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WATER CONSERVATION IN GREAT PLAINS WHEAT PRODUCTION

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Farmers' experience in 901 cases of winter wheat production in the high plains of Texas and adjacent areas shows that seasonal conditions and subsoil moisture accumulations preparatory to sowing in the fall may serve as a dependable forecast of production possibilities. Favorable July rainfall was a big factor in preparing a good soil condition for high yields and a large subsoil moisture store on hand at sowing time in the fall contributed greatly to the size of grain yields the following year.

Where contour tillage and level terracing were used to retain surface runoff water favorable sowing conditions more frequently occurred and the risk of crop failure and wind erosion damage was reduced.

Nevertheless, water conservation alone is not enough to make the best use of current soil and water resources available in the winter wheat areas of the Texas high plains. The amount and distribution of seasonal rainfall naturally vary so much that a definite program of flexibility in the use of summer fallowing, tillage methods, and the rotation of diversified crops becomes a physical necessity. The combined objectives of wind erosion control and efficient production emphasize the importance and practicability of using soil moisture and crop residues as guides to tillage methods and cropping plans.

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WATER CONSERVATION IN SOUTHERN GREAT PLAINS WHEAT PRODUCTION

By H. H. Finnell, Research Specialist, Soil Conservation Service Amarillo, Texas

The problem of efficiently utilizing the soil and water resources of the Southern Great Plains for winter wheat production is one that has occupied the thought of farmers and students almost from the beginning of agricultural development in the high plains.

Agronomists, farmers, and millers have debated the merits of different wheat varieties. The appearance of insects and diseases has given the crop industry many starts and alarms. The waxing and waning of fads in farm machinery have gradually increased the labor efficiency of wheat producing methods and equipment. The crop-management problems interjected by the uncertainties of economic depression and war demands have beclouded the scene. But most formidable of all seemed the dark clouds of dust that rolled over the Plains during the "dirty thirties" when protracted drouth made wind-erosion control more difficult than usual. Through this period men's fortunes and their soil resources suffered but also much has been learned that should be turned to use.

It is becoming more and more evident, as our knowledge of semi-arid agriculture increases, that the element of gambling in Southern High Plains wheat production is being injected because of the farmers' disregard of important advance conditions of soil and moisture rather than by the hazards of unknown variables.

These essential productive conditions accrue, exist, and are measurable previous to sowing time and adequate substitutes for them cannot be anticipated later during the crop-growing season with any reasonable degree of probability.

In the light of these facts, the efficiency of wheat production is capable of enough practical improvement to completely eliminate erosion hazards induced by injudicious sowing, to save the waste of seed and labor on unprofitable production possibilities, and at the same time, to afford highly desirable crop diversification opportunities wherein forage and grain feed crops may be successfully produced on soil and water resources that would largely be wasted in producing weeds and wheat failures under a system of straight wheat farming.

HISTORY OF THE IDEAS EXPLORED IN THESE STUDIES

A study of the relations between initial soil moisture stores and resulting wheat yields was first reported in the Southern Great Plains by Call and Halstead in 1915. (1) Continued observations were reported by Finnell in 1929 (7, 8, 9), by Halstead and Coles in 1930 (17), by Henny in 1932 (18), by Finnell in 1933 (10).

Studies of the functions of level-terraces in water conservation and crop production were started by Dickson and Finnell at about the same time in Texas and Oklahoma. Yield increases of sorghum due to terracing were first reported by Finnell (9) in 1929. Yield increases of cotton due to terracing for water conservation were first reported by Conner, Dickson, and Scoates in 1930 (2) and of wheat by Finnell (11) in 1930. Further reports were made by Finnell in 1931 (12) and 1934 (16), by Daniel in 1935 (3), by Daniel and Finnell in 1939 (4), and by Dickson, Langley and Fisher in 1940 (5).

Information along both these lines produced by the experiment stations of Kansas, Oklahoma, and Texas was made the basis of water and crop management phases of the conservation program developed and demonstrated by the Soil Conservation Service in the Southern Great Plains region from 1934 to 1942. (The field records of these demonstrations carried out under average farm conditions form the body of data analyzed in this study.) The lessons of practical application learned in the demonstration projects have since been used by Agricultural Adjustment Administration and in the framing of programs and plans of work adopted by soil conservation districts in the Southern High Plains area.

SOURCES OF DATA

The field records of the soil conservation demonstration project areas of the Southern Great Plains afford a mass of information revealing some of the behavior of water conservation practices in relation to soil, climatic, and cultural variations as they affect wheat production.

The farm results studied represent, roughly, an area of Southern Great Plains about 100 miles wide and 250 miles long, stretching in a northeast-southwesterly direction from southwestern Kansas across northwestern Oklahoma and Texas into eastern New Mexico. The records are complete on 901 farms taken during the years 1938 and 1939.

Although the records cover only a period of two years, the variation in seasonal conditions sampled is greatly augmented by the distribution of the farms among 11 separate demonstration areas in addition to the local variations recorded within areas by a network of rain gages. For example, the July rainfall varied from 1 to 5 inches and the August to October period rainfall varied from 2 to 12 inches. The yields of wheat ranged from 0 to 34 bushels. These variations are characteristic of single location records extending over periods of 10 to 20 years.

Top-soil texture was determined by a detailed soil survey of each individual field and was translated into numerical terms by devising a scale of 1 to 7 as an index of textures ranging from clay loam to loamy fine sand. From the same detailed survey information about soil depth, slopes, and erosion conditions was obtained.

The rainfall records during the preparatory and crop growing seasons were kept by cooperative observers under the technical supervision of project engineers using standard rain gages located from 2 to 4 miles apart within the demonstration areas. Regular daily and monthly records of precipitation were available from all the demonstration areas. The nearest rain gage record was applied to most fields; however, where a field was located half-way between two gages, or in a three-gage triangle, two or more records were averaged if the rainfall at adjacent points varied greatly.

The water conservation practice and age of terraces were recorded by project technicians. Three degrees of water conservation practice were recognized and differentiated by the amounts of surface water capable of being retained by the structures used.

The time of seeding, the rate of seeding, and the fallow period previous to seeding were observed and recorded by project technicians at the appropriate seasons of the year. The wheat yields were determined by project technicians in collaboration with the cooperators on the basis of bushels of grain per sowed acre. On most of the projects, these were calculated to .1 bushel but, in some cases, the nearest even bushel was recorded.

The depth of soil moisture penetration at seeding time in the fall was determined for each separate field by project technicians using a soil auger or tube and recorded in inches from the surface. The amount of fall and winter grazing utilized was recorded by project technicians in collaboration with the farmers and was calculated to the nearest .1 cow-month per acre.

ANALYSIS OF THE DATA

The first step in the study consisted of determining which factors showed a significant relation to wheat yield in order that these might be analyzed in relation to water conservation practice.

Significant increases of wheat yield resulted from each of the following: (1) initial soil moisture stores, (2) July rainfall previous to sowing, (3) level terracing and contour farming, and (4) favorable spring rainfall, while significant decreases resulted from (5) soil erosion damage, (6) delayed seeding, and (7) fall and winter grazing.

Some additional information has been obtained from studies of various subdivisions of the group. It may be briefly noted that the unfavorable effect of land slope appears to have been off-set by the effects of terracing and contour farming; that summer fallowing, as practiced on the average wheat farm, proved to be much less effective than experiments would lead one to expect; that variations in the May rainfall, which is popularly supposed to cover a very critical period in the crop year, is of little or no importance separate and apart from the rainfall of the January to May period; and that the August to October rainfall operates almost entirely through its contribution to the storage of a subsoil moisture supply for later use.

A good estimate of probable yield can be made, using only factors which are known and measurable previous to sowing time or which can be reasonably anticipated previous to sowing time. If no grazing is anticipated, no delay in sowing, and no part of the area is susceptible to wind-erosion damage, the following formula may be used:

> Multiply the number of inches of July rainfall by $2\frac{1}{3}$; divide the number of inches of depth of soil moisture penetration at wheat sowing time by 3; add these two values together, and substract $6\frac{1}{4}$.

The number obtained will be the average expected yield per acre in bushels of wheat, and the chances are 2 to 1 that this average will be within 5 bushels of the actual yield harvested.

Since the efficient use of soil and moisture resources constitutes the other half of conservation, it is always important to take advantage of favorable seasonal conditions to increase production just as it is important to avoid a waste of seed and labor when conditions are so unfavorable as to predict an almost sure failure or unprofitable yield.

Table 1. Wheat Yields Averaged According to Significant Variables Observed in the Southern Great Plains, 1938-1939

Methods or Condition	Number Fields	Mean Yield Bushels Wheat Per Sowed Acre	Significance of Differences Between Means
Fall Soil Moisture Penetration:			
0—12 inches	128	1.37	
13—24 inches	290	3.07	**
25—36 inches	308	8.49	
37 plus inches	175	12.60	
Previous July Rainfall:			
.50—1.50 inches	276	4.57	
1.51—2.50 inches	495	6.01	**
2.51—3.50 inches	85	10.19	
3.51 plus inches	45	17.42	
Portion of Field Affected by Erosion:			
0— 40%	836	6.79	
50— 80%	51	3.90	**
90—100%	14	.57	
Not Grazed	588	5.65	
Fall and Winter Grazed	313	8.17	**
September Seeding	739	6.87	
October to December Seeding	162	4.96	**
January to May Rainfall:			
2— 3 inches	213	1.62	
4— 5 inches	405	7.32	
6— 7 inches	248	8.48	**
8— 9 inches	23	11.35	
10 plus inches	12	17.42	
Without Water Holding Structures	386	5.11	
Level Terraced or Contour Farmed	146	6.31	**
Level Terraced and Contour Farmed	369	8.10	

Table 1. **Wheat Yields Averaged According to Significant Variables Observed in the Southern Great Plains, 1938-1939—Continued**

Methods or Condition	Number Fields	Mean Yield Bushels Wheat Per Sowed Acre	Significance of Differences Between Means
Wheat After Wheat:			
Without Water Holding Structures	216	4.42	
Level Terraced or Contour Farmed	74	5.69	**
Level Terraced and Contour Farmed	150	7.31	
Wheat After Sorghums:			
Without Water Holding Structures	84	5.64	
Level Terraced or Contour Farmed	37	6.35	
Level Terraced and Contour Farmed	72	7.36	
Wheat After Summer Fallow:			
Without Water Holding Structures	86	6.35	
Level Terraced or Contour Farmed	35	7.60	**
Level Terraced and Contour Farmed	147	9.26	
Previous Crop:			
Wheat	440	5.62	
Sorghum	193	6.42	**
Summer Fallow	268	8.11	
Without Water Holding Structures:			
After Wheat	216	4.42	
After Sorghums	84	5.64	*
After Summer Fallow	86	6.35	
Level Terraced or Contour Farmed:			
After Wheat	74	5.69	
After Sorghums	37	6.35	
After Summer Fallow	35	7.60	
Level Terraced and Contour Farmed:			
After Wheat	150	7.31	
After Sorghums	72	7.36	*
After Summer Fallow	147	9.26	

**Highly significant differences between means.
*Significant differences between means.
No significant differences between means.

In Table 1, the wheat yields are classified according to variations in each of the factors found to have a statistically significant relation to yield. The column showing the number of fields indicates the frequency with which different conditions occurred within the group of farms studied. The symbols in the last column of the table indicate whether the differences between mean yields are great enough to be significant or not.

Soil Texture

Although the variations in soil texture do not show up as an important factor affecting wheat yield in any of the subgroups, the fact sandier types of soil prevailed where wheat followed sorghum in the rotation, sets this subdivision apart from all the others and helps to explain the apparent divergence of moisture relations to soil and crop. It is a commonly observed fact that the sandier soils are less subject to extreme effects of drouth or wet weather. With equal slopes, they are less urgently in need of water holding structures and, for the same physical reasons, are credited with being able to make more effective use of rainfall occurring during the preparatory and crop growing season. The soils were noticeably sandier in texture in that group where wheat was sowed in sorghum stubble than in the group where wheat followed summer fallow. This observation reflects the popular conception that sandy soils are best suited to diversified farming and that summer fallowing is most effective on hard lands.

It should also be pointed out that under farm conditions wheat does not follow sorghum nearly as often as it does wheat or summer fallow. Exceptional conditions such as a thin stand of sorghum or effective late summer and early fall rainfall are usually necessary to suggest this rather difficult crop sequence.

It is recognized that the 193 cases of wheat sowing in sorghum stubble recorded in this study do not represent the average conditions found on sorghum land at wheat sowing time. However, when favorable conditions do exist in sorghum fields, the value of taking advantage of them for wheat production should not be ignored.

Fall Soil Moisture Store

Measuring the depth of moisture penetration is not an exactly accurate method of determining the store of available moisture in the soil. However, the simplicity and ease of making this determination more than compensates for small errors. It is a method which can be used just as readily by the average farmer as by any technician.

When wheat yields were classified according to depth of fall soil moisture penetration, the extremes ranged from an average of 1.37 bushels, where moisture penetration was 12 inches or less, to 12.60 bushels, where penetration was above 36 inches. (See Table 1 and Figure 1.) Almost sure failure was indicated by an initial moisture supply of less than 24 inches penetration, and a penetration of more than 36 inches was necessary to insure a profitable yield within reasonable limits. Only 13 failures occurred out of 175 sowings, or less than 7½%, where an adequate initial soil moisture supply was on hand at sowing time. With 12 inches or less of initial soil moisture penetration, 85 failures occurred out of 128 sowings, and only 7.0% yielded 6 bushels per acre or better.

As a single criterion upon which to base cropping plans, this factor of stored moisture supply is the most dependable. However, much more accurate forecasts can be made by also taking other advance conditions into consideration.

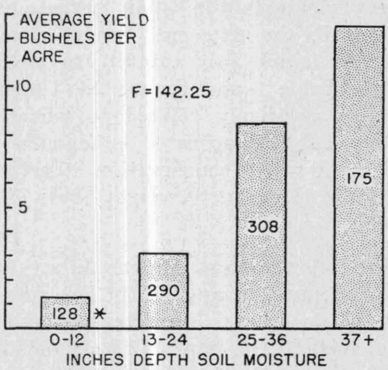
The effect on wheat yield of soil moisture supply at sowing time was highly significant under all conditions studied. Its greatest relative importance, in comparison with other factors, was shown where wheat followed wheat. Variations in soil moisture store were less effective where wheat followed sorghum. In this case, its relative weight was exceeded by that of the previous July rainfall. It was approximately of equal importance under all other conditions.

The greater importance of initial moisture supply when wheat follows wheat cannot be explained by differences in the amount of available moisture involved. The average depth of penetration on wheat stubble land was 22 inches, compared to 27 on sorghum stubble land. The soil depth wetted, per inch of summer and early fall rainfall, was 3.00 inches where wheat followed wheat, and 3.28 inches where wheat followed sorghum on sandier types of soil.

Where the group was subdivided according to crop sequence, it was noted that the July rainfall also contributed more to the fall soil moisture store where wheat followed fallow or wheat, than where a sorghum crop occupied the land until wheat sowing time.

A radical difference existed in the seasonal progress of soil moisture in the two types of crop succession. Land being prepared for sorghum continued to increase in moisture content beyond the month of June, when sorghum planting was usually done, and was ordinarily well supplied with

Figure I. RELATION OF INITIAL SOIL MOISTURE TO WINTER WHEAT YIELD IN THE SOUTHERN GREAT PLAINS.



*Indicates number of fields averaged in each group.
F = Variance Ratio.

moisture during the month of July; whereas land bearing a wheat crop approached midsummer with a continuing decline in soil moisture content, reaching its most completely exhausted condition at harvest time, about the first of July. From midsummer on until wheat sowing time in the fall, the land bearing a sorghum crop continued to be cleanly cultivated, but the soil moisture supply was used up at least as fast as it was replenished with current rainfall. Under thick stands of sorghum it was used up faster.

In years of deficient summer rainfall an initially adequate soil moisture store would be seriously depleted under a growing sorghum crop. Hence, the subsoil moisture supply at wheat sowing time is governed in about the same degree by the August to October rainfall on summer cropped land as on stubble or fallow land. The major essential difference involved is that the summer rainfall operates to build up a soil moisture store in stubble land while it operates to maintain a soil moisture store in summer cropped land.

Based on the simple averages, the effect of initial stored soil moisture supplies was to increase the wheat yield .31 bushels per inch of moist soil, but when the effect of other related factors was eliminated by calculation, one inch of moistened soil was equal to .26 bushels of wheat per acre.

July Rainfall Previous to Wheat Sowing

The amount of July rainfall previous to sowing is highly significant to wheat yields harvested 11 months later. This relationship was first pointed out in the territory represented by this study in a 10-year observation made on 60 wheat crops at Goodwell, Oklahoma (1924-1933) (10). July rainfall exerted a strong effect on yield independent of its contribution to the initial soil moisture stores.

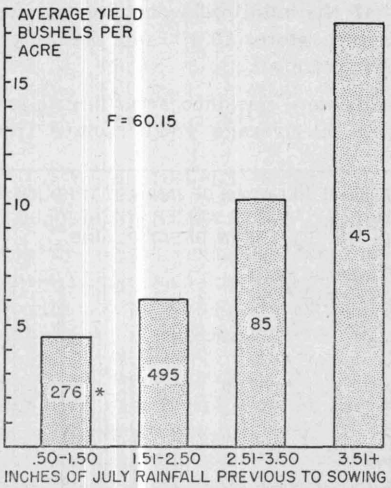
When the 901 wheat yields in this study were classified according to the previous July rainfall, the extremes ranged from an average 4.57 bushels per acre, after a 1 inch July rainfall, to 17.42 bushels after a 4 inch July rainfall. (See Table 1 and Figure 2.) Under all the conditions studied, this factor was positively related to wheat yield in a highly significant degree. July rainfall operated practically without regard to the presence or absence of water conservation structures. However, there was a marked difference in the relative weight of its effect during different years in a crop rotation.

On land where wheat followed sorghum, the July rainfall was of greater weight than any other factor. It was slightly less important where wheat followed wheat, and decidedly less important where summer fallowing was practiced in preparation for wheat. The most important effect of July rainfall upon the succeeding wheat crop seemed to be related to fertility conditions.

From the standpoint of preparation for fall sowing, ample July rainfall afforded an opportunity for early plowing or listing, the sprouting of volunteer wheat, killing of weeds, and the partial incorporation of straw and stubble residues in the soil during the warm part of the year. In the presence of ample moisture the rapid decay of incorporated organic matter was started. Although it is desirable to leave as much unrotted trash on the surface as possible, in order to prevent severe nitrate depressions in the top-soil and to provide a protective ground cover against wind erosion, at the same time a certain amount of incorporation of trash is unavoidable. From a study of the progress of soil nitrate formation after various crops and under various field conditions in the High Plains area (13), it appears that the recovery of a normal nitrate supply occurred much sooner during the following crop season on early plowed land and that this was a distinct advantage to the oncoming wheat crop. Although wheat might even suffer from an excess of available nitrogen in the soil at sowing time, it requires a progressive increase reaching a maximum during the growing period the following spring. Ample July rainfall sets the stage to accomplish this.

The advantages to soil preparation of a favorable July rainfall accounts for a large part, if not most, of the favorable relationship between the

Figure 2. RELATION OF PREVIOUS JULY RAINFALL TO WINTER WHEAT YIELD IN THE SOUTHERN GREAT PLAINS.



*Indicates number of fields averaged in each group.
F = Variance Ratio.

July rainfall and the succeeding wheat yield. The apparent reason why this factor is of measurably less importance on summer fallowed ground is that its most important functions have already been largely taken care of where fallowing operations are carried out previous to July.

In this connection, it will also be noted that the relation of July rainfall to the accumulation of soil moisture stores was not affected by different degrees of water conservation practice. It contributed to the fall soil moisture store in cases where a crop did not occupy the land during July, as where wheat followed wheat or summer fallow, but a heavy July rainfall contributed only to the current growth of sorghum when that crop was present. From the simple averages, it would appear that each inch of July rainfall accounted for 4.28 bushels of grain per acre, but when the calculated effect of other factors was eliminated it was 2.62 bushels per inch.

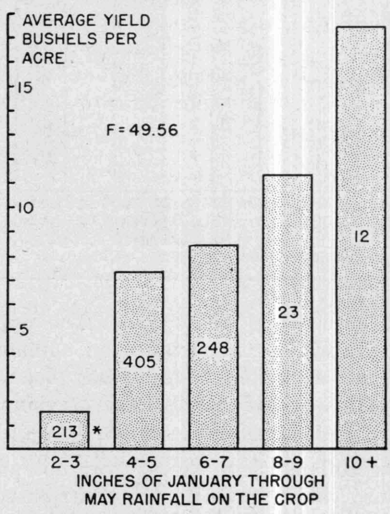
Spring Rainfall

Third in importance among the factors affecting wheat yield was the spring rainfall. The idea that the rainfall during the month of May provides a turning point between success and failure of the crop was tested and disproved. Although the May rainfall averaging 1.71 inches, in this group of 901 farms, fluctuated rather violently, the analysis showed that variation in May rainfall was not statistically significant in its effect on wheat yield independent of the January to May period of rainfall. After the effects of summer rainfall and soil moisture store had been accounted for, the spring period, January to May, inclusive, constituted the next most important moisture segment contributing to wheat yield.

The effect of these three portions of contributing moisture supply, expressed as per cent of the total influence determining yield was 15.2% for the fall soil moisture store, 10.6% for the July rainfall, and 8.1% for the January to May rainfall.

When the wheat yields were classified according to spring rainfall (January to May, inclusive), the average yields ranged from 1.62 bushels per

Figure 3. RELATION OF JANUARY THROUGH MAY RAINFALL TO WINTER WHEAT YIELD IN THE SOUTHERN GREAT PLAINS.



*Indicates number of fields averaged in each group.
F = Variance Ratio.

acre under 2-3 inches of rainfall to 17.42 bushels when it exceeded 10 inches. (See Table 1 and Figure 3.) About 7 inches of spring rainfall were needed to make a profitable yield of wheat, initial supplies being average, but indications were that a spring deficiency could be partially overcome by ample supplies of soil moisture carried over from the previous year.

The relative importance of spring rainfall, as could be reasonably expected, decreased with the intensity of water conservation practices. It was 13.4% without water holding structures, 10.3% with partial water conservation practice in effect, and 6.7% with complete water conservation consisting of terracing and contour farming. This relationship shows very clearly that the prevention of loss by runoff during the preparatory period, as well as during the crop growing season, relieves the wheat crop very substantially from the unfavorable effects of variation in the amount and distribution of the spring rainfall.

There was little difference in the importance of spring rainfall where wheat followed wheat or summer fallow, but it was markedly less important on the sandier soils of sorghum land. As calculated from the simple averages, 1 inch of spring rainfall accounted for 1.97 bushels of wheat per acre, but when the effect of other factors was eliminated it was really about half this amount, or .94 bushels.

Wind Erosion Damage

Of the 118,413 acres covered by 901 wheat records, 10.1% was subject to wind erosion during the wheat year. The subgroup most affected was that in which summer fallowing was practiced with 13% of the area subject to wind erosion, while the least affected area was that in which wheat followed sorghum, with 7.6% of the area affected by wind erosion.

Wind erosion was a significant factor in reducing wheat yield in all the subdivisions of study but one. In spite of the fact that erosion damage was less frequent on sorghum stubble, its relative effect was very high when control was lost, representing 6.1% of the total determining influence. It was lowest where wheat followed wheat, representing 4.8%.

Involved as elements in this factor were the previous damages to the soil by erosion which made it more susceptible to the recurrence of blowing, and the loss of vegetative cover exposing portions of the current crop to direct wind damage.

Although the frequency of high wind erosion damage was not great in this group, (see Table 1 and Figure 4) it is apparent that yields were very drastically diminished where a large proportion of the area of a field was subject to erosion.

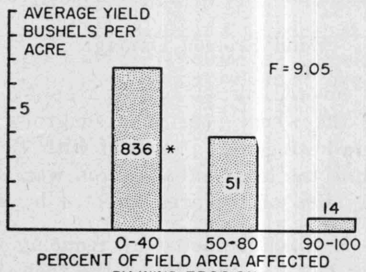
The reduction in yield indicated by simple averages was .83 bushels for each 10% of the field area affected by soil blowing. Calculated apart from inter-related factors it was .52 bushels per acre.

Worthy of note is the fact that fields which had suffered most from wind erosion damages were selected first by farmers to be terraced and contour farmed. However, after 5 years of operations during which much undamaged land also was terraced and many of the appearances of former damages were obliterated by successful cropping, the indices of erosion were not far apart in the treated and untreated subdivisions.

Date of Seeding

The delay of wheat seeding after September resulted in a significant decrease in yield. However, the weight of this factor was not sufficiently great to be noticeable in all subdivisions. Apparently, the delay of sowing was more serious where wheat was placed on summer fallowed land than in any other place in the rotation. This would naturally be expected to have a relation to the clean condition of the soil. However, the effect of delayed sowing after summer fallowing is highly significant, independent of susceptibility to wind erosion. Delayed sowing was also a significant

Figure 4. RELATION OF WIND EROSION CONDITIONS TO WINTER WHEAT YIELD IN THE SOUTHERN GREAT PLAINS.



*Indicates number of fields averaged in each group.
F = Variance Ratio.

factor on lands where water conservation practices were used, probably due to an apparent tendency to put off the sowing of terraced and contour farmed land until the latter part of the season. The losses resulting from delayed sowing, however, were great enough to warrant all possible care in carrying out timely operations. From simple averages, each 10 days' delay after September 15 appeared to reduce the yield .32 bushels per acre, but the real effect was a reduction of .44 bushels.

Fall and Winter Grazing

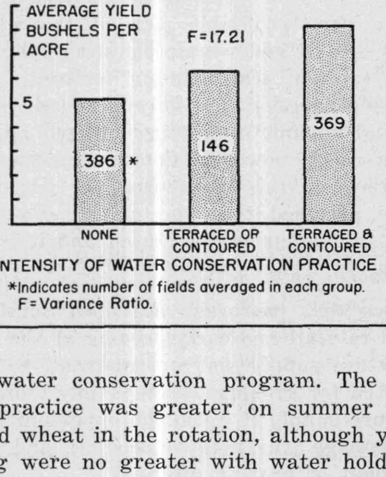
Winter wheat is almost universally grazed with cattle or sheep in the area represented, when summer and fall moisture conditions are favorable to early sowing and rapid fall growth. Three hundred and thirteen fields which were grazed yielded an average of 8.17 bushels compared to 5.65 bushels harvested from those not grazed. These averages, as shown in Table 1, appear to associate fall and winter grazing with high grain yield.

However, when the real effect of grazing utilizations was calculated, it was found that an average of .46 cow month per acre reduced the yield per acre ¾ bushels of grain. The contrary indications of the simple average resulted from the inclusion in the ungrazed group of a large number of fields which were a failure from the start having been sowed under such unfavorable conditions that no grazing capacity was produced, although grazing may have been desired.

Water Conservation Practices

The intensity of water conservation methods practiced showed a highly significant favorable relation to wheat yield, particularly where wheat followed wheat or summer fallow. When wheat yields were classified according to water conservation treatment, fields without structures averaged 5.11 bushels per acre, terraced alone or contour farmed alone, 6.31 bushels, and terraced and contour farmed together, 8.10 bushels. (See Table 1 and Figure 5.) This is an average gain of 2.99 bushels of wheat per acre

Fig. 5. RELATION OF WATER CONSERVATION PRACTICE TO WINTER WHEAT YIELD IN THE SOUTHERN GREAT PLAINS.



*Indicates number of fields averaged in each group.
F=Variance Ratio.

due to a complete water conservation program. The relative weight of water conservation practice was greater on summer fallowed land than where wheat followed wheat in the rotation, although yield increases made by summer fallowing were no greater with water holding structures than without them.

The effect of water holding structures calculated separately from their contribution to the initial soil moisture supply was to increase the yield 1.36 bushels per acre. This represents the effect of water conservation during parts of the year other than the summer and early fall preparatory period. On 386 fields without water holding structures, each inch of the July through October rainfall moistened the soil an average depth of 3.01 inches. Under terraces and contour tillage, on 369 fields, the penetration was 22.2% greater, reaching an average of 3.68 inches deep per inch of rainfall during the preparatory period.

The increased initial moisture supply represented by 4.37 inches of additional penetration due to structures caused a gain of 1.14 bushels of wheat per acre to be added to the 1.36 bushels per acre growing season results of water conservation practices. This specifically identified yield increase totaling 2.50 bushels per acre accounted for nearly all of the 2.99 bushel increase associated with water holding structures.

An opportunity to investigate the effect of the age of terraces, as an index to the effectiveness of maintenance being given them by the farmers, occurred in the subgroup of 369 farms where terracing and contour farming were practiced together. In this group the age of terraces did not significantly affect the yield of grain, indicating they were being maintained in an effective condition. However, the maximum age of any terraces was 5 years, while the average age of all those studied was slightly under 2 years. The hazards of failure of terrace systems due to excessive rainfall is not as great in the Southern Great Plains wheat belt as in many other areas, and the methods of upkeep are relatively simple.

WHEAT PASTURAGE

Since occasionally a very profitable part of the wheat production is harvested in the form of fall and winter pasturage, a study was made of the relations of soil, erosion, seasonal, and cultural practice conditions affecting wheat pasture production. The only measure of pasture production available was the actual amount of grazing utilized by the farmers. This may be accepted as a rough measure. Considering that it is the general practice to pasture wheat in this area when the wheat pasture is good, it may be reasonable assumed that the majority of fields affording a profitable opportunity for pasturing were used and it is certain that none was used upon which no forage was available.

The statistics showed that pasturage depended mainly upon favorable summer and early fall rainfall and early seeding of the crop. The accumution of a subsoil moisture supply was unimportant, which would indicate that the fall growth used for grazing draws mainly from the current rainfall and top-soil moisture supply if given the opportunity by early seeding. Land slope, erosion damage, the rate of seeding, and summer fallowing did not affect the amount of grazing afforded.

FACTORS AFFECTING SOIL MOISTURE ACCUMULATION

Since the accumulated supply of sub-soil moisture at sowing time has proved to be the single dominant factor influencing grain yields to a greater extent than any other one condition known to arise previous to or during the crop growing season, a further study was made to determine what conditions contribute to the building up of a soil moisture supply.

Named in the order of their relative importance, they are: the August to October rainfall, the July rainfall except after sorghum, the water conservation practice, the length of fallow preparatory period, and the coarseness of soil texture. Factors which did not generally affect the accumulation of a soil moisture store significantly were: the July rainfall, the soil erosion damage, the land slope, and depth of fertile soil section.

Table 2. Fall Soil Moisture Accumulations According to Preparatory Season Rainfall and Capacity of Water Holding Structures in the Southern Great Plains, 1938-1939

Method or Condition	Number Fields	Mean Depth Inches Fall Soil Moisture Penetration	Significance of Differences Between Means
August to October Rainfall:			
2— 3 inches	227	14.85	**
4— 5 inches	136	25.62	
6— 7 inches	354	27.55	
8— 9 inches	136	34.60	
10 plus inches	48	36.67	
Without Water Holding Structures	386	23.42	
Level Terraced or Contour Farmed	146	25.89	**
Level Terraced and Contour Farmed	369	27.79	

**Highly significant differences between means.

The fact that the beneficial effects of summer fallowing and of the late summer and early fall rainfall operated to benefit the wheat crop almost exclusively through the mechanism of soil moisture storage was very clearly brought out. The effects of terracing and contour tillage were divided between increasing the advance store of soil moisture and increasing the efficiency of utilization of the current rainfall coming during the crop growing period.

From Table 2, the 2 inch class under August to October rainfall showed a mean depth of moisture penetration of 14.85 inches. Where the rainfall reached 10 inches, the penetration was 36.67 inches, a difference of 21.82 inches penetration due to an 8 inch rainfall increase. This is equivalent to 2.73 inches of moistened soil per inch of rainfall, or approximately 22.8% of the precipitation becoming soil stored water available for plant use.

In Table 3 are compiled the July to October rainfall and moisture penetration means for fields in which wheat followed wheat subdivided according to water conservation practices.

In this particular crop sequence subdivision, the soil reaches harvest time exhausted of available moisture and must depend on the rainfall that follows maturity of the crop to build up a new supply. This comes, roughly, during the period July to October, inclusive. Hence, the moisture penetration measured in the fall can practically all be credited to the rainfall of the intervening period.

Table 3. Soil Storage of Rainfall Between Harvest and Seeding of Winter Wheat, Southern Great Plains, 1938-1939

Field Conditions	Number Fields	Mean July to October Rainfall	Mean Depth Soil Moisture Penetration	Penetration Per Inch Rainfall, Inches	Per Cent Rainfall Becoming Soil Stored Water
Without water holding structures..........	216	7.28	20.52	2.82	23.42
With level terraces and contour farming....	150	7.03	23.83	3.39	28.24

In all calculations, a rough factor of 1 inch of available soil stored moisture per foot of soil was used to convert the penetration measurement to available water terms. Numerous determinations within the range of soil types that prevail in this study show that to be fractionally under the actual. Therefore, such estimates may be taken to be slightly conservative.

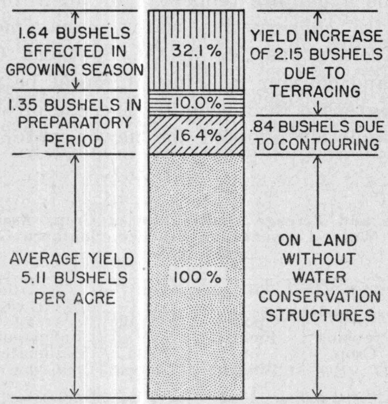
Determinations by soil moisture sampling from heavy silt loam soil at the Panhandle Experiment Station at Goodwell, Oklahoma, 1926-1929, (7) showed that 20.7% of the entire yearly rainfall became soil stored water on unterraced land and that 25.2% was saved on terraced land. (See Figure 7.) An average of the terraced and unterraced land at Goodwell, 22.95%, roughly agrees with the field observations in soil conservation demonstrations of which 492 were unterraced and 409 were terraced, averaging 22.80%.

ANALYSIS OF THE WHEAT YIELD INCREASE

The data of 146 fields level terraced or contour farmed where 106 of these were contour farmed, while 40 were terraced but farmed without regard to slope, reveals an average yield increase of 1.20 bushels per acre. The combined use of terracing and contour farming yielded an increase of 2.99 bushels per acre. Of this 2.15 bushels of the yield increase were due to the terracing and .84 bushels were due to the contour farming. Contour farming provides, during a large part of the preparatory period, as much water holding capacity as terracing only when listing is employed, but after drilling the seed only the drill marks are likely to remain for contour effect. Hence, under wheat production the effect of contour cultivation does not cover the same length of time during the crop year as the effect of terraces and, in fact, is considerably less effective than the same method employed with row cultivated crops, where lister and row cultivation maintains a contour effect through both preparatory and growing periods.

In calculating the grain yield increase from the simple averages, (Table 1 and Figure 6) terracing and contour farming practiced jointly increased the yield 2.99 bushels of which 1.35 bushels resulted from the increase of soil moisture stored before the crop was seeded, leaving 1.64 bushels of increase to be accounted for by moisture saving while the crop occupied the land. Assuming that all of the contour farming effect took place during the preparatory period, the difference between 1.35 bushels ac-

Figure 6. SOURCES OF WATER CONSERVATION YIELD INCREASE AND PERIOD OF EFFECTIVENESS



counted for through summer moisture accumulations in the soil and .84 bushels due to contouring, leaves .51 bushels creditable to the service of terraces during the summer, the balance of 1.64 bushels of yield increase being due to the operation of terraces during the fall, winter, and spring crop growing seasons.

CROP MANAGEMENT IN RELATION TO WATER CONSERVATION PRACTICES

Divided into three groups according to the intensity of water conservation practice used, there were 386 farms without water holding structures, 146 with a partial program consisting of contour farming alone or level terraces tilled without regard to slopes, and 369 with a complete program of contour farmed level terraces.

The crop succession and relative acreages of the main land uses for these groups are indicated in Table 4.

The type of farming represented in this study is clearly defined as wheat farming with from 66 to 70% of the cultivated acreage seeded to wheat.

The amount of summer fallowing increased with the intensity of water conservation practices used. This might indicate that farmers most progressive in adopting terracing and contour farming were those also making the most use of summer fallowing.

Of particular interest is the middle group in which farmers seemed disposed to undertake surface water control and conservation tentatively by going part way only. Compared to those who ignored conservation needs, they increased both the sorghum and summer fallow acreage while decreasing wheat acreage accordingly. Those who adopted a complete water conservation program decreased their wheat acreages even more, but kept sorghums about the same and devoted practically all of the acreage released from wheat to summer fallow.

There appears to be a definite tendency for operators to couple careful crop management with conservative water management. Since summer fallowing is a much older practice in the Southern Great Plains wheat area than terracing and contour farming, it might be assumed that those who have already progressed in developing the use of summer fallow more readily and more completely adopted the newer water conservation practices.

Table 4. Crop Sequence and Acreage Distribution of Crops Associated With Different Intensities of Water Conservation Practice, Southern Great Plains, 1938-1939

Group of Farms	Previous Crop	Number Fields of Wheat	Average Size of Field, Acres	% Wheat Acreage Following Designated Crop	Distribution of Cultivated Acreage Required to Approx. Maintain Successions	
					Crop	% Acreages
Without Water Holding Structures	Wheat	216	125	58.79	Wheat	70.59
	Sorghum	84	93	17.10	Sorghum	11.76
	Fallow	86	129	24.11	Fallow	17.65
With Level Terraces or Contour Farming	Wheat	74	127	53.33	Wheat	68.18
	Sorghum	35	144	18.07	Sorghum	13.64
	Fallow	37	86	28.60	Fallow	18.18
With Level Terraces and Contour Farming	Wheat	150	182	49.67	Wheat	66.67
	Sorghum	147	132	15.23	Sorghum	11.11
	Fallow	72	116	35.09	Fallow	22.22

In this connection, it is also interesting to note that according to the longest rainfall record in the Texas Panhandle, at Spearman, where an unbroken series of observations extends over 64 years, only 26, or 40% of the years received 7 inches of rainfall or more during the January to May period. According to this study, 7 inches of spring rainfall are needed to produce a profitable wheat yield without regard to carried over moisture. This observation also checks with the short term records of actual wheat production on the Goodwell, Oklahoma station (14) where it was concluded that 4 better-than-average yields might be expected out of 10 years due to favorable seasons, but that 3 additional uncertain yields might be turned into profitable yields by the use of water conservation practices.

With the average expectancy of effective periods of spring rainfall being 40%, the importance of water conservation practices and summer fallowing in good farm management becomes apparent. According to experiment station records, there would be expected also about 3 years out of 10 when the opportunity to secure advance storage of soil water and the spring rainfall would fail simultaneously. In those bad years the most profitable thing the farmer could do would be to avoid the waste of seed and labor in the fall and determine the next use of the land by the timing of the soil moisture accumulation.

PRACTICAL PROBLEMS IN WHEAT GROWING

A common sense appraisal of the weather records of the southern Great Plains confirms the prevalent supposition that rainfall is not dependable in this region. Other than the circumstances that winter follows summer with a reasonable degree of regularity, the principal condition that can be relied upon in the semi-arid High Plains is an unsystematic variation in the amount and distribution of the seasonal rainfall. However, the conclusion that is frequently drawn from this fact, that farming is impractical under such rainfall conditions, may be subject to considerable questioning.

There is no record of dependable rainfall periods upon which to base systematic crop planning. However, it has been proved by farmers' experience that worth-while productive potentialities exist in the soil and moisture resources of the area.

The task of working out the most practical way of efficiently utilizing these resources seems to require first of all a willingness to abandon some of the traditional ideas about crop rotation. The proposition is not that the needs of soil fertility can be ignored, but that both production and fertility maintenance should be accomplished in a manner more consistently in harmony with natural conditions.

Exploration to find a dependable basis for planning the crop management in the wheat land area of the southern High Plains has consisted first of identifying the factors that limit results and, second, measuring their relative importance and analyzing their behavior under various type conditions. The object of such studies was to find what may be actually counted on in lieu of the uncertain seasonal expectations. A few reliable, although not constant, conditions have been identified.

Quantities of available moisture already stored in the soil root zone may be counted on for future use. Surface crop residue already present in the field may be counted on for future use. Well maintained level terraces may be counted on as ready to prevent undue waste from excessive rains whenever they may come.

CHARACTER OF RAINFALL

As an approach to the methods of using this information in crop management, there should first be examined the nature of the water supply, its normal disposition, and the capacity of the storage facilities.

Rainfall can be divided, roughly, into three classes.

A representative rainfall record in the High Plains area (15), shows that light showers too small to penetrate the surface mulch were equally distributed throughout the year and that this type of rainfall constituted 31.1% of the total annual rainfall. The main effect of light showers is a temporary one on atmospheric conditions. No additions were made to the available subsoil moisture supply by light showers, and the surface moisture thus produced was soon evaporated.

Moderate rains, one-half to one inch, may be classified as effective in adding to the soil moisture store without runoff or undue loss by evaporation. This type of rainfall constituted 55.3% of the total annual rainfall and 87% of it came in the April to October period. Rains classified as effective supplied the surface and subsoil moisture upon which crops largely subsisted. That portion of effective rains penetrating below the surface soil mulch, into which air freely circulates, may be used currently by present vegetation or held over for future use at the will of the farmer.

Heavy rains in which more than one inch fell in 24 hours usually supplied more than could be absorbed by the soil or evaporated, thus causing surface runoff. All such rains are of maximum effectiveness up to the point at which runoff begins. Precipitation above this point was classified as excessive. It amounted to 13.5% of the total annual rainfall and 92% of it came during the 6 months of May to October.

DISPOSITION OF RAINFALL

If these characteristics of High Plains rainfall be kept in mind, the disposition of the moisture supply on wheat land can be much more readily understood and manipulated favorably.

The disposition of a rainfall of the type just described was determined at Goodwell, Oklahoma (3) by periodic soil moisture determinations over a period of four years, supplemented and verified by artificial rain studies on typical wheat land.

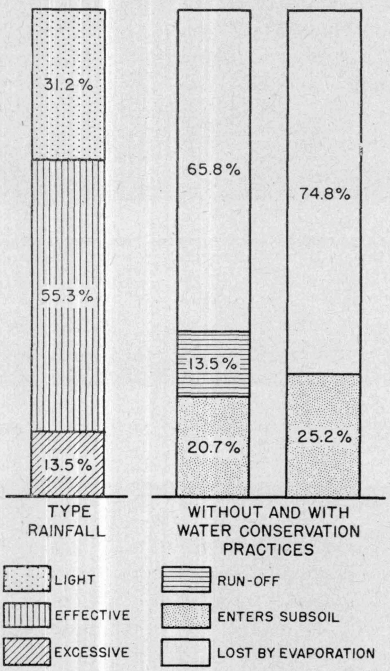
The normal disposition concluded from these studies was 65.8% loss by evaporation, 13.5% loss by runoff, and 20.7% storage in the subsoil. The total evaporation item was increased to 68.5% of the moisture supply by normal tillage operations which temporarily, from time to time, deepened the zone of surface air circulation. As a result of necessary tillage to prepare the seedbed and control weed competition, the amount, 20.7%, of the rainfall available for plant growth was reduced to 18.0%. No loss of moisture was observed by percolation beyond the root zone depth of 6 feet. However, a risk of such loss might be incurred as a result of following a fixed summer fallow schedule into the second of two consecutive wet years.

The possibilities of increasing the moisture using efficiency by methods of runoff prevention evidently are not large as measured in inches of water, but are quite important as measured in percentage of the net amounts of moisture normally available to crops. For example, under an 18 inch average rainfall, only about 3.58 inches became available to plant use and the prevention of 2.33 inches of possible runoff waste by terracing allowed .80 inches of the impounded water to soak in, thereby raising the available supply approximately 22%.

Likewise, relatively small effects of physical factors influencing the rate of infiltration and the rate of evaporation at the soil surface and acting to reduce even slightly a waste totalling 68.5% of the potential supply would be capable of greatly increasing the efficiency of water utilization.

Of interest in this connection are mulches and tillage practices (6). Although land improvements in the form of terrace or other permanent

Figure 7. AVERAGE CHARACTER OF HIGH PLAINS RAINFALL AND THE EFFECT OF WATER CONSERVATION PRACTICE ON ITS DISPOSITION



surface water control structures are the easiest and most positive type of measures developed in practical application, there will undoubtedly be practices of tillage and crop residue management woven into productive methods that are as potentially effective in increasing moisture supply by curbing evaporation waste as terracing and contour cultivation are in curbing runoff waste. Methods designed to accomplish these results are also consistent with erosion control needs and are being widely investigated and rapidly developed.

Fig. 8. Contour tillage supported by level terraces retaining surface water for increased crop production and the continuity of vegetative cover. One way to stay in business in the high plains.

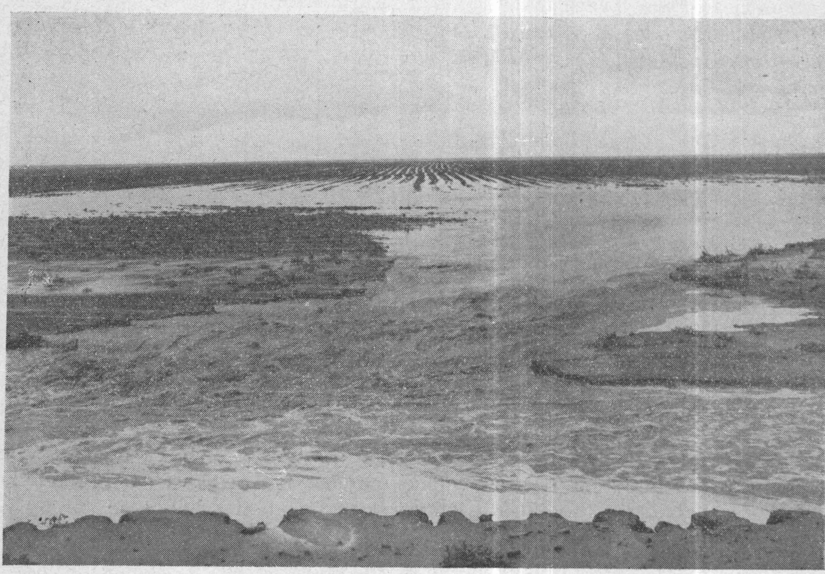


Fig. 9. A needless waste of much needed water from land with ample subsoil storage capacity. One way to go broke in the high plains.

SOIL PREPARATION

The conditions most vital to safe and efficient wheat production are: (1) the soil moisture accumulation to provide ample top-soil moisture for prompt germination of the seed which should exceed a penetration of 36 inches in order to carry the crop well through the period of rainfall uncertainty in the spring; (2) enough erosion resistant crop residue left on the surface of the field to prevent soil movement during the late winter and early spring blow season, and (3) such remaining organic matter as may be incidentally worked into the top-soil during preparatory tillage

Fig. 10. Combine harvesting of wheat on broadbase terraces in the Texas Panhandle.

Fig. 11. One method of stubble land plowing designed to leave the trash on the surface.

incorporated not later than midsummer in the presence of moisture and high temperature, in order to insure prompt decomposition resulting in a favorable initial nitrate depression followed by a rapid increase of nitrate formation timed to reach a maximum during the spring growing period of the crop.

Some facts that must be dealt with in an effort to prepare a favorable condition are: (1) a considerable quantity of effective rainfall is required to supply the initial moisture needed; (2) the time which must pass before the required amount of moisture is stored up may vary from 3 to 15 months; and (3) as time passes, the surface trash left over from the previous crop begins to wear out.

Perhaps the most clear cut starting point in preparation for wheat seeding would be at the harvest of the previous wheat crop. Starting the discussion of soil preparation here need not commit one to continuous culture of wheat, though wheat may often follow wheat in a diversified rotation. Whether such a crop succession is practical or not depends on particular conditions.

At harvest time, the soil is ordinarily completely exhausted of available moisture to a depth of 4 or 5 feet. The straw and stubble of the harvested crop occupy the land.

If harvest time rains or a thin stand of wheat have permitted weeds to start in the stubble, immediate one-way disking would be justified. But if the harvest time has been dry, it is best to let the stubble stand regardless of the amount of crop residue present. Volunteer wheat will not sprout until it rains, neither will the weeds. If the weather then continues so dry that weeds do not start after harvest, it is best to let the stubble stand on through the fall and winter. There will not be a favorable prospect for fall seeding anyway, and all the ground cover possible will be needed to prevent wind erosion.

If adequate rains come during the month of July, contour listing is the best preparation that can be given, working down the trashy ridges with disk cultivations as later rains bring on the weeds and volunteer wheat. If the July rains do not wet the soil deep enough for listing, yet the weeds start, the one-way disk or any one of a variety of subtillage machines best fit the field needs. If the stubble is light, the subtillage method would be best, leaving as much trash on the surface as possible. If no effective rains come in July but moisture is received in August, flat methods of tillage are preferable to listing. A portion of the residue remaining at the surface will be ample for wind erosion prevention if the stubble is heavy. Hence, the partial incorporation of the straw and stubble is desirable. The general principle may be followed that the later in the summer the effective rains come, the flatter and shallower should be the tillage operations.

Last minute preparation where the weeds are disked down immediately ahead of the drill produces the poorest results of any method of preparation.

Being guided by the July rainfall in the timing and kind of preparation, one may accomplish simultaneously the best use of available moisture, of available crop residues, and of nitrate formation to supply the maximum needs of the oncoming crop.

If early preparation cannot be done and a promising supply of soil moisture cannot be stored up, it is better to omit the seeding altogether or confine it to that part of the field where the better conditions exist. Emergency tillage operations or the planting of cover crops, if needed to prevent erosion, can be carried out more easily and with less waste of the scant available moisture if none is wasted on a wheat failure.

Of course, if the trash from the last crop is plentiful, emergency tillage or a cover crop will not be needed. The trashy surface soil will take care of itself against erosion while awaiting rainfall, and will aid in more efficient moisture utilization, but it must not be allowed to become weedy.

If a stubble field comes through the winter dry and insufficient spring rainfall is received to stock the soil with moisture for oats or barley, the farmer has a legitimate choice between a sorghum crop and summer fallow. The spring preparation would be the same for both. With plenty of crop residues to prevent blowing and no top-soil moisture to start weeds, cultivation may well wait until the rains and weeds start. Here, again, contour listing is a very desirable preparatory operation if done early because it provides for the best possible safeguarding and distribution of any excessive rainfall encountered.

When June, the normal planting time for sorghum, comes, a decision can be made between sorghum and summer fallow based on the productive needs of the farm unit. If feed reserves are low, either forage or grain sorghum may be employed regardless of sub-soil moisture if top-soil moisture is adequate to germinate the seed. In case of scant sub-soil moisture, a thin stand should be planted to insure grain maturity. When sub-soil moisture is low in June, summer fallow may be safely and profitably used if sorghum is not needed and crop residue in the top-soil remains adequate for wind erosion prevention. But, if considerable sub-soil moisture accumulation has occurred, fallow might be wasteful of both moisture and fertility reserves. In this circumstance, a summer feed crop becomes a cover crop in the traditional sense of the word. It may be needed to prevent a productive accumulation of moisture and soluble plant food from partially going to waste.

When summer fallow has been decided upon for want of soil moisture, there will be no risk of plant food losses by leaching. The principal precaution indicated by field experience in case of summer fallowed land is to avoid delayed seeding. September seeding or even slightly earlier is also essential if fall and winter pasturage is expected.

According to established weather records, unsystematic variation in the amount and distribution of rainfall is a normal condition in the Texas High Plains. The dependable part of the moisture supply is that which has already been stored in the sub-soil. Obviously, flexibility of crop rotations, of other enterprizes on the farm, of erosion control, and farm finance is essential to the maximum safe use of soil and water resources under these conditions. Additional equipment needed by many wheat farms, to enable safe and efficient use of soil and water resources, may be listed as follows: row crop machinery, feed storage facilities, livestock, and a soil auger.

SUMMARY

A study was made of the results of terracing, contour farming, summer fallowing, and winter grazing under varying soil and seasonal conditions as represented by 901 records of wheat production in 11 soil conservation demonstration areas of the Southern Great Plains. Recommendations derived from it apply specifically to the wheat soils of the Panhandle of Texas and immediately adjoining areas.

Significant increases of wheat yield resulted from (1) initial soil moisture stores, (2) July rainfall previous to sowing, (3) level terracing and contour farming, and (4) favorable spring rainfall, while significant decreases resulted from (5) soil erosion damage, (6) delayed seeding, and (7) fall and winter grazing.

Of greatest weight were the factors of (A) initial soil moisture, and (B) previous July rainfall, both of which are measurable in advance of seeding time. Forty-one per cent of the total influence affecting wheat yield is combined in the simple formula for estimating expected yield:

$.33 (A) + 2.32 (B) - 6.24 =$ expected bushels wheat yield per acre, where (A) is expressed as depth of penetration in inches and (B) is the July rainfall in inches.

The fall soil moisture store was the predominating factor affecting wheat yield. The fall soil moisture accumulation was derived from the rainfall of the July to October period, excepting where sorghum preceded wheat. In that case, the fall store was governed by the August to October rainfall.

The July rainfall had a highly significant positive relation to wheat yield under all conditions studied. Besides contributing measurably to the fall store of moisture, the July rainfall greatly affected the fertility condition resulting from summer tillage operations. Ample July rainfall was more important on stubble land than on summer fallowed land, although still a highly significant factor on the latter.

The spring rainfall, January to May, inclusive, was the third most important division of moisture supply although the relative weight of its influence was but one-third of that exerted by the seasonal and soil moisture conditions prevailing during the summer and early fall before seeding time.

Minor factors in net effect, but so consistently related as to be highly significant statistically, were the yield depressing effects of delay of seed-

ing beyond September, the failure of wind erosion control, and the grazing of wheat fields during the fall and winter.

The practices of terracing and contour farming gave consistent yield increases averaging 2.99 bushels per acre partly due to increasing the soil moisture accumulation during the preparatory period from 3.01 inches in depth of penetration per inch of rainfall to 3.68 inches, and partly due to the more efficient utilization of rainfall during the crop growing season.

Soil moisture accumulation during the preparatory period accounted for the entire favorable effects of summer fallowing and contour farming on wheat yield, but terraces continued to operate favorably accounting for 1.64 bushels of the 2.99 bushel yield increase by more efficient use of rainfall during the crop growing season. The 1.35 bushels of yield increase effected previous to seeding may be broken down with .84 bushel creditable to contour farming, and .51 bushel creditable to terraces. The total effect of terraces, therefore, was to increase the yield 2.15 bushels of wheat per acre with .84 bushel added by contour farming. The total effect of contour farming on wheat yield was less than that expected from the use of this method in row crop production, apparently because of the more general use of flat methods of tillage in wheat growing than in row crop cultivation.

The availability of pasturage from fall sown wheat depended mainly on plentiful top-soil moisture supply before and during the grazing season and on early seeding.

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