THE SOIL MULCH IN THE ABSORPTION AND RETENTION OF MOISTURE

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INTRODUCTION

Without irrigation successful crop production over a large part of the western United States is dependent upon moisture stored in the soil. In part, this is due to limitations in total precipitation, to its seasonal distribution, or to a combination of the two; but, in any case, the factors affecting the control of soil moisture are of greatest practical importance.

At one time the soil mulch was assumed to be the basis of all moisture control. It was regarded as essential, both in effective absorption and in retention. More recently, however, the mulch and its necessity seem matters of doubt, and while no one advocates the discontinuance of mulch-forming tillage, former ideas at least appear to be considered untenable. In discarding former theories, however, no general principle has been developed in its stead, and so far as more than local application is concerned, the situation is somewhat hazy. As indicative of the present somewhat contradictory state of affairs, the following may be noted:

REVIEW OF LITERATURE

Barker (4) found that at Lincoln, Neb., the loss of water due to direct evaporation from the soil was a small factor after the water became thoroughly distributed in the soil. Young (36), for the same conditions, concluded that a loose soil mulch was not much more effective than an unmulched soil in retarding the evaporation of moisture already established in the soil. Burr (8), working at North Platte, Neb., when starting with a soil almost filled with water, and during a season of heavy rainfall, arrived at a conclusion similar to that of Young. For a less favorable season, and with a soil comparatively dry below the second foot, Burr states that "from the viewpoint of storing water a cultivated surface is essential."

Atkinson, Buckman, and Gieseker (3) show that summer tillage saved moisture in excess of that retained in a soil not tilled, but no direct statement is made that the benefit of the tillage was due either to the mulch effect or to killing weeds.

Call and Sewell (9), after a careful study of the moisture content of a mulched and an unmulched soil, conclude that under Kansas conditions a cultivated soil is no more effective than a bare uncultivated one in preventing evaporation; and in addition conclude (10) that "in the past too much emphasis may have been placed on tillage as a direct means of conserving moisture and liberating plant food and too little on it for the purpose of destroying weeds." After a rather extensive review of literature from a variety of sources, Sewell (22) emphasizes this latter conclusion.

Merrill (27) quotes Farrell as reporting certain experiments at Nephi, Utah, in which fall plowing did not give beneficial results in moisture conservation; but further quotes Widtsoe as concluding from other data that "fall plowing undoubtedly conserves the winter precipitation."

Cardon (11) shows that at Nephi, Utah, during each of the four years 1909 to 1912, inclusive, fall-plowed soil contained less moisture than that not plowed until spring.

Harris and Jones (16), reporting on the same and additional data as that of Cardon, show graphically a similar result. In addition, they show that in the fall an unmulched soil contained practically as much moisture as did a mulched one. They conclude that weed removal is the most marked benefit of tillage.
Harris and Yao (18) state that "moisture samples taken from the Nephi substation to a depth of six feet prove in every case that fall plowing preserves more moisture than spring plowing"; a statement rather difficult to understand in the light of the statements of Corden (17) and Harris and Jones (16).

Cates and Cox (12), basing their conclusions on data secured in studies at widely separated points over the entire United States, conclude that "for removal is the most important function of cultivation in handling the corn crop, and that the amount of moisture saved by such cultivation is negligible beyond a possible slight check on run-off.

Fawcett (13, 14) shows that mulching a soil after irrigation conserves moisture, and that the deeper the mulch up to 9 inches removed by plowing experiments, the more efficient the retention. At Wenatchee, Wash. (14), in a 21-day period during June, 1948, an unmulched soil lost 1.38 per cent, one with a 2-inch mulch, 1.35 per cent, one with a 4-inch mulch, 1.25 per cent, one with a 8-inch mulch, 1.20 per cent, and one with a 9-inch mulch, 1.00 per cent of the water applied in a 6-inch irrigation. Willard and Humbert (25) show a similar result.

Harris and Bracken (15), from data secured under irrigation, state that cultivation is slightly more efficient in saving moisture than is no cultivation with weeds removed by plowing. They state that a comparison of deeply cultivated plots with those given shallow cultivation or no cultivation shows the savings are of the total moisture content at the lower soil depths.

McCall and Holtz (19) show that soils mulched during the period when moisture absorption was most active contained less moisture at the end of the period that did other soils not mulched during the same absorption period. They conclude that the mulch probably aids in obtaining moisture already in the soil.

Mathews (20), in reporting on the storage of moisture and its utilization by spring wheat, states that, as an average for all stations in the Office of Dry-Land Agriculture Investigations, Bureau of Plant Industry, United States Department of Agriculture, there are no notable differences in the moisture content by two continuous cropped plots, the one being fall plowed and the other spring plowed. He notes that rainfall conditions that favor the first in the southern Great Plains, and the second, to the north, but that there are no consistent advantages in either case. Silt (12), in Canada, reports that a packed soil contained more moisture than one not packed. This indicates either superior absorption or superior retention on the part of the firmly packed soil, although which is the more likely hypothesis is not suggested by the author.

From the foregoing it is clear that all investigations have arrived at the same conclusion. It is equally clear that all are not measuring the mulch from the same point of view. In the conservation of natural precipitation the mulch must be considered both in its effect on absorption and its effect on retention. Where the mulch is measured solely as a retarding agent, as under irrigation, the evidence is unanimous that its effect is in saving moisture. In the conservation of the value of the mulch in relation to natural precipitation, where both considerations are present, the result is less clear and the advantages, if any, are slight, neutral, or negative.

INVESTIGATIONS

Soil-moisture problems are a very important part of the program of the Adams Branch Station of the Washington Agricultural Experiment Station at Linn, Wash. Production in the territory this station serves is based on the summer-fallow system of alternate years of crop and fallow. One of the objects of this study is to determine the amount of moisture and to carry it from one season to the next. As one of the factors affecting moisture conservation, the soil moisture has been studied during the six years 1918 to 1923, inclusive.

Under field conditions it is often difficult to differentiate between the two different relationships of the mulch. This is particularly true when the period of greatest precipitation is concurrent with that of greatest evaporation, as, for instance, in the Great Plains area. Climatic conditions on the Adams Station, however, meet the requirements for differentiation to a considerable degree. The distribution of rainfall, and the seasonal fluctuation of temperature and relative humidity (figs. 1, 2, and 3), divide the year into distinct periods, during any one of which either absorption or retention becomes most prominent. During the late fall, winter, and early spring, when a good proportion of all precipitation occurs, relative humidity is comparatively high and absorption is the most important consideration.

The soil moisture content at the beginning and end of each period should, therefore, be determined by reliable measuring of the effect of the mulch in whichever function is most important for that period.

The soil of the Adams Station is a very fine sandy loam of the Ritchville series. It is a typical semiarid soil, deep and uniform. The mechanical analysis of the soil by feet to a depth of 4 feet is given in Table 1.

**Table 1.** Mechanical analysis, by feet, to a depth of 5 feet of the soil on the Adams Branch Station, Linn, Wash. (19).

<table>
<thead>
<tr>
<th>Soil section</th>
<th>Fine gravel</th>
<th>Coarse sand</th>
<th>Medium sand</th>
<th>Fine sand</th>
<th>Very fine sand</th>
<th>Gravel and clay</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Per cent</td>
<td>Per cent</td>
<td>Per cent</td>
<td>Per cent</td>
<td>Per cent</td>
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<td>Per cent</td>
</tr>
<tr>
<td>First foot</td>
<td>0.00</td>
<td>6.73</td>
<td>9.82</td>
<td>6.68</td>
<td>40.76</td>
<td>45.98</td>
<td>100.00</td>
</tr>
<tr>
<td>Second foot</td>
<td>0.00</td>
<td>9.90</td>
<td>8.06</td>
<td>6.68</td>
<td>40.76</td>
<td>45.98</td>
<td>100.00</td>
</tr>
<tr>
<td>Third foot</td>
<td>0.00</td>
<td>11.84</td>
<td>8.06</td>
<td>6.68</td>
<td>40.76</td>
<td>45.98</td>
<td>100.00</td>
</tr>
<tr>
<td>Fourth foot</td>
<td>0.00</td>
<td>10.00</td>
<td>9.66</td>
<td>6.68</td>
<td>40.76</td>
<td>45.98</td>
<td>100.00</td>
</tr>
</tbody>
</table>
The study of the mulch was made on the plots of the summer-fallow experiments. There were two series of these plots, one series being in crop and one in fallow each year. The plots were one-twentieth of an acre in area, 1 rod wide by 8 rods long.

Samples for moisture determinations were taken by foot sections to a depth of 4 feet, this depth being sufficient during the period of somewhat deficient moisture covered by the study.

Methods of sampling and of determining soil moisture are given in detail in 164 of the Washington Agricultural Experiment Station (124). Data for moisture are given in acres-inches, rather than in per cent of moisture-free soil. The volume weight of the surface 6 inches of a plowed soil is materially different from that of the same soil in an undisturbed condition, and the same per cent moisture content does not signify the same amount of moisture present in the same effective depth in the two cases. In the soil on which this study was made the volume weight of the plowed layer is approximately 60 per cent of that before sowing. The volume weight of the surface foot of the layer is 80 per cent of that of the unwatered.

The essential difference between these variations lies in the presence or absence of a soil mulch during all or a part of the period of moisture absorption. Adams Branch Station, Linds, Wash., 1918 to 1921, inclusive.

The data indicate that on the average there was some saving of moisture through weed removal by fall-plowing. Despite this saving, however, the effect of absorption more than counterbalanced the gain from killing weeds, as shown by the average moisture content of the harvest disked and early spring plowing, when compared with spring plowing with no previous treatment. A comparison of harvest-disking and wet fall-plowing with wet fall-plowing alone shows the same effect, due to the same cause.

It might be suggested that the moisture advantage of the spring-plowed soil was due entirely to the holding of snow by stubble. This factor undoubtedly is of some importance under certain conditions; but, so far as this experiment was concerned, it was relatively unimportant in determining total moisture. The effect of the mulch on absorption played a much larger part in the final result. This is indicated by comparing the moisture content of the harvest-disked and spring-plowed with that of the harvest-disked and dry fall-plowed. Stubble was not extensive in any of the plots, and as a result of the tillage neither of these variations carried a stubble cover during the period of snowfall. The lower average moisture content of the second must be attributed, therefore, to a more pronounced inhibitory effect due to the deeper mulch of the dry plowing as compared with that of the disking. This indicates that, within certain limits, the inhibitory effect is proportional to depth in the mulch. That the effect of the mulch on absorption is not due to the physical condition resulting from tillying this particular soil when dry is shown by the fact that the mulch created by the wet fall-plowing also resulted in inhibiting absorption.

It is apparent, therefore, that during each of the six fallow periods covered by these data, soil covered by a mulch during all or a part of the period of absorption contained less moisture at the end of the fallow than where no mulch existed during the same period of absorption. This indicates that the lower moisture content was due to an inhibiting effect of the mulch on absorption.

ABSORPTION

Detailed data on absorption are available for the seasons of 1920 to 1923, inclusive, and on retention for the seasons of 1921 to 1923, inclusive. In the study of absorption certain plots of the experiments, mulched and unmulched, were sampled at the beginning and at the end of each major absorption period. In the study of retention two plots were given no surface tillage whatever, but were kept free of growth by burning with a plowed strip. Loose soil was removed by winds, and the surface of these plots was as free from both weeds and mulch as could be desired. The moisture content of these plots at the beginning and the end of the retention period was compared with that of other plots during the same period. The data on absorption (Table III) will now be considered, followed by the results on retention (Table IV).

In the spring of 1921 the unmulched soil had absorbed 3.53 inches of water per acre. This was approximately 87 per cent of the total precipitation.
that had fallen between the dates of sampling. The mulched soil had absor-
bered 3.06 inches during the same period, or 56 per cent of the total pre-
cipitation. Depth of absorption is an important factor in subsequent
retention. In the unmulched soil 2.01 inches of moisture had penetrated
below the first foot, while in the mulched soil 1.84 inches had reached
this same lower level. The unmulched soil contained 12 per cent more mois-
ture in the area where it could be most effectively retained.

In the spring of 1922 the soil not mulched during the preceding winter
had absorbed 3.10 inches of moisture, and of this amount 1.28 inches was
below the first foot. The mulched soil in the same time had absorbed
2.38 inches, with 0.96 inch below a depth of 1 foot. During this period
the unmulched and mulched soils absorbed and retained, respectively,
58 per cent and 45 per cent of the total precipitation. In total absorption, the
unmulched soil was 30 per cent superior to the mulched, and in the amount
penetrating below the first foot was 22 per cent superior.

In the spring of 1923 the data show that the unmulched soil had absorbed 2.69 inches of moisture in excess of that present the previous fall.
Of this amount, 1.31 inches was below the first foot. The mulched soil
absorbed 1.58 inches, with only 0.63 inch at the lower levels. The data
for the spring sampling of the unmulched soil indicate that a loss occurred in the fourth foot of this treatment after soil moisture was determined the previous fall. This loss was due to weed growth (Russian thistle, Salsola kali tenutifolia G. F. W. Mey) subsequent to the date of dry
fall-plowing, and after the moisture samplings were made. Despite this moisture loss from the unmulched soil above that occurring from the
mulched treatment, absorption was significantly greater where the mulch
was absent to entirely recover this loss and with substantial additions in 3 all sections except in the fourth foot.

Total absorption in the unmulched

In 1922 the loss from the mulched soil amounted to 0.71 inch, and con-
sidering the gain in the lower 2 feet, this loss came entirely from the first foot. The unmulched soil sustained a loss of 1.61 inches, and of this loss 0.21 inch came from below the first foot.
Neither the mulched nor the unmulched soil lost moisture from the third foot in 1922.

In 1923 the mulched soil showed a total loss from July 6 to September 20 of 0.49 inch. Of the total loss, but 0.01 inch came from below the first
foot, and none was lost from the third foot by evaporation. The unmulched soil in the same period lost 0.95 inch of moisture, with 0.82 inch coming from below the first foot. A very small loss by evaporation was indicated from the third foot of the unmulched soil.

The data for retention show the mulch to have a positive effect in con-
serving moisture, when considered only from that standpoint, and that
efficiency in retention is increased by depth in the mulch. The comparative efficiency of the mulch in retention is shown in Figure 5.

CONCURRENT ABSORPTION AND RETENTION

Ordinarily, the mulch does not become fully effective until after the
season, but in June, 1923, a rainfall of 3.69 inches gave an opportunity to
observe it as an absorbing agent under such conditions also. In effect, the
mulch was functioning in absorption and retention at one and the same
time (Table V).
plowed land, and that the loose surface of the plowed land retains more of the precipitated water than the compact surface of the stubble land.

Carden recognized that fall plowing hindered moisture absorption, although he did not directly attribute the effect to the inhibition of rain penetration.

The various data presented here show that the mulch is an inhibitory agent in absorption and a positive agent in retention, the fundamental reasons for these reactions merit attention.

On the Adams Station the prevailing type of rainfall is characterized in the form of light, intermittent showers. Very rarely does a single rain total 0.50 inch, and the majority of the rainfall is less than 0.30 inch or less. Carden (11) says: "Most of the rainstorms at Nephi have been small and generally almost negligible." This type of rainfall undoubtedly is a factor in the inhibitory reaction of the mulch.

When sampling, the surface 6 inches of a mulched and an unmulched soil immediately after a rain, the moisture content of the mulched soil on a percentage basis is always greater, the loss being more moisture in proportion to soil in the surface area. This fact was noted by Carden (11) and Wiltsie and McLaughlin (24) and Fortier (13) have called attention to the fact that evaporation is always greater from a soil the greater the percentage of moisture present, or, as stated by the former, "the rate of loss of water from a soil increases as the initial percent of water in the soil increases." This means that drying periods of evaporation, gives the mulch the undoubted advantage, the result being due to the cumulative effect of intermittent rainfall and intervening evaporation, rather than to original superior penetration in the more firm soil. A light, intermittent rainfall contributes to the result, since heavy showers, by wetting the mulch, destroy the mulch effect, the mulch in such cases being an actual benefit in so far as it prevents surface run-off.

Bouyoucos (6) has shown that when freezing occurs in soils not saturated, there is a withdrawal of soil water from the finer colloids into the larger pore spaces. Dry-farm soils are seldom so saturated that the familiar freezing effect of more humid regions occurs, but it is possible that there might occur in freezing a certain withdrawal of moisture from the more firm soil below into the larger interspaces of a loose mulch. With subsequent thawing of a larger proportion of moisture would thus be let the surface exposed to evaporation. This factor might have a bearing on increasing the inhibitory effect of the mulch on absorption during the evaporation. The inhibitory effect has been less important on the Adams Station than the other factors outlined above, as evidenced by the fact that the mulch has functioned as a loose material and has not interfered before any freezing weather occurred.

That the inhibitory effect of the mulch on evaporation can be pronounced in the depth of the mulch was brought out by discussion of the data in Table II. The deeper mulch of the drill planting is more effective in inhibiting the more shallow mulch of the disking. Any condition which tends to retain the largest percentage of current showers near the surface undoubtedly would aggravate the inhibitory effect of the mulch on evaporation, and increased depth of the mulch has greater effect. Under normal field conditions a sti firm soil tends naturally to settle as it is wet, and a deeper mulch, requiring a larger amount of moisture to settle it, will naturally remain an effective inhibiting agent for a longer time than the more shallow. The volume and frequency of individual rains naturally have a very important bearing on this factor.

It is of course more a matter of fact, yet it was extensive enough in any case to demonstrate that upward movement occurs without a water table. That this was the case can be demonstrated in Table IV, it is very evident that moisture withdrawal, and hence movement, is well occurred in both the mulched and unmulched soils. This movement was both upward and downward, but despite the fact that downward movement, added in gravity, tends to be greater than that in an upward direction, as noted by Harris and Cuppin (17), the latter was slight in the unmulched soil, and, varying with season, there occurred a withdrawal of moisture extending into the third foot. How much upper movement might or might not have extended with greater moisture content and deeper penetration is, of course, a matter of conjecture, yet it was extensive enough in any case to demonstrate that upward movement occurs without a water table. That this was the case can be demonstrated in Table IV, it is very evident that moisture withdrawal, and hence movement, is well occurred in both the mulched and unmulched soils. It is well known that the rapid evaporation of arid regions often greatly exceeds the ability of any soil to conduct moisture to the surface by capillarity, resulting in a dry surface condition, this dry surface netting in preventing further loss of moisture as a "natural mulch." Many have felt that the "natural mulch" might make unnecessary the artificially created one, and that benefits have been ascribed to the natural one. May, in reality, be just as effectively secured by natural means and without unnecessary labor. The data presented, however, would not indicate the "natural mulch" to be equal to the artificially created one on the Adams Station, and, eliminating concurrent precipitation and its effects on soil moisture content in the mulched and unmulched soil, it seems very doubtful.
if the "natural mulch" is ever equal in efficiency to the artificial in the actual retention of moisture already in the soil.

Since there is, therefore, a proved upward movement of moisture in the soil under conditions of rapid removal by evaporation, and since the data presented show that the mulch can and does check a certain part of this movement and loss, there can be little doubt that the major deflective agent, the soil mulch has a positive effect.

The two effects of the soil mulch in absorption and retention have been shown and their inter-relationship described. The data for the period of summer rainfall indicate how these two effects may be modified by type of rainfall and intensity of evaporation. In the particular June period considered in this study there were two individual rains, each greater than 1 inch in amount and both of which penetrated well below the mulch, following these rains evaporation was rather active. With a heavy rainfall is great enough to penetrate the mulch and to establish connection with the underlying soil, as rain is long in absorption in the same manner as with lighter precipitation. If conditions favor rather intense evaporation, a large portion of the water may be removed from the soil, under such conditions there is a deficit of moisture from the unmulched soil. In conserving natural precipitation, the most important consideration is to reduce evaporation in the surface area to a point that moisture may have an opportunity to move downward into the lower soil. If the rate of evaporation is not extreme, and moisture falling on the surface is not removed, as either run-off or by evaporation, before it has an opportunity to penetrate to lower levels, there is nothing to be gaine by creating a mulch, either before or after a period of rainfall. Light showers not sufficient to penetrate the mulch have little effect one way or the other, on total moisture content, for either in a mulched or an unmulched soil such a limited amount of moisture near the surface is quickly returned to evaporation by active. The value of the soil mulch in conserving moisture in a region of summer rainfall, therefore, is entirely dependent on the volume of individual showers and on the intensity of succeeding evaporation. Practically this may result in little effect from the mulch, one way or the other, as shown, for instance, by the data reported by Call and Newell (9), by Barker (4), by Young (39), and others.

In the foregoing discussion there is no intent to convey the idea that the balance of the inhibitory effect of the mulch on absorption and its positive effect in retention is the sole determiner of the final result in tillage practice, Soil type, climate, soil moisture content, rainfall, and length of time, and of distribution of precipitation, etc., may give other factors prominence so that the pressure or absence of the mulch is not always of equal importance. In districts of heavy snowfall and of comparatively high winds the protective effect of a heavy stubble in holding snow or in checking the evaporative influence of the wind may contribute as large, for instance, to final soil moisture content and in such a case all the benefits can not be ascribed to the absence of a mulch that might hinder absorption. If precipitation is of such volume or character that the mulch functions for only a short time, there will be little effect, either one way or the other, from mulch-forming tillage. Whether evaporation is for is not active naturally has a decided influence on the result. These and other contributing factors must all be taken into account in regulating practice; yet, allowing to each factor its relative importance, the effect of the mulch as a mulch should still be given full consideration.

CONCLUSIONS

(1) The soil mulch has an inhibitory effect on moisture absorption, under conditions when individual rains are not of sufficient volume to fully penetrate the mulch.

(2) The mulch inhibits absorption by increasing the amount of current evaporation in the newly fallen moisture. The volume weight of the materials of the mulch used being less than that of an equal depth of unsaturated soil, the moisture content of the mulched soil immediately after a rain is higher on a percentage basis under these conditions of evaporation, the result is a greater total loss from the mulched soil. The final moisture content is due to a cumulative effect following several rains.

(3) The soil mulch prevents the loss of moisture already in the soil by checking evaporation.

(4) The practical use of the soil mulch in moisture conservation is dependent on climatic conditions which influence the prominence of either the inhibitory effect on absorption or the positive effect on retention, or which may nullify either or both.

LITERATURE CITED


