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Dryland Winter Wheat and Grain Sorghum Cropping Systems

Northern High Plains of Texas

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Contents

Summary

A dryland winter wheat (*Triticum aestivum* L.) and grain sorghum (*Sorghum bicolor* L.) cropping system study was conducted at the USDA Southwestern Great Plains Research Center, Bushland, from 1957 to 1970. Data for grain yields, soil water storage and use, precipitation, fallow efficiency and soil properties are presented.

Wheat grain yields were lowest for the continuous wheat (CW), intermediate for wheat in the wheat-sorghum-fallow (WSF) and highest for the wheat-fallow (WF) cropping system on a harvested-area basis. The yield differences seemingly resulted from differences in available soil water at seeding. Water-use efficiency paralleled grain yields when soil water changes and growing season precipitation were considered, but the trends were reversed when precipitation during the fallow period was included. Including fallow precipitation in total water-use efficiency points out the low effectiveness of fallow for influencing crop yields.

On a harvested-area basis, sorghum in the WSF system significantly outyielded sorghum grown continuously (CS). The increased yields were related to differences in available soil water at seeding. Trends in water-use efficiency, whether based on growing season or fallow plus growing season precipitation, were similar to the trends for wheat. However, grain sorghum used water more efficiently than did wheat (based on pounds of grain per acre produced per acre-inch of water used).

Storage efficiency decreased as the length of the fallow period increased. Storage efficiences ranged from 8.3 percent for the WF system to 20.1 percent for the CS system during the 1959-70 period.

The soil organic matter content and the distribution of dry and wet soil aggregates measured at the end of the study were significantly affected by the cropping systems. The organic matter of the surface 6 inches of soil was highest (2.04 percent) for a grass treatment, but significant differences also resulted from the different wheat and sorghum cropping systems, ranging from 1.64 percent for CS to 1.86 percent for CW. The CS system resulted in the highest percentage of fine (less than 0.84 millimeters), dry soil aggregates, indicating greater potential soil erodibility by wind than for other systems. The distribution of wet soil aggregates was related to time since harvest of the previous crop. Plant residues favored the formation of larger aggregates, but the effectiveness of the residues decreased as the length of the fallow period increased (time from harvest to sampling for aggregate size distribution). Soil bulk density was not affected by the cropping systems.

Dryland Winter Wheat and Grain Sorghum Cropping Systems-- Northern High Plains of Texas

Paul W. Unger*

WITH RESPECT TO ACREAGE PLANTED, grain sorghum is the most important crop in Texas, and it is followed in order by cotton and wheat (Yearbook Statistical Committee, 1970). Of the state total, 1,548,000 acres of grain sorghum and 2,031,000 acres of wheat were planted on the Northern High Plains of Texas. This area is bounded by the state line on the west, north and east and by the southern boundary of Parmer, Castro, Swisher, Briscoe, Donley and Collingsworth counties on the south. In this area, about 26 percent of the grain sorghum and 55 percent of the wheat were grown on dryland in 1970 (New, 1970).

Although irrigated acreage has increased somewhat in recent years, water tables and well yields are declining, and projections are that much of the irrigated acreage will revert to dryland crop production as the underground water supply is eventually depleted (Hughes and Harman, 1969). When this occurs, dryland crop production will increase in importance. The possibility of eventual water importation into the area has not been overlooked. However, it is believed that water importation would not reduce the dryland crop production acreage to below current levels.

Purpose of Publication and Objectives of Study

A dryland winter wheat and grain sorghum cropping system study conducted from 1957 to 1970 had as its objectives:

1. To determine the effects of selected cropping systems on wheat and sorghum grain yields
2. To determine the effects of the cropping systems on residue production for erosion control
3. To determine the interrelationships of soil water at seeding and growing season precipitation in their effect on grain and residue yields
4. To determine the efficiency of water storage during the fallow period
5. To compare the effects of reseeded native grass and the various cropping systems on various physical and chemical soil properties.

Location of the Study

The study was conducted at the USDA Southwestern Great Plains Research Center, Bushland. The Center, located about 14 miles west of Amarillo, lies in Potter and Randall counties. Its location is near the center of the Northern High Plains of Texas. Soils at the Center are representative of much of the land used for wheat and grain sorghum production in the area (Taylor et al., 1963).

Climate

Precipitation and temperature are the major climatic factors influencing crop production in the area. Precipitation averages from 16 inches at the western edge to 24 inches at the eastern edge of the

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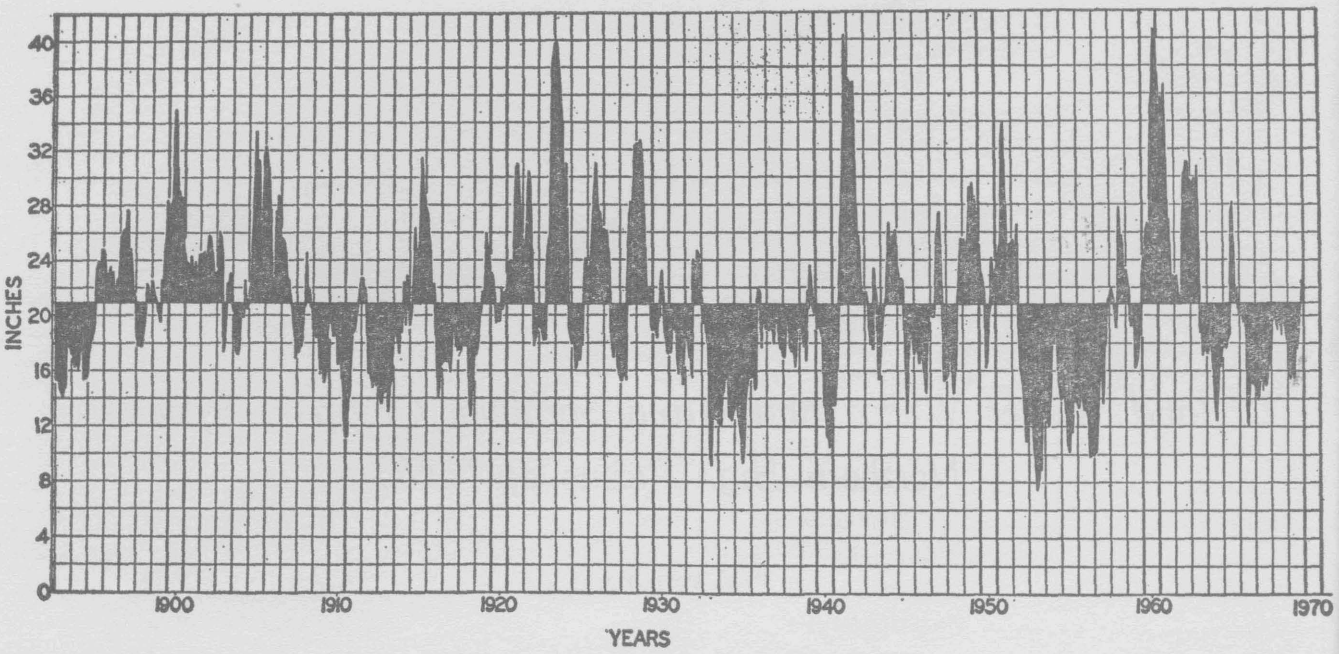

Figure 1. Long-term precipitation at Amarillo, Texas, plotted as a 12-month moving total to show above- and below-average periods, 1892-1969. Long-term average is 20.92 inches. Points on the curve represent totals for the past 12 months (unpublished data from J. T. Musick).

area, but the precipitation at a given location is highly variable (Bonnen, 1960). For example, yearly rainfall at Bushland has ranged from 9.46 inches in 1970 to 32.87 inches in 1941 for the 1939 to 1970 period. The precipitation variability from 1892 to 1969 at Amarillo near the center of the Northern High Plains area is shown in Figure 1.[1]

Precipitation at Bushland from 1939 to 1970 has averaged 18.26 inches per year. Precipitation has averaged 8.66 and 9.94 inches during the grain sorghum (June 16 to October 10) and wheat (October 11 to June 15) growing seasons, respectively. The average monthly distribution of precipitation and the average pan evaporation [Young screen pan (Bloodgood, Patterson and Smith, 1954)] are shown in Figure 2.

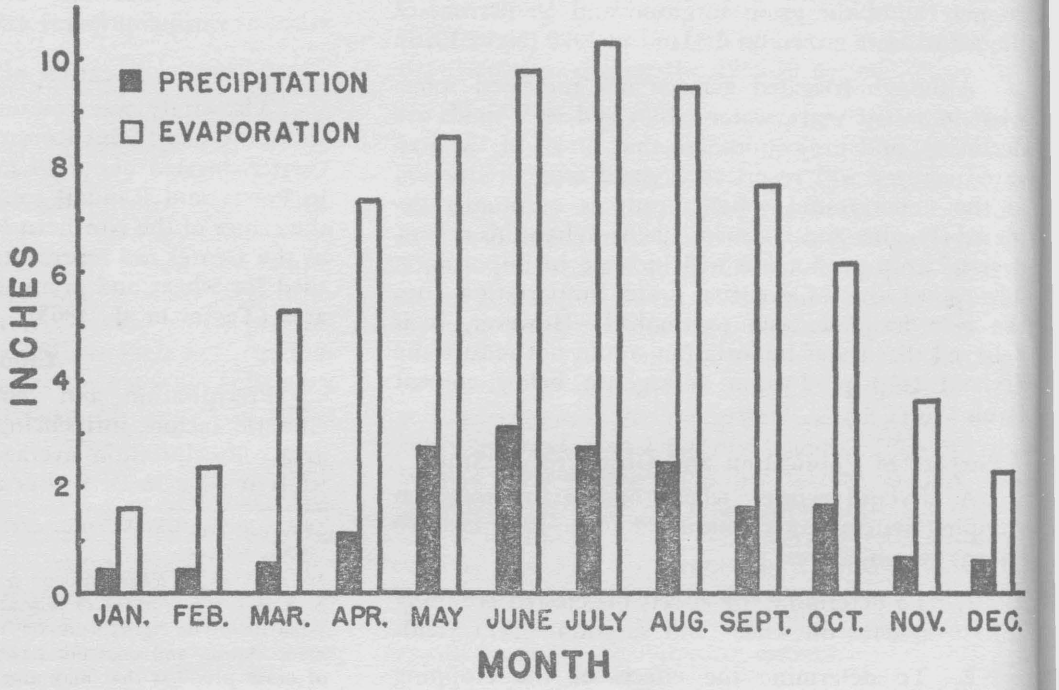

Figure 2. Monthly rainfall and evaporation at the USDA Southwestern Great Plains Research Center, Bushland, Texas. The precipitation shown is the average for a 32-year (1939-70) period. Evaporation shown for April through September is a 31-year (1940-70) average. For the remaining months, evaporation shown is an 18-year (1951-68) average.

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[1] J. T. Musick, unpublished data.

Temperature has its major effect on crop production through its influence on the length of the frost-free period, which averages from about 180 to 200 days at the northwest and southeast portions of the area, respectively (Bonnen, 1960). At Bushland, the frost-free period averages 190 days. Although not of major importance for winter wheat, low temperatures greatly influence the length of the growing season for grain sorghum. The first killing frost occurs, on the average, October 28, but occurred as early as October 7 and as late as November 22 during the 1931–70 period. The last killing frost occurs, on the average, April 18, but has occurred as early as March 22 and as late as May 14. Average monthly maximum and minimum temperatures at Bushland are shown in Figure 3.

Topography and Soils

Much of the Northern High Plains of Texas is 3,000 to 4,500 feet above sea level and slopes toward the east-southeast. The land is nearly flat, but numerous playas—normally dry—dot the area. Much of the natural drainage is into these lakes, but some occurs into canyons that extend into the area and help form the headwaters of the Brazos, Red and Canadian rivers (Bonnen, 1960). The Canadian River and the associated "breaks" of the river divide the area into two major subareas. The soils are primarily clays and clay loams, but some sandy soils are included. The principal soil at the Center is Pullman clay loam (Taylor et al., 1963). The Pullman series is a member of the fine, mixed, thermic family of Torrertic Paleustalls (order Mollisols).

Soils of the Northern High Plains are subject to erosion by wind, especially under dryland conditions. However, since the drouth of the 1930's, controlling wind erosion by maintaining crop residues on the soil surface by stubble-mulch tillage has been studied. Wheat yields with stubble-mulch tillage were equal to or higher than yields with moldboard and one-way tillage under dryland conditions in a previous study at the Research Center (Johnson, 1950).

DESCRIPTION OF THE STUDY

The Pullman clay loam of the study area had a slope of less than 1 percent. Plot size was 0.21 acre (60 by 150 feet). The plots were bordered on three sides, with natural runoff being permitted from the fourth side. The following treatments, each replicated three times, were randomly assigned to the treatment blocks:

1. Continuous wheat (CW)—wheat seeded on the same plots each year.
2. Wheat-fallow (WF)—wheat seeded on the same plots in alternate years. This cropping system provided for a fallow period of about 15 months between harvest and seeding on a particular plot. Two plots were used for this treatment in each replication.
3. Wheat-sorghum-fallow (WSF)—alternate crops of wheat and sorghum seeded on the plots, resulting in two crops being grown during the 3-year rotation. This system provided for a fallow period of 11 months between sorghum harvest and wheat seeding or between wheat harvest and sorghum seeding. Three plots were used for this treatment in each replication.
4. Wheat-sorghum-fallow with permanent ridges and furrows on 40-inch spacings (WSF-RF)—this cropping system was similar to the WSF system above, except that the tillage methods were different. This treatment was designed

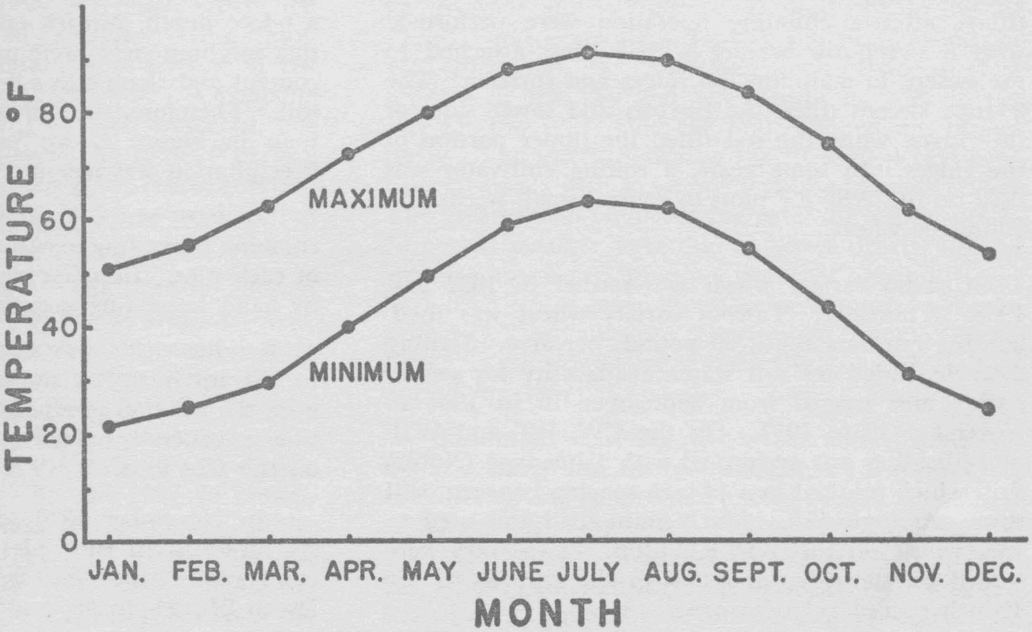

Figure 3. Average monthly maximum and minimum temperatures at the USDA Southwestern Great Plains Research Center, Bushland, Texas, for the 32-year (1939-70) period.

for the ridges to function as increased runoff zones and the furrows, because of deep chiseling, to function as increased water intake zones. Through increased water concentration and depth of water penetration in the furrows, evaporation losses should be decreased and, thus, storage efficiency increased. The system was first used for the 1966–67 crop. Plots for this cropping system were those originally designated as wheat-optional wheat, wheat-optional sorghum and sorghum-optional wheat. The optional seedings were based on 1.5 inches of water being available for plant growth in the upper 2 feet of the soil at seeding time. By 1966, the options had not been exercised because the available soil water at seeding time always exceeded this amount. Data from the wheat-optional wheat and wheat-optional sorghum plots were combined with data from the continuous wheat plots, and data from the sorghum-optional wheat plots were combined with data from the continuous sorghum plots for the 1957–66 period.

5. Continuous sorghum (CS)—sorghum seeded on the same plots each year.
6. Grass—seeded to native grasses and used as reference plots to determine the effects of grass on physical and chemical properties of soil.

All tillage before seeding wheat and sorghum, except on the WSF-RF plots, was performed with stubble-mulch equipment. This equipment had 30- to 40-inch sweeps, and the tillage was limited to about a 5-inch depth. On the WSF-RF plots, the furrows were chiseled after crop harvest, provided the soil was dry, to a 1-foot depth with a vibrating chisel. Initial tillage when the soil was wet and subsequent tillage after a chiseling operation were performed with a sweep-row weeder with buffers attached to the sweeps to maintain the ridges and furrows. The 24-inch sweeps tilled the furrows and lower sides of the ridges, while the rod tilled the upper portion of the ridges. In some years, a rolling cultivator was used on the WSF-RF plots to control small weeds and volunteer wheat.

Concho variety wheat was seeded in 1957 and 1958. Thereafter, Tascosa variety wheat was used. Seeding rate was about 30 pounds per acre. Seeding date depended on soil water availability for germination and ranged from September 10 in 1964 to November 19 in 1957. On the CW, WF and WSF plots, seeding was performed with a hoe-type (Noble) drill which resulted in a 14-inch spacing between drill rows. A single-disk, 10-inch grain drill was used to seed wheat on the WSF-RF plots. Two rows were seeded on the ridge and two in the furrows of the 40-inch spaced ridge-furrows.

Grain sorghum hybrids used were RS-610 from 1958 to 1964 and RS-626, a similar hybrid with head smut resistance, from 1965 to 1970. The seeding rate was about 2 pounds per acre. Seeding dates ranged from June 4 in 1969 to July 9 in 1962. Lister planters or unit planters mounted behind listers were used to seed sorghum in furrows spaced 40 inches apart.

A mixture of buffalo (*Buchloe dactyloides*), blue grama (*Bouteloua gracilis*) and sideoats grama (*Bouteloua curtipendula*) grasses was seeded on the grass plots April 3, 1958. Favorable soil water conditions at seeding resulted in a good stand of the grasses. Forage produced on the grass plots was not measured or utilized. In some years, the plots were mowed or sprayed with 2,4-D to control weeds.

In the interval between crops, weeds were controlled with stubble-mulch or sweep-rod weeder tillage. For weed control in sorghum, the initial cultivation was with a knife sled on all plots. The second cultivation was with a knife sled on the WSF-RF plots and with a sweep cultivator on the other plots. Cultivations largely leveled ridges and furrows on the lister-seeded plots. In some years, weeds were controlled by spraying with 2,4-D. Occasionally, hand hoeing was used to control sparse weed populations. Growing-season weeds in wheat were controlled with 2,4-D in years when heavy infestations occurred.

No fertilizers were used on either the wheat or the grain sorghum during the study. Dryland wheat has not responded to nitrogen or phosphorus fertilization on Pullman clay loam (Eck and Fanning, 1962), and nutrient deficiencies have not been observed on dryland grain sorghum.

The soil water content at seeding and harvest was determined gravimetrically from cores obtained by 1-foot increments to a 6-foot depth at three locations per plot. Although soil water was measured to a 6-foot depth, Musick and Sletten (1966) indicated that sorghum yields were more closely related to water content and change to a 4-foot soil depth of Pullman soil. Therefore, the soil water data presented, other than in Figure 4, are based on the 4-foot depth. Precipitation was measured at the plot area.

In most years, grain yields were determined by combine harvesting a swath through the entire length of each plot. In a few cases, yields were determined by hand harvesting measured areas in the plots.

Residue yields were not measured in enough years to warrant inclusion and analysis of the data. However, the residues produced, along with stubble-mulch tillage, generally effectively controlled wind erosion on the plot area.

In November 1970 soil cores were obtained at six locations in each plot to a 4-foot depth. The cores were divided into 0- to 6-, 6- to 12-, 12- to 18-, 18- to 24-, 24- to 36- and 36- to 48-inch increments.

Soil cores were composited by depth increments and used for determining soil bulk density and organic matter content. The organic matter content was determined by the Walkley-Black procedure (Piper, 1944). The organic matter content was also determined for reference samples taken at the initiation of the study.

Other soil samples were obtained in November 1970 for wet and dry aggregate determinations. For wet aggregate size distribution determinations, a sample of moist soil was obtained from the 1- to 3-inch depth at three locations in each plot. The soil was passed through a ½-inch sieve while moist, then air-dried before the distribution of water-stable aggregates on a nest of sieves was determined according to the procedure outlined by Kemper and Chepil (1965). The procedure was slightly modified by the use of 0.25- and 4.00-millimeter (mm) sieves rather than 0.21- and 4.76-mm sieves along with 1.00- and 2.00-mm sieves.

The samples for aggregate size distribution by dry sieving were obtained from the surface 1 inch of soil at three locations in each plot. These samples were air-dried before the size distribution of the dry aggregates was determined with a rotary sieve having five screens. The different sieves had 0.42-, 0.84-, 2.0-, 6.4- and 18.3-mm square openings.

RESULTS AND DISCUSSION

Wheat

Yield, soil water, precipitation, water storage and water-use data are given in Table 1 by individual years for the wheat cropping systems. Average values for the periods during which the cropping systems can be compared are given in Table 2. Winter wheat was seeded in the fall and harvested in late spring or early summer of the following year. A crop year is the year in which the wheat was harvested. Although the first crop was harvested in 1958, pregrowing season precipitation data (precipitation from harvest of last crop to seeding of the current crop) were not available for that crop. Data for all crops are presented, but only those from the 1959–70 and the 1967–70 periods will be discussed. The wheat-sorghum-fallow rotation with ridges and furrows (WSF-RF) was used during the 1967–70 period only.

Average grain yields were significantly affected by the cropping systems. Based on the area harvested, the yield per acre was lowest for continuous wheat (CW), intermediate for wheat-sorghum-fallow (WSF) and highest for wheat-fallow (WF) for the 1959–70 period. Yields averaged somewhat higher for the WSF and WF systems during the 1967–70 period than during the 1959–70 period. For the 1967–70 period, the WSF-RF system increased the average yield by 99 pounds per acre over the WSF system, but the increase was not statistically significant. Also, the yield difference (83 pounds per acre) between the WSF-RF and WF systems was not significant. The WSF-RF system was tested in only 4 crop years, a period possibly too short to make a valid test of this cropping system.

Available soil water content at seeding was lowest for the CW system, averaging 2.29 inches to a 4-foot depth for the 1959–70 period. The WSF and WF systems resulted in 1.08 and 1.38 inches greater water contents at seeding, respectively, than the CW system. Soil water contents at seeding during the 1967–70 period averaged slightly lower than during the 1959–70 period. The soil water content at seeding for the WSF-RF system was similar to that of the WSF system. A possible reason that the WSF-RF system did not increase water storage as anticipated was inadequate weed control. Herbicides were not used during the nongrowing period, and the sweep-rod weeder and rolling cultivator were not effective tillage implements for operation on the undisturbed permanent ridges.

Soil water changes between seeding and harvest averaged 0.93, 1.94 and 2.11 inches for the CW, WSF and WF systems, respectively, for the 1959–70 period. The greater changes due to the WSF and WF systems were approximately equal to the additional water stored at seeding due to these systems as compared with the CW system. Changes during the 1967–70 period were somewhat greater than during the 1959–70 period. Again, the greater changes due to the WSF, WF and WSF-RF systems as compared with the CW system were similar to the differences in water content at seeding. Changes in soil water for the WSF-RF system were similar to those of the WSF system.

Assuming that the yield differences were associated only with differences in the soil water content at seeding, each inch of additional soil water at seeding resulted in 142 and 188 pounds more grain per acre for the WSF and WF systems, respectively, during the 1959–70 period than for the CW system. During the 1967–70 period, each additional inch of stored water resulted in 182, 270 and 345 pounds more grain per acre for the WSF, WSF-RF and WF systems, respectively. The increases during the 1959–70 period compare favorably with those predicted by Johnson (1964). The greater-than-predicted increases during the 1967–70 period possibly were due to better distribution of growing season precipitation. Another possibility may have been better growing-season weed control. Weeds, primarily Tansy mustard [*Descurainia pinnata* (Walt.) Britt.], were controlled chemically in early spring during the 1967–70 period.

Soil water contents at seeding and changes between seeding and harvest indicate that appreciable amounts of "available" water were present in the soil at harvest in some years (Figure 4). Much of the available water present was due to late season rainfall, which benefited the crop only slightly. Rainfall from June 1, June 11 and June 21 to harvest averaged

4.35, 2.66 and 1.04 inches, respectively, during the study period. The average harvest date was June 28.

Growing season precipitation was identical for all systems, and total growing season water use by the crops was considered equal to growing season precipitation plus soil water changes. Water use values include some water lost by surface runoff in some seasons. Using this total, grain production averaged 54, 60 and 69 pounds per acre-inch of water used during the 1959–70 period for the CW, WSF

TABLE 1. WHEAT YIELD, AVAILABLE SOIL WATER,[1] PRECIPITATION, WATER STORAGE AND WATER USE DATA BY INDIVIDUAL YEARS FOR CONTINUOUS WHEAT, WHEAT-SORGHUM-FALLOW AND WHEAT-FALLOW CROPPING SYSTEMS ON DRYLAND

Cropping system	Year	Grain yield	Available soil water		Precipitation		Water storage		Total water used		Water-use efficiency	
			At seeding	Change[2]	GS[3]	Pre-GS[4]	Amount	Efficiency[5]	GS precipitation + soil water change	Pre-GS and GS precipitation + soil water change	GS precipitation + soil water change	Pre-GS and GS precipitation + soil water change
		Lb./acre	Inches		Inches		Inches	Percent	Inches		Lb./acre Inch	
CW	1958	885	3.93	[6]−5.13	8.17				13.30		67	
	1959	862	2.82	−1.98	9.14	9.88	4.02	40.7	11.12	21.00	78	41
	1960	1440	1.05	+2.01	17.03	5.44	0.21	3.9	15.02	20.46	96	70
	1961	663	5.20	−3.44	11.49	15.12	2.14	14.2	14.93	30.05	44	22
	1962	98	1.36	+1.56	13.65	5.64	−0.40	− 7.1	12.09	17.73	8	6
	1963	481	2.82	−0.15	10.10	8.29	−0.10	− 1.2	10.25	18.54	47	26
	1964	676	2.89	−2.30	6.99	7.68	0.22	2.9	9.29	16.97	73	40
	1965	214	0.70	+1.43	19.77	2.76	0.11	4.0	18.34	21.10	12	10
	1966	412	2.95	[6]−3.48	5.53	4.75	0.82	17.3	9.01	13.76	46	30
	1967	478	1.07	−0.72	12.38	6.43	1.60	24.9	13.10	19.53	36	24
	1968	802	0.52	[6]−0.60	8.79	2.83	0.17	6.0	9.39	12.22	85	66
	1969	486	1.43	+0.22	11.84	7.13	1.51	21.0	11.62	18.75	42	26
	1970	672	4.70	−3.80	4.38	14.13	3.05	21.6	8.18	22.31	82	30
WSF	1958	793	3.87	[6]−5.41	8.17				13.58		58	
	1959	1108	3.16	[6]−3.96	9.14	19.49			13.10	32.59	85	34
	1960	1326	2.34	0.00	17.03	13.98	2.69	19.2	17.03	31.01	78	43
	1961	676	5.38	−3.40	11.49	31.03	4.75	15.3	14.89	45.92	45	15
	1962	504	4.08	−0.68	13.65	10.88	1.39	12.8	14.33	25.21	35	20
	1963	458	3.55	−0.69	10.10	20.81	2.90	13.9	10.79	31.60	42	14
	1964	705	2.94	−2.39	6.99	17.08	2.78	16.3	9.38	26.46	75	27
	1965	261	2.58	+3.15	19.77	8.67	−0.57	− 7.7	16.62	25.29	16	10
	1966	668	3.47	[6]−4.06	5.53	20.48	1.53	7.5	9.59	30.07	70	22
	1967	590	1.98	−1.82	12.38	10.03	0.29	2.9	14.20	24.23	42	24
	1968	756	2.06	−1.90	8.79	15.05	2.67	17.7	10.69	25.74	71	29
	1969	1508	3.98	−3.06	11.84	16.22	4.12	25.4	14.90	31.12	101	48
	1970	540	4.96	−4.53	4.38	24.75	3.91	15.8	8.91	33.66	61	16
WSF-RF	1967	623	2.84	−2.76	12.38	10.03	0.29	2.9	15.14	25.17	41	25
	1968	1244	2.41	−2.33	8.79	15.05	2.80	18.6	11.12	26.17	112	48
	1969	1234	3.11	−2.11	11.84	16.22	3.49	21.5	13.95	30.17	88	41
	1970	690	4.37	−3.94	4.38	24.75	3.16	12.8	8.32	33.07	83	21
WF	1958	859	3.28	[6]−4.47	8.17				12.64		68	
	1959	1116	3.80	−3.07	9.14	26.77			12.21	38.98	91	29
	1960	1589	3.51	−0.70	17.03	24.46	4.70	19.2	17.73	42.19	90	38
	1961	715	4.78	−3.09	11.49	37.59	4.05	10.8	14.58	52.17	49	14
	1962	409	4.86	−2.07	13.65	32.24	2.05	6.4	15.72	47.96	26	9
	1963	573	3.45	−1.15	10.10	27.58	1.76	6.4	11.25	38.83	51	15
	1964	873	4.10	−2.96	6.99	26.07	1.31	5.0	9.95	36.02	88	24
	1965	260	2.87	+2.19	19.77	17.43	0.57	3.3	17.58	35.01	15	7
	1966	744	4.15	[6]−4.88	5.53	27.28	3.01	11.0	10.41	37.69	71	20
	1967	1029	1.31	+0.25	12.38	16.71	−3.75	−22.4	12.13	28.84	85	36
	1968	956	1.89	−1.70	8.79	24.89	2.62	10.5	10.49	35.38	91	27
	1969	1466	4.00	−2.81	11.84	18.74	2.44	13.0	14.65	33.39	100	44
	1970	672	5.41	−5.36	4.38	33.08	5.22	15.8	9.74	42.82	69	16

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[1] Determined to a 4-foot depth and based on wilting point values determined by the sunflower technique. Unavailable water to 4 feet totals 9.97 inches.

[2] Based on soil water changes between crop seeding and harvest.

[3] Growing season.

[4] Pregrowing season (from harvest of previous crop to seeding of current crop).

[5] Based on soil water changes and precipitation occurring during the fallow period that preceded seeding of the indicated crop.

[6] Changes in available soil water content exceeding the available soil water content at seeding apparently resulted from the inadequacy of the sunflower technique for establishing a precise wilting point for wheat and from soil drying to below the wilting point due to evaporation.

TABLE 2. AVERAGE WHEAT YIELD, AVAILABLE SOIL WATER,[1] PRECIPITATION, WATER STORAGE AND WATER USE DATA BY PERIODS FOR CONTINUOUS WHEAT, WHEAT-SORGHUM-FALLOW AND WHEAT-FALLOW CROPPING SYSTEMS ON DRYLAND

Period	Cropping system	Grain yield	Available soil water: At seeding	Available soil water: Change[2]	Precipitation: GS[3]	Precipitation: Pre-GS[4]	Water storage: Amount	Water storage: Efficiency[5]	Total water used: GS precipitation + soil water change	Total water used: Pre-GS and GS precipitation + soil water change	Water-use efficiency: GS precipitation + soil water change	Water-use efficiency: Pre-GS and GS precipitation + soil water change
		Lb./acre	Inches	Inches	Inches	Inches	Inches	Percent	Inches	Inches	Lb./acre - inch	Lb./acre - inch
1958-1970	CW	[6]628^{a}	2.41	—1.26	10.71				11.97		55	
	WSF	758^{b}	3.41	—2.21	10.71				12.92		60	
	WF	866^{c}	3.64	—2.29	10.71				13.00		69	
1959-1970	CW	[6]607^{a}	2.29	—0.93	10.92	7.50	1.03	14.8	11.85	19.35	54	33
	WSF	761^{b}	3.37	—1.94	10.92	17.38	2.40	13.9	12.86	30.24	60	25
	WF	867^{c}	3.67	—2.11	10.92	26.07	2.18	8.3	13.03	39.10	69	22
1967-1970	CW	[6]610^{a}	1.93	—1.33	9.34	7.63	1.58	20.7	10.67	18.30	62	37
	WSF	849^{b}	3.24	—2.82	9.34	16.52	2.75	16.6	12.16	28.68	69	29
	WSF-RF	948^{bc}	3.18	—2.78	9.34	16.52	2.44	14.7	12.12	28.64	81	34
	WF	1031^{c}	3.15	—2.40	9.34	23.36	1.63	7.0	11.74	35.10	86	31

[1] Determined to a 4-foot depth and based on wilting point values determined by the sunflower technique. Unavailable water to 4 feet totals 9.97 inches.

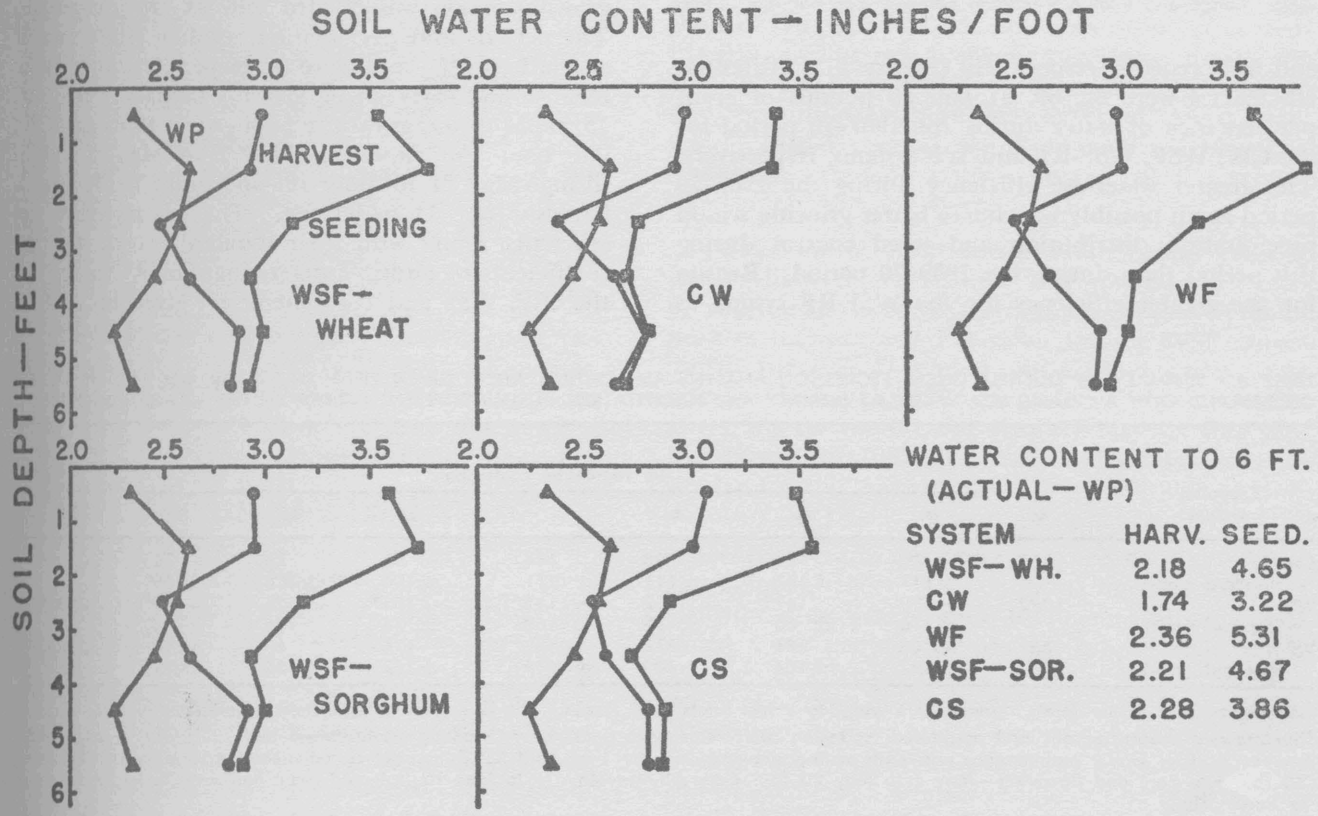
[2] Based on soil water changes between crop seeding and harvest.

[3] Growing season.

[4] Pregrowing season (from harvest of previous crop to seeding of current crop).

[5] Total soil water stored divided by total precipitation received during all fallow periods.

[6] Mean values within a group followed by the same letter or letters are not significantly different (Duncan's Multiple Range Test—5-percent level).



WATER CONTENT TO 6 FT. (ACTUAL—WP)

SYSTEM	HARV.	SEED.
WSF—WH.	2.18	4.65
CW	1.74	3.22
WF	2.36	5.31
WSF—SOR.	2.21	4.67
CS	2.28	3.86

Figure 4. Total soil water contents at the beginning (harvest) and end (seeding) of the fallow periods for the dryland wheat and grain sorghum cropping systems; also wilting point values, based on the sunflower technique and field observations. The actual minus wilting point values are an estimate of the plant available water in the soil at harvest of the previous crop and seeding of the indicated crop.

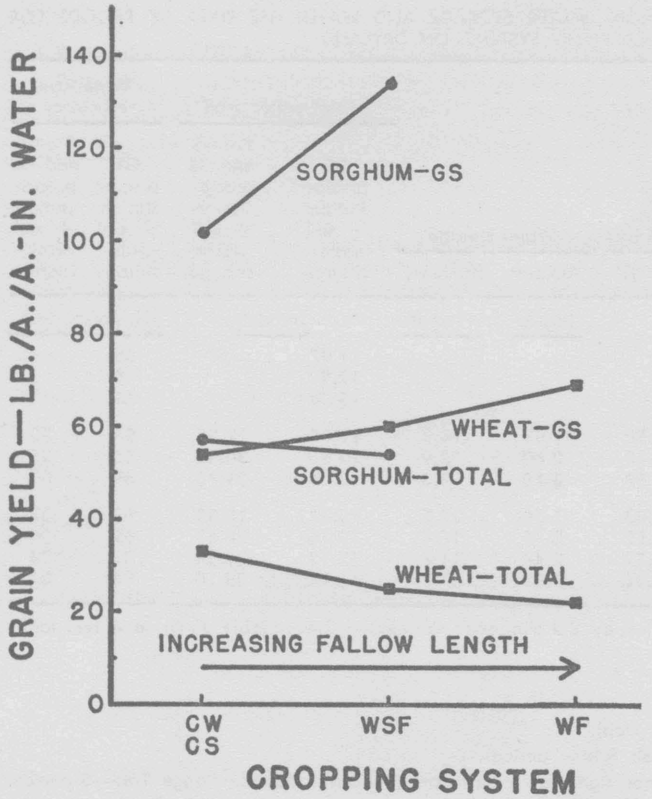


Figure 5. Water efficiency for grain production as influenced by wheat and grain sorghum in the different dryland cropping systems (lengths of fallow periods). The values are based on growing season soil water change and precipitation (GS) or growing season soil water change and total precipitation between crop harvests (total).

and WF systems, respectively (Figure 5). Water-use efficiencies were 62, 69, 81 and 86 pounds of grain per acre-inch of water during the 1967–70 period for the CW, WSF, WSF-RF and WF systems, respectively. The greater water-use efficiency during the 1967–70 period again possibly was due to better growing season precipitation distribution and weed control during this period than during the 1959–70 period. Reason for the greater efficiency for the WSF-RF system as compared with the WSF system and the greater increase in efficiency for the WF system as compared with the other systems for the 1967–70 period over the 1959–70 period is not readily apparent. Values for the 1959–70 period should be more reliable because the 1967–70 period may have been too short to make valid tests of the systems, especially under the highly variable climatic conditions prevalent in the region.

When fallow precipitation, that received from harvest of the previous crop to seeding of the current crop, was included with water used by the current crop, total water-use values averaged 19.35, 30.24 and 39.10 inches per crop during the 1959–70 period for the CW, WSF and WF systems, respectively. Corresponding total water-use efficiency values were 33, 25 and 22 pounds per acre-inch, respectively (Figure 5). The lower total water-use efficiency values obtained by including fallow precipitation indicate the low effectiveness of fallow precipitation for increasing crop yields. Trends during the 1967–70 period generally were similar to trends during the 1959–70 period, but the values were slightly higher. The values were 37, 29, 34 and 31 pounds per acre-inch for the CW, WSF, WSF-RF and WF systems, respectively.

Multiple linear regression analysis (Ezekiel and Fox, 1959) was used to establish relationships between available soil water at seeding, growing season precipitation and wheat grain yields. For this analysis, the growing season was divided into six growth periods. The periods were germination, seedling establishment and fall growth—seeding to December 31; winter maintenance and early spring growth—January 1 to April 15; rapid spring growth to boot—April 16 to April 30; late boot and flowering—May 1 to May 20; grain filling—May 21 to June 10; and grain hardening to harvest—June 11 to harvest. The net regression coefficients, along with their standard errors, and the coefficients of multiple determination (R^2 values) for the CW, WSF and WF systems are given in Table 3.

TABLE 3. SUMMARY OF MULTIPLE LINEAR REGRESSION ANALYSIS ASSOCIATING WHEAT GRAIN YIELDS IN THE CW, WSF AND WF SYSTEMS ON DRYLAND WITH AVAILABLE SOIL WATER AT SEEDING[1] AND PRECIPITATION DURING DIFFERENT PERIODS OF THE GROWING SEASON[2]

Cropping system	b_0[4]	Net regression coefficients[3]							Coefficient of multiple determination (R^2)
		b_1	b_2	b_3	b_4	b_5	b_6	b_7	
CW	161	12	51	98	184	52	76	− 76	0.797*
(Standard error)		±117	± 92	±111	± 271	±106	±108	± 69	
WSF	1092	−199	[5]149*	202	−1112**	161*	25	−122*	0.842*
(Standard error)		±110	± 68	± 82	± 180	± 71	±126	± 48	
WF	681	− 85	81	173	− 533	116	67	− 98	0.745
(Standard error)		±147	±104	±109	± 276	±103	±130	± 71	

[1] Determined to a 4-foot depth. Unavailable water to 4 feet totals 9.97 inches. The b_1 regression coefficient is associated with this factor.

[2] The growing season periods and associated regression coefficients were germination, seedling establishment and fall growth—seeding to December 31 (b_2); winter maintenance and early spring growth—January 1 to April 15 (b_3); rapid spring growth to boot—April 16 to April 30 (b_4); late boot and flowering—May 1 to May 20 (b_5); grain filling—May 21 to June 10 (b_6); and grain hardening to harvest—June 11 to harvest (b_7).

[3] The b coefficients indicate pounds of grain per acre per acre-inch of water.

[4] Y—intercept.

[5] Asterisks denote statistical significance (one—5-percent level; two—1-percent level).

Significant net regression coefficients were obtained only for the WSF system. The coefficients were positive for the seeding to December 31, January 1 to April 15 and May 1 to May 15 periods and negative for the April 16 to April 30 and the June 11 to harvest periods. Reason for the highly significant negative influence of precipitation on grain yields during the April 16 to April 30 period (rapid spring growth to boot) is not apparent but may be associated with water availability later in the growing season. For example, if adequate precipitation occurs during the April 15 to April 30 period to permit the development of large plants, "normal" or "below normal" precipitation later in the growing season may be inadequate to mature the grain properly. The negative influence of precipitation during the grain hardening to harvest period was associated with plant lodging and, possibly, hail damage as the crop approached maturity. Although not significant, coefficients for late season precipitation indicated yield reductions for the CW and WF cropping systems also.

An unexpected finding from the analyses was the lack of significant positive influences of available soil water at seeding on wheat grain yields. Actually, negative, but not significant, coefficients were obtained for the WSF and WF systems. According to Tables 1 and 2, available soil water at seeding and yields are lowest for the CW, intermediate for the WSF and highest for the WF system, but the influence of soil water at seeding on yields was not reflected in the net regression coefficients. Random variation may have been a factor, but other workers (Eck and Tucker, 1968) also have experienced difficulty in relating wheat yields to soil water and precipitation data. Also, although the data in Tables 1 and 2 suggest that the greater yields for the WSF and WF systems were related to greater available soil water at seeding for these systems than for the CW system, water intake during the growing season possibly obscured the influences of available soil water at seeding.

The coefficients of multiple determination (R^2 values) were significant for the CW and WSF systems, suggesting that significant amounts of the variations in yield were accounted for by available soil water at seeding and by growing season precipitation. The R^2 value for the WF system (0.745) approached the level necessary for statistical significance (0.754).

Grain Sorghum

Yield, soil water, precipitation, water storage and water use data for the grain sorghum cropping systems are given in Table 4 for individual years. Average values are given in Table 5 for periods in which the different cropping systems can be compared. Although the cropping systems were not fully in sequence in 1958, data for that year are included. Pregrowing season precipitation (that received between harvest of the previous crop and seeding of the current crop) for the 1958 crop was determined by establishing "normal" harvest dates for the previous crops (July 1 for wheat and November 1 for grain sorghum).

For the 1958–70 period, grain sorghum yields for the WSF treatment exceeded yields for the CS treatment by 420 pounds per acre, and the difference was statistically significant. Based on the area harvested, the yields averaged 1,137 and 1,557 pounds per acre for the CS and WSF systems, respectively. The differences are attributed to greater soil water contents at seeding and changes during the growing season for the WSF system as compared with the CS system since precipitation for both systems was identical. The greater water change for the WSF system was approximately equal to the greater water content for this system at seeding.

Average grain yields for the 1967–70 period when the WSF-RF system was in effect were 970, 1,135 and 965 pounds per acre for the CS, WSF and WSF-RF systems, respectively. The lower yield for the WSF-RF system as compared with the WSF system possibly resulted from the lower soil water content and change for the WSF-RF system. The smaller water change resulted from a lower water content at seeding with the WSF-RF system, but reasons for the lower water content are not clear. Inadequate weed control on the permanent ridge-furrows as mentioned in the wheat section, may have been a factor.

For comparable systems (CS and WSF), yields were lower during the 1967–70 period than during the 1958–70 period (Table 5). Water content at seeding and growing season change were lower during the 1967–70 period as was growing-season precipitation. Consequently, yields also were lower. However, data for the 1958–70 period should be more reliable when comparing cropping systems because of the greater number of years involved.

Based on the differences in available soil water at seeding between the CS and WSF systems, each inch of additional stored water resulted in a 609-pound-per-acre increase in grain yields for the WSF system during the 1958–70 period and a 358-pound-per-acre increase during the 1967–70 period. Water contents at seeding for the CS and WSF-RF systems were similar during the 1967–70 period, and yields also were similar for the two systems.

The yield increases due to additional stored water at seeding were in the range reported by Bond, Army and Lehman (1964). It is doubtful, however, that the yield increases were due to the amount of additional stored water per se. Of possibly greater importance was the distribution of water in the profile and the depth of wetting of the profile (Figure 4). For cotton, Fisher and Burnett (1953) reported marked increases in lint yield with increases in water in the second and third foot of soil. Similar results can be expected for grain sorghum because deep profile water would be available to the plants in latter growth stages when water is important during heading and grain filling.

TABLE 4. GRAIN SORGHUM YIELD, AVAILABLE SOIL WATER,[1] PRECIPITATION, WATER STORAGE AND WATER USE DATA BY INDIVIDUAL YEARS FOR CONTINUOUS SORGHUM AND WHEAT-SORGHUM-FALLOW CROPPING SYSTEMS ON DRYLAND

			Available soil water		Precipitation		Water storage		Total water used		Water-use efficiency	
Cropping system	Year	Grain yield	At seeding	Change[2]	GS[3]	Pre-GS[4]	Amount	Efficiency[5]	GS precip-itation + soil water change	Pre-GS and GS precip-itation + soil water change	GS precip-itation + soil water change	Pre-GS and GS precip-itation + soil water change
		Lb./acre	Inches		Inches		Inches	Percent	Inches		Lb./acre - inch	
CS	1958	1948	4.38	[6]−4.76	10.80	8.93			15.56	24.49	125	80
	1959	674	1.72	−1.46	8.60	6.50	2.18	33.5	10.06	16.56	67	41
	1960	1675	3.37	+0.10	19.81	15.57	3.11	20.0	19.71	35.28	85	47
	1961	2060	4.56	−3.51	8.81	5.10	1.09	21.4	12.32	17.42	167	118
	1962	715	2.49	−2.46	9.37	12.65	1.44	11.4	11.83	24.48	60	29
	1963	1599	3.66	−0.86	8.80	8.85	3.23	36.5	9.66	18.51	166	86
	1964	500	2.47	−0.85	8.70	4.01	−0.33	− 8.2	9.55	13.56	52	37
	1965	1376	3.70	−2.29	6.76	15.65	2.08	13.3	9.05	24.70	152	56
	1966	360	1.98	[6]−2.56	6.72	3.47	0.57	16.4	9.28	12.75	39	28
	1967	384	1.52	[6]−1.67	7.19	7.56	2.10	27.8	8.86	16.42	43	23
	1968	1350	2.48	−0.93	8.72	8.72	2.63	30.2	9.65	18.37	140	73
	1969	959	1.95	+0.57	13.76	7.77	0.40	5.1	13.19	20.96	73	46
	1970	1187	4.86	−4.16	3.21	7.60	2.34	30.8	7.37	14.97	161	79
WSF	1958	2026	4.07	[6]−4.42	10.80	17.04			15.22	32.26	133	63
	1959	1964	3.13	−2.50	8.60	16.67	4.67	28.0	11.10	27.77	177	71
	1960	1990	2.77	−0.08	19.81	22.61	3.57	15.8	19.89	42.50	100	47
	1961	2540	5.06	−4.41	8.81	24.57	2.72	11.1	13.22	37.79	192	67
	1962	1325	3.49	−3.33	9.37	19.12	1.51	7.9	12.70	31.82	104	42
	1963	1726	4.63	−1.38	8.80	18.35	1.23	6.7	10.18	28.53	170	60
	1964	1050	3.39	−1.45	8.70	12.77	0.53	4.2	10.15	22.92	103	46
	1965	1545	5.05	−3.36	6.76	22.45	4.50	20.0	10.12	32.57	153	47
	1966	1542	3.96	[6]−4.57	6.72	10.15	−1.77	−17.4	11.29	21.44	137	72
	1967	449	1.67	[6]−1.81	7.19	14.15	2.26	16.0	9.00	23.15	50	19
	1968	1682	2.81	−1.76	8.72	11.25	2.65	23.6	10.48	21.73	160	77
	1969	785	3.23	−0.99	13.76	16.22	3.07	18.9	14.75	30.97	53	25
	1970	1622	4.93	−4.61	3.21	18.51	4.01	21.7	7.82	26.33	207	62
WSF-RF	1967	235	1.02	−1.40	7.19	14.15	1.57	11.1	8.59	22.74	27	10
	1968	1586	2.03	−0.82	8.72	11.25	1.95	17.3	9.54	20.79	166	76
	1969	802	2.30	−0.07	13.76	16.22	2.22	13.7	13.83	30.05	58	27
	1970	1238	4.93	−4.65	3.21	18.51	3.93	21.2	7.86	26.37	158	47

[1] Determined to a 4-foot depth and based on wilting point values determined by the sunflower technique. Unavailable water to 4 feet totals 9.97 inches.

[2] Based on soil water changes between crop seeding and harvest.

[3] Growing season.

[4] Pregrowing season (from harvest of previous crop to seeding of current crop).

[5] Based on soil water changes and precipitation occurring during the fallow period that preceded seeding of the indicated crop.

[6] Changes in available soil water content exceeding the available soil water content at seeding apparently resulted from the inadequacy of the sunflower technique for establishing a precise wilting point for grain sorghum and from soil drying to below the wilting point due to evaporation.

The influence of depth of moist soil on yields has been illustrated by Fisher and Burnett (1953) for cotton and by Brown and Shrader (1959) for grain sorghum.

Another possible factor involved in the differences in yields between the CS and WSF systems was water intake during the growing season. Regression equations based on available soil water at seeding (X) and yields (Y) were $Y = -104.4 + 412.5X$ ($R^2 = 0.646$) for continuous sorghum and $Y = 449.9 + 298.7X$ ($R^2 = 0.305$) for sorghum in the WSF system. Yields for the CS system were more dependent on stored soil water at seeding than for the WSF system. The lesser dependency on stored soil water for the WSF system points toward a greater influence of some other factor or factors for influencing yields. One of these could be greater water intake during the growing season. (See section on Soil Properties.) The coefficients for the regression equations and the R^2 values were not greatly different when the available soil water at seeding was considered to a 6-foot depth, indicating a relatively minor influence of water in soil at a 5- or 6-foot depth on sorghum yields.

Total growing-season water use by the crops was considered equal to growing-season precipitation plus soil water change between seeding and harvest. Using this total, grain production averaged 102 and 134 pounds per acre-inch of water used during the 1958–70 period for the CS and WSF systems, respectively (Figure 5). During the 1967–70 period, the efficiency

TABLE 5. AVERAGE GRAIN SORGHUM YIELD, AVAILABLE SOIL WATER,[1] PRECIPITATION, WATER STORAGE AND WATER USE DATA BY PERIODS FOR CONTINUOUS SORGHUM AND WHEAT-SORGHUM-FALLOW CROPPING SYSTEMS ON DRYLAND

Period	Cropping system	Grain yield	Available soil water		Precipitation		Water storage		Total water used		Water-use efficiency	
			At seeding	Change[2]	GS[3]	Pre-GS[4]	Amount	Efficiency[5]	GS precipitation + soil water change	Pre-GS and GS precipitation + soil water change	GS precipitation + soil water change	Pre-GS and GS precipitation + soil water change
		Lb./acre	Inches		Inches		Inches	Percent	Inches		Lb./acre - inch	
1958-1970	CS	[6]1137[a]	3.01	—1.91	9.32	8.65	1.73	20.1	11.23	19.88	102	57
	WSF	1557[b]	3.70	—2.66	9.32	17.23	2.41	14.0	11.98	29.21	134	54
1967-1970	CS	[6] 970[a]	2.70	—1.54	8.22	7.91	1.86	23.6	9.76	17.67	104	56
	WSF	1135[b]	3.16	—2.29	8.22	15.03	2.99	19.9	10.51	25.54	118	46
	WSF-RF	965[a]	2.57	—1.18	8.22	15.03	2.41	16.1	9.40	24.43	102	40

[1] Determined to a 4-foot depth and based on wilting point values determined by the sunflower technique. Unavailable water to 4 feet totals 9.97 inches.

[2] Based on soil water changes between crop seeding and harvest.

[3] Growing season.

[4] Pregrowing season (from harvest of previous crop to seeding of current crop).

[5] Total soil water stored divided by total precipitation received during all fallow periods.

[6] Mean values within a group followed by the same letter are not significantly different (Duncan's Multiple Range Test—5-percent level).

values were 104, 118 and 102 for the CS, WSF and WSF-RF systems, respectively. The greater efficiency values for the WSF system than for the CS system reflect the greater soil water content at seeding and its effect on increased yields for the WSF system. Associated with the greater water content was deeper water storage (Figure 4). Brown and Shrader (1959) reported increased water-use efficiencies with greater depths of wetting. Possibly also involved with the greater efficiencies for the WSF system may have been greater growing-season water intake as mentioned previously.

Water use efficiency based on pounds of grain produced per acre per acre-inch of water used was higher for sorghum than for wheat. Also, the increase in efficiency for sorghum in the WSF system over continuous sorghum was greater than the increase in efficiency for wheat in the WSF system over continuous wheat (Figure 5). This difference suggests that sorghum was more responsive to fallow than wheat with respect to grain production. Similar conclusions were reached by Luebs (1962). Timeliness of precipitation with respect to the growing season may have been more favorable for grain sorghum than for wheat. Also, much of the water stored in soil at winter wheat seeding time was used or evaporated during the long winter dormant period, and spring vegetative growth was largely dependent upon precipitation. For grain sorghum, the stored water at seeding along with precipitation was more readily available for vegetative growth and grain production.

When fallow precipitation was included with water used by the current crop, total water-use values were much higher (19.88 vs. 11.23 inches and 29.21 vs. 11.99 inches for the CS and WSF systems, respectively) and water-use efficiency values were much lower (57 vs. 102 pounds per acre-inch and 54 vs. 134 pounds per acre-inch for the CS and WSF systems, respectively) than where growing season precipitation alone was used. The low efficiency values for grain sorghum production when including fallow precipitation further substantiate the low effectiveness of fallow for increasing crop production. However, efficiency values were higher for grain sorghum than for wheat when fallow precipitation was included, again suggesting that grain sorghum was more responsive than wheat to fallow precipitation with respect to grain production (Figure 5).

Multiple linear regression analysis was used to establish relationships between available soil water at seeding, precipitation during the growing season and grain yields for the sorghum. The growing season was divided into five periods which corresponded to major plant growth stages. These were germination and seedling establishment—seeding to 20 days after seeding; rapid vegetative growth—21 to 50 days after seeding; late boot and flowering—51 to 65 days after seeding; grain filling—66 to 80 days after seeding; and grain hardening to harvest—81 days after seeding to harvest. The net regression coefficients and coefficients of multiple determination (R^2 values) for sorghum in the CS and WSF systems are given in Table 6. Standard errors were calculated for the individual net regression coefficients.

The coefficients (Table 6) indicate that grain yields for the CS and WSF systems were influenced most by the available soil water content at seeding. Although the coefficient (b_1) for available water at seeding was higher for the WSF system than for the CS system, the standard error associated with this coefficient also was higher for the WSF system. Based on the coefficient and the standard error, an inch of available water at seeding would cause a range in grain yields from 383 to 431 pounds per acre for the CS system and a range from 368 to 530 pounds per acre for the WSF system in about two of three cases.

For the CS system, yields were influenced most by precipitation during the period of rapid vegetative growth, as indicated by the regression coefficient being greater than the standard error for the coefficient. Undoubtedly, yields were also influenced by precipitation during other periods. However, the high variability of precipitation during the study period, which is typical for the study area, resulted in the high standard errors. The regression coefficients exceeded the standard errors for the germination and seedling establishment (b_2) and grain filling (b_5) precipitation periods for the WSF system, indicating a positive influence of precipitation on yields during these periods.

The coefficients of multiple determination (R^2 values) were 0.893 and 0.656 for the CS and WSF systems, respectively. The R^2 values suggest a higher correlation between yields, soil water and precipitation for the CS system than for the WSF system and a greater influence of some other factors on yields for the WSF system than for the CS system. Soil fertility may have been a factor. Although dryland grain sorghum on Pullman clay loam has shown no nutrient deficiencies, it is possible that grain sorghum would respond to fertilizer in years of above-average precipitation.

Fallow

Fallowing (the practice of allowing land to remain idle and weed-free for a growing season) has been widely used to increase yield levels. As an illustration, it was arbitrarily assumed that a crop producing less than 600 pounds of grain per acre harvested would not be profitable. Data for this 13-year study show that wheat in the CW, WSF and WF systems produced less than 600 pounds of grain per acre in 6, 5 and 3 years, respectively. For grain sorghum, yields were less than 600 pounds per acre in 3 years for continuous sorghum and in 1 year for sorghum in the WSF system. Thus, fallow did increase the reliability of grain production by wheat and sorghum during the study period.

Fallowing increased the yields of wheat and grain sorghum but decreased the efficiency of total water use for grain production. This inefficiency of fallow is widely recognized. For the study area, precipitation storage has generally been around 15 percent of the precipitation received during the fallow period for winter wheat (Johnson, 1966). Precipitation, water storage and water storage efficiency values during the fallow period preceding wheat are included in Tables 1 and 2 and preceding grain sorghum in Tables 4 and 5. The distributions of water at the beginning (harvest of previous crop) and end (seeding of crop) of the fallow periods are shown in Figure 4.

For wheat, the fallow periods (interval between crops for CW) were about 3, 11 and 15 months for the CW, WSF and WF systems, respectively. For grain sorghum, the fallow periods (interval between crops for CS) were about 8 and 11 months for the CS and WSF systems, respectively.

Precipitation amounts were directly related to length of the fallow period, and, in general, water storage increased as length of the fallow period increased. A marked exception was evident for the WF cropping system. Although the fallow period for WF was 4 months longer than for WSF and precipitation averaged about 9 inches more for WF than for WSF, the WF system resulted in slightly less water storage and considerably lower storage efficiency than the WSF system. Possible reasons may have been the soil water content at harvest and distribution of precipitation during the fallow period. High precipitation in late May and June (Figure 2) when wheat approaches maturity sometimes results in relatively high soil water contents at wheat harvest, thus reducing the potential for water storage during the subsequent fallow period. On the other hand, the prevalence of lower precipitation as grain sorghum approaches maturity results in low soil water contents

TABLE 6. SUMMARY OF MULTIPLE LINEAR REGRESSION ANALYSIS ASSOCIATING GRAIN YIELDS OF CONTINUOUS SORGHUM AND SORGHUM IN A WSF SYSTEM ON DRYLAND WITH AVAILABLE SOIL WATER AT SEEDING[1] AND PRECIPITATION DURING DIFFERENT PERIODS OF THE GROWING SEASON[2]

Cropping system		Net regression coefficients[3]						Coefficient of multiple determination (R^2)
	b_0[4]	b_1	b_2	b_3	b_4	b_5	b_6	
CS	−847	[5]407**	− 10	191	226	40	68	0.893**
(Standard error)		± 24	±121	±104	±564	±275	±276	
WSF	−864	500**	170	132	−505	283	− 39	0.656*
(Standard error)		±132	±104	±137	±524	±243	±266	

[1] Determined to a 4-foot depth. Unavailable water to 4 feet totals 9.97 inches. The b_1 regression coefficient is associated with this factor.

[2] The growing season periods and associated regression coefficients were germination and seedling establishment—seeding to 20 days after seeding (b_2); rapid vegetative growth—21 to 50 days after seeding (b_3); late boot to flowering—51 to 65 days after seeding (b_4); grain filling—66 to 80 days after seeding (b_5); and grain hardening to harvest—81 days after seeding to harvest (b_6).

[3] The b coefficients indicate pounds of grain per acre per acre-inch of water.

[4] Y—intercept.

[5] Asterisks denote statistical significance (one—5-percent level; two—1-percent level).

at harvest and a greater potential for water storage during the fallow period. Thus, although storage during the fallow period was less for the WF than for the WSF system, actual water contents at seeding were greater for the WF than for the WSF system (Table 2).

Although precipitation amounts during the fallow periods for the CS and CW systems were similar (7.50 vs. 8.65 inches), water storage was about 68 percent greater for CS than for CW. The resultant storage efficiencies were 14.8 and 20.1 percent for the CW and CS systems, respectively. The soil water content at harvest for the two crops, as discussed in the preceding paragraph, was a major factor influencing water storage in the interval between crops. Another factor of importance undoubtedly was the distribution of precipitation. Lower precipitation prevailed as wheat seeding approached (August and September) compared with sorghum seeding (May and June).

Except for the WF system, water storage efficiencies were somewhat higher during the 1967–70 period than during the 1959–70 period. However, data from the longer period should give a better indication of the treatment effects on water storage than from the 1967-70 period. Water storage efficiency for the WSF-RF system was slightly less than for the WSF system. The permanent ridge-furrow system did not enhance water storage as anticipated, but the period during which this system was included possibly was too short to validly test the system.

Multiple linear regression analysis was used to establish relationships between available water remaining in the soil at harvest of the previous crop, precipitation during the fallow period and available soil water at seeding. A summary of the results for the wheat and grain sorghum cropping systems is given in Table 7.

TABLE 7. SUMMARY OF MULTIPLE LINEAR REGRESSION ANALYSIS ASSOCIATING AVAILABLE SOIL WATER AT SEEDING OF WHEAT AND GRAIN SORGHUM ON DRYLAND WITH AVAILABLE SOIL WATER AT HARVEST[1] AND PRECIPITATION DURING DIFFERENT PORTIONS OF THE FALLOW PERIOD

Crop	Cropping system	Factor or precipitation period	Y-intercept[2] and net regression coefficients[3]		Coefficient of multiple determination (R^2)
			Symbol	Value	
Wheat	CW		b_0	−0.812	[4]0.873**
		Available soil water at harvest	b_1	.316	
		Precipitation—harvest to July 31	b_2	.337	
		Precipitation—August	b_3	.366	
		Precipitation—Sept. 1 to seeding	b_4	.357	
	WSF		b_0	0.945	0.811**
		Available soil water at sorghum harvest	b_1	.297	
		Precipitation—sorghum harvest to Nov. 30	b_2	.489	
		Precipitation—Dec. 1 to April 30	b_3	.095	
		Precipitation—May 1 to June 30	b_4	.012	
		Precipitation—July 1 to Aug. 31	b_5	.225	
		Precipitation—Sept. 1 to seeding	b_6	.164	
	WF		b_0	0.303	0.732*
		Available soil water at harvest	b_1	.096	
		Precipitation—harvest to July 31	b_2	.126	
		Precipitation—Aug. 1 to Nov. 30	b_3	.101	
		Precipitation—Dec. 1 to April 30	b_4	−.203	
		Precipitation—May 1 to June 30	b_5	.113	
		Precipitation—July 1 to Aug. 31	b_6	.357	
		Precipitation—Sept. 1 to seeding	b_7	.138	
Grain sorghum	CS		b_0	1.260	0.552N.S.
		Available soil water at harvest	b_1	0.545	
		Precipitation—harvest to Nov. 30	b_2	0.345	
		Precipitation—Dec. 1 to Feb. 28	b_3	0.104	
		Precipitation—Mar. 1 to April 30	b_4	0.072	
		Precipitation—May 1 to seeding	b_5	0.093	
	WSF		b_0	2.329	0.672*
		Available soil water at wheat harvest	b_1	−0.039	
		Precipitation—harvest to July 31	b_2	0.009	
		Precipitation—Aug. 1 to Sept. 30	b_3	0.386	
		Precipitation—Oct. 1 to Nov. 30	b_4	0.226	
		Precipitation—Dec. 1 to Feb. 28	b_5	−0.180	
		Precipitation—Mar. 1 to April 30	b_6	−0.617	
		Precipitation—May 1 to seeding	b_7	−0.074	

[1] Determined to a 4-foot depth. Unavailable water to 4 feet totals 9.97 inches.

[2] Y—intercept—b_0.

[3] The b coefficients indicate inches of water storage per inch of soil water at harvest or inch of precipitation received.

[4] Asterisks denote statistical significance (one—5-percent level; two—1-percent level).

The net regression coefficients suggest relatively high water storage from precipitation occurring soon after sorghum harvest and relatively low storage after wheat harvest except for the continuous wheat system. The coefficients also suggest rather high storage of precipitation as wheat seeding is approached and rather low storage as sorghum seeding is approached. This latter suggestion is contrary to expectations as discussed earlier. A possible explanation would be the effects of temperature and other climatic conditions on evaporation. Potential evaporation is higher before sorghum seeding than before wheat seeding. Consequently, water storage as a portion of precipitation received may indeed be greater before wheat seeding than before sorghum seeding, but total water stored may still be greater before sorghum seeding than before wheat seeding due to the greater amounts of precipitation occurring before sorghum seeding. Of course, the limitations of multiple regression analysis are realized, and the suggested trends may be coincidental rather than real.

For continuous wheat, precipitation between crops had a relatively constant effect on available soil water at seeding as indicated by the net regression coefficients. Also, the high coefficient of multiple determination ($R^2 = 0.873$) suggests a minimum true correlation between the dependent and independent variables of about 0.65 ($P = 0.95$) as determined from graphs and discussion presented by Ezekiel and Fox (1959, pp. 295-298). The high coefficient of multiple determination for the CW system further suggests that available soil water at seeding can be estimated with a fair degree of accuracy from a knowledge of available water remaining in the soil at harvest and the precipitation during the nongrowing season. By having a fairly reliable estimate of available soil water at seeding time, the producer could decide whether to seed wheat (continuous wheat) or whether to fallow the land with hopes of better returns from a sorghum crop the following year or a wheat crop a year later.

The low efficiency of fallow for storing precipitation as soil water and increasing crop production points to a need for flexible crop management and cropping systems. When the soil water content is high at harvest, water storage during the fallow period is low or water may actually be lost from the soil. In such cases, the water in the soil and subsequent precipitation may be more efficiently used if another crop is seeded immediately after harvest. After wheat, grain sorghum or a forage crop for livestock could be used. The increasing cattle industry in the area presents attractive possibilities for forage production. Wheat for grain or grazing could be seeded after grain sorghum when soil water conditions are favorable. Other possibilities would be to seed wheat or sorghum continuously if soil water conditions are favorable rather than seed the alternate crop later in the fallow period.

Without drastic alterations of the soil surface (microwatersheds, waterproofing, continuous mulches, and so forth) and possibly profile modification, it is doubtful that the efficiency of fallow with respect to water storage and crop production can be markedly increased by current cropping practices and systems. Flexible management and cropping systems will have to be used to make the most efficient use of all available water supplies.

Soil Properties

Organic Matter

The organic matter content in the surface 6 inches of soil was significantly higher in 1970 for the grass treatment than for any of the other treatments (Table 8). The difference in organic matter content due to the CW and CS treatments was significant also. Although not necessarily significant, all samples for the 0- to 6-inch depth from treatments with only wheat in the cropping system had higher organic matter contents than those from systems with wheat and sorghum or sorghum alone. Apparently, wheat is more conducive to maintaining the organic matter level of a soil than grain sorghum. Similar conclusions were reached by Hobbs and Thompson (1971).

In comparison with the organic matter content of samples obtained from the surface 6 inches of soil when the study was started in 1957, only the CS treatment resulted in an organic matter content decrease. The increase in organic matter contents as a result of the grass and CW treatments were significant. The increases due to the WF, WSF and WSF-RF treatments were not significant according to the unpaired "t" test.

The organic matter contents of samples from other depths were not significantly different as a result of the treatments except for the 24- to 36-inch depth of the WF treatment over the CW treatment. This difference evidently was due to random variation because there was no logical reason for that difference

TABLE 8. SOIL ORGANIC MATTER IN 1970 AS INFLUENCED BY WHEAT AND GRAIN SORGHUM CROPPING SYSTEMS AND BY GRASS ON DRYLAND; MEAN VALUES FOR SAMPLES COLLECTED AT INITIATION OF THE STUDY IN 1957

Treatment	Soil depth (inches) 0-6	6-12	12-18	18-24	24-36	36-48
	Percent					
CW	[1]1.86^{m}	1.40^{ij}	1.22^{ghi}	0.86^{cde}	0.53^{ab}	0.44^{a}
WF	1.77^{lm}	1.34^{ij}	1.03^{efg}	$.89^{de}$	$.80^{cd}$	$.47^{a}$
WSF	1.70^{lm}	1.40^{ij}	1.09^{fg}	$.85^{cde}$	$.68^{bc}$	$.45^{a}$
WSF-RF	1.70^{lm}	1.30^{hij}	1.13^{gh}	$.92^{def}$	$.66^{bc}$	$.46^{a}$
CS	1.64^{kl}	1.30^{hij}	1.20^{ghi}	$.79^{cd}$	$.68^{bc}$	$.47^{a}$
Grass	2.04^{n}	1.45^{jk}	1.14^{gh}	$.84^{cd}$	$.70^{bc}$	$.52^{ab}$
Mean (all treatments)	[1]1.79^{f}	1.37^{e}	1.14^{d}	$.85^{c}$	$.68^{b}$	$.47^{a}$
Mean (all samples—1957)	1.66	1.22	1.03	0.86	0.64	

[1] Column or row values or mean values followed by the same letter or letters are not significantly different at the 5-percent level (Duncan's Multiple Range Test).

since the organic matter contents at other depths for those treatments were similar

In 1970, the organic matter content of samples from the 6- to 12-inch depth of the grass plots was 0.23 percent greater than that of the initial soil samples from this depth, and this increase was significant. For the other treatments and depths, the organic matter contents were similar to those of the initial soil samples. The increase in soil organic matter content for the grass plots apparently resulted from the return to the soil of all forage produced. The grass was not grazed or removed as hay. The increase due to the CW treatment and the tendency toward increases due to the WF and WSF treatments were unexpected. Generally, it is considered difficult to maintain soil organic matter contents under cropping conditions and even more difficult to increase them. Hobbs and Thompson (1971), however, reported a reversal of the downward trend in soil organic matter when a change was made from continuous sorghum or sorghum-fallow cropping systems to a fallow-wheat-sorghum cropping system. They attributed the increase to different equilibrium organic matter levels for the different systems. Namely, the sorghum systems had lower equilibrium levels than the fallow-wheat sorghum system—hence, the increase when the latter system was introduced.

The field area used for the study of this report had been cropped to wheat continuously or alternately after fallow since it was broken from sod in 1927. (The area was initially broken from sod in 1919 but returned to grass after 2 years of sorghum.) Since the area had been cropped to wheat previously, the reasons for the increases in organic matter for the 1970 samples over the 1957 samples are not readily apparent. One possible reason may be that the organic matter content was unduly low in 1957. A major drouth during the preceding 7 years resulted in either crop failures or low residue production. Microbial activity continued during the drouth, and the low residue production resulted in a net reduction of soil organic matter. After the drouth, higher residue production increased the soil organic matter level. Data reported by Unger (1968) for an adjacent dryland wheat tillage and cropping practices study (CW and WF) were similar, confirming the reliability of the organic matter data in Table 8.

Bulk Density

Although not statistically significant except for the mean values for depth, several trends in soil bulk density (Table 9) are apparent. At all except the 0- to 6-inch and the 36- and 48-inch depths, the bulk density was highest for the CS treatment. The higher bulk density for this treatment possibly was related to the lower organic matter content.

For the 0- to 6-inch depth, the bulk density was highest for the grass treatment. This depth was the plow layer for all except the grass treatment, which

TABLE 9. SOIL BULK DENSITY IN 1 AND GRAIN SORGHUM CROPPING DRYLAND

	Soil dep				
Treatment	0-6	6-12	12-18		
	G/cm				
CW	[1]0.95	1.50	1.56	1.5	
WF	1.09	1.47	1.51	1.56	
WSF	1.04	1.52	1.56	1.59	
WSF-RF	1.07	1.57	1.55	1.64	
CS	1.13	1.65	1.65	1.69	
Grass	1.51	1.57	1.46	1.59	1.
Mean (all treatments)	[2]1.13^{a}	1.55^{b}	1.55^{b}	1.61^{b}	1.5

[1] Column and row and mean values are not significantly a

[2] Mean values followed by the same letter are not significa ferent at the 5-percent level (Duncan's Multiple Range Test)

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explains the lower bulk densities for the tillage p The grass plots had not been tilled since the gr was established in April 1958. The mean bulk densit for the 0- to 6-inch depth was significantly lower than for the other depths. Again, these differences resulted from tilling the surface layer of all plots except those in grass.

Dry Aggregates

The percentages of aggregates in the different size ranges were significantly affected by the different treatments imposed during the study period (Table 10). According to Woodruff and Siddoway (1965), about 75 percent of the aggregates (clods) on large, bare, smooth, unprotected fields should be greater than (>) 0.84 mm in order to hold average annual soil losses by wind erosion to less than the tolerable level of 5 tons per acre. All cropping systems resulted in less than the required amount of large aggregates to control wind erosion effectively (Table 10). For the less than (<) 0.84-mm fraction, the amounts ranged from 35.8 percent for the WF system to 46.0 percent for the CS system, and the differences were significant as indicated in Table 10. Soil of the CS plots would be more erodible than that of other plots, while the

TABLE 10. DRY AGGREGATE SIZE DISTRIBUTION IN 1970 AS INFLUENCED BY WHEAT AND GRAIN SORGHUM CROPPING SYSTEMS AND BY GRASS ON DRYLAND

	Soil fraction size (mm)					
Treatment	<0.84	0.84-2.0	2.0-6.4	6.4-18.3	>18.3	MWD[1]
	Percent					mm
CW	[2]39.4^{k}	13.1^{cd}	17.9^{ef}	20.8^{fgh}	8.8^{b}	7.87
WF	35.8^{j}	12.7^{cd}	17.9^{ef}	22.5^{h}	11.3^{bc}	9.26
WSF	39.6^{k}	13.1^{cd}	17.6^{ef}	21.6^{gh}	8.1^{b}	7.63
WSF-RF	41.5^{k}	15.0^{de}	17.7^{ef}	17.8^{ef}	8.1^{b}	7.20
CS	46.0^{l}	14.1^{cd}	18.3^{efg}	18.7^{fg}	2.8^{a}	4.81
Grass	13.2^{cd}	13.1^{cd}	22.2^{h}	28.2^{j}	23.3^{h}	15.78
Mean (all treatments)	[2]35.9^{d}	13.5^{b}	18.6^{c}	21.6^{c}	10.4^{a}	

[1] Mean weight diameter.

[2] Column or row values or mean values followed by the same letter or letters are not significantly different at the 5-percent level (Duncan's Multiple Range Test).

odible. Crop residues on the vided good protection during rly spring erosion period. The were not tilled until April, and at that time maintained most of e surface.

the grass treatment, there were no ces in the percentages of aggregates in 2.0-, 2.0- to 6.4- or 6.4- to 18.3-mm size to treatments. For the >18.3-mm range, eatment resulted in a significantly lower percentage than the other treatments.

hough the data are not shown, separate statis- nalyses were made for the dry aggregate distri- n data from the WF, WSF and WSF-RF cropping ms. For the WF system, the wheat plots (plots n which wheat was harvested in 1970) had signifi- tly less fine aggregates (<0.84 mm) than fallow lots (plots that were fallowed during the 1969–70 wheat season). Also, the wheat plots had significantly more aggregates in the >18.3-mm range than the fallow plots. For the WSF-RF system, significant differences were found between the percentages of aggregates in the <0.84-mm range for the wheat, fallow and sorghum plots, with wheat having the lowest and sorghum having the highest percentage of aggregates in this size range. The wheat plots had significantly more aggregates in the >18.3-mm range than either the fallow or sorghum plots. Although not significant, the trends for aggregates from the WSF system were similar to those of the WSF-RF system. These data suggest that wheat was more conducive to stabilizing dry soil aggregates than sorghum but that the effects of wheat on the stability of dry aggregates were relatively short lived.

The grass treatment resulted in significantly fewer aggregates in the <0.84-mm size range than any of the other treatments and significantly more aggregates in the 6.4- to 18.3- and the >18.3-mm size ranges than the other treatments.

Another method of indicating the differences in dry soil aggregation between treatments is through the calculation of a mean weight diameter (MWD) for each treatment (Kempe and Chepil, 1965). The MWD is equal to the sum of the products of the mean diameter ($\overline{x}_i$) in millimeters of each size fraction and the proportion of the total weight (w_i) occurring in the corresponding fraction. The amount passing through the finest sieve is included. A maximum diameter of 76.2 mm was assumed for the largest fraction. The equation used was

$$\mathrm{MWD} = \sum_{i=1}^{n} x_i w_i$$

Size distribution data (Table 10) for the different treatments were used to calculate the MWD values. Data for the CW treatment were used in the following example of the calculations:

$$\begin{aligned}\mathrm{MWD} &= [(0.42\ \mathrm{mm} \times 0.394) + (1.42\ \mathrm{mm} \times 0.131) + (4.20\ \mathrm{mm} \times 0.179) \\ &\quad + (12.35\ \mathrm{mm} \times 0.208) + (47.75\ \mathrm{mm} \times 0.088)] \\ &= 7.87\ \mathrm{mm}.\end{aligned}$$

The calculated MWD's are included in Table 10. By the nature of the calculations, the percentages of coarse aggregates have a greater influence on the MWD than those of the fine aggregates, and high MWD values reflect greater amounts of coarse aggregates for a treatment than low MWD values. The MWD was higher for the grass treatment than for the tillage treatments. For the different cropping treatments, the MWD was highest for WF and lowest for CS, again indicating greater erosion susceptibility for the CS treatment than for the other treatments.

The dry aggregate size distribution data indicate that all cropping systems on dryland could lead to serious wind erosion problems. However, through use of stubble-mulch tillage which maintained most of the crop residues on the surface, wind erosion generally was controlled adequately under the prevailing conditions. However, in some years, residue production is low, and erosion by wind may be severe. Under such conditions, tillage which increases the cloddiness and roughness of the soil surface may be necessary to reduce wind erosion to tolerable levels.

Samples for the dry aggregates size distribution determinations were collected in November, and it is recognized that different size distributions may have been found had the samples been collected at some other time. For example, freezing and thawing are known to pulverize the soil surface. However, the data presented are satisfactory for determining the relative influence of the cropping systems on soil erosion susceptibility but should not be used to indicate the absolute erosion potential during the critical late winter-early spring erosion period.

Wet Aggregates

The size distribution of soil aggregates wetted under vacuum was determined by wet sieving the soil under water. The percentages of aggregates in the different size ranges as determined by the amounts retained on the different sieves and the amount passing through the finest sieve are given in Table 11. Also given are mean weight diameters calculated according to the procedure illustrated in the section pertaining to dry aggregates.

The different wheat and sorghum cropping systems significantly affected the percentages of aggregates in the <0.25- and the 4.0- to 12.7-mm size ranges but not in the intermediate ranges. The grass treatment resulted in significant differences as compared with other treatments in the <0.25-, 2.0- to 4.0- and 4.0- to 12.7-mm size ranges.

The grass treatment resulted in the lowest and the WF and WSF treatments resulted in the highest percentages of aggregates in the <0.25-mm size range. The low percentage of fine aggregates (<0.25 mm)

TABLE 11. WET AGGREGATE SIZE DISTRIBUTION IN 1970 AS INFLUENCED BY WHEAT AND GRAIN SORGHUM CROPPING SYSTEMS AND BY GRASS ON DRYLAND

Treatment	Soil fraction size (mm) <0.25	0.25-1.0	1.0-2.0	2.0-4.0	4.0-12.7	MWD[1]
	Percent					mm
CW	[2]36.5^{h}	27.2^{g}	7.6^{a}	8.9^{a}	19.9^{de}	2.26
WF	42.0^{i}	27.7^{g}	7.2^{a}	8.0^{a}	15.1^{bc}	1.48
WSF	42.0^{i}	25.0^{fg}	7.4^{a}	8.3^{a}	17.2^{cd}	1.60
WSF-RF	39.1^{hi}	29.3^{g}	7.3^{a}	7.6^{a}	16.8^{bcd}	1.58
CS	35.6^{h}	27.9^{g}	7.7^{a}	8.9^{a}	19.9^{de}	2.27
Grass	25.5^{fg}	27.1^{g}	12.2^{ab}	12.9^{bc}	22.4^{ef}	2.64
Mean (all treatments)	[2]36.8^{d}	27.4^{c}	8.2^{a}	9.1^{a}	18.6^{b}	

[1] Mean weight diameter.

[2] Column or row values or mean values followed by the same letter or letters are not significantly different at the 5-percent level (Duncan's Multiple Range Test).

for the grass treatment was attributed to the organic matter (humus) accumulation (Table 8) under the grass sod which was beneficial for soil aggregation. The influence of grass on soil aggregation was also reflected in the higher percentage of aggregates for the grass treatment in the 2.0- to 4.0- and 4.0- to 12.7-mm size ranges. The organic matter under grass held the soil together in larger aggregates. This beneficial effect of sod on soil aggregation is widely recognized.

That there were higher percentages of fine aggregates for the WF, WSF and WSF-RF treatments than for the CW and CS treatments apparently was related to the fallow period. Data in Table 11 for the WF, WSF and WSF-RF treatments are averages for the different sequences in the crop rotations. Although data for the individual sequences are not shown, the percentage of fine aggregates was greater for plots of the WSF and WSF-RF systems that were fallowed the previous cropping season than for plots that were cropped to wheat or grain sorghum. Apparently, crop residues had a beneficial effect on soil aggregation for a relatively short period. The fallow periods were sufficiently long so that most of the residues were weathered by the time of sampling and, hence, the residues no longer benefited soil aggregation. For the CW and CS systems, the intervals between crops were relatively short, and greater aggregation was apparent.

The trends in the percentages of aggregates for the different treatments for the 4.0- to 12.7-mm range were opposite the trends for the <0.25-mm range. These trends reflect the ability of residues from recent crops and grass to promote the formation of large soil aggregates. This ability was also reflected in the MWD values for the different treatments.

Soils with higher percentages of water-stable aggregates in the larger size ranges should permit more rapid water intake than soils having higher percentages of fine aggregates. The fine aggregates (<0.25 mm) result from dispersion of the soil upon wetting. This fine material readily moves into soil pores with water, clogs the pores and, in many cases, virtually seals the soil against further water entry.

Although significant differences in the distribution of the wet aggregates were found in this study, it is doubtful whether differences in water intake for the wheat and sorghum cropping systems could be detected under field conditions. First, the differences between treatments, although significant, were relatively small, and presumably the resulting influence on water intake would be small also. Second, soil for the aggregate distribution determinations was wetted under vacuum. This type of wetting reduces soil dispersion. Under field conditions, the soil is rapidly wetted by precipitation, and dispersion occurs. Differences in aggregate stability of Pullman clay loam as a result of rapid and vacuum wetting have been shown by Unger (1969). Also, raindrops striking bare soil enhance dispersion, whereas even small amounts of surface residues intercept raindrops and reduce soil dispersion. Weathered residues serve this purpose but evidently had little influence on the size distribution of wet aggregates as discussed previously. Consequently, water intake on the rotation plots (WF, WSF and WSF-RF) under field conditions may be greater than on the continuous cropping plots (CW and CS) because the rotation plots, even at the end of the fallow period, have weathered residues on the surface which intercept the raindrops. This possible difference in water intake during the growing season by soil of the rotation and continuous cropping plots may have been a major factor in greater grain production on the rotation plots as compared with the continuous cropping plots. It is doubtful that the small differences in available soil water at seeding alone were responsible for the differences in yield.

Economics of the Different Cropping Systems

In Tables 2 and 5, average grain yields for the different cropping systems are presented. The average yields, however, were based on the area harvested

TABLE 12. MEAN ANNUAL YIELDS BASED ON THE AREA HARVESTED AND AREA IN THE DIFFERENT CROPPING SYSTEMS FOR WHEAT AND GRAIN SORGHUM ON DRYLAND (1958 THROUGH 1970)

Cropping system	Mean yield (area harvested) Wheat	Sorghum	Mean yield (area in cropping system) Wheat	Sorghum	Total grain[1]
	Lb./acre				
Continuous wheat	628		628		628
Wheat-sorghum-fallow[2]	758	1557	253	519	772
Wheat-fallow[3]	866		433		433
Continuous sorghum		1137		1137	1137

[1] Accounts for differences in area harvested each year and area in the cropping systems.

[2] 3-year system.

[3] 2-year system.

TABLE 13. SUMMARY OF FIELD OPERATIONS[1] PERFORMED FOR THE WHEAT AND GRAIN SORGHUM CROPPING SYSTEMS ON DRYLAND. THE VALUES SHOWN ARE THE AVERAGE NUMBERS PERFORMED FOR THE PRODUCTION OF A CROP

Operation	Wheat			Sorghum	
	CW	WF	WSF	CS	WSF
	No./year				
Seeding	1.0	1.0	1.0	[2]1.3	[2]1.3
Sweep tillage	2.8	7.2	4.6	1.9	4.6
Cultivations				1.0	1.0

[1] Occasional operations such as spraying for weeds and insects and use of the rotary hoe to aid emergence of grain sorghum are not included because they were not performed a sufficient number of times to establish trends.

[2] Sorghum was reseeded in about 1 year in 3.

each year and did not take into account the differences in acreages devoted to the different cropping systems. For an economic analysis of the cropping systems, differences in acreages along with production requirements and returns for the different systems must be considered. In Table 12, average yields are presented on the basis of the harvested area and the area in each cropping system. Table 13 summarizes the field operations performed for each cropping system during the study period.

Data in Tables 12 and 13 along with prevailing costs and grain prices can be used to obtain estimated incomes and expenses per harvested acre for the different cropping systems. A complete economic analysis of the cropping systems, however, is beyond the scope of this paper. For those interested, the guidelines published by Grubb, Moore and Lacewell (1967) and by Osborn, Moore and Ethridge (1969) for the production of dryland wheat and grain sorghum would be useful for determining the system most suitable for a particular production enterprise.

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