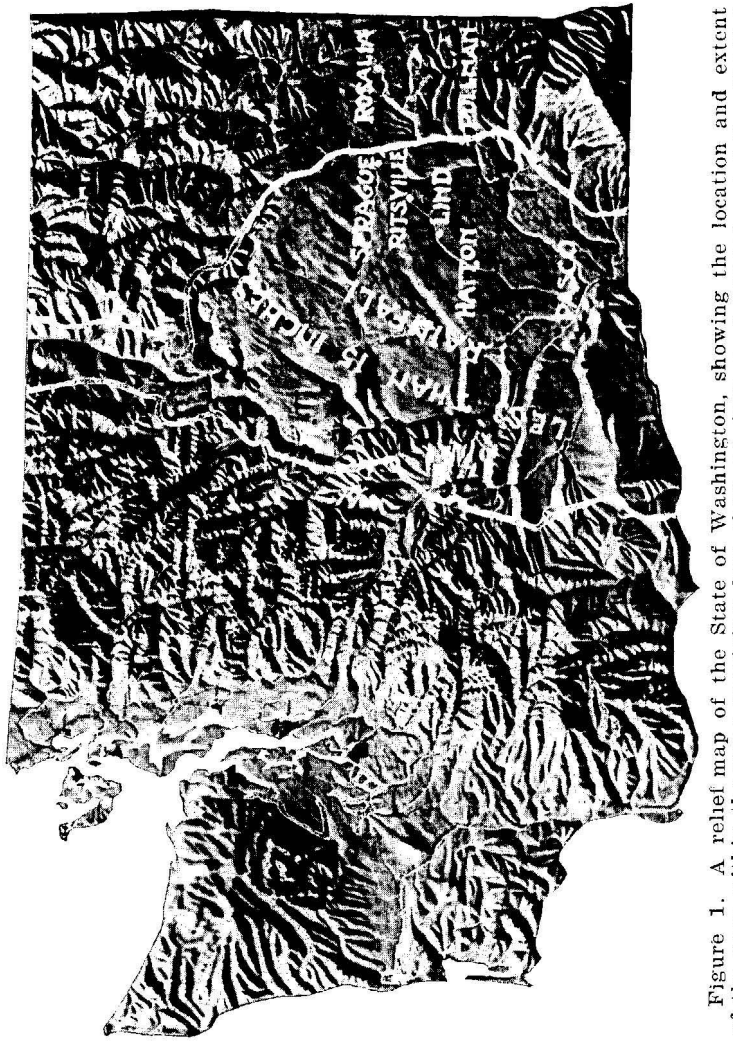


Figure 1. A relief map of the State of Washington, showing the location and extent of the area within the state receiving less than 15 inches of annual rainfall. Typical points, within and without the area, are designated to show variation in altitude, annual rainfall, soil type, etc. Figure 2 and table 3 give these variations.

Investigations in Dry Farm Tillage

FOREWORD*

Location and Control of the Branch Station:

The Adams Branch Experiment Station was established in 1915 for the investigation of dry farming problems. The station farm, located 3 miles northeast of the town of Lind, is the property of Adams County, being leased at a nominal figure to the Washington Agricultural Experiment Station for experimental purposes. Until September 30, 1920, the Office of Cereal Investigations, Bureau of Plant Industry, United States Department of Agriculture, co-operated in maintaining the station.

The field work of the experiments reported in this bulletin was done on the Adams Station farm.

Limitations in Applying Results and Conclusions:

Dry farming is used in a very elastic way to designate the growing of crops without irrigation under a wide variety of semi-arid to arid conditions. In this bulletin the term is limited to apply only to the typical summer-fallow system practiced in the Western United States under conditions where natural precipitation is the direct limiting factor in crop production. The prime object of the summer-fallow, in this case, is the conservation of moisture; and the affect of tillage variations on the moisture content of the soil following the year of fallow is the chief factor which makes one method or system superior or inferior to another.

It is taken for granted that the summer-fallow and its place are generally understood by the readers of this bulletin.

*Acknowledgement. The authors wish to acknowledge the helpful advice of Prof. F. J. Sievers, Head of the Department of Soils of the State College of Washington, and the suggestions of Mr. H. M. Wanser, Assistant in Soils and Crops on the Adams Branch Experiment Station, and to thank Mr. Dan Krehbiel, Lind, Washington, for supplying his rainfall record for the period 1897-1906.

Opinion may vary as to the average, annual rainfall above which the summer-fallow system is unnecessary, but within the limits hereafter outlined there can be no doubt of its necessity.

It is difficult, if not impossible, to place definitely the annual precipitation below which moisture becomes the **direct** limiting factor in production. In this general area, however, observation and experimental evidence indicate that with an annual rainfall of 15 inches or more, the beneficial effects of the fallow on yield are due not so much to added moisture, as to the influence of tillage on nitrification. Each year, as rainfall is above or below normal, this limit varies in either direction, and it cannot be assumed, therefore, to define exactly the area where the chief purpose of the fallow is to conserve moisture. However, as a rough dividing line, it will serve as well as any other.

Experimental data will be discussed and applied, therefore, in the light of conditions as found in that part of Washington where the annual rainfall is 15 inches and less. (See Figure 1). The results, however, are most directly applicable to the localities of lower rainfall in this area. In any case, it must be understood that conclusions and suggestions are based on soil and climatic factors, and especially on the amount, nature and distribution of rainfall peculiar to this region as a whole.

Where the beneficial effects of the fallow are due almost entirely to the influence of tillage on nitrification, the suggestions of this bulletin are not intended to apply.

THE EXTENT AND IMPORTANCE OF DRY FARMING IN WASHINGTON

The preliminary report of the 14th census, issued by the Bureau of the Census, United States Department of Commerce, places the improved farm lands of the state in 1920 at 7,129,243 acres. The same report shows the improved acreage receiving a rainfall of 15 inches or less, assumed in this case as the limit of dry farming, to be, exclusive of irrigated lands, approximately 3,161,500 acres. (This latter figure is partly estimated in certain counties on the dividing line, but the estimates, based on U. S. Weather Bureau statistics, are conservative). On this basis, 45 per cent of the present improved area of the state is dry farmed. Contemplated irrigation will probably eventually cover the drier lands of this district, yet allowing for a maximum development of irrigation, when the shifting nature of the limit assumed for dry farming is considered, it is reasonable to estimate that 20 to 25 per cent of the state's total improved acreage will always be dry farmed if continued in production.

In 1919, the state produced in round numbers 40,000,000 bushels of wheat. The district receiving less than 15 inches of rainfall produced 15,100,000 bushels, or 37.5 per cent of the total (1).

CLIMATE AND RAINFALL

The geography and topography of central Washington have such an important bearing on climate, that they should be briefly considered in discussing this factor (2).

This portion of the state is a more or less rolling plateau, with a generally increasing elevation from the south and west toward the north and east. (See Figure 1). On the west are the Cascade Mountains. These mountains shut off the district from direct oceanic influence, and have a decided effect on prevailing climate.

Prevailing winds are from the west, and are the chief source of precipitation. In crossing the mountains much of the moisture is lost from the air in rain or snow. When this same air descends on the eastern slopes, due to increasing temperature with pressure (2), its moisture capacity increases. The result is a region of low rainfall and high evaporataion east of the mountains.

After the air currents have passed on over the low interior valleys and again rise toward the north and east, their moisture holding capacity gradually decreases, and there is a more or less regular increase in annual rainfall with increase in altitude. Local changes in topography, as they influence local air-currents, may modify local rainfall, but for the area as a whole the above general statement holds true. (See Table 1).

The wide, treeless plains offer little obstruction to the passage of winds, which at certain periods, are almost constant. The evaporative affect of these winds complicates the moisture problem, and the blowing of certain lighter soil types adds to the difficulties of tillage.

Temperatures vary over rather a wide limit. During each summer there are periods when at some point the temperature goes as high as 100 degrees F., or more, and winter temperatures may go as low as 20 or 30 degrees F. below zero, but in either case such periods are usually of short duration.

Evaporation is active during much of the year, and is especially important in its affects on moisture conservation during the fall and spring.

Precipitation occurs chiefly in the fall, winter and spring; and the summers are comparatively rainless. Rains are characteristically gentle, and are seldom of great volume at any one time. A portion of the precipitation always occurs as snow, the proportionate amount having an important bearing on tillage methods.

In Table 1 are given average annual rainfall and other comparative data for certain representative points within the area. (See Figure 1 for the location of these points). Monthly and annual precipitation data for the experiment station farm, covering the period from September 1st, 1897, to August 31st, 1906, are given in Table 2, and for the period of the experiments, September 1st, 1916, to August 31st, 1920, in Table 3. This division of the precipitation year is adopted because it conforms more nearly to the actual beginning of the fallow and the ending of the crop year than does the calendar year.

The data of Table 1 explain why results in crop yield or in the operation of different methods vary so widely within the area as a whole. A study of Tables 2 and 3 strikingly points out the severity of moisture conditions during the period of the experiments. The three tables, considered together, show that not only is there variation with locality, but also from year to year, or over a period of years for each individual locality. Granting the necessity of varying methods with locality, these data indicate the desirability of equal variation even on the same farm from year to year, and emphasize the necessity of a knowledge of the effect of these variations on the result of any given operation, in order to manipulate practice intelligently.

Table 1: Altitude, Annual Rainfall, Soil-Nitrogen, and Soil-Type as Measured by Silt Content, at Typical Points in Eastern Washington

Station	Altitude	Rainfall	Soil Nitrogen	Soil Silt	Distance
	Feet	Inches	Percent	Percent	Miles
Pasco	370	7.2	0.0115	20	0
Hatton	1100	9.7	0.0430		44
Lind	1750	11.8	0.0650	45	65
Ritzville	1850	12.6	0.0900		83
Sprague	1925	15.5	0.1260		108
Rosalia	2400	19.4	0.1700		138
Pullman	2550	21.5	0.2130	70	148

Note:—The data for rainfall and altitude are taken from U. S. W. B. reports. The nitrogen data are taken from Bul. 85 of the Washington Experiment Station and from original determinations by the junior author. The data on silt are from original data of the junior author. The distance given from Rosalia to Pullman is the west to east distance.

Table 2: Monthly and Annual Precipitation by Crop Years for the Adams Experiment Station during the Period from September 1st, 1897, to August 31st, 1906

Year	Monthly Precipitation (Inches)												Average Annual Inches
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1897-1898	0.23	0.28	1.64	0.00	0.85	0.81	0.16	0.28	1.37	0.00	0.13	0.69	6.34
1898-1899	0.26	0.34	1.37	0.71	1.88	1.31	0.27	0.96	0.57	0.40	0.03	0.66	8.76
1899-1900	0.44	1.63	2.63	1.23	0.68	1.25	0.90	1.47	0.88	0.29	0.06	0.54	12.00
1900-1901	2.29	1.95	1.47	1.78	1.36	2.54	0.63	0.31	0.91	1.46	0.60	0.04	15.34
1901-1902	1.24	0.15	0.85	0.36	1.68	2.53	0.63	1.79	2.22	0.07	0.58	0.23	12.33
1902-1903	0.59	0.26	3.56	2.49	1.79	0.45	1.23	0.37	0.35	0.26	1.25	1.07	13.67
1903-1904	0.22	0.57	2.95	2.00	1.09	2.14	2.63	1.35	0.47	0.68	0.79	0.14	15.03
1904-1905	0.03	0.35	0.36	1.12	1.94	0.43	1.40	0.92	2.12	2.63	0.02	0.03	11.34
1905-1906	0.69	2.23	1.05	1.46	1.36	1.79	0.66	0.07	1.65	0.61	0.02	0.42	12.01
												Average	11.87

Note:—This record, taken from U. S. W. B. reports, was kept by Mr. Dan Krehbiel, a portion of the period the meterological station being located on th same section as that containing the Adams Experiment Station farm, and at no time farther than one and one-half miles distant. This record was discontinued with August 31st, 1906, and no other is available for the intervening period, September 1st, 1906, to August 31st, 1916.

Table 3: Monthly and Annual Precipitation by Crop Years for the Adams Experiment Station during the Period of the Experiments, September 1st, 1916, to August 31st, 1920

Year	Monthly Precipitation (Inches)												Average Annual
	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	
1916-1917	0.21	0.07	1.29	0.80	0.00	0.45	0.47	2.07	1.77	0.47	0.00	0.00	7.60
1917-1918	0.00	0.00	0.48	1.88	0.88	0.42	1.27	0.00	0.57	0.10	0.44	0.60	6.64
1918-1919	0.25	0.82	1.30	0.50	1.53	1.82	0.55	0.61	0.57	0.00	0.05	0.10	8.10
1919-1920	0.61	0.53	1.02	0.64	0.54	T	T	1.20	0.55	0.60	0.38	0.49	6.56
												Average	7.22

SOILS

The soils of central Washington are basaltic in origin. There are differences of opinion as to their early geologic formation, but in any case, they have undoubtedly been modified in recent periods, especially in location, by winds.

Soil type varies with elevation and rainfall, the sandier soils being found at the lower elevations, as is the lightest rainfall. Type grades through sandy loams, fine sandy loams, very fine sandy loams, and silt loams. The sandier types are subject to drifting. Figure 2, based on Table 1, shows graphically the relation of soil type, as measured in this case by silt content, to altitude and precipitation.

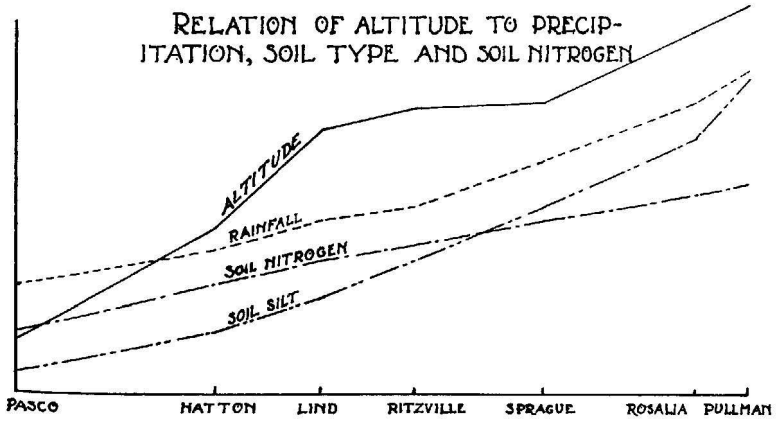


Figure 2. This graph is based on the data of table 3. It shows the uniformity of variation in rainfall and in soil type and condition throughout the dry-farming district of the state of Washington. Altitude at any given point in this area may be used as a rough measure in determining the probable value of the other factors shown in this graph. The different points taken as representative of this variation are shown on figure 1.

As an illustration of the uniformity of the soils of the area, and to identify the soil type upon which work was done, the mechanical analysis of the soil on the Adams Experiment Station farm by feet to a depth of four feet is given in Table 4.

Table 4: The Mechanical Analysis, by Feet, of the Soil on the Adams Experiment Station Farm

Sample	Fine Gravel	Coarse Sand	Medium Sand	Fine Sand	Very fine Sand	Silt and Clay	Total
1st Foot ...	0.00	0.08	0.13	9.82	45.88	45.05	100.96
2d Foot ...	0.00	0.08	0.08	8.68	46.75	44.40	99.99
3d Foot ...	0.00	0.11	0.14	8.04	52.01	39.70	100.00
4th Foot ..	0.00	0.06	0.05	6.10	50.24	43.45	99.90

This soil, a very fine sandy loam of the Ritzville series, is an average soil of the district. It is just on the border line of those types tending to drift, yet proper management will control that tendency. The great predominance of very fine sand and silt in its make up is evident. Physically, were it not for the tendency to blow, it would be an ideal dry farming soil. The wilting point of this soil is at a moisture content of about 3.8 per cent as determined after crop maturity, it being assumed that the crop, under the rather extreme prevailing condition, will remove the entire available moisture supply. When moist, this soil works into an ideal condition, but if tilled dry, the absence of clay and organic binding material causes a dusty, flour-like condition which is far from desirable.

The soluble salt content is high. This has a bearing on the availability of plant foods, and possibly on moisture relations. The continued efficiency of the soil mulch and certain problems in plow-sole formation are also influenced by this factor.

In essential plant food elements, this, and similar soils are reasonably well supplied. Potash and lime are abundant and phosphorus is relatively so. Nitrogen and organic carbon, the latter important chiefly because of its bearing on physical condition, are the soil elements most deficient.

INVESTIGATIONS

Much investigational work has been reported which covers ground similar to that of this bulletin. The most of this work, however, has been done under comparatively favorable dry

farming conditions, and suggestions based on such experimental results have not always applied under lighter rainfall.

The period covered by the experiments herein reported has been one of abnormally low rainfall with frequent, drying winds. (See Tables 2 and 3). This extreme condition has given prominence to the operation of certain principles, which it is believed are masked, if operative at all, under a more abundant moisture supply and a lower rate of evaporation. A study of climatic data indicates that as dry a period of similar duration may not immediately reoccur on the Adams Experiment Station, yet the condition is continuous in some of the drier sections of the state, and is of more or less intermittent occurrence in all localities.

All of these facts justify the offering of data covering a more limited time than might otherwise seem desirable.

FIELD OPERATIONS AND STUDIES

Field work in these experiments was done on two series of one-twentieth acre plots. These plots were alternately fallowed and cropped, one series being in fallow and one in crop each year. All were treated the same, except in preparing and maintaining the fallow. It was originally intended to use winter wheat in cropping, but seasonal conditions prevented adherence to this plan. The crops of 1918 and 1920 were spring wheat, Early Baart (Wash. 326), and that of 1919 was winter wheat, Turkey Red (Wash. 326). However, there is nothing in the data secured which indicates that this variation has in any way materially changed results.

Local practice limits tillage of the fallow after plowing to that necessary for weed control. In these experiments, the one variation from this practice was in the use of the spring-tooth harrow immediately after the plow, except in special cases, which are noted. A home-built weeder of the rod or bar type was used in controlling weeds. This was used twice each summer. Later, scattering weeds were cut with a hoe, this being the practice of the community. All plots were harrowed just previous to seeding. A hoe drill was used in this

latter operation, the ridging effect of this implement making it superior to other types for use on soils tending to blow.

A record of yield and other agronomic data was taken for each plot.

Tillage variations are given in the tabulation of data. (See Table 13).

SOIL SAMPLING

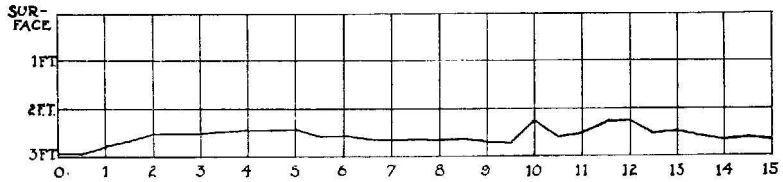


Figure 3. This diagram represents the penetration of moisture in a field soil on the Adams Experiment Station, March 7, 1921. Measurements were taken on the wall of a trench 15 feet long and 4 feet deep. It illustrates the necessity of taking soil samples to a standard depth well below the average depth of moisture penetration, and also the necessity of taking a comparatively large number of samples to secure reliable composites. In taking soil samples below the depth of moisture penetration, great difficulty is experienced in withdrawing the dry soil with an ordinary soil auger. Figure 4 illustrates a special auger used in this work.

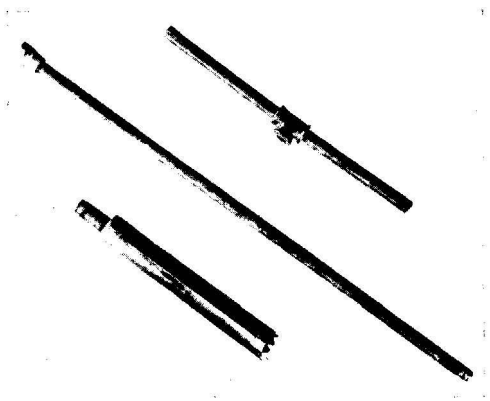


Figure 4. A Soil auger designed by the junior author, for taking samples in sandy soil types in the dry condition. This is a very satisfactory instrument.

MOISTURE AND NITRATE STUDIES

To determine as nearly as possible the cause of yield variations, moisture and nitrate-nitrogen data were secured each year, in the spring at the beginning of the crop season, and in the fall after the crop was removed. The end result is the true measure of the efficiency of any method or system, and the soil content of moisture and nitrate-nitrogen, at the beginning of the crop season after the year of fallow, are the most important data in this case. Limited facilities prevented more detailed studies.

Soil Sampling

One of the most prominent difficulties in soil investigations lies in sampling (3, 4, 5). In these studies, samples were taken on each of the two opposite end areas of the one-twentieth acre plots, the plots being 132 feet by 16.5 feet. Not less than three, and usually four borings were made in each area. Composites were then made by thoroughly mixing the entire mass of all borings to represent each area. Analytic determinations were made from these composites, the closeness of checking of the results from the two areas determining the necessity of further sampling. Sampling was continued until satisfactory checks were secured.

Moisture penetration in a field soil under dry farming conditions is not regular and uniform (see Figure 3), and it is not possible to take samples only to the depth of moisture penetration and secure results at all satisfactory. Accordingly all samples were taken to a uniform depth of four feet, this being well below the depth of average moisture penetration during the period of these experiments. This depth was also satisfactory for nitrate sampling, since the nitrates correspond in location to the soil moisture and are not found in appreciable amounts below the depth of moisture penetration.

The presence of a growing crop modifies soil condition and increases the probability of error. This is especially true of wheat after it has begun to tiller, the error before this period from crop influence being negligible. All sampling for these studies was done before the crop began to grow actively.

Analytic Methods

The moisture content was determined by drying 10-gram samples of the well mixed composites in an electric oven. The field soil on the station farm weighs 75 pounds per cubic foot on a moisture free basis. Using this weight, soil moisture was calculated in tons per acre to a depth of four feet.

Nitrate determinations were made by the phenoldisulphonic acid method (6) with modifications. This method has been questioned, but it is the best at hand for a study of this nature. The large number of samples to be run in a limited time make the simplicity and rapidity of the method strong factors in its favor. This is especially true on a branch station where laboratory help is limited. In any case, the probable error of field sampling (3, 4, 5) is greater than that of any method of analysis, and comparative data are the best that can be expected.

EXPERIMENTAL DATA

The use of the data secured in formulating conclusions might be questioned because of the comparatively slight spread observed in many instances, and because of discrepancies that occur. The low rainfall, however, naturally tends to bring all results to a more nearly common level, and percentagely the differences are as large as are found with better yields. Slight differences, if isolated, are not a valid basis for conclusions, but in this case, where there are a comparatively large number of slight variations all pointing in the same general direction, it seems justifiable to use the data in developing at least general principles, provided not too great an emphasis is placed on detail. Unexplained discrepancies emphasize the need for additional investigation.

Yield data are more inconsistent than any other secured. There is a broad general relationship between grain yield and total soil moisture, and between straw yield and total soil nitrate-nitrogen, but unexplained exceptions are so frequent that by themselves yield data are not a valid basis for determining the real effect of tillage variations. Yield is the sum total result of all factors, and the factors are so little understood under dry farming conditions that apparent discrepancies are not always explainable. In interpretation, therefore, moisture, nitrate-nitrogen, and yield data must all be considered.

In discussing practice in presenting the data, there are certain facts of universal knowledge which are taken for granted and are assumed in any discussion. Any practical farmer knows without it being specifically mentioned that **the fallow must be kept clean.**

In the presentation and later discussion of data it is intended to develop principles of moisture conservation, based on the data, and this point of view should not be confused by the reader with the management side of the problem. A statement of the superiority of any specific method in conserving moisture may be correct and necessary for a complete understanding of the operation of a given principle under all conditions, and yet the method from a management standpoint may be undesirable for various reasons. Where objections exist to any method or system from the management side of the problem they will be mentioned, but they will not be stressed in this discussion.

DATE OF PLOWING FOR FALLOW

The date of plowing is important, both directly in its effect on crop yield and indirectly in the distribution of labor.

It has been pointed out that variation in soil type and the amount of rainfall are general within the area covered by the discussions of this bulletin. (See Table 1 or Figure 3). It is necessary, therefore, in applying conclusions based on these data to the entire area, to consider the data from the standpoint of soil and climatic condition and the part that variation in such condition has had in the result.

Date of plowing should not be considered only as a matter of time, but rather as a matter of soil and climatic condition. The fall dates of plowing represent dry and wet plowing with a major moisture absorption period immediately following the plowing. The spring dates represent plowing done after the moisture absorption period is partially or completely passed for that season, and with a succeeding period of high evaporation before another major absorption period comes.

Each spring date is a variation within this variation. March 1st plowing is plowing done when the moisture content of the surface soil is largest in amount, early enough that evaporation is not as rapid as somewhat later, and while moisture is still falling on the newly turned soil. June 1st plowing represents the other extremes, the soil being dry, evaporation at a maximum, and rainfall having practically ended for the season. April 10th plowing is intermediate between the other two. At this date, total soil moisture is still practically as high as at the earliest date, but evaporation is more active and the plow layer is less moist and dries more quickly after turning. Less moisture also falls on the newly turned soil.

DATE OF PLOWING FOR FALLOW

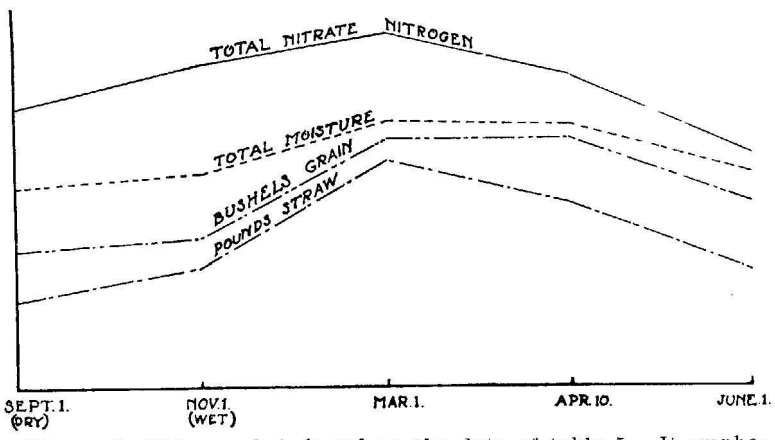


Figure 5. This graph is based on the data of table 5. It emphasizes the necessity of early spring work in preparing the fallow. It also shows that relationships exist between date (or condition), the basic soil factors, and yields. Grain yield more nearly parallels soil moisture content and straw yield the soil content of nitrate nitrogen. This indicates the greater relative importance of this latter factor under more favorable conditions.

These various considerations are not so important in the immediate presentation of the date as in later discussion, but are given at this time to emphasize the factor of condition in its bearing on all results. This will be developed more completely hereafter.

Table 5: Total Soil Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Plowed on Different Dates. (Three Year Average)

Date of Plowing	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Straw	Grain
	Tons	Pounds	Bushels	Pounds
September 1st	521	66.8	6.6	350
November 1st	536	75.4	6.8	385
March 1st	589	82.2	9.0	500
April 10th	590	73.7	9.0	455
June 1st	534	55.9	7.3	380

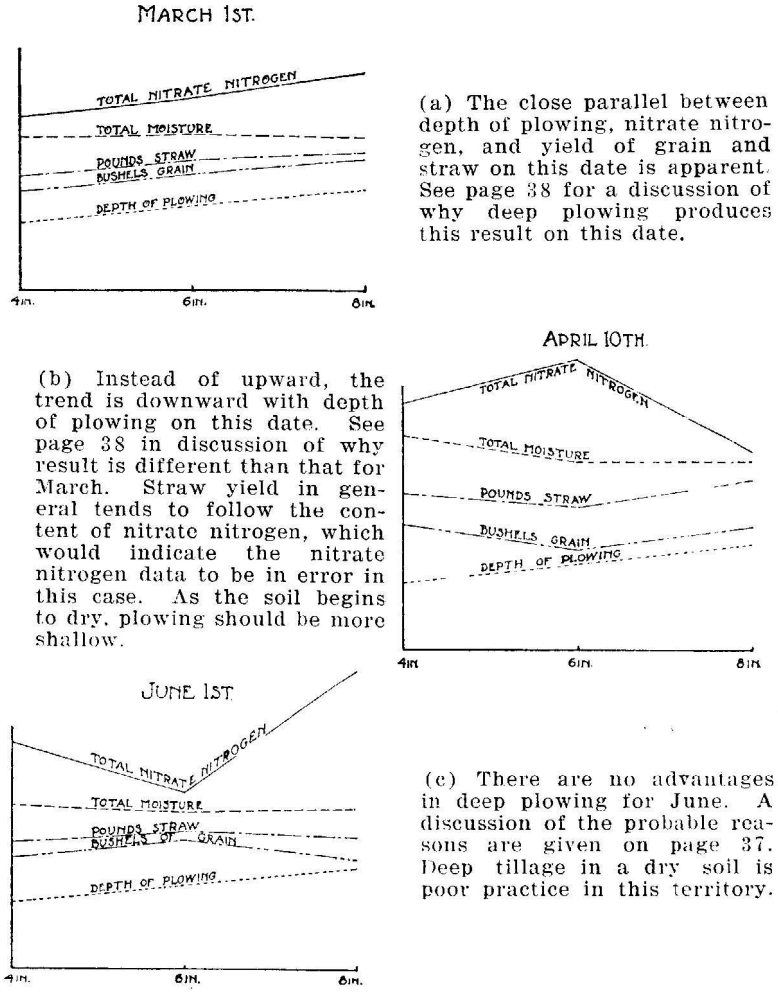
In an analysis of these data, current opinion might well be considered. Early workers, almost without exception, advocated fall plowing of fallow, supposedly to insure absorption of winter precipitation and any beneficial effects that might accrue through alternate freezing and thawing of the plow layer. Widtsoe (7) recommends, "In the very great majority of cases over the whole dry-farming territory, plowing should be done in the fall." Somewhat later Cardon (8) and others (9) (10) point out that fall plowing is not superior to spring plowing, either in storing moisture or in producing crops. This is opinion from those areas most similar to that under discussion in this bulletin.

In this experiment, fall plowing, either wet or dry, has not given as good results as spring plowing. This is true both in soil moisture content and in yield. Nitrate development, particularly for the late fall plowing, is comparatively good in the fall plowed soil. Why yield has not at least equalled that of the late spring plowing is not entirely clear, but is probably due to the fact that the particular soil type tends to develop a somewhat run-together condition when worked up and allowed to stand over winter. Even with very careful tillage the following spring the influence of this condition may be more or less persistent. At any rate, the result corresponds to farm experience in this district.

Of the spring dates of plowing, the first two show practically equal results in soil moisture content and in grain yield. In nitrate-nitrogen content and in straw yield, the earliest plowing is superior. This means that in a season of more abundant rainfall, the earliest plowing has the founda-

tion for better grain yields as well. It is very evident that the latest spring plowing is inferior to that of the other two spring dates in every respect.

DEPTH OF PLOWING FOR FALLOW



(a) The close parallel between depth of plowing, nitrate nitrogen, and yield of grain and straw on this date is apparent. See page 38 for a discussion of why deep plowing produces this result on this date.

(b) Instead of upward, the trend is downward with depth of plowing on this date. See page 38 in discussion of why result is different than that for March. Straw yield in general tends to follow the content of nitrate nitrogen, which would indicate the nitrate nitrogen data to be in error in this case. As the soil begins to dry, plowing should be more shallow.

(c) There are no advantages in deep plowing for June. A discussion of the probable reasons are given on page 37. Deep tillage in a dry soil is poor practice in this territory.

Figure 6: The three graphs of this figure are based on the data of table 6.

DEPTH OF PLOWING FOR FALLOW

Depth of plowing is important from two standpoints, the effect on yield and the cost of plowing. On this question farm opinion varies more than on any other, although there is apparent a growing tendency to plow less deep.

Many of the current ideas of what is good dry farming practice are the outgrowth of humid farming. Because of their experience under humid conditions, it is very difficult for many thorough and careful farmers to reconcile shallow plowing with "good farming." Yet after all, "good farming" is a relative term, and any practice is "good farming" if it produces consistently better results.

Three depths of plowing, four, six, and eight inches, on each of the three spring dates, are included in this experiment. Four inches is about an average of shallow plowing in actual practice. Eight inches is used as the other extreme because prevailing soil types would not seem to need excessively deep stirring. Six inches is intermediate and about an average in prevailing field practice.

Table 6: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Plowed at Different Depths on Different Dates. (Three Year Average)

Date and Depth of Plowing	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
	Tons	Pounds	Bushels	Pounds
March 1st—				
Four inches	591	75.1	7.9	430
Six inches	609	78.0	8.4	485
Eight inches ...	608	82.2	8.9	510
April 10th—				
Four inches	608	73.1	8.6	425
Six inches	569	79.5	7.9	405
Eight inches ...	569	66.0	8.5	445
June 1st—				
Four inches	538	57.9	7.3	375
Six inches	529	50.7	7.8	405
Eight inches ...	541	69.1	7.3	395

Early opinion on depth of plowing for fallow is summarized by Widtsoe (7), "Deep plowing is always to be recommended for successful dry-farming," deep plowing being elsewhere designated as eight inches or over. Cardon more recently states (8), "With the data available, however, the question

seems to be not so much how deep to plow as how well to plow." Stephens (9) finds in favor of shallow plowing (four or five inches) for spring wheat, the plowing being designated as early and April 1st being the date of other early plowing in the same series of experiments. Others (10) (11) seem doubtful of the necessity for deep plowing.

In comparing the above data it is apparent that variations in soil moisture content as affected by depth of plowing, are not the same for all dates of plowing. Deeper plowing has been most efficient in moisture conservation on the earliest date, while the reverse has been true on the intermediate date. For the late date there has been practically no differences, but the general result is similar to that of the intermediate date. It is true that in no case is the spread large, but the differences are consistent and have been similar during the whole period of the experiments.

The results of this experiment explain why farmers in the drier localities tend to plow more shallow, and offer an interesting comparison of the effect of condition, as influenced in this case by date, on the result of a given operation. To apply these results, condition must be taken into account. In terms of condition, the earliest date is similar to the average of the more favored dry farming districts, and the intermediate and late dates are similar to the drier localities.

Nitrate-nitrogen content and yield are less clear cut in their relation to depth of plowing than is moisture content. For the earliest date, there is a regular increase in both nitrate-nitrogen content and in yield with increase in depth of plowing, but for the two later dates there is no apparent relationship. The latter data are chiefly valuable in emphasizing the fact, that deep plowing offers no advantage for the less favored conditions.

HARVEST DISKING BEFORE FALLOW

Disking immediately after harvest to kill weeds and to create a mulch, supposedly favorable for moisture absorption, has been universally advocated from the earliest days of dry farming. From a theoretical standpoint this practice would seem to rest on a firm foundation for all conditions, which

experimental evidence has shown it does in certain cases (15), but local experience has not confirmed this assumption as applying in central Washington.

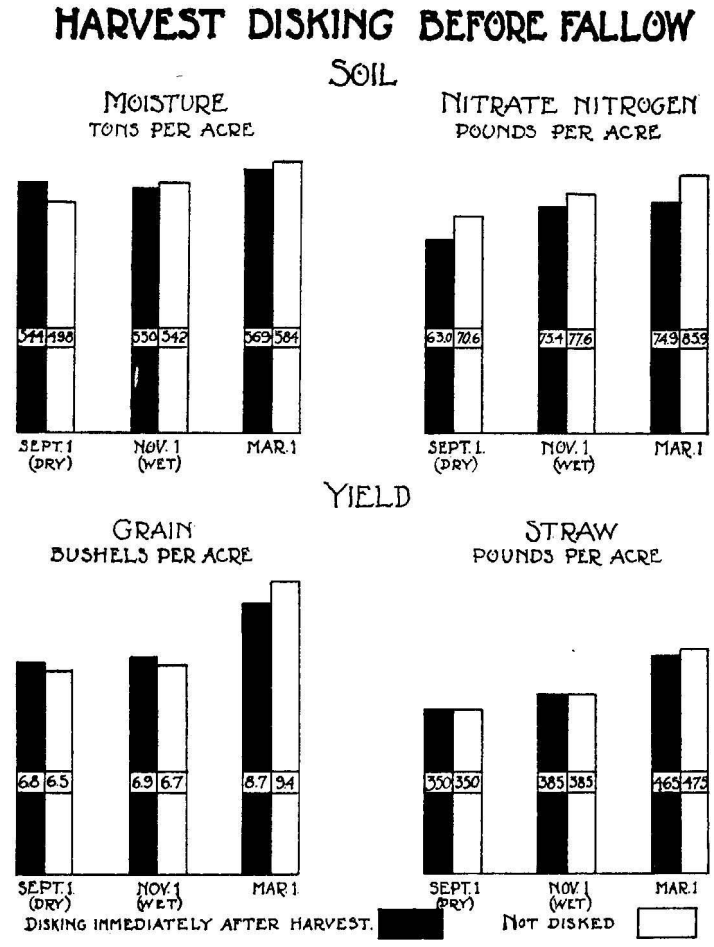


Figure 7. This graph is based on the data of table 7. It compares harvest disking previous to plowing with no disking for three dates of plowing, two in the fall and one in the spring. The disking was beneficial before the dry September 1st plowing, but this in itself gave poor results. The dry work, either disking or plowing, is indicated by the graph to be poor practice. A discussion of dry disking and plowing and the reasons for their detrimental influence for the particular conditions of this district are given on page 36.

Table 7: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without Previous Harvest Disking. (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed Sept. 1—	Tons	Pounds	Bushels	Pounds
Harvest Disked	544	63.0	6.8	350
Not Disked	489	70.6	6.5	350
Plowed Nov. 1—				
Harvest Disked	530	73.4	6.9	385
Not Disked	542	77.5	6.7	385
Plowed Mar. 1—				
Harvest Disked	569	74.9	8.7	465
Not Disked	584	83.9	9.4	575

Comparing the data for soil disked immediately after harvest and plowed dry September 1st, with that for soil not disked and also plowed dry September 1st, it is apparent that the former has a higher moisture content. It is reasonable to ascribe this advantage to killing weeds and so checking transpiration. On the other hand, when the November and March plowed plots of this treatment are compared in a similar way, the moisture advantage has changed. Except for the dry fall plowing, in itself poor practice, there seems, in this case, to be no advantage in disking stubble immediately after harvest. This agrees with farm experience and the findings of other investigators in this same general area (9) (10).

LATE FALL DISKING BEFORE FALLOW

If intending to disk stubble in the fall, the farmer has two alternatives. He may disk his soil while dry immediately after harvest, or he may wait until after fall rains and disk

Table 8: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without Previous Wet Fall Disking (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—	Tons	Pounds	Bushels	Pounds
Wet Fall Disked	609	78.0	8.4	485
Not Disked	599	82.2	9.1	485
Plowed Apr. 10—				
Wet Fall Disked	569	79.5	7.9	400
Not Disked	590	72.3	9.3	465
Plowed June 1—				
Wet Fall Disked	529	50.6	7.8	405
Not Disked	540	57.6	7.3	410

his soil wet. Harvest disking has been shown to be poor practice. Is wet fall disking advisable?

From these data, except that for total moisture for the March 1st plowing, there seems to have been a detrimental

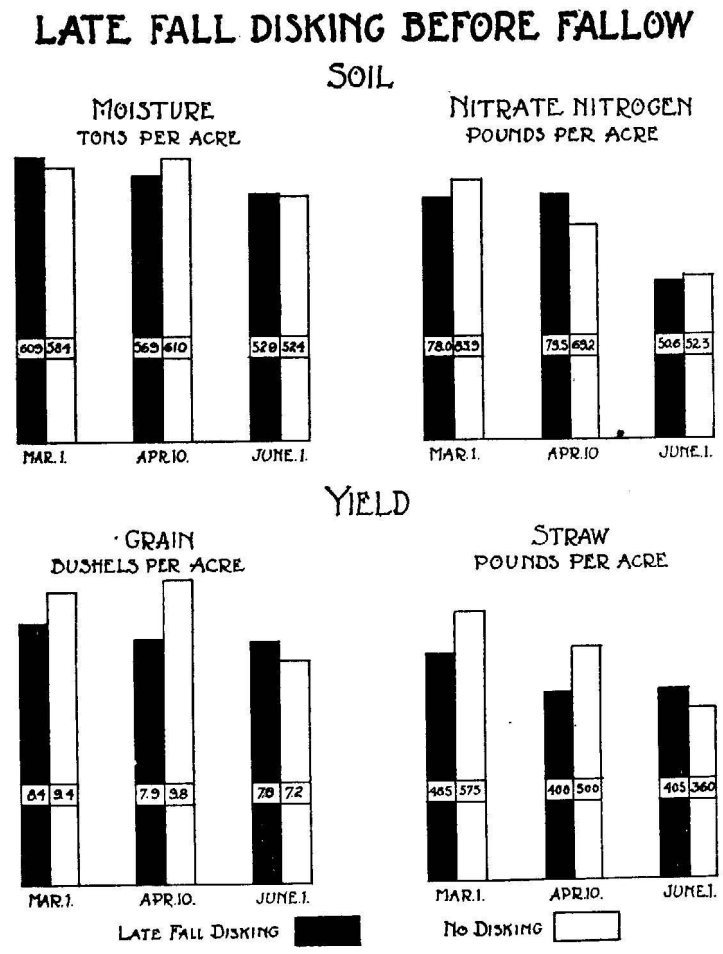


Figure 8. This graph is based on the data of table 8. It compares late fall disking previous to plowing with no disking for three dates of spring plowing. Results are variable, but at least indicate no advantage in favor of disking at this time. The date of spring plowing has more influence on the result than has the previous fall disking. Wet fall disking is discussed on page 40.

rather than a beneficial effect from the wet fall disking. Even in the case of the March 1st plowed plots, the grain yield indicates a possible error in the moisture date, for as previously

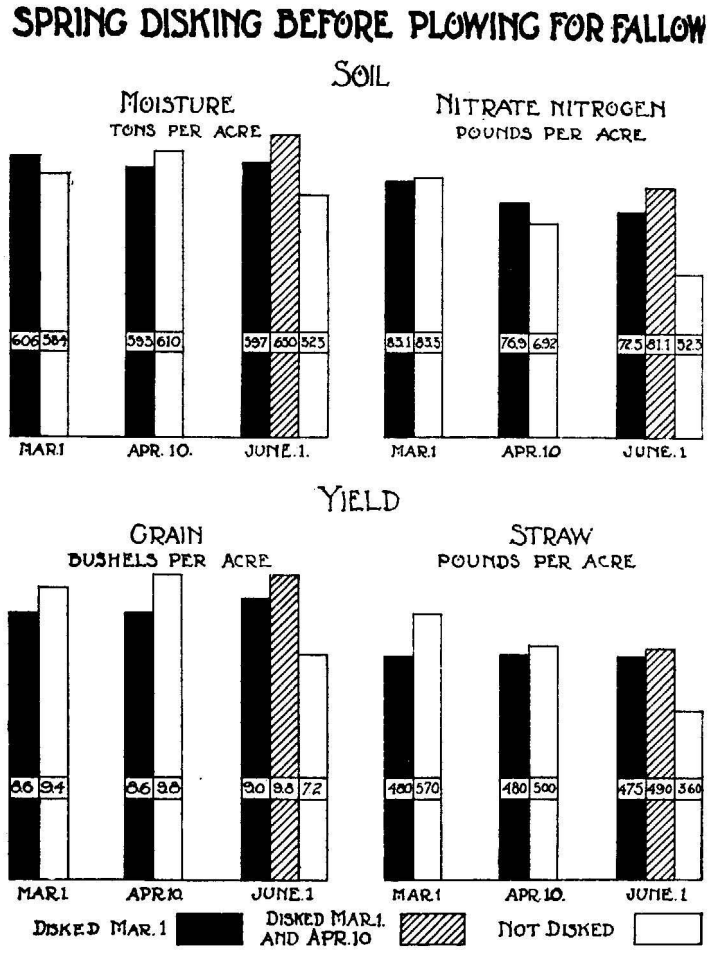


Figure 9. This graph is based on the data of table 9. It is a comparison of soils disked in the spring before plowing for fallow and those not disked. Disking has no advantage, except for late plowing, in which case an additional disking gives added benefits. The disking kills weeds and volunteer grain, and where the plowing date is so late that these drain soil moisture, it is good practice to disk. The shallow mulch of the disking does not interfere with absorption to the same extent as the deeper plowing.

pointed out there is a general relationship between grain yield and total moisture content. At any rate there has been, during the period of these experiments, no advantage in the practice.

SPRING DISKING BEFORE FALLOW

Spring disking, before plowing for fallow, has been advised for a number of reasons. The cutting up of weeds and stubble and their incorporation with the soil before plowing, the killing of early weeds and a delay in the plowing date to reduce the number of later weedings, and various effects in saving moisture where plowing must necessarily be, or is intentionally, late, have been advanced as arguments favoring the practice.

Table 9. Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow with and Without Previous Spring Disking. (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
	Tons	Pounds	Bushels	Pounds
Plowed March 1—				
Disked March 1	606	83.1	8.6	480
Not Disked	599	82.2	9.1	485
Plowed April 10—				
Disked Harch 1	593	76.9	8.6	480
Not Disked	590	72.3	9.3	465
Plowed June 1—				
Disked March 1	597	72.5	9.0	475
Disked March 1 and April 10	650	81.1	9.8	490
Not Disked	540	57.6	7.3	410

This experiment shows no advantage in disking before plowing for either of the earlier dates of plowing. For the late date of plowing there is a decided advantage even in one disking, and this advantage is increased by a second disking on an intermediate date.

Growth of weeds and volunteer grain make no serious inroads on soil moisture previous to the intermediate date of plowing, but after that time their influence is evident. The benefit of the second disking probably lies both in weed control, and in the retentive qualities of the mulch. This lat-

ter consideration will be discussed more at length hereafter.

From the standpoint of effect on yield and moisture conservation, the spring disking and late plowing has been the most efficient system practiced on the station farm. In practical operation, on light soils, the system has disadvantages. Late plowed soil settles less than earlier plowing, has fewer clods and is pulverized more completely, and as a result is more inclined to blow. The use of the system should, therefore, be restricted to districts where soil blowing is not a problem.

IMMEDIATE VS. DELAYED CULTIVATION AFTER PLOWING

It is commonly recommended that the plow be immediately followed by the harrow to smooth and firm the soil, to work down irregularities, and to create a surface mulch. In the western portion of the area covered by the discussions of this bulletin, where soils tend to blow, farmers do not stir the soil after plowing until absolutely necessary to control weeds. The ordinary smoothing harrow pulverizes the prevailing soil types very completely and its use should be discouraged for this particular condition. Whether the after tillage should be discontinued if a more suitable tool could be used is not so clear. Delay in cultivating after the plow is also practiced under conditions where working down and firming the

Table 10: Total Soil-Moisture, Total Nitrate-Nitrogen and Yield for Summer-fallow With and Without Immediate Tillage After the Plow. (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—				
Immediate Tillage	584	83.9	9.4	575
Delayed Tillage	599	82.2	9.1	485
Plowed April 10—				
Immediate Tillage	610	69.2	9.8	500
Delayed Tillage	590	72.3	9.3	465
Plowed June 1—				
Immediate Tillage	524	52.3	7.2	360
Delayed Tillage	540	57.6	7.3	410

soil has a tendency to start early weed growth, the farmer, in this case, desiring to delay such growth in order to reduce

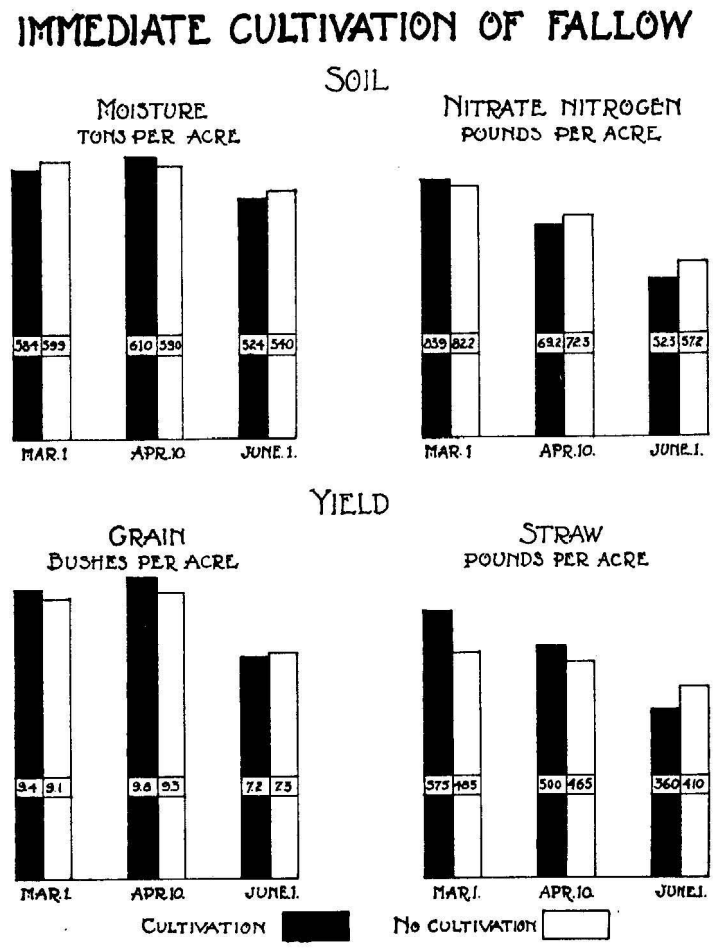


Figure 10. This graph is based on the data of table 10. It compares immediate and delayed cultivation of fallow on three spring dates. Except for the June plowing, which is so dry that the additional tillage has no settling effect, there seems to have been a slight beneficial result from the practice. The settled condition tends to give better absorption, and is especially desirable for the earlier dates when some moisture can still be expected before the dry summer season. On heavier soils with more abundant spring moisture, immediate tillage may be desirable. On light soils under more dry conditions, it has no place.

the number of necessary weedings and to delay the weeding operation until a time when other work is less pressing.

In this experiment, the plow was followed by a spring-tooth harrow. This tool ridges the soil, brings clods to the surface, and produces a condition more suited to resisting the wind than does any other available implement.

The 1918 moisture determinations for the plot plowed March 1st and given immediate tillage were for some reason in error, being undoubtedly too low, and their lack of accuracy was not checked until too late to run again. This causes a discrepancy in the moisture data for the March 1st treatments, but yield and other data indicate the probably true condition.

With the exception noted, for the earlier dates, immediate tillage results in a higher moisture content and in better yields both of grain and of straw. For the late date, the conditions are reversed or practically equal.

SUB-SURFACE PACKING OF FALLOW

A seed bed for cereals should be reasonably firm and the use of some implement to firm the plowed soil has been advocated as a necessary adjunct in dry farming. The sub-surface packer, invented by H. W. Campbell, and known as

Table 11: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow With and Without the Sub-surface Packer (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Plowed March 1—				
Packed	597	91.7	9.4	515
Not Packed	607	83.1	8.7	480
Plowed April 10—				
Packed	614	80.2	9.9	515
Not Packed	593	77.0	8.7	485
Plowed June 1—				
Packed	597	73.6	8.9	460
Not Packed	597	72.5	9.0	475
*Plowed June 1—				
Packed	628	80.6	8.7	475
Not Packed	650	81.1	9.8	460

*All plots in this experiment were disked March 1st, the plots of this treatment receiving a second disking on April 10th.

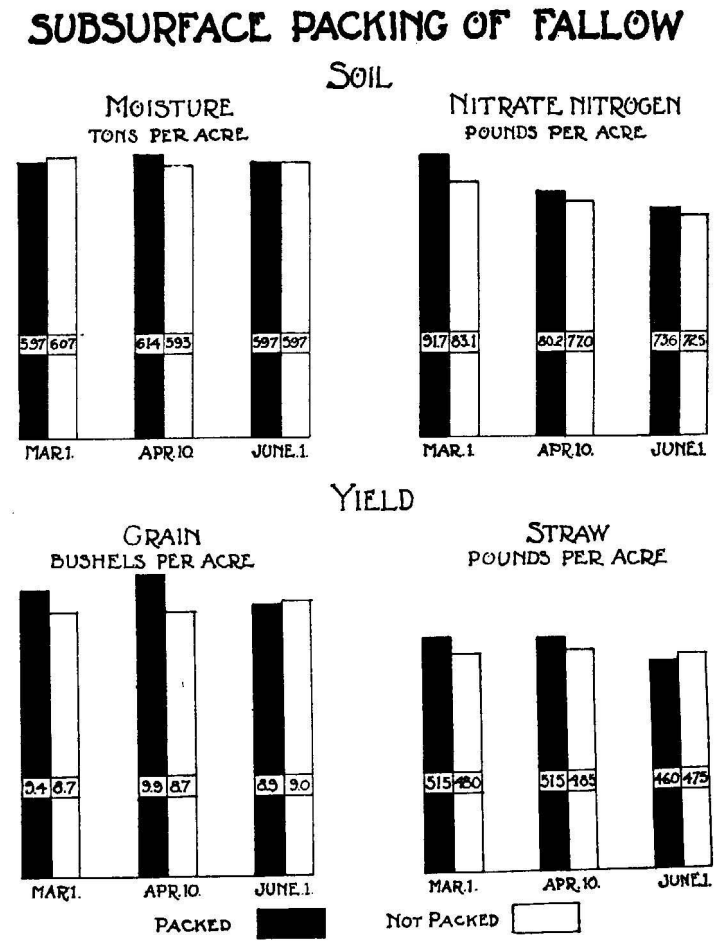


Figure 11. This graph is based on the data of table 11. It compares packed and unpacked fallow on three dates of spring plowing. On the two early dates packing promotes soil contact, and gives better absorption. Because packing makes necessary more tillage for weed control, the practice is not advisable on light soils because of probable soil blowing. On heavier soils with a better moisture content, the packer is less needed. Its practical use is doubtful. This data is useful, however, in adding emphasis to the advantages of soil contact in moisture absorption. This is discussed on page 40.

the Campbell packer, has been most widely recommended for this purpose. That it has not become of general use indicates at least doubt of its utility. American investigators as a rule have not found the tool useful, Stephens (9), among others, reporting its use as not beneficial in the Oregon section of the Columbia Basin dry farming area.

In this experiment, the packer, weighted to a load of thirty pounds per wheel, was used immediately after the plow, and was followed at once by the spring-tooth harrow.

The data indicate a certain benefit in using the packer on the first two dates. There is a discrepancy in the moisture data of the March 1st plowed treatments, which do not check with yield, but with this exception, the advantage holds for all factors. For the late date, there has been no corresponding benefit.

In practice the utility of the packer is doubtful. More work is required in controlling weeds on soil where the packer has been used, and on light soils the additional tillage tends to develop drifting. It is often suggested that the packer be used to firm the soil and so hold moisture near enough the surface to insure fall seeding without rains. On heavier soil types especially, the use of the packer develops a condition very similar to the plow-sole mentioned on page 45, and unless this condition is corrected by frequent tillage the soil will actually dry more deeply than if the packer is not used. This frequent cultivation tends in turn to unduly fine the surface soil, and there occurs a running together and cementing effect during the winter following the summer of fallow which is very undesirable. As suggested hereafter in the discussion of principles, the benefits of the packer can be secured by other and safer methods. In addition to these factors directly affecting soil condition, there are other considerations, such as costs, which have a bearing on the use of any method or implement and which, in this case, are against the use of the packer.

The chief value of these data is in emphasizing certain principles involved in moisture conservation, which will be developed and discussed hereafter.

DISKING VS. PLOWING FOR FALLOW

Where moisture is a very extreme limiting factor, and yields in no case can be large, it may be necessary to reduce production costs to a minimum. On blowing soils it may also be advisable to leave plant residues on the surface, rather than to plow them under. Under such conditions, if crop return is at all equal, disking might take the place of plowing in preparing the fallow.

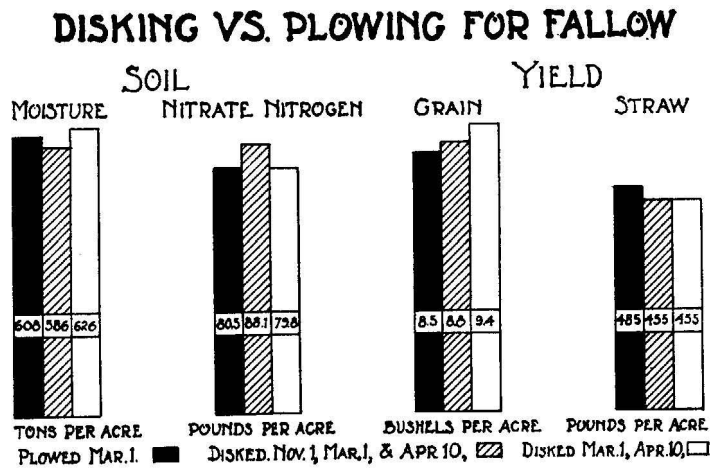


Figure 12. This graph is based on the data of table 12. It compares disking with plowing in preparing the fallow. Plowing has had no advantages over disking during the dry period of this experiment, the latter having the highest average moisture content. This result emphasizes the fact that the detrimental effect of a mulch on absorption is proportional to its depth, see discussion on page 40. "Good farming" does not depend on the use of any particular tool, but rather on developing and maintaining certain soil conditions.

Table 12: Total Soil-Moisture, Total Nitrate-Nitrogen, and Yield for Summer-fallow Prepared by Plowing, by Fall and Spring Disking, and by Spring Disking (Three Year Average)

Treatment	Total Soil Moisture	Total Nitrate-Nitrogen	Yield per Acre	
			Grain	Straw
Disked Nov. 1, Mar. 1, and Apr. 10	586	88.1	8.8	455
Disked Mar. 1 and Apr. 10	626	79.8	9.4	455
Plowed Mar. 1	597	89.0	9.2	475

Through accident, the yield data of the plot given fall and spring disking in preparing the fallow were lost in 1918. For that reason, the yield of this plot for that year has been interpolated. (See Table 13).

During the past three seasons, the average efficiency of disking in preparing the fallow has been equal or slightly superior to that of plowing. This is true in yield, in moisture conservation, and in nitrate development.

MOISTURE CONTROL IN DRY FARMING

Theories of moisture conservation, based on experimental work or experience elsewhere, have not always applied in this area. A study of the foregoing data suggests the reason.

The data shows that varying conditions within and without the soil, variation being due to the influence of date of operation or method of treatment, modify results, and justify differences in practice. (See Depth of Plowing, Table 6). It is, therefore, reasonable to assume the necessity of equal variation in practice under the even wider range in condition found from place to place (See Table 1 and Figure 2), or even from year to year for a given location. (See Tables 2 and 3).

To apply the results of these experiments, and to understand how and why practice should vary, requires a discussion of the principles involved.

SOIL MOISTURE

Moisture conservation is the chief consideration in determining most dry farm tillage operations. The factors concerned are the **absorption** of water and its **retention.**

Moisture enters the soil, both by gravity carrying the free water into the open spaces of the soil, and by capillary movement. Gravity is most active when water is present in large enough quantity to fill the pore spaces of the soil. Under ordinary conditions water is present in dry farming soils only in the form of more or less thin films covering the surface of the soil particles. This film moisture, when present in any quantity greater than the limited amount found in all air-dry soil which limited quantity need not be considered in this

discussion, is known as capillary moisture. This is the most important form of soil moisture from the standpoint of crop use. Capillary moisture moves from a more moist soil to a less moist one, within certain limits, until equilibrium is established (12) (13). Movement may be in any direction. After a rain, when the immediate surface soil is very moist, movement is downward. Later, when evaporation has dried the surface, movement may be upward. A firm soil having many points of contact between soil particles is most favorable to capillary movement of moisture. A loose and open structure, having fewer points of contact, tends to decrease movement. When a soil dries beyond a certain point, movement of moisture from a more moist soil to it is very slow (14). It is a matter of observation that a very dry soil absorbs moisture less readily than one more moist (15).

A combination of all the above factors is the theoretical basis for stirring the soil to prevent the upward movement of soil moisture and its loss by evaporation. This is the theory of the soil mulch. Under conditions of extreme evaporation, soils quickly become very dry at the surface and tend to naturally mulch themselves (14).

Absorption

Where precipitation occurs normally as heavy down-pouring rain, as more gentle rains large in quantity, or as heavy snows with large run-off, the soil surface condition most favorable for moisture absorption is a rough and open one (15). Such a surface holds the water until gravity and capillary movement can carry the largest possible amount of it downward into the soil.

Where precipitation is light, and comes regularly as gentle rains, with very seldom enough water to stand or run on the surface, gravity plays a more unimportant part, and **capillary movement, or conductivity, is the important factor in moisture absorption.** From the previous discussion of capillary movement, it is clear that a more firm soil condition favors moisture absorption in such a case.

A light, gentle type of rainfall is characteristic, either in

whole or in part, of the dry farming districts of the state of Washington. Evaporation is also active, which makes the rapidity and depth of moisture absorption of very important consideration in saving this moisture for crop use.

Tillage Practices as They Affect Moisture Absorption

The moisture problem of the fallow year begins with the removal of the previous crop. At this season, following the long dry summer, all soils in this district are practically air-dry at the immediate surface, and a cropped soil is at the wilting point to the entire depth of root penetration. The behavior of this dry soil in absorbing and retaining moisture is one of the important factors in determining tillage practice.

Weeds have a very important bearing on the moisture problem, and their control is one of the chief functions of tillage. Burr (15) found, that for Nebraska conditions, harvest disking materially added to the soil moisture supply. Examination of the data in Table 7, or of Figure 7, shows, that under conditions as found in these experiments, dry harvest disking also saved a certain amount of moisture. Soil so disked had a higher moisture content than soil not disked, when both were plowed (September 1st, dry) before other moisture had fallen. However, further study of the same data tells another story. Where such dry disked and undisked soil was allowed to stand until after rains fell before being plowed (November 1st and March 1st), the difference in moisture content favoring the disked soil was first equalized (November 1st plowing) and then reversed (March 1st plowing), the undisked soil being finally the superior in that respect. A study of Table 5, or of Figure 5, where soil dry plowed (September 1st) is compared with similar soil plowed after the fall rains (November 1st and March 1st) tells the same story. In both cases the final moisture content favors the soil left unstirred through the period of moisture absorption. This moisture advantage of the unstirred soil must be due to the dry, loose soil being less efficient as an absorbing agent than is the same dry soil in a more firm, unstirred condition. The absorptive advantage of the unstirred soil is great enough, in the first

case, to more than make up the original saving in moisture due to killing weeds.

Laboratory data, secured by the authors in studies not yet completed, indicate that the depth of penetration of a given amount of moisture is practically equal in the loose and in the compacted soil from the station farm. The difference, in the two cases, lies in the percentage of moisture to soil, which is much higher in the loose soil than in the compacted. This means that moisture films are thicker, immediately after a rain, in a loose surface soil than in an unstirred one. As a result drying winds more easily remove newly fallen moisture from the dry disked or plowed soil than from the same soil in the undisturbed condition (16) (17). Succeeding rains falling on the two soils will be conducted more deeply into the more firm soil because of better moisture content (18), this finally, as a result of collective additions following a number of rains, outstripping the loose soil in total moisture. In field practice, it has frequently been observed in plowing across disked and undisked soil in the fall, that under a disked mulch the soil is dry, while that previously unstirred is moist enough to be in good plowing condition.

The above principle applies in this area for tillage of dry soils on any date. With dry June 1st plowing (See Table 6, or Figure 6) it is operative during the fall and winter succeeding the summer of fallow.

The detrimental affect of the dry mulch on absorption is proportional to the depth of the mulch. This is shown in the generally superior moisture content of the shallow plowing over the deep plowing for all of the dates of dry plowing. There are exceptions to this generalization in the data, but they are not large enough or frequent enough to invalidate the conclusion.

As previously pointed out, the moisture content of the soil has a bearing on its capillary conductivity, and consequently on its efficiency in absorption. As the moisture content decreases and approaches the dry condition, it would be supposed that the soil should react in absorption more nearly like

the dry soil the nearer the approach to the dry state. It is important to understand the limits under which this principle is active. The soil moisture content, in addition to its direct affect on conductivity, also influences other soil physical conditions concerned in conduction. It is, therefore, necessary to consider other variations in soil moisture condition at the time tillage is performed and the ultimate result in absorption in order to arrive at a true understanding of the operation of this fundamental law.

The data on depth of plowing (See Table 6, or Figure 6) give the best comparison of the differences in result from a given operation due to a difference in the soil moisture content at the time the operation was performed. A comparison of the data for the three dates shows that the reaction to depth of plowing has been different for the early date and for the last two dates. On the early date the deep plowing is superior, while for the later dates the superiority rests with the shallow work.

At the early date of plowing, during these experiments, the moisture content of the plow layer has been higher than at any other period, being about 10 to 12 per cent, 12 per cent being close to the maximum capillary capacity of the soil type in a field condition. Evaporation at this season does not as quickly reduce the moisture content in the turned soil, in part due to the fact that rains are still falling in greater or less degree, and the soil settles or naturally firms comparatively more than when plowed under other circumstances.

Cameron and Gallagher (16) have shown that at a certain critical moisture content, which varies with soil type, drying a soil causes a sharp increase in soil volume, this progressive increase in volume with drying continuing until a certain lower moisture content is reached, after which there is no further increase in volume due to decrease in moisture content. As a corollary of this principle, an increase in the moisture content of a soil, when at its greatest volume, causes a decrease in volume within the same limits as occurs the volume increase. The work of these investigators also shows the critical moisture content to be that at which the soil is in best handling

condition, which in the case of the soil under study is about its maximum field capacity.

Applied to field conditions, the above principle means that when the moisture content of the plow layer is near the critical point, slight variations in either direction may give entirely different results in the settling of the turned soil after plowing. In the results of this experiment, at the earliest date of spring plowing, the moisture content has been such that a maximum volume decrease or settling was secured. Because of this settling, or natural firming, the deep plowing and the shallow plowing of this date have been comparatively alike in condition as far as soil contact and its affect on absorption are concerned. The result has been more nearly similar moisture content, other factors tending to favor the deeper work.

At later dates, as the soil in the plow layer becomes more dry, or dries more quickly after being turned, there is a natural tendency in conformity with the above principle to settle less after plowing. By the intermediate date, the soil moisture content has been reduced to a point, about 8 to 9 per cent, where an entirely different result is secured from tillage operations (See Table 6, or Figure 6). The soil is more loose after plowing and later reacts in absorption in the same manner as the more dry soil. The superiority of the shallow plowing of the intermediate date indicates that such is the case.

Rainfall during and succeeding the plowing period has a very important bearing on field practice as influenced by the above outlined principles, and determines the length of time over which the deeper plowing is equal or superior in result to the more shallow work. If later rainfall brings a soil tilled when comparatively dry back to the critical moisture content, the settling effect may practically equal that of a soil turned in a more moist condition. This of course varies with locality and with season, and under conditions more favored than those during the years of this study, might prolong the period well past the date chosen in this case for intermediate plowing. In any event, field operations should be governed, not by date, but by condition as it exists at the specified time, and must be

determined by an intimate knowledge of the individual locality.

The data covering date of plowing (See Table 5, or Figure 5) and wet fall disking previous to spring preparation of fallow (See Table 8, or Figure 8 and Table 12, or Figure 12) indicate that in these experiments nothing has been gained from stirring the soil in the fall. During the four years of this study, fall precipitation has been light, and while the soil was moist enough to plow well when given the wet fall treatments, the moisture content was not at a maximum, corresponding more nearly in condition to the intermediate date of spring plowing. As a result, settling was comparatively slight, and some time elapsed before contact and absorptive condition in the stirred soil equaled that in the unstirred, even though the period following the stirring was that of greatest precipitation. Had rainfall been greater, resulting in a higher moisture content at the date of plowing or disking, and in correspondingly greater settling and better contact, the result might have been different. This latter statement is of course conjecture, but conjecture based on results under a similar condition, and is interesting in that it suggests the necessity of considering condition in its effect on the outcome of a given operation no matter at what date the operation be performed.

In summing up the consideration of absorption in moisture conservation, the importance of one factor, the degree of firmness or soil contact, is apparent in all the data. It is shown in the effect of fall disking, either dry (See Table 7, or Figure 7) or wet (See Table 8, or Figure 8). It is shown in the different results secured from varying the depth of plowing on different dates (See Table 6, or Figure 6). It is shown in the better results from the immediately tilled soils (See Table 10, or Figure 10) and from the sub-surface packed soils (See Table 11, or Figure 11). It is shown in the superior moisture content of the disked fallow over that prepared by plowing (See Table 12, or Figure 12).

The data indicate that for conditions as they have prevailed during the period of these experiments, **absorption is the most important factor in saving moisture for crop use.**

Retention

The theoretical basis of moisture retention in field practice has been the loose soil-mulch. In theory, the mulch is held to break capillary connection between the surface and the underlying soil, so preventing upward moisture movement and consequent loss by evaporation. More recent studies tend to cast some doubt on the relative importance of the mulch in actually saving soil moisture. Call and Sewell (19) hold that, for Kansas conditions, evaporation is not less in the end from a mulched soil than from an unstirred one, and ascribe the beneficial effects of cultivation to killing weeds and to preventing run-off, rather than to retentive qualities in the mulch, and Harris and Jones (10) conclude that for Utah conditions the destruction of weeds is more important than the maintenance of a mulch in conserving moisture.

In this area, the season of moisture conservation is divided into two rather distinct periods, one of precipitation, during which absorption is of paramount importance, and one of comparative drouth during which retention is the major consideration. These two periods over-lap more or less, and the relative importance of the mulch in retention as compared with its detrimental effect on absorption, which has been pointed out, should be understood. In any case, the mulch, created during the dry period, persists into the next period of rainfall, so there can be no sharp definition of function in considering the mulch as such. It must be considered in both phases of its relation to the problem of moisture conservation.

The data covering the retentive affects of the mulch are less conclusive than those covering absorption, yet while probably too limited for definite conclusion, they do indicate that retention has a certain importance, aside from weed control, and should not be entirely disregarded in tillage operations.

During that portion of the absorptive period when plant growth is comparatively inactive, the data show that nothing is gained in moisture conservation by the creation of a mulch. This period extends up to and includes the intermediate date of spring plowing, as shown by the data covering date of

plowing (See Table 5 or Figure 5) and spring disking previous to spring plowing (See Table 9, or Figure 9). After the intermediate date of spring plowing, moisture losses are greater and tillage saves moisture. This is shown in the superior moisture content of the plots disked on the intermediate date and plowed in June as compared with the plots otherwise treated the same without the intermediate disking (See Table 9, or Figure 9). Weed growth, at the time of June plowing, has been very limited on plots disked at the earliest spring date, so moisture differences, in this case, cannot be ascribed wholly to killing weeds.

As additional evidence that the mulch does function in retaining moisture, the moisture advantage of the plots disked twice during the spring and plowed in June (See Table 9, or Figure 9) over those given spring disking only in preparing the fallow (See Table 12, or Figure 12) might be cited.

Previous to the intermediate date of spring plowing, the detrimental affects of the mulch on absorption outweigh or equalize its retentive qualities. After that date, or more properly condition, is passed, retention becomes relatively more important. Considering the problem from a purely moisture conservation standpoint, retention may be promoted and absorption, as it is concerned with the remaining spring rainfall, will not be seriously interferred with by a shallow mulch during this period. The feasibility of creating such a mulch is a matter of management to be decided by the individual operator depending on local conditions.

Later in the season, as temperatures become comparatively high and evaporation acts more rapidly than capillary movement of soil moisture, the soil tends to self mulch. During mid-summer and early fall, the artificial mulch is probably less necessary in retaining moisture.

In general, tillage for weed control must be given at or near the time when the mulch is most efficient as a retentive agent. It seems best, therefore, in practice, to limit all tillage for retention of moisture other than plowing to that necessary to control weeds.

SOIL NITRATE-NITROGEN

Moisture is the chief limiting factor in dry farm crop production, but soil plant food also affects the final result. The influence of tillage operations on plant foods should be at least partially considered before attempting a general application of principles.

The soil plant food element most influenced by tillage is nitrogen. Nitrogen, present in the soil in the form of organic or plant material, is dependent on the activities of certain bacteria, through a process called nitrification, to change it to the nitrate form used by plants. Nitrification under normal field conditions, is most active in the surface six to eight inches. Below the depth of one foot there is very little if any formation of nitrates. The temperature of the soil and the moisture content of the zone in which nitrification takes place are both important in promoting the process (20) (21). Any soil treatment which holds the moisture near the surface for the longest time during the warm period of the year most favors nitrification (22). In a fallowed soil this is best accomplished by maintaining a relatively firm condition with a comparatively shallow mulch.

A study of Figure 5 shows a great similarity in the curve representing total soil moisture and that representing total nitrate-nitrogen. With certain exceptions (See Figure 6), all other data tend to confirm this agreement. This relation is not a direct one, but is due to the fact that moisture conservation and nitrification are, for the particular conditions of this experiment, promoted by a similar soil condition. In this case, proper attention to moisture, the chief limiting factor, also insures the treatment best promoting nitrification.

A careful study of the data shows that, for the dry period of this study, grain yield has been proportional to total moisture and not to nitrate-nitrogen. This indicates that under such conditions, nitrate-nitrogen is not as yet, at least, a limiting factor. Straw yields, however, are affected by nitrate-nitrogen content, which of course indicates greater possibilities in grain yield for a higher nitrate-nitrogen content in a

season or locality of better moisture. This suggests that under better dry farming conditions, nitrate-nitrogen may be a limiting factor in production, and that, in such cases, more attention should be given to tillage as it has a bearing on nitrate development.

A more complete discussion of this factor is reserved for publications intended for use where nitrate-nitrogen does limit production.

INTERPRETATION OF THE DATA IN FARM PRACTICE

It is unwise to make detailed suggestions for applying specific methods under a wide range of conditions, when these suggestions are based on experimental work done under only one set of these conditions. Local variations in soil and climate may materially modify the operation of principles, and the most that can be done with safety is to point out a few of the most important factors involved, leaving the farmer to supply the details for his own particular locality.

The purpose of this bulletin is to develop the principles of moisture conservation concerned in all tillage practice under conditions such as prevail in the area covered. There are always considerations of management or economy which must be borne in mind in applying any principle to farm conditions, and in this case the superiority of any particular method in moisture conservation does not mean that it is economically feasible. The influence of the different variations in these experiments on the result of any given operation has been pointed out, and on this basis it is hoped the reader can interpret the data in terms of **conditions** and **principles,** rather than of methods or systems. If this interpretation be given, these experiments are usable over a much wider range than otherwise.

DRY FARMING IN WASHINGTON UNDER AN EXTREMELY DRY CONDITION

In the more dry districts of this state, farming has very large elements of risk. In favored seasons, yields are good and profits for that particular season are large; but average

yields are comparatively light, and without careful management, operation costs during poor years may be enough larger than income to more than balance the profits of better ones. For that reason, the expense of all operations must be kept at a minimum.

It is hoped the discussions of this bulletin will aid in understanding what is necessary tillage, and how the desired result may be secured with a minimum of labor and expense.

The data of the experiments show that a firm condition, or a modified firm condition, of the soil is most favorable in saving moisture. The degree and kind of firm condition desired depends on the period of the year.

In the fall, soil moisture is low in stubble ground, and little can be lost by evaporation. Weeds may take a certain amount, but not enough to off-set later losses from poor absorption if the soil is stirred while dry. Under ordinary conditions, **do not fall disk or plow, either wet or dry.**

In the spring, the moisture content of the surface soil is largest in amount and losses by evaporation are proportionately greater than at any other time. Tillage at this time, by killing weeds and by creating a surface mulch, lessens initial moisture losses. Because the soil is very moist, it settles and even after being stirred absorbs moisture comparatively well. On the light soil types prevailing in this region, it is very desirable that the surface be as cloddy as possible. Such a cloddy surface does not blow as readily as a more pulverized one, and the soil physical condition following rains is also better. Early tillage is best for creating the cloddy condition. **Prepare fallow as early in the spring as possible.**

Only a part of early tillage (plowing, disking, etc.) can be early enough to catch the soil when it is most moist. As the season progresses and the soil moisture approaches the lower limits at which the soil still plows well, tillage should be more shallow. **The lighter the annual rainfall, the more shallow should be the average depth of plowing or other tillage.**

In practice, continued shallow plowing results in the formation of a plow-sole just under the turned soil. Such a plow-

sole can be broken up by varying the depth of plowing. **Deep plowing is equal or superior to shallow plowing only in early spring.**

Soil blowing may modify tillage practice. The problem is not within the scope of this bulletin, yet brief attention should be given the question as influenced by the fundamentals of dry farming. The use of any method, which controls soil blowing, is good if the method also conforms to the principles of moisture conservation. The seriousness of the problem may sometimes over-shadow all other considerations, but moisture is still the factor which limits production after the blowing is stopped, and a method which merely controls the blowing without conserving moisture has not solved the problem.

Control of weeds on the fallow is essential. Tillage for this purpose should be the only tillage ever practiced when the soil is dry.

In determining tillage methods a careful study should be made of local conditions. Learn how these conditions affect absorption and retention of moisture. On this basis, determine how and when the least labor will produce the desired result. Reduce all tillage to the necessary minimum.

DRY FARMING IN WASHINGTON UNDER MORE FAVORED CONDITIONS

The same general principles apply as under the more arid conditions. Differences in soil type and rainfall (See Figure 2), however, give somewhat different results from tillage. Because of the more abundant moisture supply, practice has a wider range for variation without equally pronounced detrimental effects. In other words, operations that are distinctly detrimental under drier conditions may be only slightly so or not at all with greater rainfall.

A dry surface mulch acts exactly as it does under the more arid condition, so long as rains are not of sufficient volume to wet through the mulch. However, a greater rainfall more quickly penetrates the mulch and its detrimental affect is lessened and not so prolonged. Under the greater rainfall both the absolute and the proportionate inhibitory absorptive effect are less than in the drier districts.

The volume of precipitation and soil type have an important bearing in determining the advisability of fall tillage under the more favored conditions. As pointed out in the discussion of fall plowing on page 40, the moisture content of the soil determines very largely the physical effect of plowing, whether or not the soil settles, and its condition as affecting moisture absorption. If fall moisture is abundant, any soil will be in better condition for absorption following tillage, and fall plowing may be practiced with proportionately better results. With better rainfall, soil type is also usually heavier and the soil pulverizes less when plowed dry. This results in a condition not unfavorable for absorbing run-off from the melting snows. Any or all of these factors may be operative to the extent that the choice between fall and early spring plowing becomes one of management in getting all plowing done at the most favorable period.

There does not, however, appear to be a valid reason for either fall disking or plowing of fallow, provided the work can be done at the proper time in the spring. It may be argued that stubble and straw residues should be turned under in the fall, but the advantages of this are doubtful. Standing stubble prevents the blowing of snow from fields and checks the evaporative effect of winds. A heavy stubble is undoubtedly more efficient in saving moisture than is the stirred soil. There are exceptions to this statement, but it will hold true in the great majority of cases in this area. If stubble and straw must be worked into the soil before plowing, spring disking is as effective as is the fall work, and there are no possible detrimental results from stirring the soil at this time. However, as suggested above, the question of fall tillage is a matter of condition and of management, and must be decided by each individual farmer for himself each year, his decision being based on these factors.

When for any reason, spring plowing is to be delayed until after volunteer grain and weeds will have made considerable

growth, the soil should be disked early enough to prevent such growth. Experimental evidence shows that early disking and late plowing is a good system in conserving moisture, and it works well from a management standpoint in growing spring wheat.

For winter wheat very early spring plowing is preferable. A more settled soil condition is desirable than for spring wheat. This more firm soil holds moisture nearer the surface, and comparatively light fall rains allow seeding. Early spring plowing, at a time when the moisture content of the soil is high, favors the development of this condition with a minimum of subsequent tillage.

As suggested in outlining the limits for applying the conclusions of this bulletin, there are conditions in this state where the principal benefit of the summer-fallow is due to its effect on nitrification. The greater the rainfall, the more attention should be paid to this factor. In such cases, immediate tillage after the plow is desirable. Heavier soil types, in particular, do not break up as completely in plowing as is most desirable, and the additional tillage is necessary to work down inequalities. Without this stirring, such soils do not properly settle and tend to dry out more or less irregularly through the plow-layer. This checks nitrification. Immediate tillage after the plow is not always advisable, and local conditions may overbalance some of its advantages, yet as a general rule, the practice is desirable under the better conditions.

Weed control on the fallow is just as essential under more favored as under less favored conditions. Not only do weeds remove moisture, but they use the nitrates so necessary in producing the crop.

SUMMARY

1. The discussion of principles and conclusions are based on conditions as they exist in the state of Washington under a rainfall of 15 inches and less.

2. Under these conditions, moisture is the **direct** limiting factor in production, and the summer-fallow system of tillage for the conservation of moisture is necessary.

3. Moisture conservation depends on the **absorption** and the **retention** of precipitation.

4. Tillage operations should be planned to control absorption and retention in so far as this is possible.

5. In this district the regulation of absorption is the most important consideration in determining tillage methods.

6. With a light, intermittent rainfall, followed by drying winds, a comparatively firm soil condition most favors absorption and a loose soil condition hinders the process.

7. Under conditions where a loose soil is unfavorable in moisture absorption the detrimental affect is in direct proportion to the depth of the loose soil.

8. At a moisture content near the field capillary capacity for the given soil type, a soil tends to settle, or naturally refirm itself, to the greatest degree after stirring. Under such conditions, plowing or other tillage may be deeper without an equally deterimental affect on absorption.

9. At a lower moisture content, a soil tends to remain in a more loose condition after being stirred. As the moisture content of the plow-layer diminishes, plowing or other tillage should be more shallow, in order to avoid the detrimental affect of the loose soil on absorption.

10. The lower the average annual rainfall the more shallow should be the average depth of plowing. In general, depth of plowing should decrease with the advance of the spring season.

11. Retention of moisture is best accomplished by early spring preparation of the fallow and the control of weeds.

12. Variations in soil type and in the average annual rainfall give varying results from any specified operation or system. Each farmer should possess an intimate knowledge of local conditions in order to regulate operations properly and to apply principles accurately and in accord with best economy.

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