THE SOIL MULCH IN THE ABSORPTION AND RETENTION OF MOISTURE [1]

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INTRODUCTION

Without irrigation successful crop production over a large part of the western United States is dependent on 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 the 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 seem to be considered untenable. In discarding former theory, 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*) [3] found that at Lincoln, Nebr., 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 (*26*), 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, Nebr., 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 (*21*) 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.

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[3] Reference is made by number (italic) to "Literature cited," p. 831.

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 Cardon (*11*) 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 weed 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 checking of run-off from heavy rains.

Fortier (*13, 14*) shows that mulching a soil after irrigation conserves moisture, and that the deeper the mulch up to 9 inches, the deepest used in his experiments, the more efficient the retention. At Wenatchee, Wash. (*14*), in a 21-day period during June, 1908, an unmulched soil lost 14.38 per cent, one with a 3-inch mulch, 3.98 per cent, one with a 6-inch mulch, 2.10 per cent, and one with a 9-inch mulch, 1.06 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 pulling. They state that a comparison of deeply cultivated plats with those given shallow cultivation or no cultivation shows a decided advantage for the latter in 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 fallow period than did other soils not mulched during the same absorption period. They conclude that the mulch probably aids in retaining 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 of the Office of Dry-Land Agriculture Investigations, Bureau of Plant Industry, United States Department of Agriculture, there are no notable differences in the moisture conserved by two continuously cropped plats, the one being fall plowed and the other spring plowed. He mentions certain seasonal conditions that may favor the first in the southern Great Plains, and the second, to the north, but that there are no consistent advantages in either case.

Shutt (*23*), in Canada, reports that a packed fallow 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 investigators have not 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 retentive agent, as under irrigation, the evidence is unanimous that its effect is positive in saving moisture. In measuring the value of the mulch in relation to natural precipitation, where both considerations come into play, 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 Lind, 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 the fallow is to conserve moisture and to carry it from one season to the next. As one of the factors affecting moisture conservation, the soil mulch 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. During the summer temperatures are

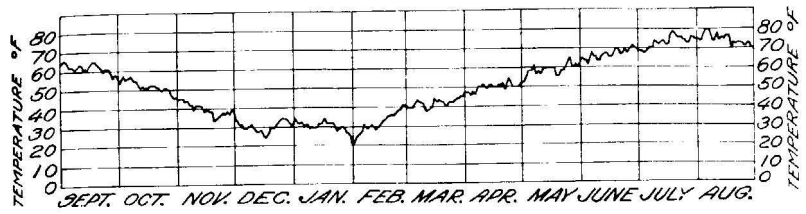

FIG. 1.—Mean daily temperature, based on an 11-year average, at Lind, Wash. During the period from November 15 to March 15, when mean temperatures are comparatively low, evaporation is less active than at any other time, and the opportunity for precipitation to be absorbed by the soil is correspondingly greater. The general relationship between mean temperature and rate of evaporation is shown in Figure 2

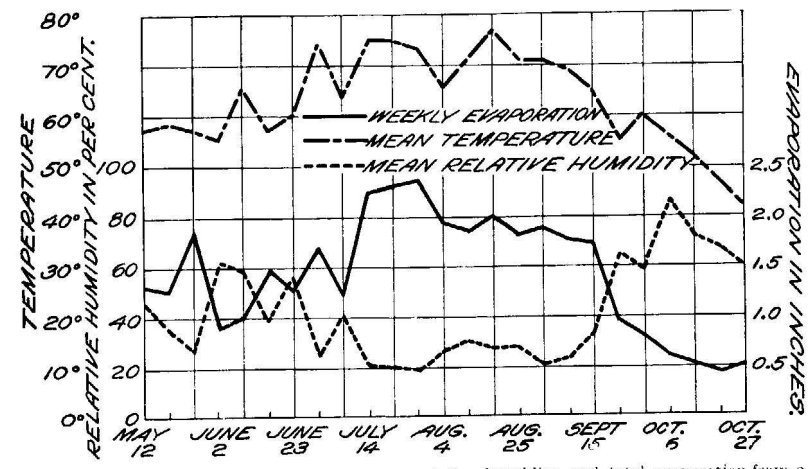

FIG. 2.—Relation between mean temperature, mean relative humidity, and total evaporation from a free water surface, by weeks, at Lind, Wash., May 9 to October 30, 1924. The dates given represent weekly centers

high, relative humidity is low, and little or no rainfall occurs. Retention then becomes paramount. The fallow period, from a moisture standpoint, extends from the removal of one crop to the beginning of the growing season of the next. Practically, on the Adams Station, it therefore consists of a first period of absorption, extending through the first fall, winter, and spring, followed during the summer by a period in which retention is important, and this, in turn, followed by a second period of absorption. The soil moisture content at the beginning and end of either of these periods should, therefore, give a basis for reliably measuring 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 Ritzville 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 I.

TABLE I.—*Mechanical analysis, by feet, to a depth of 4 feet of the soil on the Adams Branch Station, Lind, Wash. (19).*

Soil section	Fine gravel	Coarse sand	Medium sand	Fine sand	Very fine sand	Silt and clay	Total
	Per cent	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*	*Per cent*
First foot	0.00	0.08	0.13	9.82	45.88	45.05	100.96
Second foot	.00	.08	.08	8.68	46.75	44.40	99.99
Third foot	.00	.11	.14	8.04	52.01	39.70	100.00
Fourth foot	.00	.06	.05	6.10	50.24	43.45	99.90

The study of the mulch was made on the plats of the summer-fallow experiments. There are two series of these plats, one series being in crop and one in fallow each year. The plats are 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.

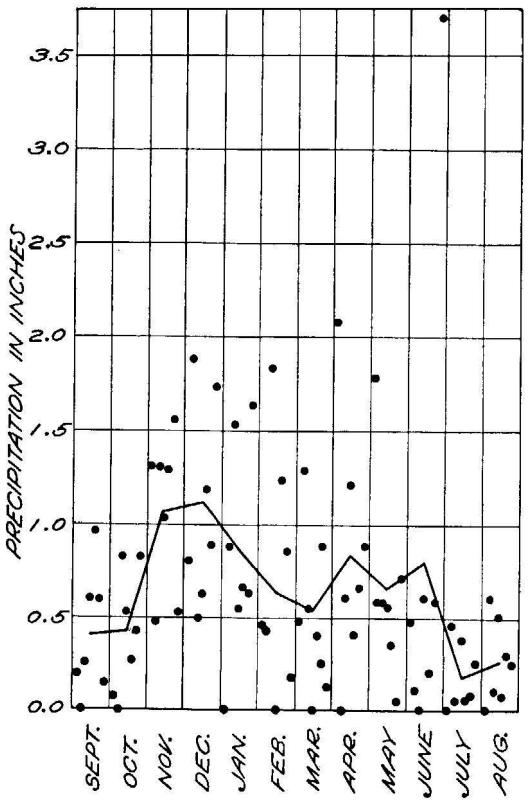

FIG. 3.—Precipitation by months, at Lind, Wash., September 1, 1916, to August 31, 1923. The tendency for greater precipitation during the winter months is apparent, as well as the unusual rainfall of June, 1923

Methods of sampling and of determining soil moisture are given in Bulletin 164 of the Washington Agricultural Experiment Station (*19*).

Moisture data are given in acre-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 stirring. The volume weight of the surface foot of such a plowed soil is 80 per cent that of the unstirred. Moisture content of the surface foot, where necessary, was calculated on this basis.

In Table II are given total soil moisture data for certain tillage variations in preparing the fallow, which indicate the reaction of the mulch in absorption each year during the period 1918 to 1923, inclusive.

All of the tillage variations as given in Table II were maintained in a well-mulched condition during the summer period of retention. So far as this period and the succeeding period are concerned, the result for all should have been similar. The essential difference between the variations was in the presence or absence of a soil mulch during all or a part of the first period of absorption. The only plats on which no mulch existed at any time during this first period were those of the early spring plowing with no previous treatment. All of the others were mulched for varying periods, either with a light mulch created by disking in August immediately after harvesting the preceding crop, or with a heavier mulch created by plowing at some later date.

Not once during the 6-year period did any of the mulched plats equal the unmulched plats in final moisture content. In several instances the shallow mulch of the harvest-disked and spring-plowed plats was almost as efficient in saving moisture, but this efficiency was not due to equality in moisture absorption. This is shown by comparing the dry fall-plowing alone and the dry fall-plowing with previous harvest-disking. As far as absorption was concerned, these two treatments should have given an identical effect, the difference between the two being in the presence or absence of weed growth in the stubble in the interim between harvest and the date of dry fall plowing. The comparative result between these two treatments is not always the same, due to the fact that weeds were not always present in the stubble, but the

TABLE II.—*A comparison of total and conserved soil moisture in the soil to a depth of 4 feet after the year of fallow, for six variations in fallow preparation*

[The essential difference between these variations lies in the presence or absence of a soil mulch during all or a part of the first major period of moisture absorption. Adams Branch Station, Lind, Wash., 1918 to 1923, inclusive]

Tillage variations	Soil moisture in acre-inches to a depth of 4 feet after the year of fallow								
	1918	1919	1920	1921	1922	1923	Average	Conserved moisture [a]	Comparative amount of conserved moisture
Dry fall-plowed	3.35	4.97	4.89	5.07	4.67	5.00	4.66	2.58	100
Harvest-disked, dry fall-plowed	4.34	5.34	4.76	4.82	5.48	5.03	4.96	2.88	111
Harvest-disked, wet fall-plowed	3.94	5.54	4.58	5.05	5.24	4.76	4.85	2.77	107
Harvest-disked, early spring-plowed	4.61	5.63	4.87	5.52	6.18	5.52	5.39	3.31	128
Wet fall-plowed	3.75	5.49	4.80	5.04	5.18	5.57	4.97	2.89	112
Early spring-plowed	4.70	5.98	5.32	5.76	6.47	5.60	5.64	3.56	138

[a] Residual moisture, 2.08 acre-inches to a depth of 4 feet, average of four seasons.

data indicate that on the average there was some saving of moisture through weed removal by harvest-disking. Despite this saving, however, the effect on absorption more than counterbalanced the gain from killing weeds, as shown by the slightly lower average moisture content of the harvest disking 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-disking and spring-plowing with that of the harvest-disking and dry fall-plowing. Stubble was not extensive on any of the plats, 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 tilling this particular soil when dry is shown by the fact that the mulch created by the wet fall-plowing also reacted 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 first 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 plats 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 plats were given no surface tillage whatever, but were kept free of growth by shaving with a sharp hoe. Any loose soil was removed by winds, and the surface of these plats was as free from both weeds and mulch as could be desired. The moisture content of these plats at the beginning and the end of the retention period was compared with that of other plats mulched 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 67 per cent of the total precipitation

TABLE III.—*Soil-moisture content in acre-inches by foot sections to a depth of 4 feet in mulched and unmulched soils, at the beginning and at the end of the first absorption period of the fallow, together with gains in moisture during the absorption period, Adams Branch Station, Lind, Wash., 1920 to 1923, inclusive*

Soil section	1920–1921						1921–1922					
	Mulched, fall plowed			Unmulched, stubble			Mulched, fall disked			Unmulched, stubble		
	Aug. 16, 1920	Apr. 14, 1921	Gain	Aug. 16, 1920	Apr. 14, 1921	Gain	Aug. 10, 1921	Apr. 7, 1922	Gain	Aug. 10, 1921	Apr. 7, 1922	Gain
First foot	0.24	1.52	1.28	0.24	1.76	1.52	0.28	1.70	1.42	0.27	2.09	1.82
Second foot	.49	1.65	1.16	.49	1.66	1.17	.56	1.42	.86	.52	1.59	1.07
Third foot	.56	1.14	.58	.57	1.32	.75	.64	.69	.05	.63	.75	.12
Fourth foot	.57	.61	.04	.57	.66	.09	.60	.65	.05	.63	.72	.09
Total gain			3.06			3.53			2.38			3.10
Gain below first foot			1.78			2.01			.96			1.28
Rainfall during interval, in inches			5.26			5.26			5.30			5.30

Soil section	1922–1923						3-year average					
	Mulched, fall plowed			Unmulched, stubble			Mulched			Unmulched		
	Sept. 7, 1922	Mar. 23, 1923	Gain	Sept. 7, 1922	Mar. 23, 1923	Gain	Fall	Spring	Gain	Fall	Spring	Gain
First foot	0.26	1.21	0.95	0.25	1.63	1.38	0.26	1.48	1.22	0.25	1.83	1.58
Second foot	.54	1.15	.61	.52	1.57	1.05	.53	1.41	.88	.51	1.61	1.10
Third foot	.61	.60	.01	.64	1.04	.40	.60	.81	.21	.61	1.04	.43
Fourth foot	.57	.60	.03	.63	.49	.14	.58	.62	.04	.61	.62	.01
Total gain			1.58			2.69			2.35			3.12
Gain below first foot			.63			1.31			1.13			1.54
Rainfall during interval, in inches			5.08			5.08			5.21			5.21

that had fallen between the dates of sampling. The mulched soil had absorbed 3.06 inches during the same period, or 58 per cent of the total precipitation. 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 1.78 inches had reached this same lower level. The unmulched soil contained 12 per cent more moisture 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 tenuifolia* 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 sufficiently greater where the mulch was absent to entirely recover this loss and with substantial additions in all sections except in the fourth foot. Total absorption in the unmulched

soil was actually the absorption shown by the data, plus the undetermined loss. On the basis of the data, the unmulched soil absorbed 53 per cent and the mulched soil absorbed 31 per cent of the total intervening precipitation. The unmulched soil was 69 per cent superior in total absorption and slightly over 200 per cent superior in the amount of moisture below the first foot.

In every instance the unmulched soil was superior as an absorbing agent. The comparative efficiency of the mulched and unmulched soils in absorption is shown graphically in Figure 4.

In 1922 the loss from the mulched soil amounted to 0.71 inch, and, considering 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 0.04 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

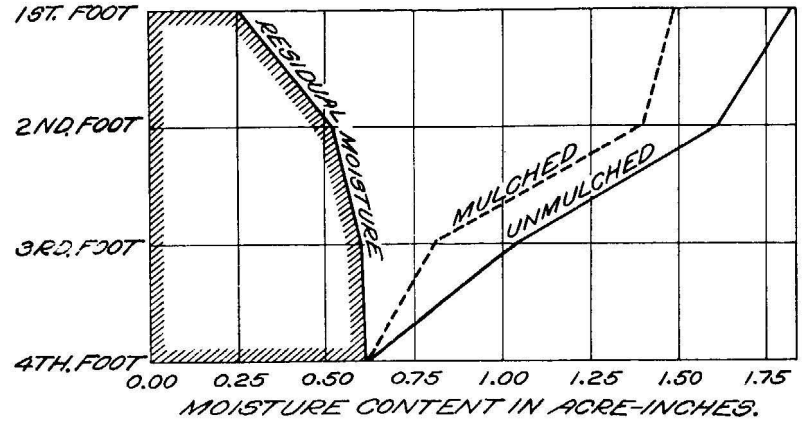

FIG. 4.—Average moisture content in acre-inches of mulched and unmulched soils at the end of the first period of moisture absorption during the fallow year, Adams Branch Station, Lind, Wash., 1920 to 1923, inclusive

RETENTION

Data showing the relation of the mulch to retention are given in Table IV. These data show that during the summer of 1921 the soil covered by a 6-inch soil mulch lost 1.02 inches of moisture. Of this total loss by evaporation, 0.12 inch came from below the first foot. In the lower 2 feet of this soil there was a gain by downward movement of 0.27 inch. The soil covered by a 4-inch mulch lost a total of 1.59 inches of moisture, or 56 per cent more than the 6-inch mulched soil. Of this amount 0.55 inch came from below the first foot, and 0.10 inch came from the third foot. The unmulched soil lost 2.02 inches of moisture. This was 198 per cent of that lost from the 6-inch mulch. Of the total lost from the unmulched soil, 0.85 inch came from below the first foot, and 0.32 inch came from the third foot.

of moisture, with 0.32 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 conserving 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, on the Adams Station, the mulch need be considered only as a retentive agent during the summer 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).

TABLE IV.—*The soil-moisture content in acre-inches by foot sections to a depth of 4 feet, in mulched and unmulched soils, at the beginning and at the end of the period of extreme summer evaporation during the year of fallow, together with moisture losses occurring during the period, Adams Branch Station, Lind, Wash., 1921 to 1923, inclusive*

Soil section	1921									1922					
	6-inch mulch			4-inch mulch			Unmulched			Mulched			Unmulched		
	Apr. 14	Sept. 3	Loss	Apr. 14	Sept. 3	Loss	Apr. 14	Sept. 3	Loss	Apr. 7	Sept. 6	Loss	Apr. 7	Sept. 6	Loss
First foot	1.63	0.73	0.90	1.76	0.72	1.04	1.66	0.49	1.17	1.70	0.81	0.89	2.09	0.69	1.40
Second foot	1.65	1.26	.39	1.66	1.21	.45	1.56	1.03	.53	1.42	1.28	.14	1.59	1.15	.44
Third foot	1.18	1.18	.00	1.32	1.08	.24	1.41	.98	.43	.69	.96	[a] .27	.75	.95	[a] .20
Fourth foot	.62	.89	[a] .27	.66	.80	[a] .14	.61	.72	[a] .11	.65	.70	[a] .05	.72	.75	[a] .03
Total loss			1.02			1.59			2.02			.71			1.61
Loss below first foot			.12			.55			.85			.18			.21
Loss from third foot by upward movement			.00			.10			.32			.00			.00
Gain in fourth foot			[a] .27			[a] .14			[a] .11			[a] .05			[a] .03

Soil section	1923									3-year average		
	Mulched			Unmulched			Mulched			Unmulched		
	July 6	Sept. 20	Loss.	July 6	Sept. 20	Loss	Spring	Fall	Loss	Spring	Fall	Loss
First foot	1.34	0.89	0.45	1.42	0.79	0.63	1.56	0.81	0.75	1.72	0.66	1.06
Second foot	1.74	1.39	.35	1.51	1.21	.30	1.60	1.31	.29	1.55	1.13	.42
Third foot	1.41	1.33	.08	1.29	1.17	.12	1.99	1.16	[a] .07	1.15	1.03	.12
Fourth foot	.72	1.11	[a] .39	1.11	1.21	[a] .10	.66	.90	[a] .24	.81	.89	[a] .08
Total loss			.49			.95			.73			1.52
Loss below first foot			.04			.32			.02			.46
Loss from third foot by upward movement			.00			.02			.00			.04
Gain in fourth foot			[a] .39			[a] .10			[a] .24			[a] .08

[a] Gain.

TABLE V.—*Soil moisture content in acre-inches to a depth of 4 feet of a mulched and an unmulched soil at the beginning and at the end of a period of summer precipitation, Adams Branch Station, Lind, Wash., 1923*

Soil section	Mulched			Unmulched		
	May 31	July 6	Gain	May 31	July 6	Gain
First foot	1.03	1.34	0.31	1.48	1.42	−0.06
Second foot	1.41	1.74	0.33	1.32	1.51	0.19
Third foot	1.12	1.41	0.29	1.15	1.29	0.14
Fourth foot	0.59	0.72	0.13	1.01	1.11	0.10
Total gain			1.06			0.37
Gain below first foot			0.75			0.43
Rainfall during interval, in inches			3.69			3.69

Of the total rainfall of 3.69 inches occurring between May 31 and July 6, 1923, the mulched soil absorbed 1.06 inches. This was 28.7 per cent of the entire amount. Of the total amount absorbed, reference to Table IV shows that practically one-half was lost by evaporation during the remainder of the summer, as well as such limited additional rain as fell in the interim. By September 20 only 15.4 per cent of the entire June rainfall remained in the mulched soil. The unmulched soil had absorbed and retained only 0.37 inch of the June rainfall on July 6, or 10 per cent of the total. By September 20, even this small amount had been lost, as well as an additional 0.58 inch from that previously in the soil.

In a general way, the conditions prevailing during this period and the final result were both very similar to those characteristic of the Great Plains area, and their proper interpretation should give a basis for understanding the somewhat divergent data from this region and that west of the Rocky Mountains.

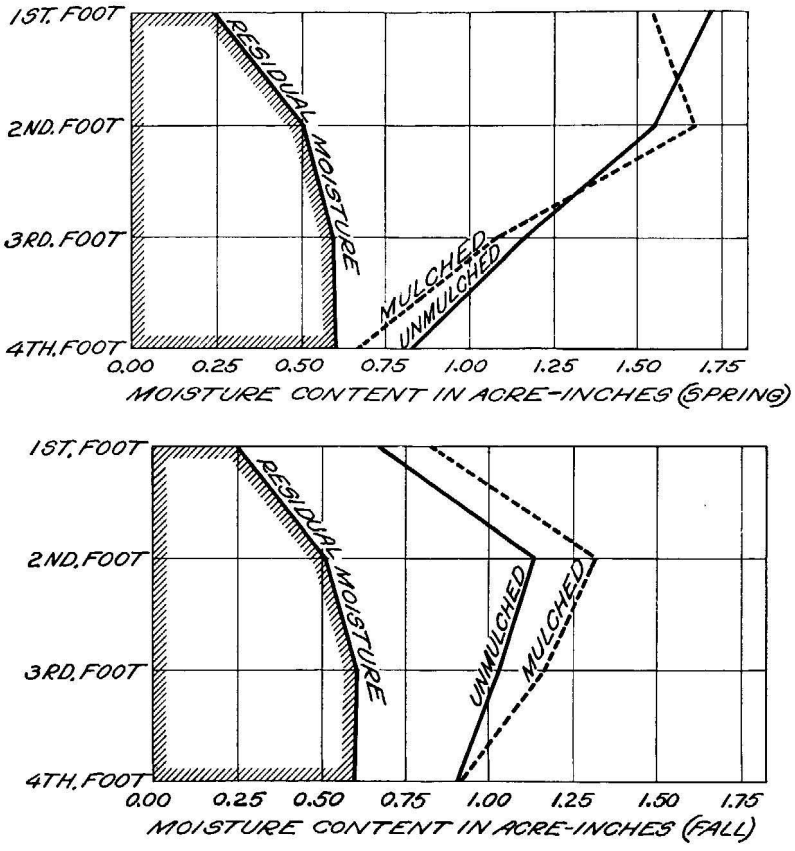

FIG. 5.—Average moisture content in acre-inches of mulched and unmulched soils in the spring and in the fall of the fallow year, Adams Branch Station, Lind, Wash., 1920 to 1923, inclusive

DISCUSSION

In most instances data have not been reported by other investigators in a form lending itself to a true evaluation of the mulch. The data from the Nephi (Utah) Substation, as reported by Cardon (*11*) and by Harris and Jones (*16*), the two being in substantial agreement, do, however, lend themselves to a measurement of the absorptive effect. Data after Cardon are shown graphically in Figure 6.

Regarding these data, Cardon (*11*) says:

"The facts thus brought out seem to indicate that at Nephi stubble land allows the winter precipitation to penetrate to greater depths than fall-

plowed land, and that the loose surface of the fall-plowed land retains more of the precipitation of winter than the compact surface of the stubble land."

Cardon recognized that fall plowing hindered moisture absorption, although he did not directly attribute the effect to the mulch as an inhibiting agent.

The various data presented having shown the mulch to be 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 characteristically in the form of light, intermittent showers. Very rarely does a single rain total 0.50 inch, and the majority of individual showers amount to 0.30 inch or less. Cardon (*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 loose soil having more moisture in proportion to soil in the surface area. This fact was noted by Cardon (*11*) and by Harris and Jones (*16*).

Widtsoe 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 per cent of water in the soil increases." This means that drying winds or other factors favoring evaporation immediately following a rain will more quickly remove moisture from the loose soil of a mulched surface than from the more firm soil in an undisturbed condition. After an intervening period of evaporation, a second shower falling on the two soils, because of the larger amount of moisture remaining in the unstirred soil, is absorbed and conducted more deeply into the unstirred soil than where the mulch is present. Alway and McDole (*2*) have shown that depth of penetration increases in direct proportion to initial moisture content, as has also been noted by Burr (*8*) and by Buckingham (*7*). Such deeper penetration, following a series of showers with intervening periods of evaporation, gives the unstirred soil its final moisture 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 entirely through the mulch, destroy the mulch effect, the mulch in such cases being an actual benefit in so far as it prevents surface run-off.

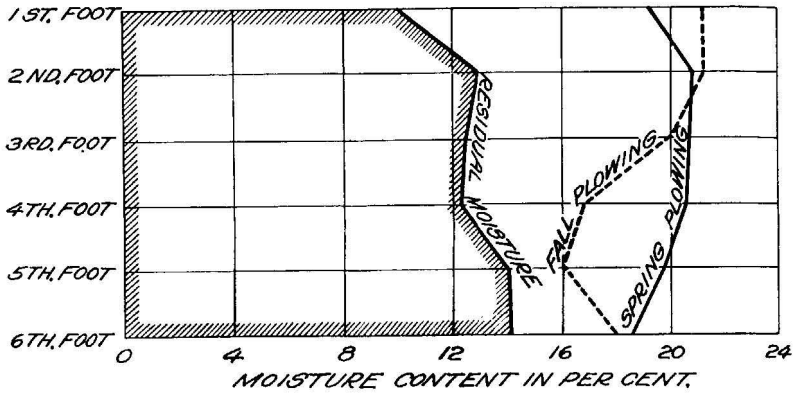

FIG. 6.—Average moisture content in per cent of moisture-free soil of fall-plowed and spring-plowed soil at the end of the first winter of the fallow, Nephi, Utah, 1909 to 1912, inclusive

Bouyoucos (*6*) has shown that when freezing occurs in soils not saturated, there is a withdrawal of soil water from the finer capillaries into the larger pore spaces. Dry-farm soils are seldom so saturated that the familiar heaving 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, a larger proportion of moisture would thus be left

near the surface exposed to evaporation. This factor might have a bearing on increasing the inhibitory effect of the mulch on absorption during the colder seasons of the year, but if so it has been less important on the Adams Station than the other factors outlined above, as evidenced by the fact that the inhibitory effect has been apparent before any freezing weather occurred.

That the inhibitory effect of the mulch on absorption tends to be proportional to the depth of the mulch was brought out by discussion of the data in Table II. The deeper mulch of the dry fall plowing was a more effective inhibiting agent than 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 absorption, and increased depth in the mulch has such an effect. Under normal field conditions a stirred soil tends naturally to settle as it is wet, and a deeper mulch, requiring a larger amount of moisture to entirely wet through it, will naturally remain an effective inhibiting agent for a longer time than would one more shallow. The volume and frequency of individual rains naturally have a very important bearing on this factor.

In no instance has the writer been able to find a record of the mulch failing to conserve moisture when it is clearly shown that it was confined to that single function. The data presented in this study for the summer periods are, therefore, in complete agreement with the findings of others so far as this one phase is concerned.

In general, the theoretical operation of the soil mulch in preventing the loss of soil moisture through evaporation might seem too well known to require an extended discussion; yet, because the issue has been confused in some cases, a certain elaboration is desirable. It has generally been considered as established beyond controversy that soil moisture moves within the soil in response to the forces of capillarity. In accordance with this concept, as evaporation removes moisture from the surface soil, other moisture moves up from more moist underlying soil, and being in turn removed by evaporation, a more or less continuous movement from below to the surface is established. The stirring, incident to creating the soil mulch, decreases the number of points of capillary contact, and, by exposing additional surface to evaporating agencies, increases evaporation in the immediate surface soil to a rate beyond the ability of capillary movement to replace losses. As a result, the surface soil becomes dry, and being already loosened by the stirring, the mulch effect is created. Buckingham (*7*), Alway and Clark (*1*), and others have shown that such a dry soil retards capillary movement, hence, when present as a loose surface layer, necessarily would check evaporation.

In introducing the review of literature in their discussion of the soil mulch, Call and Sewell (*9*) make the statement that "capillary movement without the presence of a water table (with a dry subsoil) has not been demonstrated." From the data presented in Table IV, it is very evident that moisture withdrawal, and hence movement, occurred in both the mulched and unmulched soils. This movement was both upward and downward, but despite the fact that downward movement, aided by gravity, tends to be greater than that in an upward direction, as noted by Harris and Turpin (*17*), this latter was slight in the unmulched soil, and, varying with season, there occurred a withdrawal of moisture extending into the third foot. How much deeper this upward 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 a capillary movement seems the logical conclusion, since Buckingham (*7*) and Bouyoucos (*5*) both have shown that internal evaporation and diffusion have very little effect on moisture movement within the soil.

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 naturally dry surface condition, this dry surface acting in preventing further loss of moisture as a "natural mulch" (*7*). Many have felt that such a natural mulch might make unnecessary the artificially created one, and that benefits have been ascribed to the latter which 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 soil mulch can and does check a certain part of this movement and loss, there can be little doubt that as a purely retentive agent, the soil mulch has a positive effect.

The two effects of the soil mulch in absorption and retention have been shown and their operation has been 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. When volume of rainfall is great enough to penetrate the mulch and to establish connection with the underlying soil, the mulch no longer acts in absorption in the same manner as with lighter precipitation. If conditions favor rather intense evaporation, tillage given immediately after such rainfall, by renewing the mulch, may retain a certain part of the moisture which has penetrated below the mulched area. When the mulch is not reestablished after the rain, under such conditions there is greater loss 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, either as run-off or by evaporation, before it has an opportunity to penetrate to lower levels, there is nothing to be gained 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 removed if evaporation be 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 Sewell (*9*), by Barker (*4*), by Young (*26*), 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, temperature, relative humidity, the volume, character and distribution of precipitation, etc., may give other factors prominence so that the presence 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 very largely, for instance, to final soil moisture content; and in such a case all of 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 or 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 where 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 stirred mulch being less than that of an equal depth of unstirred soil, the moisture content of the mulched soil immediately after a rain is higher on a percentage basis. When conditions favor 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.

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