used must be less than the minimum slope that produces sufficient channel scouring to injure the terrace. The average depth of flow can be adjusted and the capacity maintained by changing the shape of the cross section of the channel. If other factors remain constant, a narrow, deep channel will produce a higher velocity with greater erosive power than a wide, shallow channel because the average depth of flow is less in the shallow channel. A channel cross section that is wide in proportion to its depth not only retards velocities but also facilitates tillage operations over terraced fields.

From the standpoint of construction, a channel of uniform cross section is desirable. In order that such a channel may take care of the increasing amounts of water being intercepted, the gradient is increased along successive segments of the channel. A variable channel gradient also gives more desirable flow characteristics because the flatter grade in the upper reaches of the terrace tends to retard channel flow and so reduces the tendency for water to pile up in the lower portion of the channel. The final gradient will be limited by the maximum permissible velocity above which scouring will result. Thus, by proportioning the channel area, shape, and slope, the necessary channel velocity and capacity can be secured.

The recommended terrace specifications given under Planning the Terrace System have been developed from experimental and exploratory data collected under actual field conditions. They will ordinarily be found to suffice if applied under conditions for which they are recommended. For the man inexperienced in engineering they form a safe basis for terrace design and can generally be used without further computation. The exceptional conditions for which these specifications are not entirely adequate may require the computation of runoff from agricultural areas and the determination of theoretical channel velocities and capacities. Where problems of this type are encountered a competent engineer should be consulted.

TYPES OF TERRACES

During the period of evolution through which terracing has passed a wide variety of terrace types has been advocated. Always much care must be exercised in their selection, construction, and use. Years of experimenting and extensive field observations have revealed valuable information relative to the different types of terraces and their application to existing conditions.

The ultimate objective of all terraces is soil conservation. This objective is achieved by terraces that provide for the interception and diversion of surface runoff or the impounding of surface runoff for increased absorption. From a functional point of view terraces are classified as (1) interception and diversion types and (2) absorption types.

When the construction characteristics are considered, it is found that a well-constructed channel somewhat below the original ground surface is the most dependable structure for intercepting and diverting runoff, whereas a ridge constructed well above the original ground surface, with as little channel as possible, is the best structure for impounding runoff for increased absorption over a wide area above the ridge. From a construction point of view, therefore, it seems useful to classify terraces as (1) the channel type and (2) the ridge type. Classification according to construction should include also a third type, the bench terrace, which is used on the steeper slopes. For the sake of brevity the terms "channel terrace," "ridge terrace," and "bench terrace" will be used in this bulletin when referring to the different types of terraces.

In some sections of the country both absorption and diversion are important objectives of terracing, but there are large areas where diversion is of first importance and other areas where absorption is the principal requirement.

Regions of moderate rainfall and favorable soil conditions will have intermediate terrace requirements, and a dual-purpose terrace combining the desired features of both types can be used. Cross-sectional dimensions of all terrace types will differ throughout the country according to the soil type, terrain, rainfall characteristics, and types of machinery to be worked over them. But the fact that dimensions must be adjusted to meet local conditions does not invalidate the classification of all terraces according to function.

Figure 7 shows the cross-sectional difference between the channel terrace and the ridge terrace. Both types are shown singly to assist in visualizing the finished cross sections desired for each, and one is superimposed on the other to bring out more clearly the variation between the two terraces.

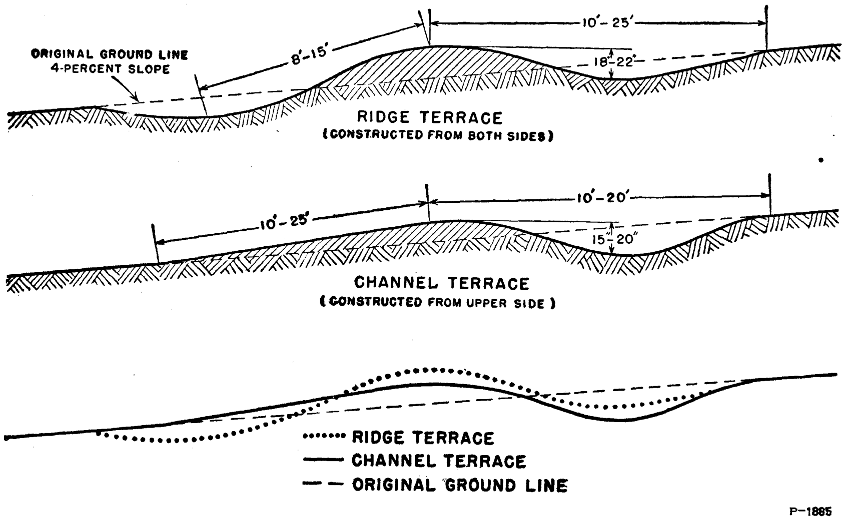

FIGURE 7.—Terrace cross sections after settlement and cultivation.

CHANNEL TERRACES

The channel terrace acts primarily as a drainage channel to conduct excess rainfall from the fields at nonerosive velocities. Since low-velocity surface drainage is required, the channel and not the ridge is of primary importance. A wide, relatively shallow channel of low gradient that has gentle side slopes and ample water capacity will give the most desirable results (fig. 8). The excavated earth is used to bring the lower side of the channel to a height sufficient to provide necessary capacity. A high ridge is not desirable since it seriously interferes with tillage operations, increases construction costs, and frequently requires for its formation a large part of the topsoil scraped from the field. In the channel terrace the ridge should be considered as supplemental to the channel and should blend gradually into the surface slopes to afford a minimum of interference with machinery operations (fig. 9).

In general, the channel terrace is applicable to soils that are relatively impervious and to conditions in the Southeast, the Middle Atlantic States, the Tennessee and Ohio Valleys, and those parts of the Mississippi Valley where there is a reasonably good distribution of rainfall throughout the growing season. In these States the

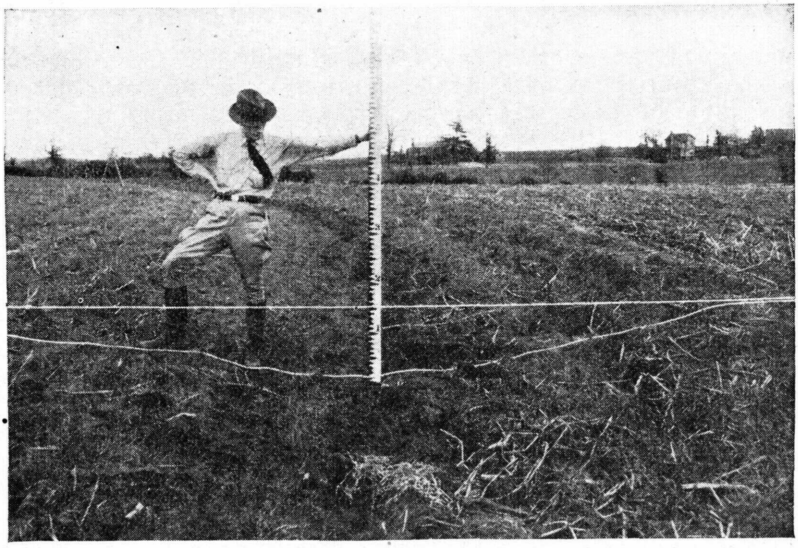

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FIGURE 8.—A channel terrace in the Piedmont area. It is important that a wide channel with ample capacity be provided.

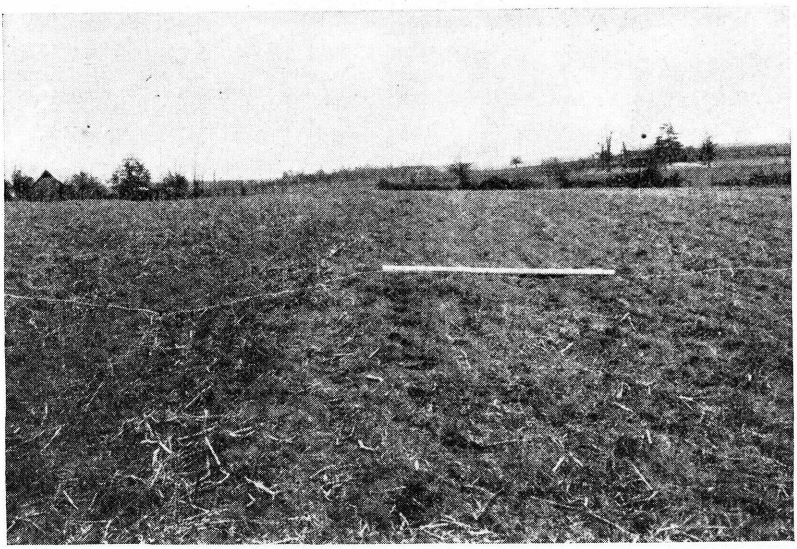

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FIGURE 9.—This channel terrace has been blended into the surface slopes and the channel capacity maintained by proper plowing. The terrace will offer a minimum of inconvenience to tillage operations.

amounts and rates of rainfall are relatively high, and since the retention of all the rainfall would be difficult and damaging to growing crops, the surplus rainfall must be removed through surface drainage.

RIDGE TERRACES

Erosion control by the ridge terrace is accomplished indirectly by water conservation. In order to increase absorption the terrace is constructed so as to flood collected runoff over as wide an area as possible. If this is to be done most effectively the surface slopes on which the terraces are built should be fairly flat, the ridge should be

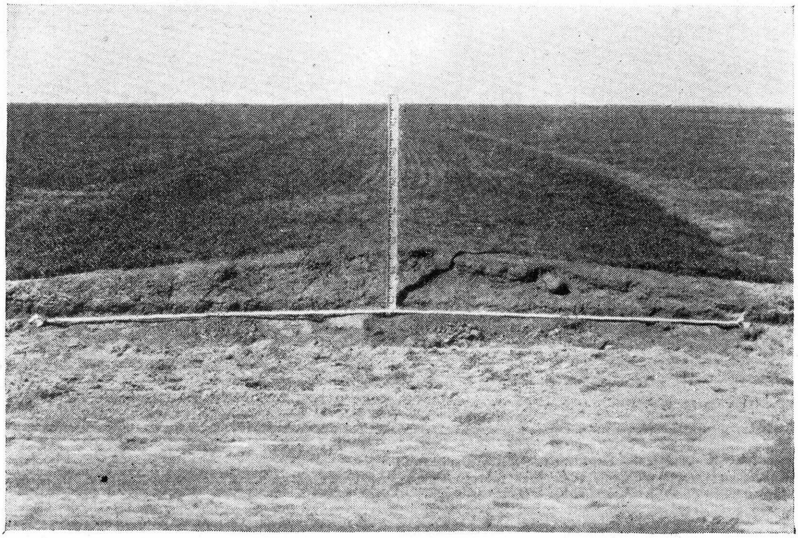

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FIGURE 10.—The ridge terrace is used in the Great Plains for erosion control and moisture conservation. It is important that the ridge be high enough to spread the collected runoff over a wide area and wide enough to allow satisfactory operation of tillage equipment.

of sufficient height to pond water over a relatively large surface, and the earth required for the ridge so excavated as to avoid concentration of runoff on a small area (fig. 10).

The degree to which these conditions can be attained is limited by the construction methods that are necessary and the slope of the land. In this type of terrace the ridge is of greater importance than the excavated channel, which is more or less incidental to the construction of the ridge. When maximum absorption is desired the terraces must be designed for ample storage capacity and placed on level grades with closed ends. As a factor of safety the ends are often left open so that excess rainfall can escape before the terrace overtops. In some areas the ends of the terraces are partly blocked depending on the necessity of safety outlets for excessive rainfalls not included in

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the design frequency. If the impounded water from level terraces would result in excessive crop damage, a slight channel grade, particularly near the outlet, may be necessary.

The ridge terraces are adaptable to areas of low precipitation and to soil types that will absorb the accumulated runoff fast enough

NM-2758

FIGURE 11.—Runoff impounded by level terraces is needed for increased production in the southern Great Plains during normally dry seasons.

to prevent damage to growing crops. These areas are largely confined to absorptive soils and gentle slopes in the drought and wind-erosion areas of the Great Plains. The ridge terrace may also be used with considerable success on certain restricted areas of sandy soils and gentle slopes where the rainfall is heavier, such as the sandy coastal plains of the Southeast. Thorough examination of the soil absorption and rainfall rates should always be made before this type of terrace is used. A ridge terrace, on a Texas field, is shown in figure 11.

BENCH TERRACES

Terracing as now practiced in many foreign countries consists of building relatively steep land into a series of level or nearly level strips running across the slope. The strips are separated by almost vertical risers, which are retained by rock or a heavy growth of vegetation. This type of terrace is known as the bench terrace and exemplifies the original meaning of the word "terrace." It is one of the oldest mechanical methods of erosion control, having been used for many centuries in thickly populated countries where economic conditions necessitated the cultivation of steep slopes. The use of the bench terrace on steep slopes not only retards erosion losses but also makes cropping operations on these slopes easier.

Population density and scarcity of flat lands do not as yet demand extensive cultivation of excessively steep slopes in the United States. Some cultivation of field crops on steep, bench-terraced slopes has been practiced in sections of the Southeast for several generations (fig. 12), and the continuation of this practice may be necessary in hilly or mountainous sections. In the highly productive citrus and avocado districts of southern California bench terraces have been used to a considerable extent on steep valley side slopes. In other States there are scattered examples of their use in connection with truck farming or vineyard and orchard cultivation. Wherever the absence of adequate flat lands or the special adaptability of particular slopes to high-income crops necessitates the cultivation of steep slopes the bench terrace will probably continue to be used in the United States. Owing to its limited use, the most desirable design and construction practices have not as yet been thoroughly investigated in this country, so this discussion of the bench terrace will of necessity be limited to a brief review of past practices and recommendations based thereon.

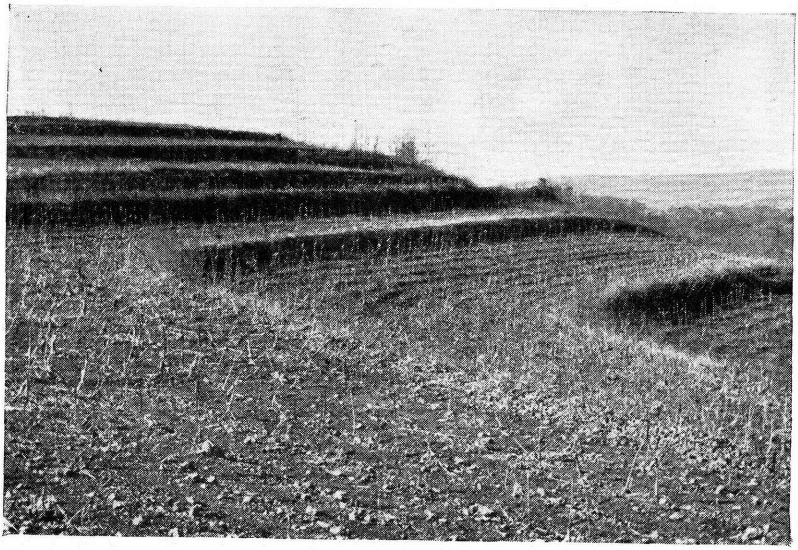

FIGURE 12.—Bench terraces on a 20-percent slope in the South. These benches have been developed over a period of years by leaving the ridges in permanent vegetation and allowing the soil to move down the slope between terraces.

The ordinary method of developing the bench terrace in the Southern States was to construct a series of small ridges usually at intervals and grades selected according to the judgment of the surveyor. Some of the specifications used compare favorably with our regular terrace recommendations, whereas others vary from them materially. The ridges were not cultivated and were allowed to grow to briars, weeds, or grasses. They were also frequently used as a place to pile rock and roots collected from the fields. Contour cultivation was

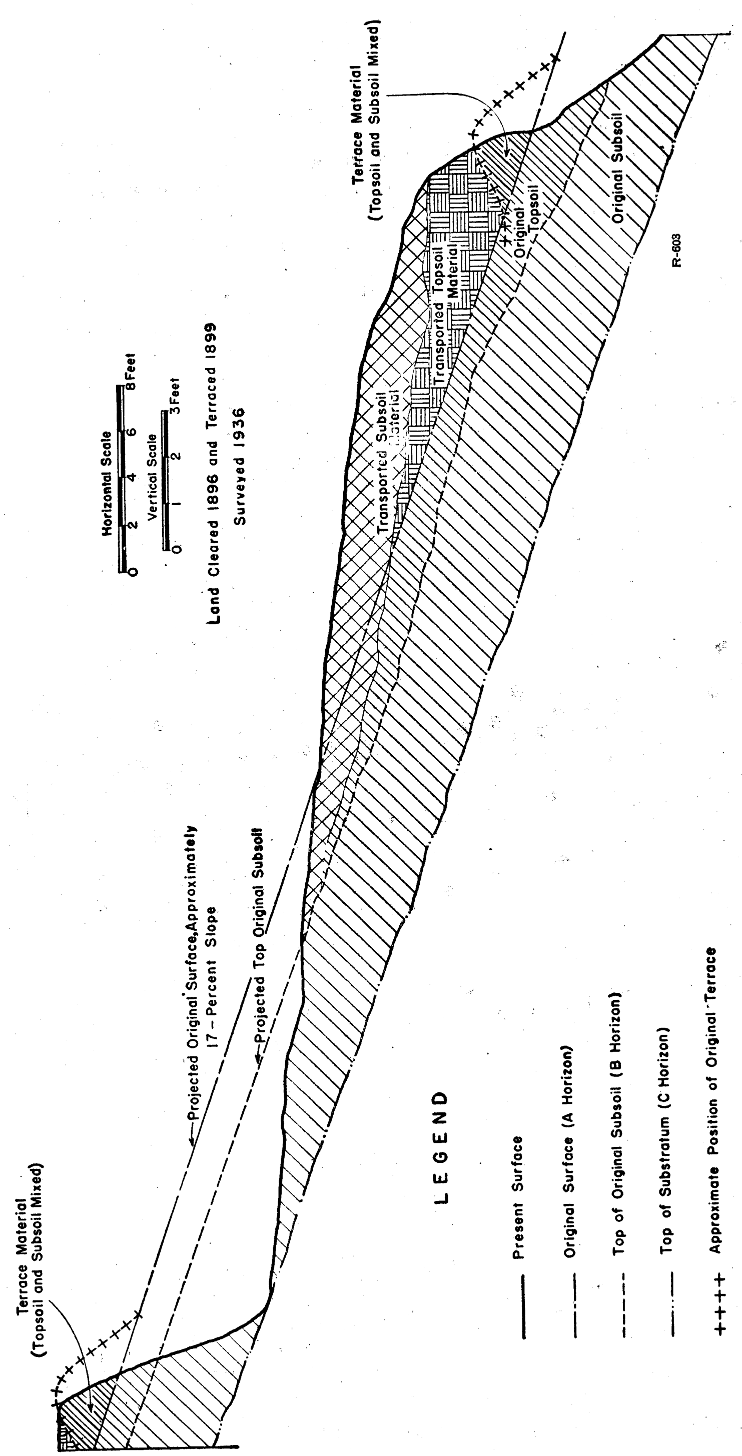

FIGURE 13.—Cross section of a bench terrace. The inverted soil profile has been developed by soil movement between terraces. Unless the topsoil is relatively deep in comparison with the vertical interval between terraces, subsoil is eventually exposed over the entire surface.

practiced on the interval between ridges. The upper side of the interval between ridges was lowered by erosion, and the soil retained by the ridges raised the lower side. In addition to this leveling of the interval by erosion, the process was intentionally hastened by turning plow furrows downhill whenever possible during the regular cultivation operations. Several years of alternate soil transportation and deposition down the slope were usually sufficient to form a series of fairly level strips with steep, protected risers between. On some terraces the surface runoff was allowed to flow over the terraces, whereas on others an attempt was made to maintain a ridge on the crest of the riser or a water furrow just above it so that runoff could be diverted from the field and discharged at the end of each terrace.

Figure 13 shows a soil profile through a bench terrace after many years of formation and use. A study of this profile not only shows what happens to the soil during the leveling process, but also reveals some of the important soil aspects that must be considered in developing satisfactory specifications for bench terracing. Bench terracing should be discouraged on soil strata subject to sliding. The depth of topsoil, the character and permeability of the subsoil, and the depth to the parent material are features that should be considered in arriving at the most satisfactory spacing specifications. If the spacing is too wide with respect to the depth of topsoil, and if the subsoil cannot be successfully cropped, too much unproductive soil will eventually be exposed over the surface and render the entire field useless for crops.

Spacing specifications also vary with surface slopes, type of equipment, and the tillage practices to be used on the land. The completion of bench terraces during the initial construction operations does not seem practical, except possibly under special conditions, because of the extensive moving of earth involved. Where this has been attempted in the past it has resulted in high construction costs and often has led to unfavorable cropping conditions owing to the abrupt disturbance and distribution of the soil.

Before the use of bench terraces in any area is considered, a thorough study should be made to determine whether there is justification for cropping the steep slopes that require this type of protection. If suitable lands with flatter slopes are available or if a profitable return cannot be expected, cropping of the steeper slopes by the use of bench terraces should be discouraged. The construction of bench terraces on flatter slopes that are suitable for the ridge or channel terrace should also be discouraged.

PLANNING THE TERRACE SYSTEM

GENERAL CONSIDERATIONS

Certain fundamental engineering principles are involved in designing and constructing terraces, but a high degree of theoretical training is not so important as the faculty of good judgment, combined with an agricultural background and a general understanding of the various phases and measures of erosion control. It will usually be advisable for farmers who have not had training in the use of surveying equipment and in the planning of a terracing system to have the surveying and planning done by an agricultural engineer or someone who has had the necessary training and experience.

In the preliminary planning, all necessary terracing for the entire farm should be considered in order that terracing on any part of the farm may be fitted into the complete terrace system without difficulty or unnecessary expense. The possibility of rearrangement of fields, fences, and roads to conform to good land-utilization and farm-management policies should be kept in mind. Terracing is usually planned according to drainage units, that is, areas that can be satisfactorily handled through one outlet or system of outlets. Such factors as ridges, drains, roads, large gullies, abrupt changes in slopes,

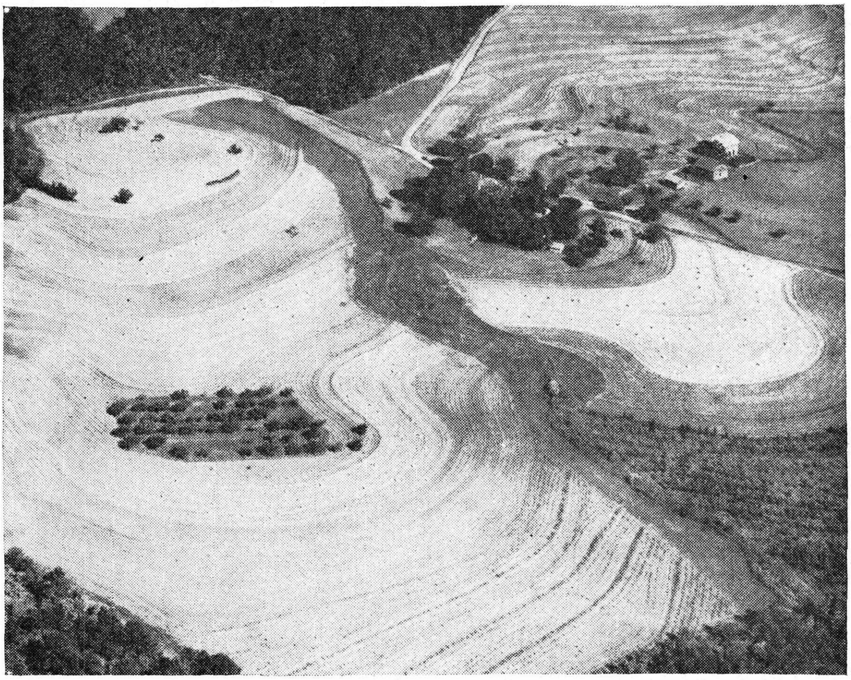

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FIGURE 14.—A complete system of terraces discharging into a meadow outlet. This water-disposal system provides a complete foundation for conservation farming that will increase and maintain crop yields.

property or field lines, and terrace lengths are some of the main determinants of boundary or division lines between terracing units. Adjacent farms may often have fields in the same drainage unit, in which case a joint terracing system may be used to advantage for both fields provided a satisfactory agreement can be made between the two landowners for joint construction and maintenance of the terraces and outlets. Protected outlets or disposal areas must be provided to carry the discharge from the terraces (fig. 14). The concentrated flow of water from terraces will cause excessive damage if permitted to discharge into channels or depressions that have not been protected against erosion.

When the field to be terraced receives any appreciable amount of runoff from an adjacent area it will be necessary to divert this runoff from the terrace system by some form of diversion or interception ditch. If this is not done the added runoff will probably cause overtopping of the first terrace it encounters, which will ultimately lead to failure of each succeeding terrace down the slope. The diversion ditch must have ample capacity and nonerosive grades and must be protected from silting by erosion-control measures on the contributing drainage area.

In making estimates of rates of runoff for the purpose of determining size of ditches, outlets, or weir openings in control structures some standard procedure applicable to the area under consideration should be followed. The runoff curves and tables prepared by C. E. Ramser for small agricultural areas are as accurate as any available at the present time for eastern United States. Ramser's reduction ratios of 0.60 for 1 acre, 0.70 for 10 acres, 0.75 for 30 acres, and 0.90 for 100 acres can be applied for rates of runoff from graded-terrace areas, and an additional reduction of about 25 percent can be made in estimating runoff rates from level-terrace areas. It is generally agreed that no reduction in runoff rate should be made for terraced areas larger than 100 acres.

TERRACE OUTLETS

The first step in planning the terrace system is to select the locations for the outlets or disposal areas. If protected areas or stabilized channels are not available, they must be provided before the terraces are constructed. Adequate outlets can usually be provided by protecting natural depressions with a cover of vegetation that will withstand the force of water moving down them. In some cases constructed channels will be necessary because of the absence of natural outlets or because gullying or other erosion damage has made the use of natural locations impracticable. Constructed channels may be protected with vegetation if suitable varieties can be established. If adaptable vegetation is not sufficient for protection, mechanical structures will be necessary as a safeguard against erosion in the channel.

Owing to the hydraulic problems involved in estimating the amount of runoff, in designing the channels, and in determining the ability of various types of vegetation to withstand expected velocity, assistance should be secured from an engineer trained in the solution of such problems before constructing channels for outlets. Farmers' Bulletin No. 1814, Terrace Outlets and Farm Drainageways, contains more detailed information on design and construction of outlets.

In selecting the location for outlets the best use should be made of the established watercourses on the field to be terraced. Draws and swales are the natural places for concentration and flow of water during the period of runoff and should be used wherever feasible for either a natural outlet stabilized with vegetation or as a location for a constructed channel. The disposal of water on other farms up or down slope may have a bearing on the selection of outlet locations, and for this reason the outlets must fit into the watershed-drainage pattern.

Vegetated outlets should be prepared one or two seasons in advance of terrace construction depending on the length of time required to establish the necessary cover. *In no case should terraces be constructed before outlets are available to receive the discharge* (fig. 15).

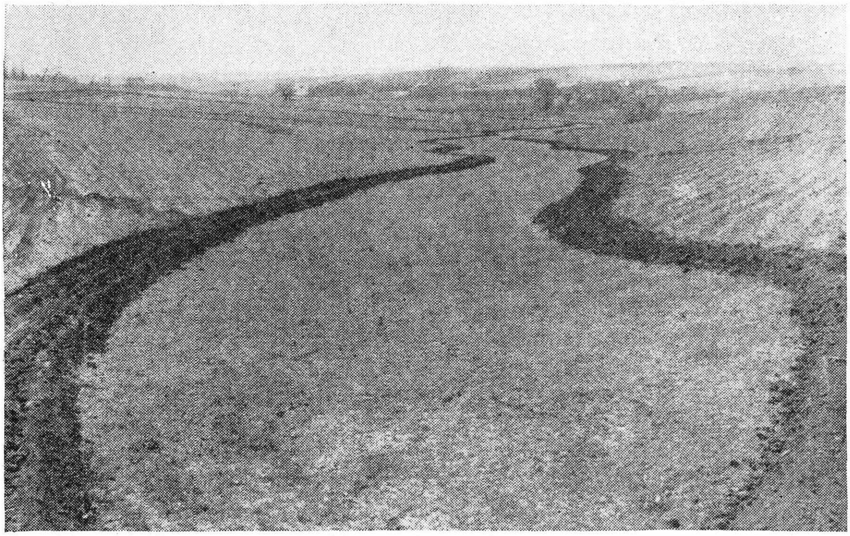

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FIGURE 15.—Ridges along the sides protect newly seeded meadow outlet. Terraces will be constructed when the sod is well established.

A vegetated outlet may be any cnannel, depression, or area stabilized with vegetation sufficiently to permit safe disposal of terrace discharge. A few of the most common types are meadow outlets, deep narrow draws, gullies, disposal areas, sod flumes, and constructed channels. Many factors will influence the establishment and success of vegetated outlets. Such factors as the availability of adaptable vegetation for protection must be determined locally, other factors or principles that should be observed generallv are discussed in the following paragraphs.

A meadow outlet is a relatively flat, shallow swale that can be protected with adaptable grasses or legumes in an area large enough to form an economical pasture or hay unit. The shape of the cross section must be such as to insure a wide shallow flow rather than a deep narrow stream whose velocities would be destructive. To prevent overflow and gullying along the edges, the vegetation should extend several feet beyond the edge of any expected flow of water. In order to maintain nonerosive velocities low gradients are required. Grades of less than 6 percent have usually proved satisfactory. On erosive soils, however, a 6-percent grade may be too steep for safety. Although a shallow wide cross section is desirable, there must be sufficient fall from the terrace ends to the flow line of the outlet to prevent silting either in the channel or in the ends of the terrace.

About 1-foot minimum fall is usually adequate for the narrower outlets, and a 1-foot fall in 50 feet of horizontal distance should be enough for wider outlets.

A deep narrow draw is a relative term, and only a few principles can be cited that will be applicable to all conditions. If, as in a few draws, the shape of the cross section and the grade is comparable to that of a constructed channel, calculations should be made to determine the probable velocity of flow and the suitable cover or structures required for protection. Where the cross section, grade, and expected flow are favorable and adequate protection with vegetation is reasonably certain, a dense cover of the most resistant adaptable vegetation should be installed. Special amounts of seed and fertilizer will usually be required, and protection from uncontrolled grazing and burning is necessary. Many narrow draws are completely protected as a safeguard against damage. If the side of the draw is deep, it will be necessary to provide sod flumes or some other protection to carry the discharge from terraces into the outlet.

Gullies ordinarily should not be used for terrace outlets unless sufficient grading work is done to provide a cross section that can be protected economically. In the Southeastern States, however, experience has shown that kudzu will usually provide adequate protection for an eroding gully event with the addition of water from a terrace system. Gullies and other outlets may have abrupt drops or chutes in the flow line that cause turbulence and tend to accelerate cutting or deposition. It may be necessary to protect such places by dams or flumes in order to insure adequate control throughout the length of the channel.

Areas where terraces may be discharged without causing damage are referred to as disposal areas (fig. 16). Such locations should be used wherever they are available and adequate for the purpose. A good pasture sod, well maintained, makes an ideal disposal area if the soil is not too erosive for safe protection by the established sod. It is obvious that only permanent pastures should be used for outlets. A dense growth of woods with sufficient undergrowth and ground litter may also serve as a disposal area on gentle to relatively steep slopes. Grazing or fires in wooded areas may make them unfit for use as disposal areas by destroying the litter and small growth. Other permanent areas of dense vegetation may be used for disposal areas, such as meadows of perennial grasses and legumes. Rocky and gravelly areas are used in a few places where there is no danger of causing erosion by discharging water onto them. In discharging the concentrated flow from terraces into disposal areas care must be taken to spread the water so that it covers a wide area and thus reduce the probability of gullying or rilling.

A flume protected by dense sod to carry water down a steep bank is practicable for small flows. The limiting factors are the depth and velocity of the water and the ability of the sod to withstand its force. Sod flumes have been used successfully to carry water from individual terraces into outlets having steep banks. Their use is not recommended for discharge from several terraces or for heights of more than 10 or 12 feet. The flume should be deeply recessed into the bank

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FIGURE 16.—A terrace discharging onto pasture sod. The water spreads as it leaves the terrace channel. Much of it will be absorbed and stored in the soil.

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FIGURE 17.—Constructed terrace outlet stabilized with Bermuda grass. Velocity of the water is 7½ cubic feet per second.

and sloped to as flat a grade as possible. A layer of good topsoil is necessary in many places to insure required growth, and the sod blocks or strips must be held in place by wire netting or stakes until the roots are firmly established.

Constructed or artificial channels may be protected with vegetation if the expected water velocity is sufficiently low. The ability of different types of vegetation to withstand water velocity varies widely. A dense turf of Bermuda grass has in numerous locations carried velocities of 8 to 10 feet per second without noticeable damage (fig. 17), and a well-rooted mat of kudzu vines will stand even high velocities. Experience shows that bluegrass sod is limited to velocities of 5 to 7 feet, and most other adaptable grasses to somewhat smaller velocities. Annual and perennial lespedezas have a relatively low value for channel protection, being limited to velocities of 3 or 4 feet per second. There are other grasses, such as kikuya and centipede, adaptable only to special climates or soils that compare favorably with Bermuda grass for channel protection.

The best locations for artificial outlets include among other factors the least interference with tillage operations, favorable gradients, spacing so as to secure the most favorable length of terraces, and suitable conditions for establishing the required vegetative lining. If mechanical protection is to be used, a location to permit the shortest length of outlet may be desirable for economic reasons. Caution should be used in locating artificial outlets to assure compliance with State laws governing the disposition of surface water. State laws have regulations that should be understood before (1) diverting from one watershed to another, thereby causing damage to lower lands; (2) improving a channel, natural or artificial, in such a way as to cause damage by increasing the rate of flow to other lands; (3) constructing artificial channels to collect surface water and cast it onto the lands of another. It has been held also that a landowner has no right by means of drains to and along a highway to cast surface water on his neighbor's land on its way to a ravine which might have been reached directly from his own premises.

LOCATING THE CHANNEL TERRACES

The individual terraces on a field must be located so as to provide the necessary control of surface water, make farming operations as easy as possible, and perform satisfactorily with minimum maintenance requirements. There are a few general principles applicable to most conditions that will assist in attaining these objectives. Experience on the part of those locating terraces will be required, however, if the best job is to be obtained. The capacity of the top terrace must not be overtaxed by runoff or the whole system will be endangered. This means that the top terrace must be placed at a point near the top of the slope where the drainage area above is no greater than the drainage area above any other terrace of equal length. A trial location of the top terrace should first be made and location then moved uphill if it is necessary to intercept surface flow above critical areas or to place the terrace in better position with respect to the configuration of the field surface. If short abrupt changes in slope occur, terraces should be just above rather than on or at the foot of them. Evidence of excessive erosion near the top of the field indicates that surface runoff has attained critical erosive velocities at that point and that the terrace should be above in order to intercept the flow. Minor adjustments should also be made in the location of successive terraces on the field in accordance with these principles. Such adjustments should not exceed 15 to 20 percent of the applicable vertical interval of the terraces. Sharp bends in the terrace retard the flow and cause silt deposits that may block the channel or interfere with cultivation of the field. Many bends may be smoothed out by adjusting the terrace location slightly. Occasionally a critical place in a field below the top terrace will necessitate locating a terrace at that point first. The terraces above should be located according to the determined spacing, but the last terrace must be sufficiently near the upper limits of the slope to be safe from overtopping.

A short terrace is much easier to maintain than a long one and requires less channel capacity. In order to decrease the length of drainage in one direction the terraces may be crested at points about midway between the outlets. The point of a ridge is an ideal location for the terrace crest and assures flow in both directions to the low points where outlets should be located. If possible, terraces should not be extended around the points of sharp ridges. If this must be done, the terraces should be strengthened at these points by increasing the height of the ridge and enlarging the channel. Likewise, terraces should not be carried across depressions that collect considerable amounts of surface water, particularly if the terrace makes a sharp bend at this point. Although it is possible to enlarge the terrace sufficiently to carry the water that drains to such depressions safely, often the cost and labor involved will be excessive. Such places in a terrace require inspection and maintenance after each period of runoff owing to silt blocking the channel or excess water damaging the ridge.

In planning terraces it should be kept in mind that farm roads must be provided for access to all parts of the farm. Roads through a field should be located on the contour just below a terrace or on the ridges where the terraces are crested. Vegetated outlets should not be used for farm roads. It is evident that farm vehicles will seriously damage if not destroy the turf in the channel bottom or create ruts that will be quickly enlarged by erosion unless expensive repair measures are undertaken promptly.

LOCATING THE RIDGE TERRACES

Since level, ridge terraces are used to conserve moisture by impounding the water for increased absorption, there is usually limited need for outlets and in many terrace systems they may be disregarded. On some steeper slopes, however, ridge terraces are used for the dual purpose of conserving water and controlling water erosion. In such cases it may be necessary to discharge a considerable part of the runoff especially where high-intensity rainfall occurs. Under these conditions outlets may be required and the entire problem of locating the individual terraces, of their spacing, and of the discharge into outlets is handled in a manner similar to that described for the channel terrace.

On more nearly level slopes under the proper soil and climatic conditions these terraces will not require outlets although there may be occasional brief periods when discharge will occur. On slopes of less than 3 percent with smooth uniform surfaces, the terrace spacing should be regulated so as to impound all the runoff for the required intensity recurrence interval, usually the maximum rainfall intensity to be expected once in 10 years, and to provide for coverage by the

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FIGURE 18.—Harvesting grain on a terrace, using a large combine.

impounding water over as much of the field as possible and for the least interference with tillage operations (fig. 18). In deciding on the best spacing to use it is necessary first to determine the effective height to which the terraces will be constructed. The effective height will be the elevation of the blocks in the ends of the terraces above the natural ground level, usually the height of the blocks is from one-half to three-fourths the height of the terrace ridge. The capacity of the terrace will determine the maximum spacing.

To make farming operations easier on relatively flat uniform slopes, adjustments can usually be made in the terrace locations so that sets of two or more terraces will be exactly parallel. This eliminates the necessity for point rows except between sets of parallel terraces. The flat field surfaces lend themselves to considerable horizontal adjustment in terrace locations without significant changes in the amount of cut or fill required to build the ridges. In making such adjustments it is usually economical to prepare a topographical map of the field and make trial locations of the terraces on the map before staking them out on the ground.

Excess water from above must be diverted by enlarging the top terrace or by other means to prevent damage to the terraces or the field. Where additional water is needed for crop growth a regulated quantity from above is sometimes directed into a terraced field and allowed to flow from one terrace interval to the next by openings in alternate ends of the terraces. Part of the water is utilized by absorption in each terrace interval, and in many dry-farmed areas this will insure substantial increases in crop yields. This practice requires specially designed terraces and controls in order to regulate the flow from above and should be done under the supervision of someone familiar with the principals of hydraulics and experienced in calculating rates of runoff in the locality.

TERRACING AND SOIL TYPES

Both terrace design and construction may be influenced to a considerable extent by the characteristics of the different soils. For example, the erodibility or permeability of a particular soil may modify the selection of the terrace spacing, grade, and cross-sectional dimensions, and the soil structure and its physical condition will have a marked effect on construction features, such as size and type of equipment, difficulty of construction, season of construction, and time and power required. The ease with which terraces can be constructed will be directly affected by soil characteristics. On some soils terrace construction may even be impracticable owing to the unstable nature of the soil or the presence of rock or hardpan near the surface.

Knowledge of differences in erodibility and permeability of the various soils tends to encourage, upon first thought, material changes in terrace specifications to compensate for such differences. A closer examination of the factors involved, however, indicates that any changes made must be held within close limits, or the safety of the entire terrace system may be endangered. Rainfall intensities are frequently so great that even the most pervious soils cannot absorb all the rain that falls. Storms of long duration usually produce a saturated or partially saturated soil condition, which will materially reduce infiltration rates and thus contribute a relatively high rate of runoff from a soil that under ordinary conditions would be very pervious. Once runoff is under way, some of the more permeable soils are very erodible.

Since terraces must be built to withstand the unusual storms that may occur during the design period, it does not seem advisable to deviate from standard terrace specifications on account of ordinary variations in soil. When there is a combination of favorable conditions, some variation from standard specifications may be made without endangering the safety of the terrace system.

TERRACING AND CULTURAL PRACTICES

Tillage Equipment and Terrace Design

In the development of terracing specifications, consideration must be given to necessary tillage-machinery operations. If the terrace spacing is too close or the terrace slopes too steeply, the proper operation of tillage machinery becomes impracticable. The minimum terrace spacing and side slopes that permit practicable machinery operation on a terraced field will vary in different regions according to the size of machinery that is customarily used for field work. In the Southeastern States, where small equipment is used, narrower terraces and closer spacing can be used than in the Central and Western States, where larger tillage equipment is ordinarily employed.

Major adjustments in standard terrace designs to allow for better operation of tillage machinery cannot be justified because many of the initial difficulties encountered in operating machinery on terraced land can be overcome or greatly diminished by proper operation of the equipment. The operation of tillage equipment on the contour or approximately parallel to the terraces not only reduces soil movement between terraces but also aids materially in terrace maintenance and eliminates many of the difficulties encountered in operating tillage machinery. Regulating the location or position at which the various implements operate over the terraces also eliminates certain of these difficulties.

Cropping Practices and Terrace Design

The development of terracing specifications at the soil and water conservation experiment stations has been largely in conjunction with contour cultivation and soil-improving rotations that include a high percentage of clean-cultivated crops (corn and cotton). Outside the experiment stations the expansion of rotations to include winter cover crops and more small-grain or forage crops, which are generally considered more resistant to erosion, and the practice of using strip cropping with terracing have introduced a temptation to disregard the terracing practice established at the stations and to deviate materially from conventional terrace design. It is assumed that the changed cropping practices will reduce the runoff and erosion sufficiently to justify a large increase in terrace spacing or a reduction in channel capacity. This tendency to depart from standard specifications is greatest in areas where terracing is new and experience lacking. Departure from established practice under the most favorable conditions and within certain limits may be justified because well-established, close-growing crops provide considerable protection against surface runoff. Experimentation and field observations indicate, however, that any such deviation from standard recommendations must be held within comparatively narrow limits and made only after full consideration of its effect on erosion and runoff during storms that produce maximum rates of runoff. The more complete protection that is provided by permanent grass covers must not be confused with the partial protection that is provided when annual farm crops are grown either in rotations or alternated in strips across the slope.

In order to determine what alteration a particular cropping practice will permit in terrace-design specifications it is necessary to consider the protection it will afford during a complete rotation and rainfall cycle. The degree to which the crop protects the soil during adverse seasons and the stage of crop growth during seasons of intense rainfalls are of particular importance. A certain cropping system may materially reduce annual or average runoff and soil loss, but if comparable reductions cannot be assured during the rains of higher intensities, which are used as a basis in establishing terrace specifications, it would be unsafe to make material changes in the terrace design to allow for this reduction.

Runoff data from the soil and water conservation experiment stations indicate that fields with clean-cultivated crops experience moderately high runoff rates more frequently than do fields with close-growing crops and that the average annual soil loss from the former is usually much higher than from the latter. A study of these records, however, indicates that rates of runoff from close-growing crops are not of like degree during all storms that produce the higher rates of runoff. If these storms occur at a critical crop period the rate of runoff and soil movement may be comparatively high.

The primary purpose of using good cropping practices on terraced land is to improve the soil fertility, reduce the annual soil movements between terraces, and minimize terrace maintenance rather than to permit major adjustments in terrace specifications.

TERRACE SPECIFICATIONS

The previous discussion of slopes, rainfall and runoff rates, soil characteristics, vegetal cover, tillage, and cropping practices as related to terrace design gives some appreciation of the many factors involved in establishing terracing specifications and the relative importance of each for any particular area. It has not been found practicable to assign definite values to each of these variables and to treat each as a separate item in determining final terrace specifications. For such a procedure the problem is too complex and the variables too indefinite. Standard specifications can be established by using actual field and experimental data on terracing in a certain area as a guide for terrace design in similar areas. Some deviation from standard specifications may be made to provide for the exceptional areas where favorable or unfavorable conditions may arise that have not definitely been provided for in the standard specifications. In establishing standard specifications every effort has been made to provide a terracing system that will give the most satisfactory erosion control and adequate surface drainage as well as offer a minimum of obstructions to efficient tillage operations.

LIMITING LAND SLOPES

On slopes above 10 to 12 percent, it is difficult to build and maintain terraces that have adequate capacity and can be farmed with modern machinery. These steeper slopes are ordinarily not recommended for production of the more common cultivated crops except in areas where conditions require it. In the majority of agricultural areas the channel terrace is applicable to the slopes that, under a good land use program, are generally considered suitable for the production of cultivated crops.

The upper limit of land slopes on which the ridge terrace can be used most effectively for water conservation is, in general, about 3 percent. Where this terrace is used on lands having greater slopes the actual area ponded is too small to conserve much moisture unless the terrace ridge is built unreasonably high. If it is impracticable to secure the desired storage capacity, a modified form of the ridge terrace, providing for some drainage, may be used on slopes up to 10 or 12 percent.

Where it is necessary to use slopes above 12 percent for orchards and the production of farm crops, the bench terrace may be applied, if terracing is required. This type of terrace may be adapted to 25- to 30-percent slopes.

SPACINGS

In the Northern States, where the ground is not subject to erosion during the several months of the year when it is frozen and where crop rotations usually include few row crops and more of the erosion-resistant forage or small-grain crops, terrace intervals may be slightly greater than is permissible in the Southern States. The rainfall intensities also are generally lower in the Northern States. It is apparent, therefore, that terrace-spacing recommendations for the Northern States should differ from those for the Southern States.

As a result of field observations and terrace-spacing studies on the soil- and water-conservation experiment stations,[3] C. E. Ramser established some general terrace-spacing recommendations for the Southern and Northern States. The terrace spacings given in tabulated form in table 1 and in graphic form in figure 19 are based on these recommendations. The minimum and maximum values vary from the average by 15 percent. If exceptionally good cropping practices, erosion-resistant soil, and low rainfall intensities are characteristic of the area to be terraced, the terrace spacing might be increased as much as 15 percent with reasonable safety. But if the rotations include a relatively high percentage of row crops, if the soils are erodible, and if the rainfall intensities are high, terrace spacing should probably be decreased as much as 15 percent. With intermediate combinations of favorable or unfavorable factors, corresponding intermediate increases or reductions should be made in the spacing. It will often be found that a favorable factor is offset by an unfavorable one, and in such instances any deviation from recommended average spacings cannot be justified. For example, the value of a good erosion-resistant rotation may be offset by a very erodible soil or by high rainfall intensities so that the combined results are about the same as though all factors were average.

Besides the recommended vertical interval between terraces on various slopes, table 1 gives the corresponding horizontal distance between terraces, the acreage of each terrace interval per mile or per 100 feet of terrace, and the feet of terrace required per acre of land. This information enables the reader to estimate readily the number of acres of land that a given length of terrace will serve, or the amount of terracing that will be necessary for a given acreage of land.

Convenient thumb rules that give the approximate vertical interval recommended for average conditions in the Northern and Southern

[3] At the time these studies were made these stations were known as erosion experiment stations.

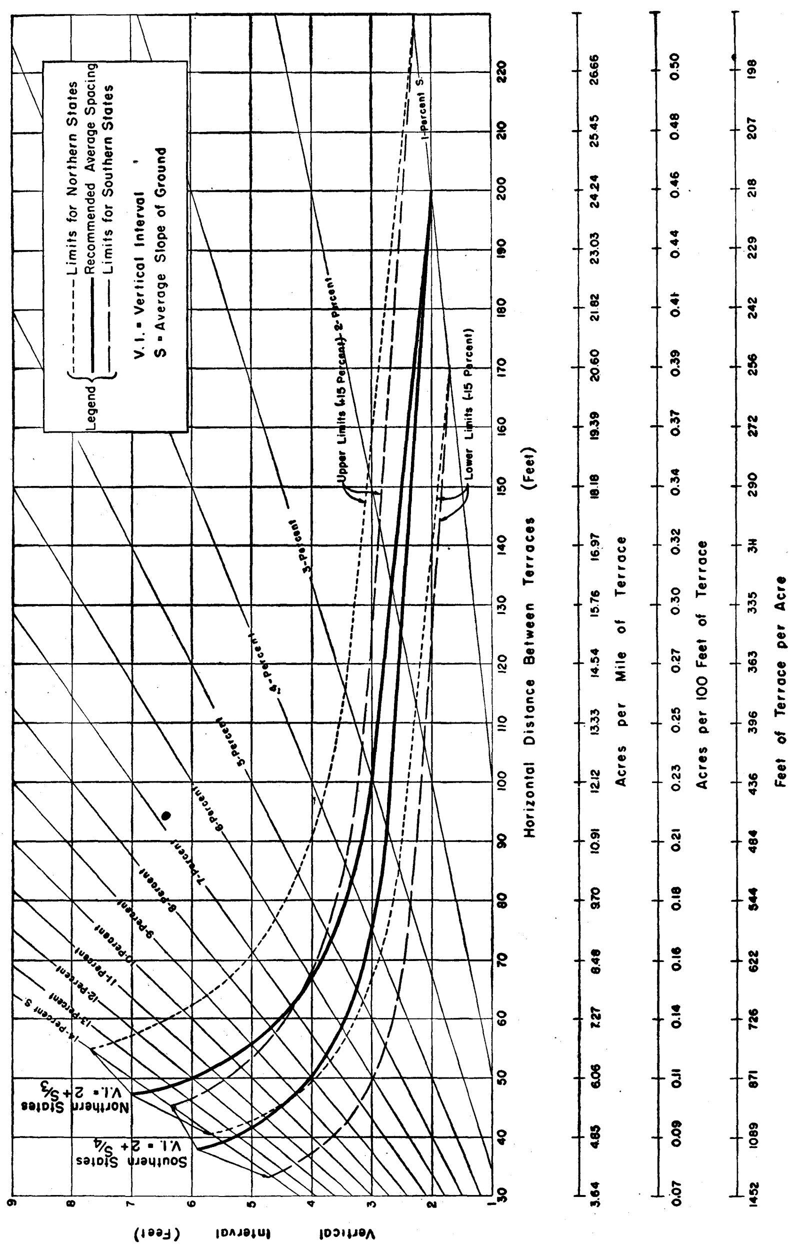

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FIGURE 19.—Recommended terrace spacings and related data for channel terraces.

States have been developed. In the Southern States the approximate vertical interval in feet can be determined by dividing the slope by 4 and adding 2 to the resultant quotient, $VI=2+S/4$. The vertical interval in feet recommended for Northern States can be determined by dividing the slope by 3 and adding 2 to the resultant quotient, $VI=2+S/3$. For example, the average vertical interval in feet recommended for terraces in the Northern States on a 6-percent slope is $6/3+2=2+2=4$.

Many terraces will be laid out by terrace surveyors and farmers who prefer to use a chart rather than a table for determining the required vertical interval, horizontal spacing, and miles of terracing for various slopes and acreages. For their convenience figure 19 has been prepared. It is essentially a graphic presentation of the information given in table 1. The chart can be used very easily when one understands what the different lines and scales represent.

The 14 sloping straight lines on the chart represent land slopes. These lines intersect the heavy curved lines at points that give recommended spacings for terraces on slopes represented by the lines. The upper heavy line is for average field conditions in the Northern States, the lower for average field conditions in the Southern States. Approximately parallel to each of the heavy curved lines are two dotted lines that indicate the maximum and minimum spacings recommended. The line above the heavy curve represents the upper limit, and that below, the lower limit. The vertical scale on the left gives the vertical interval in feet, and the horizontal scales at the bottom give corresponding horizontal distance between terraces, acres per mile or per 100 feet of terrace, and feet of terrace required per acre.

To illustrate the use of the chart, suppose a 3-percent slope is to be terraced in the Northern States, and suppose the field conditions are about average. To find the spacing desired, follow the 3-percent slope line to the point where it intersects the heavy curved line for the Northern States. From this point trace a line to the vertical-interval scale on the left. The number on the scale at that point gives the vertical interval as 3 feet. To find the corresponding horizontal spacing and the miles or feet of terrace required per acre on the 3-percent slope, draw a perpendicular line downward from the point where the slope line intersects the heavy line. Readings at points where this line cuts the four scales at the bottom of the chart give a horizontal distance between terraces of approximately 100 feet, 12.0 acres per mile or 0.2 acre per 100 feet of terrace, and 436 feet of terrace for each acre of land.

If favorable field conditions justify the use of the maximum spacings recommended, the 3-percent slope line is followed to the point where it intersects the upper dotted line. The vertical interval for this point is about 3.5 feet, the horizontal distance is about 115 feet, the approximate acres per mile or per 100 feet of terrace is 13.9 and 0.26 respectively, and about 379 feet of terrace will be required for each acre to be terraced.

It is also possible to read from the chart specifications for points that lie anywhere between the maximum and minimum lines. If perpendicular lines are dropped from the points where the 3-percent line intersects the maximum and minimum lines for Northern States,

TABLE 1.—*Recommended terrace spacings* [1] *and related data for channel terraces*

Southern States—$VI=2+S/4$

Percent slope (*S*)	Vertical interval (*V I*)			Horizontal distance			Acres per mile of terrace [2]			Acres per 100 feet of terrace [2]			Feet of terrace per acre [2]		
	Minimum [3]	Mean	Maximum [3]	Minimum [3]	Mean	Maximum [3]	Minimum [3]	Mean	Maximum [3]	Minimum [3]	Mean	Maximum [3]	Minimum [3]	Mean	Maximum [3]
	Feet	*Feet*	*Feet*	*Feet*	*Feet*	*Feet*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Acres*	*Feet*	*Feet*	*Feet*
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.88	0.390	0.459	0.528	256.23	217.80	189.39
2	2.12	2.50	2.87	106.25	125.00	143.75	12.88	15.15	17.42	.244	.287	.330	409.98	348.48	303.03
3	2.34	2.75	3.16	77.92	91.67	105.42	9.44	11.11	12.78	.179	.210	.242	559.03	475.18	417.16
4	2.55	3.00	3.45	63.75	75.00	86.25	7.73	9.09	10.45	.169	.172	.198	683.29	580.80	505.00
5	2.76	3.25	3.74	55.25	65.00	74.75	6.70	7.88	9.06	.127	.149	.172	788.42	670.15	582.74
6	2.97	3.50	4.02	49.58	58.33	67.08	6.01	7.07	8.13	.114	.134	.154	878.58	746.79	649.37
7	3.19	3.75	4.31	45.53	53.57	61.61	5.52	6.49	7.47	.105	.123	.141	956.73	813.14	707.03
8	3.40	4.00	4.60	42.50	50.00	57.50	5.15	6.06	6.97	.098	.115	.132	1,024.94	871.20	757.56
9	3.61	4.25	4.89	40.14	47.22	54.31	4.86	5.72	6.58	.092	.108	.125	1,085.20	922.49	802.06
10	3.82	4.50	5.17	38.25	45.00	51.75	4.64	5.45	6.27	.088	.103	.119	1,138.82	968.00	841.74
11	4.04	4.75	5.46	36.70	43.18	49.66	4.45	5.23	6.02	.084	.099	.114	1,186.92	1,008.80	877.16
12	4.25	5.00	5.75	35.42	41.67	47.92	4.29	5.05	5.81	.081	.096	.110	1,229.81	1,045.36	909.01
Northern States—$VI=2+S/3$															
1	1.70	2.00	2.30	170.00	200.00	230.00	20.60	24.24	27.87	0.390	0.459	0.528	256.23	217.80	189.39
2	2.27	2.67	3.07	113.47	133.50	153.52	13.75	16.18	18.61	.260	.306	.352	383.89	326.29	283.74
3	2.55	3.00	3.45	85.00	100.00	115.00	10.30	12.12	13.94	.195	.230	.264	512.47	435.60	378.78
4	2.83	3.33	3.83	70.76	83.25	95.74	8.58	10.09	11.60	.162	.191	.220	615.60	523.24	454.98
5	3.12	3.67	4.22	62.39	73.40	84.41	7.56	8.90	10.23	.143	.168	.194	698.19	593.46	516.05
6	3.40	4.00	4.60	56.67	66.67	76.67	6.87	8.08	9.29	.130	.153	.176	768.66	653.37	568.15
7	3.68	4.33	4.98	52.58	61.86	71.14	6.37	7.50	8.62	.121	.142	.163	828.45	704.17	612.31
8	3.97	4.67	5.37	49.62	58.38	67.13	6.01	7.08	8.14	.114	.134	.154	877.87	746.15	648.89
9	4.25	5.00	5.75	47.22	55.56	63.89	5.72	6.73	7.74	.108	.128	.147	922.49	784.02	681.80
10	4.53	5.33	6.13	45.30	53.30	61.29	5.49	6.46	7.43	.104	.122	.141	961.59	817.26	710.72
11	4.82	5.67	6.52	43.81	51.55	59.28	5.31	6.25	7.18	.101	.118	.136	994.29	845.00	734.82
12	5.10	6.00	6.90	42.50	50.00	57.50	5.15	6.06	6.97	.098	.115	.132	1,024.94	871.20	757.56

[1] The spacings are based on recommendations of C. E. Ramser.
[2] Includes only the interval above each terrace.
[3] The minimum is 15 percent below the mean, and the maximum 15 percent above.

these lines will intersect the horizontal scale of distances between terraces at about 115 and 85 respectively. This means that a variation of as much as 30 feet is allowed to take care of the variation in soil and cropping conditions on 3-percent slopes. The person who plans the terrace system must judge whether field conditions will allow spacings above or below the average and how much above or below. He can then follow the 3-percent slope line down to that point between the maximum and minimum lines that he believes represents the conditions of the particular field that is being terraced, and select the corresponding specifications from the proper scales.

The chart could also be used readily to determine terrace spacings on slopes that lie between those included in the table. Approximate readings for a 3½-percent slope, for example, can be easily made by following a slope line midway between the 3-percent and the 4-percent lines to the points where it intersects the curved lines. Such refinement, however, is usually not necessary in ordinary terracing work.

The spacings given in table 1 and shown graphically in figure 19 are primarily for the channel terrace. When the ridge terrace is used, the spacings given for Northern States are generally recommended. Since this type of terrace has not been used in experimental work as much as the graded or channel terrace, spacing specifications have not been so completely developed for it as for the latter. Practically the same spacings will generally apply for both types because any material increase in the terrace interval for the level terrace would ordinarily permit more erosion on the slopes between terraces and give less uniform water distribution. The ideal spacing for the ridge terrace would seem to be that which would give the most uniform moisture distribution and minimum soil movement between terraces as well as the least interference with tillage practices and a low construction cost. The water-storage capacity of a level terrace with closed ends is an important and often a limiting factor in determining spacings. It should be sufficient to take care of the maximum runoff accumulation that can be expected from the contributing drainage area during the design period. This runoff may be as high as 4 or 5 inches in the semiarid regions and 7 or 8 inches in the more humid areas.

On fairly uniform slopes the average slope of the area can be used in computing the vertical interval for the terraces. If the slopes vary considerably the weighted average of all the slopes that a terrace is to cross should be used in computing the vertical terrace interval for each terrace. On some fields it might be advisable to reduce or increase the indicated interval slightly for certain terraces in the system in order to place them advantageously. It may also be necessary to make adjustments between terrace intervals in order to get proper alinement of terraces at the outlet ditch. In order to secure these features it is usually more desirable to decrease the spacings somewhat.

GRADES

Since experimental results show that both the rate of surface runoff and the soil loss in runoff increase with steeper terrace grades, the minimum grade that will provide satisfactory drainage is desirable for the channel terrace. As a variable grade retards the rate of runoff and provides drainage in a more satisfactory manner than the uniform grade, its use is generally preferable for terraces more than 300 feet in length.

In determining the final grade, the total length of the terrace should be estimated and a variable grade established that increases toward the outlet by regular increments. The grade is commonly changed every 300 to 500 feet. Wherever convenient, it is usually desirable to break grades at critical points such as gullies, fills, or low spots. Maximum grades of over 4 inches per 100 feet of length are seldom advisable since steeper channel grades usually allow excessive amounts of soil to be washed from the terrace channel. A possible exception may be found in areas with heavy clay soils or where relatively high rates of runoff are encountered. Under either of these conditions, a fall of as much as 5 inches per 100 feet of length for the last segment of a 1,600- or 1,800-foot terrace may be advisable.

The ridge terrace is ordinarily built with a level grade. Wherever some drainage is desired either one or both ends of the terrace can be left open or even a slight grade provided if necessary.

LENGTHS

In general, 1,200 to 1,600 feet is the maximum distance that a terrace should drain water in one direction. On gullied land a length of 1,200 feet should seldom be exceeded. When a few terraces in a system must exceed the maximum lengths recommended they are handled most satisfactorily by draining the excess length to a convenient natural or vegetated outlet in the direction opposite to the outlet for the main part of the terrace. Or the entire terrace may be drained in one direction, if the channel cross section is increased toward the lower end to provide additional capacity.

The maximum length of the ridge terrace, particularly when both ends are left open or when a slight grade is used toward the outlet, should not exceed that recommended for the channel type. This would mean that a maximum total length of 2,400 to 3,200 feet might be used for a level terrace if necessary. If closed ends are used, occasional blocking of the terrace channel provides a margin of safety against excessive water concentration should breaks occur at any point, and if this practice is followed there appears to be no need for restrictions in permissible terrace lengths.

CROSS SECTIONS

The three main requirements of satisfactory terrace cross sections are: (1) Ample channel capacity; (2) channel and ridge side slopes flat enough to permit the operation of farm machinery along the terrace without undue breaking down of the terrace or hindrance to tillage operations; and (3) economical cost of terrace construction.

The customary cross sections for both the channel and ridge terraces are shown in figure 7. The channel terrace provides channel capacity primarily by means of a graded, excavated waterway; the ridge terrace obtains its capacity by means of a ridge that floods the excess rainfall over a wide area. The water depth of a settled terrace of either type should be from 15 to 22 inches, and the minimum water cross-sectional area of the channel should seldom be less than 8 to 10 square feet. Larger cross-sectional water areas are usually necessary for the ridge terrace. Long terraces should have a cross-sectional area greater than 8 to 10 square feet toward the lower end because there will be a greater accumulation of water in the lower reaches of the terrace.

The side slopes of the channel or ridge should seldom be steeper than 4:1, and 5:1 is preferable. Steeper side slopes may be permissible in the Southeastern States, where small equipment is generally used, but the flatter side slopes are necessary where larger machinery is used. The total width of terraces may vary from 15 to 40 feet, depending on the land slopes and the type of machinery to be provided for.

TERRACE STAKING, REALINEMENT, AND MARKING

After the preliminary plan for the terrace and outlet system has been decided upon and the final terrace spacing and grades selected, the staking of the terrace system can be begun. The person doing the field staking must understand the use of a level and how to determine grades, elevations, slopes, and vertical intervals. He must also have had sufficient experience in terrace construction to know how far it is practical to deviate from the true grade lines in the final realinement of terrace stakes.

PRELIMINARY STAKING

The upper terrace is staked first, the drainage divide being used as a starting point from which to measure the vertical interval for the first terrace. An exception to this rule may be made if it is desired to have a definite location for some particular terrace in the system. This terrace would then be located first, and a sufficient number of terraces staked between it and the drainage divide to insure that the maximum vertical interval for any one terrace would not be exceeded, and any reduction necessary in the spacing of terraces could be divided proportionately. After the upper terrace is staked, each of the succeeding terraces is staked in turn.

In order to get proper alinement of terraces at the outlet ditch it will usually be found most convenient to start staking at the outlet end of the terrace. The selected terrace-channel grades can then be used to locate all other stakes from there to the other end of the terrace. If the outlet ditch has terraces emptying into it from one side only, there is no particular advantage in starting to stake a terrace from the outlet end. Stakes should be set at 50-foot intervals except on curves and through draws, where a 25-foot spacing should be used. It is customary and usually most convenient to have the stakes indicate the location of the center line of the ultimate terrace ridge. There is not, however, any objection to setting the stakes so that they indicate the center line of the channel or a line midway between the ridge and channel if the field surveyor prefers to follow either of these practices. It is not always possible to secure the most satisfactory terrace lay-out in the first attempt. After a few lines have been staked, topographical features will sometimes be encountered that will favor changes in terrace lines. If such changes are extensive it is usually best to pull up all stakes set and start over again. Even experienced engineers cannot always select the most desirable starting point without first setting a few preliminary stakes and then making such readjustments as seem desirable.

REALINEMENT OF TERRACE LINES

After the terrace lines have been staked some realinement is usually necessary on each proposed terrace in order to eliminate undesirable sharp curves, to obtain greater ease of construction, and to secure a

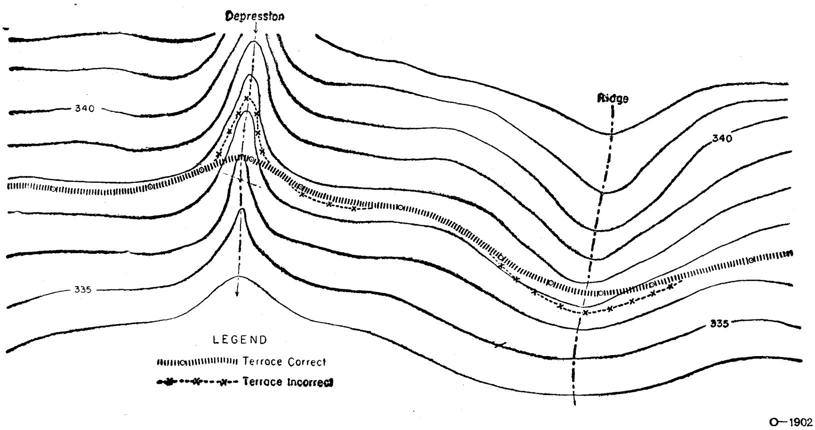

FIGURE 20.—Realining the terrace line by straightening sharp curves through depressions and over ridges facilitates both terrace construction and tillage operations.

finished terrace that will offer a minimum of inconvenience in later tillage operations.

The realinement needed will vary with the relief of the field but will usually consist of moving certain stakes up or down the slope where there are sharp curves in terrace lines until the most desirable terrace line is secured. The general procedure is illustrated in figure 20. Good field judgment must be exercised in order to secure the most satisfactory realinement of terraces.

The movement of terrace lines up and down slopes will of necessity be restricted by the drainage and construction features encountered. Usually the straightening should be limited in upward movement so that not more than 6-inch additional cuts will be necessary in the terrace channel. An exception might be made when a wide, sweeping bow can be eliminated by a slightly deeper cut, provided the other terraces of the system will follow uniformly. The straightening of terraces through depressions should not be such as will introduce excessive ridge heights and pond areas. Usually the maximum ridge height should not exceed 3 feet. If a gully has formed, the settled height of the terrace ridge above the break or fill in the gully should seldom exceed 3 feet.

MARKING TERRACE LINES

If a final check of the terrace and outlet locations shows that the entire lay-out will be satisfactory, the terrace lines should be marked with a plow furrow since stakes are easily lost and more difficult to follow with the larger terracing equipment.

TERRACE CONSTRUCTION

Terraces may be constructed with light equipment adapted to the power available on the farm whether it be horses or mules or tractors, or they may be built with heavier, more expensive equipment specially designed for terracing. The cost on the one hand will be labor and time with little cash outlay, and on the other the cash outlay will be greater with a corresponding saving in time and labor. Where needed, terraces are worth the effort or money required to build them by either method, provided a good job is done. A terrace half finished or not completed across low places may do more harm than good; insufficient channel capacity will invite overtopping and failure; a narrow ridge will prevent the best use of tillage equipment and may contribute to inefficient use of the field. Good terrace construction requires a knowledge of the best procedure to use with the equipment selected. Much time and effort will be saved if the operator has a thorough understanding of the best way to use the machine that is available to him for terrace construction.

EQUIPMENT

Within the past 10 years there has been considerable development in the methods of terrace construction because the recent increase in terracing activities has directed attention to construction phases and the improvement and development of terracing equipment. Many efficient terracing machines have been developed, such as the tractor-drawn two-wheeled blade grader, the motor-operated road maintainers, the elevating graders specially designed for terracing, and the rotary-type terracer (figs. 21 and 22). All these are efficient machines when used under proper conditions; however, owing to their relatively high initial cost, they are usually available to farmers on only a rental or a contract basis that requires an outlay of cash. If such equipment is not available or if the cost of its use is prohibitive, consideration should be given to the use of farm implements for terrace construction. A number of farm implements are adaptable for such work, and, although more labor is usually necessary to complete a first-class terrace, very little, if any, cash outlay will be required (figs. 23 and 24). In some parts of the country there is a

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FIGURE 21.—The rotary-type terracer developed by the Agricultural Engineering Department of Iowa State College.

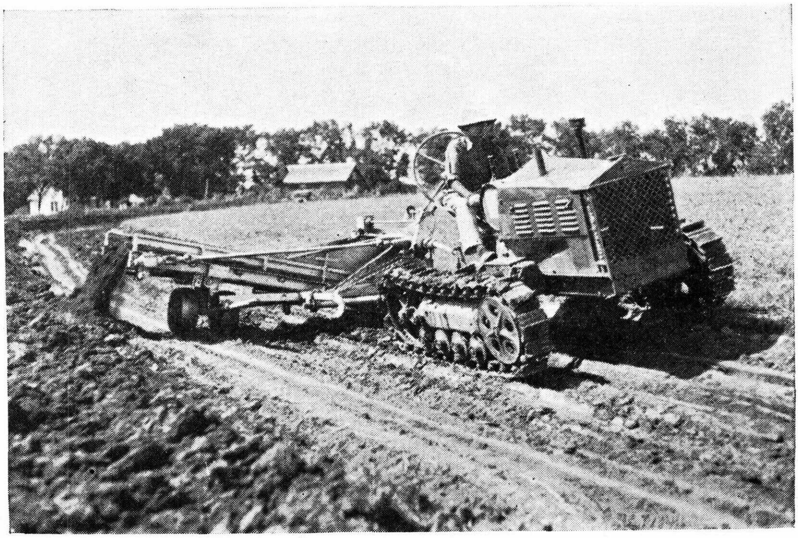

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FIGURE 22.—The elevating-grader terracer developed by the Agricultural Engineering Department of the University of Missouri.

SC–228

FIGURE 23.—Partly constructed ridge terraces in the Great Plains, where slopes are relatively flat and uniform.

KAN–51

FIGURE 24.—Terrace construction with a plow and V-drag. It requires considerable work to construct satisfactory terraces with this type of equipment.

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FIGURE 25.—Terracing with a light blade and farm tractor.

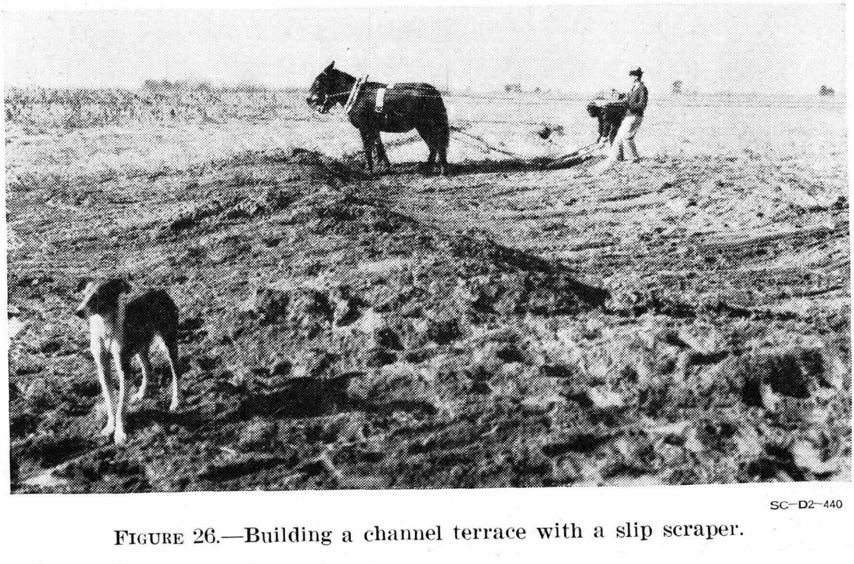

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FIGURE 26.—Building a channel terrace with a slip scraper.

surplus of labor on many farms during the late fall, winter, and early spring seasons that can be used to advantage in constructing terraces with farm equipment. Horse- or tractor-drawn light blades (fig. 25), tractor-drawn moldboard plows, one-way disks, and disk attachments for tractors, slip scrapers (fig. 26), and fresnos have all proved practicable for terrace construction. On heavy soils the two-bottom tractor-drawn moldboard plow has proved to be very effective for terracing, and on light sandy soils the slip scraper has been used extensively.

CONSTRUCTION PROCEDURE

In terracing a field the uppermost terrace should be constructed first, and after it, in turn, each succeeding terrace down the slope. If the lower terraces are constructed first they are likely to be badly damaged should a rain occur before the upper ones are completed. The top terrace should not only be constructed first, but it should also be especially well constructed because the safety of the lower terraces is dependent upon it. If the top terrace fails, the other terraces down the slope are very likely to fail, owing to the overload they will receive. The delayed terracing method (extending the construction of all terraces in a field over a period of several years), which has been advocated in some areas in order to initiate terracing over a larger area without increasing the expenditure of time and funds, is a dangerous procedure and cannot be generally recommended. Usually the few rounds made on each terrace the first 1 or 2 years do not provide sufficient capacity to withstand runoff, and much overtopping and damage to the field results. Terraces are sometimes not completed to sufficient size, and they remain a source of trouble thereafter. It is desirable to complete the construction of terraces in as short a time as possible, but when the work must be distributed over a period of years the practice of constructing a few of the upper terraces the first year and building additional terraces each succeeding year is to be preferred to the practice of starting all the terraces at one time and doing only a little work on each terrace every year until all are completed.

The practice of doing only the main excavating and earth moving with the terracing equipment reduces initial construction costs and, if necessary, can be recommended provided the terraces are watched carefully during the first year or two. Sufficient work should be done with the terracing equipment, however, to obtain minimum channel requirements for the area. Later, if the field is properly plowed and disked, these operations will smooth down the terrace slopes and enlarge the channel so as to provide the recommended factor of safety.

It requires considerable experience and perseverence to develop proficiency in terrace construction. The following are a few of the more important points to be observed in the operation of terracing equipment:

1. Unless necessary, never remove soil from areas that later will require filling.
2. Move the soil as few times as possible.

3. It is generally easier to move soil down the slope.
4. It is difficult to move lose earth over loose earth with a blade terracer.
5. Earth can be moved most efficiently if the blade is cutting some undisturbed earth at all times.
6. Move as much earth each trip as the power will permit.
7. Regulate the blade so that uniform cuts will be secured. This is particularly important on curves.
8. Do not disturb the topsoil from a wider area than is necessary.
9. It is usually desirable to secure the necessary terrace height as early during construction as possible.
10. Under varying sod conditions adjust the angle of the blade so that satisfactory scouring will be secured.

In building channel terraces most of the earth should be moved from the upper side. The exact amount of excavation from the upper side will vary with the degree of slope and the equipment used. On the steeper slopes the terraces will be relatively narrow and all excavation can be made from the upper side if reversible equipment is used. On the more level slopes, with wider terrace cross sections, a few rounds at the lower side of the ridge will be desirable in order to complete the required section in the most economical manner. In building most of the terrace from one side, a reversible machine is more efficient because all the excavated material is moved downhill. In using the plow or any implement that is not reversible, a system is ordinarily used whereby the ridge is worked in one operation and the channel in another. In this way almost 75 percent of the excavation is made from the upper side.

In areas where water conservation is desired and the ridge terrace is used, construction from both sides is advisable because this type of construction gives a wide, high ridge with a minimum depression above or below the terrace and is suited to the relatively flat slopes in these areas (fig. 27). When some construction is done from the lower side of a terrace, care should be exercised not to leave a distinct channel below the terrace ridge in which runoff may accumulate and possibly break over at low points. Such concentration usually leads to undesirable washing between terraces.

A detailed method of constructing terraces with heavy blade machines is illustrated in figures 27, 28, and 29. Figure 30 illustrates a method of constructing channel terraces with a moldboard plow that has proved practicable under many conditions found in the Corn Belt. It is impracticable to describe or illustrate detailed procedure for constructing terraces with all types of light equipment. As a matter of fact, different procedures are often necessary in using the same equipment under different conditions. Information is usually available on a regional basis that will prove valuable to those inexperienced in terrace constructing desiring to use light machines.

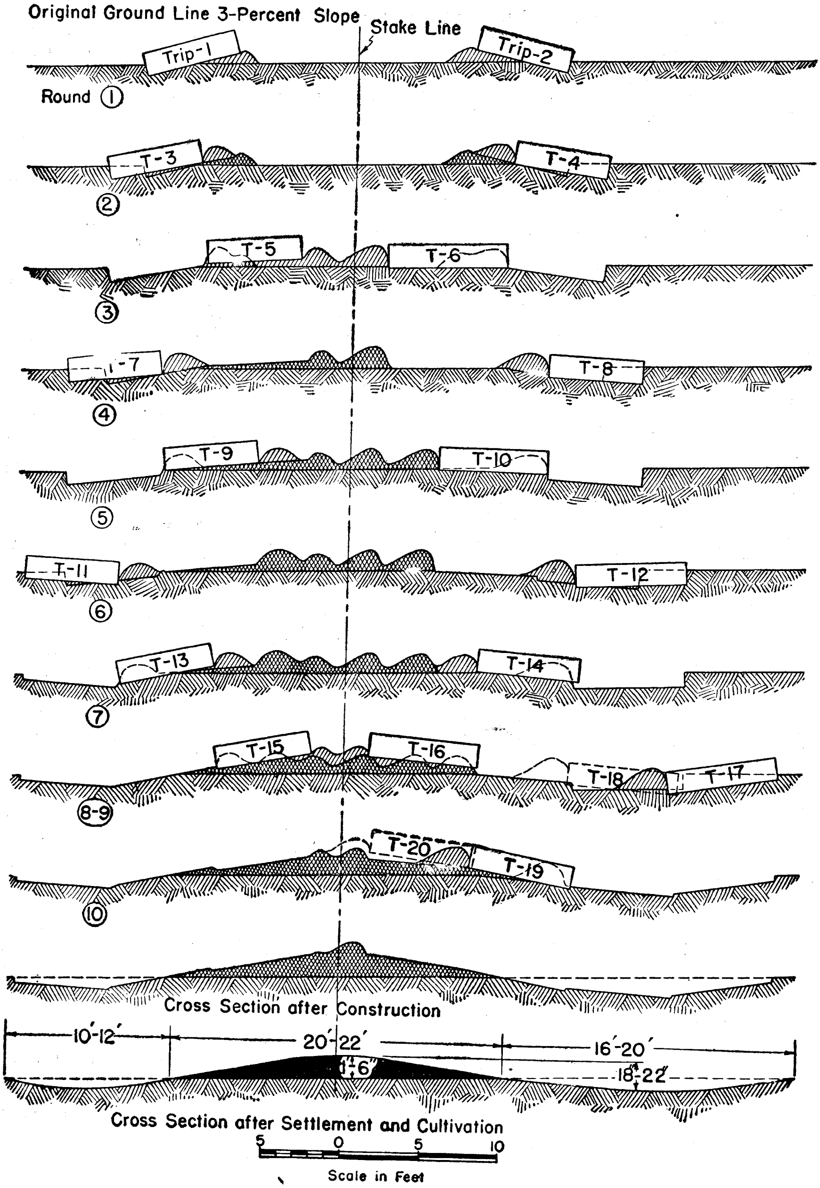

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FIGURE 27.—Progressive steps in constructing a ridge terrace in the Great Plains with a 10-foot blade terracer. The terrace is constructed from both sides. With inexperienced operators and on certain soils it may be desirable to secure the necessary center height during the first few rounds.

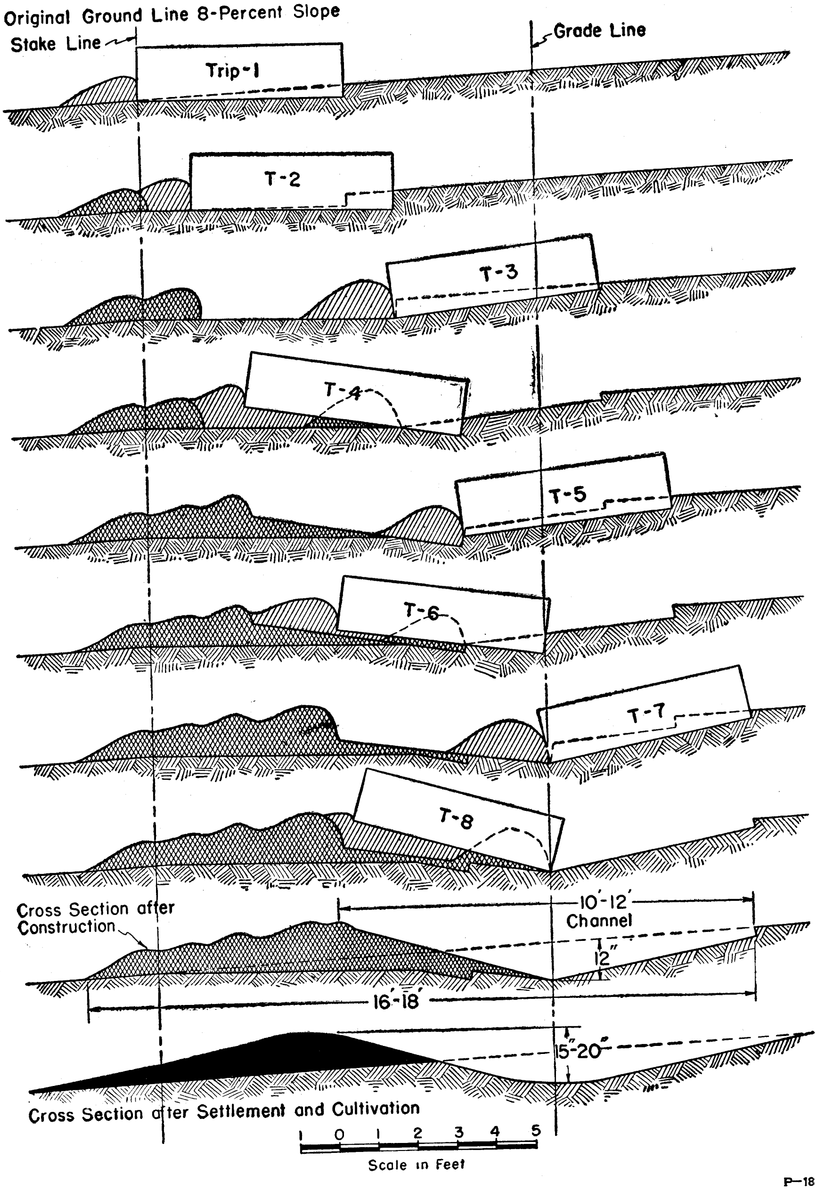


FIGURE 28.—Progressive steps in constructing a channel terrace in the Southeast with a 10-foot blade terracer. The terrace is constructed from the upper side only.

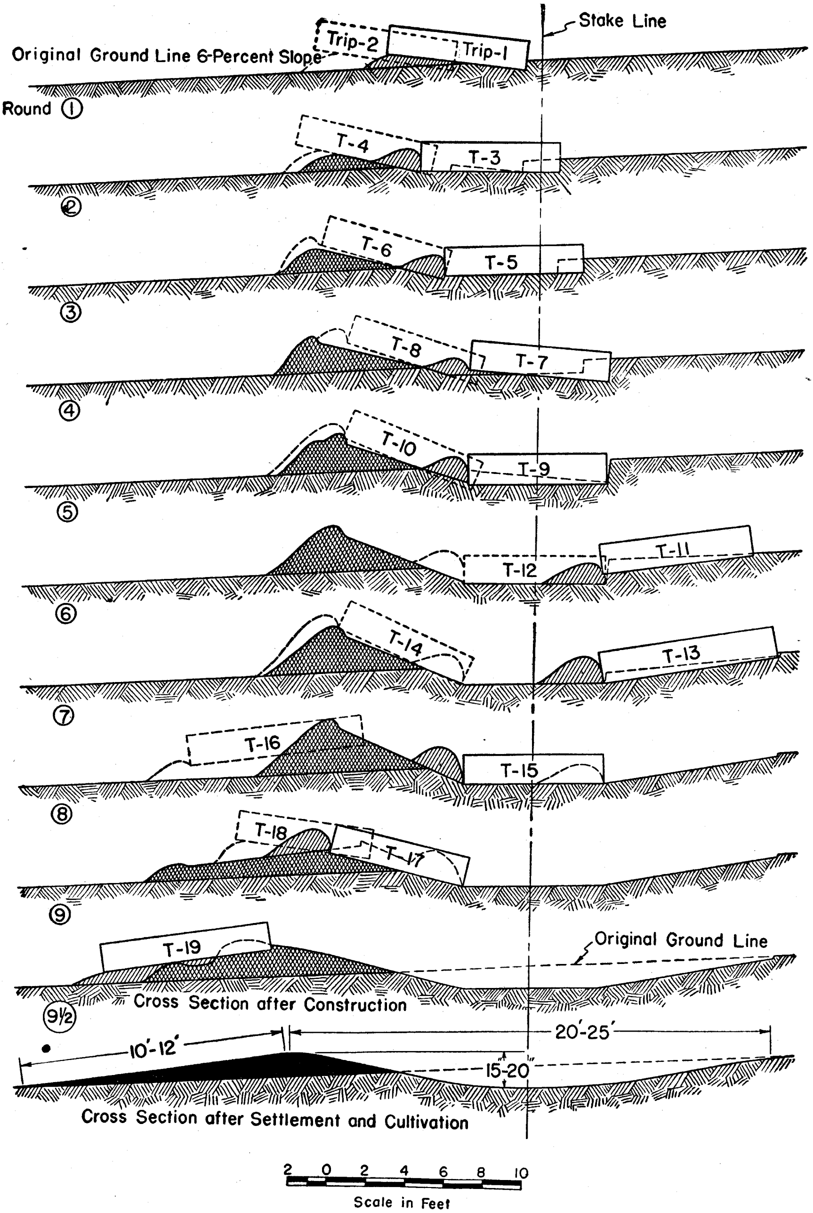


FIGURE 29.—Progressive steps in constructing a channel terrace in the Midwest with a 10-foot blade terracer. The terrace is constructed from the upper side only.

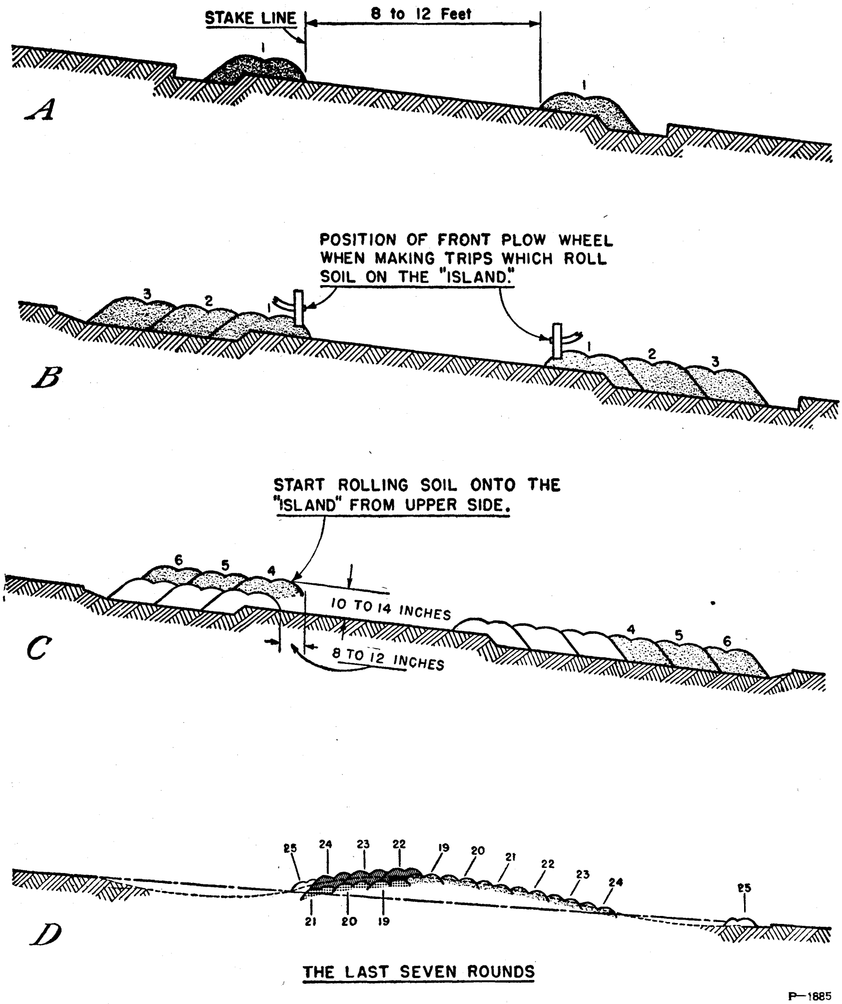


FIGURE 30.—Progressive steps in constructing a channel terrace with a two-bottom plow and farm tractor. The numbers on the furrow cuts represent the sequence of plow rounds. Note the plowing of overlapping furrows to form the channel on the upper side.

SUPPLEMENTAL WORK

Where terraces cross gullies or even slight depressions it is necessary to do some extra fill work in order to maintain the proper terrace location and ridge elevation. A slip scraper, fresno, or rotary scraper is usually used for this work. Failure to build fills properly is a common cause of trouble in terracing. Where an appreciable gully has developed, the fill should be made somewhat in the manner required for earth dams. It must be well compacted and impervious. A substantial bond should be provided between the fill and the gully sides. The fill must be made high and wide enough to prevent overtopping or wash-outs. Usually the height of the terrace at points where fills are made should be increased 15 to 20 percent to compensate for the extra settlement that will occur in the filled portion.

Where outlet ditches or field fences prevent the regular equipment from going the full length of the terrace it is frequently necessary to do some hand work on terraces. It is important that all such parts be completed to full channel capacity as one weak place in a terrace is sufficient to cause its failure.

A terrace cannot be considered complete until it has been carefully checked for correct grade and height. To assure proper channel capacity and the flow of water in the direction desired, low places on the ridge and high spots in the terrace channel should be marked and corrected before the equipment leaves the field. On the level terrace it is usually necessary to determine only the low points in the ridge. The level and rod are used in checking, and sufficient readings are taken to determine accurately where corrections are necessary. Elevations and grades should be checked very carefully around bends and across gullies and at terrace outlets. A common fault in terrace construction is to provide too much grade near the terrace outlet. If correctional work is required over an appreciable length of the terrace, it can usually be done most satisfactorily by using the regular terracing equipment.

COSTS

The cost of terracing will vary widely in accordance with soil and cover conditions, the size of terraces constructed, the equipment used to build them, and the experience of the constructors. For those without experience valuable time and labor will be saved by attending demonstrations or by studying proved methods before attempting to build a terrace with plow, scraper, blade, or disk.

Records of constructing terraces with heavy equipment in many parts of the country indicate an average cost range of about $30 to $45 per mile. On lighter soils in good working condition the cost may be as low as $20 per mile or less and on heavy soils as high as $55 or more. The figures are based on a large amount of work and a wide variety of conditions. If inexperienced operators or poorly adapted equipment is used or adverse conditions exist on the field, the costs may be much higher.

The cost of constructing terraces with farm or light equipment can be reckoned in terms of labor and fuel costs. These will also vary with conditions as pointed out for heavy-equipment construction. Using a two-horse or two-mule team and a slip scraper, two men will usually construct 600 to 800 feet of terrace in a 10-hour working day on light soils. With a two-bottom plow and tractor, farmers in the Middle West are able to construct about 1,600 to 2,400 feet of terrace per day. Light blades and V-drags require more labor, particularly if the ground is hard, necessitating plowing to loosen the soil. A single

FIGURE 31.—A special disk attachment for farm tractors has proved efficient for terrace construction.

disk attachment for a tractor has produced lower construction costs for terracing than any of the other equipment described. From three-fourths to a mile of terrace can be constructed in a day on heavy soils (fig. 31).

FARMING TERRACED LAND

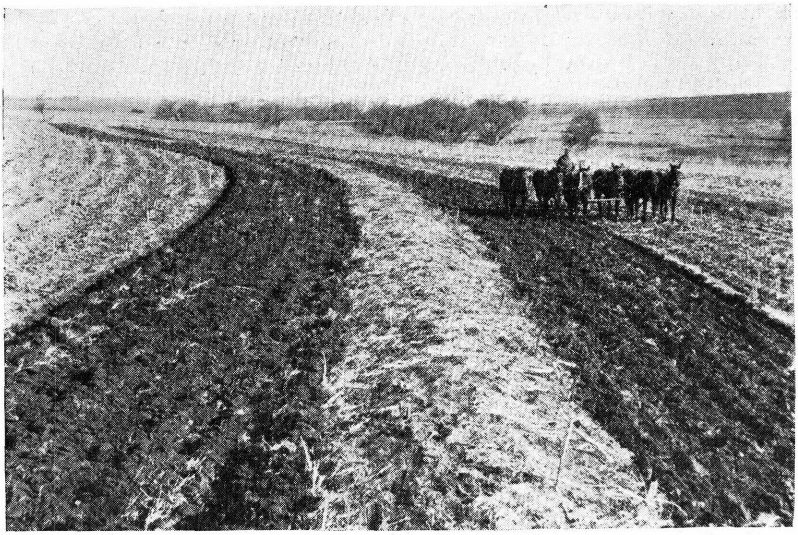
The construction of a well-designed system of terraces does not in itself stop erosion. Construction is only the beginning. The success of the terraces depends on whether they are properly maintained and farmed after construction. Too often erosion-control efforts cease with the construction of the terraces, and construction cost is wasted because of faulty cropping and tillage practices. A surprisingly large

SC–900

FIGURE 32.—Contour plowing the interval between terraces aids in moisture conservation and erosion control and facilities proper terrace maintenance.

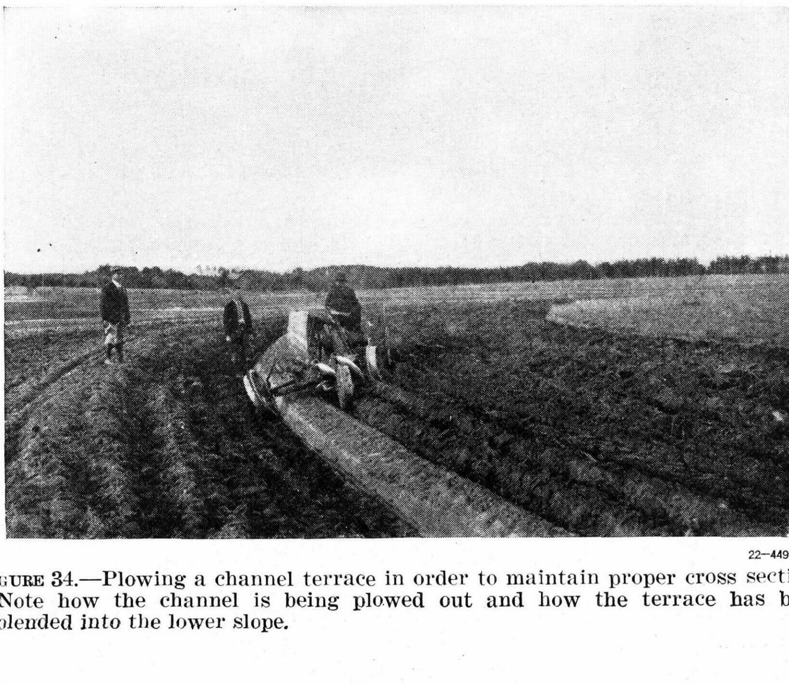
number of the terraces that have been in use for 5 years or more are no longer effective because the continued practice of one-crop farming and tillage up and down the slopes have reduced the capacity of the terrace channels to such an extent that frequent overtopping has resulted.

One of the most desirable tillage practices for terraced land is contour farming—the plowing and planting of crops parallel to the terraces. This produces a series of miniature depressions and ridges between terraces, and these aid in moisture conservation and erosion control. Operating tillage equipment parallel to the terraces, particularly equipment that penetrates the soil, also results in minimum damage to the terrace ridge and channel (fig. 32). By plowing parallel to the terrace and regulating the location of dead furrows and



NEB-23

FIGURE 33.—A terrace ridge can be made wider and the side slopes reduced by backfurrowing toward the ridge.



22-449

FIGURE 34.—Plowing a channel terrace in order to maintain proper cross section. Note how the channel is being plowed out and how the terrace has been blended into the lower slope.

backfurrows, terraces can be maintained and their cross sections changed so as to provide the most desirable slopes for any particular field (figs. 33 and 34). The method of locating dead furrows and backfurrows to enlarge or maintain the channel of the channel terrace and the ridge of the ridge terrace is illustrated in figure 35. The

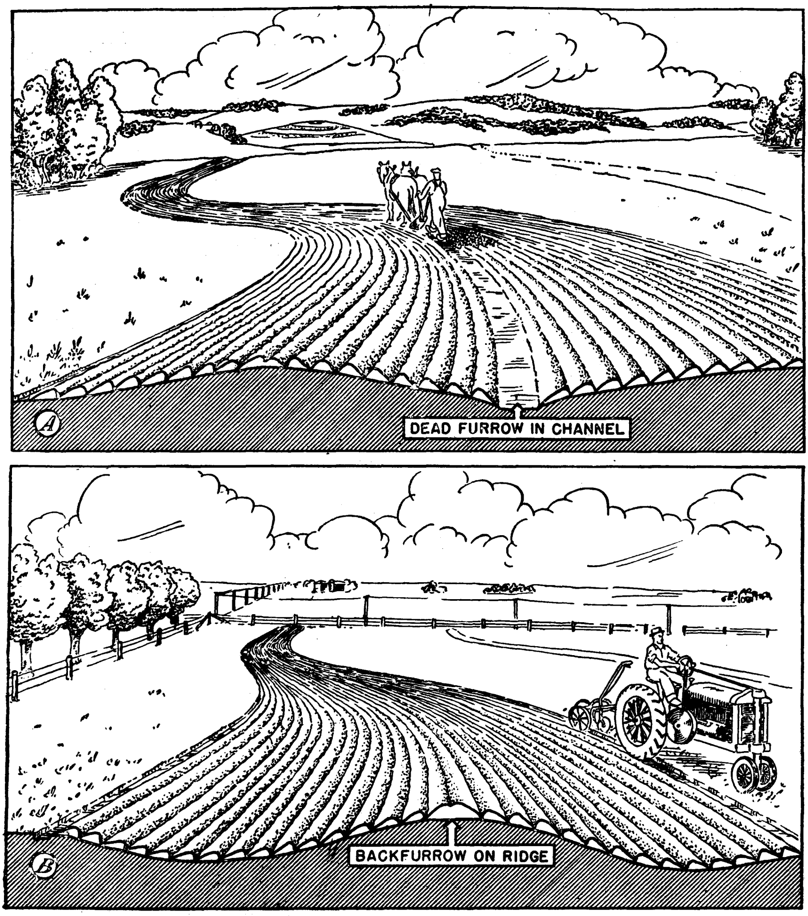
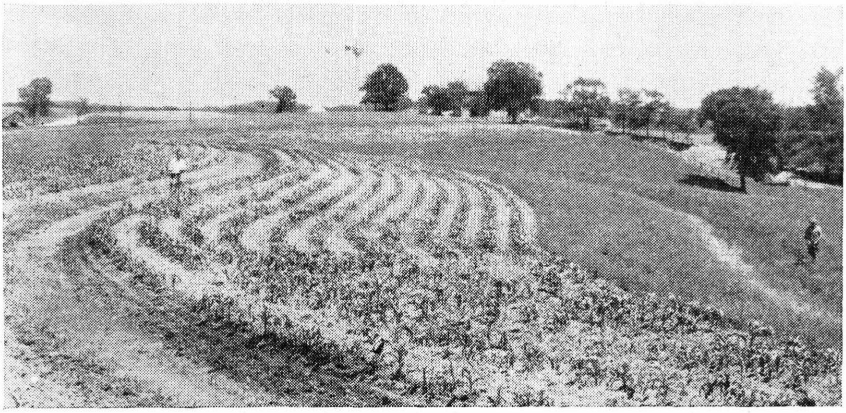


FIGURE 35.—Maintaining terraces by plowing: *A*, The channel of the channel terrace can be enlarged by plowing it out. Between channels turn as many of the furrows uphill as possible to offset the natural soil movement down the slope. *B*, The ridge of the ridge terrace can be enlarged by backfurrowing to it. The location of the dead furrow should be varied from year to year to avoid excessive depression at any one point.

location of the other backfurrows and dead furrows may be varied from year to year according to the surface condition of the field and the most convenient manner of finishing irregular strips or short rows. It is desirable to turn uphill as many of the furrows between terraces as possible.

The irregularity of slopes and the differences in terrrace sections and types of equipment used make it difficult to establish definite rules for plowing terraced land so as to maintain the terraces properly and adjust surface slopes. Considerable ingenuity must be exercised by the plowman since the starting and finishing points will vary not only from field to field but from year to year on the same field. He must keep in mind the most desirable terrace cross section and the principle of maintaining and developing the channel by plowing it out, of maintaining the ridge by backfurrowing to it, and of varying the other dead furrows and back furrows over the field so as to develop the most desirable surface slopes between terraces.

The two-way plow is not commonly used for plowing unterraced fields, but it appears to have some distinct advantages for plowing



WIS–39

FIGURE 36.—Strip cropping combined with terracing. Adjacent strips are centered on consecutive terraces. The men are standing on the terrace ridges.

terraced fields. It will eliminate the necessity of backfurrows or dead furrows in undesirable locations. A further advantage is that the furrows between terraces can be turned up the slope. This will give the soil an upward movement that will partly offset the natural downhill movement caused by erosion and tillage. This type of plow has been used in plowing terraced land on several of the experimental farms of the Soil Conservation Service and has shown good results.

Good terrace sections can usually be maintained with little or no additional maintenance work if contour tillage and proper methods of plowing are practiced. Under exceptional conditions, where it may not be possible to maintain proper cross sections by the regular plowing operations, it will be necessary to use the blade or scraper on the terraces at regular intervals. The lighter terracing machines or home-made V-shaped drags with ordinary farm power units can ordinarily be used satisfactorily.

In some areas strip cropping is combined with terracing to control erosion more completely (fig. 36). There are several methods of arranging the alternate strips of close-growing and row crops on a terraced field. The type of rotations, the crops, and the proportions of each crop to be produced will determine in part the arrangement and width of strips. In combining the two control measures (1) use strips as nearly uniform in width as possible in order that rotation of crops may be practiced, (2) have at least one boundary line of each strip fall between adjacent terraces so that a portion of each terrace interval will be protected by a close-growing crop, (3) eliminate point rows insofar as possible by absorbing irregular areas in strips of close-growing crops, and (4) use the minimum number of strips that will provide effective erosion control in order that the necessary tillage operations may not become unduly complicated or burdensome.

A combination of strip cropping and terracing that provides for close-growing crops on alternate terrace intervals and for row crops on the intervening one merely complicates the tillage and harvesting operations and does not provide any better erosion control than would be effected by terracing and by rotating the same crops in the usual method. The most effective methods of combining terracing and strip cropping are illustrated in figure 37.

When a field is in contoured row crops it is impossible to avoid short or point rows unless the land slope happens to be very uniform. These point rows may be arranged in many different ways, and the arrangement selected depends largely on the preference of the land operator. His choice may be influenced by such factors as past practice or the type of tillage equipment he uses. Figure 38 indicates three of the more common row arrangements, showing point rows in the terrace channel, at the base of the terrace ridge, and between terraces.

Many combinations of these arrangements are possible. The relative merits of each will depend largely upon local conditions and individual choice. A combination that appears to have some merit is to run the long rows parallel along alternate terraces and allow the short or point rows to terminate along the intervening terrace. By this method only every other terrace will receive point rows and these will terminate both in the channel and against the ridge. It is contended by some that terminating point rows on the terraces is conducive to erosion because these rows are slightly off the contour and they also tend to concentrate the turning of cultivating machinery on the terraces. This objection can be offset to some extent by always using parallel rows on the area occupied by the terrace and by ending the point rows just above or below this area. The third arrangement suggested in figure 38 throws point rows between terraces and more nearly equalizes the digression of the point rows from the contour.

The row arrangement shown in figure 39 reduces even more the variation of the point rows from the true contour. One or more master rows are equally spaced between terraces, and the point rows are allowed to fall between the master rows or between the master row and the terrace, according to the row arrangement used. This arrangement of rows requires more field work than any other discussed in this bulletin.

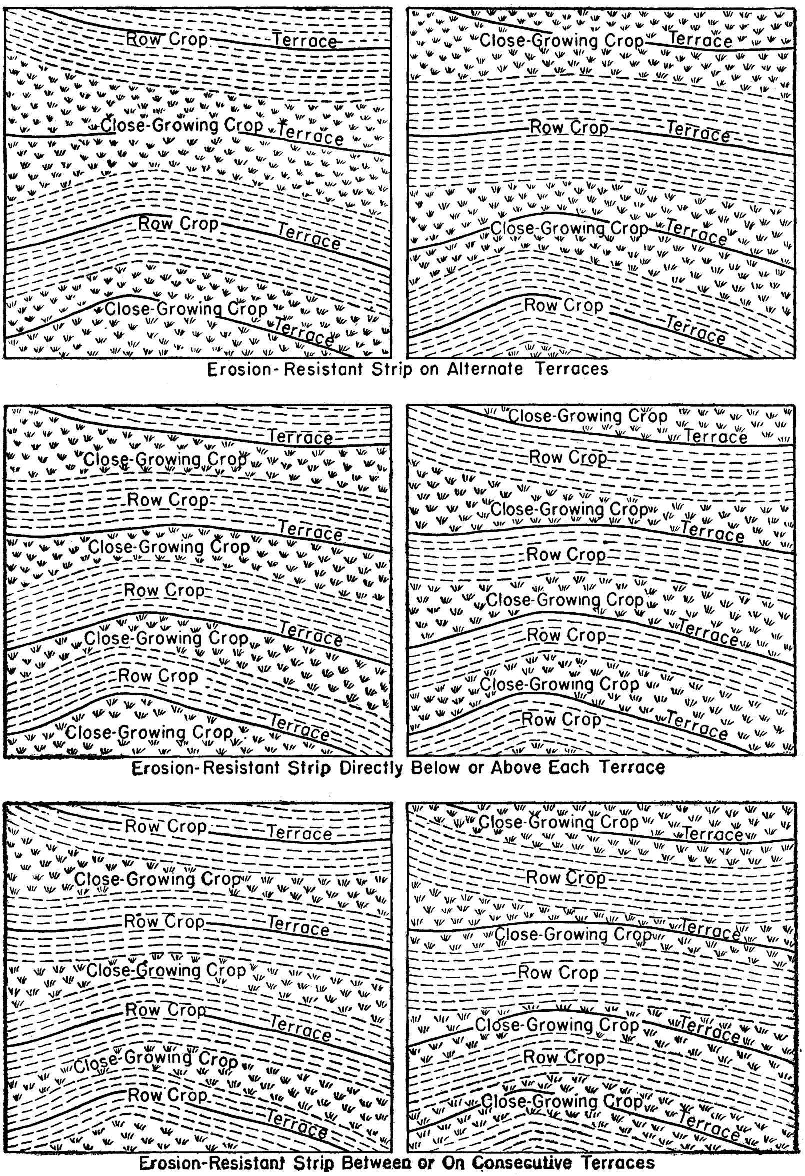


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FIGURE 37.—Three suggested methods of combining strip cropping and terracing.

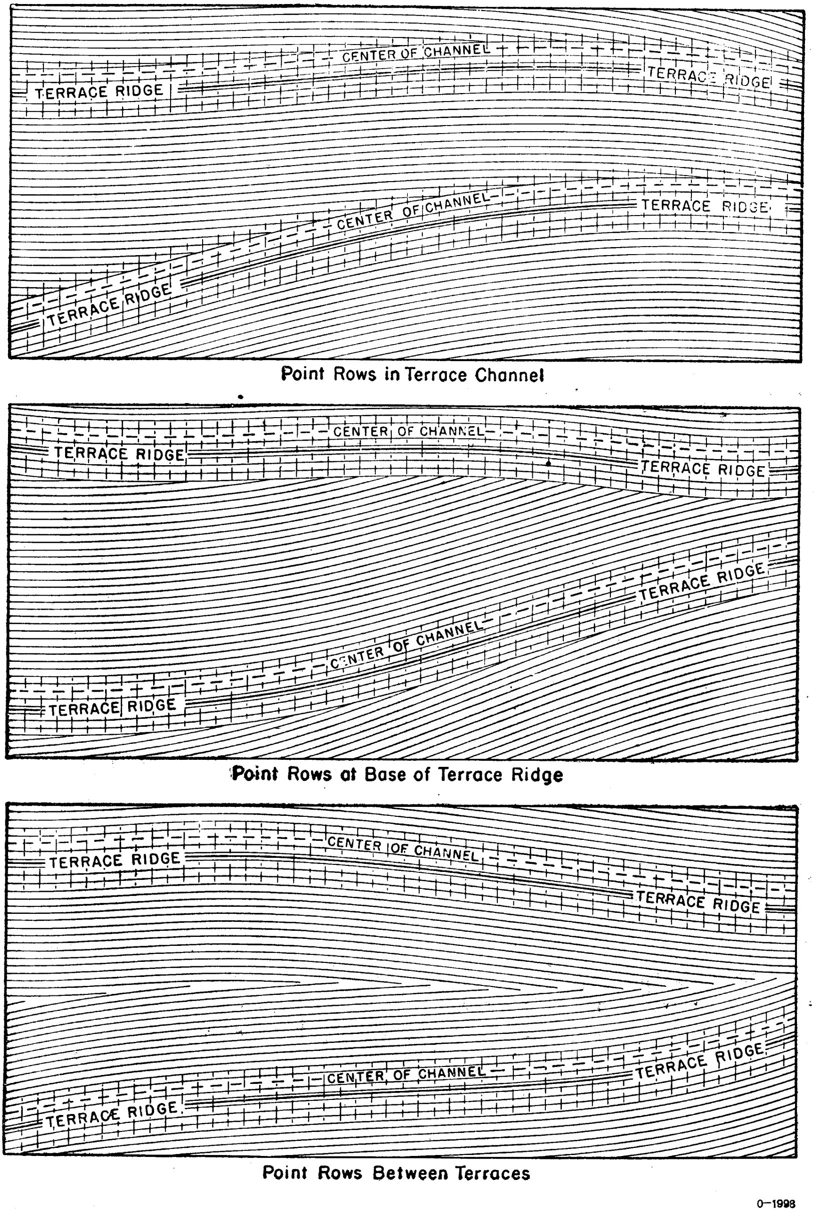


FIGURE 38.—Three suggested arrangements of point rows in relation to terraces.

It should again be emphasized that terraces require frequent inspection, particularly during the first year after construction, when the ridges and fills are settling. During this period they should be inspected after each heavy rain. If breaks in the terrace are discovered they should be repaired as soon as possible. If the runoff has concentrated between terraces and washed silt barriers into the channel these should be removed so that the channel will be clear for the next rain. This work can usually be done most conveniently with a shovel at the time of inspection. Ordinarily the most careful inspection is required where the terrace crosses gullies, where bends occur, and at the outlet end.

Some farmers object to terracing because they believe that it will interfere with their regular farming operations. At the same time

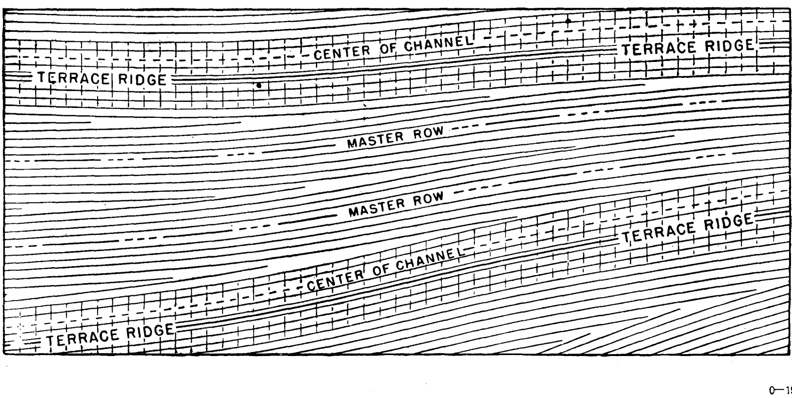
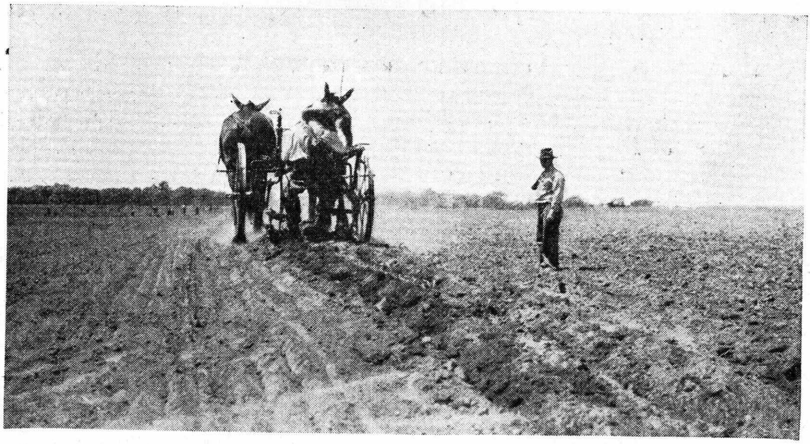
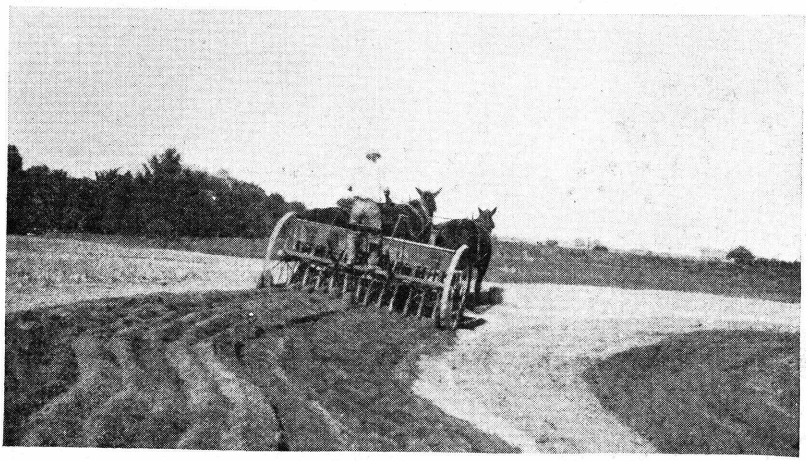


FIGURE 39.—Arranging point rows between master rows on terraced land places all the rows more nearly on the contour than does any of the methods shown in figure 38. This is the most intricate of the four suggested arrangements.

they usually fail to appreciate the fact that gullies that are gradually developing on their farms will eventually cause more serious interference with their farming operations than terracing possibly could and that the continual loss of topsoil will eventually make their entire farming operations futile. Farming terraced land is not unduly difficult if the farmer is willing to give up straight rows and try contour farming (fig. 40). Although contour farming introduces minor inconveniences it is usually found that the advantages far outweigh the disadvantages. Farmers have found that even the turning of equipment necessitated by short rows is not nearly as difficult as was anticipated. After the operator becomes accustomed to point rows he can carry on his regular farming operations with very little damage to crops. It has also been found much easier to operate machinery on the contour than up and down hill.

FIGURE 40.—Farm machinery can be satisfactorily operated over terraces if they are properly constructed and if contour tillage is practiced, as shown in the three pictures.





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Much more satisfactory results from terracing will be secured if farmers will adopt with regard to their terraces a policy similar to that followed by State highway departments with regard to their highways. Both highways and terraces must have good design and construction features and should be used and maintained according to recommended practices. With proper use and care terraces will ordinarily function for many years.

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