Issued October 16, 1913.

U. S. DEPARTMENT OF AGRICULTURE.

BUREAU OF PLANT INDUSTRY—BULLETIN NO. 284.

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THE WATER REQUIREMENT OF PLANTS.

I.—INVESTIGATIONS IN THE GREAT PLAINS IN 1910 AND 1911.

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WASHINGTON:
GOVERNMENT PRINTING OFFICE.
1913.

BUREAU OF PLANT INDUSTRY.

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THE WATER REQUIREMENT OF PLANTS.[1]

I.—INVESTIGATIONS IN THE GREAT PLAINS IN 1910 AND 1911.

INTRODUCTION.

The term "water requirement" is used in this paper to indicate the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced. The water requirement of a grain-producing field crop may be expressed either in terms of the total dry matter produced or on the basis of the grain alone and is found by dividing the total weight of the water absorbed during the whole period of growth by the total dry weight or by the weight of the grain, respectively. The results of earlier investigations have shown that some of the crop plants differ materially as regards their water requirement. The subject thus becomes one of considerable economic importance in connection with the agriculture of semiarid regions, since the crop or variety which is most economical in the use of water, other things being equal, is evidently the one best adapted to regions having a limited water supply.

The water requirement of a given crop, or the transpiration ratio, as it is sometimes called, has long been known not to be constant, but to be dependent upon and influenced by variations in many environmental factors, such as the temperature and humidity of the air, the velocity of the wind, the intensity of the solar radiation, and the fertility of the soil. The water requirement of small-grain crops grown in a cool, humid region is much lower than that of the same crops when grown in a dry region, such as the western part of the Great Plains, where they are subjected also to high winds and greater solar radiation.

It has consequently seemed desirable to determine at different points in the Great Plains the water requirement of the crop plants which have appeared best adapted to these regions. These experiments have included also the measurement of the water requirement of several different varieties of each of the more important crop plants under conditions designed to make the results as nearly comparable

[1] The investigations here described were carried on at every stage in cooperation between the Office of Biophysical Investigations and the Office of Alkali and Drought Resistant Plant Investigations. The names of the authors have been placed alphabetically on the title-page.

as possible, with a view to determining those varieties which are most efficient in the use of water.[1]

The writers have also attempted the measurement of the water requirement of crops growing under field conditions. Such measurements are of practical value in determining the total amount of water used in the production of the crop. The uncertainty regarding the amount of run-off and of surface evaporation makes such determinations rather indefinite so far as the actual water requirement of the crop itself is concerned. It seemed very desirable, however, to obtain this field check upon the results of the pot experiments, and a gratifying agreement between the two series has been obtained.

DETERMINATION OF THE WATER REQUIREMENT OF CROPS IN POT CULTURES.

EXPERIMENTAL METHODS.

The determination of the amount of water used by a crop necessitates the measurement (1) of the amount of water added to the soil during the growth of the crop and (2) of the difference in the water content of the soil at the beginning and at the end of the experiment. The most accurate way of making the second determination is by weighing the whole system. Weighing also furnishes the best method of determining whether the soil contains at all times a suitable moisture supply for the crop. Weighing, however, necessitates the use of a pot or soil container of some kind, and this constitutes a departure from field conditions. However, in a comparative study of the water requirement of different crops, grown as nearly as possible under the same conditions, a rational pot culture may fairly be assumed to affect the different crops in a nearly uniform way and therefore to introduce no serious error in determining the relative water requirements of the several crops compared.

PREVENTION OF EVAPORATION.

Some uncertainty in determining the water requirement always results from the evaporation of water directly from the soil surface. A check pot without plants, in which the soil surface is freely exposed, can not safely be held to represent the loss by evaporation from the soil surface of a pot in which plants are growing. This is sufficiently demonstrated by considering the difference in the amount of evaporation from the check pots themselves. (Leather, 1910, p. 141.)[2] The growing plant, according to the character of its foliage and the

[1] A large amount of work by other investigators has already been done in connection with the determination of the water requirement of plants. The researches bearing on this subject, however, do not appear to have ever been brought together, and this has led the writers to present the results of different investigations in some detail in another publication (1913, B. P. I. Bul. 285).

[2] Bibliographic citations in parentheses in the text of this bulletin refer to the "Literature cited," p. 49.

FIG. 1.—GALGALOS WHEAT. FIG. 2.—SWEET CLOVER. FIG. 3.—BLACKHULL KAFIR.

GENERAL VIEWS IN THE SHELTER AT AKRON, COLO., JULY 13, 1911.

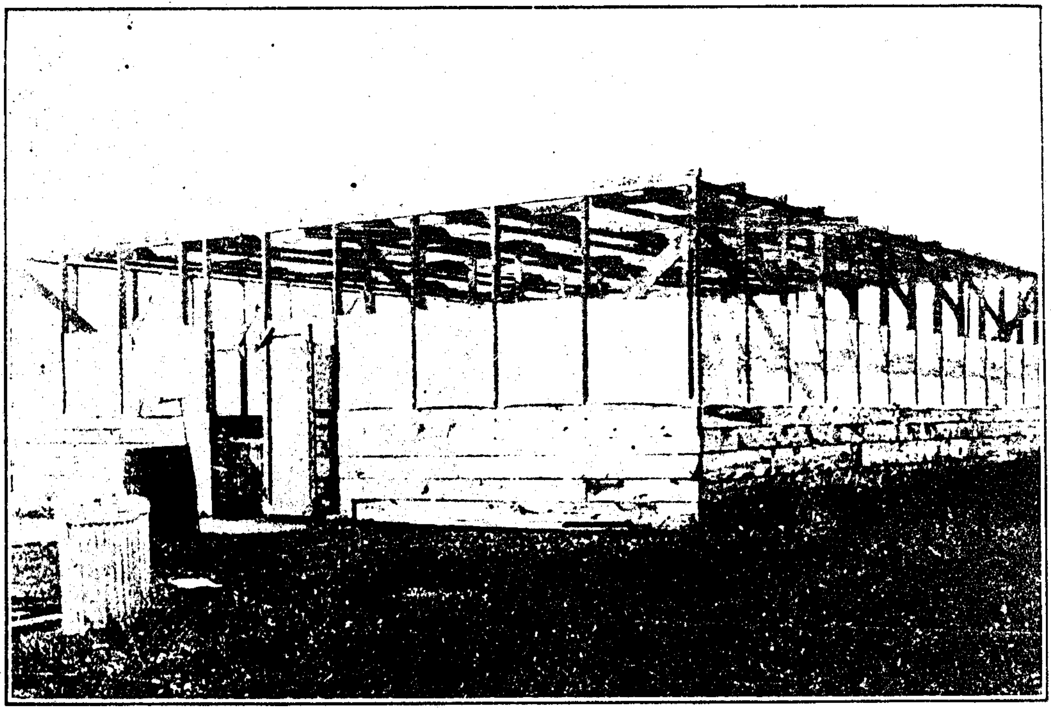

FIG. 1. GENERAL VIEW OF THE SHELTER USED IN THE EXPERIMENTS DURING 1911.

FIG. 2.—METHOD OF TRANSPORTING CANS.

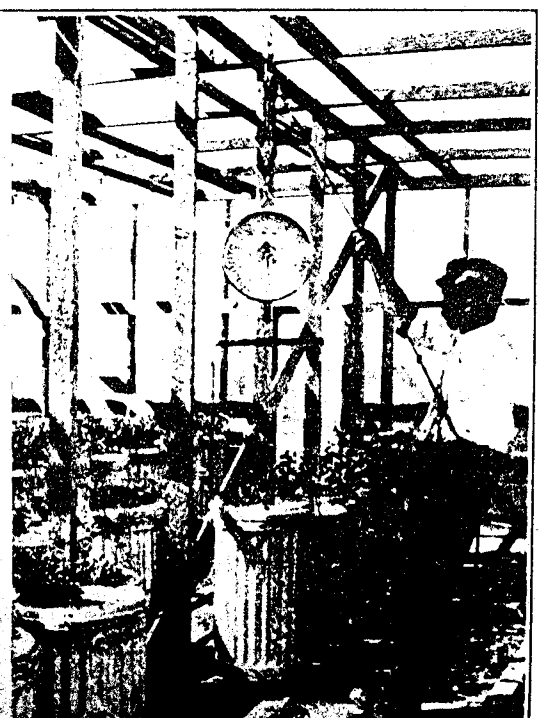

FIG. 3.—METHOD OF WEIGHING CANS.

distribution of its root system, will also materially modify the surface evaporation from the soil. Kiesselbach and Montgomery (1911) have found that the loss of water from the soil surface can be minimized by the use of a 3-inch layer of gravel combined with a loosely fitting metal cover without interfering with the normal development of the corn plant. Lawes (1850) in his pioneer experiments closed the top of his pots with a tight-fitting cover, save for a small opening around the plants. The objection to closing the pots completely has, of course, been based upon the fear that the aeration would thereby be reduced to such an extent as to interfere with the normal development of the plants. It is evident, however, that the reduction of evaporation by the layer of gravel or by the closely fitting cover employed by Lawes must reduce the aeration to a corresponding degree, since the exit of water and the entrance of air under such conditions are both diffusion processes. The writers accordingly determined to try the expedient of eliminating the loss of water due to evaporation by using pots with tight-fitting covers provided with openings for the plants and sealing the openings around the stems of the plants as perfectly as possible with wax. It was believed that sufficient aeration would be secured (1) from the air which is drawn into the soil to replace the water transpired and subsequently expelled in part when more water is added; (2) from the air actually dissolved in the water added to the pots; and (3) from the air drawn into the pots by the contraction of the air in the interstitial spaces of the soil mass due to the daily fluctuations in temperature.

The results of the experiments have shown that this conclusion was justified. The growth was luxuriant and healthy (Pl. I), and the roots were found at the conclusion of the experiments to have penetrated into every portion of the soil mass. There was no tendency on the part of the root system to become massed either about the center of the pot, where the moisture was added, or at the walls, and there was no odor other than that of well-aerated soil.

DESCRIPTION OF THE POTS.

Substantial cans of heavily galvanized corrugated iron have been used in our experiments as soil containers for growing the experimental plants. (Pl. II, figs. 2 and 3.) Cans of one size have been used throughout, namely, 16 inches (40 cm.) in diameter and 26 inches (66 cm.) high, having a capacity of about 250 pounds (115 kilos) of soil. (Fig. 1.) Cans of this size provide a soil mass fully adequate for the normal development of the plants and are capable of being readily transported. (Pl. II, fig. 3.) The advantages of a large container have been noted by Leather (1910, p. 167). Each can is fitted with a heavy galvanized-iron cover through which holes are punched, suitable in size and number to accommodate the crop which it is desired to grow. For the small-grain crops, 20 holes one-half inch in diameter have been used; for sorghum and alfalfa, 8 holes 1 inch in diameter; and for corn and sugar beets, 6 holes 1½ inches in diameter. In the center of each cover is a hole 1½ inches in diameter which is used for watering and which is normally kept closed with a stopper. These holes are punched so as to turn the edge upward and outward. The joint between the can and cover is sealed with a strip of surgeon's adhesive plaster 2 inches wide. Each can is provided with two heavy bale ears for suspending the can while weighing; also two folding handles.

FILLING THE POTS.

The soil, containing a sufficient amount of moisture to work well, is tamped into the cans. Especial care is taken to have the soil at the top of the pots built up above the can and well compacted, so as to be in firm contact with the cover. Otherwise a settling of the soil will subsequently occur and break the wax seals around the stems of the plants. Before applying the cover, an excavation is made in the center of the soil in the can, into which a 5-inch unglazed flowerpot is inserted at such a height that the top of the pot will be in contact with the cover when the latter is in place. (Fig. 1.) The soil immediately around the lower part of the flowerpot is replaced by fine gravel. This arrangement provides additional surface for the absorption of water, so that the cans usually take water readily, thus greatly facilitating the process of watering. A vertical section of the can showing the unglazed pot in position surrounded by gravel is shown in figure 1.

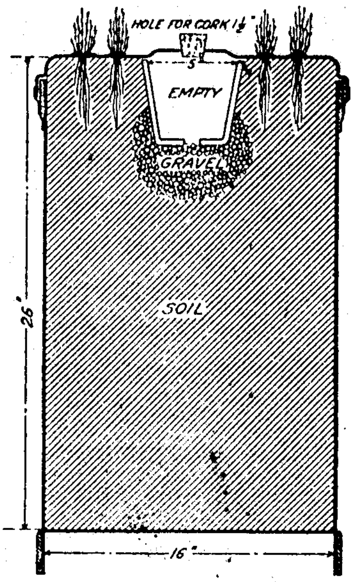

FIG. 1.—Pot used in measuring the water requirement of plants.

PLANTING AND SEALING.

The seeds, after having been kept between moist blotters until germination has started, are planted through the openings in the cover of the pot, moist soil being packed lightly over the seed to the level of the cover. The exposed soil surface is then protected from evaporation by a thin layer of wax, which can be quickly applied in a melted condition with a brush. The wax which we have found most satisfactory for this work consists of a mixture of 8 parts of pure beeswax and 2 parts of tallow. Most plants will readily push through this wax. After the plants have become established, the wax seal can be thickened. This method of preventing evaporation and excluding rain has proved satisfactory and is especially useful in the case of the small grains. (Briggs and Shantz, 1912.)

Surgeon's adhesive plaster has also been used for closing the opening around the stem of the plant. After the seeds are planted, the top of the pot is covered with soil until the plants have appeared through the openings. The loose soil is then removed and a small square of adhesive plaster, cut through to the center from one side, is slipped around the seedling, and pressed into firm contact with the cover. The adhesive tape does not accommodate itself to the growth of the plants as well as the wax and is not as satisfactory in preventing the entrance of rain water. The seals of either material need occasional attention to keep them in good condition.

METHOD OF WATERING.

Water was added by means of 2-liter flasks, the necks of which were cut so as to deliver 2 liters when brimful. This form of flask could be filled quickly and accurately by immersion without further adjustment. The filled flask was inverted in a funnel placed in the opening in the center of the cover. This arrangement acted virtually as a Mariotte system, keeping the water at constant level in the receiving flowerpot until the flask was emptied. (See fig. 2.) When not watering, the hole in the lid was closed with a long cork stopper. The quantity of water added at one time was always 2 liters or a multiple thereof. This method of procedure, combined with the weighings made every second day, formed a valuable check upon the amount of water added, since it was always possible to determine from the weighings of a series of pots whether water had been added to any particular pot and the approximate quantity. Otherwise some uncertainty will occasionally arise regarding the amount of water added to a particular pot when 600 liters or more are being added to the whole series daily.

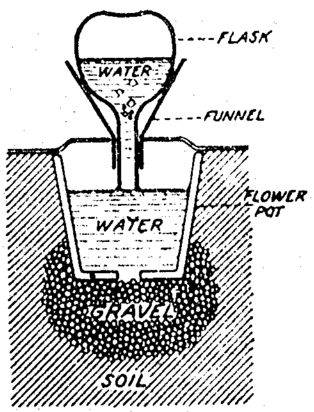

FIG. 2.—Sketch showing the device used in adding water to the pots.

The water used was pumped from a deep well and carried some lime.

WEIGHING THE POTS.

The daily weighings were made upon a spring balance with a 12-inch dial having a capacity of 150 kilograms and readable to 0.1 kilogram. At Akron in 1911 this balance was checked frequently with a platform balance with agate beam bearings and having a sensibility of 5 grams, and in 1910 daily with a check pot which contained no plants and was completely sealed. Spring balances have a rather large temperature coefficient, which does not affect the results of this work, however, except in the initial and final weighings. Here the temperature correction, which may amount to several tenths of a kilogram with a load of 100 kilos, must be known or the balance must be checked frequently with a standard weight. The latter plan has been followed in our work.

For convenience in weighing, a steel track was installed in 1911 directly over each row, being fastened to the roof timbers of the inclosure. This track supported a small trolley, which in turn carried the lifting device and the balance. A small differential block was at first used to lift the pots. But the passage of the chain over the blocks caused the balance to vibrate badly while the pot was being lifted, so a double block and rope tackle was later substituted, one person holding the can suspended while a second recorded the weight. (Pl. II, fig. 2.) In this way the pots could be weighed at the rate of about one a minute.

CROPPING AND DRYING.

The plants growing in the pots were harvested at the stage when similar crops are harvested in the field. Grain crops were ripe and alfalfa and sweet clover were in flower. The plants were cut even with the soil surface, except that alfalfa and sweet-clover plants were cut in such a way as to leave the crown uninjured, and were placed in sacks of known weight. The green weight was taken and the cropping allowed to become air dry. It was then placed in a steam drying oven and maintained at a temperature of 110° C. until reduced to constant weight. The total dry weight, the weight of the sack, and the weight of grain were then determined.

THE SCREENED INCLOSURE.

To protect the plants from birds and possible hailstorms, it has been necessary to conduct the pot experiments in a screened inclosure. The inclosure at Akron in 1911 (Pl. II, fig. 1) was 36 by 40 feet and accommodated 200 pots, arranged in five double rows running east and west, with walks between. The framework was constructed of 2 by 4 inch studding, with a flat roof 10 feet above the ground. The roof timbers were spaced at intervals of 3 feet, to which the ¼-inch galvanized network was tacked. The walls of the inclosure to a height of 3 feet consisted of tight boards. To break the force of the wind during storms, a strip of thin cheesecloth 3 feet wide was placed over the netting immediately above the board base. A strip of 2-inch mesh wire netting was placed over the cheesecloth, so that it was supported by netting on both sides. This thin cloth screen did not appear to interfere with the ventilation of the inclosure, the plants moving in the lightest breeze, but it served effectually to break the force of high winds. This protection would not introduce any serious error in the determination of the water requirement, since an increase in the wind velocity above a moderate breeze has only a slight influence on the transpiration of a freely exposed plant. (Brown, 1910.)

EFFECT OF THE SHELTER ON THE WATER REQUIREMENT.

The plants grown in the inclosure were shaded to some extent by the network. This amounted to a reduction of about 26 per cent in the direct radiation from the sun at 10.30 a. m., based upon measurements with a silver disk pyrheliometer inside and outside the inclosure. Nearly half of the radiation thus cut off directly would, however, enter the inclosure indirectly by reflection and radiation from the screen, and the same would apply to the radiation from the sky. In addition to the effect of the screen, some shading resulted from the framework. An idea of this can be gained from Plate II, figure 2. The reduction in radiation, while so small as probably to have no effect on assimilation, would tend to reduce the water requirement of the plants in the inclosure compared with plants grown outside, since the inside plants were not required to dissipate so large an amount of solar radiation.

To test experimentally the effect of the inclosure, 12 standard pots of one of the tumbleweeds, *Amaranthus graecizans*, were grown from August 5 to September 15, 6 pots being placed inside the inclosure, while the others were left outside in a freely exposed position. The mean water requirement of each series (p. 33) was as follows:

Inside the inclosure	277±4
Outside the inclosure	275±7

These results would indicate that the effect of the slight shade and protection of the inclosure had no influence on the water requirement of this plant, the difference in the two series being less than the probable errors of observation. The difference in the radiation intensity inside and outside the inclosure can not, however, be regarded as without effect upon the transpiration of more succulent plants. Later experiments with wheat and alfalfa have shown that the use of a screen similar to that of the inclosure reduces the water requirement measurably. The absolute value of the water requirement obtained in the inclosure is, therefore, probably somewhat below that of an isolated plant growing in a freely exposed position. Under field conditions, however, the plants grow in close proximity and shade one another to some extent. The conditions in the inclosure therefore appear to approximate field conditions more closely than if the plants were grown in the open. The determination of the relative water requirement of the different crop plants is, however, the main problem from an economic standpoint. Aside from a possible differential effect when widely separated genera are used, which is suggested by the results obtained with *Amaranthus graecizans*, it does not appear that the *relative* water requirement of the different plants would be measurably affected by the slight shading due to the inclosure.

COMPUTATION OF THE WATER REQUIREMENT.

Each pot is weighed (with an error of not more than 100 grams at most) soon after the seeds are planted and again immediately after the crop is harvested. The initial minus the final weighing when added algebraically to the water supplied, expressed in the same units, gives the total weight of water absorbed by the plant. This method of calculation gives a water consumption that is too high by an amount equal to the dry weight of the tops and too low by an amount equal to the green weight of the roots—errors which offset each other in part.

Each water-requirement determination in our experiments is based upon measurements carried on simultaneously in six pots. The water requirement of the plants in each pot is determined separately and the mean of the six determinations taken to represent the water requirement of the plant under investigation. This procedure also affords a basis for computing the probable error of the mean water requirement.[1]

WATER REQUIREMENT OF WHEAT AND SORGHUM IN COLORADO AND TEXAS, 1910.[2]

The results of the water-requirement measurements of wheat and sorghum in 1910 at Akron, in northeastern Colorado, and at Amarillo, near the center of the Panhandle of Texas, including data for the individual pots, are given in Table I. In this series of experiments the water was not applied at the top of the pot, as already described, but was led through a small pipe to a gravel layer in the bottom of the pot. This method was not found satisfactory. The

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[1] To those unaccustomed to thinking in terms of "probable error" it may be said that the probable error serves as a measure of the extent of the agreement among the individual observations. The more nearly the individual observations agree, the smaller is the probable error. If the experiments had been conducted with 12 cans instead of 6, and if both sets were representative, the chances are even that the mean of the second lot (m_2) would have agreed with the mean of the first lot (m_1) within the limits of the probable error ($\pm a$) of the latter; or, algebraically, that $m_1+a>m_2>m_1-a$. The chances are 4.5 to 1 that the mean of the second set will agree with the first within limits equal to twice the probable error, i. e., 4.5 to 1 that $m_1+2a>m_2>m_1-2a$, and similarly, 21 to 1 that $m_1+3a>m_2>m_1-3a$.

The probable error of the difference of two means, each affected with a probable error, is equal to the square root of the sum of the squares of the two probable errors. If the difference of the two means is no greater than its probable error, the chances are even that the difference is fictitious. If the difference of the means is twice its probable error, the chances are 4.5 to 1 that a measurable difference exists between the two series; and, similarly, if the difference is equal to three times its probable error the chances are 21 to 1 that the series are measurably different. This last is often taken as the criterion of an actual difference in two series.

[2] The writers are indebted to Mr. E. F. Chilcott for conducting the tests at Amarillo, Tex., in 1910, and o Prof. A. F. Kidder and Mr. Homer Martin for assistance at Akron, Colo., during the same year.

upward capillary movement, particularly in the case of the Akron soil, was so slow that it was impossible to maintain the upper part of the soil mass at a suitable moisture content without getting the lower part too wet. This virtually decreased the soil mass and may be responsible in part for the higher water requirement obtained in 1910 as compared with 1911. The soil used at Akron in 1910 was not as productive as that used in the 1911 experiments, and this may also have increased the water requirement.

TABLE I.—*Water requirement of wheat and sorghum.*

AKRON, COLO., 1910.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka wheat, G. I. 1440 (*Triticum durum*), Apr. 18 to Aug. 2.	1	29.2	....	21.38	....	....	732
	2	53.5	....	36.65	....	....	685
	3	45.1	....	22.90	....	....	508
	4	26.85	....	20.68	....	....	770
	5	22.4	....	13.14	....	....	586
	6	25.5	....	17.97	....	....	705
Mean	....	....	....	....	....	....	664±30
Red Amber sorghum, S. P. I. 17548 (*Andropogon sorghum*), May 25 to Sept. 28	25	112.9	....	42.1	....	....	373
	26	126.0	....	46.3	....	....	367
	27	153.7	....	62.0	....	....	403
	28	180.5	....	57.4	....	....	318
	29	164.3	....	58.5	....	....	356
	30	234.6	....	75.0	....	....	320
Mean	....	....	....	....	....	....	356±9

AMARILLO, TEX., 1910.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
Kubanka wheat, G. I. 1440 (*Triticum durum*), Apr. 5 to July 19.	1	93.6	21.1	83.3	23	3,940	890
	2	73.3	15.4	68.2	21	4,430	930
	3	102.7	23.2	87.1	23	3,750	848
	4	81.9	18.8	64.8	23	3,440	791
	5	92.4	21.4	80.1	23	3,740	868
	6	114.3	31.5	90.4	28	2,870	790
Mean	....	....	....	....	....	3,695±140	853±16
Red Amber sorghum, S. P. I. 17548 (*Andropogon sorghum*), May 10 to Aug. 28	7	334.9	81.0	114.1	24	1,419	341
	8	302.0	57.1	108.1	19	1,894	358
	9	326.2	72.8	120.3	22	1,653	369
	10	359.4	43.1	126.6	12	2,938	352
	11	336.6	78.2	121.9	23	1,558	362
	12	340.3	67.6	126.3	20	1,879	371
Mean	....	....	....	....	....	1,890±130	359±3

SUMMARY OF RESULTS IN 1910.

Crop.	Location.	Mean water requirement based on— Grain.	Mean water requirement based on— Dry matter.
Wheat	Amarillo, Tex.	3,695±140	853±16
	Akron, Colo.	....	664±30
Sorghum	Amarillo, Tex.	1,890±130	359±3
	Akron, Colo.	....	356±9

It will be noted that the water requirement of wheat based on the dry matter produced was about 28 per cent higher at Amarillo than at Akron, while that of the sorghum was the same in both cases. The yield of grain was poor in each case, and no weight is to be attached to the water requirement of the grain. The variety of sorghum used is grown for forage only.

WATER REQUIREMENT OF WHEAT AND SORGHUM IN TEXAS, 1911.[1]

The water-requirement measurements at Dalhart, Tex., in 1911 were confined to two crops, wheat and sorghum. This station is located in the extreme northwestern part of the Panhandle of Texas, and has an elevation of about 4,000 feet and an annual rainfall of about 16 inches. Sorghum is one of the best crops of this region, while wheat is uncertain. Six standard pots of each crop were grown in a screened inclosure of the same type as that used at Akron in 1911, but smaller. This was placed in a freely exposed position, so that the crops were subjected to the strong winds of that region. The pots were placed in two rows running east and west, the sorghum being placed on the north side to avoid shading the wheat. The period of growth was chosen to conform as nearly as possible to that of the same crops in the field. A summary of the results is given in Table II. The water requirement of the wheat based on dry matter was 673 ± 17. The water requirement based on grain was 3,830. Comparing these results with similar measurements made at Akron, Colo., the same year (p. 17), it will be seen that the wheat grown at Dalhart required 43 per cent more water than at Akron for the production of the same amount of dry matter and 230 per cent more water for the production of the same amount of grain. This discrepancy in the ratios, combined with the low grain yield in the pots at Dalhart, leads the writers to question the water-requirement ratio obtained for grain at this station.

The water requirement for Red Amber sorghum at Dalhart in 1911 was 313 ± 10 when based on dry matter and $1,092 \pm 47$ when based on grain. This is only 5 per cent higher than the water requirement for this variety at Akron during the same year (p. 27), while the water requirement based on grain is 27 per cent less than at Akron. It should be stated in this connection that Red Amber sorghum is a variety grown for forage rather than for seed.

[1] The writers are indebted to Mr. F. L. Kennard and Mr. W. D. Griggs for conducting the tests at Dalhart, Tex., in 1911.

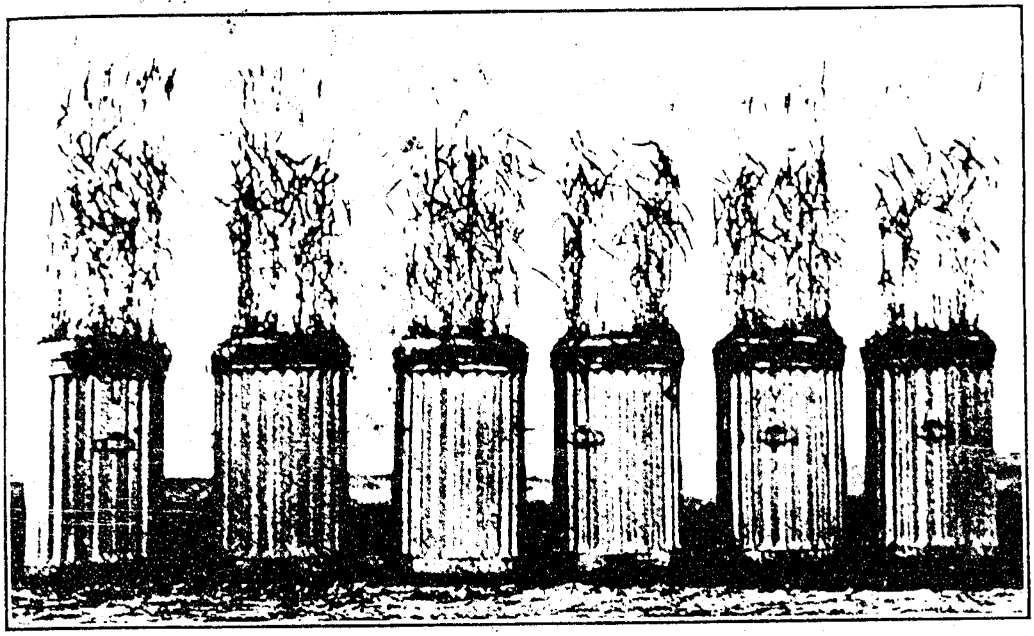


FIG. 1.—MARVEL BLUESTEM WHEAT, GROWN MAY 13 TO AUGUST 7, 1911 (POTS 13 TO 18).
Water requirement, 531 ± 5.

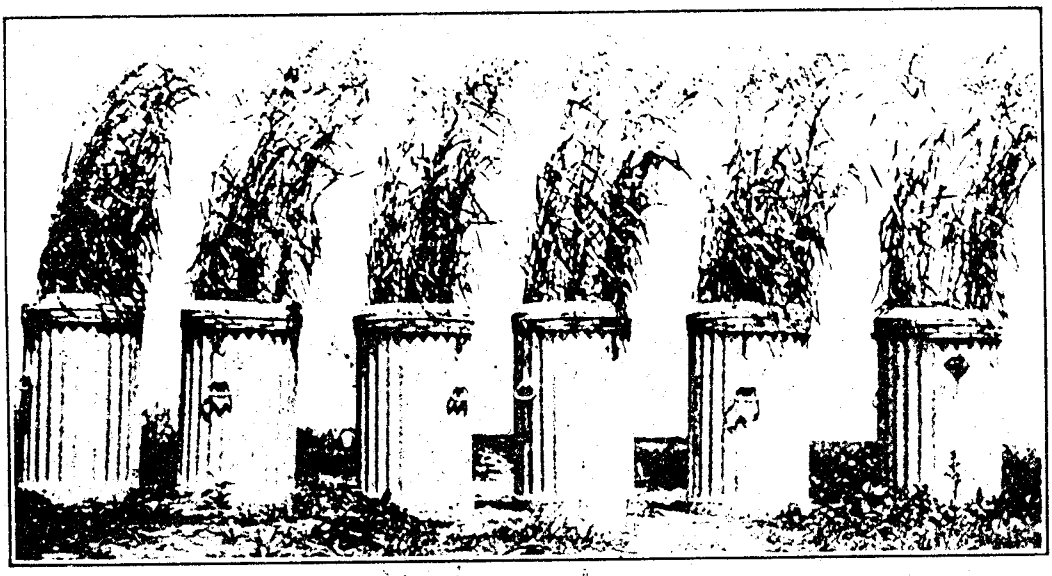


FIG. 2.—SWEDISH SELECT OATS, GROWN MAY 13 TO AUGUST 7, 1911 (POTS 49 TO 54).
Water requirement, 615 ± 7.

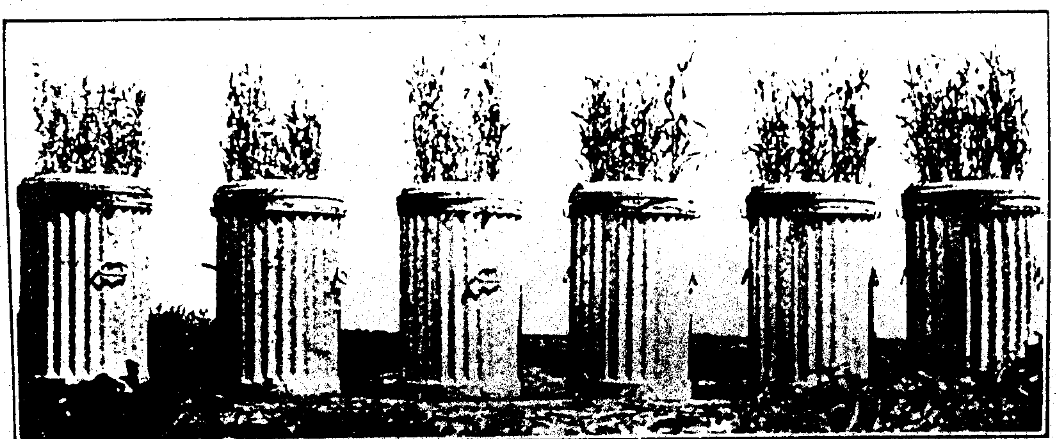
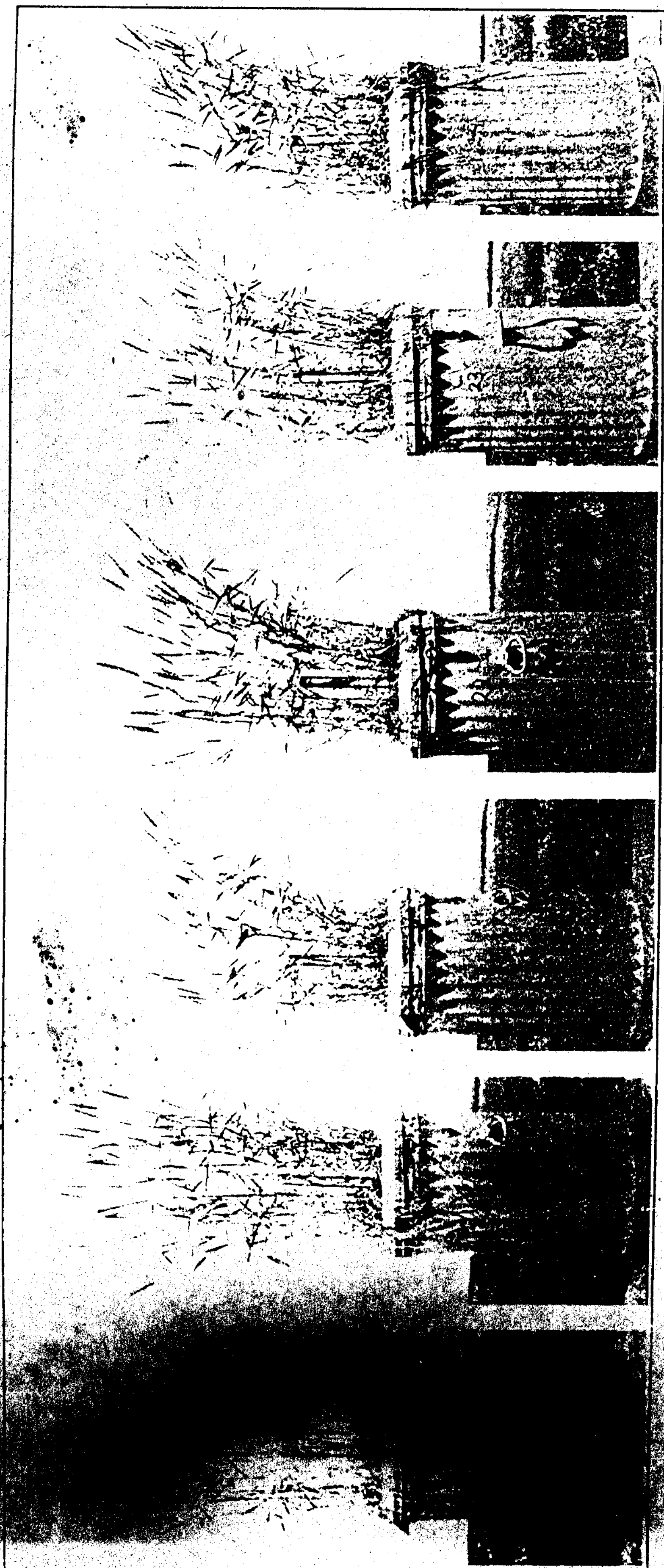


FIG. 3.—BELDI BARLEY, GROWN MAY 13 TO AUGUST 1, 1911 (POTS 61 TO 66).
Water requirement, 513 ± 2.



GALGALOS WHEAT, GROWN MAY 13 TO AUGUST 1, 1911 (POTS 19 TO 24).

Water requirement, 496 ± 4.

TABLE II.—*Water requirement of wheat and sorghum at Dalhart, Tex., in 1911.*

Crop.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka wheat, G. I. 1440 (*Triticum durum*), Apr. 25 to July 18	1	48.4	8.4	29.9	17	3,560	618
	2	49.4	11.1	31.0	22	2,790	628
	3	43.7	8.5	31.4	19	3,690	719
	4	43.9	8.2	29.6	19	3,610	674
	5	41.8	6.3	31.8	15	5,020	761
	6	42.5	6.3	27.2	15	4,320	640
Mean						3,830±200	673±17
Red Amber sorghum (*Andropogon sorghum*), May 14 to Sept. 12	7	285.8	88.7	81.0	31	913	283
	8	274.2	72.7	81.4	27	1,119	297
	9	289.9	80.5	84.2	28	1,045	291
	10	243.9	67.2	88.1	28	1,310	361
	11	286.9	90.9	85.6	32	942	298
	12	241.3	68.1	83.3	28	1,222	345
Mean						1,092±47	313±10

WATER-REQUIREMENT MEASUREMENTS IN COLORADO, 1911.[1]

Akron, Colo., where most of the water-requirement measurements described in this bulletin have been made, is a point in northeastern Colorado about 100 miles east of Denver. It is an open, treeless, rolling plains country. Dry farming has received considerable attention, but most of the land is still covered with the native short grass. (Shantz, 1911.) The annual rainfall is about 18 inches, three-fourths of which falls during six months, April to September. The humidity is normally low, and the hot summer days are followed by cool nights. The sky is seldom perfectly clear and sunshine is frequently followed quickly by cloud. The storms are often extremely local in character and many times are attended with high winds and occasionally with hail. As Akron is located in the center of the Great Plains, from east to west as well as from north to south, the measurements serve also to represent roughly the water requirement of crops for the Great Plains as a whole.

WATER REQUIREMENT OF DIFFERENT VARIETIES OF WHEAT.

Five varieties of wheat, including one of emmer, were tested as regards their water requirements at Akron, Colo., in 1911. The series included one variety of *Triticum durum*, the Kubanka; three varieties of *Triticum aestivum*, Marvel Bluestem (Pl. III, fig. 1), Galgalos (Pl. IV), and Spring Ghirka; and one variety of *Triticum dicoccum*, or emmer. The Kubanka series consisted of 17 pots, 6 of which were fertilized. The unfertilized pots were distributed at the two ends of the inclosure, Nos. 1 to 6, inclusive, being at

[1] The writers are indebted to Messrs. Auguste Bonrquet, Alan Peter, and Homer Martin for assistance in the Akron, Colo., experiments in 1911.

the south end and the remainder at the north end. Referring to Table III it will be seen that the mean water requirement of the unfertilized Kubanka wheat for the 11 pots was 468±8, while the water requirement of the grain alone was 1,196±15. The pots of Kubanka wheat located at the north end of the inclosure appear to have a slightly higher water requirement. This part of the inclosure was occupied by the corn and sorghums, and since these latter plants did not reach any considerable development until the wheat was practically ripe the wheat plants in the north end of the inclosure were severely exposed to the winds during practically the whole period of growth. While the wind moved freely through the shelter at all times, the other plants were not whipped as were these isolated plants.

Six pots of Kubanka wheat, Nos. 7 to 12, inclusive, were fertilized. 20 grams of potassium nitrate and 20 grams of sodium acid phosphate being added to each pot. This amount of fertilizer was divided into five parts and each part was dissolved in a liter of water and added to the pots at intervals, additional water being added after the fertilizer. The water requirement of the fertilized Kubanka wheat was 422±6, while that of the grain alone was 1,184±36. It thus appears that the use of fertilizer reduced the water requirement only slightly, so far as the total dry matter is concerned, the difference between the fertilized and unfertilized pots being about three times the probable error. In the case of the grain, the addition of fertilizer appeared to have no effect upon the water requirement. As we have already stated, the soil used in the experiments of 1911 was a rich, dark loam selected with the belief that no additional fertilizer would be required to give a minimum water requirement and the results indicate that sufficient plant food was available.

The other wheat varieties tested all gave a higher water requirement than Kubanka, the values obtained based upon the total dry matter being as follows:

Kubanka	468± 8
Galgalos	496± 4
Spring Ghirka	506± 3
Marvel Bluestem	531± 5
Emmer	534±14

The grain requirement is in the same order as the dry-matter requirement except in the case of emmer, which gave a grain requirement practically identical with Kubanka wheat. In this connection it should be remembered that the "grain" of emmer includes the entire spikelet. The glumes or chaff constitute about 21 per cent of the weight of the harvested grain. Consequently the water requirement for the production of the true grain is 1,490. This value is now comparable with the grain yields of the wheat varieties. The water requirement of the different varieties is then as follows:

Emmer (including glumes)	1,180±42
Kubanka	1,191±14
Galgalos	1,245±13
Spring Ghirka	1,382±43
Emmer (without glumes)	1,490±53
Marvel Bluestem	1,786±60

The above summary shows emmer to have a water requirement for grain production higher than any other wheat with the exception of the Marvel Bluestem.

It is of special interest to note that Marvel Bluestem, a variety grown extensively in humid regions, gave a higher water requirement, both for dry matter and for grain, than any of the other varieties of wheat tested, requiring 13 per cent more water than Kubanka wheat to produce an equal amount of dry matter, and nearly 50 per cent more to produce an equal amount of grain.

TABLE III.—*Water requirement of different varieties of wheat at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Kubanka, G. I. 1440 (*Triticum durum*), May 13 to Aug. 2	1	110.6	43.9	49.5	40	1,128	448
	2	120.1	48.4	61.6	40	1,272	513
	3	87.4	33.1	39.9	38	1,205	456
	4	104.1	40.0	44.75	38	1,119	430
	5	113.4	45.6	50.9	40	1,116	449
	6	73.9	25.8	29.4	35	1,139	398
	199	84.8	35.6	40.5	42	1,138	477
	200	75.0	30.5	37.2	41	1,219	496
	202	90.5	36.1	47.3	40	1,310	523
	203	65.2	25.1	30.55	39	1,217	469
	204	110.6	43.8	54.45	40	1,243	492
Mean						1,191±14	468±8
Kubanka, G. I. 1440 (*Triticum durum*), May 13 to Aug. 2 (fertilized)	7	92.6	32.7	36.45	36	1,114	394
	8	128.9	45.2	57.2	35	1,265	444
	9	79.7	24.7	34.4	31	1,392	432
	10	110.0	41.8	44.1	38	1,055	401
	11	114.8	44.0	50.15	38	1,139	437
	12	89.3	33.1	37.8	37	1,142	423
Mean						1,184±36	422±6
Marvel Bluestem, G. I. 3082 (*Triticum aestivum*), May 13 to Aug. 7	13	121.3	30.7	68.6	25	2,233	565
	14	120.4	38.0	61.95	32	1,630	514
	15	132.6	39.4	71.4	30	1,811	538
	16	127.0	38.7	67.1	31	1,734	528
	17	121.4	37.6	64.1	31	1,704	528
	18	140.2	44.7	71.6	32	1,602	510
Mean						1,786±60	531±5
Galgalos, G. I. 2398 (*Triticum aestivum*), May 13 to Aug. 1	19	109.5	43.9	54.65	40	1,244	499
	20	119.6	45.1	60.7	38	1,345	507
	21	104.5	42.2	52.65	40	1,247	504
	22	121.2	49.3	58.7	41	1,190	484
	23	108.2	43.3	52.0	40	1,200	480
	24	116.4	47.0	58.5	40	1,244	502
Mean						1,245±13	496±4

TABLE III.—*Water requirement of different varieties of wheat at Akron, Colo., in 1911*—Continued.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Spring Ghirka, G. I. 1517 (*Triticum aestivum*), May 13 to Aug. 4	25	113.2	39.5	55.9	35	1,415	494
	26	125.5	44.8	63.1	36	1,408	503
	27	120.2	38.2	63.2	32	1,654	526
	28	120.7	44.5	61.2	37	1,375	507
	29	109.1	39.2	54.6	36	1,393	500
	30	110.5	53.2	55.7	48	1,047	504
Mean						1,382±43	506±3
Emmer, G. I. 2951 (*Triticum dicoccum*), May 13 to Aug. 4	79	111.1	50.9	52.3	46	1,027	471
	80	120.4	57.9	59.8	48	1,032	497
	81	120.5	52.1	71.8	43	1,378	596
	82	87.4	39.5	45.4	45	1,149	519
	83	103.4	46.0	57.7	45	1,254	558
	84	121.2	54.9	68.2	45	1,242	562
Mean						1,180±42	534±14

WATER REQUIREMENT OF DIFFERENT VARIETIES OF OATS.

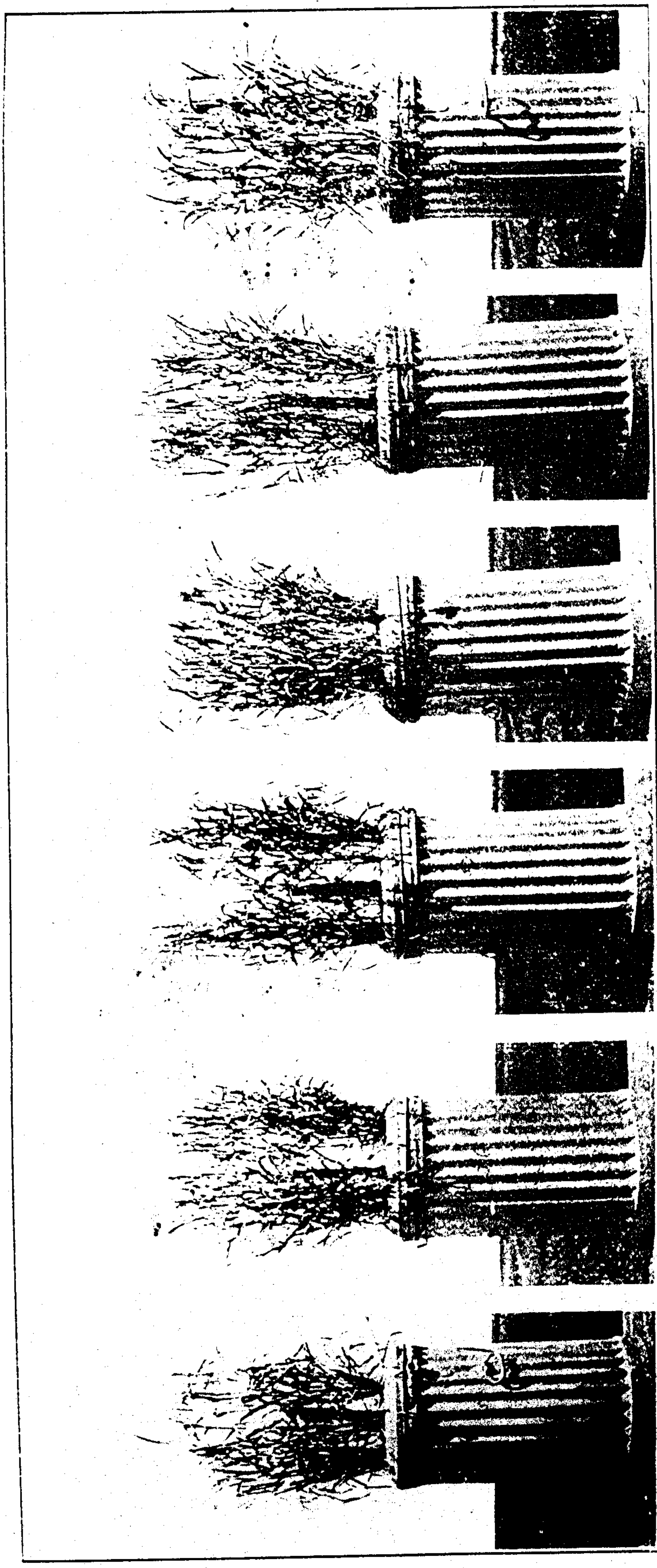
The experiments with oats at Akron, Colo., in 1911 included four varieties, namely, Sixty-Day, Canadian, Burt, and Swedish Select. (Table III and Pl. III, fig. 2.)

A summary of the water requirements of the different varieties of oats, based on dry matter, is here given:

Canadian	598±14
Sixty-Day	605± 5
Swedish Select	615± 7
Burt	639± 7

Very little difference is shown by the different varieties in their water requirement when based on the production of dry matter; in fact, the difference between the Canadian and the Burt is less than three times the probable error. In the case of the Sixty-Day and the Burt the difference is four times the probable error, indicating a small but real difference in the water requirement of these varieties. This is of especial interest when we consider the growth habits of the different varieties. The luxuriant broad-leaved Canadian, a plant which seems ill adapted to a dry country, has apparently the lowest water requirement, while the least leafy plant, the Burt, has the highest. However, the small-growing Sixty-Day and Burt varieties are far more economical than the Canadian in the use of water when the grain yield is considered. This is shown in the following summary of the water requirement of the different varieties based on grain production:

Sixty-Day	1,383±30
Burt	1,500±57
Swedish Select	1,632±35
Canadian	2,204±140



HANNCHEN BARLEY, GROWN MAY 13 TO AUGUST 12, 1911 (POTS 55 TO 60).

Water requirement, [illegible]

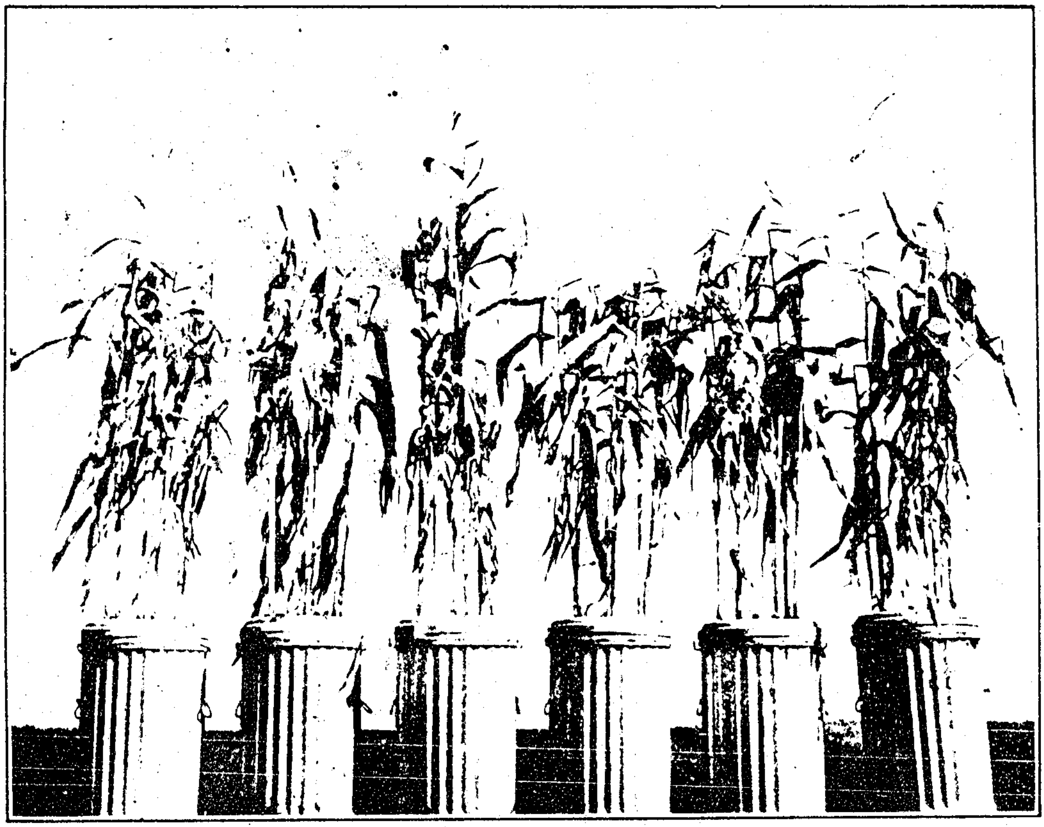


FIG. 1.—IOWA SILVERMINE CORN, GROWN MAY 24 TO SEPTEMBER 4, 1911 (POTS 115 TO 120).

Water requirement, 120 ± 3.

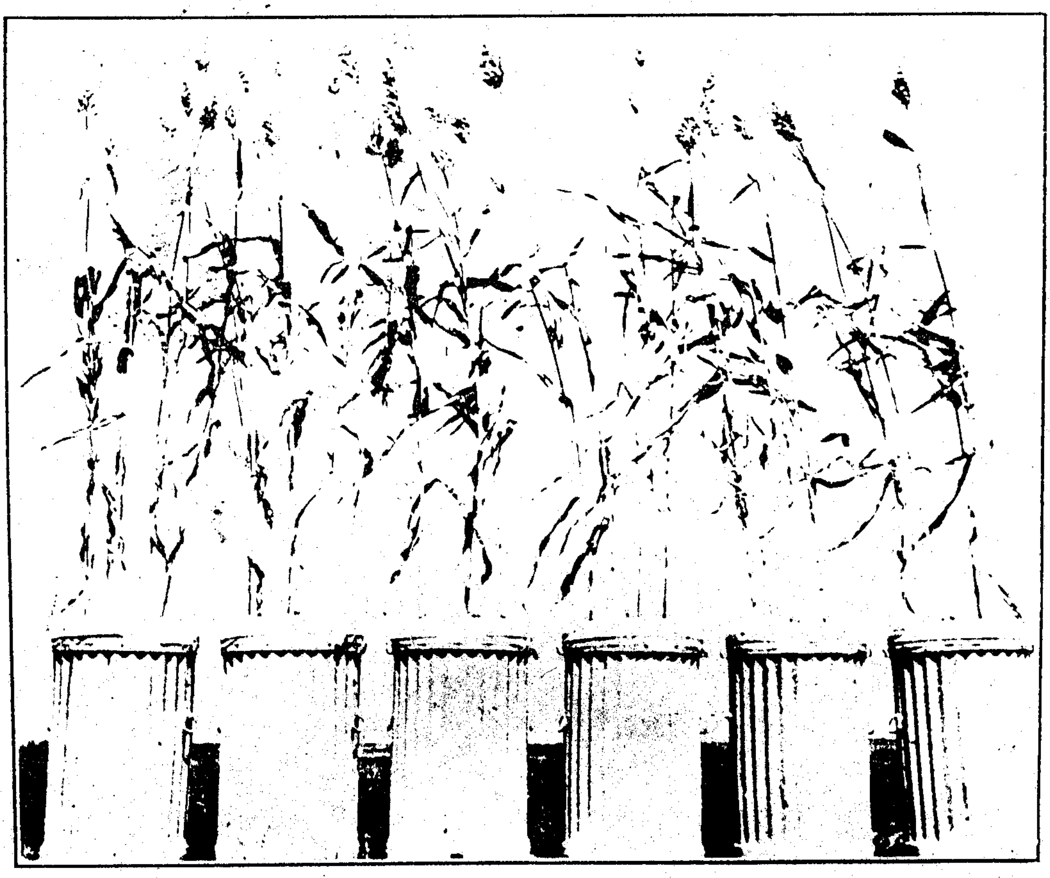


FIG. 2.—WHITE DURRA, GROWN MAY 12 TO SEPTEMBER 5, 1911 (POTS 145 TO 150).

Water requirement, [illegible]

Swedish Select is intermediate both in habit of growth and in its water requirement based upon either dry matter or grain. As compared with Kubanka wheat, the oat plants appear to require about 30 per cent more water for the production of an equal amount of dry matter and even the best varieties of oats require 15 per cent more water than Kubanka wheat for an equal production of grain.

TABLE IV.—*Water requirement of different varieties of oats at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on— Grain.	Water requirement based on— Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Sixty-Day, G. I. 165 (*Avena sativa*), May 13 to Aug. 2	31	124.1	52.9	75.7	43	1,431	610
	32	117.1	53.7	71.0	46	1,321	606
	33	38.3	15.2	22.0	40	1,447	574
	34	119.3	53.6	71.4	45	1,332	598
	35	124.5	51.7	78.0	42	1,509	626
	36	138.0	67.0	84.55	49	1,262	613
Mean						1,383±30	605±5
Canadian, G. I. 444 (*Avena sativa*), May 13 to Aug. 12	37	46.5	8.2	25.7	18	3,134	553
	38	125.0	39.0	79.1	31	2,028	633
	39	135.2	46.2	81.3	34	1,759	601
	40	112.7	32.4	60.4	29	1,864	536
	41	125.8	41.6	84.8	33	2,038	674
	42	110.6	27.3	65.5	25	2,400	592
Mean						2,204±143	598±14
Burt, G. I. 293 (*Avena sativa*), May 13 to Aug. 12	43	137.6	53.5	90.9	39	1,698	660
	44	141.8	53.7	89.6	38	1,668	632
	45	160.8	75.2	106.9	47	1,422	665
	46	124.8	54.1	77.8	43	1,438	623
	47	143.6	73.3	87.0	51	1,187	606
	48	149.9	61.2	97.1	41	1,586	648
Mean						1,500±57	639±7
Swedish Select, G. I. 134 (*Avena sativa*), May 13 to Aug. 7	49	174.2	76.0	108.7	44	1,430	624
	50	181.2	67.7	109.3	37	1,615	603
	51	150.2	53.4	98.9	36	1,851	658
	52	172.0	62.4	103.3	36	1,660	601
	53	168.0	62.3	103.4	37	1,661	616
	54	196.7	73.3	115.4	37	1,575	587
Mean						1,632±35	615±7

WATER REQUIREMENT OF DIFFERENT VARIETIES OF BARLEY.

Four barleys, including three varieties of *Hordeum vulgare*, the Beldi (Pl. III, fig. 3), White Hull-less, and Beardless, and one variety of *Hordeum distichon*, the Hannchen (Pl. V), were included in the experiments at Akron, Colo., in 1911 (Table V). The results of the water requirement determinations with varieties of barley, based upon the dry matter produced, are [illegible]

Hannchen.. 527±8
White Hull-less.................................. 542±3
Beldi.. [illegible]±2
Beardless.. [illegible]±9

Like the oats, the several varieties of barley tested showed practically no difference in the water requirement when based on dry matter, the agreement being even more striking. Thus, in the case of the three varieties of *Hordeum vulgare* the water requirement is 543 ± 2, 542 ± 3, and 544 ± 9. The other species, *Hordeum distichon*, is slightly lower, namely, 527 ± 8, but no weight can be attached to so slight a difference when the probable errors are considered.

When the water requirement is based upon the grain produced, three of the varieties are again in practical agreement. The White Hull-less is, however, a little higher than the others, and this hull-less character should be considered in comparing the water requirements. If the hulls are removed from the grain of the Beldi the water requirement is increased from 1,155 to 1,220, which is still much lower than the water requirement for the hull-less barley. The increase due to removing the hulls is even less in the case of Hannchen barley. It is evident, therefore, that the higher water requirement for grain production by hull-less barley is only partly due to the naked grain and that for the production of an equal amount of true grain the other varieties considered require somewhat less water. A summary of the water requirement of the different varieties of barley tested, when calculated upon the basis of grain produced, is given below:

Hannchen	1,134 ± 27
Beldi	1,155 ± 18
Beardless	1,210 ± 38
Beldi (hulled)	1,220 ± 19
White Hull-less	1,475 ± 40

Here, again, a great difference exists in the habits of the plants, the Beldi being a dwarf variety with a stem so short as to make harvesting difficult, while the other varieties have a more luxuriant habit of growth, with numerous large well-developed leaves. From the results of these experiments barley appears to require about 15 per cent more water than Kubanka wheat for an equal amount of dry matter, being nearly midway between the oat plant and Kubanka wheat in its water requirement. In the production of grain the best varieties of barley require only about 5 per cent less water than does Kubanka wheat.

TABLE V.—*Water requirement of different varieties of barley at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Hannchen, G. I. 531 (*Hordeum distichon*), May 13 to Aug. 12.	55	102.0	45.1	54.6	44	1,210	535
	56	149.8	66.2	71.3	44	1,077	476
	57	135.8	59.3	72.5	44	1,222	534
	58	146.0	64.1	75.7	44	1,181	518
	59	142.1	74.5	74.6	52	1,000	525
	60	142.3	73.6	82.0	52	1,114	576
Mean						1,134±27	527±8
Beldi, G. I. 190 (*Hordeum vulgare*), May 13 to Aug. 1	61	85.9	35.4	45.7	41	1,291	532
	62	92.3	45.9	50.4	50	1,098	546
	63	77.5	37.1	42.7	48	1,151	551
	64	97.6	45.7	52.8	47	1,155	541
	65	85.9	44.0	47.2	51	1,072	550
	66	100.4	46.4	54.0	46	1,164	538
Mean						1,155±18	543±2
White Hull-less, G. I. 595 (*Hordeum vulgare*), May 13 to July 31	67	107.0	43.2	60.7	40	1,405	567
	68	140.2	51.2	73.3	37	1,431	522
	69	114.2	48.2	61.1	42	1,268	535
	70	134.9	44.1	73.0	33	1,655	541
	71	104.6	38.0	56.8	36	1,494	543
	72	124.8	42.4	67.6	34	1,594	542
Mean						1,475±40	542±3
Beardless, G. I. 716 (*Hordeum vulgare*), May 13 to Aug. 1	74	119.5	57.6	64.7	48	1,123	542
	75	84.4	36.8	49.7	44	1,350	589
	76	106.2	48.6	58.9	46	1,211	554
	77	88.6	35.3	45.6	40	1,291	515
	78	70.0	33.9	36.4	48	1,073	520
Mean						1,210±38	544±9

WATER REQUIREMENT OF RYE AND BUCKWHEAT.

The determinations of the water requirements of rye and buckwheat (see Pl. X, fig. 3) at Akron, Colo., in 1911 were limited to one variety of each. The results are given in Table VI. From the table it appears that rye has a surprisingly high water requirement, the ratio of the water transpired to the dry matter produced being 724 ± 7, or nearly 54 per cent more than for Kubanka wheat. The grain requirement is also exceptionally high, the plants requiring 2,200 pounds of water for the production of 1 pound of grain.

If these ratios are confirmed by subsequent tests, the use of rye as a soiling crop would appear to be a very doubtful expedient in regions of limited rainfall. Wheat, for example, would produce the same amount of dry matter with the expenditure of only two-thirds the amount of water required in the case of rye. Every 300 pounds of rye produced per acre means the removal of 1 inch of stored rainfall. The production of a moderate crop of 1,500 pounds of dry matter per acre means then the removal of 5 inches of stored water, unless the conditions are such that the necessary water for growth is supplied through rains during the growing season. The removal of 5 inches of water would deplete the available stored moisture supply in the average semiarid cultivated soil of the Great Plains, even after summer fallowing for a season. It is doubtful, therefore, if rye should be used as a soiling crop on land that is to be planted to a money crop in regions of limited rainfall. Its use should at least be confined to the fall and early spring, when the water requirement, owing to the cooler weather, is considerably reduced. (See "Alfalfa," under "Water requirement of legumes," p. 29.)

In this connection it is interesting to consider the results obtained by Von Seelhorst for rye and wheat at Gottingen, Germany. (1906, 1908.) They are in practical agreement with our results, but Von Seelhorst is inclined to favor rye as a soiling crop, notwithstanding its higher water requirement, because its period of maximum consumption of water comes so much earlier in the season than does that of wheat. This allows the accumulation of water in the soil before the next crop is ready to use it. While this would be an important consideration in a region of ample and well-distributed rainfall, in a region such as the Great Plains the chief consideration is not *when* the water is removed but *how much* water is removed by the soiling crop.

Buckwheat gave a mean water requirement for the dry matter produced of 578±13, which is about 23 per cent higher than Kubanka wheat and intermediate between barley and oats. The water requirement of the grain in the case of buckwheat is, however, exceptionally low, being 13 per cent less than for Kubanka wheat and the lowest of all the small grains measured except millet.

TABLE VI.—*Water requirement of rye and buckwheat at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on — Grain.	Water requirement based on — Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Spring rye, G. I. 73 (*Secale cereale*), May 13 to Aug. 5	85	88.1	28.4	63.7	32	2,242	723
	86	89.0	28.5	69.5	32	2,439	781
	87	80.2	24.7	55.8	31	2,259	696
	88	78.4	25.4	55.9	32	2,200	713
	89	89.1	29.7	64.4	33	2,168	722
	90	88.6	31.7	62.8	36	1,981	709
Mean						2,215±37	724±7
Buckwheat (*Fagopyrum fagopyrum*), June 10 to Sept. 16	193	109.9	62.5	57.7	57	923	525
	194	116.7	67.0	64.9	57	969	556
	195	67.1	35.1	39.9	52	1,137	594
	196	59.5	31.9	36.1	54	1,131	607
	173	93.3	55.3	56.8	59	1,027	609
Mean						1,037±33	578±13

WATER REQUIREMENT OF DIFFERENT VARIETIES OF CORN.

Three varieties of corn (*Zea mays*) were included in the water-requirement experiments at Akron, Colo., during the season of 1911. (Table VII.) Northwestern Dent is an early-maturing variety grown extensively in the northern part of the Great Plains, where the season is rather short for maize. Its water requirement was found to be 368 ± 10. Iowa Silvermine (Pl. VI, fig. 1) is a variety which is very popular in corn-growing States and has a vigorous habit of growth, with well-developed leaves. Its water requirement was 420 ± 3, which is considerably above that obtained for Northwestern Dent. Neither of these varieties gave so low a water requirement as did Esperanza, a drought-resistant Mexican variety introduced by Mr. G. N. Collins, of the Office of Crop Acclimatization and Adaptation Investigations. This variety gave a water requirement of 319 ± 5, which is only about three-fourths of the water requirement of the Iowa Silvermine. Esperanza, however, produced no ears at Akron. Owing to our failure to secure a good pollination of the ears, no significance can be attached to the water requirement for the production of grain in the case of the different varieties of corn tested.

A comparison of the results obtained with corn and sorghum shows the surprising and important fact that Esperanza corn produced dry matter as economically as did Dwarf milo and white durra. Even the large, luxuriant Iowa Silvermine required only 26 per cent more water than the Dwarf milo, one of the most successful drought-resistant crops of the southern Great Plains. It would seem from these results that in corn we have a wonderfully efficient plant, and that varieties may be chosen which will compete successfully with plants of the sorghum group as regards economy in the use of water. Where corn is grown far apart and with only one plant in a hill, as is the practice in dry regions, and where the ground is kept free from weeds it is not surprising that the rotation of fall wheat after corn has in many places supplanted the rotation of fall wheat after summer tillage. While during extremely dry years grains give a greater money return when grown on summer-fallowed land, one year with another, the money return from the corn crop more than compensates for the lower grain yield during the exceptionally dry years.

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TABLE VII.—*Water requirement of different varieties of corn at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on —	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Northwestern Dent (*Zea mays*), May 24 to Aug. 23	109	179.0	72.8	55.2	41	758	308
	110	173.5	58.6	60.35	34	1,029	348
	111	154.1	28.2	58.75	18	2,083	381
	112	160.1	37.7	61.05	24	1,619	381
	113	151.8	25.3	61.45	17	2,429	405
	114	145.9	13.0	56.2	9	4,320	385
Mean						2,040±342	368±10
Iowa Silvermine (*Zea mays*), May 24 to Sept. 4	115	232.5		102.7			442
	116	260.5		104.55			401
	117	221.8		93.3			421
	118	224.2		93.85			418
	119	232.4		96.66			416
	120	237.7		100.0			421
Mean							420±3
Esperanza, M. 66 (*Zea mays*), May 12 to Sept. 4	121	288.8		83.4			289
	122	262.6		84.7			323
	123	279.5		93.8			335
	124	317.9		103.1			324
	125	268.4		83.75			312
	126	287.0		95.85			334
Mean							319±5

WATER REQUIREMENT OF DIFFERENT VARIETIES OF SORGHUM.

Five varieties of sorghum (*Andropogon sorghum*) (Pls. VI to VIII) were tested as regards their water requirements at Akron, Colo., in 1911. The data are given in detail in Table VIII. The water requirement of the five varieties, based on the dry matter, is as follows:

Blackhull kafir	278±5
Red Amber sorghum	298±4
Brown kaoliang	301±3
White durra	321±2
Dwarf milo	333±3

The adaptation to dry-land conditions of this remarkable group of forage plants is well shown in their unusually low water requirement, which taken as a group is well below all the other plants tested, with the exception of Esperanza corn and millet. The excellent agreement of the individual pot experiments is shown by the small probable error and justifies considerable confidence in the results as indicating the relative water requirements of the different varieties tested. It would therefore appear that Dwarf milo requires about 20 per cent more water than Blackhull kafir for an equal amount of dry matter.

The other varieties are intermediate, Red Amber sorghum requiring about 7 per cent, Brown kaoliang 8 per cent, and White durra 15 per cent more water than the kafir.

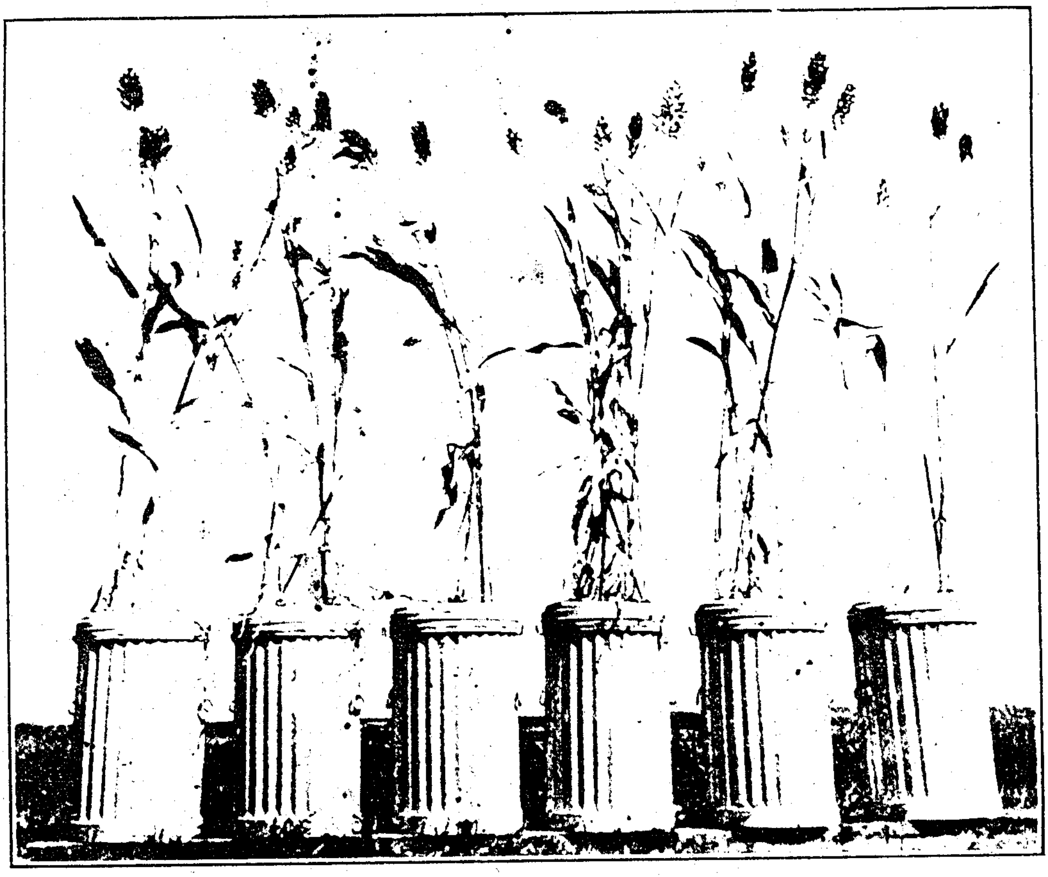

FIG. 1.—BROWN KAOLIANG, GROWN MAY 12 TO SEPTEMBER 6, 1911 (POTS 151 TO 156).

Water requirement, 301 ± 3.

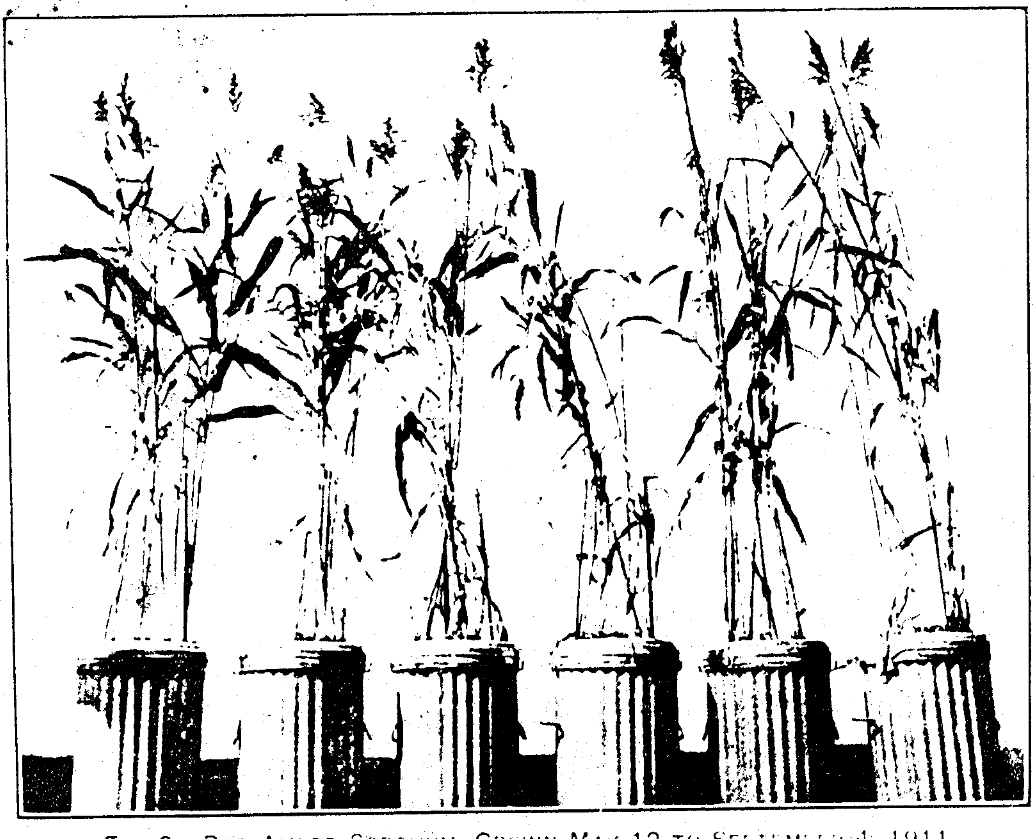

FIG. 2.—RED AMBER SORGHUM, GROWN MAY 12 TO SEPTEMBER 4, 1911 (POTS 127 TO 132).

Water requirement, 298 ± 4.

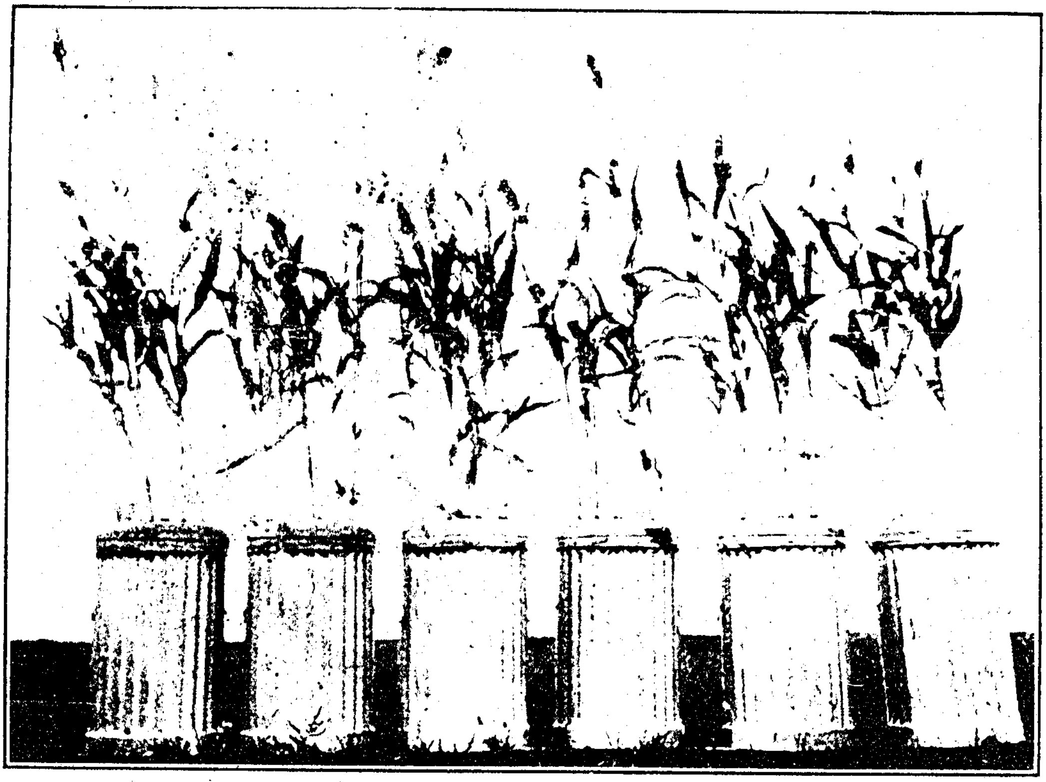

FIG. 1.—DWARF MILO, GROWN MAY 12 TO SEPTEMBER 14, 1911 (POTS 133 TO 138 [illegible]

Water requirement, [illegible] ± 8.

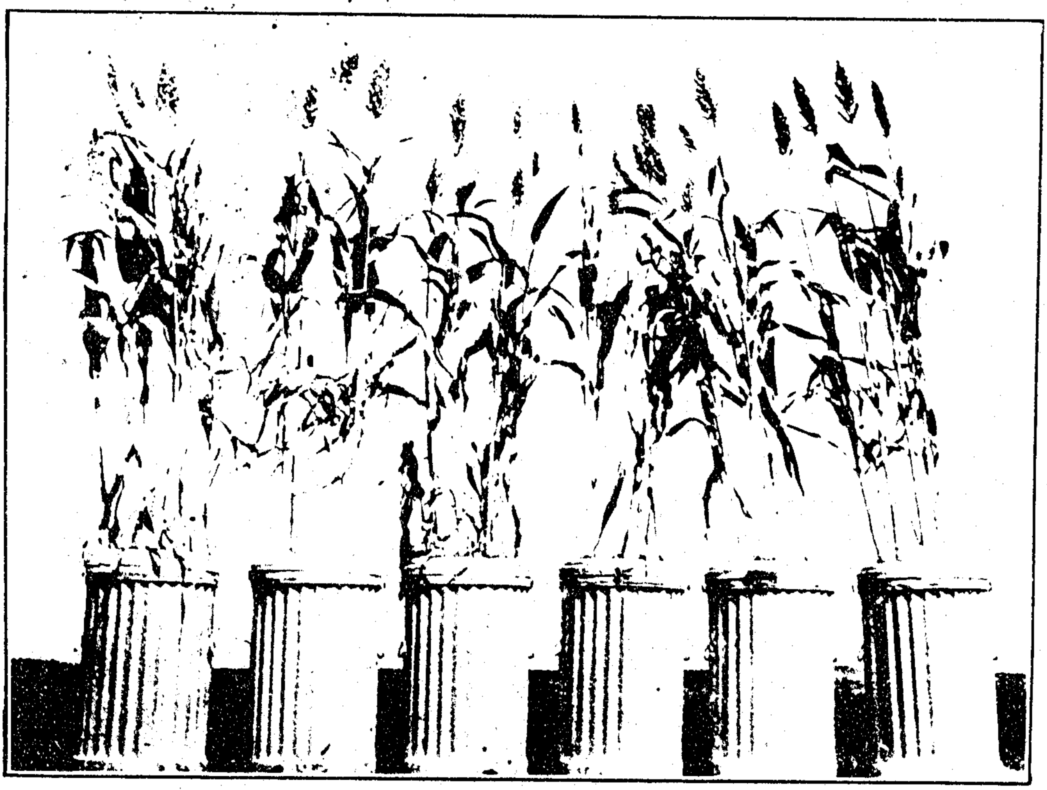

FIG. 2.—BLACKHULL KAFIR, GROWN MAY 12 TO SEPTEMBER 3, 1911 (POTS 139 TO 144).

Water requirement, 278 ± 5.

The water requirement of the five varieties of sorghum based upon grain production is as follows:

Brown kaoliang	726 ± 12
Blackhull kafir	803 ± 26
White durra	806 ± 12
Dwarf milo	1,123 ± 57
Red Amber sorghum	1,494 ± 202

It is of interest to note in this connection that Red Amber sorghum is not a grain sorghum, but is grown exclusively for forage. Of the grain varieties tested Brown kaoliang requires the least water, while Dwarf milo requires the most, its water requirement being 55 per cent greater than that of the kaoliang. White durra and Blackhull kafir have practically the same water requirement—about 11 per cent higher than the kaoliang. It is probable that the water requirement based on grain is too high in the case of Dwarf milo, since some of the flowers were slightly damaged by a midge before it was discovered and killed.

The group as a whole shows a remarkably low water requirement whether based on dry matter or on grain. The sorghums most efficient in the use of water consume about 60 per cent of the water required by Kubanka wheat in the production of either dry matter or grain.

TABLE VIII.—*Water requirement of different varieties of sorghum at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on — Grain.	Water requirement based on — Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Red Amber, S. P. I. 17543 (*Andropogon sorghum*), May 12 to Sept. 4	127	279.5	44.2	81.1	16	1,835	290
	128	303.1	81.1	94.7	27	1,168	312
	129	297.9	31.0	85.2	10	2,748	286
	130	300.4	71.3	94.2	24	1,321	313
	131	334.9	108.4	96.9	32	893	289
	132	329.7	97.7	97.3	30	996	295
Mean						1,494 ± 202	298 ± 4
Dwarf milo, S. P. I. 24970 (*Andropogon sorghum*), May 12 to Sept. 4	133	222.9	70.9	75.5	31	1,065	338
	134	238.1	74.4	82.0	31	1,102	344
	135	232.0	99.5	74.3	43	746	320
	136	249.4	68.7	84.2	28	1,226	338
	137	251.5	63.0	83.3	25	1,322	331
	138	265.6	67.5	86.2	25	1,276	325
Mean						1,123 ± 57	333 ± 3
Blackhull kafir, S. P. I. 24975 (*Andropogon sorghum*), May 12 to Sept. 3	139	310.0	108.1	85.1	35	787	274
	140	333.5	125.0	90.1	38	720	270
	141	335.7	94.7	89.1	28	941	265
	142	280.9	99.9	87.0	36	871	310
	143	333.5	126.2	88.2	38	699	264
	144	335.6	120.2	96.4	36	802	287
Mean						803 ± 26	278 ± 5

TABLE VIII.—*Water requirement of different varieties of sorghum at Akron, Colo., in 1911*—Continued.

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
White durra, S. P. I. 24997 (*Andropogon sorghum*), May 12 to Sept. 5	145	292.8	111.6	92.2	38	826	315
	146	257.8	110.4	80.4	43	728	312
	147	300.1	118.9	94.8	40	797	316
	148	248.3	101.3	82.9	41	818	334
	149	309.0	124.5	99.4	40	798	322
	150	291.3	109.2	94.55	38	866	324
Mean						806±12	321±2
Brown kaoliang, S. P. I. 24993 (*Andropogon sorghum*), May 12 to Sept. 6	151	297.3	119.2	85.1	40	714	286
	152	247.2	102.6	76.5	42	746	309
	153	244.7	91.7	77.8	38	848	318
	154	223.5	90.4	66.0	40	730	295
	155	263.2	116.9	77.2	44	660	293
	156	229.3	105.6	69.4	46	657	302
Mean						726±12	301±3

WATER REQUIREMENT OF DIFFERENT VARIETIES OF MILLET.

Millet is a remarkable plant with respect to economy in the use of water, both in the production of dry matter and of grain. The two varieties tested at Akron, Colo., in 1911 (Table IX), namely, Kursk and German, gave, respectively, a water requirement for the dry matter produced of 287±2 and 263±15, the latter figure being 44 per cent less than the water requirement of Kubanka wheat. The water requirement of the grain of Kursk millet was found to be 923±40, which is 23 per cent less than for Kubanka wheat and the lowest of any of the small grains measured. The ratios just given furnish an adequate explanation of the success of millet as a crop for semiarid regions. The amount of water required to produce a pound of rye (dry matter) would produce 2½ pounds of millet, and the same ratio applies to the grain as well. The water economy exercised by millet in the production both of dry matter and of grain is a fact of the greatest significance to farmers in regions of limited rainfall.

TABLE IX.—*Water requirement of different varieties of millet at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Kursk, S. P. I. 22420 (*Chaetochloa italica*), May 12 to Aug. 9.	157	159.7	45.5	47.3	29	1,040	296
	158	206.3	67.8	58.0	33	856	281
	159	234.9	73.3	67.1	31	916	286
	160	183.8	47.5	53.2	26	1,120	289
	161	229.0	81.2	64.6	36	796	282
	162	198.3	69.9	56.6	35	810	285
Mean						923±40	287±2
German, S. P. I. 26845 (*Chaetochloa italica*), May 12 to Aug. 21.	163	219.0	....	49.5	....	....	226
	164	175.9	....	48.1	....	....	273
	165	88.9	....	21.8	....	....	245
	166	105.5	....	25.5	....	....	242
	167	92.6	....	34.2	....	....	369
	168	120.7	....	26.5	....	....	220
Mean						....	263±15

WATER REQUIREMENT OF LEGUMES.

The legumes occupy an important position in dry-land agriculture, both in regard to their value as forage crops and from the standpoint of nitrogen fixation. The three legumes which have been most used in this connection are alfalfa, or lucern, Canada field peas, and sweet clover, and these species were tested at Akron, Colo., in 1911 as regards their water requirement. (Table X.)

The alfalfa made a splendid growth in the pots and three cuttings were made during the summer, the first on July 19 (Pl. IX, fig. 2), the second on September 18 (Pl. X, fig. 2), and the third on October 22. The first two crops attained their normal development, the plants being in full flower when the cuttings were made. The third cutting was made when the plants were about half grown. Considerable differences are, of course, to be expected in the water requirement of a crop grown at different seasons of the year, owing to changes in the climatic conditions. This is well illustrated in the case of the three crops of alfalfa, which gave the following water requirement:

Alfalfa:	
First crop, May 13 to July 19	1,008±26
Second crop, July 19 to September 18	1,354±22
Third crop, September 18 to October 22	520±9
Crops combined, May 13 to October 22	1,068±16

The increase in the water requirement of the second crop is doubtless to be attributed to the hot weather of the latter part of July and of August, which came when this crop was making its most rapid growth. The third crop showed a very material reduction in the water requirement, due presumably to the cool weather of late September and of October.

The unusually high water requirement shown by alfalfa is not promising for the success of this plant as a dry-land crop. Alfalfa is far higher in its water requirement than any of the other plants tested, being practically double that of wheat and the other small grains, three times that of corn, and four times that of millet and sorghum. Too much emphasis should not, of course, be placed upon the determinations until they have been supported by the results of succeeding years; but, from the results of the experiments thus far, the writers question the practicability of growing alfalfa in regions of limited rainfall, when forage crops like sorghum and millet are available, which will produce the same amount of dry matter with one-fourth the amount of water.

If the growing of alfalfa is to be attempted in regions of limited rainfall, these experiments would indicate the advisability of a thin stand in rows or hills, with clean cultivation, thus securing for each plant the water supply of a relatively large soil mass. It would appear that the crop could also be profitably limited to two cuttings, one made in the spring and the other in the fall, keeping the top growth small during the summer through pasturage or mowing. By following this procedure, the alfalfa would be growing most actively at seasons of the year when the crop shows its lowest water requirement. The writers are not aware that this plan has ever been given a practical test.

Sweet clover, owing to its adaptability and luxuriant habit of growth, is at present being tested in a number of localities regarding its value as a dry-land crop. While considered at first chiefly from the standpoint of its value as a green manure, it has also recently found considerable favor as a hay crop, stock gradually acquiring a taste for it in spite of the coumarin which at first proves so offensive.[1] From either standpoint the water requirement of sweet clover is an important consideration to the dry-land farmer. The experiments with this plant at Akron in 1911 gave a water requirement for sweet clover during the period from May 13 to July 19 of 675 ± 5 (Pl. IX, fig. 1). This period is identical with the period covered by the first alfalfa crop and shows the water requirement of sweet clover to be practically two-thirds that of alfalfa. A second crop (Pl. X, fig. 1) of sweet clover from the same roots grown from July 19 to September 21 gave a water requirement of 793 ± 12, an increase over the first crop of 18 per cent, as compared with a corresponding increase of 34 per cent in the case of the second alfalfa crop. The sweet-clover plants failed to develop a third crop from the old roots. The season taken as a whole produced three crops of alfalfa with a water requirement of $1,068 \pm 16$ and two crops of sweet clover with a water requirement of 709 ± 9. Sweet clover required 39 per cent less water than alfalfa for the production of the same amount of dry matter. In other words, 1½ pounds of sweet clover were produced with the same amount of water required to produce 1 pound of alfalfa.

The Canada field pea in 1911 gave a water requirement of 800 ± 17 for the period from May 13 to August 7. It is thus intermediate between alfalfa and sweet clover in its water requirement. It is not strictly comparable with the results obtained with these two legumes, due to the different periods of growth. Moreover, the peas, through their recumbent habit of growth, were shaded to some extent by the pots and by other plants, which would tend to give a water requirement below the true value. From a comparison with the grain crops it would appear that the water requirement of field peas on a basis of the total dry matter produced is from 50 to 75 per cent greater than that of the small grains.

[1] See Westgate, J. M., and Vinall, H. N., "Sweet clover," U. S. Department of Agriculture, Farmers' Bulletin 485, 1912.

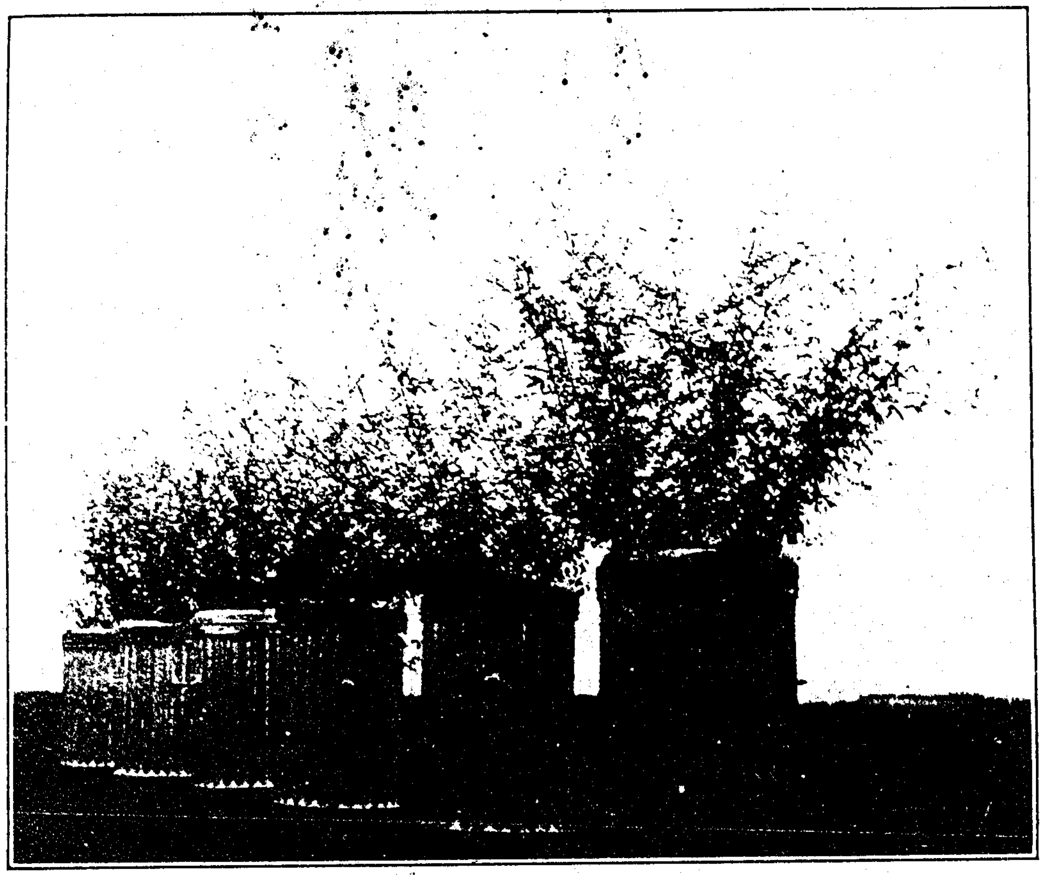

FIG. 1.—SWEET CLOVER, GROWN MAY 13 TO JULY 19, 1911 (POTS 97 TO 102, POT 102 IN THE FOREGROUND).

Water requirement, 670 ± 5.

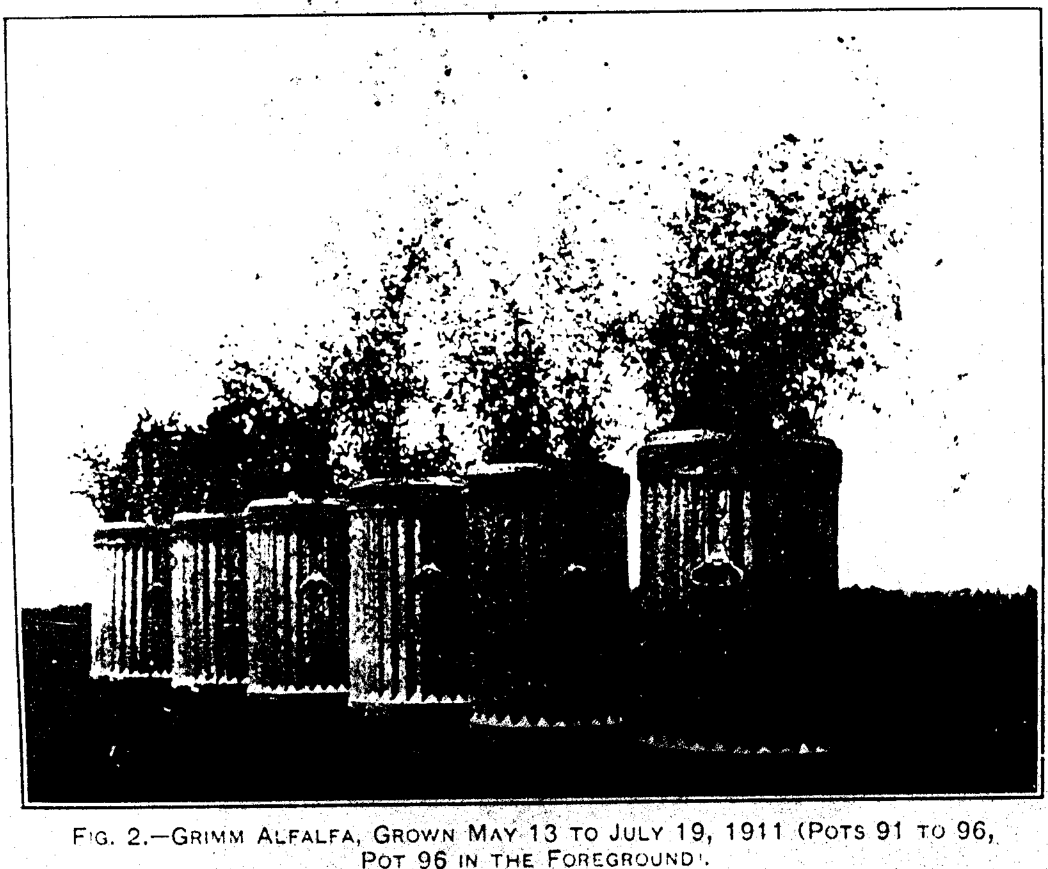

FIG. 2.—GRIMM ALFALFA, GROWN MAY 13 TO JULY 19, 1911 (POTS 91 TO 96, POT 96 IN THE FOREGROUND).

Water requirement, 1008 ± 26.

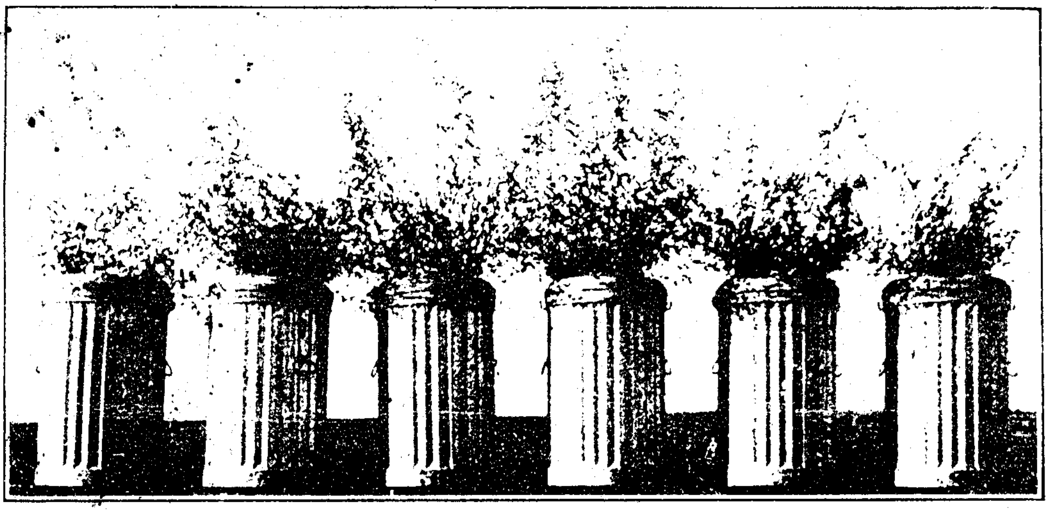

FIG. 1.—SWEET CLOVER, GROWN JULY 19 TO SEPTEMBER 21, 1911 (SECOND AND LAST CROP; POTS 97 TO 102).

Water requirement, 793 ± 12.

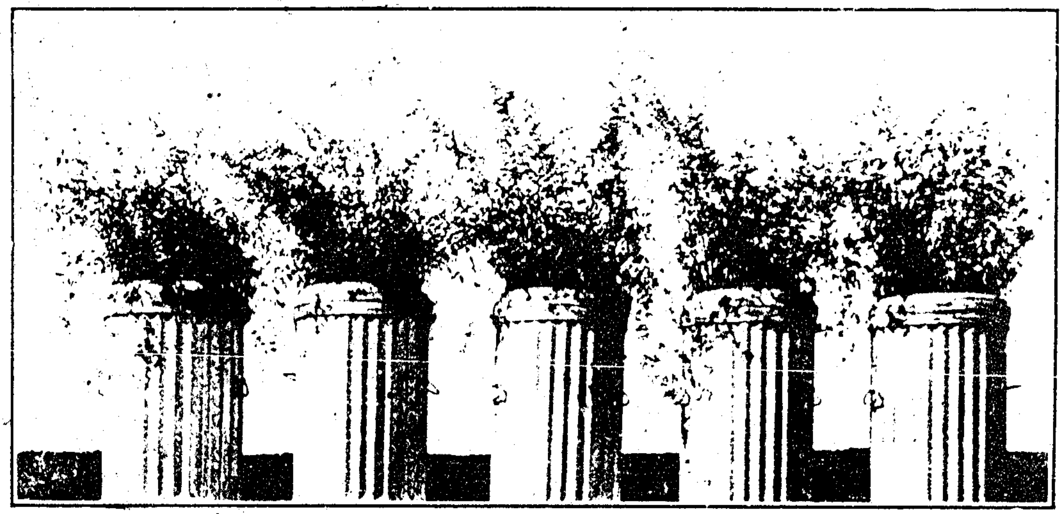

FIG. 2.—GRIMM ALFALFA, GROWN JULY 19 TO SEPTEMBER 18, 1911.

Water requirement, 1351 ± 22. Second crop; pots 91 to 95. Pot 96 is similar to the others, but being in use in physiological experiment is not included.

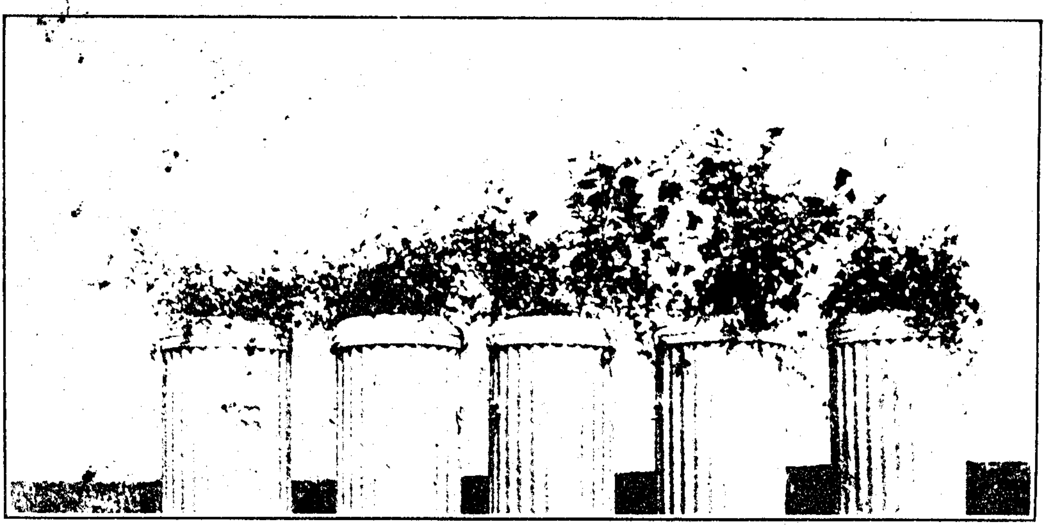

FIG. 3.—BUCKWHEAT, GROWN JUNE 10 TO SEPTEMBER 16, 1911 (POTS 173, AND 193 TO 196).

Water requirement, 578 ± 13.

TABLE X.—*The water requirement of legumes (alfalfa, Canada field peas, and sweet clover) at Akron, Colo., in 1911.*

Plant and period of [illegible].	Pot No.	Dry matter.	Grain.	Water.	Grain.	Water requirement based on—	
						Grain.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Alfalfa, Grimm, S. P. [illegible] (*Medicago sativa*), [illegible] to July 19	[illegible]	86.0	....	86.7	....	....	1,008
	[illegible]	69.5	....	71.9	....	....	1,035
	[illegible]	78.2	....	84.1	....	....	1,148
	[illegible]	82.2	....	68.1	....	....	[illegible]
	[illegible]	[illegible]	....	70.3	....	....	1,051
	[illegible]	[illegible]	....	85.1	....	....	980
Mean							1,008±[illegible]
Second crop, [illegible] to Sept. 18	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,389
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,332
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,295
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,417
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	1,431
Mean							1,354±22
Third crop, Sept. 18 to Oct. 22	91	[illegible]	....	[illegible]	....	....	514
	92	36.8	....	[illegible]	....	....	530
	93	38.6	....	18.1	....	....	469
	94	34.7	....	17.6	....	....	507
	95	36.6	....	20.0	....	....	546
	96	27.9	....	15.4	....	....	552
Mean							520±9
Crops combined for season, May 13 to Oct. 22	91	195.6	....	210.6	....	....	1,076
	92	191.7	....	205.2	....	....	1,070
	93	196.2	....	211.5	....	....	1,078
	94	192.1	....	180.4	....	....	940
	95	175.4	....	192.2	....	....	1,096
	96	227.4	....	262.2	....	....	1,148
Mean							1,068±16
Sweet clover, S. P. I. 21216 (*Melilotus alba*), May 13 to July 19	97	141.0	....	98.0	....	....	695
	98	144.7	....	97.4	....	....	673
	99	160.8	....	110.2	....	....	685
	100	155.3	....	104.6	....	....	673
	101	158.0	....	108.0	....	....	684
	102	185.4	....	118.8	....	....	641
Mean							675±5
Second crop July 19 to Sept. 21	97	64.0	....	52.7	....	....	823
	98	71.3	....	52.1	....	....	730
	99	84.9	....	68.4	....	....	806
	100	75.7	....	63.3	....	....	836
	101	68.4	....	55.0	....	....	804
	102	21.3	....	16.15	....	....	758
Mean							793±12
Crops combined for season, May 13 to Sept. 21	97	205.0	....	150.7	....	....	736
	98	216.0	....	149.5	....	....	692
	99	245.7	....	178.6	....	....	728
	100	231.0	....	167.9	....	....	[illegible]
	101	226.4	....	163.0	....	....	720
	102	206.7	....	134.95	....	....	653
Mean							700±[illegible]
Canada field pea, S. [illegible] (*Pisum sativum*), [illegible] Aug. 7	[illegible]	[illegible]	[illegible]	[illegible]	36	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Mean	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

WATER REQUIREMENT OF POTATOES AND SUGAR BEETS.

The Irish potato in the 1911 experiments at Akron, Colo., gave a water requirement practically identical with that of Kubanka wheat, namely, 448 ± 11. (Table XI.) When calculated on the basis of the dry matter in the tubers alone the water requirement was 994 ± 38. The potatoes made a perfectly normal growth in the cans and developed a fair crop of tubers of moderate size. (Pl. XI, fig. 4.)

Experiments with the sugar beet gave a water requirement for this plant of 377 ± 8, or, when based upon the dry matter of the root alone, of 629 ± 18. These plants also developed normally, although the roots were of only moderate size. (Pl. XI, fig. 5.) It is interesting to note that this crop agrees very closely with corn in its water requirement.

Potatoes and sugar beets have a comparatively low water requirement. As harvested and sold they contain a high percentage of water. The water requirement on the basis of the green weight of tubers and roots is therefore especially low, being 166 ± 4 for potatoes and 110 ± 3 for sugar beets.

TABLE XI.—*Water requirement of potatoes and sugar beets at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Tubers or roots.	Water.	Tubers or roots.	Water requirement based on—	
						Tubers or roots.	Dry matter.
		Grams.	*Grams.*	*Kilos.*	*Per cent.*		
Potato, Irish Cobbler (*Solanum tuberosum*), June 10 to Sept. 19.	169	138.9	74.0	66.2	53	894	477
	170	151.9	74.0	66.4	49	897	438
	171	122.0	48.2	58.8	40	1,220	482
	172	159.2	69.8	68.2	44	977	428
	174	132.6	55.7	54.8	42	984	413
Mean						994 ± 38	448 ± 11
Sugar beet, Morrison-grown Kleinwanzleben (*Beta vulgaris*), June 10 to Sept. 19	175	153.6	89.7	65.0	58	725	423
	176	180.0	107.7	65.6	60	609	364
	177	207.7	128.5	71.7	62	558	345
	178	181.1	108.1	68.4	60	633	378
	179	141.6	82.5	55.4	58	671	391
	180	185.1	115.6	66.8	62	578	360
Mean						629 ± 18	377 ± 8

WATER REQUIREMENT OF RAPE.

Rape, which is used somewhat in dry farming as a pasture crop, was tested at Akron, Colo., for its water requirement during the period from August 18 to October 17, 1911. The crop was sown following oats, without the addition of fertilizer, and it is possible that the water requirement was somewhat increased by the lack of plant food. The water requirement obtained for this plant was 441 ± 12 (Table XII), as compared with a water requirement of 1,450 for a

FIG. 1.—AMARANTHUS RETROFLEXUS (PIGWEED), GROWN AUGUST 5 TO SEPTEMBER 15, 1911 (POTS 7 TO 12; FERTILIZED).

Water requirement, 274 ± 3.

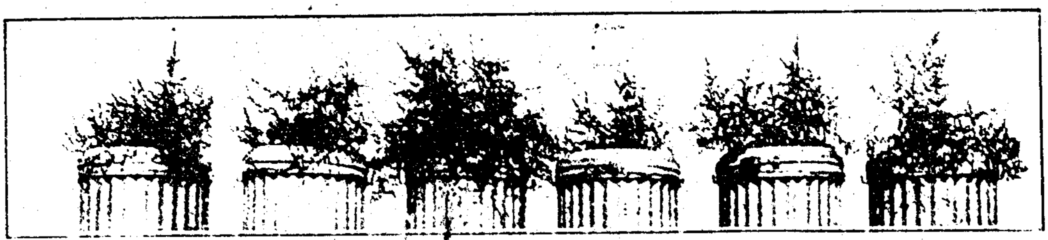

FIG. 2.—AMARANTHUS GRAECIZANS, GROWN AUGUST 5 TO SEPTEMBER 15, 1911 (POTS 31 TO 36).

Water requirement, 277 ± 4.

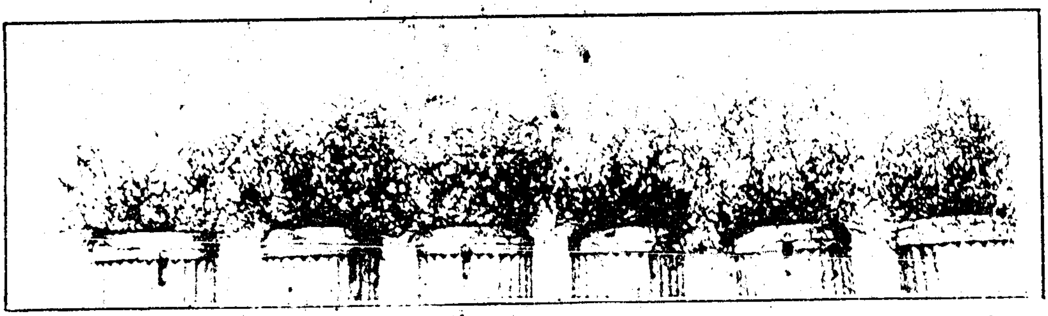

FIG. 3.—SALSOLA PESTIFER (RUSSIAN THISTLE), GROWN JUNE 10 TO SEPTEMBER 6, 1911 (POTS 181 TO 186).

Water requirement, 336 ± 5.

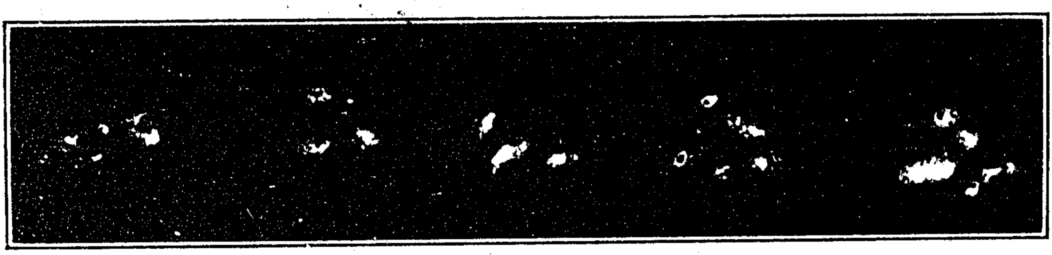

FIG. 4.—IRISH COBBLER POTATOES, GROWN JUNE 10 TO SEPTEMBER 19, 1911 (FROM POTS 169 TO 174).

Water requirement, based on dry matter of tubers, 894 ± 38; based on total dry matter, 448 ± 11.

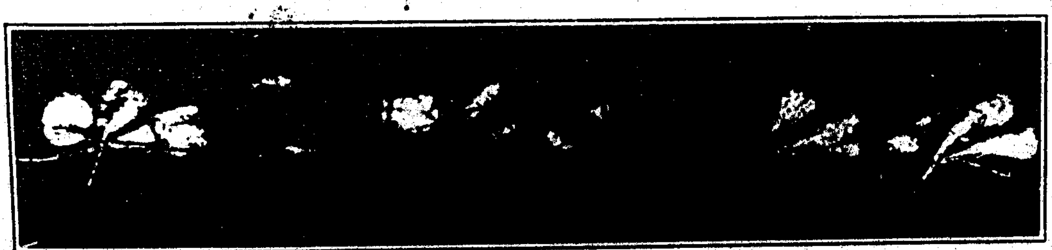

FIG. 5.—MORRISON-GROWN KLEINWANZLEBEN SUGAR BEETS, GROWN JUNE 10 TO SEPTEMBER 19, 1911 (FROM POTS 175 TO 180).

Water requirement, based on dry matter of roots, 621 ± 18; based on total dry matter, 377 ± 8.

new crop of Grimm alfalfa grown following barley during practically the same period. It would therefore appear that the water requirement of rape is only about one-third that of a new crop of alfalfa.

TABLE XII.—*Water requirement of rape at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*	
Rape (*Brassica napus*), Aug. 18 to Oct. 17	37	48.0	21.7	452
	38	18.1	8.7	481
	39	16.9	6.9	408
	40	27.3	12.25	449
	41	11.1	4.2	378
	42	14.5	6.95	479
Mean				441±12

WATER REQUIREMENT OF WEEDS AND NATIVE PLANTS.

Four plants which grow without cultivation in eastern Colorado were used in the water-requirement experiments at Akron in 1911. (Table XIII.) Only one of these, *Artemisia frigida* (mountain sage) is a true native plant. It is abundant in the northern and central portion of the Great Plains. The other three plants are among the worst weed pests of this region. Two of these, the Russian thistle (Pl. XI, fig. 3) and *Amaranthus graecizans* (Pl. XI, fig. 2), are tumbleweeds, while the third, *Amaranthus retroflexus* (Pl. XI, fig. 1), is the ordinary redroot or pigweed, a common weed throughout the United States.

The water requirement based upon the production of dry matter is here summarized:

Artemisia frigida	765±24
Salsola pestifer	336± 5
Amaranthus retroflexus (outside)	356± 4
Amaranthus retroflexus (fertilized)	274± 3
Amaranthus graecizans	277± 4
Amaranthus graecizans (outside)	275± 7

Artemisia grew fairly well, somewhat better than in the native sod. Its water requirement is high—65 per cent higher than Kubanka wheat and 157 per cent higher than Red Amber sorghum. Only two of the cultivated crops tested, alfalfa and Canada field pea, have a higher water requirement. This is especially interesting, since *Artemisia frigida* from a morphological point of view would seem to be admirably adapted to a dry country. It is covered with a dense silvery pubescence, which protects it from sun and wind. This would tend to reduce the transpiration, but since the plant grows slowly it fails to show a high degree of efficiency in the use of water.

From the standpoint of water economy the weeds are decidedly efficient. For an equal production of dry matter the Russian thistle requires about the same amount of water as Dwarf milo, *Amaranthus retroflexus* (redroot) about the same quantity as Northwestern Dent corn, and *Amaranthus graecizans* (a tumbleweed) about the same quantity as Blackhull kafir.

Probably more water is needlessly lost through the growth of these and similar weeds than from any other cause. When soil moisture is available they make a rapid and luxuriant growth, and the water consumed by them is a complete loss, except in so far as they contribute organic matter to the soil. Sorghum, corn, or millet could take the place of these weeds with no greater consumption of soil moisture.

One set of pots of *Amaranthus retroflexus* was fertilized. This set showed clearly the effect of the additional amount of plant food, especially nitrogen, the plants being unusually luxuriant (Pl. X, fig. 1) and of a dark-green color. The water requirement of this set was 23 per cent lower than that of a similar but unfertilized set grown in soil which had just produced a heavy crop of wheat. *Amaranthus graecizans* was used to check the effect of the shelter upon the water requirement. Six pots were grown in a freely exposed position outside the shelter, and six inside the shelter. The two sets agreed as to their water requirement.

TABLE XIII. *Water requirement of weeds and native plants at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.	Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*				*Grams.*	*Kilos.*	
Salsola pestifer, June 10 to Sept. 6	181	193.0	68.8	356	Artemisia frigida, June 10 to Sept. 21	187	17.9	14.8	827
	182	178.5	58.6	328		188	36.5	24.0	658
	183	144.0	50.2	349		189	44.4	31.3	705
	184	150.3	51.3	341		190	16.2	14.35	886
	185	164.4	51.6	314		191	30.2	22.45	743
	186	167.6	54.9	328		192	51.9	39.95	773
Mean				336±5	Mean				765±24
Amaranthus retroflexus, Aug. 5 to Sept. 15 (outside the shelter)	1	96.0	33.7	351	Amaranthus retroflexus, Aug. 5 to Sept. 15 (inside the shelter), fertilized	7	133.4	37.0	277
	2	46.9	17.9	382		8	89.0	26.0	292
	3	72.2	25.75	357		9	134.6	36.7	273
	4	66.5	23.5	353		10	136.4	36.8	270
	5	98.9	35.1	355		11	116.8	30.9	265
	6	88.0	29.5	335		12	128.7	34.0	264
Mean				356±4	Mean				274±3
Amaranthus graecizans, Aug. 5 to Sept. 15 (inside the shelter)	31	35.3	10.0	283	Amaranthus graecizans, Aug. 5 to Sept. 15 (outside the shelter)	79	70.2	17.3	246
	32	29.2	8.1	277		80	45.9	11.5	251
	33	69.1	18.4	266		81	62.9	17.05	271
	34	24.9	6.5	261		82	55.3	16.8	304
	35	37.8	11.35	300		83	51.6	15.2	295
	36	27.1	7.5	277		84	69.7	19.15	275
Mean				277±4	Mean				275±7

WATER REQUIREMENT OF CROPS GROWN OUT OF SEASON.

After the first crop of small grains was removed from the cans at Akron, Colo., in 1911, some of the pots were planted to a second crop. The results obtained from this second crop when the plants were grown out of their normal season are given in Table XIV. None of these plants reached maturity and the amount of dry matter harvested was small. The water requirement of alfalfa was 36 per cent more and that of sweet clover 84 per cent more than for the normal crop. Barley and wheat were 3 and 8 per cent higher than when grown in season. Canada field peas, oats, and spring rye had a much lower water requirement than when grown in season, the decrease being 20 per cent for Canada field peas, 26 per cent for oats, and 35 per cent for spring rye. The lower water requirement of these plants is of interest, since they are what might be called cool-weather crops and make a better growth under this condition than do other crops less adapted to cool weather. The results suggest that during late fall and early spring, rye, oats, and Canada field peas are exceptionally efficient plants, giving a large amount of growth in proportion to the water consumed and that during the warmer portion of the year they are relatively inefficient.

TABLE XIV.—*Water requirement of crops grown out of season at Akron, Colo., in 1911.*

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*	
Wheat, Kubanka (G. I. 1440), Aug. 9 to Oct. 22	25	8.6	4.5	523
	26	10.6	7.4	698
	27	18.8	7.8	415
	28	9.1	4.3	477
	29	14.8	6.05	409
	30	16.1	8.15	506
Mean				505±27
Oats, Sixty-Day (G.I.165), Aug. 16 to Oct. 22	55	27.1	10.95	404
	56	30.3	15.8	522
	57	31.6	13.2	418
	58	32.4	15.15	468
	59	21.5	9.4	437
Mean				450±11
Barley, Beldi (G. I. 190), Aug. 3 to Oct. 22	61	37.2	23.7	637
	62	7.9	31.1	556
	63	38.7	22.7	586
	64	50.0	25.0	500
	65	53.6	29.85	557
	66	52.1	26.75	513
Mean				558±13
Rye, spring (G. I. 73), Aug. 9 to Oct. 22	85	50.0	26.5	530
	86	29.3	14.9	508
	87	67.7	30.7	454
	88	5.9	2.7	458
	89	18.5	8.35	451
	90	38.9	16.8	432
Mean				472±12

Plant and period of growth.	Pot No.	Dry matter.	Water.	Water requirement based on dry matter.
		Grams.	*Kilos.*	
Sweet clover (S. P. I. 21216), Aug. 3 to Oct. 22	74	44.6	60.85	1,364
	75	52.0	61.0	1,173
	76	37.9	50.7	1,338
	77	43.6	52.1	1,195
	78	35.8	52.2	1,458
Mean				1,306±31
Alfalfa, Grimm, (S. P. I. 25695), Aug. 3 to Oct. 22	67	35.4	52.05	1,470
	68	27.6	38.0	1,376
	69	29.4	41.55	1,413
	70	22.6	33.2	1,469
	71	29.5	46.1	1,563
	72	33.3	46.95	1,410
Mean				1,450±19
Canada field pea (S. P. I. 22637), Aug. 9 to Oct. 22	103	52.1	30.35	582
	104	34.0	20.2	594
	105	54.1	33.8	625
	106	44.9	30.5	679
	107	49.1	32.6	664
	108	47.9	32.25	673
Mean				636±14

TABLE XIV.—*Water requirement of crops grown out of season at Akron, Colo., in 1911*—Continued.

SUMMARY OF MEANS.

Crop.	Period of growth.	Pot Nos.	Water requirement based on dry matter.	Crop.	Period of growth.	Pot Nos.	Water requirement based on dry matter.
Wheat, Kubanka (G. I. 1440).	Aug. 9–Oct. 22	25–30	505±27	Rye, spring	Aug. 9–Oct. 22	85–90	472±12
Oats, Sixty-Day.	Aug. 16–Oct. 22.	55–60	450±11	Alfalfa, Grimm	Aug. 3–Oct. 22	67–72	1,450±19
Barley, Beldi.	Aug. 3–Oct. 22	61–66	558±13	Sweet clover	Aug. 3–Oct. 22	74–78	1,306±31
				Canada field pea.	Aug. 9–Oct. 22	103–108	636±14

SUMMARY OF WATER-REQUIREMENT MEASUREMENTS IN COLORADO, 1911.

Table XV shows that the water requirement of different varieties of the same crop differs but little as compared with the variation in the water requirement of different crops. The water requirement of the most efficient variety is 88 per cent of that of the least efficient in the case of wheat; oats, 94 per cent; barley, 97 per cent; millet, 92 per cent; corn, 76 per cent; and sorghum, 84 per cent.

A summary of the water requirement of the different crops grown at Akron, Colo., in 1911 is given in Table XV. In cases where several varieties of the same crop have been tested, the mean water requirement of the different varieties is given; and where several cuttings were made during the season, as with alfalfa and sweet clover, the mean for the season is given. It will be seen that wheat occupies a central position in this series, falling next to barley, the water requirement of which is very nearly the geometric mean of the limits of the series.

TABLE XV.—*Summary of the water requirement of crops grown at Akron, Colo., in 1911.*

Crop.	Period of growth.	Pot Nos.	Water requirement based on		Remarks.
			Grain.	Dry matter.	
Wheat:					
Kubanka	May 13 to Aug. 2	1–6, 199–204	1,191±14	468±8	
	do	7–12	1,184±36	422±6	Fertilized.
Bluestem	May 13 to Aug. 7	13–18	1,786±60	531±5	
Galgalos	May 13 to Aug. 1	19–24	1,245±13	496±4	
Spring Ghirka	May 13 to Aug. 4	25–30	1,382±43	506±3	
Emmer	do	79–84	1,180±42	534±14	
Oats:					
Sixty-Day	May 13 to Aug. 2	31–36	1,383±30	605±5	
Canadian	May 13 to Aug. 12.	37–42	2,204±140	598±14	
Burt	do	43–48	1,500±57	639±7	
Swedish Select	May 13 to Aug. 7	49–54	1,632±35	615±7	
Barley:					
Hannchen	May 13 to Aug. 12.	55–60	1,134±27	527±8	
Beldi	May 13 to Aug. 4	61–66	1,155±18	543±2	
White Hull-less	May 13 to July 31	67–72	1,475±40	542±3	
Beardless	May 13 to Aug. 1	74–78	1,210±38	544±9	
Rye:					
Spring	May 13 to Aug. 5	85–90	2,215±37	724±7	

TABLE XV.—*Summary of the water requirement of crops grown at Akron, Colo., in 1911*—Continued.

Crop.	Period of growth.	Pot Nos.	Water requirement based on— Grain.	Dry matter.	Remarks.
Millet:					
Kursk	May 12 to Aug. 9	157–162	923±40	287±2	
German	May 12 to Aug. 21	163–168	....	263±15	
Buckwheat	June 10 to Sept. 16	193–196, 173	1,037±33	578±13	
Corn:					
Northwestern Dent	May 24 to Aug. 23	109–114	2,040±340	368±10	
Iowa Silvermine	May 24 to Sept. 4	115–120	....	420±3	
Esperanza	May 12 to Aug. 21	121–126	....	319±5	
Sorghum:					
Red Amber	May 12 to Sept. 4	127–132	1,494±200	298±4	
Dwarf milo	do	133–138	1,123±57	333±3	
Blackhull kafir	May 12 to Sept. 3	139–144	803±26	278±5	
White durra	May 12 to Sept. 5	145–150	806±12	321±2	
Brown kaoliang	May 12 to Sept. 6	151–156	726±12	301±3	
Alfalfa:					
Grimm	May 13 to July 19	91–96	....	1,008±26	
	July 19 to Sept. 18	91–96	....	1,354±22	
	Sept. 18 to Oct. 22	91–96	....	520±9	
	May 13 to Oct. 22	91–96	....	1,068±16	Combined for season.
Sugar beet:					
Morrison-grown Kleinwanzleben	June 10 to Sept. 19	175–180	629±18	377±8	Based on dry matter and dry roots.
			110±3	....	Based on green roots.
Canada field pea	May 13 to Aug. 7	103–108	2,218±100	800±17	
Rape	Aug. 18 to Oct. 17	37–42	....	441±12	
Sweet clover	May 13 to July 19	97–102	....	675±5	
	July 19 to Sept. 21	97–102	....	793±12	
	May 13 to Sept. 21	97–102	....	709±9	Combined for season.
Potato:					
Irish Cobbler	June 10 to Sept. 19	169–172, 174	994±38	448±11	Based on dry matter and dry tubers.
			166±4	....	Based on green tubers.
Amaranthus retroflexus	Aug. 5 to Sept. 15	1–6	....	356±4	Outside the shelter.
		7–12	....	274±3	Fertilized.
		31–36	....	277±4	Inside the shelter.
Amaranthus graecizans	do	79–84	....	275±7	Outside the shelter.
Artemisia frigida	June 10 to Sept. 21	187–192	....	765±24	
Salsola pestifer	June 10 to Sept. 6	181–186	....	336±5	

SUMMARY OF WATER REQUIREMENT OF CROPS BASED UPON THE MEANS OF DIFFERENT VARIETIES.

Crop.	Water requirement.	Relative water requirement compared with wheat.	Crop.	Water requirement.	Relative water requirement compared with wheat.
Alfalfa	1,068	211	Wheat	507	100
Canada field pea	800	158	Potato	448	88
Artemisia (native)	765	151	Rape	441	87
Spring rye	724	143	Sugar beet	377	74
Sweet clover	709	140	Corn	369	73
Oats	614	122	Weeds	322	63
Buckwheat	578	114	Sorghum	306	60
Barley	539	106	Millet	275	54

Millet, sorghum, and corn have a water requirement ranging from 275 to 370, the small grains from 510 to 700, and the legumes from 710 to 1,070. Sorghum and corn are long-season crops, making their best growth during hot, dry weather. The small grains are short-season crops, which grow well during cool weather. Notwithstanding these facts, the water requirement of the small grains is higher than that of sorghum and corn.

Of the crops which produce grain, millet and sorghum consume about one-half the amount of water required by oats, barley, and wheat for the production of an equal quantity of dry matter.

Forage crops cover the whole range in water requirement, millet producing almost four times as much dry matter with the same amount of water as alfalfa, three times as much as spring rye, and two and one-half times as much as sweet clover.

The water requirement of the introduced weeds is comparatively low, while the native plant *Artemisia frigida* has a relatively high water requirement.

The water requirement of millet and sorghum based on grain production is about one-half that of oats and about two-thirds that of wheat and barley.

DETERMINATION OF THE WATER REQUIREMENT OF CROPS IN THE FIELD.

The determination of the water requirement of crops growing in the field under normal conditions is attended with a good deal of uncertainty, owing to the fact that the evaporation from the soil surface is not known. The actual change in the soil-moisture content during the experiment can be measured, and the probable error of these measurements can be calculated; but these measurements necessarily include the evaporation from the soil surface, which should not, of course, be charged to the water requirement of the plant under investigation. A second element of uncertainty arises in connection with the precipitation. The total precipitation during the growth period is usually included in the determination of the water requirement. It is evident that this may give values which are entirely too high, particularly in regions of torrential rainfall, owing to the run-off which occurs during such rains. The writers have endeavored to avoid this error in their field measurements by making daily determinations of the soil-moisture content and charging to the crop only that portion of the rainfall which actually penetrates the soil, as shown by the differences in the daily soil-moisture determinations before and after each rain. This will be referred to in more detail later.

WATER REQUIREMENT OF KUBANKA WHEAT GROWN UNDER FIELD CONDITIONS IN COLORADO.

FIELD EXPERIMENTS IN 1910.

A one-half acre plat of Kubanka wheat (G. I. 1440), grown on land which had raised a cultivated crop the previous year, was used in the 1910 experiments at Akron, Colo. The conditions were not particularly favorable, owing to the lack of uniform distribution of the moisture in the soil, as is often the case in regions of limited rainfall.

The initial moisture content was determined to a depth of 6 feet by a series of samples taken on six consecutive days during the period of germination, each sample consisting of a composite of three cores. These samples were taken in 1-foot sections with a soil-sampling tube, and the moisture content of the different sections was determined separately, for the purpose of checking their uniformity. A similar series of daily determinations was taken during the six days immediately preceding harvest. The crop at this time showed a lack of uniformity, owing to the inequality of the moisture supply in different parts of the plat. Each daily determination was therefore made in triplicate, one sample being taken in the best wheat, a second in wheat of medium quality, and the third in the poorest wheat. Each sample consisted of three cores, as before. The average moisture content of these 18 samples, each sample consisting of three cores extending to a depth of 6 feet, was taken to represent the final moisture content of the soil.

The season of 1910 was exceptionally dry, the total precipitation during the interval between the initial and final sampling amounting to only 1.09 inches. This was chiefly confined to three rains of 0.31, 0.30, and 0.38 of an inch. The increase in soil-moisture content, as shown by the difference in the daily samples taken immediately preceding and following each rain, was added to the loss of water represented by the difference between the initial and final soil-moisture determinations. The total represents the amount of water used by the crop expressed as a percentage of the dry weight of the soil. The apparent specific gravity or weight of the soil per unit volume was determined from a large number of samples, and from this the amount of water lost per unit area was calculated.

The amount of dry matter on the unit area was determined by harvesting three quadrates of grain, each 10 square yards in area, one being chosen from the best wheat, one from wheat of medium quality, and one from the poorest. Each sample was dried at 110° C. and the total dry weight and the weight of the grain determined. The mean of the three determinations in each case was taken to represent the average production of dry matter and grain on the plat.

From these determinations the following data were obtained for Kubanka wheat under field conditions in 1910:

Water requirement, dry matter	570
Water requirement, grain	1,900
Dry matter produced per acre ....pounds..	2,315
Grain produced per acre (11.7 bushels) ....do....	700
Water used per acre ....tons..	615
Rainfall equivalent of water used ....inches..	6
Actual rainfall during period ....do....	1
Stored precipitation ....do....	5

In connection with the stored precipitation it should be stated that heavy rains, amounting in all to about 5 inches, occurred early in the season, before and soon after the crop was planted and before the initial moisture determinations were made. The stored precipitation should not therefore be considered as having all been carried over from the preceding fall.

FIELD EXPERIMENTS IN 1911.

A similar series of determinations was also carried on with Kubanka wheat during the season of 1911. In this work duplicate samples were taken every second day to a depth of 6 feet in 1-foot sections, each sample consisting of a composite of two cores. The wheat was grown on summer-fallowed land, but owing to the drought of the preceding season the initial water supply was limited, and while the precipitation during the growing period considerably exceeded that of the preceding year the yield was less. The precipitation during the growing season amounted to 3.7 inches, which came mainly in five rains of 0.92, 0.72, 0.64, 0.76, and 0.35 of an inch. Owing to the dry weather, the Russian thistle made a considerable growth on the plat before the wheat shaded the ground. The Russian thistle on the quadrate harvested was also cut and weighed, and a correction was made for the amount of water used by this plant, assuming its water requirement to be the same as that found in our pot experiments. The total rainfall during the growing period, accounted for by the soil-moisture determinations made before and after each rainfall, amounted to 3.15 inches.

A statement of the water requirement and other data connected with the production of the 1911 Kubanka wheat crop under field conditions follows:

Water requirement, dry matter	862
Water requirement, grain	2,380
Dry matter produced per acre ... pounds..	1,765
Grain produced per acre (10.7 bushels) ... do....	645
Water used per acre ... tons..	761
Rainfall equivalent of water used ... inches..	6.7
Rainfall accounted for from daily sampling ... do....	3.15
Stored precipitation ... do....	3.55

The water requirement of wheat grown under field conditions in 1911 is much higher than that obtained from the pot experiments or under field conditions during 1910. The writers are inclined to the opinion that this discrepancy is due to the assumption that the seasonal rainfall, or particularly that part of it which penetrates the soil, is as available to the crop as that already stored in the ground. Crops like wheat reduce the moisture content of the surface foot of soil to the wilting coefficient (Briggs and Shantz, 1912), or below, during the early stages of their growth. If during this period rains do not replenish the moisture supply of the surface foot, the roots in this area soon become inactive. Consequently, subsequent rains which do not penetrate beyond the surface foot appear to be of much less value than an equal amount of water in the neighborhood of the active roots, owing to the fact that the water from the rain is largely lost through evaporation before the plants can establish new rootlets to take advantage of this temporary water supply. That a condition of this kind exists in the Great Plains is indicated by the fact that the water requirement of the wheat crops of 1910 and 1911, when the seasonal precipitation is ignored, agrees within the limits of experimental error with each other and with the water requirement of Kubanka wheat as determined in the pot experiments. The comparison may be made from the data given in Table XVI.

TABLE XVI.—*Comparison of the water requirement of Kubanka wheat crops grown under field conditions and in pots, at Akron, Colo.*

Class of experiments.	Water requirement—			
	Including rainfall during growth—		Excluding rainfall during growth—	
	Based on dry matter.	Based on grain.	Based on dry matter.	Based on grain.
Field experiment, 1910	700	2,315	486	1,780
Field experiment, 1911	862	2,380	466	1,614
Pot experiment, 1911			468±8	1,196±15

DETERMINATION OF AVAILABLE PRECIPITATION BY DAILY SOIL SAMPLING.

It is of interest to compare the increase in soil-moisture content found by sampling in the experiments just described with the actual rainfall as measured by the rain gauge. The results for the principal rains which occurred during the growing seasons of the two years are given in Table XVII. For convenience in comparison, the increase in soil moisture has been expressed in terms of inches of rainfall. The penetration refers to the thickness of the layer of moist soil at the time of the first sampling following the rain.

TABLE XVII.—*Comparison of the amount of rainfall with the increase in soil water as determined by daily sampling at Akron, Colo., in 1910 and 1911.*

Date.	Precipitation—		Depth of penetration.	Date.	Precipitation—		Depth of penetration.
	Actual.	Found by sampling.			Actual.	Found by sampling.	
1910.	*Inches.*	*Inches.*	*Inches.*	1911.	*Inches.*	*Inches.*	*Inches.*
June 24	0.31	0.36		May 27–28	0.92	1.00	
July 1	.30	.34		June 16	.65	.80	6.5
July 4	.38	.18		June 25	.64	.55	5.0
				July 12	.76	.55	4.5

In 1910, samples were taken daily and each determination is based upon the mean of nine cores. In 1911, samples were taken every second day, four cores being used in each determination. When rain fell, additional samples were taken as soon as the rain had ceased. The measurements in Table XVII serve to give an idea of the accuracy which was attained by this method. No heavy torrential rains occurred in either year during the growing period, so that the determinations did not include measurements made under the most unfavorable conditions for the absorption of the rainfall. Although the daily samples need to be taken only to a depth of 2 feet for the purpose of determining the amount of rainfall which has been absorbed, it is necessary to include a number of cores in each determination to insure a reliable value, and the determinations represent in the aggregate considerable work. In regions free from torrential rains or where the measurements can be carried on during the dry season it appears practicable from the results in Table XVII to restrict the measurements to the initial and final determinations and to add to the water lost, as calculated by these measurements, the intervening rainfall as measured by the rain gauge. In regions of torrential rains, however, this procedure would be attended with great uncertainty, due to the run-off and to rain-gauge errors, so under such circumstances the writers believe daily sampling or sampling every second day, with additional sampling following each rain, to be necessary. Even this method probably gives a water requirement which is somewhat high, due to the fact that plant roots in the more advanced stages of growth are often inactive in the first 6 inches of the surface soil, which in dry periods is the only portion moistened except by the heaviest rains.

The daily moisture curves for 1910 and 1911 give no indication that the rains penetrated the second foot. While the number of determinations is too small to warrant definite conclusions on this subject, the experiments so far indicate strongly that rains of even 0.6 and 0.8 inch are of little value to a wheat crop in the Great Plains, provided the preceding weather has been so dry that the plants have exhausted all available water to a depth of a foot or more, so that all the active rootlets are confined to lower depths.

WATER REQUIREMENT AS AFFECTED BY CLIMATIC CONDITIONS.

The variation in the water requirement of a given crop in a given locality from year to year may be looked upon as a measure of the integrated result of the climatic factors which are constantly varying during the period of growth. In attempting to effect a correlation between the water requirement and the intensity of the climatic factors as expressed by daily measurement, one is at once confronted with the difficulty arising from the fact that the plant during a large part of its growing period is steadily increasing in size and weight. As a result, severe climatic conditions have a far less influence upon the water requirement in the early stages of growth, when the leaf area is small, than during the period when the crop is developing dry matter most rapidly. Therefore, in order to make an effective comparison of the water requirement with climatic conditions it is necessary to weigh the climatic factors at various stages of the growth of the crop, according to the dry weight of the crop at these chosen stages.

A summary of the climatic conditions prevailing at each station in the Great Plains where water-requirement experiments were made in 1910 and 1911 is given in Table XVIII.[1] The daily measurements are summarized in 5-day periods, and the table shows the average daily temperature during this period, the mean of the maximum temperatures, the mean of the minimum temperatures, and the extreme temperatures during the period; the total rainfall and the total evaporation from a free water surface, as well as the average wind velocity, are also given.

TABLE XVIII.—*Climatic data for Akron, Colo., and Dalhart, Tex., in 1911.*

OBSERVATIONS AT AKRON, COLO.

Date.		Mean soil temperature.	Air temperature (°F.).					Precipitation.	Evaporation.	Wind velocity per hour.
Month.	Days (inclusive).		Average—Of means.	Average—Of maxima.	Average—Of minima.	Maximum.	Minimum.			
		°F.						*Inches.*	*Inches.*	*Miles.*
April	1 to 5	......	46	64	29	77	24	0.16	0.98	8.5
	6 to 10	......	44	59	26	67	16	0	.93	8.8
	11 to 15	51	41	57	23	69	19	0	1.18	7.0
	16 to 20	58	50	67	29	69	25	Trace.	1.12	7.7
	21 to 25	58	51	62	40	81	39	1.74	1.02	10.8
	26 to 30	53	49	62	36	75	20	.73	.62	11.6
May	1 to 5	48	44	55	34	68	28	.03	.34	9.4
	6 to 10	64	60	76	43	87	30	.04	1.17	8.5
	11 to 15	66	64	80	45	84	35	Trace.	1.52	10.2
	16 to 20	65	58	76	42	91	36	.16	1.72	11.4
	21 to 25	65	64	78	45	91	34	0	1.37	8.9
	26 to 31	64	59	73	47	85	36	.92	1.20	9.7
June	1 to 5	74	70	87	50	90	47	Trace.	1.68	8.2
	6 to 10	75	69	88	49	93	43	Trace.	1.64	7.3
	11 to 15	79	70	90	50	96	45	.07	1.62	5.9
	16 to 20	72	67	78	54	90	48	.65	1.30	8.0
	21 to 25	81	73	91	55	92	51	.66	1.67	6.3
	26 to 30	79	73	92	58	98	50	.10	1.85	8.5
July	1 to 5	80	71	88	57	93	54	.12	1.70	7.8
	6 to 10	84	73	90	56	94	46	.01	1.72	7.3
	11 to 15	80	70	86	56	93	54	.77	1.69	7.5
	16 to 20	75	67	80	55	86	53	.44	.88	6.4
	21 to 25	79	68	84	52	92	46	0	1.69	7.3
	26 to 31	83	73	90	56	95	49	Trace.	2.09	6.4

[1] These data form a part of the climatic measurements made in cooperation with the Office of Dry-Land Agriculture, Bureau of Plant Industry, at each of the dry-land stations.

TABLE XVIII.—*Climatic data for Akron, Colo., and Dalhart, Tex., in 1911*—Continued.

OBSERVATIONS AT AKRON, COLO.—Continued.

Date.		Mean soil temperature.	Air temperature (°F.).					Precipitation.	Evaporation.	Wind velocity per hour.
			Average—			Maximum.	Minimum.			
Month.	Days (inclusive).		Of means.	Of maxima.	Of minima.					
		°*F.*						*Inches.*	*Inches.*	*Miles.*
August	1 to 5	75	67	87	53	91	48	.29	1.02	10.1
	6 to 10	83	73	91	57	99	49	.82	1.87	7.4
	11 to 15	80	74	89	61	96	56	.19	1.35	5.9
	16 to 20	83	73	92	58	97	53	0	1.50	7.6
	21 to 25	71	61	74	48	84	41	Trace.	1.39	9.6
	26 to 31	73	67	85	50	94	45	0	1.80	8.3
September	1 to 5	73	67	86	53	94	49	1.75	1.63	7.4
	6 to 10	73	64	79	52	87	49	.16	1.04	6.9
	11 to 15	75	70	86	57	95	52	.12	1.27	5.8
	16 to 20	66	59	75	44	86	39	0	1.44	8.9
	21 to 25	67	61	80	44	88	36	0	1.00	6.0
	26 to 30	66	61	76	49	85	48	.37	.80	6.8
OBSERVATIONS AT DALHART, TEX.										
April	1 to 5	54	54	72	41	84	33	0.06	1.04	9.5
	6 to 10	53	49	63	36	76	30	0	1.24	10.7
	11 to 15	57	50	66	33	79	25	0	1.45	9.2
	16 to 20	60	57	74	40	82	33	0	1.45	8.4
	21 to 25	58	55	65	45	81	43	.42	.80	9.7
	26 to 30	61	57	74	43	83	30	.11	1.59	11.8
May	1 to 5	62	55	70	47	80	36	0	1.03	10.9
	6 to 10	70	68	88	51	93	36	.05	2.21	12.7
	11 to 15	64	62	77	54	84	48	2.14	1.42	9.4
	16 to 20	66	65	80	51	89	43	.09	2.29	13.3
	21 to 25	69	70	84	52	92	41	0	1.59	10.1
	26 to 31	68	68	81	57	90	52	1.09	1.38	8.7
June	1 to 5	74	77	92	59	97	54	0	1.82	9.0
	6 to 10	79	77	93	59	96	53	0	2.01	8.8
	11 to 15	80	76	90	57	95	53	0	1.80	6.5
	16 to 20	81	74	89	58	96	56	.09	1.87	7.0
	21 to 25	82	82	98	62	105	59	0	2.41	8.7
	26 to 30	....	80	93	65	95	58	.19	2.47	12.6
July	1 to 5	....	81	93	63	97	61	0	2.11	9.2
	6 to 10	....	78	92	66	94	64	.17	1.85	9.7
	11 to 15	....	75	87	63	96	61	.59	1.24	6.4
	16 to 20	....	75	89	64	95	61	2.65	1.16	6.3
	21 to 25	....	72	83	60	93	54	.11	1.12	8.4
	26 to 31	....	75	92	62	95	59	.13	2.23	7.4
August	1 to 5	....	74	89	62	93	56	.03	1.71	8.2
	6 to 10	....	82	90	63	104	61	0	2.35	7.7
	11 to 15	....	82	95	65	101	61	0	1.95	5.9
	16 to 20	....	83	98	66	102	64	0	2.18	6.4
	21 to 25	....	64	74	55	100	52	1.66	1.22	7.6
	26 to 31	....	68	82	53	93	49	.18	1.48	6.7
September	1 to 5	....	74	91	56	94	55	0	1.56	..8
	6 to 10	....	71	85	58	93	55	.06	1.16	6.4
	11 to 15	....	77	93	61	96	58	.10	1.53	6.4
	16 to 20	....	67	86	50	94	44	0	1.65	7.1
	21 to 25	....	74	91	57	95	43	0	1.46	7.7
	26 to 30	....	72	87	61	93	58	.42	1.41	8.4

The evaporation from a free water surface is the simplest factor that can be chosen as a basis for correlation with the water requirement, since both measurements are obviously influenced by temperature, humidity, and wind velocity, although not necessarily to the same degree. Table XIX gives the water requirement of wheat and sorghum grown in Colorado and Texas during 1910 and 1911, together with the total evaporation from a free water surface during the growing period, computed from the data given in Table XVIII and from corresponding data for 1910. Table XIX also gives the ratio of the water requirement of the crop grown in Texas to the Colorado crop for each year, together with the corresponding evaporation ratio during the growing period. It will be noted from this table that the water-requirement ratio of sorghum is less in each case than the corresponding evaporation ratio, while the water-requirement ratio of wheat is higher in each case than the corresponding evaporation ratio. Thus, while the figures indicate an increased water requirement accompanying an increase in evaporation from a free water surface, the effect is very much greater with wheat than with sorghum. The Panhandle of Texas is recognized as more suitable for raising sorghum than for raising wheat, and these determinations suggest that climatic factors other than evaporation, such as temperature, for example, may be responsible for this. However, it should be kept in mind that the amount of evaporation given in the tables refers to that taking place during the whole period of growth, while the evaporation during the period of active growth would undoubtedly have more influence upon the water requirement than during the initial and final stages.

TABLE XIX.—*Comparison of the relative evaporation and of the relative water requirement in the Great Plains in 1910 and 1911.*

Station.	Year.	Crop.	Growing period.	Evaporation.		Water requirement.	
				Actual.	Relative.	Actual.	Relative.
Akron, Colo.	1910	Wheat	Apr. 18 to Aug. 2[illegible]	27.7	100	661	100
Amarillo, Tex.			Apr. 5 to July 19	34.0	122	853	128
Akron, Colo.	1910	Sorghum	May 25 to Sept. 28	33.0	100	356	100
Amarillo, Tex.			May 10 to Aug. 28	37.7	114	359	101
Akron, Colo.	1911	Wheat	May 13 to Aug. 2	24.8	100	468	100
Dalhart, Tex.			Apr. 25 to July 18	28.5	115	673	143
Akron, Colo.	1911	Sorghum	May 12 to Sept. 4	35.0	100	298	100
Dalhart, Tex.			May 14 to Sept. 12	41.9	120	313	105

A summary of the evaporation measurements in Colorado and in the Panhandle of Texas for the April to September period is given in Table XX as a basis for comparing the years of 1910 and 1911 with the normal evaporation of those regions. It will be noted that June and July, 1910, at Amarillo were exceptionally severe months. The season of 1911 at Dalhart was normal, so far as the evaporation was concerned, while at Akron the year 1910 was slightly below and 1911 slightly above the normal.

TABLE XX.—*Monthly evaporation at Akron, Colo., and at Amarillo and Dalhart, Tex., for the period from April to September, inclusive, 1907 or 1908 to 1911.*

Station.	Year.	Evaporation.							
		April.	May.	June.	July.	August.	September.	Seasonal total.	Normal.
Akron, Colo.	1908	4.74	7.70	8.64	8.47	7.83	8.55	45.93	45.18
	1909	4.74	6.82	7.00	9.40	8.53	5.86	42.35	
	1910	6.39	5.79	8.71	9.78	7.14	5.81	43.62	
	1911	5.85	7.32	9.76	9.77	8.93	7.18	48.81	
Amarillo, Tex.	1907	6.36	8.04	9.59	10.68	9.40	7.91	51.98	54.02
	1908	7.31	9.28	10.38	8.07	8.57	6.77	50.38	
	1909	8.14	10.02	10.34	9.97	9.66	8.42	56.55	
	1910	8.50	8.03	12.00	12.18	8.80	9.10	58.61	
	1911	7.36	10.10	11.48	7.48	8.89	7.28	52.59	
Dalhart, Tex.	1908	6.93	10.93	12.08	9.19	9.90	7.95	56.98	58.32
	1909	8.53	9.90	10.89	11.69	10.56	7.85	59.42	
	1910	8.54	8.19	12.02	11.63	8.81	8.45	57.64	
	1911	7.57	9.92	12.38	9.71	10.89	8.77	59.24	

SUMMARY.

The term "water requirement" is used in this paper to indicate the ratio of the weight of water absorbed by a plant during its growth to the weight of dry matter produced. The investigation had for its object the determination of the differences in water requirement exhibited by the more important crop plants and some of their varieties with a view to determining those which are most efficient in the use of water under the semiarid conditions existing in the Great Plains.

The plants were grown in large pots having a capacity of about 115 kilos of soil. The pots were provided with tight covers, with openings for the plants, the space between the cover and the stem of the plant being sealed with wax. The loss of water was thus limited to that occurring from the transpiration of the plants. Water was added, as required, from graduated flasks to a 5-inch flowerpot set in the soil immediately below the cover. Adequate aeration was secured through the changes in the air volume of the soil accompanying the changes in soil-moisture content. The plants were grown in an inclosure covered with a screen of one-fourth-inch mesh as a protection against possible hailstorms. The results of the different water-requirement measurements made at Akron, in northeastern Colorado, in 1911 are shown in Table XXI.

TABLE XXI.—*Summary of water-requirement measurements of varieties and crops at Akron, Colo., in 1911.*

BASED ON DRY MATTER PRODUCED.

Crop.	Variety.	Water requirement. Of variety.	Of crop.	Relative, compared with wheat.
Alfalfa	Grimm	1,068±16	1,068	211
Pea, field	Canada	800±17	800	158
Artemisia frigida		765±24	765	151
Rye	Spring	724±7	724	143
Sweet clover		709±9	709	140
Oats	Burt	639±7	614	122
	Swedish Select	615±7		
	Sixty-Day	605±5		
	Canadian	598±14		
Buckwheat		578±13	578	114
Barley	Beardless	544±9	539	106
	Beldi	543±2		
	White Hull-less	542±3		
	Hannchen	527±8		
Wheat	Emmer	534±14	507	100
	Marvel Bluestem	531±5		
	Spring Ghirka	506±3		
	Galgalos	496±4		
	Kubanka	468±8		
Potato	Irish Cobbler	448±11	448	88
Rape		441±12	441	87
Sugar beet	Kleinwanzleben	377±8	377	74
Corn	Iowa Silvermine	420±3	369	73
	Northwestern Dent	368±10		
	Esperanza	319±5		
Weed	Amaranthus retroflexus	356±4	322	63
	Salsola pestifer	336±5		
	Amaranthus graecizans	275±7		
Sorghum	Dwarf milo	333±3	306	60
	White durra	321±2		
	Brown kaoliang	301±3		
	Red Amber	298±4		
	Blackhull kafir	278±5		
Millet	Kursk	287±2	275	54
	German	263±15		

BASED ON GRAIN PRODUCED.

Crop.	Variety.	Water requirement. Of variety.	Of crop.	Relative, compared with wheat.
Pea, field	Canada	2,218±100	2,218	163
Rye	Spring	2,215±37	2,215	163
Oats	Canadian	2,204±140	1,680	124
	Swedish Select	1,632±35		
	Burt	1,500±57		
	Sixty-Day	1,383±30		
Wheat	Marvel Bluestem	1,786±60	1,357	100
	Spring Ghirka	1,382±43		
	Galgalos	1,245±13		
	Kubanka	1,191±14		
	Emmer	1,180±42		
Barley	White Hull-less	1,475±40	1,244	92
	Beardless	1,210±38		
	Beldi	1,155±18		
	Hannchen	1,134±27		
Buckwheat		1,037±33	1,037	76
Millet	Kursk	923±40	923	68
Sorghum	Dwarf milo	1,123±57	790	58
	White durra	806±12		
	Blackhull kafir	803±26		
	Brown kaoliang	726±12		

The standard field crops differ greatly as regards their efficiency in the use of water. Alfalfa, for example, uses four times as much water as millet and the more efficient sorghums in the production of a pound of dry matter. Corn ranks next to sorghum and millet in efficiency in the use of water. The water requirement of the small-grain crops is approximately twice that of millet, but only one-half that of alfalfa. On the basis of grain production alone, the water requirement of millet and the grain sorghums is approximately one-half that of oats and two-thirds that of wheat and barley.

Varieties of the same crop show measurable differences in their water requirement. This suggests the possibility of developing strains which are much more efficient in the use of water than those now grown in dry-land regions.

Determinations were also made during 1910 and 1911 of the water requirement of wheat grown under field conditions. The moisture content of the soil at the beginning and at the end of the experiments was determined through extensive sampling, and the rainfall absorbed by the soil during the period of growth was also computed from daily moisture determinations. The water requirement of Kubanka wheat determined in this way for 1910 and 1911 was found to be 700 and 862, respectively. The water requirement of Kubanka wheat in the pot experiments of 1911 was only 468. Both seasons were deficient in rainfall during the growing period, none of the rains penetrating below the first foot. The rains also occurred at a time when the crop was drawing its moisture supply mainly from stored moisture in the subsoil. If the water supply through rains during the growing season is ignored, the water requirement based upon the amount of stored water removed becomes 486 and 466 for the two years, respectively, which agrees well with the pot determinations. These determinations therefore suggest that wheat is able to make little direct use of light rains coming at a time when the crop is drawing its principal water supply from lower depths.

Measurements of the water requirement of wheat and sorghum at Akron, Colo., and Amarillo and Dalhart, Tex., afford some indication of the influence of climatic conditions on the water requirement. The evaporation from a free water surface in northern Texas during the growth period of wheat and sorghum averaged about 18 per cent above that at Akron, Colo. The water requirement of sorghum was practically the same in the two regions, while the water requirement of wheat averaged 36 per cent higher in northern Texas. This indicates that sorghum is relatively better adapted to northern Texas and that wheat is relatively better adapted to Colorado.

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