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Soil Factors Influencing Crop Production in the Arkansas Valley Colorado

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INTRODUCTION

Farm crops in the Arkansas Valley in 1925 had a value of $11,500,000. This is representative of the annual crop production. Conservatively estimated, this enormous yield could, by a better understanding of soil conditions and a more careful utilization of water, be increased at least 10 per cent.

The object most to be desired at present, however, is not increase in total production, but production that will yield the farmer a net profit. Great economic loss results here, as in other places, from expenditure of labor and application of water on soils of low productivity, whereas the expenditure of the same labor and water on better soils would return good profits. A more complete use of better lands, adjustment of crops to soils, full utilization without waste of water, thorough drainage, control of alkali, and preservation of the soil in a high condition of tilth and state of productiveness, are among the things necessary for agricultural prosperity.

DESCRIPTION OF THE AREA

The Arkansas Valley extends as a narrow belt across the southeastern part of Colorado, from the Kansas line to the foot of the Rocky Mountains at Canon City.

The region, as a whole, is a broad, eastward-sloping plain which rises from an elevation of 3,400 feet above sea level at Holly, near the Kansas line, to 5,333 feet at the foot of the mountains. In this plain Arkansas River has cut a broad, shallow flood plain bordered by river terraces and by higher, undulating uplands. The term valley is popularly applied to this region and is so used in this circular. It refers not only to the valley proper but also to the irrigated parts of the upland.

PURPOSES OF THE REPORT

The purposes of this report are to discuss some of the important features of the soils in their relation to crop production and to give a clear, comprehensive idea of the soil groups as determined by a recent soil survey. This soil-survey report, accompanied by a soil map of the region, will be published soon.

MOISTURE CAPACITY OF SOILS

The most important controlling factor in crop production is moisture. A farmer may have the best of soil and may carefully plant and cultivate his fields, but unless he has the necessary moisture he can not produce a crop.

By moisture capacity is meant the quantity of water which a soil is able to take up, to hold, and to release again to the crop. The quantity of water available to a crop is dependent on several things, among which are the texture of the soil, the thickness of the soil, the soil structure, and the supply of organic matter.

A sand soil takes up moisture readily, but if it is of medium or coarse texture it lets much of it escape downward into loose gravel or the deep subsoil. A clay soil, on the other hand, takes up moisture very slowly, but when it has become saturated it holds much of the moisture so tightly that plants can not use it. A medium or coarse sand containing 18 per cent water is nearly saturated, but clay, like Billings clay or Ordway clay, containing 18 per cent moisture holds nearly every bit of it. Clay soils also crack and lose much water by evaporation. Soils of medium texture, such as loam, silt loam, or very fine sandy loam, have a better moisture capacity and consequently a higher productive value than soils which contain either more sand or more clay.

Soils with deep subsoils, like the members of the Prowers, Rocky Ford, or Otero series, hold more available moisture than shallow soils like those of the Minnequa or Penrose series. The farmer can not do much to change the condition of the lower part of the subsoil, but he can deepen the surface soil by gradually deepening cultivation and by growing deep-rooting crops such as alfalfa, clover, sweet clover, and sugar beets. Though he can not materially change the soil texture, he can considerably improve the structure, and that is equally important.

After a road across a stubble field has been used but a short time the soil in it becomes packed and hard. When plowed, the soil is dry and cloddy even though that at both sides of the road is loose and moist. The soil in the road has the same texture as that at the sides, but the structure is different.

Other common ways of causing bad structure are overirrigation and cultivation when the soil is too wet. In this respect, heavy clay and silt soils require more careful management than do sandy soils. The surface crusting and slick spots so common to the soils of this region are structural conditions. Any soil or subsoil condition which has a tendency to produce and maintain for any considerable time a layer of soil that is too moist or too dry is unfavorable for plant growth. Plant roots reaching the moist layer tend to develop laterally instead of downward. Loss of moisture results in the drying out of the roots or a sudden rise of the water table causes their submergence, conditions equally fatal to the plant.

An impervious condition of the subsoil may be the result of the heaviness and compactness of the soil, of a zone of high lime or gypsum accumulation, or of a layer of shale material lying near the surface. In any case, the surface run-off is rapid, and the moisture-holding capacity of the surface soil is small. The soil soon dries out, and plants wither and die. Studies in the area indicate very strongly that unfavorable moisture conditions in the subsoil are most largely responsible for the loss of fruit trees.

Soil structure can be improved by cultivation under the right moisture condition, by varying the depth of cultivation to prevent the formation of a plow sole, by growing deep-rooted crops, by thorough drainage and washing out of alkali, and by increasing the percentage of organic matter in the soil. Although the soils are well supplied with nitrogen, manure is found very beneficial, partly on account of its influence in improving soil structure. Manure, well-rotted straw, grass, and weeds, or a crop of alfalfa, red clover, or sweet clover plowed under, are beneficial to soils of all textures in improving the structure and increasing the moisture-holding capacity.

DRAINAGE

Roots of most crops will not grow in a soil permanently saturated with water. If the roots have penetrated the soil before its saturation, growth stops until drainage is established, or the plant dies. Plant roots require air, which is excluded from a saturated soil.

Since moisture is a limiting factor in crop production, it might seem that ideal irrigation would consist of applying only the quantity of water needed for the plants and that lost by evaporation. This is rarely possible, and if possible would not be desirable. Both the water and the soils of this region may contain impurities which must be carried out, as are the impurities of the body, or the soils would soon become seriously toxic or poisonous.

Soils having deep, fairly open subsoils and a means for the escape of moisture have their own drainage systems, but in level or shallow soils or in soils having impervious subsoils artificial drainage is necessary under certain conditions. In small valleys or slightly basinlike areas where the soils have open subsoils, in level areas where the subsoil is heavy or impervious, and in areas where the impervious subsoil comes to or near the surface on slopes, drainage is restricted. To these areas might be added soils of the river valley in which a high water table is maintained by the river or by inflow from tributary streams and drainage ditches.

Numerous drainage systems have been successfully installed in the small valleys in the areas of the Prowers soils and in the broader basin areas of the Otero soils. In these areas the subsoils are open. The poorly drained Billings soil of Canon City, the Ordway soils, and Minnequa clay at Hasty have heavy or impervious subsoils and are more difficult to manage. Seeped spots on the slopes, where the downward movement of water is checked by impervious shale or limestone or by the heavy lime layer of the Fort Lyons soils, are not extensive but where present are also difficult to manage. In the river bottoms the heavy soil texture and the rapid filling of the ditches caused by undermining of the gravelly substratum seem to be the principal difficulties. An understanding of subsoil conditions is essential to the successful establishment of any drainage system. It is of primary importance in determining whether sufficient benefit will be derived to justify the expense. All soils can be drained and reclaimed from alkali, but this may be, and in places in the Arkansas Valley is believed to be, at present impractical.

ALKALI

Aside from moisture and natural soil fertility, the most important factor in controlling crop production in the Arkansas Valley is the presence of alkali in the soil. This term is used in the popular sense to include not only sodium carbonate, but also sodium sulphate, sodium chloride, and other salts. Lime is everywhere abundant, because the soils are young and are derived from lime-bearing material, and because rainfall is scant.

Alkali is present in varying quantities in the shales from which the soils were derived and in the soils themselves. Alkali conditions are the natural accompaniment of an arid or semiarid climate, just as acid conditions are of a humid climate. Alkali is a serious factor in restricting production, principally because its control is not well understood.

Injury from alkali is both direct and indirect. The direct effect is its toxic influence on germinating seeds and on growing plants.

In testing soils for alkali the Bureau of Chemistry and Soils has for a number of years used the electrolytic bridge. A soil solution containing a high percentage of dissolved material has a lower resistance than one containing a low percentage. A soil to be tested is placed in a cup, distilled water is added, and the soil is thoroughly mixed. A 50 cubic centimeter cell is filled with the material and its resistance is tested in the bridge. From tables which have been carefully worked out the parts of alkali to 100,000 parts of soil can be approximately ascertained.

In order to determine the effect of alkali in the Arkansas Valley on the germination of seed, a series of experiments was carried on in the research laboratory of the American Beet Sugar Co., at Rocky Ford, Colo.

For this experiment[1] eight boxes, each 4 feet long, 6 inches wide, and 4 inches deep, were made. One used for a check was filled with good alkali-free loam. Another was filled with soil of the same kind, to which enough finely pulverized alkali crust had been added

[1] This work was carried on at the laboratory of the research department of the American Beet Sugar Co., through the courtesy and assistance of the superintendent, A. W. Skuderna, who had the boxes made and records kept.

to raise its alkali content to approximately 0.2 per cent. To the soil put into the other boxes increasing quantities of alkali were added, so that a series ranging from the check up to 2 per cent was obtained. In each box were planted 500 kernels of wheat, and the soil was brought to optimum moisture content by spraying with distilled water. The soils were moistened in this way twice a day throughout the experiment. Each morning counts were made of plants which had come above the surface of the ground.

Table 1 shows the date of planting, the approximate percentage of alkali in soils of each box, and the number of plants which germinated each day for 12 days. Minor inconsistencies are believed to be the result of unequal watering and the washing of alkali from some of the seed.

TABLE 1.—*Relation between germination of wheat and alkali content of soil; 500 kernels planted in each of eight boxes July 8*

Date	Number of kernels germinated in—							
	Check (alkali-free soil)	0.2 per cent alkali sample	0.4 per cent alkali sample	0.6 per cent alkali sample	0.8 per cent alkali sample	1 per cent alkali sample	1.5 per cent alkali sample	2 per cent alkali sample
July 10	7	1	1					
July 11	62	29	1	3				
July 12	146	60	1	4				
July 13	169	96	3	5				
July 14	337	167	8	12				
July 15	342	235	77	34	14	5	11	3
July 16	381	289	182	50	27	16	19	4
July 17	395	315	250	79	37	17	22	6
July 18	401	365	320	93	48	19	33	7
July 19	402	382	379	168	63	30	36	8
July 20	404	386	384	191	95	44	43	15

Expressed in percentage the germination at the end of 12 days was as follows:

Sample	Per cent germination
Check	81
0.20	77
.40	77
.60	38
.80	19
1.00	9
1.50	9
2.00	3

It should be noted that although total germination at the end of 12 days was practically as high in the soil having 0.2 and 0.4 per cent alkali as in the check that germination had been much retarded, a very important factor in obtaining a stand under field conditions. On the sixth day after germination had started, for example, 342 grains had germinated in the check box, 77 in the 0.4 per cent alkali soil, and only 34 in the 0.6 per cent alkali soil. This experiment was repeated a number of times, and practically the same results were obtained each time. Experiments were also made with other plants. Some showed greater tolerance than wheat, but the ratio between alkali content and germination remained constant.

As it was noted in the field that alkali in heavy soils seems less harmful than in soils of light texture, an experiment was tried to determine to what extent this is true. Two soils, one Rocky Ford fine sandy loam and the other Las Animas heavy clay loam, were selected and alkali was added to each in the same proportion. The boxes were then divided through the middle, and one end was filled with light soil and the other with heavy soil. These were planted with wheat in the same way and counts were kept. Expressed in percentage, germination at the end of 11 days is shown in Table 2. This experiment seemed to indicate that 0.2 per cent alkali in a very light sandy soil was practically as toxic as 1 per cent alkali in a very heavy soil.

TABLE 2.—*Percentage of germination of wheat in sandy soil and clay loam soil*

Soluble salts in sample (per cent)	Percentage of germination in sandy soil	Percentage of germination in clay loam soil	Soluble salts in sample (per cent)	Percentage of germination in sandy soil	Percentage of germination in clay loam soil
Check	85	88	0.8	21	80
0.2	90	93	1.0	19	92
.4	65	90	1.5	0	50
.6	25	93	2.0	0	5

The results of this experiment were so striking that a third experiment was carried out in which Rocky Ford fine sandy loam, Minnequa silt loam, and Billings clay were used. The results were practically the same for the very light and very heavy soils, with germination in the silt loam midway between. During one of these experiments wheat grains which had lain for 21 days in moist alkali soil without germinating were taken out, washed, and placed in soil which did not contain alkali in injurious quantities. One-fifth of these seeds then germinated, a fact which suggests that the failure to germinate in the first case was due to the presence of alkali.

These experiments do not represent field conditions; the conditions were more favorable to high germination than conditions usually existing in the field. Nor do they furnish reliable data as to the quantity of alkali which will seriously retard or entirely prevent germination. They do, however, show conclusively that increasing quantities of alkali retard germination in proportion to the quantity of alkali, and that large quantities of alkali prevent germination. They also indicate that since alkali is less harmful in a clay soil, which requires larger quantities of moisture to permit plant growth, than in a sandy soil, in which smaller amounts are necessary, that the injurious effects of alkali can be reduced by improving the soil structure by adding humus and thus increasing its moisture-holding capacity. After seeds have germinated and the plants have become well established they seem to become more resistant up to a certain point of alkali concentration. In heavy soils this seems to be about 1 per cent.

One other striking condition was noted in these experiments. In soils containing 0.2 per cent, 0.4 per cent, and in some cases 0.6 per cent alkali, although the germination was retarded and total germination was lower than in the alkali-free soil, the plants which did grow were more vigorous and larger than in the alkali-free soil. In some cases, at least, this did not result from the smaller number of plants in the same space. In Table 1, for example, the number of plants in the soil of 0.2 and 0.4 per cent concentration was only very slightly less than in the alkali-free soil, but the growth was better. At the close of each of these experiments the alkali content of the soil was found to be lower than at the beginning, owing to surface irrigation for even this short time.

Alkali in sufficient quantities to be seriously toxic occurs only in comparatively small areas. Its influence on the physical condition of the soil is more widespread. In small quantities it results in the deflocculation or breaking down of the soil grains, which causes the soil to bake and crust. If alkali-free soil is put into a cup, is moistened, and mixed into a thick paste, and alkali such as that found in the Arkansas Valley is then added, it at once becomes distinctly more sticky. If set aside and allowed to dry, it shrinks, cracks, and becomes much harder than does the alkali-free soil.

Throughout this region small spots here and there do not take water readily, and on them growth is small and stunted or cultivated plants will not grow. In these spots there is no appearance of alkali, and the soil does not, in many cases, look different from that around it. Many examinations have been made of such spots, and in nearly every case the alkali content, although far below the toxic point as indicated by the germination experiments, was higher than in the surrounding productive areas. These spots are not quickly improved by drainage as, in many places, they occur in well-drained soils.

Shales in the deep subsoil and valley slopes have already been referred to as sources of alkali. Rain, irrigation, and seepage water dissolve a part of the alkali, carry it into small streams and drainage ditches, and finally empty it into the river. This water, with its load of alkali, is taken out lower down the valley, more alkali is accumulated, and again the water is returned to the river. Thus the alkali content of the river water increases downstream. The alkali content of water in the storage reservoirs is commonly lower than that of the river water during the irrigation season, because the reservoirs are filled, for the most part, during winter and early spring when the river water is more nearly pure.

Numerous tests were made of water as it was being applied to the soil and of that which came out of the soil through the drainage ditches. Where the irrigation water was comparatively pure, water in the adjacent drainage ditches was found to contain from fifteen to more than thirty times as many parts of alkali to 100,000 parts of the water, indicating that large quantities of impurities are removed by drainage.

In order to determine the relative purity of water in the river at different points, tests were made from Pueblo to Lamar on the same day (August 9) during flood stage of the river, water being taken from the middle of the river at each road crossing and tested with the electrolytic bridge. These determinations check very closely with laboratory determinations made by chemists of the American

Beet Sugar Co. Readings made a few days previously between Canon City and Pueblo are also given in Table 3.

TABLE 3.—*Parts of soluble salt present in Arkansas River water at various points*

Date	Place	Approximate distance from Pueblo	Parts of soluble salt to 100,000 parts of water
1926		*Miles*	
Aug. 5	Canon City	41	28
Do	4 miles east of Canon City	37	20
Do	North Florence	30	23
Do	2½ miles east of Florence	28	32
Do	Portland	25	23
Aug. 9	Pueblo	0	28
Do	North Vineland	6	33
Do	North Avondale	13	42
Do	Boone	20	38
Do	Nepesta	25	46
Do	Fowler	32	52
Do	Manzanola	42	71
Do	Rocky Ford	54	68
Do	Swink	60	101
Do	La Junta	64	113
Do	Hadley	72	120
Do	Las Animas	83	145
Do	Caddra	97	258
Do	Prowers	107	251
Do	Lamar	115	400

From Table 3 it will be noted that the water above Pueblo contains very little soluble salt, but that below Pueblo the quantity of soluble salt increases in an almost constant ratio downstream. The last of the flood water was taken out between Prowers and Lamar, so the reading at Lamar represents drainage and seepage water rather than flood water.

RELATION OF ALKALI TO DRAINAGE

Since it is necessary to use irrigation water containing considerable soluble salt, thorough drainage and careful use of water become especially important. Any soil of the Arkansas Valley, in which drainage conditions are allowed to become such that evaporation from the surface continues for some time, will accumulate so much alkali that it will not produce crops. On the other hand, any soil in the valley in which the moisture movement can be kept continuously downward sufficiently long can be reclaimed and made to produce crops. The value of the land in certain cases, however, may not justify the cost of reclamation.

During the progress of the soil-survey work, alkali determinations of each 6-inch layer to a depth of 5 feet were made in all parts of the valley where alkali in injurious quantities had accumulated. The examples of determinations in Table 4, made on the same date, are representative of the position, but not the quantity, of alkali in all alkali and seeped areas in the valley.

Table 4 shows the alkali concentration in each 6-inch layer of the soil to a depth of 5 feet in a bare, crusted spot of Minnequa clay at

Hasty, on Otero clay loam 1½ miles west of Cheraw, and on Minnequa clay loam about 9 miles southwest of Rocky Ford.

TABLE 4.—*Percentage of soluble salts at various depths in three types of soil*

Depth at which sample was taken (inches)	Minnequa clay (percentage of solubles salts	Otero clay loam (percentage of soluble salts)	Minnequa clay loam (percentage of soluble salts)
0 to 6	3.00	0.29	0.22
6 to 12	1.10	.37	.41
12 to 18	.57	.47	.88
18 to 24	.49	.64	1.04
24 to 30	.38	.53	1.08
30 to 36	.30	.47	1.18
36 to 42	.29	.39	1.38
42 to 48	.28	.35	1.46
48 to 54	.28	.34	1.94
54 to 60	.28	.34	2.29

Minnequa clay represents all undrained areas in which the water table has for a long time been near the surface. In it the principal accumulation of alkali is in the surface 6-inch layer, and the percentage decreases downward to the present water table, which in this sample was at 42 inches. No cultivated crop can grow on this soil in its present condition. Otero clay loam represents all drained areas in which the water table has been lowered. Two years before the determination was made this was a seeped area on which crops would not grow. At the time of the test the principal concentration of alkali, instead of being at the surface, was between depths of 18 and 24 inches and the soil sustained a growth of alfalfa. The problem is to manage the water and soil so that the alkali will remain as low as that or go deeper. Minnequa clay loam represents areas in which the shaly substratum contains alkali in considerable quantities and in which the heaviest concentration is between depths of 54 and 60 inches. Crops can be grown on soils of this kind so long as the alkali remains deep in the subsoil. A rise of the water table, however, would quickly bring the salts to the surface.

In order to determine the changes in alkali movement in soils of different kinds which have recently been drained determinations were made and records kept in 12 districts. Beginning May 10 and at approximately 30-day intervals to September 10, tests were made to a depth of 5 feet at the same point in each district. The results of these tests are rather striking and would have been more so had not the sampling of May 10 immediately followed rather heavy spring rains which lowered the surface accumulation of salts. Results of these readings at two points are given in Tables 5 and 6.

TABLE 5.—*Fluctuations in the percentage of soluble salts in recently drained Las Animas clay loam, May 10 to September 10, 1926* [1]

Depth at which sample was taken (inches)	Percentage of soluble salts on—				
	May 10	June 10	July 10	Aug. 10	Sept. 10
0 to 6	0.44	0.37	0.25	0.21	0.23
6 to 12	.65	.47	.35	.31	.33
12 to 18	[2] **.74**	.49	.39	.44	.38
18 to 24	.58	.50	.41	.52	**.40**
24 to 30	.47	.45	**.46**	.52	.39
30 to 36	.39	**.55**	.40	**.69**	.37
36 to 42	.38	.49	.39	.65	.34
42 to 48	.29	.51	.34	.47	.26
48 to 54	.28	.51	.28	.35	.21
54 to 60	.27	.51	.20	.20	.20

[1] Salt-grass pasture northwest of Holly. Drainage installed in the fall of 1925. Soil plowed and planted to corn in the spring of 1926; some irrigation. Test 50 feet from main drainage ditch.
[2] Bold-faced figures indicate location of zone of maximum accumulation.

Table 5 shows that the point of maximum concentration dropped from the 12 to 18 inch layer in May to the 30 to 36 inch layer in June, that it was slightly higher in July, that it was lower in August, and that it was higher again in September. The danger point, 0.4 per cent concentration, shifted from the surface layer in May to the second layer in June, to the fourth in July, to the third in August, and to the fourth in September.

TABLE 6.—*Fluctuations in percentage of soluble salts in recently drained Otero clay loam planted to sugar beets* [1]

Depth at which sample was taken (inches)	Percentage of soluble salts on—				
	May 10	June 10	July 10	Aug. 10	Sept. 10
0 to 6	0.29	0.20	0.31	0.20	0.20
6 to 12	.40	.42	.37	.24	.44
12 to 18	.64	.52	.44	.45	.79
18 to 24	**.78**	.69	.52	.57	**.81**
24 to 30	.78	.70	.56	.67	.70
30 to 36	.64	.81	.61	.74	.53
36 to 42	.47	**.97**	**.71**	**.77**	.57
42 to 48	.35	.77	.61	.77	.58
48 to 54	.33	.65	.56	.67	.68
54 to 60	.28	.56	.52	.58	.65

[1] Near drainage ditch three-fourths mile west of Crowley. Bold-faced figures indicate zone of maximum concentration.

Near Crowley the point of equilibrium in May was in the fourth or fifth layer. In June it had dropped to the seventh layer, but in September it was again in the fourth layer. The point of 0.4 per cent concentration dropped from the second layer in May and June to the third layer in July and August and went back to the second layer in September.

The most striking point brought out by this study was the extent and rapidity of the fluctuation of alkali. The work was done with considerable care, possible sources of error were avoided as far as possible, and the results as a whole were found to be consistent with soil conditions. During June, July, and August, when crops were being irrigated, the movement of alkali was downward. During

September, when the soil was allowed to dry out, the movement was upward. Movement downward was more marked in soils of medium and light texture than in those of heavy texture and in cultivated and irrigated land than in uncultivated and pasture land.

INFLUENCE OF ALKALI ON THE QUALITY OF CROPS

As sugar beets are rather resistant to alkali, soils in which there is a heavy concentration are used extensively for this crop. Beets grown on such land, however, are low in purity. Probably for this reason beets grown in the Lamar district have a slightly lower sugar content and give a lower sugar yield to the acre than those grown in either the Las Animas or Rocky Ford districts, where a larger percentage of the beets is grown on alkali-free soils. The lower yield in the Lamar district may also be caused by the warmer, drier weather prevailing in the lower part of the valley.

The statement is frequently made that the cantaloupes produced now are not so good as those formerly grown in the valley. If this is true it may be the result of growing some of them on strongly alkali land. In this case the sugar content, as in sugar beets, would probably be lowered. Most of the cantaloupes, however, are grown on land comparatively free from alkali, and if there has been deterioration in flavor it has probably come through breeding for shipping qualities and appearance rather than for flavor.

SOIL NITRATES

In the greater part of the humid regions of the United States the plant food most needed and for which enormous expenditures are made is nitrogen. Without nitrogen plants can not grow. In the Arkansas Valley there appears to be an abundance of nitrogen supplied, it is believed, through bacterial activity. Because of this large supply of nitrogen, large yields of corn and other crops are obtained. Extensive studies have been made by the State Agricultural College of Colorado to determine to what extent nitrates in excessive quantities may become harmful. Soil survey work does not throw any light on this phase of the subject, but a check of results obtained by the director of the nitrate laboratory at Rocky Ford shows a close relation between soil nitrates and soil texture. Samples taken from soils of heavy texture in all cases are richer in nitrates than samples taken from soils of light texture.

Recommendations made by the department of agronomy of the State Agricultural College of Colorado are crop rotation, in which tilled crops alternate with untilled crops; the plowing under of green manure, especially sweet clover; the use of barnyard manures; and on lands rich in nitrates, a top-dressing of straw or an application of superphosphate (acid phosphate). These methods, because they improve the soil structure, increase its moisture-holding capacity, diminish the injury from surface crusting, and lower the toxicity of alkali, are most fully indorsed.

FERTILIZERS

Experiments in the use of commercial fertilizers have been carried on for some time in the Arkansas Valley by the Division of Soil

Fertility Investigations of the United States Department of Agriculture. Results obtained indicate that on certain soils and under certain seasonal conditions fertilizers rich in phosphates can be used with profit on sugar beets and probably on other crops. Soils of the valley are well supplied with plant food, but in many cases the foods are not properly balanced. The use of commercial fertilizers adjusted to the soil types should assist in obtaining this balance.

CROP ROTATIONS

The purpose of crop rotation is to get a well-balanced relation between cultivated and uncultivated crops, between crops that are shallow rooted and those which root deeply, and between leguminous and nonleguminous crops. Well-balanced rotations are necessary for the maintenance of soil productivity.

The following rotations, based on a long series of observations and experiments, are recommended by the research department of the American Beet Sugar Co. and are believed to be applicable not only to the soils of the Rocky Ford series but also to those of the Prowers and Otero series, and, with certain modifications, to other soils in the valley. Rotations for farms sufficiently large to allow the use of alfalfa are as follows: (1) A 5-year rotation consisting of alfalfa, 2 years; corn, 1 year; sugar beets, 1 year; small grain and alfalfa, 1 year. (2) A 7-year rotation consisting of alfalfa, 3 years; small grain, 1 year; sugar beets, 1 year; miscellaneous crops, 1 year; and small grain seeded to alfalfa, the seventh year. For the farm not large enough to include alfalfa, a recommended rotation is small grain seeded to red clover, 1 year; red clover for seed, 1 or 2 years; corn or vine crops, 1 year; sugar beets, 1 year; and small grains and red clover, 1 year. Vine crops thrive the first year after alfalfa is plowed under.

HUMAN ADJUSTMENT

In the Arkansas Valley, as in every other part of the United States, a better adjustment, not only of crops to soils but of men to soils, is needed. The prosperity of a community and of a State depends on the prosperity of the individual. His failure is a misfortune not only to himself but to the community and State. No man of small means should go into a region where he is not thoroughly acquainted with both soils and crops and immediately buy land for farming purposes. To do so is especially hazardous for the man who goes from a nonirrigated to an irrigated region. Here he meets new problems with which he is entirely unacquainted. Irrigated regions offer splendid opportunities, but the man who is to profit needs to study conditions first through actual farm experience for a year or more before buying his land.

Figure 1 shows a deserted farmstead. The soil is of excellent quality, but success was impossible because of lack of water. Figure 2 shows a farm abandoned on account of the rise of ground water and the accumulation of alkali. The soil is good, but is nearly worthless to the owner until a drainage district has been formed and the land reclaimed by cooperation of the owners. Figure 3 shows a crop of red clover, producing 12 bushels of seed to the acre, being harvested from land no better than that shown in Figures 1 and 2, but supplied with a fair quantity of water and free from alkali.

SOILS

To the casual observer the soils of this region as a whole look much alike. Light, sandy, or silty, slightly brownish gray soils predominate over uplands, along the benches, and in the stream valleys. These soon become dry and are blown by the prevailing strong winds. The farmer finds rather marked and important differences in the soils. He finds that some require much more water than others, that some are loose, mellow, and easy to cultivate, whereas others become hard and cloddy and can be pulverized only under the right moisture conditions, and that some give better yields of one crop and others of another. The character of the subsoil is important not only on account of the deep rooting of plants which grow on it, but also because of its influence on irrigation, its water-holding capacity, and its influence in the development of seeped and

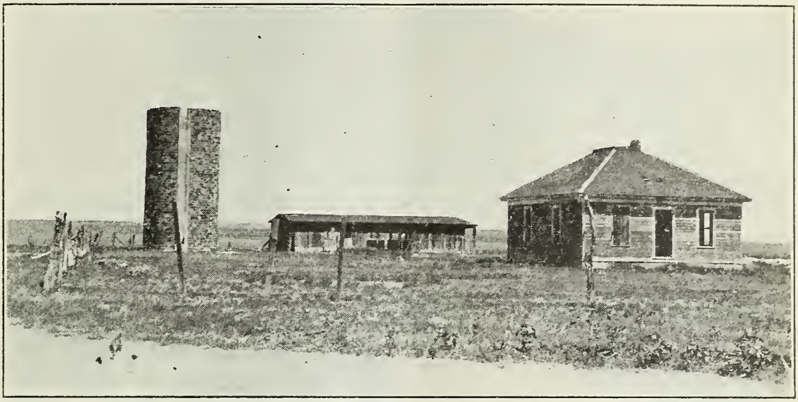

FIG. 1.—Good soil abandoned on account of lack of water

FIG. 2.—Good soil abandoned on account of an accumulation of alkali

alkali areas. Could the farmer who cultivates the surface soil see the subsoil also, many things would be more clearly understood.

In the soil survey of the Arkansas Valley the soils have been examined in several thousand places to a depth of 5 feet and where possible to a greater depth. The soil classification is based on subsoil as well as surface soil conditions.

PROWERS SOILS [1]

Covering the greater part of the uplands on the north side of Arkansas River from the Kansas State line westward to the vicinity of McClave is light-brown fine, silty, wind-blown soil material called loess. In thickness it ranges from 2 or 3 to about 10 feet. The surface is nearly level or gently undulating, with small, shallow valleys crossing it at right angles to the river valley.

The uncultivated soils have a thin, granular surface layer under which is a brown, mellow silty layer about 9 inches thick. Below this

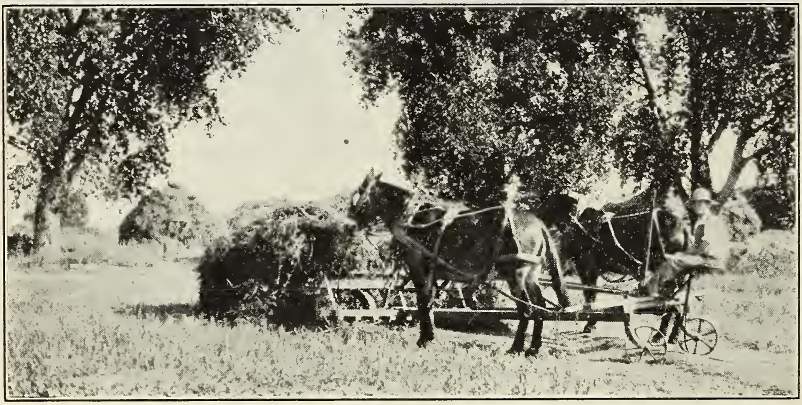

FIG. 3.—Good soil well supplied with water and free from alkali

the soil is light brown and uniform in color to a depth of 5 or more feet. Between depths of about 15 and 36 inches below the surface, the soil is heavier and white specks of lime are scattered through it. The deep subsoil is open, friable silt loam or clay loam.

On the slight ridges and better drained areas the soil is light loam or silt loam. Where the surface is more nearly level, as west of May Valley, the upper soil is darker and the subsoil is heavier and contains an abundance of lime spots. Such soil is clay loam. In the small valleys and poorly drained areas, the soil contains a little more organic matter and in places alkali has accumulated. The alkali makes the material slightly more sticky than the better drained soils. Such soil has been classed as a poorly drained phase of Prowers clay loam. The nearly level appearance of the country and three of the most important crops grown in the Arkansas Valley are shown in Figures 4, 5, and 6.

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[1] The location and extent of the Prowers soils, and of others described in this circular, are shown on a soil map of the Arkansas Valley area. Unpublished.

FORT LYONS SOILS

Extending from a short distance east of Fort Lyon station westward nearly to La Junta is a gradual valley slope. On the more level

Fig. 4.—Alfalfa growing on Prowers loam

part of this slope the soils are brown or slightly reddish brown and have mixed through them enough coarse sand and small, sharp gravel to make them feel rough when handled. The texture is heavy loam or clay loam. Below an average depth of about 15 inches is distinctly reddish brown rough clay loam which continues to a depth

Fig. 5.—Sugar beets on Las Animas silty clay loam near Lamar

of about 20 inches. In its lower part are many white spots of lime. Below this is a thick light-gray or nearly white layer very rich in lime. This is from 15 to 24 inches thick and is underlain by yellowish sandy and gravelly material. This clay loam is well drained, owing largely to its sloping position, and is highly productive. Northward toward the higher land it is not so deep and is underlain, at a depth varying from 3 to 5 feet, by shale. These soils have been called the Fort Lyons soils.

From McClave eastward a loam soil has been partly covered by the thick surface deposit of loess from which the Prowers soils were derived, but on the steeper slopes bordering the small streams it has been partly uncovered and in places stretches as narrow belts at both sides of the small stream valley. Here the heavy subsoil layer checks underground movement of water, and seeped areas develop in places on the slopes. From McClave westward to Kreybill is a nearly level region in which fragments of shale are mixed in the surface soil. This soil is deep and the reddish-brown layer of the subsoil is very thin or is not present. Near Wiley and in several

FIG. 6.—Corn growing on Apishipa silty clay loam

places farther east areas of light loam or fine sandy loam extend along the slopes of the small valleys.

OTERO SOILS

The Otero soils are brown or reddish brown, slightly rough, and have a thin, finely granular, slightly crusted layer over the surface. Below this and continuing to a depth of about 12 inches below the surface is a loamy layer containing a few white spots of lime in the lower part. Below this the subsoil, which continues to a depth of 30 or 36 inches, is heavier and contains an abundance of lime spots. The deep subsoil is light-brown or yellowish-brown sandy clay.

Soils of this group differ from the Prowers soils in having a more reddish-brown color and in having a subsoil with more lime occurring in well-defined spots. They differ from the Fort Lyons soils in not having the highly developed layer of lime accumulation.

These soils cover much of the upland from Horse Creek westward to Pueblo. They predominate around Cheraw, Crowley, along Patterson Hollow, southwest of Fowler, and in many other parts of the nearly level uplands. Sand and sandy loam usually cover the higher and clay loam the lower areas. In places the soil of poorly drained areas, like those southeast of Olney Springs south of Cheraw and in Patterson Hollow, has accumulated alkali until it is very sticky. The texture is little heavier than in other low areas which do not seem so heavy. Sticky areas have been indicated on the soil map as a poorly drained phase of Otero clay loam. Figures 7, 8, and 9 show some of the important crops on the Otero soils.

ROCKY FORD SOILS

From a point a short distance east of Swink and extending along the south side of the river beyond the city park at Pueblo is a series of old river terraces or benches. A similar but higher terrace, known as Lincoln Park, extends along the south side of the river at Canon City. On these terraces the Rocky Ford soils have developed

FIG. 7.—Sugar beets on Otero clay loam near Cheraw

from old alluvial material. These soils are dark grayish brown to a depth of about 10 inches. Between depths of 10 inches and 5 or more feet the material is lighter brown. The subsoil, between depths of 18 and 30 inches, is heavier in texture and contains some lime spots, but these are not so abundant as in the Otero soils. The deep subsoil is light silt or fine sandy loam, underlain at varying depths by a substratum of sand and stream gravel. This coarse stream gravel underlies all of the river terraces except those near the foot of the hill slopes where the terrace extends over shale.

The lighest textured soil, commonly fine sandy loam containing some stream gravel, occupies the river side of the terraces and heavier soils lie on the side adjacent to the hill slopes. The soil of the larger part of the Rocky Ford terraces, extending from near Swink to Fowler, and that of the Avondale terrace is light, fine-textured loam or silt loam. The St. Charles terrace is occupied principally by fine sandy loam. The heavier and less well drained parts of these terraces are for the most part light clay loam. Their heavy texture results from the heaviness of the substratum where the terrace extends over the lower slope of shale material. Lincoln Park terrace consists largely of fine sandy loam. Along the highway between Las Animas and Fort Lyons is a strip of Rocky Ford silty

FIG. 8.—Cantaloupes on Otero clay loam near Holbrook Lake

clay loam. Figures 10, 11, 12, 13, and 14 show some of the special crops grown largely on the Rocky Ford soils.

In the preceding groups, composed of soils having completely developed layers, it will be noted there are included the larger part of the highly productive soils of the valley. The large crops of alfalfa, sugar beets, and wheat in Prowers County are grown principally on

FIG. 9.—String beans on Otero clay loam near Crowley

the Prowers soils. Alfalfa, sugar beets, and melons in Crowley County are grown largely on the Otero soils. Alfalfa, sugar beets, and special crops in Otero, Pueblo, and Fremont Counties are grown largely on the Rocky Ford soils.

MINNEQUA SOILS

The Minnequa soils are characterized by their light-brown or grayish-brown surface soils and yellowish-brown or yellow sticky subsoils underlain by soft, rotten shale. On the hill slopes south of Rocky Ford, surrounding the gravel-capped hills and extending to the uplands, is a slope phase of Minnequa clay loam. On the more

FIG. 10.—Bermuda onions on Rocky Ford loam near Rocky Ford

nearly level uplands to the south, on both sides of Timpas Creek and covering large areas in the Wilson country, deeper, more uniform clay loam predominates. In the higher parts of the Wilson country on all the low ridges and divides is a silt loam soil which is here weathered rather deeply and which approaches in crop value the silty soils of the Prowers series.

FIG. 11.—Cutting cantaloupes for seed on Rocky Ford loam

In many places in the lower parts of the valley there has developed on level, usually poorly drained areas, a very heavy type of soil from a somewhat similar parent material. This soil, which is extensive in the vicinity of Hasty, is in most places clay or heavy clay loam. It contains considerable alkali.

Between the highly productive silty soil of the Wilson country and the unproductive soil at Hasty there are many wide variations, but the deep substrata are similar.

ORDWAY SOILS

Around Ordway and Sugar City is a group of dark-brown or slightly olive brown soils of heavy texture which have come from the weathering of a highly gypsiferous shale. Near the canal north of Ordway this unweathered shale has a soil covering only 2 or 3 feet thick, but farther south the soil and rotten shale soil material are from 6 to 10 or more feet thick. In places near Lake Meredith, Bob Creek, and smaller streams this heavy soil material lies over a sandy substratum. There are two main types of the Ordway soils, a clay loam occupying the higher, better drained areas, and a clay occupying low strips and the large body of soils surrounding Lake Meredith.

FIG. 12.—Cabbage on Rocky Ford loam near Rocky Ford

BILLINGS SOILS

Along the north side of Arkansas River from near Olney Springs to Pueblo and in the small, open valley northeast of Canon City is dark-brown or slightly olive brown heavy soil, which has a wide distribution outside of the area covered by the soil survey. Similar soils have been recognized on the western slope of Colorado. These soils in this region consist of weathered Pierre shale and shale outwash. The principal type is clay.

PENROSE SOILS

On the high mesa west of Pueblo is a group of shallow soils very rich in lime. These soils have developed from the weathering of thin-bedded shaly limestone, are shallow, and contain an abundance of shaly fragments on the surface and scattered through the soil and subsoil. A small area around Penrose is under cultivation.

Soils of the preceding groups are characterized by more uneven relief, by less uniformity of texture and depth, and by having a heavy, nearly impervious substratum of partly decomposed rock material. This, for the most part, is shale, but in places the deep subsoil is soft, rotten sandstone and in other places harder shaly limestone.

On these soils moisture control is more difficult, injury from seeped areas and alkali spots is greater, and as a whole yields are somewhat lower than on the Prowers, Las Animas, Rocky Ford, or Otero soils.

FIG. 13.—Zinnias and balsam grown for seed on Rocky Ford clay loam at Rocky Ford

LAS ANIMAS SOILS

The soils of the Las Animas series, which have been deposited in the valley of Arkansas River, are brown or dark brown and are composed of alternating layers of clay, silt, sand, and gravel. There

FIG. 14.—Sweet peppers growing on Rocky Ford fine sandy loam near Canon City

is an open gravel substratum. The soil layers do not result from weathering, as in the Prowers and Otero soils, but from deposition. Where depositing river currents were swift, only sand and gravel were deposited. Where the overflow water was still or flowing quietly, clay and silt were deposited. During the process of building up these soils the river channel has swung many times across the flood plain, so that layers of different materials are deposited one above the other.

The heavier and most extensively farmed soils of this series are the clay, silty clay loam, and clay loam. These extend along the outer valley edge of the flood plain and contain alkali in varying quantities. In some places they are poorly drained, and in others, as along the south side of the valley near Melonfields, they extend over and are influenced by the underlying shale. The soils near the river are lighter brown in color, lighter in texture, and are so shallow that in many places they are practically nonagricultural.

LAUREL SOILS

From Pueblo westward to Canon City the predominating soils of the river valley are brown or dark brown and in places where the soil has been washed from the red sandstone are reddish brown. They are fine and loamy and contain considerable finely divided mica. The deep subsoil consists of the typical sand and stream gravel. The water table is rather high, but very little alkali is present. The fine sandy loam, loam, and silt loam members of the series occur, but the areas are small and on the soil map all have been indicated as fine sandy loam.

The Laurel soils are used extensively for the production of lettuce, celery, and other truck crops.

The soils of the Arkansas River valley or river flood plain have one common characteristic—an open gravelly substratum. In the lower areas the water table is maintained in this substratum at river level. In slightly higher areas it is often raised to the top of the gravelly substratum by seepage from the adjacent uplands. All soils of the valley have been divided into two groups. Those from Pueblo eastward are the Las Animas soils and those from Florence to Canon City are the Laurel soils.

MANVEL SOILS

The sediment carried by the small streams of the eastern part of the valley consists largely of silty and fine sandy material eroded from the adjacent loess-covered uplands. The surface soil is brown or dark grayish brown, and the subsoil is light brown. In the small valleys this soil in many places is from 6 to 10 or more feet thick and is very slightly stratified. Where it has been carried out into the Arkansas Valley flood plain it forms broad alluvial fans, thickest where the stream enters the main valley and thinnest where this soil is spread out over the soils deposited by the river. The silt loam, which occurs extensively at Manvel Farm, west of Granada, and the fine sandy loam, found at Amity, Holly, and some other places, are the members of this series mapped.

APISHIPA SOILS

In the valleys of Timpas Creek, Apishipa Creek, St. Charles River, and some of the smaller streams there is a brown or slightly olive brown heavy soil which has been eroded largely from shale hills.

It is slightly stratified with thin layers of sand and gravel but is uniformly heavy, the principal texture being silty clay loam. The soil contains considerable alkali and in many places supports a growth of chico or greasewood. Such soils have been called the Apishipa soils. In the valley of Huerfano River some included areas have a reddish-brown or purplish-brown color and are more loamy than the typical Apishipa soils.

CONCLUSION

The following conclusions are based on three years of careful and intensive study of the soils and subsoils of the Arkansas Valley. Much concern has been felt in this region because in a comparatively short time crop yields are believed to have declined and the quality of some crops to have deteriorated. The question may well be asked if soil studies in any way indicate the cause of these troubles. It is true that in places orchards have died and that in other sections soils have become water-logged and filled with alkali. In spots, the soils have become hard and refractory. This has resulted largely from the planting of orchards on soils unsuited to them, from their neglect after they have been planted, from attempts to cultivate low-grade lands, from attempts to grow crops with inadequate water supply, and from the installation of extensive irrigation systems without necessary provision for drainage. Evidence was not found that crops grown on the better grades of land give lower yields or poorer quality crops than they once did, and it seems extremely doubtful that this is true.

There are, however, serious problems to be solved. These are the rapid burning out of humus under existing climatic conditions, deflocculation of the soil grains through the loss of humus and the use of water containing alkali, decrease in the moisture capacity of the soil through bad structure brought about by overirrigation and cultivation when wet, development of seep and alkali areas, and the expenditure of labor and the use of water on soils of poor grade, which would yield much larger returns if applied to available soils of higher grade.

The solution of all these problems, with the exception of the last, is fairly well known. Soil can be brought back to its original vigor, tilth, and productivity by adding humus, by proper crop rotation, and by careful, judicious use of water. Seep and alkali areas can and are being reclaimed by adequate drainage, by keeping the moisture moving downward, and by growing crops. Much can be done to improve orchard conditions by planting the trees on the right kind of soil and keeping it in the right moisture condition. Crop adaptations and fertilizer requirements can and are being worked out.

The greatest need of the Arkansas Valley is better cooperation in carrying out community projects and a more complete application of principles already known. The pessimistic view has been expressed that in irrigated regions things may in time go from bad to worse and that man may eventually be compelled to give up the fight and see his farms revert to the wild state in which the white man found them.

Soil studies in the Arkansas Valley do not furnish a basis for such conclusions. Measured and plotted on a map, the proportion of first-class land is found to be high. The climate is good, and the available water, if conserved and carefully applied, will irrigate a large, highly productive area. Crop adaptation is wide and cultural methods are good. So long as the climate remains constant and men produce their food from the soil so long, there is good reason to believe, will the Arkansas Valley remain fruitful.

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December 1, 1928

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