MOISTURE STORAGE AND USE BY DRYLAND WINTER WHEAT CROPPING SYSTEMS

By

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Moisture in Cropping Systems

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ABSTRACT

Water storage and use of soil continuously cropped to winter wheat, soil alternately cropped to winter wheat and fallowed, and soil alternately cropped to winter wheat and planted to watermelons, were compared in a dryland experiment during the 1962-1963 period, beginning with the time of seeding.

From seeding of the 1962 crop to seeding of the 1963 crop the annually cropped soil and wheat-after-watermelon soil stored 2.34 centimeters or 4.10 percent of the annual precipitation and 0.52 centimeters or 0.91 percent; and used 54.70 centimeters or 95.90 percent and 56.52 centimeters or 101.58 percent, respectively. There was a water loss from wheat-after-fallow land and water use was 58.12 centimeters or 101.58 percent. The watermelon and fallow phases of the two alternate cropping systems stored 6.67 centimeters of water or 11.69 percent and 9.58 centimeters or 16.79 percent; and used 50.37 centimeters or 88.31 percent and 47.46 centimeters or 83.20 percent, respectively.

The initial moisture content of the soil at the beginning of each period was found to be negatively correlated with the amount of subsequent water storage and with percent of the precipitation stored, and positively correlated with the amount of subsequent water use. Precipitation during each period was found to be negatively correlated with the percent of the precipitation used during the period.

The data obtained for grain and straw yield for each cropping system indicated that satisfactory yields are obtainable from growing wheat continuously as compared with growing it in alternate years with fallow or fallow-watermelon during a season of high precipitation.

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INTRODUCTION

Previously, areas receiving less than twenty inches of rainfall per year were generally regarded to be unfit for crop production, except where artificially watered at great costs. Now the practice of crop growing in semi-arid regions, those receiving between ten and twenty inches of rainfall per year, has developed, until at present much of the previously considered drylands in many countries is being successfully utilized as a result of application of intelligent dry farming practices to meet the ever increasing need for more food in the world.

Dry farming started when Chinese on the drylands of Western China and the American Indians in the arid States and in parts of Mexico grew crops under very dry conditions. Crops were also produced in the dry parts of Northern Africa without irrigation. The ancient civilization of the Orient, the Euphrates Valley, Palestine, and Egypt developed in dry climates (5).

The unfavorable climatic conditions are among the chief causes of poor crops. Farmers try to avoid the undesirable features of the climate by choosing more suitable crops and adapting rotation and management practices to the climate. In much of the Beqa'a plain, one of the more important problems confronting the dryland wheat farmer is maximum utilization of the erratic and variable rainfall that occurs mostly during the winter months. Cropping sequence, in addition to tillage and other management practices, can materially affect moisture utilization and crop yield. Continuous cropping has proved to be impractical in the driest sections of the plain, so alternate cropping of wheat and fallow has become the standard practice for wheat production for many years. Many farmers plant watermelons on the fallowed ground in order to obtain a cash return from the land.

Due to severe wind erosion and high evaporation rates, with subsequent low moisture storage during much of the fallow period, fallowing, in many instances, has failed to serve its primary purpose as a moisture conserving practice.

As a part of a larger dryland research program at the Agricultural Research and Education Center, located in North Central Beqa'a in Lebanon, winter wheat is grown in three cropping systems presently practiced in the Beqa'a plain. These cropping systems are: continuous cropping of wheat; alternate cropping of wheat and fallow; and alternate cropping of wheat and watermelons. This study was conducted during the 1962-1963 period at the Center in order to compare the moisture storage and use of the three cropping systems and to investigate if there is yield and quality advantage for wheat grown under any of these systems to justify its use under the conditions of the experiment.

It is hoped that this study will provide a basis for further experimentation in this area because of the great need for knowledge of moisture conservation practices which are essential for a continuing agricultural economy in the Beqa'a plain.

REVIEW OF LITERATURE

Total water storage during the fallow period has been reported by Thysell (48), Zook and Weakley (53), Staple and Lehane (47), and Kuska and Mathews (30). All of these workers found that total moisture storage between harvest of one crop and seeding of the next crop was only a small portion of the precipitation. Mathews and Army (34) summarized and analyzed moisture storage data during the fallow period of an annually cropped and alternately cropped-fallowed wheatland for over 450 crop-fallow periods. They showed that on the average 2.02 inches of water or 16.1 percent of the precipitation was stored during the fallow portion of an annual cropping system. Under an alternate crop-fallow system, an average of 3.96 inches or 23.6 percent of the precipitation was stored between the harvest of one crop and the seeding of the next. The amount of moisture stored during the fallow period was found to be related to soil moisture content at the beginning of the fallow period, and the amount of precipitation during the fallow period. Morgan (36) from his experiments on fallow found that only 1.77 to 4.25 inches of water or 10.1 to 22.8 percent of the total precipitation was stored in the surface three feet of soil during the fallowing period from harvest until the following seeding. Summarizing soil moisture data collected at Mandan, North Dakota from 1915 to 1954, revealed that during an entire fallow period (about 21 months) only 4.36 inches of a possible 22.73 inches were stored (17).

Storage at different portions of the fallow cycle have been reported by Thysell (48) and Staple and Lehane (47) for spring wheat. Their results indicated that the greater part of the storage took place during the first fall and winter when the land was in stubble, a lesser amount from the following spring until fall, and still less during the second winter when the land was bare. Kuska and Mathews (30) found very little gain in moisture during the summer months of a fallow period. Haas and Willis (17) brought out that for soil annually cropped to spring wheat and alternately cropped and fallowed, water storage was similar for both systems from harvest to June 1 of the first year. Eighty-four percent of the water stored during an entire fallow period had accumulated by July 1. Conservation of water over the second winter of fallow averaged only 0.02 inches. For the same period of time, the annually cropped soil conserved 1.67 inches.

The quantity of water used by wheat has been reported by several investigators (11, 13, 33, 47, 48). Haas and Willis (17) found that 15.67 inches of water was used in the annual cropping system. Hopkins (23) reported the following transpiration ratios* for wheat grown under the two different

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* Transpiration ratio is defined as the number of pounds of water required to produce each pound of dry matter exclusive of roots.

systems:

	Wheat after fallow	Wheat after wheat
Whole plant	489	746
Grain	1,275	2,082

Richardson (41) reported an average transpiration ratio of 380 for the wheat plant, while the ratio for grain was reported to vary from 660 to 1,188. The transpiration ratio for wheat did not vary greatly with soil saturation of from 30 to 90 percent of the water-holding capacity, but on the whole the water requirement for dry matter was greater in moist than in dry soil and was lowest for soils maintained at moderate degrees of soil saturation. The water requirement for grain, however, consistantly and markedly increased as the degree of soil saturation increased.

Depth of soil from which wheat plant can remove moisture has been studied by a number of workers. Karraker and Bortner (26) report that wheat plants obtain water chiefly from the top two to three feet of the soil and do not root effectively below these depths. Cole and Mathews (10) brought out that below a depth of three feet the extent to which wheat could remove water was affected by increasingly sparse root development that differed with different soils. The quantity of water between field capacity and the minimum point for wheat decreased from surface downward, due to a slight reduction in the field capacity and an increase in the quantity of water that wheat could not remove. Haise _et al_. (18) found that wheat plants could absorb moisture at tensions which exceeded 26 atmospheres at depths where roots were well disseminated. Soil moisture below the 3- or 4-foot depth remained at less than a tension of 15 atmospheres, due to limited root growth at these depths. Dunham (14) and Furr and Reeve (16) reported that growth continued in wheat even after soil moisture levels at all depths sampled had been reduced below the wilting coefficient.

Effect of tillage practices and time of starting cultural operations has been reported by many workers. Kuska and Mathews (30) reported that land plowed immediately after harvest, and that remaining in stubble until plowed in the spring, were almost identical in total water storage, but differed in storage during the receptive portion of the fallow cycle. Wiese and Army (50) did not find any significant effect of the three different weed control methods, namely, disk, subsurface tillage, and chemical weed control, on total moisture and moisture distribution in the top four feet of the soil profile. All methods of fallow were highly inefficient in storing the precipitation. Call and Hallsted (8) showed that late-fall-plowed ground contained 2.7 percent of available moisture at seeding time, early-fall-plowed ground 4.2 percent and summer-fallowed ground 8 percent. Kuska (29) found that the best method of fallow was plowing in May, before vegetation had grown enough to reduce materially the water content of the soil, and cultivating enough to keep the ground clean during the rest of the season. Several studies show that moisture storage has not been influenced by the type of implement used, provided that satisfactory weed control was attained (6, 22, 50).

The relationship between annual precipitation and soil moisture, and wheat yield and quality has been studied to a large extent by many workers. Hallsted and Coles (19) and Harrs and Maughan (21) reported that planting wheat in soils containing less than 20 percent moisture at the time of seeding may result in crop failure. With about 15 percent of soil moisture the crop practically depends on rainfall after seeding. The depth to which a given soil is wet at seeding time bears a very close relationship to the yields obtained. Sandy soils must be wet deeper than heavier soils to carry the same amount of water (20). It is possible to estimate with an appreciable degree of certainty the probable yield of wheat by means of meteorological observations made during the winter or the period from April to August, inclusive (25). Barkley (4) found an 80 percent correlation between August-September rainfall and final yield of wheat. Lees (32) concluded that every inch of rain stored by fallowing is capable of producing 3.5 bushels of wheat. A decrease of one inch in annual precipitation, it was found, meant fewer good crops, more failures, and more important, a material increase in the number of times consecutive years of failure might be expected (35). On the basis of long time weather records, Army _et al_. (1) brought out that alternate wheat-fallow can be expected to produce more than 10 bushels of wheat per acre approximately 80 percent of the time, whereas continuous cropping can be expected to produce more than 10 bushels of grain only 50 percent of the time. Owing to soil moisture differences, Ramon Fernandez and Laird (40) found an increase in grain yield of 85 percent and straw yield of 187 percent in heavily fertilized wheat. Wheat grown on fallow produced higher yields and grain contained a higher percentage of protein than wheat grown on land cropped continuously. Fallowed land contained more moisture and nitrate nitrogen (7). Ladd (31) found a higher protein content in wheat grown in dry regions than that from a region of higher rainfall. Neidig and Snyder (37) obtained higher yields of wheat with a low protein content under high moisture conditions. They also obtained higher yield in soil cropped continuously to wheat in a season of abundant rainfall than in dry season, especially when rains were lacking during the fruiting and ripening period. Some authors have found a depression in wheat yields in years with too much rainfall. Sando (45) and Weltoh (49) reached the conclusion that a decrease in rainfall is accompanied by an increase in yield of wheat, subnormal rainfall is more beneficial in autumn and early spring than in the winter or late spring. Fisher (15) studied the effect of excess rain on yield under Rothamsted conditions and concluded that the harmful effect of additional rainfall is in removing nitrates from the soil. Rain in October was found to be beneficial. This is the reverse of the condition found by Sando (45) and Weltoh (49). Pallesen and Laude (38) indicated that rainfall is of greatest advantage to winter wheat before and during the period before planting to the time wheat enters the winter semi-dormant stage. The beneficial effect of each inch of rainfall during October and November was over three bushels per acre on fallowed land and slightly less than three bushels on continuously cropped land.

Critical periods for wheat as regards moisture supply have been investigated by a number of research workers. Azzi (3) found that the highest requirement for water was during the 15 days period prior to spike formation. In another article (2),he reported the two ten-day periods immediately preceding heading to be most critical. Kezer (27), Robertson _et al_. (42) and Robins and Domingo (44) concluded that the heading stage is the most critical for wheat as regards moisture supply. Reduction in yields of up to 30 percent was observed when severe moisture stress occurred during the heading stage. Plant height was also depressed by moisture stress prior and during heading (44). Pallesen and Laude (38) did not find any beneficial effect of above-average rainfall during the period of rapid stem growth and heading. Kezer and Robertson (28) studied the critical period of applying irrigation water to wheat and concluded that water applied at the jointing stage increased the yield of straw and grain but not the grain quality. Water applied at heading resulted in slightly lower yields than when applied at jointing, however, the quality of grain was materially improved. Early irrigation at germination and tillering increased the straw yield more than the grain yield but produced grain of poor quality. Kezer (27) reported that best quality of wheat and best quality of protein can be produced with irrigation at the heading and blossoming stage.

No mention has been made in any of the available literature with regard to using watermelons in rotation with winter wheat.

MATERIALS AND METHODS

This study was conducted during the 1962-63 period at the Agricultural Research and Education Center of the American University of Beirut situated 80 kilometers East of Beirut in the Beqa'a, Lebanon. The area has the typical climate of semi-arid regions. An average annual precipitation of 37.6 centimeters, mainly distributed during the winter months, was recorded at the Center during the eight-year period, 1955 to 1963. The mean annual temperature ranges from about $-5^{o}C$ in January to about $37^{o}C$ in August. The average snowfall is about 30 centimeters. Ordinarily the snow cover disappears in March. Early in the growing season the soil is usually saturated, but with the beginning of rapid vegetative growth, reduction in the amount of precipitation, increase in air temperature and prevalance of hot dry winds, evaporation exceeds precipitation and the soil becomes dry to the depth of significant root penetration, which in this study did not exceed 60 centimeters.

The soil is briefly described as a calcareous clay loam with a pH of around 8.0. The surface 60 centimeters of the soil contains about 25 centimeters of water at field capacity, as determined in the field by the method described by Piper (39) and about 12 centimeters at the permanent wilting point, as determined in greenhouse using sunflower seedlings (39).

Five plots, each with a size of 5 x 27 meters, were established in each of the four replications of a randomized complete block experiment in the year 1961 as a part of a larger dryland research program at the Center. One plot was continously cropped to winter wheat, two plots were alternately cropped and fallowed, and two plots were alternately cropped and fallowed with watermelons present during the last portion of the fallow period. All phases of the rotation were to occur every year.

Soil moisture studies were started from November 6, 1962, when the winter wheat was planted for the second year of the rotation. All plots were moldboard plowed and disk harrowed for the seedbed preparation. An application of four kilograms of nitrogen per dunum in the form of ammonium sulfonitrate and of four kilograms of P_2O_5 per dunum in the form of superphosphate was made prior to planting. The plots were seeded with a tractor driven grain drill at the rate of eight kilograms of seed per dunum. Florence aurore, a winter wheat variety commonly grown in the area, was used.

Soil samples were collected from all of the plots during the growing season and during the fallow period. Two locations per plot were sampled by 15 centimeters increments to a depth of 60 centimeters by means of a post-hole soil auger. A total of 19 samplings were made from November 6, 1962 to November 9, 1963. Soil samples were oven dried at 110°C and the percent of water in the soil was calculated. Conversion of percent moisture by weight to centimeters per volume was based on the average bulk density value which was determined by sampling the experimental area using a Uhland sampler.

During the course of this study weeds were controlled satisfactorily by spraying the plots once on March 14, 1963 with 2,4-D at the rate of 2 pounds per acre and cultivating several times whenever needed.

Watermelons were planted on the appropriate plots on May 31, 1963 in rows that were one meter in width. Distance between plants in the row was two meters. Only one melon was allowed to grow per plant through thinning of the flowers. Melons were harvested on October 16, 1963 from each plot and the weights were expressed in kilograms per dunum (1000 square meters).

Five square meters were harvested from each plot of wheat on June 26, 1963 by means of hand sickles. Weight of total plant, grain and straw were all expressed in kilograms per dunum. Percent nitrogen in the grain harvested from each plot was determined by the Modified Kjeldal Method (24) and the values were multiplied by 5.70 to obtain the corresponding protein percentages. Weight of 1000 kernels of wheat harvested from each plot was determined and the values were expressed in grams.

Wheat plots were plowed on July 9, 1963. All the plots were plowed, disk harrowed and fertilized by November 9, when the wheat was planted for the following year.

The period between seeding and harvesting of wheat, which was 33 weeks, was divided into five intervals and that between seeding and harvesting of watermelons, which was 15 weeks, into two intervals in order to investigate the critical periods for the two crops as regards the moisture use.

Water conserved or stored during any of the periods was calculated by subtracting the water content of the soil at the beginning of the period from the water content of the soil at the end of the period. The values were expressed either as a gain (+) or as a loss (-). Subsequent computations included the percent storage efficiency* for those periods in which water was stored.

The term water use generally refers to that moisture removed from the soil upon which a crop is growing. In this study, the term "water use" refers not only to the water used by crop, but also to that lost by run-off, evaporation, or seepage during both the crop and fallowed periods. Water use was computed by adding the soil water at the beginning of the period to the amount of precipitation during the period and subtracting the soil water at the end of the period. Water use per day was also calculated for each period for the three cropping systems.

All of the data were analyzed statistically by the analysis of variance technique (9). Through the correlation

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$$\text{* Storage efficiency} = \frac{\text{cms. of water stored}}{\text{cms. of precipitation received}} \times 100$$

technique, moisture storage and use were evaluated in terms of total quantity of precipitation during each period and moisture supply at the beginning of each period.

RESULTS AND DISCUSSION

Cropping Systems and Response of Wheat Characteristics

The grain and straw yields, protein content, weight of 1000 kernels and plant height at harvest obtained from the wheat grown on the three cropping systems used are shown in Table 1. It will be noted that the cropping systems had little, if any, effect on the characteristics that were studied. The failure of the wheat-watermelons and wheat-fallow systems of cropping in showing any advantage over the continuous cropping system can be attributed to the occurance of an above average rainfall during the course of this experiment. In fact, about 19 centimeters of extra rain were received as compared with the average annual precipitation during the 8-year period, 1955-1963. The grain and straw yields were generally lower in all of the systems than the results obtained for the same variety of wheat grown at the Center during the years with average rainfall (52). This indicates that excess rainfall appeared to be harmful with regard to the wheat yield. This condition has also been reported by Sandoh (45) and Weltoh (49) who reached the conclusion that a decrease in rainfall is accompanied by an increase in yield of wheat. The harmful effect of additional rainfall may be the result of leaching of nitrates from the soil, a condition

Table 1 - Grain and straw yield, protein content, 1000 kernel weight and plant height at harvest of wheat grown under three cropping systems.

Cropping system	Grain + straw kgs./du.*	Grain kgs. /du.*	Straw kgs. /du.*	Protein content of grain %*	1000 kernel weight gms.*	Pl.Ht. at harvest cms.*
Continuous wheat	275	82	193	9.36	36.82	84
Wheat-watermelon	265	96	169	9.38	39.54	93
Wheat-fallow	215	77	138	9.01	37.39	86

* Differences not statistically significant at P = 0.05.

which was reported by Fisher (15).

In order to compare the three cropping systems with regard to the wheat yields, the values obtained for the grain and straw yields of wheat grown under the two alternate cropping systems should be divided by two, as these systems produce a wheat crop once in two years. On this basis, for the 1962-63 season, the two alternate cropping systems fall far beyond comparison with the continuous cropping system as regards the grain and straw yields. Although the wheat-watermelons system produces a crop of watermelons (an average of 176 kilograms per dunum in this experiment), the yield is not high enough to be compared with the wheat yield that could have been obtained from the fallowed land.

The data indicate that fallowing was of no benefit under the conditions that prevailed during the course of this experiment. This appears to be reasonable as the practice of fallowing is generally recommended in areas that receive less than 15 inches of annual precipitation to insure against crop failure. Higher yields of wheat have been obtained from continuous cropping systems than alternate cropping systems in seasons of abundant rainfall than in dry seasons (37). However, the amount of moisture stored by fallow may determine the success of a wheat crop in a dry season that may follow.

Water Storage and Cropping Systems

Water storage as well as its use in the plots that were planted to wheat and by those that were fallowed or planted to watermelons have been considered separately because they are not comparable in all aspects.

Averages for centimeters of water stored, centimeters of precipitation received and percent of precipitation stored in the different subperiods from November 6, 1962 to November 9, 1963, for the three cropping systems, are presented in Table 2. The maximum amount of storage took place early during the growing season, namely, during the November 6 to December 27 period. The three systems stored most of the 16.41 centimeters of the precipitation that was received during the period. More water was stored by the continuous cropping system (81.90 percent) than the wheat-watermelons (64.53 percent) and the wheat-fallow (50.76 percent) systems. This is attributed to the fact that the continuously cropped plots started with a lower moisture content (8.74 centimeters) than the wheat-watermelons (11.06 centimeters) and wheat-fallow (12.72 centimeters) plots at the time of seeding. It has long

Table 2 - Centimeters of precipitation received, average centimeters of water stored and percent of precipitation stored by three cropping systems during different sub-periods of a 1-year period.

Period	Water storage - cms.*			Precipitation cms.	% of precipitation stored*		
	Contin. wheat	Wheat-watermelons	Wheat-fallow		Contin. wheat	Wheat-watermelons	Wheat-fallow
Nov. 6 - Dec.27	+13.44	+10.59	+8.33	16.41	81.90	64.53	50.76
Dec.27 - Feb. 8	-2.26	+0.34	+1.21	12.57	-	2.70	9.63
Feb. 8 - Mar.29	+1.50	-3.33	-4.43	14.20	10.56	-	-
Mar.29 - May 5	-5.38	-2.11	-0.51	6.53	-	-	-
May 5 - June 26	-4.71	-6.53	-6.79	0.96	-	-	-
Total Seeding-harvest (Nov. 6-June 26)	+2.59	-1.04	-2.19	50.67	5.11	-	-
June 26 - Oct.16	-2.52	-1.71	-1.86	0.00	-	-	-
Oct. 16 - Nov. 9	+2.27	+3.27	+2.97	6.37	35.64	51.33	46.62
Total Harvest-seeding (June 26 - Nov.9)	-0.25	+1.56	+1.11	6.37	-	27.63	17.42
Total Seeding-seeding Nov. 6, '62 - Nov. 9, '63	+2.34	+0.52	-1.08	57.04	4.10	0.91	-

* Means joined by the same line do not differ significantly from each other at $P = 0.05$.

been observed that a soil containing considerable water absorbs additional water much more slowly than does land with a low moisture content. This phenomenon will be clarified later in the discussion of other results. From December 27 to June 26, the period of growth and maturity of the wheat plants, water was lost continuously from the soil. The (-) signs indicate that there was an actual loss of water from the soil in addition to the precipitation that was received during the period. From seeding to harvest, 2.59 centimeters or 5.11 percent of the total of 50.67 centimeters of the precipitation that was received were stored in the continuously cropped land. There was a water loss from the wheat-watermelons and wheat-fallow plots with more loss from the wheat-fallow soil. The loss is due to the higher moisture levels of these plots at the time of seeding. From harvest to seeding, 6.37 centimeters of rain were received. During this period the plots were most of the time in stubble until plowed before seeding of the next crop. There was a water loss from the continuously cropped plots, while the wheat-watermelon and wheat-fallow plots each stored 27.63 percent and 17.42 percent, respectively, of the total summer precipitation. From November 6, 1962 to November 9, 1963 (seeding to seeding), storage was higher for the continuously cropped plots, being 2.34 centimeters or 4.10 percent of the annual precipitation, as compared to 0.52 centimeters or only 0.91 percent of the precipitation in the wheat-watermelons and -1.08 centimeters (water loss) in the wheat-fallow plots.

The average cumulative storage curves with cumulative precipitation are shown for the three cropping systems in Figure 1. The curves show that the relative amount of storage of water was always higher in the continuously cropped plots and lowest in the wheat-fallow plots. They also reveal that the major storage took place early during the growing season, November to January, and from then on water was lost continuously from all of the plots as presented by the steady drop in the storage curves. There was a little gain in soil moisture because of the 6.37 centimeters of rain that were received after October 19, 1963. This gain is manifested by the slight rise in the curves. The precipitation curve shows that most of the rainfall was received from November 6 to March 29 and there was no rain after May 11 until October 19. The great differences between the level of the precipitation curve and storage curves indicate the magnitude of water that was lost from the soil during the course of this experiment.

Table 3 shows the centimeters of water stored, centimeters of precipitation received and average percent of precipitation stored for the watermelons and fallow plots. From November 6 to May 31, when the watermelons were planted, both systems were fallowed, consequently the amount of storage was almost the same, being only slightly higher for the watermelon than for the fallow plots because of the lower initial

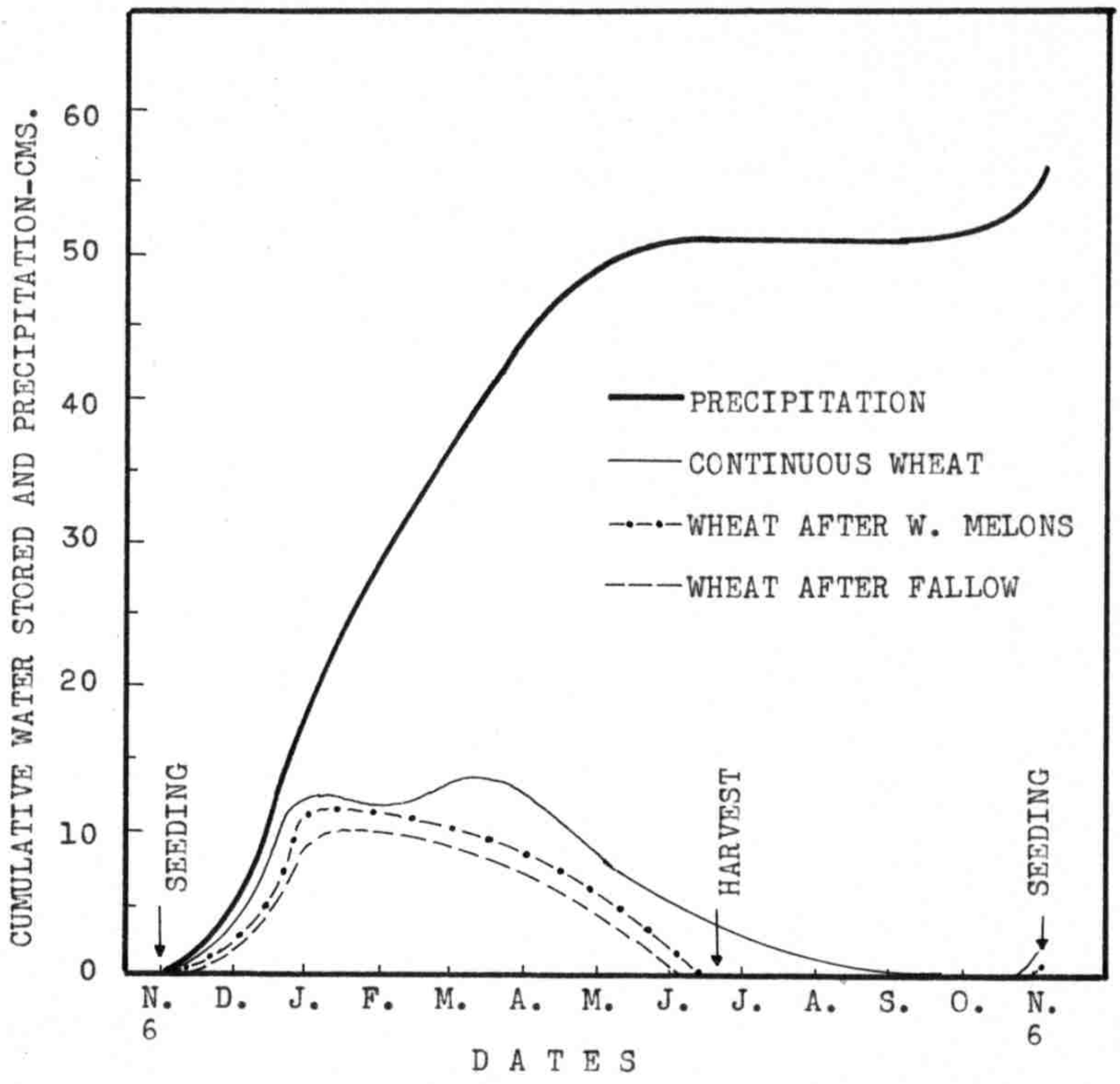

Figure 1— Cumulative precipitation and average soil water stored by three cropping systems during a one-year period, November 6, 1962-November 9, 1963.

Table 3 - Centimeters of precipitation received, average centimeters of water stored and percent of precipitation stored by watermelon and fallow plots during different sub-periods of a 1-year period.

Period	Water storage-cms.*		Precipitation	% of precipitation stored*	
	Watermelons	Fallow	cms.	Watermelons	Fallow
Nov. 6 - Dec.27	+14.77	+14.73	16.41	90.00	89.76
Dec.27 - Feb. 8	-4.41	-2.55	12.57	-	-
Feb. 8 - Mar.29	+3.10	+1.53	14.20	21.83	10.77
Mar.29 - May 5	+0.78	+0.67	6.53	11.94	10.26
May 5 - May 31	-3.31	-2.90	0.96	-	-
Total Nov. 6 - May 31	+10.93	+11.48	50.67	21.57	22.66
May 31 - June 26	-0.29	-0.20	0.00	-	-
Total Nov. 6 - June 26	+10.64	+11.28	50.67	20.99	22.26
June 26 - Aug. 27	-5.13	-3.63	0.00	-	-
Aug. 27 - Oct. 16	-5.02	-3.63	0.00	-	-
Total May 31 - Oct. 16	-10.44	-7.46	0.00	-	-
Total Nov. 6 - Oct. 16	+0.49	+4.12	50.67	0.97	8.13
Oct. 16 - Nov. 9	+6.18	+5.46	6.37	97.01	85.71
Total Nov. 6, '62-Nov. 9, '63	+6.67	+9.58	57.04	11.69	16.79

* Means joined by the same line do not differ significantly from each other at P = 0.05.

moisture content of those plots at the wheat seeding time. Both systems stored about 90 percent of the precipitation that was received during the November 6 - December 27 period. Moisture was lost from the soil until May 31. By this time both systems had stored about 22 percent of the total 50.67 centimeters of rainfall. From seeding to harvest of the wheat, the watermelon plots stored 10.64 centimeters (20.99 percent) and the fallow plots 11.28 centimeters (22.25 percent). From May 31 to October 16, when the watermelons were harvested, the watermelon plots lost considerably more water than the fallow plots because a crop was growing on the former plots. The total storage for the year was 6.67 centimeters (11.69 percent) for watermelon plots and 9.58 centimeters (16.79 percent) for fallow plots.

Figure 2 illustrates that the average storage for the watermelon and fallow plots has been almost the same during the November 6 - June 26 period, being slightly higher for the fallow. After this period, fallowed land stored more moisture as shown by the level of its storage curve which stayed much above the level of the storage curve for the watermelon plots.

The average storage on fallowed land of only 9.58 centimeters, or 16.79 percent of the precipitation, is relatively small. Some of the precipitation falling on the ground is not stored because of run-off. Some of the moisture may be lost due to deep percolation. Scattered weeds in the plots might sometimes deplete stored moisture through transpiration but

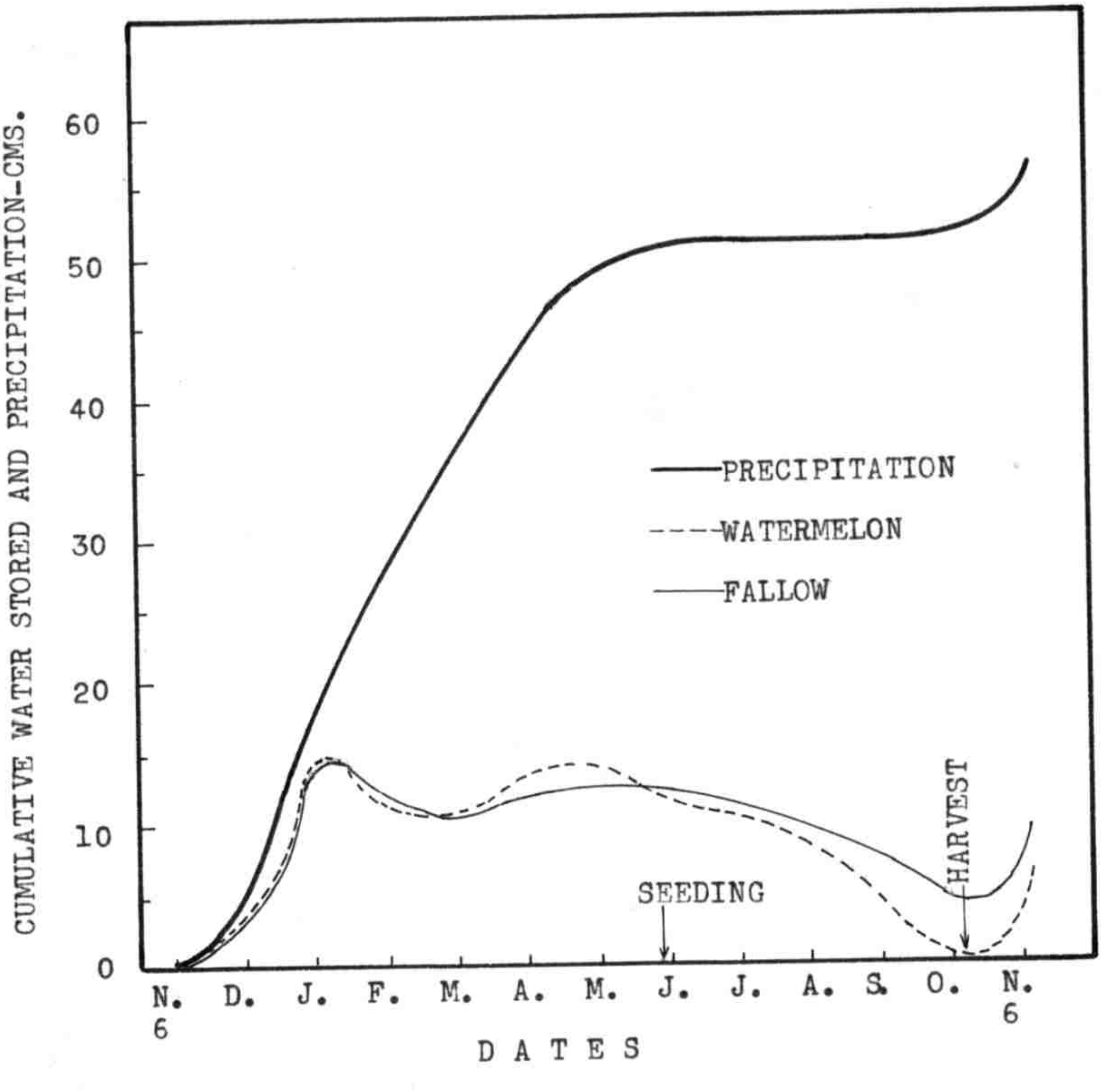

Figure 2—Cumulative precipitation and average soil water stored by watermelon and fallow during a one-year period, November 6, 1962-November 9, 1963.

weeds were satisfactorily controlled. Most of the 83.21 percent loss of moisture during the fallow period can probably be attributed to evaporation from the soil (43). Although losses due to evaporation are naturally less during the winter months, considerable moisture can be lost by evaporation when snow cover is not present (51). Moisture storage is not likely to be greatly improved unless a method of materially reducing evaporation losses is devised.

Water Use and Cropping Systems

The average centimeters of water used, centimeters of precipitation received, and average percent of precipitation used are shown in Table 4 for the three cropping systems. Wheat-fallow and wheat-watermelons used considerably more water than the continuous cropping system early in the season, November 6 - December 27, because they started with a higher moisture level. From December 27 to February 8, water use was almost the same for the three cropping systems with continuous cropping using more water and above the precipitation that was received during the period (117.98 percent). The maximum water use took place during the February 8 - March 29 period, being highest for the wheat-watermelons and wheat-fallow systems. These two systems used 123.45 percent and 131.20 percent of the precipitation, respectively. Continuous cropping system used 89.44 percent of the precipitation during the same period. From March 29 to June 26, when the wheat was

Table 4 - Centimeters of precipitation received, average centimeters of water used and percent of precipitation used by the three cropping systems during different sub-periods of a 1-year period.

Period	Water use - cms.*			Precipitation cms.	% of precipitation used*		
	Contin. wheat	Wheat-watermelons	Wheat-fallow		Contin. wheat	Wheat-watermelons	Wheat-fallow
Nov. 6 - Dec.27	2.97	5.82	8.08	16.41	18.10	35.47	49.24
Dec.27 - Feb. 8	14.83	12.23	11.36	12.57	117.98	97.30	90.37
Feb. 8 - Mar.29	12.70	17.53	18.63	14.20	89.44	123.45	131.20
Mar.29 - May 5	11.91	8.64	7.04	6.53	182.39	132.31	107.81
May 5 - June 26	5.67	7.49	7.75	0.96	590.62	780.21	807.29
Total Seeding-harvest (Nov. 6 - June 26)	48.08	51.71	52.86	50.67	94.89	102.05	104.32
June 26 - Oct.16	2.52	1.71	1.86	0.00	-	-	-
Oct.16 - Nov. 9	4.10	3.10	3.40	6.37	65.93	48.67	53.38
Total Harvest-seeding (June 26 - Nov. 9)	6.62	4.81	5.26	6.37	103.92	72.37	82.58
Total Seeding-seeding Nov. 6, '62 - Nov. 9, '63	54.70	56.52	58.12	57.04	95.90	99.09	101.58

* Means joined by the same line do not differ significantly from each other at P = 0.05.

harvested, the water use was nearly similar for the three systems. The total water use for the seeding to harvest period was lowest for the continuous cropping system, 48.08 centimeters or 94.89 percent of the precipitation, and almost similar for the wheat-watermelons and wheat-fallow systems, 51.71 centimeters or 102.05 percent of the precipitation and 52.86 centimeters or 104.32 percent of the precipitation, respectively. The three systems used all of the precipitation that was received from seeding to harvest, the wheat-watermelons and wheat-fallow using more due to the presence of more moisture at the seeding time. From harvest to seeding, when only 6.37 centimeters of rainfall were received, water use was highest for the continuous cropping system and lower and almost similar in the other two systems. Higher water use of the continuously cropped system is attributed to the higher moisture of those plots at the time of harvest. The total water use for the year, that is, from seeding to seeding, was 54.70 centimeters or 95.90 percent of the precipitation for the continuous wheat, 56.52 centimeters or 99.09 percent of precipitation for the wheat-watermelons and 58.12 centimeters or 101.88 percent of the precipitation for the wheat-fallow plots.

Figure 3 shows that the cumulative water use curve for the continuous cropping was always below the precipitation curve. The water use curves for the wheat-watermelons and wheat-fallow plots followed each other closely and stayed

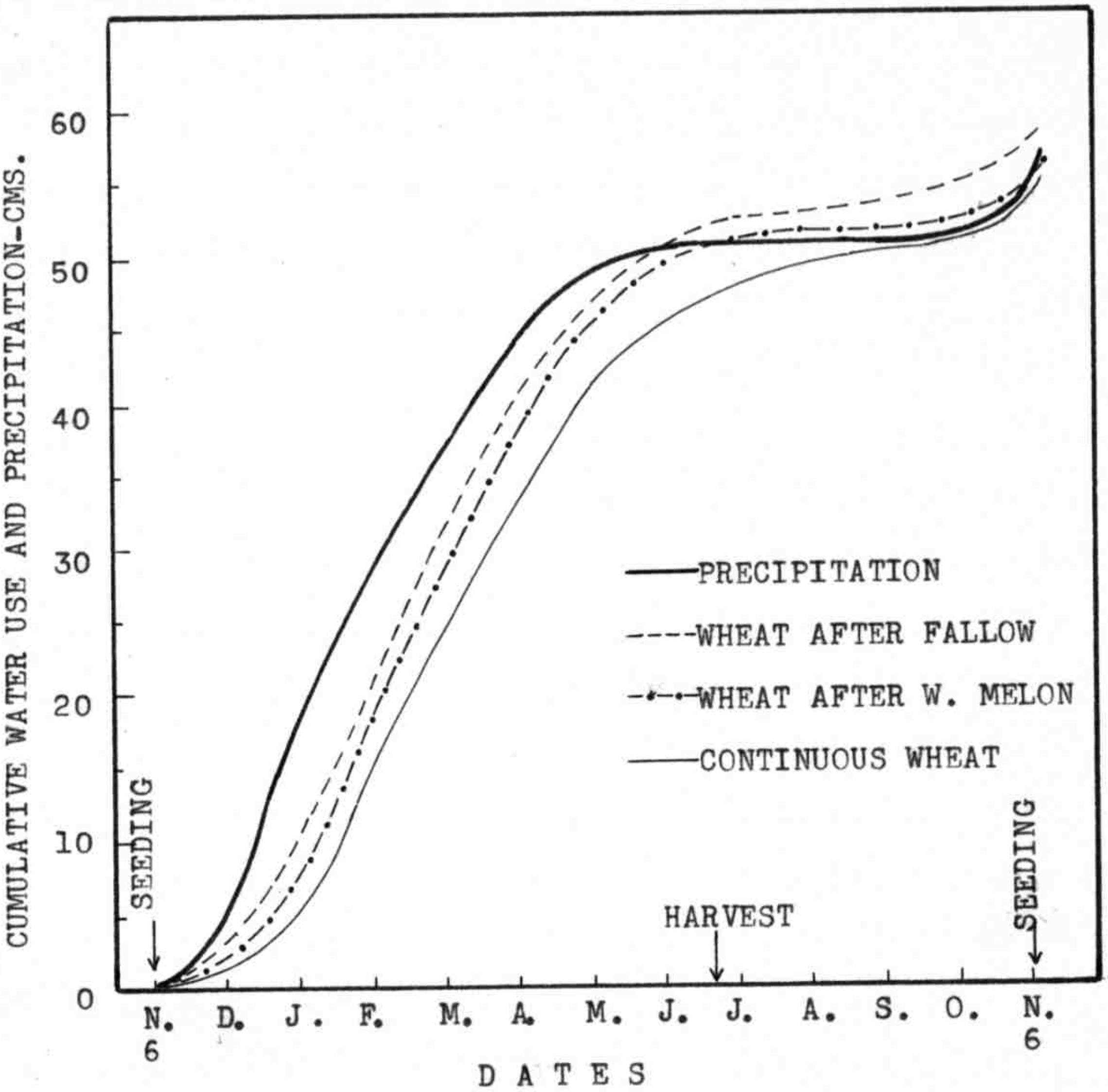

Figure 3— Cumulative precipitation and average water use by three cropping systems during a one-year period, November 6, 1962-November 9, 1963.

above the curve for the continuously cropped plots. The two curves crossed the precipitation curve shortly before the harvest time and stayed above the rainfall curve from then on. This indicates that these two systems used more water than was supplied by the rainfall. However, close to the seeding time (November 9, 1963) the water use curve for the wheat-watermelons system followed the precipitation curve and ended very slightly below it.

The figures for the average daily water use in Table 5 show that the greatest water use by the wheat-watermelons and wheat-fallow systems occurred from February 8 to March 29 and by the continuous cropping system during the two periods, namely, December 27 to February 8 and March 29 to May 5. The average daily water use from seeding to harvest was 0.209 centimeters for continuously cropped plots, 0.225 centimeters for the wheat-watermelons plots and 0.230 centimeters for the wheat-fallow plots. The average daily precipitation received was 0.220 centimeters. The average daily water use for the seeding to seeding period was 0.151 centimeters, 0.155 centimeters, and 0.160 centimeters, respectively, for the forementioned systems. The average daily precipitation for the same period was 0.156 centimeters.

Table 6 shows the average water use, precipitation and percent of precipitation used by the watermelon and fallow plots. Water use was nearly similar for both systems from November 6 to May 31, when the watermelons were planted. Du-

Table 5 - Daily precipitation and average daily water use by three cropping systems during different sub-periods of a 1-year period.

Period	Average daily water use-cms.*			Average daily precipitation cms.
	Continuous wheat	Wheat-water-melons	Wheat-fallow	
Nov. 6-Dec. 27	0.058	0.114	0.158	0.322
Dec.27-Feb. 8	0.362	0.298	0.277	0.306
Feb. 8-Mar. 29	0.249	0.344	0.365	0.278
Mar.29-May 5	0.331	0.240	0.196	0.181
May 5-June 26	0.111	<u>0.147</u>	<u>0.152</u>	0.019
Seeding-harvest (Nov.6-June 26)	0.209	<u>0.225</u>	<u>0.230</u>	0.220
June 26-Oct. 16	0.022	<u>0.015</u>	<u>0.016</u>	0.00
Oct. 16-Nov. 9	0.178	<u>0.135</u>	<u>0.147</u>	0.277
Harvest-seeding (June 26-Nov.9)	0.050	<u>0.036</u>	<u>0.040</u>	0.048
Seeding-seeding (Nov.6, '62 - Nov.9, '63)	0.151	0.155	0.160	0.156

* Means joined by the same line do not differ significantly at P = 0.05.

Table 6 - Centimeters of precipitation received, average centimeters of water used and percent of precipitation used by watermelons and fallow during different sub-periods of a 1-year period.

Period	Water use - cms.*		Precipitation	% of precipitation used*	
	Watermelons	Fallow	cms.	Watermelons	Fallow
Nov. 6 - Dec. 27	1.64	1.68	16.41	9.99	10.24
Dec. 27 - Feb. 8	16.98	15.12	12.57	135.08	121.00
Feb. 8 - Mar. 29	11.10	12.67	14.20	87.61	89.22
Mar. 29 - May 5	5.75	5.86	6.53	88.06	89.74
May 5 - May 31	4.27	3.76	0.96	444.79	391.67
Total Nov. 6 - May 31	39.47	39.09	50.67	78.43	77.14
May 31 - June 26	0.29	0.20	0.00	-	-
Total Nov. 6 - June 26	40.03	39.29	50.67	79.00	77.54
June 26 - Aug. 27	5.13	3.63	0.00	-	-
Aug. 27 - Oct. 16	5.02	3.63	0.00	-	-
Total May 31 - Oct. 16	10.44	7.46	0.00	-	-
Total Nov. 6 - Oct. 16	50.18	46.55	50.67	99.03	91.87
Oct. 16 - Nov. 9	0.19	0.91	6.37	2.98	14.28
Total Nov. 6, '62-Nov. 8, '63	50.37	47.46	57.04	88.31	83.20

* Means joined by the same line do not differ significantly from each other at $P = 0.05$.

ring this period the watermelon plots used 39.74 centimeters of water or 78.43 percent of the precipitation and fallow plots lost 39.09 centimeters of water or 77.14 percent of the precipitation. During the period when watermelons were growing (May 31 to October 16) 10.44 centimeters of the stored moisture in the soil were used to produce an average of 176 kilograms of watermelons per dunum. During this period, in which no precipitation was received, the fallow lost 7.46 centimeters of water. The total water use for the watermelon and fallow plots were 50.37 centimeters or 88.31 percent of the total precipitation and 47.46 centimeters or 83.20 percent of the precipitation, respectively.

The cumulative water use curves shown in Figure 4 also show the similarity of moisture use by both watermelon and fallow plots until May 31. After this date and until November 9, water use was higher in the watermelon plots.

The average figures for the daily water use, which are presented in Table 7, show that the maximum water use occurred during the December 7 to February 8 period. The average daily water use was the same for both systems during the November 6 to May 31 period, being 0.191 centimeters and 0.191 centimeters for the watermelons and fallow plots, respectively. The daily precipitation received during this period was 0.247 centimeters. The daily water use for the period when the watermelons were growing was 0.077 centimeters and 0.055 centimeters for the watermelons and fallow plots, respectively,

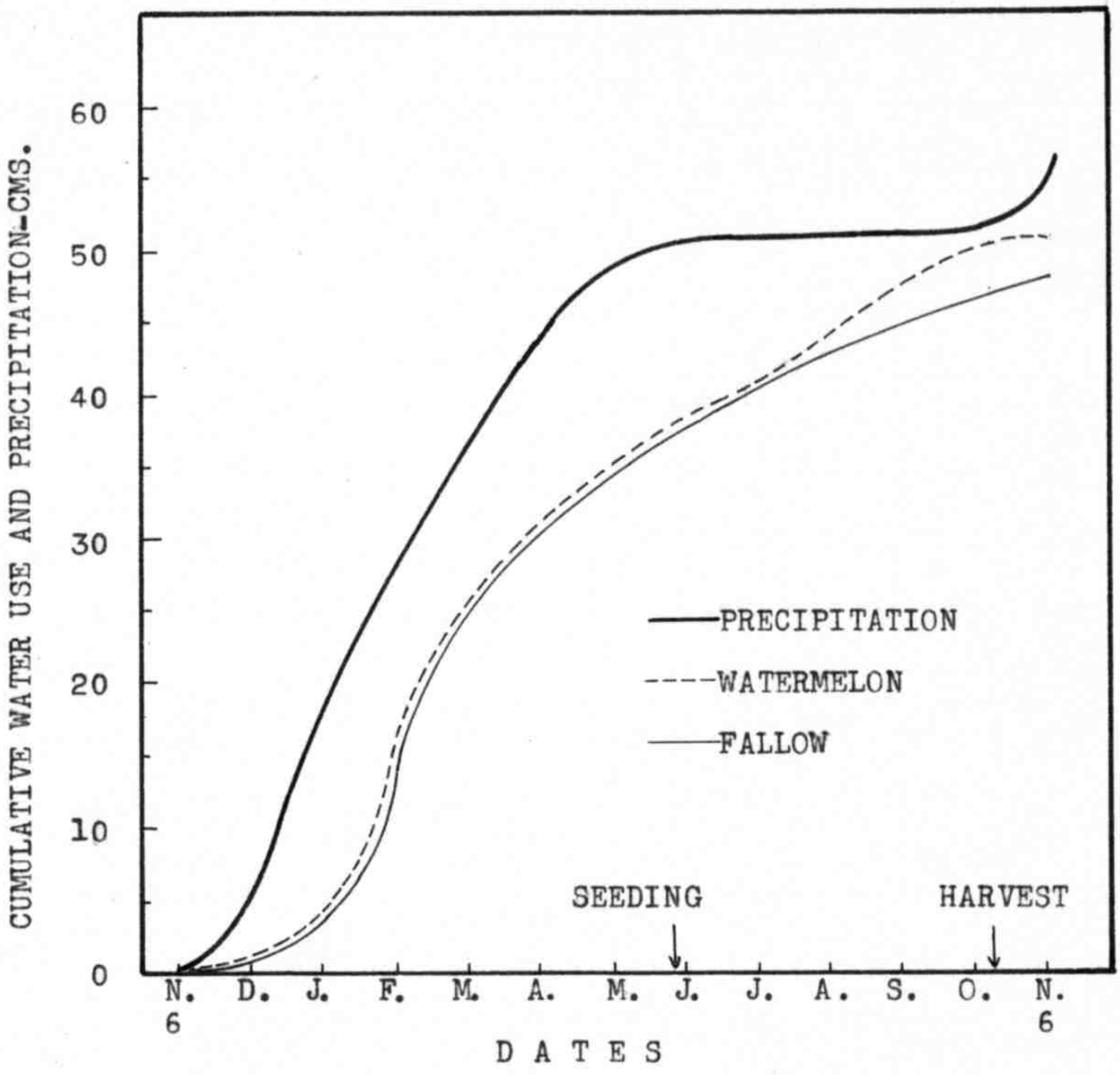

Figure 4—Cumulative precipitation and average water use by watermelon and fallow during a one-year period, November 6, 1962-November 9, 1963.

Table 7 - Daily precipitation and average daily water use by watermelons and fallow during different sub-periods of a 1-year period.

Period	Average daily water use-cms.*		Daily precipitation cms.
	Watermelons	Fallow	
Nov. 6 - Dec.27	0.032	0.033	0.322
Dec.27 - Feb. 8	0.414	0.369	0.306
Feb. 8 - Mar.29	0.218	0.248	0.278
Mar.29 - May 5	0.160	0.163	0.181
May 5 - May 31	0.164	0.145	0.037
Total Nov. 6 - May 31	0.192	0.191	0.247
May 31 - June 26	0.012	0.008	0.000
Total Nov. 6 - June 26	0.174	0.171	0.220
June 26 - Aug. 27	0.084	0.060	0.000
Aug. 27 - Oct. 16	0.102	0.074	0.000
Total May 31 - Oct. 16	0.077	0.055	0.000
Total Nov. 6 - Oct. 16	0.148	0.137	0.149
Oct. 16 - Nov. 9	0.008	0.040	0.149
Total Nov. 6, '62 - Nov. 9, '63	0.138	0.130	0.156

* Means joined by the same line do not differ significantly from each other at P = 0.05.

and the total daily average for the year was 0.283 centimeters and 0.130 centimeters. The daily precipitation received was 0.160 centimeters. The critical period for watermelons as regards the moisture use was between August 27 and October 16.

The use of 47.46 centimeters of water (83.20 percent of the precipitation) by fallow before a crop is seeded is certainly an extravagance which cannot be afforded in a region of limited rainfall. As discussed earlier, evaporation is responsible for much of this water loss and unfortunately no economical methods have yet been devised for controlling evaporation.

The use of about 50 centimeters of water for production of about 80 kilograms of grain per dunum, or about 16000 kilograms of water for each kilogram of grain, is a real luxury consumption. The transpiration ratio for grain as reported by Richardson (41) varies from 660 to 1,188. The transpiration ratio of 16000, as found in this study, is almost as high as 20 times the reported ratio. Such a large ratio appears reasonable because water use of wheat, in this study, refers not only to the water used by crop, but also to that lost by run-off, evaporation, or deep seepage. Therefore, the values obtained for the water use are several times larger than the actual water use by the crop, as much of the water is lost through evaporation from the soil surface, through run-off and deep percolation, and was not used by the crop. Also, the low yields that were obtained were another contributory factor to such a high transpiration ratio. With the amount of water used by the wheat in this experiment, a theoretical yield of 20 times as high as those obtained could have been attained, assuming that water is the only limiting factor in wheat production and other factors like soil fertility, plant population, etc., are at their optimum levels for such theoretical high yields.

This discussion emphasizes the need for more efficient moisture conserving practices in an annual cropping system. It appears that alternative cropping of wheat and fallow will not increase yields significantly in years of abundant rainfall. Moreover, fallowing, as practiced at present, must be regarded as a rather inefficient moisture conservation practice. Alternate cropping of wheat and watermelons does not differ much from the wheat-fallow system because the land is left fallow most of the time and only during the last four months of the fallow periods watermelons are present.

Fallowing is, however, the only practical method of moisture conservation in the semi-arid areas at present. Although it rarely stores more than 20 percent of the total precipitation, this extra carry-over moisture to a dry year may determine the success of the wheat crop in that year.

Precipitation and Initial Moisture in Soil as Correlated with Water Storage and Use

Through the correlation technique, the water storage and the percent of the precipitation stored and the water use and the percent of the precipitation used were evaluated in terms of the amount of precipitation that was received during each period and the initial moisture content of the soil at the beginning of the period. The data are shown in Table 8. There was a rather high positive correlation between precipitation and the amount of water storage, however, the correlation coefficients between the amount of water stored and the percent of the precipitation stored were all low and insignificant.

The correlations between precipitation and water use were low and insignificant, while those between precipitation and percent of the precipitation used were all negative and significant. Negative and rather high correlations were found between the initial moisture in the soil and subsequent storage. These correlations were high and highly significant for the watermelons and fallow plots. This means that a high initial moisture in soil decreases the subsequent storage because of the retarded penetration of water into a wet soil. The correlations between the initial moisture in the soil and percent of precipitation stored were mostly negative and high and highly significant except for the fallow plots. A high initial moisture in soil increased the subsequent water use,

Table 8 - Correlation coefficients (r) showing the degree of relationship of moisture storage and use and percent of precipitation stored and used with precipitation during each period and moisture content of the soil at the beginning of the period.

Item correlated	Correlation coefficients (r)				
	Continuous wheat	Wheat-watermelons	Wheat-fallow	Watermelons	Fallow
Precipitation and centimeters stored	0.625	0.591	0.623	0.638*	0.344
Precipitation and % of precipitation stored	0.372	0.084	-0.043	0.118	0.146
Precipitation and centimeters used	0.193	0.338	0.620	0.338	0.368
Precipitation and % of precipitation used	-0.795*	-0.735**	-0.710*	-0.664*	-0.684*
Initial moisture content and centimeters stored	-0.555	-0.626	-0.424	-0.838**	-0.934**
Initial moisture content and % of precipitation stored	-0.773**	-0.957**	-0.916**	-0.989**	-0.523
Initial moisture content and centimeters used	0.934**	0.920**	0.861**	0.695*	0.664*
Initial moisture content and % of precipitation used	0.292	0.053	0.158	0.641*	0.619

* Significant at P = 0.05.
** Significant at P = 0.01.

as evidenced from the high positive correlation coefficients which were also significant. This emphasizes the importance of the stored moisture in soil for the crop use, especially during the periods when no precipitation is received. There was a little correlation between the initial moisture in soil and the percent of precipitation used by the continuous wheat, wheat-watermelon, and the wheat-fallow plots. The correlations were higher for the watermelon and fallow plots because of the lower water use of those plots.

It is not presumed that precipitation and initial water content of the soil are the only factors that affect the water storage and use. Water penetration into a soil is influenced by many factors, among them the quantity that falls at one time, the rapidity with which it falls, the condition of the soil surface, soil properties, the quantity of water already in the soil and the season at which the precipitation occurs. After water enters the soil, its retention is influenced by the presence or absence of vegetation, the depth of wetting, and weather conditions that follow. The determination of all the different factors was not possible with the field experiment.

The data for water storage and use emphasize the inefficiency in the storage and use of water under the presently practiced cropping systems. The phenomenal loss of water can be largely attributed to evaporation. It is estimated that (22) evaporation losses in the Great Plains area in the United States probably account for 70-75 percent of the precipitation. It is safe to assume the same evaporation losses for the Beqa'a plain because of similarity in the weather conditions of the two areas. Only a minor reduction in evaporation from the soil surface, especially in years of deficient rainfall, would increase the water available for plant use. Development of techniques and practices for controlling and reducing evaporation losses during the fallow and cropping periods would have a great impact on the cultural and cropping practices in the Beqa'a. Previous research in dryland agriculture has dealt mainly with methods of utilizing the moisture available for crop growth. Methods have been suggested to reduce run-off and improve infiltration. Detailed studies of evaporation, which under dryland conditions involve the loss of approximately three-fourths or more of the precipitation, and practical means of controlling and reducing such losses are of vital importance for a continuing and improved agricultural economy.

SUMMARY AND CONCLUSIONS

A dryland moisture experiment was conducted at the Agricultural Research and Education Center, Beqa'a, North Lebanon during the November 6, 1962 to November 9, 1963-period. Moisture storage and use studies were made of all of the phases of the three winter wheat cropping systems, namely, continuous cropping of wheat, alternate cropping of wheat and fallow, and alternate cropping of wheat and watermelons.

The data obtained for moisture storage indicate that the maximum storage took place early during the growing season. From seeding to harvest the continuously cropped soil stored 2.59 centimeters or 5.11 percent of the total of 50.67 centimeters of precipitation that were received during this period. There was a water loss from wheat-after-watermelon and wheat-after-fallow soil. The watermelon and fallow plots stored 10.93 centimeters or 21.57 percent and 11.48 centimeters or 22.66 percent of the seeding to harvest precipitation, respectively. From seeding to seeding the continuously cropped soil stored 2.34 centimeters and wheat-after-watermelon stored 0.52 centimeters of the total annual precipitation of 57.04 centimeters. There was a water loss from the wheat-after-fallow-soil because of the higher initial moisture content of the soil at the time of seeding. The watermelon and fallow phases of the two alternate cropping sequences stored 6.67 centimeters or 11.69 percent and 9.58 centimeters or 16.79 percent of the annual precipitation, respectively.

Water use was the highest for wheat grown after fallow and the lowest for wheat grown after wheat. From seeding to harvest the continuously cropped land used 48.05 centimeters or 94.89 percent; wheat-after-watermelon used 51.71 centimeters or 102.05 percent; and wheat-after-fallow used 52.86 centimeters or 104.32 percent. The total water use for the year was 54.70 centimeters or 95.90 percent, 56.52 centimeters or 99.09 percent, and 58.12 centimeters or 101.58 percent for the three systems, respectively. The three systems used almost all of the 57.04 centimeters of the annual precipitation. Water use of watermelon and fallow soils was almost the same from seeding to harvest of wheat, being 40.03 centimeters and 39.29 centimeters, respectively. The total annual water use was 50.37 centimeters or 88.71 percent and 47.46 centimeters or 83.20 percent for the watermelon and fallow, respectively.

The average daily water use data indicate that the maximum water use for wheat grown after watermelon and wheat grown after fallow took place during the February 8 to March 29 period. However, the two periods of December 27 to February 8 and March 29 to May 5 were found to be critical with regard to the water use of wheat grown after wheat. December 27 to February 8 was found to be the period of the maximum water use for both watermelon and fallow phases of the rotations.

The initial moisture content of the soil at the beginning of each period was found to be negatively correlated with the amount of subsequent water storage and with percent of the precipitation stored during the period; and positively correlated with the amount of subsequent water use. The quantity of precipitation during each period was found to be negatively correlated with the percent of the precipitation used during the period.

The data obtained for grain and straw yield and other characteristics of wheat grown under the three cropping systems indicated that continuous cropping system was superior to the two alternate cropping systems under the conditions of the experiment where a far above average precipitation was received. The yields obtained were generally lower than those obtained during the years with average rainfall.

The data for moisture storage and use emphasize the inefficiency in the storage and use of water under the presently practiced cropping systems. The tremendous water loss in the cropping systems can be attributed to evaporation which is responsible for three-fourths or even more of the water loss. Such losses call for a need of more efficient moisture conservation practices and decrease in evaporation from the soil.

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