STATION TECHNICAL BULLETIN 1 MARCH 1943

Water Requirement of Wheat at the Sherman Branch Experiment Station

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INTRODUCTION

WHEAT is the major crop on the dry lands of the Columbia River Basin. The wheat yields in this area fluctuate considerably from year to year. As in most other wheat-producing areas, the amount and distribution of the annual precipitation more than any other one climatic factor is responsible for this yield fluctuation although high temperatures during the growing season may also affect yields adversely even when soil moisture is adequate. More often, however, low yields are caused by a combination of both high temperature and inadequate soil moisture.

Any improved farm practice that will increase or better stabilize wheat yields of this region will likely be the result of: (1) getting more of the water that falls as precipitation into the soil, (2) conserving this water in the soil during the fallow period and handling the fallow so as to promote optimum nitrification, (3) protecting the soil from excessive erosion, (4) maintaining soil fertility at a satisfactory level, and (5) producing better adapted crop varieties that will yield satisfactorily with the available water supply. Investigations along these lines have been carried on by research workers in the past, with added emphasis in recent years on methods of controlling excessive soil erosion, which is a basic consideration in stabilizing or maintaining crop yields. Additional information still is needed on many of the complex problems involved in soil moisture, soil fertility, and plant growth relations.

In connection with the cooperative field experiments conducted at the Branch Experiment Station at Moro, Oregon, supplementary studies relating to soil moisture, nitrates, and water requirement (ratio of water used to weight of dry matter harvested) were undertaken in an attempt to learn more about the factors responsible for yield and quality variations in wheat. In this bulletin are reported the results of some of these supplementary studies, especially those dealing with the yield and water requirement of wheat when grown in large pots under controlled moisture conditions.

WATER REQUIREMENT OF DIFFERENT VARIETIES OF WHEAT GROWN IN SEALED OR OPEN POTS 1912 to 1917 AND 1919 to 1928

Studies to determine the water requirement of wheat and the periodic use of water by wheat when grown in large galvanized iron pots and in the field

* Cooperative investigations between the Oregon Agricultural Experiment Station and the Division of Cereal Crops and Diseases of the Bureau of Plant Industry.

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have been carried on at Moro since 1912. In that year only one variety, Kubanka, was grown. From 1914 to 1917, inclusive, Pacific Bluestem, a spring wheat, was grown in sealed pots by the method described by Briggs and Shantz. (1)* From 1919 to 1921, Baart and Hard Federation spring wheats

Table 1. WATER REQUIREMENT OF SPRING AND WINTER WHEAT AT MORO, OREGON, IN THE YEARS 1912 TO 1917, INCLUSIVE, AND 1919 TO 1928, INCLUSIVE.

Variety and year	Yield		Water used	Water requirement†	
	Total	Grain		Based on total crop	Based on grain
	Grams	*Grams*	*Kilos*		
Spring wheat					
Kubanka (6 sealed pots)					
1912	104.0	29.0	61.3	589	2,114
1913	258.6	75.8	136.0	526	1,794
Average	181.3	52.4	98.7	558	1,954
Pacific Bluestem (6 sealed pots)					
1914	184.6	45.4	131.9	715	2,905
1915	204.7	47.3	135.3	661	2,860
1916	208.5	68.2	86.5	415	1,268
1917	160.9	53.8	103.2	641	1,918
Average	189.7	53.7	114.2	608	2,238
Baart (4 sealed pots)					
1919	117.2	26.8	65.5	559	2,444
1920	145.9	48.9	82.5	565	1,687
1921	131.0	48.7	66.5	508	1,366
Average	131.4	41.5	71.5	544	1,832
Hard Federation (4 sealed pots)					
1919	131.7	46.8	70.4	535	1,504
1920	166.9	58.1	78.3	469	1,348
1921	130.9	51.2	62.1	474	1,213
Average	143.2	52.0	70.3	493	1,355
Winter wheat					
Turkey (6 sealed pots)					
1922	252.2	92.7	126.8	503	1,368
1923	167.3	46.2	54.9	328	1,188
1924	124.2	38.4	57.2	461	1,490
1925	245.5	78.8	83.7	341	1,062
1926	408.5	139.2	162.3	397	1,166
1927	338.6	115.7	96.3	284	832
1928	374.2	137.8	120.8	323	877
Average	272.9	92.7	100.3	377	1,140
Turkey (6 open pots)					
1922	205.4	68.5	140.0	682	2,044
1923	141.0	55.5	63.2	448	1,139
1924	104.6	37.6	71.7	685	1,907
1925	230.3	77.3	95.3	414	1,233
1926	380.2	120.6	178.2	469	1,478
1927	255.5	78.8	100.0	391	1,269
1928	345.2	123.5	133.8	388	1,083
Average	237.5	80.3	111.7	497	1,450

* Reference by number is to literature cited, page 27.
† Water requirement is the ratio of water used to dry matter produced.

were similarly tested. From 1922 to 1928, inclusive, Turkey winter wheat was grown in both sealed and open pots. In 1926, Marquis and Hard Federation spring wheats were grown in open pots with no mulch and in open pots with about ¼ of an inch of sand as a mulch. In 1927, Hybrid 128 and Turkey winter wheats were similarly grown. The water requirement data for these trials are given in Table 2. All pots were filled each year with soil from a field that had been fallowed the previous year. No fertilizers were added to the soil except for the varieties Kubanka and Pacific Bluestem in the years 1912 to 1917.

Although not grown in the same years, the data in Table 1 indicate that the water requirement for spring wheat is appreciably greater than for winter wheat. This is what would be expected because of the earlier maturity of the winter wheat and the cooler temperatures prevailing during its growing period.

Table 2. WATER REQUIREMENT OF MARQUIS AND HARD FEDERATION SPRING WHEATS AND TURKEY AND HYBRID 128 WINTER WHEATS GROWN IN OPEN POTS WITH AND WITHOUT A SAND MULCH AT MORO, OREGON, IN 1926 AND 1927.

Variety and treatment	Year	Water used	Total crop	Grain	Water requirement	
					Based on total crop	Based on grain
		Kilos	*Grams*	*Grams*		
Open pots—no mulch						
Marquis	1926	71.261	93.5	26.5	762	2,689
Hard Federation	1926	64.921	84.3	27.5	770	2,361
Hybrid 128	1927	64.660	128.9	47.9	502	1,350
Turkey	1927	66.361	130.1	42.9	510	1,547
Average	....	....	....	......	636	1,987
Open pots—sand mulch						
Marquis	1926	65.114	92.1	28.8	707	2,261
Hard Federation	1926	57.315	84.6	27.4	677	2,092
Hybrid 128	1927	58.014	126.3	52.1	459	1,114
Turkey	1927	57.617	135.3	55.5	426	1,038
Average	....	....	....	......	567	1,626

For the two spring varieties grown in 1919 to 1921, inclusive, based on total crop, the water requirement of Baart was 10.3 per cent greater than that of Hard Federation; based on grain, the water requirement of Baart was 35.2 per cent greater.

Based on the total weight of the crop, the water requirement of Turkey winter wheat was 31.8 per cent greater when grown in open pots than when grown in sealed pots. Based on grain, the water requirement was about 27 per cent greater for the open pots. This greater water requirement for the wheat grown in open pots was due to loss of water through evaporation in addition to that transpired by the plants and to the higher yields of both grain and straw that were rather consistently obtained from the sealed pots. The rainfall during the growing season was included in the water used by the wheat in the open pots with no attempt to determine how much of the rainfall was lost by evaporation. A light sand mulch reduced the evaporation and decreased the average water requirement about 10 per cent when based on total crop and about 18 per cent when based on weight of grain as is shown by the results obtained in 1926 and 1927, recorded in Table 2.

WATER REQUIREMENT OF WINTER WHEAT WHEN GROWN IN POTS AND IN FIELD PLOTS

The water requirement based on grain and the yield data for Turkey winter wheat grown in pot trials are given in Table 3, together with the yields of the same variety grown in field plots where periodic soil moisture determinations were made. The field plot yields are averages from 8 to 10 plots each year, with a different cultivation method during the fallow year for each plot. The water requirement data for the pot trials are averages each year for the three treatments listed in Table 5.

There was a fairly close agreement in the water requirement, based on grain, of the wheat grown in pots and in the field during the first 7 years, 1923 to 1929, but in the later 9 years, 1930 to 1938, the water requirement of the wheat grown in the field was markedly higher. The high water requirement for the field plot trials nearly always occurred in years with low yields when crop growth was arrested because of drought. The lowest water requirement for the wheat grown in pots was 1,101 in 1928. In that year also the lowest water requirement, 926, was obtained for the wheat grown in field plots.

In the last column of Table 3 are shown the bushels of wheat produced for each inch of water used. The water used was determined by adding the precipitation during the growing season to the difference in the quantity of water in the soil to a depth of 6 feet in the early spring and at harvest time, as determined by soil moisture determinations. The quantity of wheat produced for each inch of water used by the crop ranged from 4.2 bushels in 1928 to 1.5 bushels in 1932. The average for the 16 years was 2.5 bushels for each inch of water used.

Table 3. WATER REQUIREMENT, BASED ON GRAIN, AND OTHER DATA ON TURKEY WINTER WHEAT GROWN IN POT AND FIELD TRIALS AT MORO, OREGON, IN THE YEARS 1923 TO 1938, INCLUSIVE.

Year	Water requirement based on grain		Acre yield field plots	Wheat yield for each inch of water used, field plots
	Pots	*Field plots*		
			Bushels	*Bushels*
1923	1,189	1,251	31.5	3.3
1924	1,527	1,447	19.7	2.6
1925	1,439	1,522	24.1	2.8
1926	1,461	1,456	23.1	2.9
1927	1,280	1,096	34.1	3.8
1928	1,101	926	38.5	4.2
1929	1,606	1,677	10.4	2.2
1930	1,013	2,081	14.4	2.0
1931	1,328	2,272	14.5	1.8
1932	1,349	2,706	13.3	1.5
1933	1,062	1,727*	17.1*	2.4
1934	1,369	1,893	16.2	2.2
1935	1,193	2,400	10.3	1.9
1936	1,116	2,054	19.4	2.0
1937	1,199	1,783	26.8	2.3
1938	1,322	1,583	29.7	2.7
Average	1,285	1,742	21.4	2.5

* Baart spring wheat was grown in the field plot trials in 1933.

EFFECT OF COMMERCIAL FERTILIZER, MANURE, AND STRAW ON WATER REQUIREMENT

NITRATE CARRYING FERTILIZERS

It is well known that soil fertility may have a marked effect on the quantity of water used by a growing crop and the efficiency of the soil solution in producing plant growth. In 1930 to 1933, inclusive, Federation spring wheat was grown in pots in soil that had grown wheat for at least 40 years. Each year the pots were filled with surface soil in the early spring, first from field plots that had been fallowed the previous year, and second from adjacent plots that had been cropped to winter wheat the previous year. Except for a check series, two nitrate fertilizers, ammonium sulphate and sodium nitrate, and a complete fertilizer, were added to the cropped soil, as indicated in Table 4.

Table 4. WATER REQUIREMENT OF FEDERATION SPRING WHEAT GROWN IN UNCOVERED POTS AT MORO, OREGON, IN 1930 TO 1933, INCLUSIVE, IN SOIL FALLOWED THE PREVIOUS YEAR AND IN CROPPED SOIL RECEIVING DIFFERENT FERTILIZER TREATMENTS.

Treatment and year	Average yield per pot		Water requirement	
	Total crop	Grain	Based on total crop	Based on grain
	Grams	*Grams*		
Soil cropped to wheat the previous year. 200 pounds per acre $(NH_4)_2SO_4$ added.				
1930	83.5	34.4	709	1,710
1931	93.0	41.6	681	1,526
1932	86.7	38.7	815	1,830
1933	89.4	38.1	696	1,632
Average	88.2	38.2	725	1,675
Soil cropped to wheat the previous year. 200 pounds per acre $NaNO_3$ added.				
1930	77.6	31.7	763	1,866
1931	112.1	51.6	683	1,483
1932	75.3	31.8	901	2,139
1933	87.0	36.1	728	1,751
Average	88.0	37.8	769	1,810
Soil fallowed the previous year.				
1930	66.5	28.6	854	1,987
1931	96.8	41.5	626	1,462
1932	56.6	24.0	1,022	2,396
1933	61.3	26.5	890	2,055
Average	70.3	30.2	848	1,975
Soil cropped to wheat the previous year. 400 pounds per acre complete fertilizer (Vigoro 4-8-4) added.				
1930	71.1	30.4	818	1,914
1931	74.8	32.0	781	1,830
1932	58.9	25.7	983	2,254
1933	73.1	30.1	797	1,934
Average	69.5	29.6	845	1,983
Soil cropped to wheat the previous year. No treatment.				
1930	41.4	18.0	1,312	3,040
1931	56.3	23.9	934	2,217
1932	57.5	24.7	1,036	2,415
1933	50.1	21.5	1,019	2,372
Average	51.3	22.0	1,075	2,511

The total crop and grain yields were highest for the cropped soil to which nitrate carrying fertilizers were added. There was little difference between the yield obtained from the addition of sodium nitrate or ammonium sulphate. Both these fertilizer treatments produced more straw and grain than was produced on fallowed land without fertilizer applications, and water to produce the crop was more efficiently used, as indicated by the difference in water requirement. Significantly lower yields, with a higher water requirement, were obtained from the soil that had been cropped to wheat the previous year and no fertilizer added, indicating that there was an insufficient supply of nitrates in the soil to produce a high yield even with ample moisture.

The results from this trial show that the average dry land soils of the Columbia River Basin, which are low in total nitrogen, ordinarily will not produce a heavy wheat crop even with ample moisture unless the soil either has been fallowed for a long enough period to allow nitrates to accumulate or enough nitrate carrying fertilizers are added to the soil to meet the normal needs of the growing crop.

MANURE AND STRAW

Winter wheat and spring wheat were grown at Moro in large uncovered pots, the soil of one series being fallowed and another cropped. During the fallow season the only water received by the soil was the precipitation, as no water was added from the time one crop was harvested until the next crop was planted. The growing crop received water as needed. The quantity of water lost was determined by frequent weighings. The soil moisture was kept well above the wilting point, but no attempt was made to keep the soil at a uniform or optimum moisture content. Water was added to the growing crop at about 3-to-4-day intervals during the period of rapid growth. Rainfall during the growing season was added to the quantity of water supplied in determining the water requirement. The proportion of water lost by evaporation and by transpiration was not determined.

Winter wheat. In Table 5 are recorded the yields (grain and total crop) and the water requirement of Turkey winter wheat grown in the same soil in open pots alternately cropped and fallowed by three methods: (1) coarse barnyard manure added at the rate of 10 tons per acre in the spring of the fallow year with total crop removed; (2) total straw returned to the soil, burned, and the ashes mixed with the topsoil; (3) total straw returned to and mixed with the topsoil.

The soil used in this experiment was obtained from the farm of Mr. James Hill, near Pendleton, Oregon, in 1922. It is a typical eastern Oregon silt loam with a total nitrogen content in the first foot of approximately .1 per cent.

It will be noted from Table 5 that the yields varied greatly in different years despite the fact that enough water was supplied to meet the needs of the plants. The low yields in some seasons were caused by adverse climatic conditions, especially high temperatures, and in some years by attacks of powdery mildew. This disease, the only one that was troublesome in both the winter and the spring wheat, was partly held in check by dusting the plants with sulphur.

There were no significant differences in the yields obtained from the three treatments for the first 10 years. After five crops of wheat were grown, the yields obtained from the soil to which manure was added were consistently higher than those obtained from the other treatments. Because of the more

Table 5. Yield and Water Requirement of Turkey Winter Wheat Grown After Fallow in Open Pots at Moro, Oregon, with Residues Added as Indicated, for the Years 1923 to 1940, Inclusive.

Year	Manure added				Straw burned				Straw returned			
	Average yield per pot		Water requirement		Average yield per pot		Water requirement		Average yield per pot		Water requirement	
	Total crop	Grain	Based on total crop	Based on grain	Total crop	Grain	Based on total crop	Based on grain	Total crop	Grain	Based on total crop	Based on grain
	Grams	*Grams*			*Grams*	*Grams*			*Grams*	*Grams*		
1923	197.5	61.7	411	1,328	211.2	67.2	374	1,179	227.3	78.8	345	1,059
1924	117.5	38.0	595	1,828	126.5	42.1	486	1,398	131.2	48.4	503	1,354
1925	229.5	75.0	484	1,475	290.9	79.5	379	1,389	248.6	75.0	438	1,453
1926	307.8	100.2	517	1,593	313.6	118.2	510	1,352	297.7	109.8	516	1,437
Average	213.1	68.7	502	1,556	235.6	76.8	437	1,330	226.2	78.0	451	1,326
1927	357.7	123.9	396	1,094	299.6	91.8	446	1,483	363.9	114.2	407	1,262
1928	427.3	160.3	405	1,079	442.4	148.2	390	1,169	497.1	164.3	341	1,054
1929	147.0	47.4	505	1,572	138.2	45.8	528	1,610	146.0	45.5	509	1,637
1930	185.2	75.0	393	972	161.2	66.0	444	1,084	175.8	72.9	407	983
Average	279.3	101.7	425	1,179	260.4	88.0	452	1,337	295.7	99.2	416	1,234
1931	243.6	84.1	472	1,366	244.0	82.7	446	1,318	253.9	86.9	445	1,301
1932	209.8	66.8	465	1,460	168.7	57.8	481	1,403	202.1	75.2	440	1,184
1933	217.6	90.5	414	995	187.9	74.6	436	1,097	191.8	75.1	429	1,095
1934	229.0	90.3	488	1,235	158.9	59.8	533	1,416	179.8	56.2	539	1,455
Average	225.0	82.9	460	1,264	189.9	68.7	474	1,309	206.9	73.4	463	1,259
1935	247.3	102.1	405	982	195.6	69.9	447	1,252	158.2	58.0	494	1,345
1936	227.6	98.7	423	975	176.2	68.7	476	1,222	164.5	68.2	477	1,152
1937	249.3	104.3	426	1,015	165.9	65.8	509	1,283	162.5	63.0	503	1,298
1938	235.4	107.1	487	1,071	136.9	56.5	605	1,468	140.5	56.8	577	1,427
Average	239.9	103.1	435	1,011	168.7	65.2	509	1,306	156.4	61.5	513	1,306
1939	290.6	108.6	453	1,217	158.3	55.7	609	1,730	175.1	64.1	557	1,524
1940	221.4	80.5	572	1,577	136.8	47.9	710	2,029	149.5	49.7	645	1,950
Average	256.0	94.6	513	1,397	147.6	51.8	660	1,880	162.3	56.9	601	1,737
Average for all years	241.2	89.7	462	1,269	206.3	72.1	489	1,382	214.8	75.7	476	1,333

vigorous plant growth, the wheat in the manured pots required more water, but yielded enough more to make the water requirement less than for the wheat grown with the straw returned to the soil or burned. For the 8-year period, 1933 to 1940, the grain yield from the pots to which manure had been added to the soil averaged approximately 58 per cent more than from the pots to which no manure had been added. The manured pots, however, required 25 per cent more water. The trend in yield by 4-year periods is shown in Figure 1.

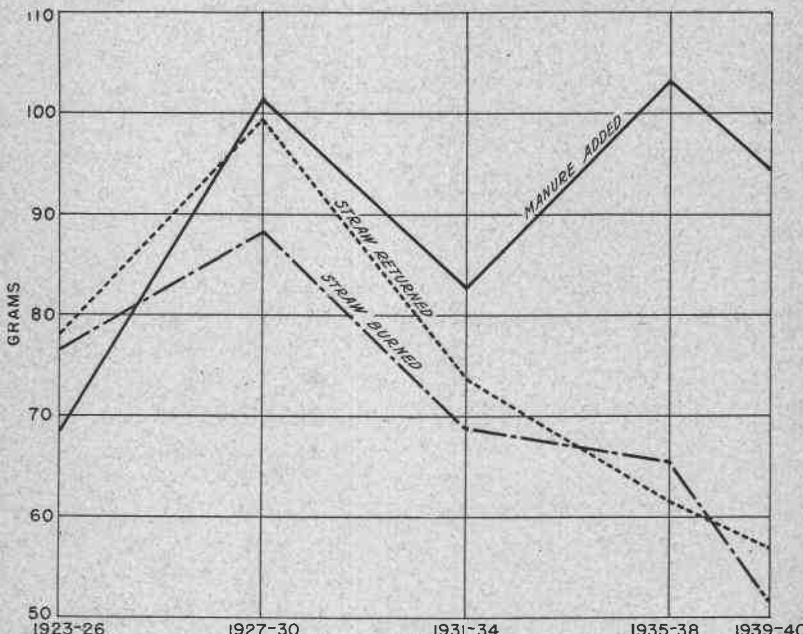

Figure 1. Average grain yields by 4-year periods of Turkey winter wheat grown after fallow in uncovered pots at Moro, Oregon, with straw burned, straw returned to the soil, and straw removed and barnyard manure added at the rate of 10 tons per acre.

Table 6 shows the annual and average 4-year yields of the grain and straw and the percentage of grain in the total crop for the Turkey winter wheat grown in the pot trials for the years 1923 to 1938, inclusive. The percentage of grain in the total crop was approximately the same for each of the three treatments during the first 10 years. For the remaining 6 years, there was a tendency for the ratio of grain to straw to become narrower for the pots to which manure had been added to the soil. In other words, the difference in grain yields between the manured pots and the others was greater than the difference in straw yields. As may be observed from Figure 2, the plants in the manured pots often did not grow so tall as those in which the straw was burned or turned under. Figure 3 shows a general view of the shelter used for the pot experiments and Figure 4 shows the early growth made by spring wheat in pots with previous fertilizer applications made to the soil.

Table 6. YIELD AND PERCENTAGE OF GRAIN IN TOTAL CROP OF TURKEY WINTER WHEAT GROWN IN OPEN POTS AT MORO, OREGON, WITH RESIDUES ADDED AS INDICATED.

Year	Manure added		Straw burned		Straw returned	
	Total crop	Per cent grain	Total crop	Per cent grain	Total crop	Per cent grain
	Grams		*Grams*		*Grams*	
1923	197.5	31.2	211.2	31.8	227.3	34.7
1924	117.5	32.3	126.5	33.3	131.2	36.9
1925	229.5	32.7	290.9	27.3	248.6	30.2
1926	307.8	32.6	313.6	37.7	297.7	37.0
Average	213.1	32.2	235.6	32.5	226.2	34.7
1927	357.7	34.6	299.6	30.6	363.9	31.1
1928	427.3	37.5	442.4	33.5	497.1	31.0
1929	147.0	32.2	138.2	33.1	146.0	31.1
1930	185.2	40.5	161.2	40.9	175.8	41.4
Average	279.3	36.2	260.4	34.5	295.7	33.7
1931	243.6	34.5	244.0	33.0	253.9	34.2
1932	209.8	31.8	168.7	34.2	202.1	35.7
1933	217.6	41.5	187.9	39.7	191.8	39.1
1934	229.0	39.4	158.9	37.6	179.8	31.2
Average	225.0	36.8	189.9	36.1	206.9	35.1
1935	247.3	41.3	195.6	35.7	158.2	36.6
1936	227.6	43.3	176.2	38.9	164.5	41.4
1937	249.3	41.8	165.9	39.6	162.5	38.7
1938	235.4	45.5	136.9	41.2	140.5	40.2
Average	239.9	43.0	168.7	38.9	156.4	39.2

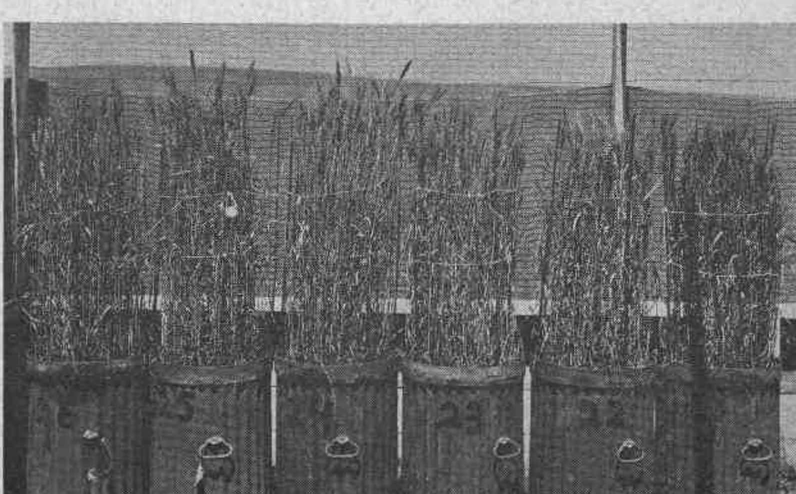

Figure 2. Turkey winter wheat.

Pots 25 and 26, total straw returned.
Pots 23 and 24, straw burned.
Pots 21 and 22, strawy manure added.
Photograph June 15, 1931.

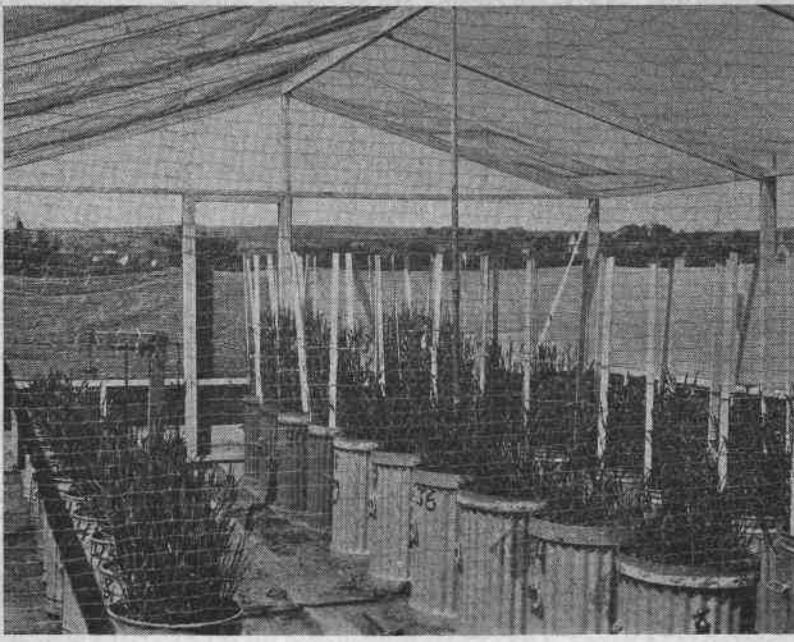

Figure 3. General view of a corner of the shelter used for pot experiments.

Figure 4. Federation Spring Wheat.

Pot 40 contained soil fallowed the previous year.
Pot 42 contained soil cropped to winter wheat the previous year.
Pot 44 contained soil cropped the previous year plus 200 pounds nitrate of soda per acre.
Pot 46 contained soil cropped the previous year plus 200 pounds ammonium sulphate per acre.
Pot 48 contained soil cropped the previous year plus 400 pounds of Vigoro per acre.
Pot 50 contained soil, which was previously cropped to alfalfa, fallowed in 1929.

Photograph May 10, 1930.

Spring wheat. Since 1929 spring wheat has been grown in the same soil in uncovered pots with four treatments: (1) binder stubble returned; (2) straw removed and coarse manure added; (3) total straw returned; and (4) total straw returned and burned. The soil used in these pots was taken from plots of a field experiment on the Moro Station where similar treatments have been used since 1923. The yields obtained from the spring wheat, as shown in Table 7, are not comparable with those obtained from winter wheat (Table 5) because smaller pots and a different soil were used for the spring wheat. There were 6 pots of soil for each treatment, with 3 in crop and 3 in fallow each year. Three-year average yields and water requirement are shown in Table 7 and the trend in grain yield is shown graphically in Figure 5.

As with winter wheat, no significant differences in yield were noted for a period of years. Beginning with the 1935 crop, and thereafter, the spring wheat

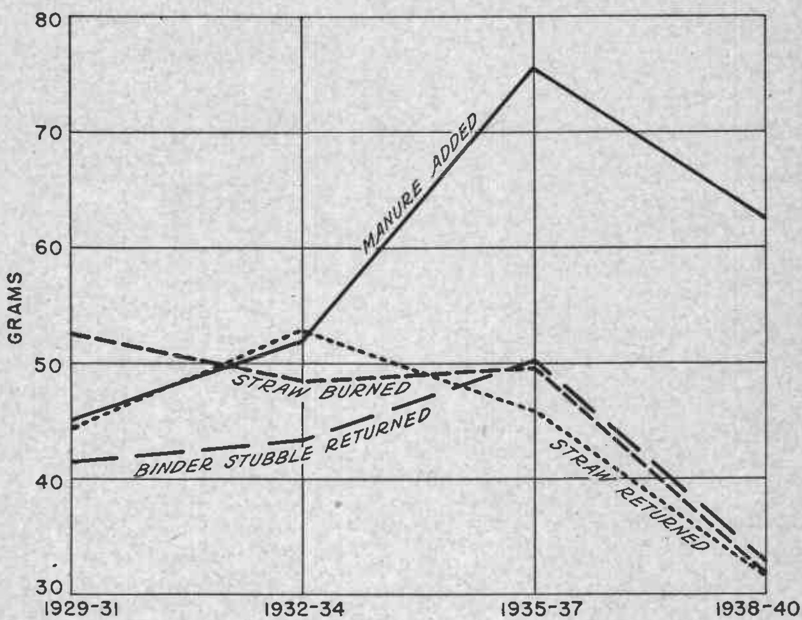

Figure 5. Average grain yield by 3-year periods of Federation spring wheat grown after fallow in uncovered pots at Moro, Oregon, with the straw returned to the soil, stubble returned, straw burned, and with straw removed and barnyard manure added at the rate of 10 tons per acre.

yields from the pots to which manure was added to the soil were consistently higher than from any of the other treatments. The average yields from the soils to which a small amount of the stubble was added, the total straw added, and the total straw burned were practically identical. For the first 6 years the pots to which the total straw was returned consistently outyielded those where the stubble only was added. For the last 5-year period, however, the yield from the pots to which the total straw was added was slightly less than from those of any of the other treatments.

In the field plots at Moro, where lack of soil moisture has been the dominant factor in influencing yields, the application of barnyard manure has not increased wheat yields nor has the returning of all straw shown any tendency to reduce yields. This disagreement in the results from the field and pot trials can be explained by the fact that in the field soil moisture often becomes so depleted toward the end of the growing period that the crop on the manured plots is unable to develop in accordance with potential basic growth.

At the Pendleton Field Station, where soil moisture conditions are more favorable, the addition of barnyard manure has increased yields, as indicated from the data in Figure 6, which shows the annual yields of winter wheat after fallow for an 11-year period with manure added at the rate of 10 tons per acre prior to spring plowing and without manure. Similar results were obtained when the manure was applied in the spring of the crop year as a top dressing. In other experiments at Pendleton to determine the effect on yield of various methods of crop residue disposal, the beneficial effects of nitrogenous fertilizers were clearly indicated (2).

Table 7. AVERAGE YIELD AND WATER REQUIREMENT OF FEDERATION SPRING WHEAT GROWN IN UNCOVERED POTS AT MORO, OREGON, BY 3-YEAR PERIODS, BEGINNING WITH 1929.

3-year periods and treatment	Average yield per pot		Water requirement	
	Total crop	Grain	Based on total crop	Based on grain
1929-31				
Manure added	124.7	45.0	592	1,690
Total straw returned	121.7	44.4	592	1,700
Binder stubble returned	112.4	41.4	605	1,665
Total straw burned	134.5	52.9	526	1,436
1932-34				
Manure added	156.7	52.0	503	1,640
Total straw returned	149.4	52.5	531	1,535
Binder stubble returned	132.4	43.9	553	1,752
Total straw burned	135.4	48.6	536	1,575
1935-37				
Manure added	202.1	75.5	497	1,335
Total straw returned	120.2	46.2	595	1,544
Binder stubble returned	129.5	50.4	578	1,469
Total straw burned	130.5	49.5	576	1,520
1938-40				
Manure added	174.1	62.6	620	1,734
Total straw returned	87.1	30.6	809	2,314
Binder stubble returned	89.9	32.2	812	2,294
Total straw burned	88.5	31.8	834	2,372

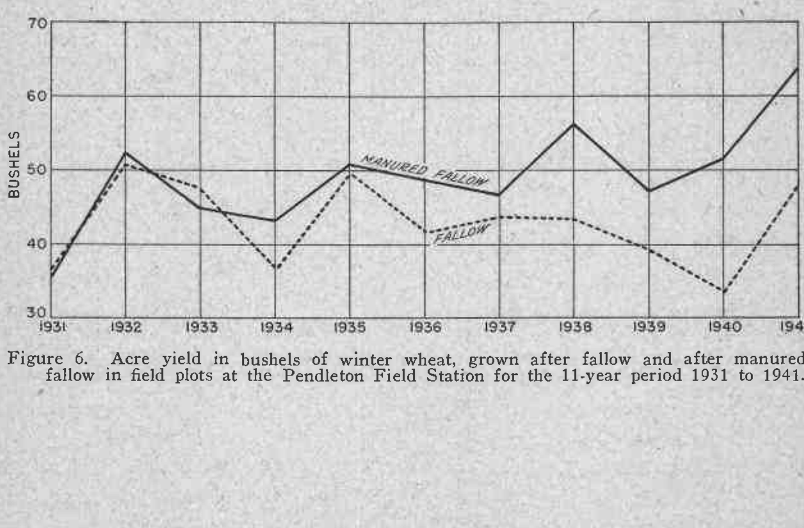

Figure 6. Acre yield in bushels of winter wheat, grown after fallow and after manured fallow in field plots at the Pendleton Field Station for the 11-year period 1931 to 1941.

WATER REQUIREMENT AND YIELD OF SPRING WHEAT WHEN GROWN IN POTS WITH LIMITED SOIL MOISTURE

No method for testing the adaptation of crop varieties has yet been devised that has proved to be a satisfactory substitute for replicated nursery or field plot trials. Carefully controlled pot experiments have furnished valuable information in regard to water and fertility requirements of plants, but such experiments have not been considered satisfactory for determining the reaction of different varieties of crop plants in the field.

In most of the experimental work to determine the difference in water used by or the water requirement of crop plants, sufficient quantities of water usually have been added to the soil to maintain normal plant growth. In actual field practice such a soil moisture condition rarely obtains. In dry land regions especially, there frequently are periods during the season when the soil moisture supply becomes so nearly depleted that the plants suffer from drought.

Pot trials were conducted at Moro in 1934 to 1937, inclusive, by growing a number of spring wheat varieties in pots with varying quantities of water furnished the plants during the growing season. In these trials the pots used were large ash cans of two sizes, one holding approximately 185 pounds of dry soil and the other 135 pounds. An equal quantity by weight of surface soil, which was thoroughly mixed, was placed in pots of similar size and each variety or method triplicated. Only three plants were grown in each pot. After the plants had emerged, about ½ inch of sand was added to each pot as a mulch to prevent excessive evaporation. The plants received the rainfall that occurred during the growing season.

Results in 1934. In 1934 Baart, Federation, and Pacific Bluestem spring wheats were grown in pots under moderate and severe drought conditions. One series of each variety was grown in soil with an initial moisture content of 16 per cent. Another series contained one plant of each of the varieties in each pot, with one replicate containing 16 per cent initial soil moisture, one 19 per cent and one 22 per cent. As is shown in Table 8, somewhat higher total and grain yields were obtained from the pots with highest initial soil moisture, especially when grown under moderate drought conditions. Under extreme drought, there was only a slight advantage in yield by having the soil moisture content higher than 16 per cent at the beginning.

By May 26, the plants in all pots were beginning to wilt and 10 pounds of water were added to each pot. By June 11, all plants were again showing severe drought injury. On June 17, half of the pots received an additional 10 pounds of water. Plump grain was produced by the plants receiving two waterings and badly shrunken seed by the plants watered only once.

Federation when grown alone was much superior in grain yield to either Baart or Pacific Bluestem. When one plant of each variety was grown in the same pot, Baart exceeded the other two varieties in total yield and equalled the grain yield of Federation when grown under conditions of extreme drought (one watering) and moderate drought (two waterings).

In another trial where Hope, Baart, and Marquis were grown under severe drought conditions, Baart exceeded the other two varieties in grain yield when one plant of each variety was grown in the same pot. When each variety was grown alone, both Hope and Marquis produced more grain than Baart.

Table 8. TOTAL CROP AND GRAIN YIELD OF FEDERATION, BAART, AND PACIFIC BLUESTEM SPRING WHEAT GROWN IN LARGE POTS AT MORO, OREGON, IN 1934.

	Federation		Baart		Pacific Bluestem	
	Total	Grain	Total	Grain	Total	Grain
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Grown alone						
Moderate drought*	35.3	9.0	35.9	6.7	39.3	6.2
Extreme drought*	34.6	5.6	31.8	2.2	30.9	3.0
Average	35.0	7.3	33.9	4.5	35.1	4.6
Grown together						
Moderate drought†	10.9	3.1	11.5	2.3	11.9	1.1
Moderate drought*	9.3	2.0	16.1	3.4	14.7	2.4
Moderate drought‡	16.3	5.1	13.9	4.4	14.1	1.7
Average	12.2	3.4	13.8	3.4	13.6	1.7
Extreme drought†	10.6	1.6	8.4	0.9	6.5	0.2
Extreme drought*	5.6	0.7	12.6	1.5	11.3	1.1
Extreme drought‡	10.1	1.4	10.4	1.1	10.6	0.5
Average	8.8	1.2	10.5	1.2	9.5	0.6
Average of both	10.5	2.3	12.2	2.3	11.6	1.2

* 19 per cent of moisture at beginning.
† 16 per cent of moisture at beginning.
‡ 22 per cent of moisture at beginning.

Results for 1935-1937. After the preliminary trials in 1934, Baart, Hope, and White Federation were grown in separate pots, one series unwatered and

Table 9. TOTAL CROP AND GRAIN YIELD AND WATER REQUIREMENT OF HOPE, BAART, AND WHITE FEDERATION SPRING WHEAT GROWN IN LARGE OPEN POTS UNDER EXTREME AND MODERATE DROUGHT CONDITIONS AT MORO, OREGON, FOR THE YEARS 1935 TO 1937, INCLUSIVE.

	Yield					
	Hope		Baart		White Federation	
	Total	Grain	Total	Grain	Total	Grain
	Grams	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*
Yield						
Extreme drought						
1935	23.7	3.3	23.5	3.5	27.1	5.7
1936	34.4	4.0	33.8	4.8	38.4	7.0
1937	39.4	5.7	38.1	7.7	40.2	13.5
Moderate drought						
1935	38.5	6.9	39.5	6.1	38.0	11.7
1936	49.7	10.6	51.3	9.1	58.4	23.4
1937	48.9	9.2	50.2	8.1	47.5	12.3
Average	39.1	6.6	39.4	6.5	41.6	12.3
Water requirement						
Extreme drought						
1935	369	2,653	366	2,458	320	1,523
1936	382	3,356	388	2,946	338	1,861
1937	423	2,923	440	2,176	418	1,245
Moderate drought						
1935	376	2,095	369	2,387	379	1,232
1936	419	2,033	407	2,406	355	885
1937	436	2,318	428	2,650	451	1,741
Average	401	2,563	400	2,504	377	1,415

one series watered when the soil moisture content was reduced to 6 per cent. Each spring, from 1935 to 1937, the pots were refilled with the same soil used in 1934. After thorough mixing, 6 pots were planted with each of the three varieties.

Table 9 gives the results obtained from 1935 to 1937, inclusive. The results for each of the 3 years, so far as the reaction of each variety was concerned, were consistent. The results for the 3 years are averaged and the water requirement is given for each of the three varieties. The average yields of Hope and Baart and the average water requirements were practically identical for both total crop and grain. White Federation only slightly exceeded the yields of Hope and Baart in total crop but it produced nearly twice as much grain as the other varieties. This difference in grain yield in favor of White Federation might have been due in part to its earlier maturity. In observing the reaction of the varieties while growing, however, it was noted that Baart usually showed drought injury before White Federation, despite the fact that the latter variety was a little ahead in plant growth. This conforms with the field results with these two varieties at Moro. At some other locations in the Columbia River Basin, especially at Lind, Washington, Baart has consistently outyielded White Federation.

DAILY USE OF WATER BY WHEAT

The daily rate at which water is used by spring wheat during its period of growth in the Great Plains under field conditions was studied by Cole and Mathews. (3) They concluded that where easily available water was present, the rate of use was rather constant from the time the plants began rapid growth until ripening and averaged 0.17 of an inch daily during this period.

Data on daily use of water by winter wheat are available both from field and pot trials at Moro. Two plots of winter wheat were sampled for moisture at approximately weekly intervals in the years 1923 to 1938, inclusive. The average date of the first sampling was March 29, and the average date of the latest sampling was July 7. The first sampling was made in the early spring when the soil contained about its maximum moisture content. At this time the winter wheat plants were usually in the three- or four-leaf stage. The last sampling was made when the crop was matured, just prior to or immediately following harvesting with the binder.

The soil was sampled to a depth of 6 feet, with four samples taken on each plot. The quantity of water used by the crop was computed from the difference in the moisture content of the soil between dates of sampling, based on 80 pounds as the weight of a cubic foot of soil, plus any rainfall that occurred. No attempt was made to determine the loss of water from evaporation after a rain. Very little, if any, of the moisture from light showers penetrated the soil to a sufficient depth to reach the zone of root growth, but as pointed out by Cole and Mathews, light showers may have about the same effect on the crop as the addition of an equal quantity of water to the soil because of reduction of transpiration as a result of the lower temperatures and increased humidity that usually follow rain. At any rate, the water loss by evaporation and run-off should be taken into consideration in determining the amount of water needed to grow a crop under field conditions. At Moro, the loss from run-off during the growing season usually is negligible.

In determining the daily moisture usage under the conditions prevailing at Moro, it must be kept in mind that the soil moisture never approached field capacity during the period that the crop was making its rapid growth. In most years there was a deficiency of soil moisture during the latter part of the growing season. In 8 of the 16 years, this deficiency in moisture was great enough

Table 10. AVERAGE DAILY USE OF WATER BY TURKEY WINTER WHEAT AT MORO, OREGON, FOR THE YEARS AND PERIODS INDICATED.

Average dates between samplings	Average daily use of water
	Inches
All years, 1923-1938—average yield 21.8 bushels	
3/29 to 4/10	.078
4/10 to 4/20	.080
4/20 to 4/29	.101
4/29 to 5/8	.148
5/8 to 5/15	.122
5/15 to 5/23	.142
5/23 to 5/31	.089
5/31 to 6/8	.056
6/8 to 6/15	.079
6/15 to 6/22	.066
6/22 to 6/29	.035
6/29 to 7/7	.041
Average	.086
Years when yields exceeded 19 bushels per acre—average yield 29.2 bushels	
4/2 to 4/14	.073
4/14 to 4/23	.080
4/23 to 5/2	.127
5/2 to 5/11	.152
5/11 to 5/19	.129
5/19 to 5/28	.190
5/28 to 6/4	.098
6/4 to 6/11	.056
6/11 to 6/18	.109
6/18 to 6/25	.098
6/25 to 7/3	.038
7/3 to 7/11	.047
Average	.100
Years when yield was less than 19 bushels per acre—average yield 14.4 bushels	
3/25 to 4/7	.072
4/7 to 4/19	.079
4/19 to 4/30	.076
4/30 to 5/8	.137
5/8 to 5/15	.120
5/15 to 5/23	.087
5/23 to 5/31	.084
5/31 to 6/8	.054
6/8 to 6/15	.048
6/15 to 6/22	.035
6/22 to 6/29	.033
6/29 to 7/6	.025
Average	.070
1927 and 1928—average yield 39.8 bushels per acre	
4/4 to 4/16	.052
4/16 to 4/25	.103
4/25 to 5/3	.178
5/3 to 5/10	.180
5/10 to 5/17	.158
5/17 to 5/25	.205
5/25 to 6/2	.106
6/2 to 6/9	.009
6/9 to 6/16	.091
6/16 to 6/23	.086
6/23 to 6/30	.057
6/30 to 7/8	.047
Average	.106

to result in rather severe drought injury and low yields. The quantity of water used, therefore, was doubtless less than it would have been had the soil been adequately supplied with moisture during the entire growing period.

In Table 10 is recorded the average daily use of water for winter wheat from early spring to harvest for the years 1923 to 1938, inclusive; also for the 8 years when yields exceeded 19 bushels per acre, for the 8 years when the yields were less than 19 bushels, and for the two highest producing years (1927 and 1928) when the average yield was 39.8 bushels per acre.

Curves showing the average cumulative use of moisture by winter wheat during its growing period in the field plots are shown in Figure 7. One curve shows the average for all years, 1923 to 1938 inclusive. The average grain yield for the period was 21.8 bushels. Another curve shows the cumulative use for the 8 years when the yields were more than 19 bushels per acre each year, with an average yield of 29.2 bushels. Another curve shows the cumulative water use for the 8 years when the yields averaged only 14.4 bushels per acre. The average date for the first and last samplings for the high and low producing years varied slightly from the average for all years as shown in Table 10,

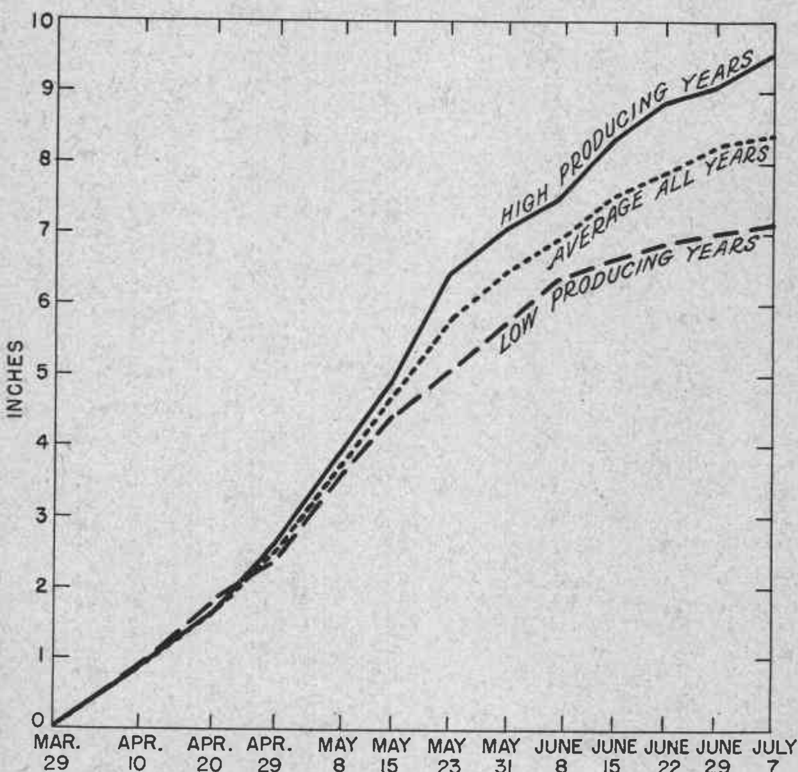

Figure 7. Average cumulative use of water in inches in soil growing winter wheat at Moro, Oregon, for the years 1923 to 1938, inclusive; for the 8 high producing years (average yield 29.2 bushels); and for the 8 low producing years (average yield 14.4 bushels).

but for purposes of comparison in the graph in Figure 4 these average dates are assumed to be identical.

It will be noted that the curves are of the same type for the high and low producing years and for the average for all years, although in the high producing years more water was used. These curves show that the wheat plants did not use moisture at so rapid a rate during the first 30-day period of their spring growth as they did later. The highest daily use occurred during the month of May. The average date when the wheat plants were fully headed was June 7. For the 2 weeks prior to ripening, there was a substantial decrease in the daily rate.

In Figure 8 is shown a curve for the average cumulative use of water in pounds daily in open pots for the years 1923 to 1938, inclusive, where water adequate in quantity was supplied to the soil during the growing season. The rainfall computed on the basis of the surface area of the pot was added to the weight of the water artificially applied. The average rainfall at Moro for the months of April to July, inclusive, for 1923 to 1938, inclusive, was only 2.13 inches.

The same general type of curve, similar to standard sigmoid curves for growth, was obtained when the plants were grown in open pots or sealed pots and in the field.

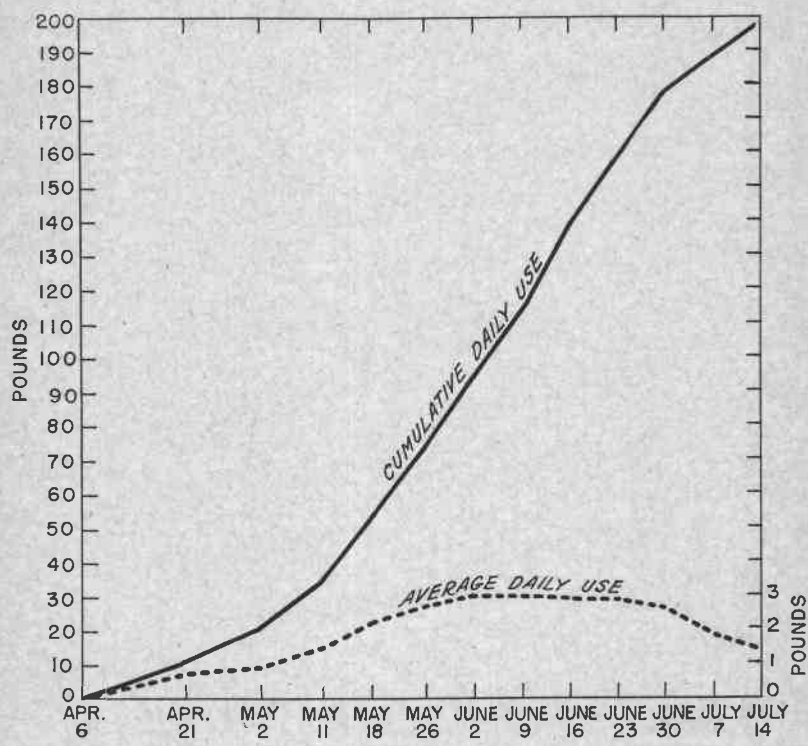

Figure 8. Average cumulative daily use and average daily use of water in pounds for Turkey winter wheat grown in uncovered pots at Moro, Oregon, for the years 1923 to 1938, inclusive.

EFFECT ON YIELD OF THE DISTRIBUTION OF WATER IN THE SOIL

The distribution, as well as the quantity, of water in the soil may markedly affect crop yields. An abundance of moisture in the upper two feet of the soil in the early spring may result in such a vigorous growth during the first part of the growing season that severe drought injury may occur later unless subsoil moisture is available or adequate water is supplied by rain. In Figure 9 is shown graphically the average moisture content on several dates during the growing season of the soil of two .1-acre plots growing Turkey winter wheat in 1927, a year when high yields were obtained, and in 1931 when low yields were obtained. The graphs show the moisture content for three 2-foot sections of soil for several dates during the growing season as well as the rainfall between sampling dates.

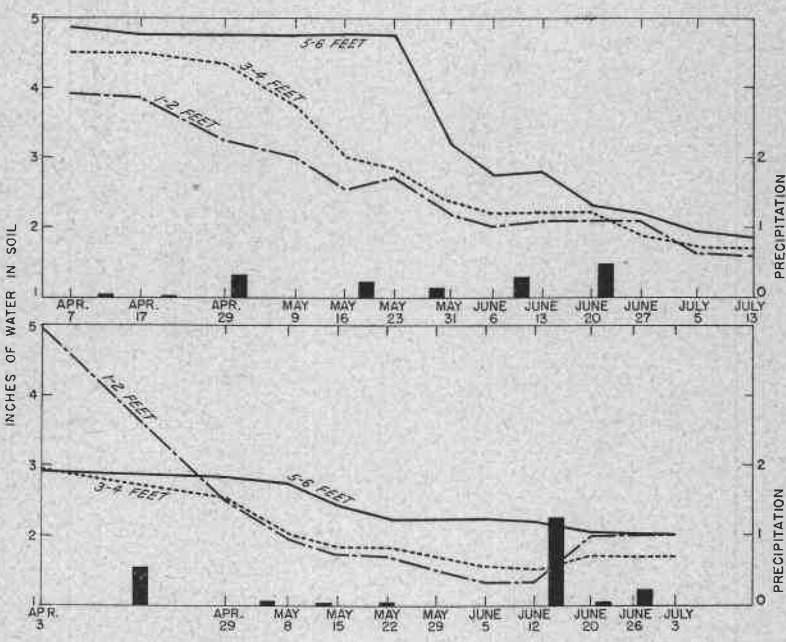

Figure 9. *Above:* Precipitation at Moro, Oregon, from April 7 to July 13, 1927, and inches of water by 2-foot sections in the soil of plots 181 and 183 on various dates in 1927, when the yield averaged 42.1 bushels of wheat per acre.
Below: Precipitation at Moro, Oregon, for April 3 to July 3, 1931, and inches of water by 2-foot sections in the soil of plots 181 and 183 on various dates in 1931 when the yield averaged 12.8 bushels of wheat per acre.

The soil of these two plots, on April 7, 1927, contained averages of 12.7 per cent moisture in the upper two feet, 14.6 per cent in the third and fourth feet, and 15.7 per cent in the fifth and sixth feet. During the early period of growth the wheat plants used the moisture most rapidly from the upper two feet. After the last of April the plants started to use an appreciable quantity of water from the third and fourth feet, but did not start to draw on the moisture in the fifth and sixth feet until after May 23, which was about the time the wheat plants started heading. The total rainfall between April 7 and July 3, when the wheat was ripe, was only 1.59 inches. The largest amount in any weekly period was .5 inch, which occurred between June 20 and 27, about 2 weeks before harvest. As indicated by the soil moisture data, the water absorbed by the soil from this rain was utilized by the crop, which had not suffered from drought. The average yield from the two plots was 42.1 bushels per acre. Assuming that the plants used no water below the sixth foot, each inch of available water (difference in soil moisture between April 7 and July 13 plus rainfall) produced 5 bushels of wheat.

In the year 1931, the average moisture content of the soil of these two plots in the early spring was 16.2 per cent in the upper two feet, 3.5 per cent higher than in 1927. Below the second foot, however, the moisture content was only about 10 per cent, as compared with about 15 per cent in 1927. The wheat plants rapidly exhausted the moisture in the first two feet so that by April 29 the moisture content of the first and second and the third and fourth feet was only slightly above 8 per cent. The wheat began to suffer from drought early in May. The drought injury continued for the rest of the growing season, the plants were short, and many heads were not fully exserted from the boot. Between June 20 and 27, there were 1.28 inches of rainfall, but as suggested by the soil moisture determinations little, if any, of the moisture was taken up by the wheat plants, probably because the plants had reached a sufficiently advanced stage of maturity or had suffered so much from drought injury that new roots were not formed as is usually true following rains even after heading. The older roots in the surface soil apparently were unable to function. In 1927, the high producing year, the ½ inch of rain that occurred about 2 weeks prior to the harvest date was used by the crop. In 1931, the 1.28 inches of rain, which also occurred about 2 weeks prior to harvest, was not utilized by and was of little or no benefit to the crop. The average yield from the two plots in 1931 was only 12.8 bushels per acre or 1.72 bushels of wheat for each inch of water used as contrasted to 5 bushels per inch of water in the more favorable season of 1927.

The difference in the yields obtained from these plots in 1927 and in 1931 strikingly emphasizes the importance of subsoil moisture in influencing wheat yields on the dry lands of the Columbia River Basin. In this area there is usually insufficient rainfall during the latter part of the growing season to meet the needs of the growing plants, and if subsoil moisture is not available during this period, drought injury and consequent low yields almost invariably result.

DISCUSSION AND SUMMARY

The results from the water requirement experiments reported in this bulletin for winter and for spring wheat grown in pots are in general agreement with the more extensive experiments conducted by Briggs and Shantz (1) and Shantz and Piemeisel at Akron, Colorado (4); by Dillman at Mandan, North Dakota (5); Kiesselbach in Nebraska (6); and by Richardson in Australia (7). The experiments at Moro extended over a period of several years, thus giving opportunity to acquire information about the differences in water requirement caused by seasonal climatic variations. For the 7-year period, 1922 to 1928, the water requirement for Turkey winter wheat grown in sealed pots ranged from a low of 283 in 1927 to a high of 504 in 1922, the average for the 7-year period being 379. In the 7 years the average water requirement for the same winter wheat variety in open pots was 511 or 34.5 per cent greater than when grown in sealed pots. The water requirement in open pots was reduced about 10 per cent by a light (about ½ inch) sand mulch.

There was a rather close agreement in the water requirement, based on grain produced, of wheat grown in pots and in the field, except in drought years, when the water requirement of the wheat grown in the field was much higher. Based on total water used (quantity in the soil in the early spring plus rainfall during the growing season) the number of bushels of wheat produced for each inch of water used ranged from 1.5 to 4.4 bushels with an average of 2.7 bushels for a 16-year period, under field conditions.

In a 4-year trial (1930 to 1935) with Federation spring wheat in open pots, the addition of a nitrate carrying fertilizer at the rate of 200 pounds per acre to soil cropped to wheat the previous year, increased the yield 72 per cent over soil receiving no fertilizer, and 26 per cent over soil fallowed the previous year. This indicates that with increased precipitation, nitrate carrying fertilizers would increase wheat yields on this soil. The value of summer fallow for nitrate accumulation is indicated by the differences in the average yield and water requirement of the wheat grown in the pots with fallow soil and with cropped soil. The average yield was 37 per cent greater for the fallowed soil, and the average water requirement was 27 per cent more for the wheat grown in soil that was cropped the year previously and given ample water during the growing season.

Results that appear to have significance in relation to future soil fertility problems on some of the Columbia River Basin wheat lands were obtained by growing winter wheat and spring wheat in soil alternately cropped and fallowed in large pots with the addition of (1) straw, (2) manure, and (3) with the straw burned. The higher yields obtained from the manured pots and similar results obtained from field plot experiments at the Pendleton Field Station would seem to indicate that in the higher rainfall sections of the Columbia River Basin there is already a soil fertility deficiency that likely will become more pronounced if these soils are continued in exclusive wheat production. The exhaustion of soil fertility in the relatively small volume of soil in the pots might be expected to occur more rapidly than under field conditions. In the pots it required five crops of wheat, with the soil alternately cropped and fallowed, to reduce significantly the yield from top soil where there was no loss of fertility from either erosion or percolation. Under field conditions the fertility loss from soil erosion might be large on sloping lands. In seasons with high fall and winter precipitation there also may be some leaching of nitrates from the soil following a season of fallow.

In the areas of lower rainfall, as at Moro, no increased yields of wheat after properly prepared fallow have been obtained from the field plots where barnyard manure or commercial fertilizers have been added. On early spring-plowed, weed-free fallow sufficient nitrification usually occurs to meet the needs of the quantity of plant growth that the moisture will support. Nitrogenous fertilizer on such land generally stimulates early vegetative growth to such an extent that seed production is reduced because of lack of moisture to carry the crop through to maturity.

There is ample evidence of nitrogen and organic matter depletion in dry farm soils (8) (9) (10) (11) (12), but under extremely dry conditions soil fertility depletion may not become a serious problem for a long time if the soil is protected from erosion. In localities with enough precipitation to produce high yields, the supply of nitrogen and organic matter will have to be replenished in some manner if the yields are to be maintained. Of the various soil amendments tried, barnyard manure has proved most satisfactory for maintaining yields on the high producing wheat lands but on the large mechanized wheat farms this soil amendment is not available. The results from both pot and field plot trials show that utilization of the straw, which is needed for reducing soil and water losses, will not prove adequate in maintaining soil fertility. The higher yields from adding small quantities of a nitrogenous commercial fertilizer with the straw suggest the advantage of this practice as at least being better than the destruction of all organic residues. The plowing under of legumes or growing of grass-legume mixtures in crop rotations with wheat are of course alternatives that may prove more satisfactory and economical in maintaining the soil's supply of nitrogen and organic matter, but their practical possibilities have not yet been fully determined.

Whether crop plants grown in soil with limited soil moisture will react in the same manner as when grown with ample soil moisture has not been definitely established. Because of the difficulty in pot experiments of keeping the total mass of soil at anywhere near a uniform moisture content while the crop is growing, it has been assumed that the pot method for testing plants for resistance to soil drought is not feasible. Under field conditions the soil moisture fluctuates constantly, however, depending upon the quantity removed by the crop and that added by precipitation. Judging by the results from limited trials with spring wheat varieties when grown in pots with varying quantities of water supplied to the soil, much information might be acquired from such pot trials about the ability of crop varieties to produce when subjected to soil drought. In these trials, Hope, Marquis, Federation, White Federation, and Baart were grown under conditions of moderate and extreme soil drought. The trials showed that when plants of several varieties were grown in the same pot, the plant response was not the same as when each variety was grown alone. Baart wheat proved to be a superior variety when grown in competition with other varieties in the same pot, but this superiority of Baart was not evident when the varieties were grown in separate pots. Why Baart possessed this competitive superiority was not determined. White Federation produced much more grain than Baart when grown under conditions of either moderate or extreme soil drought. The results of these trials are recorded in Tables 8 and 9.

The rate at which the wheat plant uses moisture during its growth was determined from both field and pot trials. From weekly samplings to a depth of 6 feet of soil growing winter wheat it was found that the quantity of water taken from the soil each week increased gradually as the crop started rapid growth, remained about constant for the period preceding and immediately following heading, and then gradually declined as the plants approached maturity. On the average winter wheat used about .1 of an inch of water daily from the time it started rapid growth until it began to ripen. More than .1 inch daily probably would be used if the soil moisture content was high enough so that the water would be easily available. One-tenth inch of water daily, however, would seem to be about an adequate supply to prevent serious drought injury except during periods with excessively high temperatures, when the transpiration rate would be abnormally high. From this information, it can be readily determined at any time during the growing season when drought injury will begin unless water is supplied by rain. Curves showing the cumulative daily use of water by winter wheat when grown in the field and in uncovered pots are shown in Figures 7 and 8.

The distribution of water in the soil, as well as the total quantity available, may markedly influence wheat yields. A given quantity of water about equally distributed through 6 feet of soil is more desirable than an equal quantity distributed through only the surface 2 or 3 feet. The moisture in the lower depths under conditions usually prevailing at Moro is needed to supply the wheat plants with water during the latter part of the growing season when rainfall normally is not nearly enough to supply the needs of the growing crop. A high moisture content of the surface soil often induces early vigorous vegetative growth and consequent drought injury later if ample moisture is not available. Figure 9 shows the soil moisture content at intervals during a season when winter wheat yields were more than 40 bushels per acre. Figure 9 also shows the periodic moisture content of soil of the same plots in a typical drought year when the yield was less than 15 bushels per acre.

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