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WATER PENETRATION IN THE GUMBO SOILS OF THE BELLE FOURCHE RECLAMATION PROJECT.

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CONTENTS.

INTRODUCTION.

The readiness with which water penetrates into any soil determines to a great extent the amount that will be available to crops. An accurate knowledge of water movement within a soil often furnishes an indication of the farm practices that will be most successful. Thus under irrigation the rapidity of water percolation may determine in what way and at what time water may be most effectively applied. On dry land a knowledge of moisture movement often shows what results may be expected from different cultural methods calculated to increase the quantity of water entering the soil.

The gumbo soil of the Belle Fourche (S. Dak.) Reclamation Project offers problems in water penetration materially different from those in soils of other types. These differences are due largely to its peculiar physical characteristics.

This bulletin presents the results of certain studies of the penetration of water into the gumbo soils of the Belle Fourche project.

Knorr,[1] working on the sandy loam soils at Scottsbluff, Nebr., found that plats irrigated in the fall were more moist and moist to greater depths in the spring than plats not fall irrigated. When

[1] Knorr, Fritz. Experiments with crops under fall irrigation at the Scottsbluff Reclamation Project Experiment Farm. U. S. Dept. Agr. Bul. 133, 17 p., 5 fig. 1914.

irrigated during the following summer, the moist soil absorbed water much more readily than the dry soil. The dry soil required a longer flow of water to saturate it to a depth of 18 inches than did the soil containing more moisture. By irrigation, the water content of the moist soil was increased to a depth of 6 feet, while the dry soil showed no increase in water content below the second foot. Continuing the flow of water on the dry soil in order to get water into the lower depths was tried, but was discontinued for the reason that the dry soil absorbed the water so slowly that a large amount of the flow was lost by run-off.

The results obtained by Knorr on the sandy loam soils and those obtained from the experiments described in this paper on the gumbo soils are strikingly different. They bring out clearly the impracticability of trying to use the same methods on all soils. The character of the soil is an important factor in determining the degree of success of any method of water application.

DESCRIPTION OF THE GUMBO SOIL OF THE BELLE FOURCHE RECLAMATION PROJECT.

The soil of the Belle Fourche Reclamation Project is a very heavy clay of the type classified by the Bureau of Soils as Pierre clay.[1]

The United States Bureau of Soils, in a reconnoissance soil survey of western South Dakota, found that the soils of this type covered about seven and three-quarter million acres in South Dakota, or about 30 per cent of the total area surveyed.[2] It is a residual soil, formed by the decomposition of shale, the partly decomposed shale being found at a depth of approximately 4 feet below the surface. This depth varies considerably with the location.

Fine soil particles make up the greater portion of the soil. A mechanical analysis of the surface soil of this type shows that soil particles of the different sizes are present in the percentages shown in Table I.

TABLE I.—*Mechanical analysis of Pierre clay.*[a]

Soil.	Fine gravel.	Coarse sand.	Medium sand.	Fine sand.	Very fine sand.	Silt.	Clay.
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Pierre clay	0.2	1.1	1.4	5.5	13.0	43.2	35.0

[a] Strahorn, A. T., and Mann, C. W. Op. cit.

Analyses of the subsoil are not available, but the textures of the second foot and third foot indicate that the percentage of clay at

[1] Strahorn, A. T., and Mann, C. W. Soil survey of the Belle Fourche area, South Dakota. U. S. Dept. Agr., Bur. Soils [Adv. sheets—Field Oper., 1907], 31 p., 1 fig., 2 maps. 1908.

[2] Coffey, G. N., and others. Reconnoissance soil survey of western South Dakota. U. S. Dept. Agr., Bur. Soils [Adv. sheets—Field Oper., 1909], 80 p., 2 fig., 7 pl., 1 map. 1911.

these depths may be somewhat higher than in the first foot. The difference is not great, and as a whole the mechanical composition of the first 3 feet may be considered uniform.

WATER CAPACITY OF THE GUMBO SOIL.

The water-carrying capacity of this soil is high, and the minimum point to which crops can utilize the water is correspondingly high. The soil, when filled, will carry about 30 per cent of water, of which about 15 per cent is available for the use of crops. The character of the soil is such, however, that the crops do not root deeply, owing either to the lack of water in the lower depths or to the impervious nature of the soil. In spite, therefore, of the large quantity of water that can be obtained by the crop from the soil near the surface, the shallowness of feeding materially reduces the quantity of water actually available.

PRODUCTIVITY OF THE GUMBO SOIL.

The producing capacity of the soil is high. There is no evidence of a deficiency of any mineral element essential to crop production. When sufficient water is supplied, abundant crops are obtained. The high productive capacity of this soil is evidenced by the yields obtained on plats not irrigated in 1915, when the rainfall was unusually favorable both in amount and in distribution. The average acre yields obtained were 72.2 bushels of barley, 36.2 bushels of winter wheat, 57.6 bushels of spring wheat, 125.6 bushels of oats, and 44.5 bushels of corn.

CHANGES IN THE VOLUME OF THE SOIL DUE TO WETTING AND DRYING.

The large amount of clay present makes this soil subject to extreme changes in volume with changes in its water content. When the soil is wet it swells and compacts; when dried it shrinks and cracks. That the change in volume is great enough to cause a material change in physical structure is shown by the results of the following experiment, which was made for the purpose of obtaining a measure of this change.

The volume of oven-dried compact samples of soil was determined. These samples were then immersed in water and allowed to expand freely and the volume redetermined. The volume of the soil from the first foot increased 2.2 times. The volume of that from both the second and third feet increased 2.5 times.

These changes in volume, due to variations in moisture content, result in the following structural differences:

When dry this soil is usually covered with a natural mulch about 2 inches deep caused by the crumbling of the surface soil. Beneath this mulch is a layer of soil honeycombed with cracks. The number of these cracks and the depth to which they extend depend somewhat upon the manner in which the soil has been dried. Where a close-drilled crop has been grown, they are small and numerous and break the soil into small lumps to a depth of about 15 inches. Below this depth the soil is generally compact and practically free from cracks, no matter how dry it may be.

When the soil becomes wet it expands, and thus the cracks are closed. When any excess of the expanding force in the cracked layer occurs, the whole force of expansion in the uncracked area has the effect of crowding the soil particles closer together. For this reason the wet soil is always compact throughout and free from open spaces.

Considering these structural differences between the wet and the dry soil, it can readily be seen that the moisture content of the soil may have a great influence upon water movement; but a study of water movement in both the wet and the dry soil is necessary in order to obtain information as to how water penetration takes place under actual field conditions.

On the Belle Fourche project it has been found in field practice that the water content of the surface soil at the time the water is applied determines to a great extent the quantity that will be absorbed, especially when the water is applied rapidly. When both the surface soil and the subsoil are dry, over an inch of rain, even if it comes in a torrential manner, will be absorbed with very little loss, because much of the water makes its way into the soil through the cracks. On the other hand, when the surface soil is wet these cracks are closed and a rain of as little as one-fourth of an inch may be largely lost by run-off. Any rain falling on a wet surface must fall very slowly in order to be absorbed.

That the condition of the surface soil determines the amount of water absorbed is especially true when irrigation water is applied. A comparatively small rain, by wetting the surface and causing the cracks to close, often stops irrigation. There are times when it is possible to irrigate successfully in the afternoon, when an attempt to irrigate during the forenoon of the same day has resulted in the run-off of practically all the water applied.

These facts indicate that water movement through this soil when wet is very slow.

RATE OF MOVEMENT OF WATER IN LOOSE, SATURATED SOIL.

In order to make actual determinations of the rate at which water moves in this soil when it is saturated, the following experiment was performed:

Sections of blotting paper were fitted, as bottoms, into a number of cans that were open at both ends. Each can was filled with a composite sample of a foot section of soil and then immersed in water. After the soil had become thoroughly saturated the cans were removed from the water and placed upon a screen. All the soil was then removed except a 3-inch layer in the bottom of each can.

The time taken for an inch of water to pass through these 3-inch layers of saturated soil was four hours for the first-foot sample and 12 hours for the second-foot sample. These results show that water moves slowly in the saturated soil. The rate of movement in these samples is not the same as that under field conditions, because in the field the soil is confined and can not swell freely and is therefore more compact than the soil in these cans.

RATE OF MOVEMENT OF WATER IN WET SOIL UNDER FIELD CONDITIONS.

To determine at what rate water moves in the wet soil under field conditions, the following experiment was performed on a plat that had been fallow for several seasons. The soil in this plat was wet

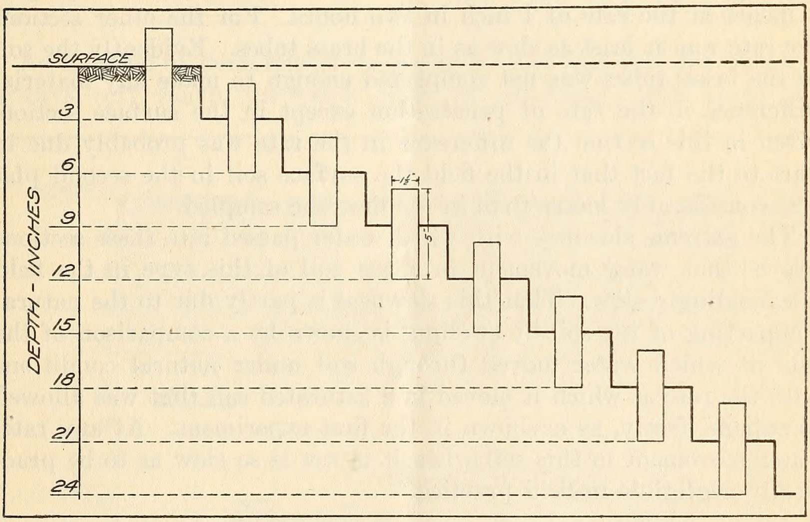

Fig. 1.—Diagram showing the method used to obtain samples of undisturbed soil from different depths by means of brass tubes.

and compact to a depth of over 3 feet. Samples were taken by means of brass tubes 1½ inches in diameter and 5 inches long, in the manner shown in figure 1.

Each of these tubes when removed was found to contain between 2 and 2½ inches of soil. After being removed, the tubes were immersed in water in order that they might become thoroughly moistened. They were then placed in an upright position on a blotter and filled with water. The rapidity with which water passed into the soil was then recorded. In the tubes containing the soils from the surface, water passed into the soil at the rate of about 1 inch in 12 hours. In all the others the rate was uniformly much slower. No differences in the rapidity of water movement were shown between any of the samples taken at any of the various depths below

3 inches. In all of the tubes containing soil taken from below the first 3 inches the water level fell less than one-eighth of an inch in 48 hours, and part of this was due to evaporation.

The smallness of the tubes used may have caused some compacting during the process of sampling; also the plat sampled was undoubtedly more compact than one that had not been continuously fallowed. For this reason a part of the experiment was duplicated on land that had been fallow for only a few months. Samples were taken with tin cans 5 inches in diameter and with thin cutting edges. By this means samples were taken from the surface and from depths of 3 and 6 inches without any mechanical compacting of the soil in sampling. The penetration in these cans was then studied in the same way as in the brass tubes. Water passed through the surface 3 inches at the rate of 1 inch in two hours. For the other sections the rate was at least as slow as in the brass tubes. Evidently the soil in the brass tubes was not compacted enough to make any material difference in the rate of penetration except in the surface section. Even in this section the difference in the rate was probably due in part to the fact that in the field the surface soil in the second plat was considerably looser than in the first one sampled.

The extreme slowness with which water passed into these sections proves that water movement in a wet soil of this type in the field is exceedingly slow. That this slowness is partly due to the natural compacting of the soil by swelling is shown by a comparison of the rate at which water moved through soil under natural conditions with the rate at which it moved in a saturated soil that was allowed to expand freely, as is shown in the first experiment. At any rate, water movement in this soil when it is wet is so slow as to be practically negligible in field practice.

PENETRATION OF WATER INTO DRY SOIL IN THE FIELD.

The experiments already described indicated that in this type of soil a dry condition was most favorable for water movement. In order to measure the maximum water penetration in the soil, a number of experiments were made on a plat that was extremely dry. The plat was covered with a very thin dust mulch. Beneath the mulch the soil was cracked into very small lumps to a depth of 15 inches; below 15 inches it was very hard, dry, and compact.

The first experiment in this series was made for the purpose of determining the permeability of the soil at various depths. For this purpose, borings 8 inches in diameter, extending below the surface to depths of 6, 9, 12, 15, 18, 21, and 24 inches, were made. Two gallons of water was then poured into each hole. A like quantity of water was applied to an equal area at the surface by means of a tin can set 1 inch into the soil.

The time required for the water to disappear from each hole and the depth to which it penetrated, as measured both from the bottom of the hole and from the surface of the ground, is shown in Table II.

TABLE II.—*Time required for 2 gallons of water to disappear from 8-inch holes bored to different depths in the soil and the depth to which the water penetrated.*

Specification.	Hole No.							
	1	2	3	4	5	6	7	8
Depth of hole .... inches..	Surface.	6	9	12	15	18	21	24
Time required:								
Minutes	4	36	39	100	....	....	....	....
Hours	....	....	....	....	18	23	30	24
Depth of soil penetrated.... inches..	16	19	16	10	6	4½	5	6
Depth below surface to which water penetrated .... inches..	16	25	25	22	21	22½	26	30

As the line of demarcation between the wet and the dry soil was always very sharp, the exact depth of penetration was easily de-

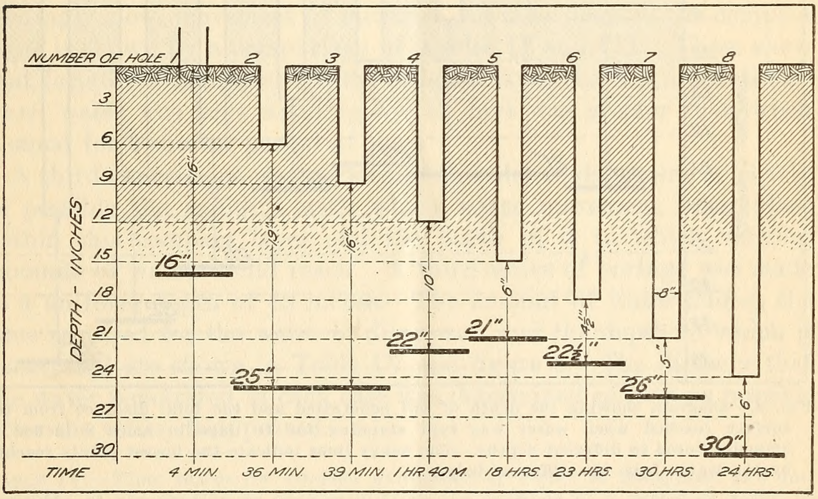

FIG. 2.—Diagram showing the time required for 2 gallons of water to disappear from holes 8 inches in diameter bored to different depths in the soil and showing also the depths to which it penetrated. The heavy lines indicate the lowest points reached by the water from the different holes. The heavy figures below each hole indicate the total distance from the surface and the light figures the distance below the bottom of the hole.

termined. The plan of the experiment and the results are shown graphically in figure 2.

A study of Table II and figure 2 shows that, at least for the cracked area, the time required for the water to disappear depended upon the distance from the surface of the point of application. No doubt, this was because the water applied near the surface escaped through cracks in the soil. That this was the case is shown by the wide differences between the cracked and uncracked layers as to the time required for the water to disappear. In all parts of the uncracked area water disappeared very slowly.

Water penetrated to practically the same depth from the surface in all the holes except the first and the last. In all the holes except the first, water evidently penetrated to a point where further movement took place with difficulty. That the water applied at the surface did not reach the depth where movement was difficult was doubtless due to the fact that the quantity of water was not sufficient to reach that depth. The fact that the water from most of the holes penetrated to a depth of from 21 to 25 inches below the surface would indicate that a layer of impervious soil exists at that depth

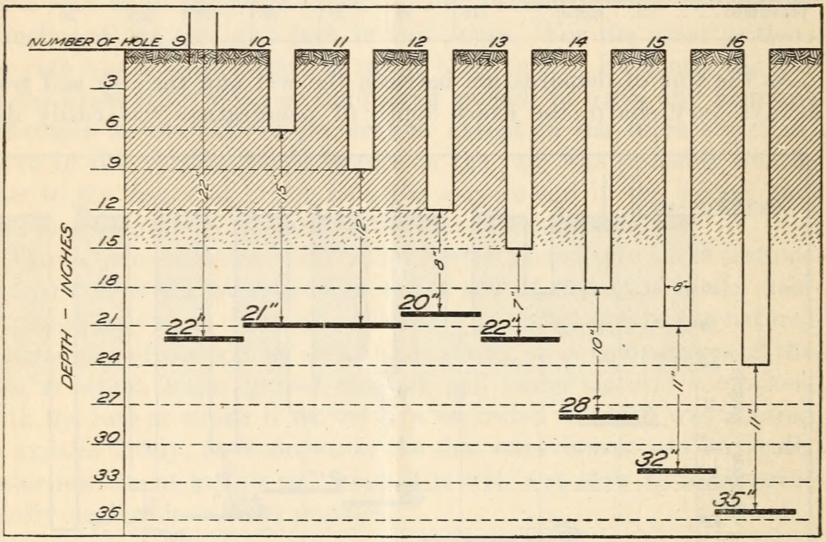

Fig. 3.—Diagram showing the depth of soil penetrated and the total distance from the surface reached when water was kept standing for 10 days in holes 8 inches in diameter bored to different depths. The heavy lines indicate the lowest points reached by the water from the different holes.

were it not for the fact that water added at about this depth penetrated through as many inches of soil as did that introduced 9 inches higher. The depth to which the water penetrated in all holes in the compact layer indicates that the water movement throughout this portion of the soil was very uniform.

A second experiment was made to determine the distance to which water introduced into the soil at various depths would penetrate in a given length of time. For this purpose a set of borings duplicating those in the previous experiment was made, and water was kept standing in each of them for a period of 10 days. At the end of that time the depth to which the water had penetrated was measured. The results of this experiment are shown in Table III and figure 3.

TABLE III.—*Depth of soil penetrated and total distance from the surface reached where water was kept standing for 10 days in holes 8 inches in diameter bored to different depths.*

Specification.	Hole No.							
	9	10	11	12	13	14	15	16
Depth of hole.................inches..	Surface.	6	9	12	15	18	21	24
Depth of soil penetrated......do....	22	15	12	8	7	10	11	11
Depth below surface to which water penetrated...............inches..	22	21	21	20	22	28	32	35

Water added at all points within the cracked area penetrated almost exactly the same distance. In each case it penetrated through the cracked soil and about 7 inches into the compact soil beneath. Where water was applied below the cracked area the total distance reached by water penetration varied with the depth below the surface at which the water was applied. The distance that it penetrated into the compact soil was quite uniform. That a constant, though exceedingly slow, movement of moisture did take place in the compact layer is shown by a comparison of Tables II and III. These show that for all the points within the compact layer the depth penetrated when water was kept standing for 10 days was greater than when it stood for a shorter period of time.

A third experiment was performed in order to determine as nearly as possible the rapidity with which water movement takes place within this compact layer and the depth in it to which varying amounts of water would reach. A third series of borings was made to a uniform depth of 18 inches. The amount of water added, the time required for the water to disappear, and the depth to which it penetrated are shown in Table IV and figure 4. The distance that the water penetrated in each case was determined as soon as possible after the water disappeared.

TABLE IV.—*Time taken for various quantities of water to disappear and the depths of penetration in each case from the bottoms of a series of holes 18 inches deep.*

Specification.	Hole No.							
	17	18	19	20	21	22	23	24
Water added:								
Quarts..............................	1	2	....	....	....	....	....	....
Gallons.............................	....	....	1	1	2	2	4	[a] 2
Time required to disappear:								
Hours...............................	....	3	5	32	48	57	43	....
Minutes.............................	5	10	40	40	30	30	....	....
Days................................	....	....	....	....	....	....	....	10
Depth of penetration below the bottom of the hole............inches..	5	6	3	5	5½	5½	5	6½
Depth of penetration below the surface.......................inches..	23	24	21	23	23½	23½	23	24½

[a] Three times.

The smaller quantities of water penetrated practically as deep as the larger amounts that stood for a much longer time. In five minutes the water in hole No. 17 penetrated to a depth as great as was reached by that in some of the others in several days.

There is an apparent lack of consistency in the time required for some of the larger quantities of water to disappear. This is due to the fact that in some cases the amount of water added was sufficient to raise the water level to a point that allowed it to escape laterally through the cracked soil. This is shown also by the lack of difference in the depth of penetration of the different quantities. The best measure of time and depth of penetration is found in hole No. 24, in which a supply of water was maintained by the addition of 2 gallons at three separate times. Ten days were required for the

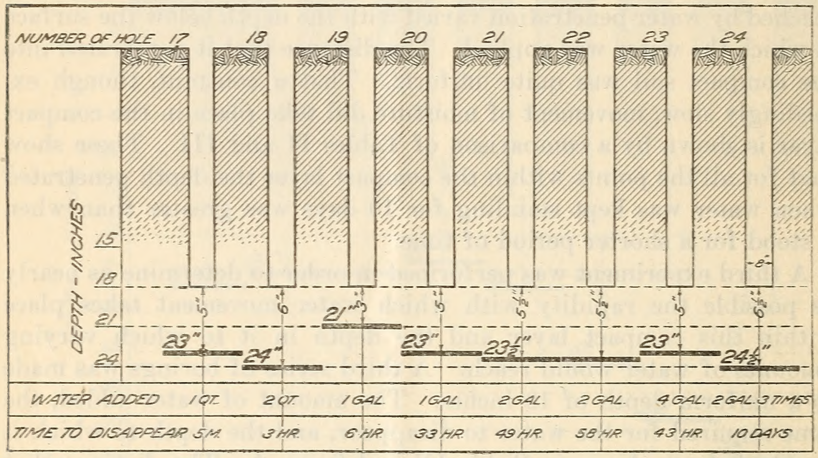

Fig. 4.—Diagram showing the time taken for various quantities of water to disappear and the depth of penetration in each case from the bottoms of a series of holes 8 inches in diameter and 18 inches deep. The heavy lines indicate the lowest points reached by the water from the different holes.

disappearance of the entire quantity, but the total depth of penetration during this time was only a little over an inch more than it was from those holes in which water stood for a much less time. These experiments indicate that while the water movement is comparatively rapid in the dry soil it is very slow in the wet soil.

Since there is no evidence of a layer of soil actually impervious to water, it appears that the exceedingly slow movement of water is due to the fact that the soil in contact with the water quickly becomes so swollen and compact that further movement of water within it is very difficult. Penetration into the dry soil almost stops, not because of the resistance offered by the dry soil itself, but on account of the extremely slow movement of the water through the layer of wet soil that is between the source of water supply and the dry soil.

That this slow movement in the dry subsoil is due to the compacting of the wet soil above is further shown by laboratory experiments on dry soil under field conditions. It was found that where the soil was allowed to swell freely the water would move at least an inch in five minutes in the heaviest section of the soil. Since the rate of movement under field conditions is so much slower, there is no doubt that the compacting of the wet soil in the field is so great that it renders any movement of water through it almost impossible. Water movement in the dry subsoil is therefore limited by the rapidity with which the water can make its way through the wet soil above.

SUMMARY.

Water movement in the gumbo soils of the Belle Fourche Reclamation Project may be summed up as follows:

On a dry soil, penetration takes places rapidly to a depth of about 2 feet because of the cracked condition of the soil near the surface. After the layer of easily penetrated soil becomes wet, it becomes so swollen and compact that it is nearly impervious, and further water movement is very slow.

The fact that moisture can move only very slowly in the wet surface soil would make it necessary to run water over the soil for a very long time in order that any considerable portion might be absorbed. This is not practicable, for the experiment with a dry subsoil showed that water from the surface penetrated almost as deep in a few minutes as it did in 10 days, so that the increase in the amount of moisture absorbed where the water stands for any considerable length of time over that taken in when the soil is simply covered would be so small as to be negligible. After a field has once been covered with water little benefit can result from having water continue to stand on or flow over the soil.

It is interesting to note the radical difference in water absorption between this soil and the sandy loam soil at Scottsbluff. The maximum rate of absorption is obtained on the wet soil at Scottsbluff and on the dry soil on the Belle Fourche project. These diametric differences apparently are due to the physical differences between the two soils and show clearly that a satisfactory practice on one type of soil may not be equally successful under other soil conditions.

The results of these experiments and observations can easily be applied in field practice, and recommendations for methods and practices may be based upon them.

The following points relative to the application of water by irrigation to these gumbo soils are clearly shown:

(1) Water should be applied only when the surface is dry.

(2) The quantity of water absorbed will depend upon the dryness and consequent cracked condition of the surface soil.

(3) After a field has once been covered with water, little further absorption takes place, and no benefit can result from having water stand on or flow over the soil for more than a few minutes.

(4) The depth to which the water will penetrate depends upon the depth to which the soil has been dried and cracked.

The following points brought out in this bulletin apply to the cultural practices for these gumbo soils under either irrigation or dry-land conditions:

(1) No particular method of cultivation will be superior to others in influencing the quantity of water absorbed, since this depends upon the degree to which the surface soil is dried and cracked. The soil after harvest is usually so dry that penetration takes place very readily, and any ordinary quantity of rain that falls is absorbed, regardless of the cultural treatment.

(2) Since the dry soil is naturally broken up to depths as great as would be reached by either deep plowing or subsoiling, these operations can be of no great benefit in water absorption.

(3) Some method, such as dynamiting, by which the soil below the cracked area could be broken up, might result in a temporary increase in the depth to which water could easily penetrate. The natural swelling of the soil, however, would cause it again to become compact every time it was wet. This would make it necessary for the operation to be repeated each year, which would involve an expense too great for this method ever to be considered seriously.

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