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The Utilization of Moisture on Heavy Soils of the Southern Great Plains.

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PART 1

INTRODUCTION

Experience of the problems of crop production has brought out a large number of superficial ideas relating to farm methods in the winter wheat belt of the southern high plains region. Some are useful and others are not, but very few of them are based upon a clear understanding of the relationships existing between important factors or upon the knowledge of the relative importance of various factors.

First among the current ideas on this subject is the notion that quantity of precipitation is of primary importance. A little more thoughtful expression would be that moisture is the limiting factor of crop production. In respect of the fact that moisture, an indispensible factor, is subject to more hazards than some others, for example fertility, that is probably true; but some very important factors make themselves felt mainly by their reaction on moisture though they are in the simple relationship independent of precipitation. An example is wind. It is the disposition of rainfall rather than fluctuation of quantity that governs production. (1)

The difference in moisture getting and moisture using efficiency of different types of soil, particularly light and heavy soils, is readily apparent. Whenever the crop is depending on current rainfall, drouth damages it on heavy soils long before it affects neighboring fields on sandy soil. It is popularly felt that much of the difficulty of handling moisture in heavy soils would be overcome if methods of culture could be devised which would enable a quicker penetration of moisture into the topsoil to avoid a portion of the great surface evaporation loss. A study of this problem shows briefly that while the object sought is soundly needed little can be done in a practical way to meet this requirement aside from contour tillage to prevent runoff and the maintenance of organic matter to promote ready absorption.

Another group of students accepts the hazards of variable seasons as a more or less fixed impediment and lay the emphasis on rotation and crop planning which seek to avoid failures and realize the greatest possible return from each seasonable opportunity. Variable spacing, summer fallowing, opportunity, planning and planting date manipulation are undoubtedly of value in this category.

The use of all such devices is fraught with pitfalls that can be avoided only by an application of clearly understood fundamentals. It is for the purpose of unscrambling the values of some of the underlying factors which may enable a more effective selection of method to fit the requirements of the existing condition that these analyses are attempted. To know the relative importance of all factors both controlled and uncontrolled should aid in a further solution of moisture problems by valuing conditions correctly and placing the emphasis on vital operations.

It is fully appreciated that studies of a similar nature under varying soil or climatic conditions would arrive at values in variance with those here found, but relative values are probably more significant than the absolute in this case.

SELECTED REFERENCES IN LITERATURE

Chilcott (1) concludes after assembling massive data from great plains experiments that crop yields are governed by inhibiting factors other than limitation of annual rainfall.

Briggs and Shantz (2) found transpiration dependent on the following factors in the importance of the order named: Humidity, Evaporation, Temperature, Solar radiation, and Wind velocity.

Shantz (3) discussed the water requirement in humid and semiarid regions and states, "Any limiting factor increases the water requirement and increases the amount of soil moisture required to produce a unit of plant growth." This would be construed to mean unfavorable conditions of fertility, temperature, humidity, wind or light.

Harris (4) demonstrated the relations of the following factors to evaporation from the moist surface of soil: Initial moisture, Humidity, Wind, Sunshine, Temperature, Texture, Compactness, Mulches, and Salt concentrations.

Harris and Jones (5) analyzed extensive soil moisture data under a rainfall of 13.48 inches with dry season in the summer finding that depth of plowing did not affect the final amount of stored moisture in the soil; that cultivation proved of value mainly to save moisture of the soil from weeds; that moisture penetrated more rapidly in moist soil than in relatively dry soil; that the crop used subsoil moisture by extending the root system rather than by a capillary rise of water to meet the crop requirements; that from .50 to 1.00 inch of rain was necessary to connect the moisture in mulched fallow land; that from 54 to 65 per cent of the total precipitation entered the soil; that less than one year of precipitation was capable of being stored in the soil within six feet of the surface.

Cole and Matthews (8) show the importance of initial moisture to the production of spring wheat in the northern great plains region to be sufficient for useful predictions on seasonal possibilities.

These studies are in essential agreement with results obtained from experiments reported herein. A very extensive list of references might be cited but only those nearest related to local problems and representative of the literature as a whole are mentioned.

PLAN OF FIELD WORK

The writer in planning the project from which the data used are derived stated as a purpose of the experiment "——to study the effects of preparation methods, types of crops and summer fallowing on the reception, retention, movement, and usage of soil moisture."

The plots are not scheduled in a way to meet the approved cropping systems for surety of production or with reference to conserving fertility, but simply to provide the variables desired for the study.

Table 1.—Field Schedule

Plot No.	Cropping and Cultural Plan
	(Level tillage preparation)
1303	Wheat in continuous culture
1304	Wheat—Fallow, alternating
1305	Fallow—Wheat, alternating
1306	Wheat—Fallow—Fallow, third crop rotation
1307	Fallow—Wheat—Fallow, third crop rotation
1308	Fallow—Fallow—Wheat, third crop rotation
1309	Manure—fallow continuous, weeds plowed in June
1310	Fallow continuous, clean culture
	(Listed tillage preparation)
1311	Wheat in continuous culture
1312	Wheat—Fallow, alternating
1313	Fallow—Wheat, alternating
1314	Wheat—Fallow—Fallow, Third crop rotation

1315 Fallow—Wheat—Fallow, third crop rotation
1316 Fallow—Fallow—Wheat, third crop rotation
1317 Manure-fallow continuous, weeds listed in June
1318 Fallow continuous, clean culture
(Fall listed)
1319 Milo continuous culture, 3½ foot rows
1320 Milo continuous culture, 7 foot rows
(Planting time preparation only)
1321 Milo continuous culture, 3½ foot rows
1322 Milo continuous culture, 7 foot rows
1323 Sudan grass close drilled, continuous culture
(Fall plowed)
1324 Sudan grass close drilled, continuous culture

DESCRIPTION OF THE SOIL

The soil is fairly representative of the type described by the Bureau of Soils as Amarillo Silty Clay Loam. A detailed survey was made and a six foot profile constructed. Figure 1 shows a photograph in an excavation about 200 feet from series 1300 with a diagram of the profile range in scale superimposed on it. There is some plot variation in color in the respective layers but the texture is very uniform. The main features of this type are a dark brown silty clay loam soil, a subsurface of dark compact clay loam, and subsoil of lighter silty clay ranging in color from a reddish brown through a white mottled calcareous clay to a solid white substratum containing a high percentage of soft textured calcium carbonate.

It is commonly called the tight land or wheat land as distinguished from the sandy soils of the locality. The surface and subsurface absorb water slowly. The top soil runs together to form a thin crust which checks after rains. When crops exhaust the soil moisture to a low point during prolonged drouth deep cracks are formed.

CLIMATIC FEATURES

The average annual rainfall for a 17-year period, 1911-27, is 17.48 inches. It is of the single peak distribution type with the heaviest rain in the growing seasons. (Fig. 2). The mean annual temperature is 55.6°F. A mean monthly temperature of 70° or more occurs through June to September with August the hottest month being slightly above 80°. Average daily range of temperature is 31°.

The warm and wet seasons coincide as measured by a correlation of .7141±.09. The relation of rainfall to relative humidity, .3834±.14, and to wind velocity, .2402±.18 is in each case of a very low order.

Mean relative humidity varies from season to season between 53.8 and 68.0 per cent by periods, averaging 61.3 per cent. The variation of wind velocity by periods has been from 7.00 miles per hour to 10.50, averaging 8.79, as measured in the field at a 30 inch level from the ground. The frost free period is about 180 days. Shallow tank evaporation ranges from 60 to 69 inches annually. The number of clear days ranges from 200 to 250 annually. The experiment station is located in level country 3300 feet above sea level.

EXPERIMENTAL METHODS AND PRELIMINARY STUDIES

The procedure of obtaining data is for the most part by methods well recognized in this type of work, but for the sake of explicitness of terms a brief summary of methods would seem desirable.

The field work covers four crop seasons from March 4, 1924 to September 28, 1927 divided into 12 periods averaging 109 days each but varying in length according to moisture and crop conditions. This provides for the group of the whole 264 plot period records. The subgroupings to eliminate temperature gives two groups of 132 records and to eliminate rainfall provides for the dry group 66 records, for the medium group 110, and for the wet group 88.

Table 2, Cultural Classification Distribution

			No. Occurrences of					
Period No.	Season	No. Days	No Crop No Cult.	No Crop Shallow Cult.	No Crop Listed	Early Stage Growth	No Crop Plowed	Late Stage Growth
1	Spring	71	4	10	0	1	0	7
2	Summer	77	0	2	5	4	3	8
3	Fall	86	12	4	0	0	0	6
10	Winter	182	13	0	2	6	1	0
5	Spring	132	1	9	2	0	4	6
6	Fall	114	2	9	3	6	2	0
7	Winter	121	9	0	6	6	1	0
8	Spring	88	14	2	0	0	0	6
9	Summer	141	6	3	0	7	0	6
10	Winter	182	133	0	2	6	1	0
11	Spring	70	5	9	2	0	2	4
12	Summer	109	0	7	2	5	2	6
	Totals		80	55	24	41	15	49

Table 3, Period Mean Conditions

Period No.	Ave. Daily Rain-fall	No. Rainy Days	Mean Tem-pera-ture	Ave. Daily Wind Miles	Mean Rel-ative Humidity	Ave. Soil Moisture Loss or Gain	Ave. Total Daily Moisture Used
	Ins.		Deg.	Miles	%	Ins.	Ins.
1	.0507	12	46.6	210	65.8	-.834	.062
2	.0455	15	73.5	184	60.0	-.491	.051
3	.0502	17	69.7	215	57.6	-.030	.053
4	.0038	11	36.0	179	65.4	-1.440	.016
5	.0324	17	58.9	244	53.8	-1.929	.046
6	.0871	36	68.9	187	64.5	3.042	.060
7	.0114	9	38.2	177	61.0	.445	.009
8	.0702	19	38.2	194	68.0	1.604	.051
9	.0715	29	74.2	169	58.6	-1.590	.082
10	.0080	13	43.2	204	59.0	.850	.004
11	.0444	7	67.4	252	55.6	-.055	.047
12	.1163	28	74.9	172	67.3	2.216	.096

The periods have not been set forth by calendar but are terminated by the progress of crops. The stages used are, beginning of spring growing season for small grains, beginning of the fruiting period for small grains, planting time for summer crops, small grain harvest, fall grain sowing, and summer crop harvest or fall frost. Sometimes the summer crop planting has coincided with wheat harvest and likewise sometimes wheat sowing coincides with fall harvest.

The factors for which satisfactory measures are available and which are used in multiple correlations are:

A—Average Daily Rainfall
K—Moderate Fraction of Rainfall
L—Extreme Fractions of Rainfall
B—Mean Temperature
C—Culture (Coded)
D—Wind Velocity
E—Mean Relative Humidity
F—Initial Moisture in Six foot Soil Section
N—Pre-Season Nitrates

Dependent variables to which correlation with the above factors have been applied are:

H—Final Moisture in Six foot Soil Section
X—Total Water Usage
Y—Crop Yields (Coded)
W—Period Rate of Loss or Gain in Soil Moisture (Coded)

A—Average Daily Rainfall

This factor is obtained by dividing the total rainfall as recorded by the local observer for the United States Weather Bureau by the number of days in the period. Period rainfalls vary from .45 of an inch to 12.68 inches. Length of periods vary from 70 to 182 days.

K and L Rainfall Fractions

To determine exactly what size rain is required to be effective in adding to soil moisture and the point at which losses begin to occur from runoff series of experiments were performed in the field whereby artificial rain was produced repeatedly and in amounts from .25 to 2.47 inches. The field observations were made by soil samples taken at a point within a few feet of the rain gage which was used to measure the various falls. The cultural condition at the time these tests were made was clean and representative of that in which the soil would be found, if well tended, the greater part of the year. Three trials were made of each of 6 sized rains and moisture tests are the average of 6 sized rains and moisture tests are the average of six samples representing the depth of 18 inches from each plot. Table 4 shows a summary of the results.

Table 4.—Effect of Size of Rain on Soil Moisture Increase

Average Size of Rain	Soil Moisture Gain, Inches 3 Days	7 Days	Per cent of Rain in Soil at 7 Days
.26	.14	.03	None
.45	.26	.04	8.8
1.10	.39	.25	22.7
1.47	.47	.24	16.3
1.94	.54	.24	12.3
2.47	.76	.34	13.7

In each case where an inch or more of water was applied surface runoff began after from .80 to 1.01 inches had fallen. The water was sprayed into the air and fell in large drops. The rate of application was rapid, less than fifteen minutes being required to make the heaviest applications. The dashing rate of fall and the fact that the atmosphere and surrounding plots were dry, increasing the evaporation rate, reduced the efficiency of such tests below that of natural rainfall. However, the relations of size to efficiency are taken to approximate actual conditions and the classification of rainfall is made on this basis. Refer to Table 7 under Disposition of Rainfall for comparison to actual conditions.

The division of rainfall into three classes A, B, and C (See Table 6) according to character of fall and effectiveness for increasing soil moisture provides a means of separating total rainfall into two fractions for correlation study.

K—Moderate Fraction of Rainfall

This fraction of the total rainfall includes all of Class B plus Class C with the calculated excessive portion eliminated. The whole is reduced to a daily basis.

L—Extreme Fractions of Rainfall

This factor covers all of Class A plus the excessive portion of Class C. It is thus supposed to be a measure of the part subject to entire loss from evaporation (small showers) and the part subject to partial loss from runoff.

B—Mean Temperature

Temperature is calculated as the means for the period from data of the local weather observer which, like the rainfall, is recorded in the field by standard instruments.

C—Culture

The code adopted roughly indicates the depth of tillage during the period observed since the rate of moisture withdrawal during selected dry periods follows it in the following ratio, using the amount of water lost from uncultivated uncropped plots as a unit:

No crop, no cultivation	1
No crop, shallow culivation	2
No crop, listed	3
Early stage crop growth	4.5
No crop, plowed	9.3
Late stage crop growth	22

This study of usage of soil water was made during dry periods when all plots lost moisture and the steady decrease was not seriously interrupted by rainfall.

In order to have a classification which would include all the plots in any one period early and late stages of crop growth have been added to the above schedule. Note Table 2. It must be assumed that the different degrees of culture stand in the same order as to soil moisture removal in wet seasons as in dry.

D—Wind Velocity

The daily wind mileage has been averaged for each period. Wind is recorded by a Robinson cup anemometer set 30 inches above the ground level in the open field so that it represents the velocity felt by the average growing crop, in other words, that velocity effective near the surface of the soil.

E—Mean Relative Humidity

Relative humidity has been recorded by a continuous registering hair strand hygrometer which is checked frequently by wet and dry bulb thermometer readi ıgs. The calculated period mean is used.

F—Initial Moisture in Six Foot Soil Section

Soil moisture has been determined from tube samplings by one foot cores to depth of six feet on each plot at the close of the periods. Percentage of moisture on the water free basis was calculated from the weight losses obtained at the end of 48 hours in a drying over at 110°F. This is converted to inches of soil water for the full depth by using a standard density factor.

N—Pre-Season Nitrates

Nitrates have been determined only in the topsoil and only once a year, January, for the length of the entire experiment. The values expressed indicate the amount of nitrate nitrogen in the topsoil six inches during the winter, in other words the available nitrogen being carried over into the next year for use of the following crops. The values used are parts per million multiplied by two resulting in approximately the pounds per acre six inches of nitrate nitrogen.

H—Final Moisture in Six Foot Soil Section

This factor is derived as F.

X—Total Water Usage

The total amount of water both used and wasted for each plot period is calculated by taking the total amount of rain for the period minus the soil water gained or plus that lost. The value is reduced to a daily basis.

W—Rate of Gain

The average daily rate of loss or gain to soil moisture is coded to a plus value.

Y—Crop Yield

There are three types of crops grown in the series, so the values have been coded on the basis of percentage of mean yield for wheat, milo, and sudan separately. Total dry weight has been used in so much as it represents the actual removals from the plots. Variation in total yield has not been great for different crops. Wheat averaged 2006 pounds per acre, milo 2224 and Sudan 2241. Individual yields, however, have ranged from zero to 310 per cent of mean.

PART II

DISPOSITION OF RAINFALL

The approach to the problem of making better use of available rainfall is made through first studying the character of the rainfall and learning what normally becomes of it. The distribution, reliability, and character of rainfall is brought out in tables 5 and 6 and Fig. 2.

Table 5—Distribution and Reliability of Rainfall

17 Year Average, 1911-1927, Goodwell, Oklahoma

Period or Class	Mean Rainfall	Standard Deviation	Coefficient of Variability
January	.278 ± .04	.244	27.9
February	.622 ± .09	.550	88.5
March	.746 ± .13	.805	107.9
April	1.523 ± .12	.776	50.9
May	2.432 ± .26	1.610	66.2
June	2.370 ± .25	1.577	66.5
July	2.403 ± .29	1.788	74.4
August	2.424 ± .25	1.529	63.0
September	2.210 ± .21	1.337	60.4
October	1.065 ± .21	1.319	123.8
November	.637 ± .11	.698	109.5
December	.652 ± .14	.859	131.7
Annual	17.362 ± .61	3.760	21.5
Class A	5.483 ± .17	1.072	19.5
Class B	6.067 ± .28	1.757	28.8
Class C	5.930 ± .48	2.992	50.4

Table 6—Character of Rainfall at Goodwell, Oklahoma

Year	Total Rainfall	Class A	Class B	Class C	No. Excessive Rains
1911	15.88	5.67	7.21	3.00	3
1912	17.24	5.33	6.02	5.89	3
1913	18.99	6.37	4.66	7.96	6
1914	21.92	4.05	4.31	13.56	10
1915	25.88	7.47	7.99	10.42	8
1916	11.66	4.09	3.17	4.40	3
1917	17.63	4.55	7.19	5.89	4
1918	20.13	6.69	4.77	8.69	4
1919	17.45	6.66	4.43	6.36	4
1920	14.79	3.70	6.50	4.59	4
1921	16.91	5.15	7.08	4.68	3
1922	13.00	5.33	4.69	2.98	2
1923	24.12	6.75	10.08	7.29	7
1924	12.00	6.51	4.39	1.10	1
1925	15.93	5.47	8.42	2.04	3
1926	17.29	4.59	6.76	5.94	5
1927	16.34	4.83	5.47	6.04	5
Annual Mean	17.48	5.483	6.067	5.930	5
Percentage of Total	100.00	31.36	34.70	33.92	
Period of Moisture Study 1924-27 Means	15.39	5.35	6.26	3.78	3.5
Percentage of Total	100.00	34.78	40.67	24.56	

Class A—.50 inch or less on isolated days.

Class B—.51 to 1.00 isolated and .26 to .50 consecutive to a rain classing as A or more.

Class C—1.01 plus isolated and .51 to 1.00 consecutive to a rain classing as B or more.

Spring and early fall periods show the greater reliability, i. e. the rainfall is more likely to approach normal at these times. However, mid-summer is comparatively reliable as against the winter rainfall. The probability of normal distribution is very remote, but near normal annual total may be expected occasionally.

In classifying the character of rainfall, Table 6, it should be noted that about equal amounts of each class constitutes a normal, but the four year period under study falls somewhat below the average in total annual and in Class C rainfall while about normal amounts of Classes A and B were received.

This verifies the prediction which might have been made from a comparison of the variabilities of A, B, and C rainfall in Table 5. In other words the probability is greater than the normal amount of small showers will be received than any other kind of rain and the annual fluctuation is mostly due to the variability of the excessive fraction.

The average daily rainfall of .0421 inch is sometimes more than doubled for certain periods. Four such wet periods were selected when all uncropped plots made gains in soil moisture to determine the percentage of the rainfall that became soil moisure in favorable seasons. Only uncropped plots were used in calculating Table 7.

Table 7—Soil Moisture Gains in Selected Wet Seasons

Year	Season	Period Days	Total Rainfall Inches	Ave. Daily Rainfall	Soil Gain Inches	Per cent Rainfall in Soil
1926	Spring	88	6.18	.07	2.41	39.15
1925	Summer	111	10.21	.09	2.92	28.59
1927	Summer	109	12.68	.11	2.80	22.13
1923	Fall	77	10.45	.12	2.52	24.18

It is noticeable here that the amount of water entering the soil was about the same in each case but two factors seem to affect the percentage of total which soaked in. This is the first hint of a greater effectiveness being probable when soils are cool. The same tendency of decreased efficiency with excessive amount noticed elsewhere is also apparent here.

When the entire rainfall is taken into account for the period of this study and the sum of all uncropped and uncultivated plot moisture increases taken by period averages we find 30.69% of the total rainfall became soil moisture under favorable cultural conditions. This represents the amount that penetrated beyond the surface few inches and joined the permanent body of soil moisture. Ordinary tillage including both necessary and unnecessary operations exposed 2.7% of the total to loss by evaporation which reduces the quantity left available for actual use by crops and weeds to approximately 18% of the rainfall.

Calculation from the detailed data of Class C rainfall not presented here indicates 13.5% of the total normally in danger of loss by runoff.

Therefore, with known losses of 31.3% (rains too small to penetrate the surface layer of soil), 13.5% (runoff), and 2.7% (used by tillage) added to the 18.0% made available to plant use, 65.5% of the rainfall is accounted for. The remainder of 34.5% must be asigned by elimination to evaporation from Classes B and C rainfall and passage to the substratum beyond reach of crop roots. Since observation fails to reveal an instance when appreciable quantities of moisture sufficient for movement downward have been below the 6 foot level it seems fitting to charge the entitre remainder to evaporation.

The above moisture reception calculations included all uncropped plots of which there were 80 uncultivated instances distributed through 10 periods of observation and 94 cultivated distributed through 12 periods.

Discussion

The main criticism which the writer sees in the apportionment set out above is the assumption of the 18.0% portion to be all that is made useful to crops. If it were true that crops do not get more than is stored in the soil then the apportionment would be correct. When crops are growing during the precipitation there is certainly some use made by shallow roots of the current moisture which on a bare plot would soon be lost again by the drying out of the surface few inches, and before it would have a chance to be measured and accounted for. Also runoff is a factor that is highly variable even on a uniform textured soil, for the slightest uneveness in the field means that spots will fail to get their share and other spots, too often an inaccessible corner or a roadside will be flooded with useless water.

Since runoff is partly a problem of distribution in the field and partly a problem of loss from the field it is probably not correct to say that 13.5% is actually lost to all useful purposes, but it is sufficient to know that so large an amount of potentially useful moisture undergoes the risk of loss when it is so nearly within grasp. More than 13.5% is doubtless lost on sloping land and because it is so easy to save by terracing and contour tillage, the first steps toward making more efficient use of moisture in the region represented by these experiments should be to take care of the runoff loss if any exists.

In considering the other fractions to determine what kinds of losses may be successfully checked and whether the possible saving would be enough to justify the effort we are confronted by two disappointments.

Undoubtedly the greatest loss suffered is that of evaporation and it is also the hardest with which to deal. The most feasible way of avoiding a part of it appears to be to maintain on new land or rebuild on old land the organic matter supply of the soil. A spongy topsoil can make a marked difference in the amount absorbed and the time required to do it. Return of much vegetable matter to a soil under this climatic condition is, on the other hand, incompatible with the rapid use of the land. Therefore, it does not appear that much headway is likely to be made by farmers in this direction until the soil is reduced to such a sterile condition as to force atention to its needs.

The other item offering a possibility of some saving can be very practically taken care of but unfortunately does not allow much room for improvement. The total amount lost by tillage exposure is rather small, 13% of the soil water or only 2.7% of the total rainfall. To avoid unnecessary depth and frequency of cultivation covers the entire requirement and farm operators have already sufficient reason for doing that. The only difficulty the writer has observed in this respect was occasionally someone who overzealously attached a mysterious importance to cultivation when it is not needed to protect the soil moisture from weeds, or to deep cultivation when it was untimely for aiding the fertility condition.

It is true that when the soil is moist a deep plowing will use more moisture than a crop in the early stage of growth, but the type of farming in general use rarely brings in such an operation so it need not be decried. Moderately deep plowing may be used to the advantage of the fertility condition more often than it usually is.

Care must be taken to plow only when the moisture is sufficient to prevent an extremely rough broken cloddy structure. If plowing is done when the topsoil is very dry the return to normal condition is delayed and with it the formation of nitrates. This is presumably due to the interruption of bacterial functions taking place instead of the desired stimulation, and to the requirements of more rainfall to restore favorable conditions than would otherwise be needed.

Since plowing in order to be immediately beneficial necessitates the using up of soil moisture by the operation a time should be chosen when this moisture being present will be of least use for crop production. Early winter may occasionally present the desired opportunity. Early spring is satisfactory for plowing if late planted summer crops are planned or summer fallow.

In summary, the fact that so little of the rainfall is actually used by crop sugests that improvement is easily possible.

PART III

FACTORS AFFECTING THE BEHAVIOR OF SOIL MOISTURE

It should be remembered on going into a study of factors that help to build up soil moisture and that tend to remove it, the amount of water being dealt with is narrowed to about one-fifth of the total rainfall. In the preliminary studies the data of an arbitrary storage zone (2nd, 3rd, and 4th feet of soil) were separated and studied in the same way as the entire soil section (1st to 6th feet, inclusive) has been handled. Since the only important difference in the bearing of factors was a substantially greater influence of culture on the removal of the storage zone moisture than on the moisture of the six foot soil section only the latter tables are presented.

Table 8—Classes of the Group of the Whole

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
A—Rainfall	12	.0493 ± .0013	.0321	65.2
K—Moderate Fraction	12	.0281 ± .0009	.0219	77.9
L—Extreme Fractions	12	.0211 ± .0005	.0128	60.7
B—Temperature	12	58.3 ± .59	14.3	24.5
C—Culture	264	5.02 ± .154	3.73	74.3
D—Wind	12	198.9 ± 1.08	26.1	13.1
E—Humidity	12	61.3 ± .19	4.65	7.5
F—Initial Moisture	264	13.60 ± .11	2.78	20.4
H—Final Moisture	264	13.71 ± .12	2.89	21.0
W—Rate of Change	264	.1206 ± .001	.0257	21.6

Table 9—Correlation of Factors, Group of the Whole
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Factor	L	B	C	D	E	F	H	W
K	.6938 ± .10	.6045 ± .12	.1325 ± .04_	.2302 ± .18	.4559 ± .15_	.0655 ± .04	.2852 ± .04	.3667 ± .03
L		.7567 ± .11	.2455 ± .04_	.2086 ± .18	.1840 ± .18	.0865 ± .04	.1934 ± .04	.1010 ± .04
B			.2663 ± .04	.0375 ± .19_	.2528 ± .13	.0254 ± .14	.0970 ± .04	.0726 ± .04
C				_.0188 ± .04_	.0482 ± .04	.0836 ± .04_	.3030 ± .03_	.4199 ± .03
D					_.5926 ± .12_	.0328 ± .04_	.1735 ± .04_	.1536 ± .04
E						_.0079 ± .04	.3166 ± .03	.2811 ± .04
F							.5616 ± .02_	.3954 ± .03

Table 10—Multiple Correlations and Score of Factors
n264

Factor	Score H - Final Moisture in Six Foot Soil Section	Score W - Rate of Moisture Gain
K—Moderate Fraction	12.9	25.4
L—Extreme Fractions	-6.1	-8.0
B—Temperature	10.6	5.5
C—Culture	-22.2	-28.9
D—Wind	.2	-3.8
E—Humidity	13.3	6.7
F—Initial Moisture	34.4	-21.9
R—Multiple Correlation Coefficient	.7720	.6925

Table 11—Classes of the Low Temperature Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
A—Rainfall	6	.0294±.0311	.1137	286.7
C—Culture	132	4.348±.214	3.65	83.9
D—Wind	6	201.3±29.0	106.1	52.7
E—Humidity	6	62.16±6.19	22.6	36.2
F—Initial Moisture	132	13.51±.137	2.34	17.3
H—Final Moisture	132	13.29±.176	3.03	22.8
W—Rate of Change	132	.1180±.0016	.0274	23.2

Table 12—Classes of the High Temperature Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
A—Rainfall	6	.0691±.0333	.1217	176.1
C—Culture	132	5.643±.22	3.75	66.4
D—Wind	6	196.5±36.9	134.9	68.6
E—Humidity	6	60.44±5.45	19.9	32.9
F—Initial Moisture	132	13.69±.184	3.14	22.9
H—Final Moisture	132	14.03±.156	2.66	18.9
W—Rate of Change	132	.1233±.0014	.0245	19.8

Table 13—Correlation of Factors, Low Temperature

Seasons, Mean 45.18°F. n 132

Factor	C	D	E	F	H	W
A-	.1311±.05	.2867±.25	.4187±.22	.1052±.05	.2016±.05	.1554±.05
C-		.2611±.05	-.1549±.05	-.0003±.05	-.3219±.05	-.4818±.05
D-			-.6231±.16	-.1319±.05	-.2793±.05	-.1828±.05
E-				.2603±.05	.3788±.05	.1681±.05
F-					.5753±.04	-.2572±.05

Table 14—Correlation of Factors, High Temperature

Seasons, Mean 71.43°F n 132

Factor	C	D	E	F	H	W
A-	.0654±.05	-.6236±.16	.8952±.05	-.1390±.05	.2652±.05	.4274±.05
C-		-.2124±.05	.1432±.05	.1429±.05	-.3586±.05	-.4195±.05
D-			-.6444±.16	.0363±.05	-.0634±.05	-.1364±.05
E-				-.2078±.05	.2460±.05	.4692±.05
F-					.5698±.04	-.5409±.04

Table 15—Multiple Correlations and Score of Factors

Temperature Subgroupings, n 132

Factor	H- Final Moisture Low Temp.-	H- Final Moisture High Temp.	W- Rate of Gain Low Temp.-	W- Rate of Gain High Temp.
A—Rainfall	20.5	-3.4	25.0	1.9
C—Culture	-18.5	-23.6	-23.9	-28.0
D—Wind	-19.3	8.0	-21.4	9.4
E—Humidity	-8.9	30.0	-15.4	34.9
F—Initial Moisture	32.5	34.7	-14.1	-25.6
R—Multiple Correlation Coefficient	.7120	.8680	.6410	.7820

Table 16—Classes of the Dry Period Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
B—Temperature	3	39.13±.54	44.7	114.2
C—Culture	66	3.48±.23	2.8	80.4
D—Wind	3	186.6±.227	188.5	101.0
E—Humidity	3	61.8±48.1	39.4	63.7
F—Initial Moisture	66	13.42±.194	2.37	17.6
H—Final Moisture	66	13.38±.203	2.48	18.5
W—Rate of Change	66	.1187±.0011	.0143	12.0

Table 17—Classes of the Midmoist Period Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
B—Temperature	5	63.2±13.5	45.2	71.5
C—Culture	110	5.69±.25	3.9	68.5
D—Wind	5	221±34.3	114.6	51.8
E—Humidity	5	58.38±5.87	19.6	33.5
F—Initial Moisture	110	13.94±.172	2.68	19.2
H—Final Moisture	110	13.19±.197	3.07	23.2
W—Rate of Change	110	.1119±.0018	.0284	25.3

Table 18—Classes of the Wet Period Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
B—Temperature	4	66.5±17.1	50.8	76.3
C—Culture	88	5.34±.26	3.68	68.9
D—Wind	4	180.5±16.3	48.5	26.8
E—Humidity	4	64.6±5.8	17.3	26.7
F—Initial Moisture	88	13.29±.223	3.12	23.4
H—Final Moisture	88	14.61±.193	2.69	18.4
W—Rate of Change	88	.1330±.0016	.0232	17.4

Table 19—Correlation of Factors, Group of Dry Periods

Mean Daily Rainfall .077, n 66

Factor	C	D	E	F	H	W
B	.0401±.08	.9604±.11	-.9061±.21	.0647±.08	.3732±.07	.4371±.06
C		.0327±.08	-.0841±.08	.0089±.08	-.1172±.08	-.1386±.08
D			-.6689±.67	.0796±.08	.2659±.07	.2812±.07
E				.0269±.08	-.4027±.06	-.4720±.06
F					.7179±.04	-.3179±.07

Table 20—Correlation of Factors, Group of Midmoist Periods

Mean Daily Rainfall .044, n 110

Factor	C	D	E	F	H	W
B	.0591±.06	-.1712±.29	-.5046±.22	-.0233±.06	.0497±.06	.1113±.06
C		-.1719±.06	.0415±.06	.0841±.06	-.3972±.06	-.4967±.05
D			-.6217±.18	-.1351±.06	-.1973±.06	-.0123±.06
E				.3242±.06	.2993±.06	-.0204±.06
F					.5978±.05	-.3898±.06

Table 21—Correlation of Factors, Group of Wet Periods

Mean Daily Rainfall, .086, n 88

Factor	C	D	E	F	H	W
B	.2610±.06	-.8737±.08	-.5372±.09	.0835±.07	-.0369±.07	.1980±.07
C		-.2776±.06	-.0775±.07	.0993±.07	-.3402±.06	-.5326±.05
D			.5977±.09	-.3274±.06	-.0024±.07	.4118±.06
E				-.1268±.07	.3812±.06	.5208±.05
F					.5390±.05	-.4414±.06

Table 22—Multiple correlations and Score of Factors

Rainfall Subgroupings, n 66, n 110, n 88

Factor	H - Final Moisture			W - Rate of Change		
	Dry	Midmoist	Wet	Dry	Midmoist	Wet
B—Temperature	6.1	12.1	19.8	31.7	20.2	24.6
C—Culture	10.0	32.2	-18.2	5.8	-21.5	23.5
D—Wind	-13.3	3.5	6.5	18.9	11.4	15.2
E—Humidity	28.2	13.0	24.5	13.5	24.5	24.6
F—Initial Moisture	42.2	39.0	27.7	10.0	22.3	-11.8
R—Multiple Cor. Coefficient	.8560	.7780	.8500	.5570	.6735	.8350

Table 23—Temperature and Rainfall Group Classes

Group	No. Periods	Mean of Group	Standard Deviation	Coefficient of Variability
B—Temperature	Low 6	45.16±2.07	7.55	16.7
	High 6	71.43±.80	2.91	4.0
A—Rainfall	Dry 3	.0077±.0067	.0054	71.0
	Average 5	.0446±.0020	.0068	15.3
	Wet 4	.0862±.0126	.0375	43.5

Discussion

The factor of evaporation rate being of composite nature has been substituted by the independent measures of Humidity, Temperature, and Wind. It is not difficult to interpret the influence of the independent factors in terms of evaporation and since heterogenous combinations of these factors occur the detailed method seems preferable.

The independent variables of Rainfall, Culture and Initial Moisture have direct casual relations to Final Moisture and Rate of Gain, and fall naturally into a group measurable or taking effect directly in the soil. The group of atmosphereic condition, Temperature, Wind, and Humidity fluctuate independently of soil conditions and effect changes within the soil but slowly.

The conditions of the experiment as a whole and in the various period groups can best be grasped by a study of the means and variabilities of the factors in Tables 8, 11, 12, 16, 17, and 18. Table 23 indicates the narrowness of classification attainable in subdividing the data. The temperature division is somewhat more sàtisfactory from a statistical standpoint but it is notable that the desired number of periods of corresponding value is lacking.

Rainfall

Two important facts stand out in the study of the bearing of rainfall upon soil moisture. Variation of rainfall is a negligible factor in warm seasons compared to the significance of powerful agents which govern the disposition of it.

Moderate rainfall is more efficient in increasing moisture of the soil than extremely light or extremely heavy and is more important to rate of gain than to amount stored up. Rainfall of the cooler seasons exerts a stronger influence on soil moisture quantity because it is free from the hazards of soil heat and dry winds.

The increased efficiency of rain in cool weather emphasizes the importance of paying special attention to conservative culture in the spring season. While early spring rains are not highly dependable (Table 5), when they do happen to be ample exceptional advantage can be taken of them, either to grow spring grains or secure soil moisture for full rate sorghum crops.

In the summer culture, humidity, and initial moisture are the factors governing soil moisture and amount of rainfall is not significant.

Initial Moisture

The stability of a body of moisture which has reached a dispersion sufficient for practical equilibrium has been ably discussed by Shantz[3]. In every group here studied initial moisture has proved to have dominant bearing on final moisture content. This means that through periods of three to five months no other factor is likely to completely reverse conditions. Intensive culture is about the only factor that can quickly reduce a high initial moisture content so if at any time soil moisture cannot be advantageously used when present it may be saved through a reasonable time of dry weather by protecting it from weeds and deep cultivation.

In the case of factors that add to or take from the soil moisture the direction of influence upon final moisture and rate of gain is the same, but for initial moisture high soil content distinctly lowers the rate of gain in all seasons of the year. This appears to mean that with the continued building up o fa moisture supply the point of diminishing increase is often reached. For the Amarillo Silty Clay Loam as read from plots in continuous fallow this is near 16 inches total water in the 6 foot soil section. For the greatest moisture using efficiency, therefore, crops should be introduced whenever a productive soil moisture supply has been procured regardless of any fixed cropping plans. This is particularly applicable to times approaching the normally wet season of the year. The greatest wastefulness of any single crop system is in inefficient moisture using.

Winter grains, Spring grains, and Summer crops provide three separate planting seasons in the year from which timely crops can be selected to make use of soil moisture. It is also true that summer fallow plans can often be profitably abandoned for the planting of summer crops when spring moisture increases provide a body of available moisture, unless heavy additions of organic matter are in progress.

To sum up the status of initial moisture, once a body of moisture has come to rest having penetrated the soil as deeply as the rapid first movement will take it, it then remains in place until such powerful external forces as evaporation and osmosis are applied to it by exposure to rising temperature, circulating air, or roots of growing plants. The circulation of air does not reach deeply into the soil to remove moisture unless aided by cultivation. In no case does it affect the lower moisture like plant roots.

The relative importance of current rainfall and initial moisture is useful crop planning information. Rainfall at its greatest effectiveness, in cool seasons, is roughly just 2-3 of the importance of initial moisture in determining moisture content. If we assume that a high moisture content at the close of the period corresponds to a past crop producing possibility than the soil moisture at any planting time becomes quite an important factor even at the beginning of the normally wet season of the year[6]. Very effective use of this fact is made in determining when and when not to sow spring grains such as oats, barley, and spring wheat, as these crops are a failure more often than a success, when planted blindly. The failure of a spring grain costs more than the loss of seed, rent, and labor because it uses up the current moisture of the spring season to no purpose and destroys the possibility of summer crop success. On the other hand when moisture conditions are such as to enable the growth of spring grains they are very desirable in the crop system as a distributor of labor, source of feed, and a better crop than sorghums to prepare the land for wheat.

The same principle is used in determining the grain sorghums spacing that will probably give the highest yield under a given soil moisture condition. A high percentage of accuracy has been recorded in the predictions of favorable milo spacing in the short time it has been practiced.

Culture

The operations included in the scale of cultural intensity may be roughly divided into two classes which cover all the uses the farmer makes of soil moisture whether it be directly or indirectly productive. Productive uses include growing crops and such tillage as promotes the current fertility condition. The growth of weeds or the tillage of weed control are ways of using soil moisture which must be avoided as far as possible. When weeds cannot grow as in winter or exceedingly dry seasons tillage for moisture conseravtion is futile, but when it becomes a choice between weeds and cultivation and there is considerable moisture at stake cultivation is preferable, and becomes a useful practice.

No simple correlations are found of culture with climatic variables large enough to be significant. A desirable relationship would be the following of a high initial moisture by an intensive productive culture. Since eight of the plots studied are continuous cultures by schedule rather than by reason this correlation does not exist and the practice has often been one of replanting exhaused plots when others rich with moisture and plant food remain idle. A thoughtful planning of the cropping system for safety and moisture using efficiency would avoid this and establish a definite relation between initial moisture and culture.

Culture reduces the moisture content directly and lowers the rate of gain by using a part of the current moisture which might otherwise be stored. This factor is somewhat less prominent in cool weather than in warm. In the matter of the relationships to the total amount of water used and wasted (Factor X) culture shares responsibility equally with initial moisture.

The consistent behavior of the factor in all kinds of seasons enables a fair degree of accuracy of prediction for final moisture content to be based on it. When crops mature during a certain period the soil is practically sure to be exhausted or nearly so of available moisture. Under only one condition does culture fail to exercise a marked influence on moisture content and that is when rainfall is at a minimum.

Humidity

The relation of humidity to rainfall is $.41 \pm .22$ in cool periods and $.89 \pm .05$ in warm periods indicating that the high relative humidities experienced in winter are due more to low temperature reduction of the air carrying capacity than to variations in the absolute moisture present.

Low humidity accompanied the maintenance of high moisture content of soil in winter, but was associated with a low rate of moisture increases in the summer. The same behavior of humidity is noted between dry and wet seasons as between cool and warm seasons respectively.

The great importance of high humidity in summer time is attached to the fact that of those factors controlling evaporation it is the only one that can contribute a large degree of relief. Wind though at a minimum in summer does not vary much and temperatures normally high cannot be averted.

Temperature

It is readily appreciated that the mean air temperature fluctuates more than the soil temperature and also that seasonally it lags behind the atmospheric condition in rising and falling. Cultural conditions involve another cause of variation in soil heat so that it is only in a very general way that air temperature represents soil conditions. However, since the periods are of considerable length and since moisture usage and crop yield are probably influenced directly by air temperature it has been accepted as a more or less desirable variable for study.

The weight of temperature upon determining the amount of soil moisture in the six foot soil section is as would be expected small enough to be of doubtful significance. The effect of temperature upon the relationships of wind, humidity, and rainfall is quite noticeable. Only the factors of culture and initial moisture are independent of temperature.

Other things being equal temperature increases evaporation to a high arte and thereby affects all results relating to crop growth and moisture usage. It is not so readily understood why the influence of temperature on rate of gain should change from the expected detrimental effect in dry times to a significantly beneficial relation in average to wet seasons. The inadequacy of mean air temperature as pointed out above for an index to soil conditions may call for explanation in a study of such factors as daily range, rising and falling progress of soil temperature, and relative temperatures of soil and precipitated water.

When all is considered temperature is not a highly important factor aside from its relation to the evaporation rate which has somewhat more effect on the efficiency of current rainfall than upon the disposition of soil moisture.

Wind

High negative correlations exist between wind and humidity in all groups of seasons but it runs highest in the cropped periods. The relation of wind to final moisture content of the soil is so uncertain as to be regarded of no importance but there is undoubtedly a decrease of moisture gain due to high winds in cold weather. While the evidence is not conclusive, it is probable that this is correctly accounted for by the drifting of snow from the field to sheltered places such as road grades, fences, and wind breaks. During light snows large drifts often accumulate about barriers while the fields are swept bare. Leaving high stubbles or stalk fields stand through the winter for the purpose of catching snow is advocated by some but the snowfall is normally so low that the real advantages of such a practice are in doubt.

PART IV

THE RELATION OF FACTORS AFFECTING CROP YIELDS

When the study is confined to plots and periods producing crops the bulk of data is smaller than that used in any of the other groups, but the cropped group has the certain advantage of covering nine combinations of climatic conditions. The study of total usage of water includes the entire group of 264 plot periods. The same classifications are used as in Part III excepting that the additional factor of pre-season nitrates is introduced into the crop yield study.

The total water usage is calculated in the same manner as the factor used by Cole and Matthews ([6]). The mean found in the Panhandle of Oklahoma for periods during which crops were being produced was .073 of an inch daily. This is higher than found in the northern great plains ([6]) which was .060 and .070. The higher water requirement of plants under rapid evaporation conditions is only partly responsible for the increase. Since the total water usage includes all surface evaporation waste and this amounts to three times the transpirationof plants the direct evaporation should probably be changed with the larger quantity.

Table 24—Classes of the Cropped Plot Group

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
K—Moderate Fraction	9	.0383±.0098	.0438	114.3
L—Extreme Fractions	9	.0265±.0054	.0234	91.6
B—Temperature	9	65.4±4.33	19.3	29.5
D—Wind	9	203±14.9	66.6	32.8
E—Humidity	9	60.9±2.6	12.0	19.6
F—Initial Moisture	48	13.65±.24	2.50	18.2
N—Pre-season Nitrates	48	6.39±.687	7.13	111.5
Y—Total Crop Yield	48	99.9±7.61	79.0	79.0

Table 25—Correlations, Group of Cropped Plots, n 48

Factor	L	B	D	E	F	N	Y
K	.4516±.16	.1793±.21	-.6257±.11	.8316±.07	-.3865±.07	-.3254±.07	.4180±.06
L		.6749±.10	-.7430±.09	.3739±.20	-.0189±.07	-.3288±.07	.2836±.07
B			-.3070±.20	-.1580±.21	.0524±.07	-.1775±.07	-.2808±.07
D				-.7017±.11	.1221±.07	.4950±.06	-.6231±.04
E					-.2109±.07	-.4217±.06	.7369±.03
F						.2582±.07	.0745±.07
N							-.4124±.06

Table 26—Multiple Correlation and Score of Factors

Cropped Plot Group n 48

Factor	Score Y_ Total Crop Yield
K—Moderate Fraction Rainfall	2.7
L—Extreme Fractions Rainfall	9.4
B—Temperature	-24.8
D—Wind	-18.5
E—Humidity	21.7
F—Initial Moisture	12.6
N—Pre-Season Nitrates	-9.9
R—Multiple Correlation	.9065

In considering the total water usage we have placed together under one head all the moisture that leaves the surface and subsoil by any method. Cole and Matthews found a relation of .30±.08 between this and the total rainfall. At Goodwell, Oklahoma, the relation of .7041±.02 was found when all records of both cropped and uncropped plots are used for all seasons of the year. When the study is limited to plots and periods producing yields only the correlation is .5418±.06. The difference is probably traceable to the mere fact that the rainfall comes nearer being disposed of in the southern area soon after it falls than in the northern.

The average amount used is .048-inch which is the same as the average daily rainfall for a long period. In the group of cropped plots the average daily usage was .073-inch. During these same periods an average daily precipitation of .065 was received. The difference of .008 represents the withdrawal of soil moisture from the store which was accumulated before the crops came on. With an average length of crops season of 114 days there is .91 inch of water used by crops on the average that does not fall during the growth period. If it can be assumed that no weeds grow and crop plants use the full amount of moisture normally available (3.14 inches) it is then found that crops derive 29% of their moisture from pre-season accumulations in the soil and 71% of what they use from the current rainfall. The amount thus calculated as used by crops or during recorded crop periods would be 30% of the rainfall of said periods which our study from another angle shows is too much. Field records show that a small amount of weed growth does take place in preparatory periods so the entire 18% of total rainfall (3.14 inches) available is not used within the crop periods. Just how much of the 3.14 inches which plants use goes to weeds outside of crop periods cannot be determined from the material at hand. In any individual case it would be governed by the success of cultivation.

Table 27—Classes of the Group of the Whole on

Total Water Usage

Variable	No. of Occurances	Mean of Class	Standard Deviation	Coefficient of Variability
K—Moderate Fraction	12	.0281±.0009	.0219	77.9
L—Extreme Fractions	12	.0211±.0005	.0128	60.7
B—Temperature	12	58.3±.59	14.3	24.5
C—Culture	264	5.02±154	3.73	74.3
D—Wind	12	198.9±1.08	26.1	13.1
E—Humidity	12	61.3±.19	4.65	7.5
F—Initial Moisture	264	13.60±.11	2.78	20.4
X—Total Water Usage	264	.0484±.0014	.034	70.2

Table 28—Correlations, Group of the Whole, n 264

Factor	L	B	C	D	E	F	X
K	.6938±.10	.6045±.12	.1325±.04	.2302±.18	.4559±.15	-.0655±.04	.6082±.02
L		.7567±.11	.2455±.04	-.2086±.18	.1840±.18	.0865±.04	.7251±.02
B			.2663±.04	.0357±.19	-.2528±.13	.0254±.14	.5951±.02
C				-.0188±.04	-.0482±.04	.0836±.04	.4856±.02
D					-.5926±.12	-.0328±.04	-.1041±.04
E						-.0079±.04	.1548±.04
F							.3566±.03

Table 29—Multiple Correlation and Score of Factors

Group of the Whole n 264

Factor	X- Total Water Usage
K—Moderate Fraction	22.0
L—Extreme Fractions	27.6
B—Temperature	-3.6
C—Culture	19.9
D—Wind	3.6
E—Humidity	-3.0
F—Initial Moisture	19.3
R—Multiple Correlation	.8685

A significant correlation exists between the total amount of water used up and the size of yield produced during the period of growth but it is by no means large enough to suggest that the crops get the most of the moisture. The coefficient is .5126±.07.

In comparing the conditions of the cropped group with the group of the whole the rainfall was considerably heavier in the former. Temperature and wind were both slightly higher and humidity a little lower. Initial moisture was practically the same. The interrelation of factors was the main in the same direction but a wide variation in degrees is notable.

Discussion

The score of either fraction of the rainfall in its bearing upon crop yield is less than any of the other factors studied. The relations found in the soil moisture study lead to the expectation of a minimum importance of rainfall quantity to crop yield. Of most interest probably is the fact that the extreme fractions of rainfall though they are worth little in building up a moisture supply in the soil appear to aid materially with crop production. Credit for this seems to be due the frequent small shower. It is possible that the benefits come more from the alleviation of extreme temprature and humidity conditions than the actual supply of soil moisture.

The high temperatures experienced in crop periods were more detrimental to growth than any other single condition, but temperature is closely approached in importance by humidity and wind. Crop yields are, therefore, dominated by the three factors that control evaporation which force rainfall fluctuation and fertility condition into the back ground. Initial moisture is the only soil factor that exerts enough influence to be strongly felt in offsetting unfavorable atmospheric conditions. The supposition might be expressed that the lowest growing season rainfall that might be expected would be sufficient to produce an average crop if initial moisture were high and evaporation low. The interrelation of temperature, wind, and humidity is not consistent excepting in one instance. High winds are usually accompanied by low humidity in the growing season. The correlation is .7017±.11. None of the other correlations are of high order. If high temperature is added to the above unfavorable combination the most destructive atmospheric condition possible exists. Low temperature may oppose it, however, somewhat more than aid it.

When taken for the year round temperature has little bearing upon total water usage, nor does wind and humidity. The quantity available to be given up coupled with the culture applied determines the usage. Initial moisture is the only factor contributing strongly both to high yield and high total water usage. All the others are high in importance in one case and low in the other.

The relatively high detrimental effect of wind as an individual factor seemed out of proportion to what could be expected from increased transpiration and the consequent lessening of moisture using efficiency so that greenhouse experiments with moisture, temperature, light, and humidity controls were carried out with a wind variable (7). The results showed a markedly decreased yield substantiating the field observations. Wind not only requires a larger consumption of moisture per pound of dry matter produced but retards the rate of growth and delays the maturity even when the increased moisture demands are supplied.

All told atmospheric conditions total 65.0% of the influence accounted for as determining crop yields.

Rainfall and soil moisture account for but 24.7% if items so small as not to be significant individually are included in the total. In so much as quantity of rainfall is usually considered of paramount importance to crop production it is interesting to note the relative importance of current rainfall and initial soil moisture. Rainfall and initial moisture are wholly independent of each other in practically every grouping studied. From a practical standpoint these two factors may either be known in advance or depended on in all but the most exceptional seasons. Rainfall fluctuations need not be feared, but an unfavorable combination of atmospheric factors which largely determine the efficiency with which crops use moisture will cut down sharply on yields.

The possibilities of making better use of rainfall as to getting more moisture into the soil have been pointed out in Part II. The ways of preventing inexcusable waste of moisture that has been stored in the soil are clear. However, the studies of soil moisture behavior, total water usage, and crop yields impress the fact that possibilities of controlling conditions in respect to major results are rather limited. The number of small ways in which pressure may be brought to bear are nevertheless very important because they are capable of tipping the balance toward success on the numerous occasions when seasonal combinations are doubtful. The crudest reasoning can reap the benefits of the good year and in a measure avoid the calamity of the poor year, but the greatest skill is necessary to turn the uncertain prospect to good account.

The main lesson of the entire study is that no one factor dominates crop production, permitting important gains to be made by proper attention to all the details of method and management. The following summary lists the facts thought to be significant from a study of the first five years results of these experiments. The study is being continued with confidence that many situtions not presented during the 1924-28 period will arise in the future and ultimately enable a somewhat definite code of cultural management to be devised which will reduce the hazards of moisture fluctuations.

Summary

1. From 22 to 39 per cent of the total rainfall of a wet period may enter the subsoil. An average of about 20 per cent of the annual rainfall becomes subsoil moisture in the heavy type of plains soil studied.

2. Showers up to about one-half inch in size do not increase soil moisture unless they follow one another on consecutive days.
3. Rains of more than one inch occasion some runoff unless they fall very slowly or are held on the field by contour tillage or level terraces.
4. An arbitrary classification of rainfall on this basis shows that for the period 1911-27 light, medium, and heavy precipitation in nearly equal in total amounts annually, being 31.3, 34.7, and 33.9 per cents respectively.
5. The variation from normal is least in the case of the light shower and greatest in the case of the heavy rain.
6. Runoff from heavy soils with a minimum slope is estimated at 13.5 per cent of the total rainfall.
7 About 20.7 per cent of the total rainfall becomes soil moisture of which 2.7 is lost from exposure by the ordinary tillage operations, leaving 18.0 per cent available for plant use.
8. Approximately 65.8 per cent of the rainfall evaporates from the surface during and immediately following precipitation. Of this amount 31.3 per cent is constituted by showers too small to add to the permanent store of soil moisture.
9. Rainfall is distinctly more effective in building up soil moisture in cool than in warm weather.
10. Moderate sized rains are more efficient in all seasons in storing soil moisture than the combined extreme fractions as measured by the percentage of total becoming soil water.
11. The stability of moisture content, whether it be high or low, endures for periods of three to five months.
12. Cultural conditions which remove moisture very rapidly, such as deep plowing or plant growth, alone threaten the immediate loss of a body of stored moisture.
13. The rate of gain was decreased by a high initial moisture content of the soil. The data indicate that the point of diminishing increases is reached if summer fallowing is carried too far.
14. The deeper the cultivation or more advanced the stage of plant growth, the more moisture is removed from the soil in a given time. This relation is not materially modified by rainfall or temperature conditions.
15. High humidity very greatly increases the efficiency of rainfall in the warm seasons of the year.
16. Temperature is relatively unimportant to quantity of moisture stored or rate of gain in the soil.
17. Temperature is highly significant in modifying the relationships of rainfall, wind, and humidity to the behavior of soil moisture.
18. Under the conditions of this experiment an average of .91 inches of water was used by the crop from the soil in addition to the current rainfall of the period. The average length of growing season was 114 days.
19. The extreme fractions of rainfall aid crop growth materially though they add nothing to the soil moisture.
20. Initial soil moisture exerts an influence on yield about equal to that of the quantity of current rainfall.
21. High temperature, high wind, and low humidity are the principle inhibiting factors to crop growth. High wind and low humidity are associated, but temperature varies independently.
22. Wind exerts a physical injury retarding growth in adidtion to the reduction of moisture using efficiency in which it is combined with temperature and humidity.
23. Total amount of water disposed of during the crop period is not highly correlated with crop yield, however, culture scores about 20% on water usage in the crop of the whole.
24. Total water usage is almost wholly determined by initial moisture, rainfall, and culture.

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