Seasonal Changes in Soil Moisture As Related to Rainfall, Soil Type and Crop Growth

by R. H. Shaw, J. R. Runkles and G. L. Barger

Department of Agronomy

AGRICULTURAL AND HOME ECONOMICS EXPERIMENT STATION, IOWA STATE COLLEGE

RESEARCH BULLETIN 457 FEBRUARY 1958 AMES, IOWA

CONTENTS

Seasonal Changes in Soil Moisture as Related to Rainfall, Soil Type and Crop Growth[1]

BY R. H. SHAW, J. R. RUNKLES AND G. L. BARGER[2]

In early 1954 it was believed that soil moisture reserves in Iowa were at an unusually low level and that crop production potential was seriously reduced. To estimate the supply of soil moisture present at that time, a statewide study of soil moisture conditions was initiated.

An examination of these data in relation to crop production potential for the following season showed a lack of basic information on water use and availability in Iowa, although many fragments of general information were available. To obtain information on these problems an expanded program was established on soil moisture measurement and water utilization.

BACKGROUND AND OBJECTIVES

Production of any agricultural crop is dependent upon an available supply of water during the growing season. The water needed by crops is drawn from the soil moisture supply, which can be replenished either by precipitation, condensation, irrigation or movement up from a water table. Water added to the soil surface may be lost either by runoff, evaporation or percolation, or it may be stored in the soil for future use. Water lost from the soil profile may be water gained for ground water or stream flow.

The primary source of moisture is from precipitation. Information on precipitation amounts is readily available for most areas from Weather Bureau climatological data. Another source of moisture, which has often been considered as adding only negligible amounts of water to the soil, is dew. However, work by Thornthwaite and Holzman,[3] and by Harold and Dreibelbis[4,5] have shown that appreciable amounts of condensation can take place. Although only some of this condensation water actually gets into the soil, it all helps to reduce evapotranspiration losses. When water is evaporating from the plant surface, less water is required for transpiration of the crop.

Precipitation amounts alone do not provide the precise information needed for water availability. Actually, only that which enters into and is stored in the soil is available for plant use. To estimate stored moisture, losses must be determined.

Runoff losses vary widely with the season and are particularly affected by the amount and character of rainfall. Browning et al.[6] determined the average yearly runoff during 11 years of study in southwest Iowa on a deep loess soil of 9 percent slope. They found annual runoff was 18.9 percent of the annual precipitation for continuous corn, 12.6 percent for rotation corn, 9.9 percent for oats, 3.8 percent for rotation clover and 1.2 percent for continuous bluegrass. During this period, annual precipitation was 28.9 inches—almost 5 inches below normal. Although the highest percentage runoff for corn land was in February, greatest actual runoff occurred in the summer months. In oat land the greatest runoff occurred in late winter and early spring. June runoff was highest in several crops because of the high June rainfall.

Percolation losses in Iowa have generally been smaller than runoff losses. Browning et al.[7] found that, for a 6-year period, the average percolate from continuous corn and bluegrass ranged from 5 to 13 percent of the annual precipitation. Over 75 percent of the percolate from corn was during the 3-month period, April, May and June. For bluegrass, 65 percent of the total yearly percolate occurred in September, October and November. These results were obtained during a period of below-normal precipitation. During periods of greater precipitation, percolation amounts would be expected to be higher.

Galligan[8] estimated annual runoff and percolation in Iowa to be 5.2 inches, or 17 percent of the annual precipitation. This was based on streamflow measurements

---

[1] Project 1276 of the Iowa Agricultural and Home Economics Experiment Station. The authors wish to acknowledge the help of those who have given considerable time and effort to the collection of the soil moisture samples which made this study possible. In particular, we appreciate the help of the area agronomists, the farm supervisors, farm managers and their assistants who have given considerable time and effort in the location of the experimental areas and the collection of the samples. We especially recognize the valuable assistance of E. R. Duncan, who has given valuable advice during the progress of the study.

[2] Professor of agricultural climatology; formerly assistant professor of soils, Iowa State College, now associate professor of soils, South Dakota State College; and Area Climatologist, U. S. Weather Bureau and associate professor of agricultural climatology; respectively.

[3] C. W. Thornthwaite and B. Holzman. Measurement of evaporation from land and water surfaces. U. S. Dept. Agr. Tech. Bul. 817. 1942.

[4] L. L. Harrold and F. R. Dreibelbis. Agricultural hydrology as evaluated by monolith lysimeters. U. S. Dept. Agr. Tech. Bul. 1050. 1951.

[5] L. L. Harrold and F. R. Dreibelbis. 1955 progress report. Soil and Water Conservation Station, Coshocton, Ohio.

[6] G. M. Browning, R. A. Norton, A. G. McCall and F. G. Bell. Investigations in erosion control and the reclamation of eroded land at the Missouri Valley Loess Conservation Experiment Station, Clarinda, Iowa, 1931-42. U. S. Dept. Agr. Tech. Bul. 959. 1948.

[7] Ibid.

[8] W. E. Galligan. Supply and use of water in municipalities and agricultural industries in Iowa. Water Resources of Iowa. A symposium held at Iowa State College, Ames, Iowa. 1950.

from 13 streams in Iowa. Losses from individual locations for different periods would vary considerably from this average because of soil, crop and weather factors.

In addition to direct loss of rainfall from runoff and percolation, stored soil water may ultimately be lost by evaporation or transpiration. These will be considered together as evapo-transpiration.

Estimates of water consumption through evapo-transpiration have varied. Measurements made in weighing lysimeters by Harrold and Dreibelbis[9] show evapo-transpiration losses of 17.4 to 24.6 inches for corn from May through September, 12 to 14.2 inches for wheat from April through June and 18.7 to 26.3 inches for meadow from April through August. Rhoades and Nelson[10] report that irrigated corn ordinarily uses 16 to 25 inches during the growing season. Normal rainfall in Iowa during the period April through September is over 22 inches. This places Iowa in a favorable climate for corn production. With normal rainfall during the summer and an adequate subsoil moisture reserve in the spring, the production capacity of Iowa soils is large.

Specific information on soil moisture storage and water use in Iowa is not available. A research program was outlined to obtain some of this information.

Specific objectives of the program are: (1) to establish "normals" for soil moisture conditions in Iowa at different seasons of the year; (2) to determine the precipitation conditions at specified times of the year which will replenish low soil moisture supplies; (3) to determine the water requirement for producing a range of corn yields; and (4) to determine evapo-transpiration losses and to relate these to meteorological factors.

To evaluate these objectives fully will require data collected over a period of years under different weather conditions. This bulletin summarizes the data collected from 1954-56 and presents information on the first three objectives.

SHORT-PERIOD WATER USE STUDY—FALLOW AND CORN

An experiment at the Agronomy Farm was set up to study short-time soil moisture losses and to evaluate the sampling variability involved when Viehmeyer samples were used. The latter are discussed by Shaw, et al.[11] During three of the four sampling periods used, little or no precipitation fell, and water loss could be assumed to be due entirely to evapo-transpiration. During the last period very heavy rains fell, and runoff and percolation losses were large.

Fallow

A 100 x 300-foot area of Webster silty clay loam with a flat, uniform-appearing surface, but with the usual variable subsoil of glacial till, was kept free of all vegetation throughout the growing season. This area was divided into six areas or replications. Three locations were chosen at random from each of three replications, and three subsamples were taken in the immediate area. Samples were taken with a Viehmeyer tube in 1-foot-long increments down to 5 feet on four dates, July 9, 15, 21 and 29. Each individual 1-foot increment was dried for 48 hours at 105° C. and the moisture percentage determined. These moisture determinations were converted to inches of water by the following formula:

$$\text{Inches of water} = \frac{\text{Percent on a dry wt. basis} \times \text{inches of soil in sample} \times \text{bulk density.}}{100}$$

A constant bulk density of 1.3, based on samples taken and data available from the literature, was assumed for all soils.

The data from these samples are summarized in fig. 1. During much of this period, the soil surface was dry. Water loss during the first period was 0.05 inch per day. With a few light showers during the period July 15 to 29, loss increased to 0.07 inch per day. By July 29 the soil surface was very dry, and little loss occurred. Average loss per day was 0.05 inch. Heavy rains in late August filled the soil to its field capacity, and runoff and/or percolation losses were large.

Corn

An area approximately 100 x 300 feet on the edge of a large area of corn on a Webster silty clay loam was

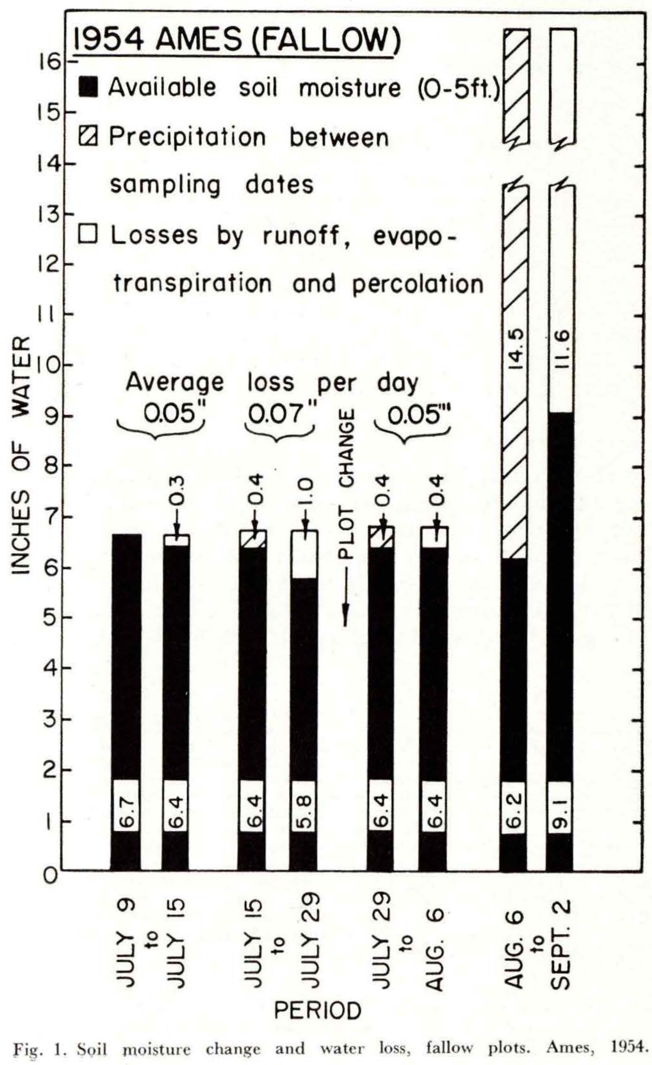

Fig. 1. Soil moisture change and water loss, fallow plots. Ames, 1954.

[9] Harrold, op. cit., p. 3.

[10] H. F. Rhoades and L. B. Nelson. Growing 100 bushel corn with irrigation. U. S. Dept. Agr. Yearbook of Agriculture, 1955. pp. 394-400.

[11] R. H. Shaw, D. R. Nielsen and J. R. Runkles (unpublished research). Iowa Agr. Exp. Sta. 1955.

selected for sampling. Three replications were sampled. Within each replication, three hills chosen at random were sampled—in the hill, 10 inches from the hill and 20 inches from the hill. Each boring consisted of five, 1-foot-long increments taken to a depth of 5 feet. The moisture percentages were converted to inches of water using a volume weight of 1.3.

These data are summarized in table 1 and fig. 2. Except for the last period, all losses were due to evapo-transpiration. On certain dates the soil surface had a moisture content less than the 15-atmosphere tension moisture because of surface evaporation. The 15-atmosphere tension moisture percentage was assumed to be the wilting percentage.

Average losses per day, from July 9 to 15, were 0.17 inch and, from July 15 to 28, were 0.16 inch. The soil surface was dry most of this period, and only small amounts of rain fell. Loss must have been largely due to transpiration. From July 28 to Aug. 6, when soil moisture was becoming more limiting, loss per day was only 0.08 inch. Losses from fallow soil for approximately the same periods were 0.05, 0.07 and 0.05 inch, respectively.

Average daily open-pan evaporation losses for the same periods were 0.42, 0.26 and 0.26 inch. Field losses would not be expected to equal evaporating pan losses, but the ratio between the two would give an indication of moisture stress in the soil. This ratio was 0.40, 0.62 and 0.31 for the three periods.

STATE SOIL MOISTURE STUDY

Nature of the Data

Field sampling sites were selected to represent different major soil types over the state. At different times since the beginning of this study, the number of locations has varied from 12 to 17. All of the locations are plotted in fig. 3. Where possible, plots were located on experimental farms. The most level and uniform land available in the area was selected for the plot site to reduce runoff to a minimum. A 40 x 40-foot area in a larger area planted to the crop under consideration was chosen. This was divided into two replications. Plots not located on the experimental farms were located in farmers' fields. Based on the data obtained in the Agronomy Farm study, six separate borings or cores were taken from each plot at each sampling time, three in each half or replication of the plot. These borings were taken in 1-foot increments to a depth of 5 feet. In cornfields, the cores were taken in the hill, 10 inches from the hill and 20 inches from the hill, each distance being from a different hill. On meadow land the three borings were randomized in each replication. These three borings were then composited in a soil moisture can by 1-foot increments and the moisture content determined by drying at 105°C. for 48 hours.

Facilities were not available to separate runoff, percolation and evapo-transpiration, and they were all

TABLE 1. AVAILABLE SOIL MOISTURE IN INCHES IN CORN LAND AT AMES ON FIVE SAMPLING DATES, SAMPLING TUBE DATA, 1954.

(Average of 27 borings)

Depth-feet	July 9	July 15	July 28	Aug. 6	Sept. 2
0-1	0.3	-0.2†	-0.5	-0.4	1.2
1-2	0.6	0.3	0.0	0.1	1.2
2-3	1.1	1.0	0.5	0.1	1.7
3-4	1.6	1.5	1.0	0.9	1.7
4-5	1.4	1.4	1.3	1.3	1.7
Total	5.0	4.0	2.3	2.0	7.5
Precipitation between sampling dates		0.0	0.40	0.35	14.52

†Negative values indicate soil moisture less than 15-atmosphere tension moisture.

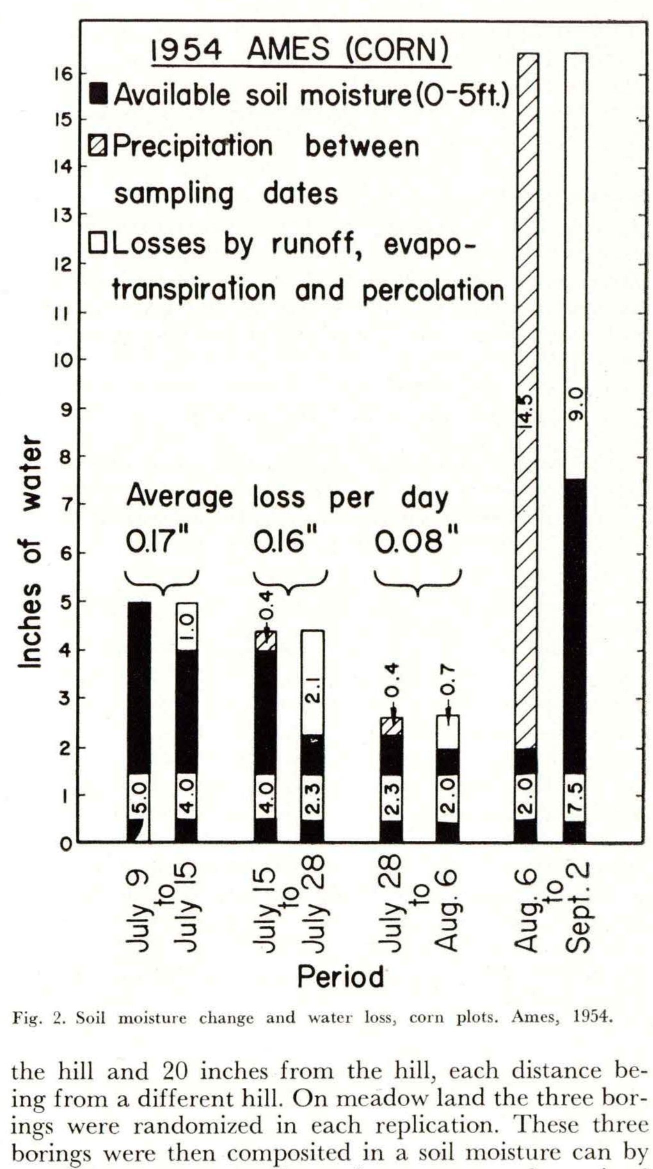

Fig. 2. Soil moisture change and water loss, corn plots. Ames, 1954.

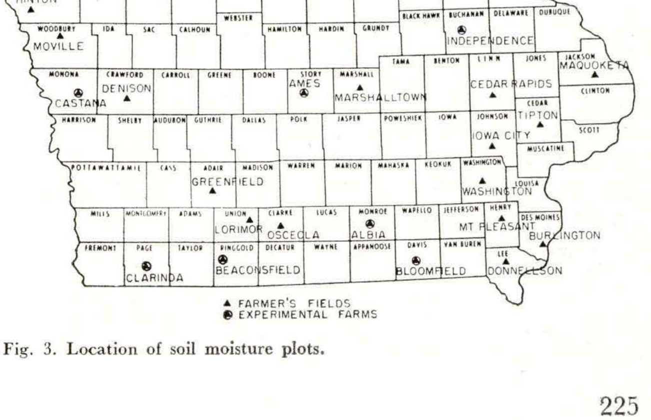

Fig. 3. Location of soil moisture plots.

grouped together as "water lost." The water lost during each sampling period was determined as follows:

Water lost = water stored in soil on date A + rainfall between dates A and B — water left in soil on date B

Data on the amount of water above the wilting percentage at each location by 1-foot increments for each sampling date are available in mimeographed form from the authors. The total water loss and precipitation during each period, and the loss per day, are given in tables 2 through 8 for corn, meadow and oats in 1954, 1955 and 1956.

Soil Moisture and Weather Pattern

The gains, losses of soil moisture and amounts of water loss are presented for selected locations in figs. 4 through 9. The following section is a brief discussion of the weather experienced during the experiment.

1953-54

The fall of 1953 was very dry with low rainfall and low soil moisture supplies in most areas. Average precipitation between the February and April sampling dates was 6 inches, 2.5 inches above normal.

From April to early June, precipitation averaged slightly above the normal of 5.4 inches. During June, precipitation averaged over 1 inch above normal for the corn locations. At Kanawha over 10 inches of rain fell in a 4-day period. By early July the only plots with less than 5 inches of available moisture were the Beaconsfield and Albia corn plots and the Independence, Ames, Clarinda, Beaconsfield and Albia meadow plots.

The month of July was very dry except in extreme north-central Iowa. Average rainfall for this period was more than 2 inches below the normal of 3.6 inches. By early August, soil moisture was largely depleted in the top 3 feet of soil at most locations, and some plots were dry down to 5 feet. In August, all areas had above-normal precipitation. Average precipitation for the corn locations was 7 inches, with the heaviest amounts falling the last half of the month. Ames received the heaviest amount, 14.7 inches.

Almost normal precipitation occurred in September and from mid-September to mid-November.

1954-55

Precipitation from the date of the fall sampling in November 1954 to April 1955 was 7.1 inches, 1.8 inches below normal. Precipitation during the spring was the normal of 7.6 inches. From mid-June to early August, precipitation was about 2 inches below the normal of 5.9 inches. Except for locally heavy rains in central, east-central and southeast Iowa, the fall of 1955 continued dry; only 5.4 inches fell from August to November compared with a state normal of 10.1 inches.

1955-56

Precipitation during the winter of 1955-56 was over 4 inches below the normal of 7.5 inches and was especially low in western and southern Iowa. Good rains occurred in north-central, northeast and east-central Iowa by early June. During June, much of western Iowa had up to 4 inches of rainfall. During July, heavy rains fell in southwest Iowa and parts of north-central, northeast and east-central Iowa. Northwest and much of west-central and central Iowa were very dry. During August, most stations received near-normal or above-normal rainfall. September was very dry in most of the state except for locally heavy rains in west-central Iowa. No rains of any consequence fell after that until early

TABLE 2. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1954 FOR CORN PLOTS.

	Approximate period													
	10 Feb. to 15 Apr.		15 Apr. to 1 June		June		July		August		September		15 Sept. to 15 Nov.	
Location	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days†	Loss in.
Primghar	63	4.4	54	4.4	21	4.8	33	6.4	32	4.4	26	2.9	61	1.9
Moville	....	......	53	7.0	22	4.5	30	6.1	35	3.5	26	1.1	61	1.3
Hull	63	4.3	....	......	....	......	....	......	....	......	....	......	....	......
Hinton	63	3.0	....	......	....	......	....	......	....	......	....	......	....	......
Kanawha	....	......	47	2.9	23	10.9	32	5.6	30	4.4	....	......	....	......
Saratoga	....	......	....	......	28	7.9	32	6.1	30	3.5	....	......	....	......
Independence	64	3.2	40	5.1	38	7.2	31	6.8	29	6.2	....	......	81	3.1
Castana	....	......	....	......	25	5.9	29	6.4	33	4.9	27	2.4	63	1.9
Denison	....	......	....	......	22	2.6	31	8.0	32	3.9	27	2.0	61	2.2
Ames	62	2.9	55	6.7	32	5.8	28	3.4	27	9.6	....	......	56	6.5
Marshalltown	61	3.8	48	4.1	31	7.4	31	4.5	29	3.0	37	4.5	40	2.0
Cedar Rapids	66	2.6	37	4.6	29	3.6	38	8.0	29	5.4	....	......	....	......
Iowa City	....	......	....	......	28	3.5	39	7.3	28	4.2	....	......	....	......
Clarinda	67	3.4	....	......	37	3.8	34	5.0	30	5.4	37	1.8	37	1.3
Beaconsfield	....	......	....	......	33	5.2	32	2.7	32	6.0	41	3.2	33	1.5
Osceola	....	......	39	5.0	37	5.2	32	5.4	32	5.0	39	4.4	....	......
Greenfield	....	......	....	......	37	7.6	....	......	....	......	39	3.8	....	......
Albia	70	3.9	....	......	....	......	21	1.4	28	5.5	....	......	....	......
Bloomfield	64	4.3	42	3.2	....	......	....	......	30	3.2	33	3.0	....	......
Washington	66	3.1	39	3.2	19	4.1	39	7.1	31	4.2	....	......	49	3.7
Mt. Pleasant	....	......	....	......	28	6.3	36	5.3	34	4.8	....	......	49	4.1
Av. total loss in period	3.7		4.6		5.6		5.6		4.8		2.9		2.6	
Av. No. of days	65		45		29		32		31		33		54	
Av. loss per day	0.06		0.10		0.19		0.17		0.16		0.09		0.05	
Av. precipitation at sampling locations	6.0		5.7		5.8		1.4		7.1		4.0		4.1	
Normal precipitation (state av.)‡	3.5		5.4		4.5		3.6		3.8		4.0		4.0	
Gain or loss in soil moisture	+2.3		+1.1		+0.2		—4.2		+2.3		+1.1		+1.5	

†Includes data for various periods 1 Sept. to 1 Dec.
‡Based on period 1899-1943.

TABLE 3. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1955 CORN PLOTS.

	Approximate period							
	15 Nov. to 15 Apr.		15 Apr. to 15 June		15 June to 1 Aug.		1 Aug. to 1 Nov.	
Location	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Primghar	128	2.1	68	3.6	41	7.5	94	5.1
Kanawha	......	......	54	4.9	57	10.2	83	5.5
Saratoga	......	......	....	......	50	7.4	95	7.1
Independence	134	3.0	69	6.7	51	8.7	94	5.0
Castana	126	2.7	....	......	37	7.0	92	4.9
Ames	163	4.9	60	7.0	....	......	....	......
Marshalltown	140	5.1	....	......	53	10.7	84	4.2
Cedar Rapids	169	5.3	73	8.5	54	9.8	94	8.5
Clarinda	136	4.3	76	3.6	48	8.1	89	6.0
Beaconsfield	137	4.2	....	......	50	8.2	91	6.7
Albia	187	12.1	70	7.4	53	10.0	84	6.2
Bloomfield	183	11.4	72	11.9	46	9.9	89	6.1
Av. total loss in period	5.5		6.7		8.9		5.9	
Av. No. of days	150		68		49		89	
Av. loss per day	0.04		0.10		0.19		0.07	
Av. precipitation at sampling locations	5.3		7.6		4.0		5.4	
Normal precipitation (state av.)	7.1		7.6		5.9		10.1	
Gain or loss in soil moisture	—0.2		+0.9		—4.9		—0.5	

TABLE 4. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1956 FOR CORN PLOTS.

	Approximate period							
	1 Nov. to 15 Apr.		15 Apr. to 15 June		15 June to 1 Aug.		1 Aug. to 1 Nov.	
Location	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Doon	......	......	....	......	48	6.9	93	8.9
Primghar	155	2.7	60	3.3	55	6.9	87	5.2
Kanawha	160	3.3	63	6.0	54	7.0	87	5.1
Clarion	......	......	71	5.9	46	4.3	87	5.4
Saratoga	168	2.5	51	5.5	53	8.5	90	8.3
Independence	151	1.5	67	7.6	53	6.9	91	8.6
Elkader	......	......	51	4.8	54	7.0	90	9.3
Castana	159	1.5	....	......	54	7.5	86	6.4
Ames	168	3.4	59†	4.1	57	6.9	85	6.3
Marshalltown	163	3.4	69†	6.2	47	8.2	87	7.0
Cedar Rapids	152	2.9	66	5.6	56	8.3	84	9.0
Tipton	......	......	46	10.0	54	8.0	84	8.2
Maquoketa	......	......	44	5.9	54	10.0	84	10.5
Clarinda	162	1.6	66	2.8	57	9.2	87	6.0
Beaconsfield	160	1.4	50	3.7	56	9.0	87	8.1
Albia	161	3.2	62	2.8	52	9.1	91	9.1
Bloomfield	161	3.7	64	3.0	52	7.6	89	10.1
Burlington	159	6.0	64	5.5	47	10.4	85	6.6
Av. total loss in period	3.0		5.2		7.9		7.6	
Av. No. of days	160		60		53		87	
Av. loss per day	0.02		0.09		0.15		0.09	
Av. precipitation at sampling locations	3.3		6.0		6.7		6.9	
Normal precipitation (state av.)	7.5		7.6		5.9		10.1	
Gain or loss in soil moisture	+0.3		+0.8		—1.2		—0.7	

†Assumed same as soybeans.

TABLE 5. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1954 FOR MEADOW PLOTS.

	Approximate period													
	10 Feb. to 15 Apr.		15 Apr. to 1 June		June		July		August		September		1 Oct. to 15 Nov.	
Location	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Kanawha	69	3.5	....	......	23	10.3	32	4.0	30	4.4	....	......	....	......
Saratoga	....	......	....	......	28	6.2	33	5.4	29	3.9	....	......	....	......
Saratoga	....	......	....	......	....	......	31	6.3	31	3.6	....	......	....	......
Independence	65	2.0	....	......	....	......	31	3.6	29	3.3	....	......	....	......
Independence	....	......	....	......	38	8.2	31	3.3	29	8.0	....	......	83	5.5
Castana	....	......	....	......	25	5.9	29	6.4	33	5.7	27	3.1	63	1.8
Ames	62	2.9	....	......	....	......	....	......	....	......	....	......	....	......
Clarinda	67	3.1	40	3.6	37	4.2	34	2.3	30	5.3	38	3.5	36	1.6
Lorimor	....	......	42	6.5	....	......	....	......	....	......	....	......	....	......
Beaconsfield	....	......	44	6.5	33	7.3	32	1.4	31	4.7	41	3.7	33	3.0
Albia	72	4.6	....	......	....	......	21	1.4	28	3.8	30	0.9	....	......
Bloomfield	....	......	42	8.1	....	......	....	......	30	4.1	33	2.2	....	......
Av. total loss in period	3.2		6.2		7.0		3.8		4.7		2.7		3.0	
Av. No. of days	67		42		31		30		30		34		54	
Av. loss per day	0.05		0.15		0.23		0.13		0.16		0.08		0.06	
Av. precipitation at sampling locations	4.9		5.1		6.8		1.6		6.4		3.7		3.1	
Normal precipitation (state av.)	3.5		5.4		4.5		3.6		3.8		4.0		4.0	
Gain or loss in soil moisture	+1.7		—1.1		—0.2		—2.2		+1.7		+1.0		+0.1	

TABLE 6. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1955 FOR MEADOW PLOTS.

Location	Approximate period							
	15 Nov. to 15 Apr.		15 Apr. to 15 June		15 June to 1 Aug.		1 Aug. to 1 Nov.	
	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Kanawha	......	......	54	6.4	57	9.8	83	6.4
Saratoga	......	......	....	......	50	8.6	95	6.1
Independence	......	......	69	6.3	50	6.2	94	6.0
Castana	126	2.3	79	8.0	43	4.8	92	5.4
Ames	......	......	60	8.9	38	4.7	95	6.9
Clarinda	136	4.2	....	......	48	6.1	89	3.8
Beaconsfield	......	......	....	......	50	6.3	91	5.7
Albia	187	8.0	70	10.0	53	9.8	84	7.6
Bloomfield	183	9.8	72	11.9	46	8.4	89	6.0
Av. total loss in period	......		8.6		7.2		6.0	
Av. No. of days	......		67		48		90	
Av. loss per day	......		0.13		0.15		0.07	
Av. precipitation at sampling locations	......		7.2		4.9		5.4	
Normal precipitation (state av.)	......		7.6		5.9		10.1	
Gain or loss in soil moisture	......		—1.4		—2.3		—0.6	

TABLE 7. WATER LOSS AND AVERAGE PRECIPITATION DURING SELECTED PERIODS IN 1956 FOR MEADOW PLOTS.

Location	Approximate period							
	1 Nov. to 15 Apr.		15 Apr. to 15 June		15 June to 1 Aug.		1 Aug. to 1 Nov.	
	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Doon	......	......	....	......	48	5.8	93	7.5
Kanawha	160	1.8	70	7.2	46	7.1	87	7.3
Saratoga	168	2.2	51	7.2	53	7.6	90	9.0
Independence	151	1.2	67	8.3	53	7.5	91	7.6
Elkader	......	......	51	6.5	54	7.1	90	9.8
Castana	159	1.2	51	5.1	55	5.6	86	6.0
Ames	169	1.8	63	6.3	53	3.9	84	7.7
Cedar Rapids	......	......	....	......	....	......	84	9.2
Clarinda	162	2.4	74	3.9	57	7.8	86	7.7
Beaconsfield	160	2.3	59	5.1	56	8.6	87	8.2
Albia	161	2.5	62	5.5	52	8.1	91	9.1
Bloomfield	161	2.4	64	6.4	52	6.7	89	8.2
Washington	......	......	63	7.6	47	4.6	85	4.1
Burlington	159	4.4	64	8.3	47	8.3	85	5.3
Donnellson	......	......	....	......	....	......	88	8.4
Av. total loss in period	2.1		6.4		6.8		7.5	
Av. No. of days	161		62		52		88	
Av. loss per day	0.013		0.11		0.13		0.09	
Av. precipitation at sampling locations	3.0		4.9		7.0		6.5	
Normal precipitation (state av.)	7.5		7.0		5.9		10.1	
Gain or loss in soil moisture	+0.9		—1.5		+0.2		—1.0	

TABLE 8. WATER LOSS AND AVERAGE PRECIPITATION FOR SELECTED PERIODS FOR OAT PLOTS.

Location	Approximate period					
	1954		1955		1956	
	15 Apr. to 1 June		15 Apr. to 15 June		15 Apr. to 15 June	
	No. days	Loss in.	No. days	Loss in.	No. days	Loss in.
Primghar	54	4.4	....	......	....	......
Moville	53	7.0	....	......	....	......
Kanawha	....	......	....	......	63	5.1
Clarion	45	7.1	....	......	....	......
Saratoga	....	......	....	......	51	6.9
Independence	40	5.6	....	......	65	10.0
Elkader	....	......	....	......	51	6.2
Castana	....	......	50	9.8	59	5.3
Ames	55	8.1	60	9.9	....	......
Marshalltown	....	......	65	10.3	69	9.3
Cedar Rapids	....	......	....	......	66	7.5
Iowa City	37	3.5	....	......	....	......
Beaconsfield	....	......	....	......	58	6.3
Albia	....	......	....	......	62	5.0
Mt. Pleasant	35	4.6	....	......	....	......
Av. total loss in period	5.8		10.0		6.8	
Av. No. of days	46		58		60	
Av. loss per day	0.13		0.17		0.11	
Av. precipitation at sampling locations	6.0		6.7		5.8	
Normal precipitation (state av.)	5.4		7.6		7.6	
Gain or loss in soil moisture	+0.2		—3.3		—1.0	

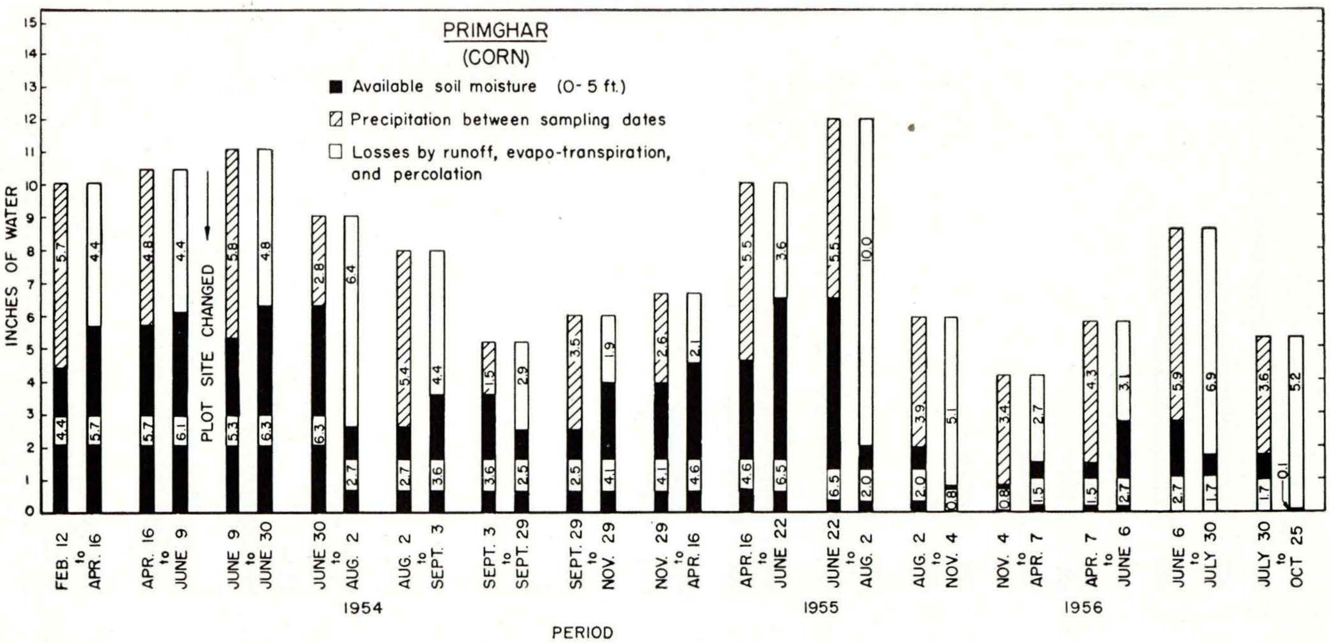

Fig. 4. Soil moisture change and water loss. Primghar, corn.

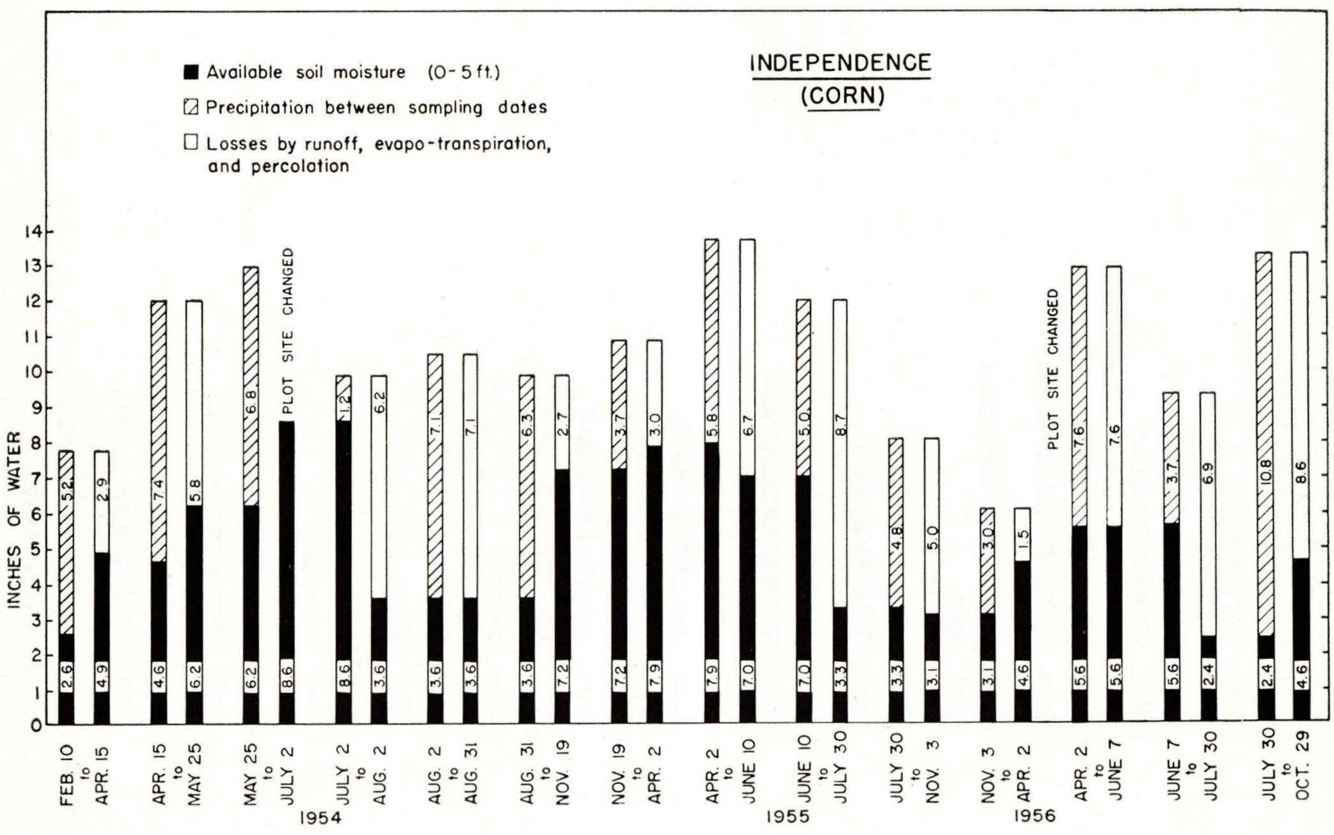

Fig. 5. Soil moisture change and water loss. Independence, corn.

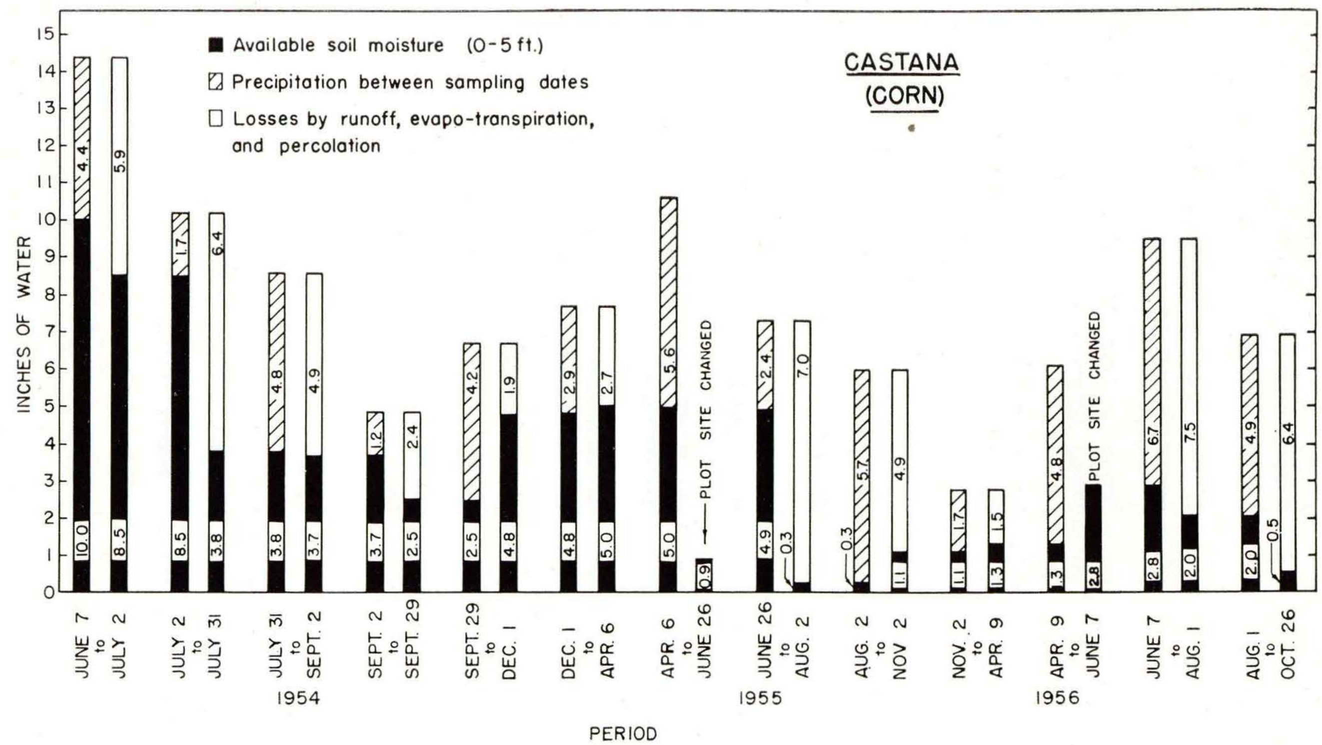

Fig. 6. Soil moisture change and water loss. Castana, corn.

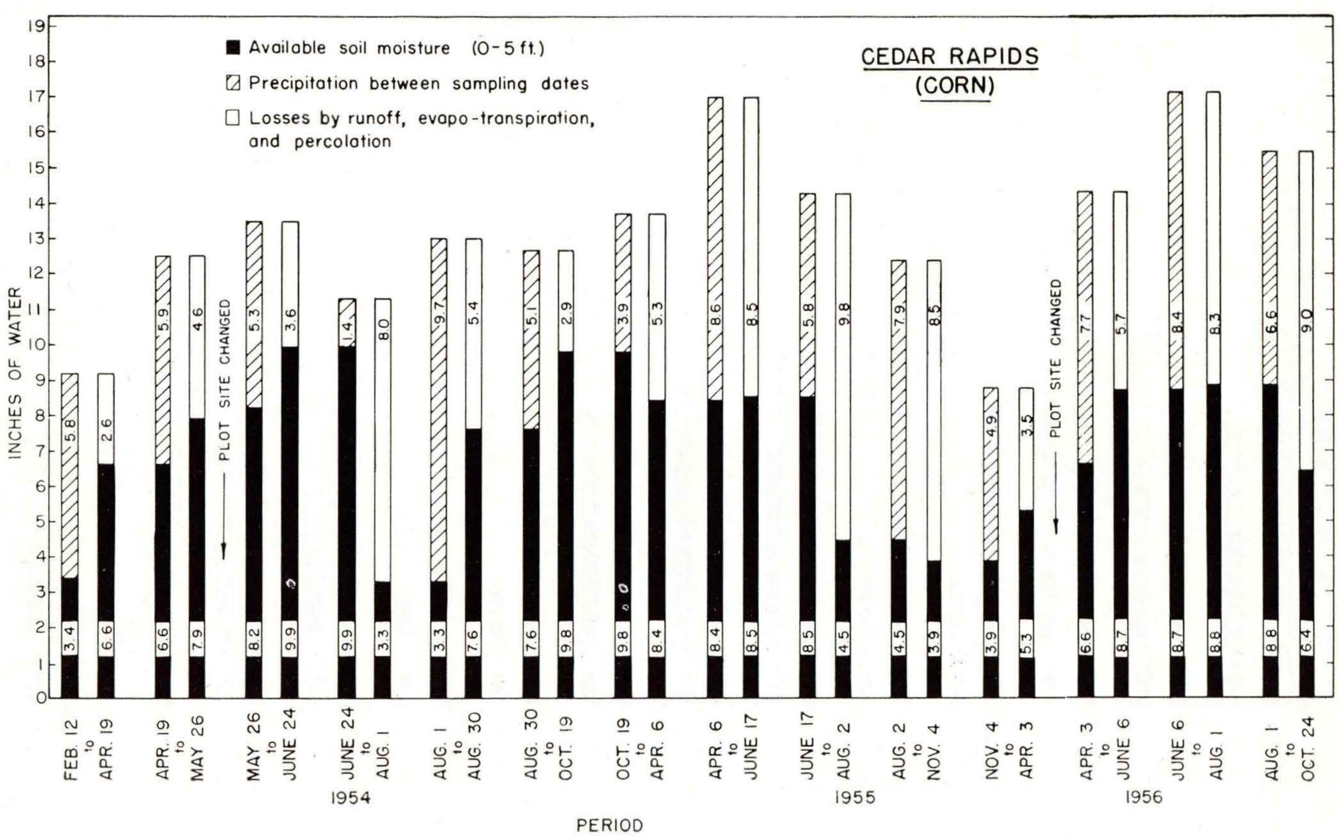

Fig. 7. Soil moisture change and water loss. Cedar Rapids, corn.

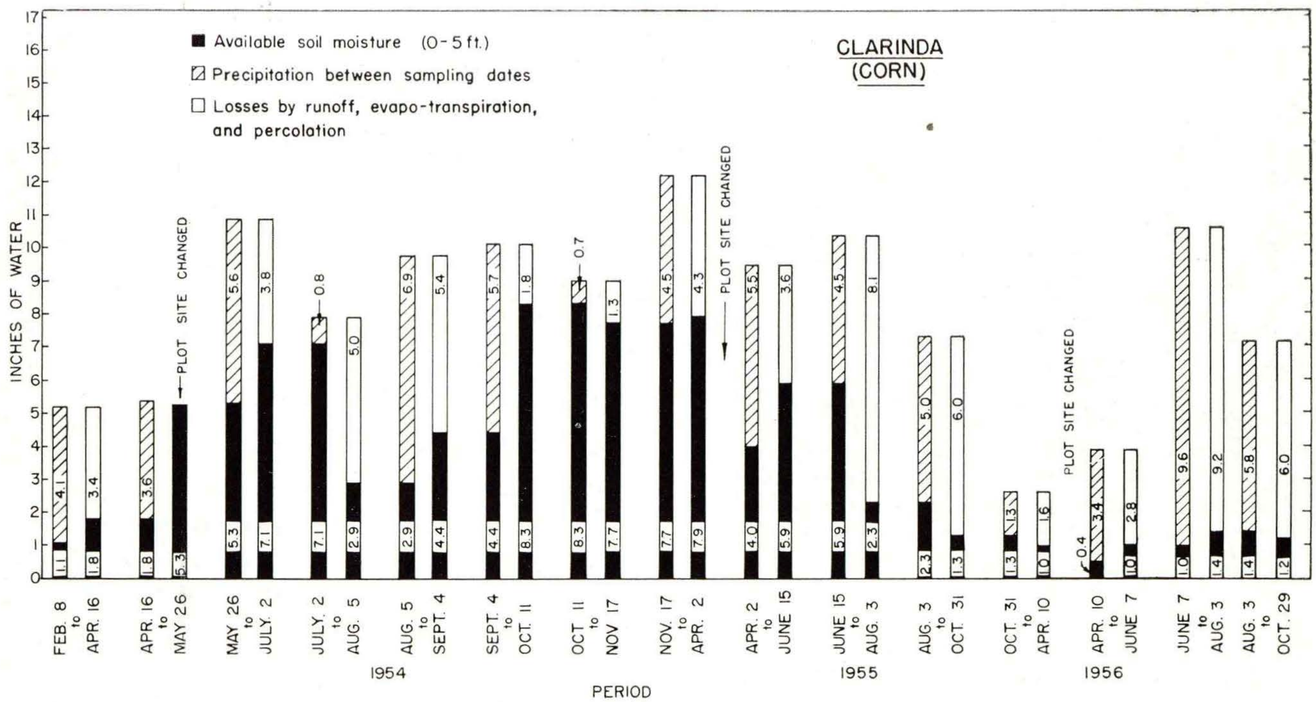

Fig. 8. Soil moisture change and water loss. Clarinda, corn.

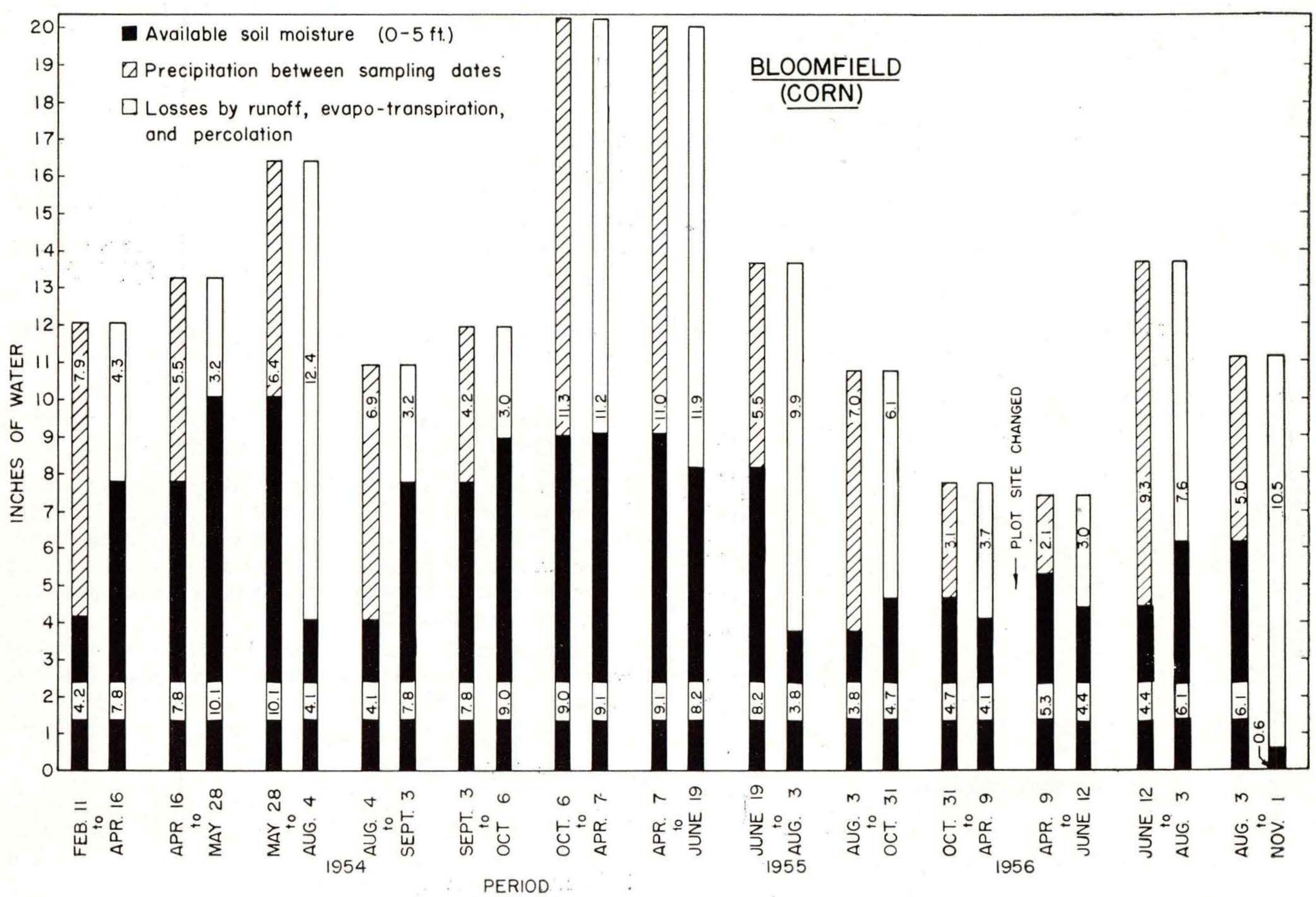

Fig. 9. Soil moisture change and water loss. Bloomfield, corn.

November, shortly after most of the soil moisture samples were taken.

Seasonal Changes

Little information is available for Iowa on how the amount of soil moisture changes with different amounts of rainfall during the year. Browning, et al.[12] have reported 10 years of soil moisture data from the Missouri Valley Loess Conservation Experimental Station, Clarinda, for the period 1931-42. Some of these data have been summarized by Shaw and Runkles.[13] The best data on seasonal changes in soil moisture would be obtained by having a number of years of data for each location, which could be used to determine the relation for that soil condition. Since such data were not available, the data from all locations with various soil types were analyzed together. Considerable variability should be expected in data from such a wide range of soil types. The regression analysis of these data presented in the following sections must be interpreted with this in mind.

CORN

Winter—Early Spring

In 1954 the data covered the period, February to April. No attempt was made to separate these points into wet or dry surface soil. Water loss for the period was computed as:

$$Y_W = 2.04 + 0.28x$$

where Y_W = water loss (scale on left side of graph)

x = precipitation between sampling dates.

The correlation between water loss and precipitation was $r = 0.69^{**}$[14]

The above-normal precipitation for the period resulted in considerable increase in soil moisture (fig. 10).

$$Y_S = -1.28 + 0.60x, \quad r = 0.82^{**}$$

12 Browning, op. cit., p. 3.
13 R. H. Shaw and J. R. Runkles. Soil moisture and water utilization in Iowa. Agron. Jour. 48:313-318. 1956.
14 In the following pages,
* means significant at the 5-percent level of probability.
** means significant at the 1-percent level of probability.

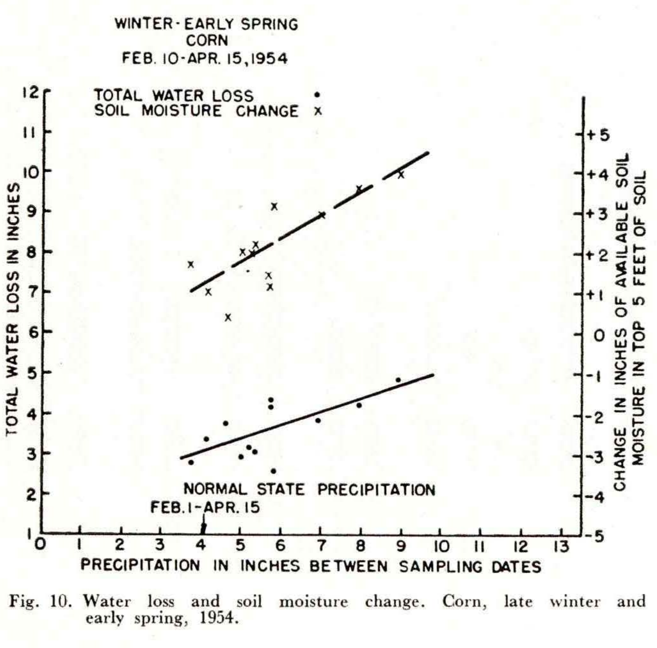

Fig. 10. Water loss and soil moisture change. Corn, late winter and early spring, 1954.

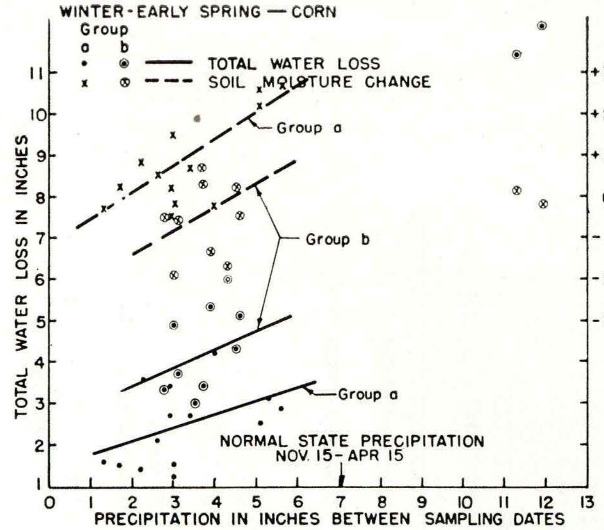

Fig. 11. Water loss and soil moisture change. Corn, winter-early spring, 1954-55 and 1955-56.

where Y_S = soil moisture change (scale on right side of graph).

With normal precipitation of 4.1 inches, an average increase in soil moisture of about 1 inch would be expected.

During the period, November to April, no water is usually lost from corn by transpiration. All of the water lost from within the soil is by percolation or evaporation which is a soil-surface process. Subsoil water is little affected by evaporation. The data for 1954-55 and 1955-56 were classed into two groups according to available moisture in the top 2 feet of soil at the beginning of the period. Those in the dry group *a* had less than 1 inch of available moisture in each foot, or over 1 inch in 1 foot but a total of less than 2½ inches in the top 2 feet. Under these conditions, surface evaporation was believed to be somewhat limited. Those in the wet group *b* had more than 1 inch in each foot, or 2½ inches or more in the top 2 feet.

Linear regression equations (fig. 11) and correlation coefficients were computed for each group. For water loss:

Group *a* $Y_W = 1.41 + 0.35x, \quad r = 0.68^{**}$
Group *b* $Y_W = 2.92 + 0.27x, \quad r = 0.19$

Water loss was much smaller in the dry group *a* than in the wet group *b*. Two locations, Albia and Bloomfield, 1954-55, were not included in the regression because their precipitation was considerably above any other location and because they both represent locations with very tight subsoils.

Soil moisture increased more when the period started with low, group *a*, soil moisture than with high, group *b*, moisture.

Group *a* $Y_S = -1.22 + 0.64x, \quad r = 0.84^{**}$
Group *b* $Y_S = -2.79 + 0.70x, \quad r = 0.43$

With normal precipitation, locations in group *a* would be expected to have an average gain of over 3 inches of soil moisture, while those in group *b* would gain about 2 inches. However, more data with normal to above-normal precipitation are needed to evaluate this interval.

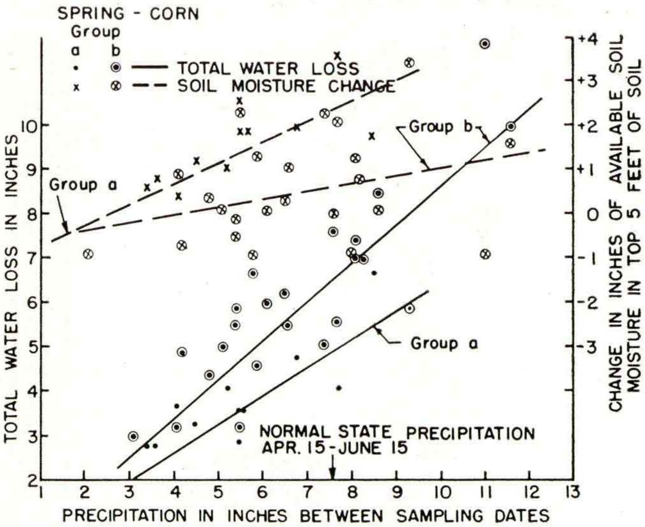

Fig. 12. Water loss and soil moisture change. Corn, spring, 1954, 1955 and 1956.

Spring

The data covered the period from mid-April to early or mid-June and were divided into two groups (fig. 12) in the same manner as the winter-early spring period. Water loss was ½ to over 2 inches greater for the group starting with good soil moisture in the top 2 feet. The relationships were:

Group *a* $Y_W = 0.72 + 0.57x, \quad r = 0.83^{**}$
Group *b* $Y_W = 0.63 + 0.81x, \quad r = 0.86^{**}$

Most locations had some gain in soil moisture during this period. The relationships were:

Group *a* $Y_S = -0.72 + 0.43x, \quad r = 0.74^{**}$
Group *b* $Y_S = -0.54 + 0.16x, \quad r = 0.30$

With normal rainfall, an average gain of 2½ inches would be expected for locations with low soil moisture in the top 2 feet, while those with good moisture would be expected to show a small average gain. However, the correlation in the last group was very low.

Late Spring—Early Summer

June. In June 1954, all data were grouped into the wet class. Only one location was classed dry, and it was a borderline case. Water loss was expressed by the regression equation:

$$Y_W = 2.12 + 0.56x, \quad r = 0.59^{*}$$

Soil moisture change was expressed by the equation:

$$Y_S = -2.12 + 0.44x, \quad r = 0.50$$

With normal precipitation of 4.5 inches, the average change in soil moisture was almost zero, but the correlation was not significant. Only with above-normal precipitation was soil moisture increased. Kanawha, which had over 12 inches of rainfall between sampling dates, was not included in the regression because of excessive runoff there compared with the other stations.

July. Water loss was similar at most locations regardless of precipitation, except for Ames, Albia and Beaconsfield. Water loss at these locations was low because of low moisture supplies. These were all group *a*, or dry stations. For the other stations:

$$Y_W = 5.70 + 0.36x, \quad r = 0.41$$

All locations showed a decrease in soil moisture. Little change occurred at Ames, Albia and Beaconsfield because there was little to lose. At the other locations:

$$Y_S = -5.61 + 0.65x, \quad r = 0.59^{*}$$

With normal precipitation of 3.6 inches, an average soil-moisture loss of 3.5 inches would be expected.

Mid-June to early or mid-August. During the latter part of this period corn roots had penetrated to a depth of several feet. The data were classed into two groups on the basis of the 5-foot profile: group *a,* dry, total available moisture less than 4 inches; group *b,* wet, total available moisture 4 inches or greater. The computed linear regressions (fig. 13) were:

Group *a* $Y_W = 4.95 + 0.42x, \quad r = 0.70^{*}$
Group *b* $Y_W = 6.73 + 0.46x, \quad r = 0.55^{**}$

As expected, group *a* had a lower water loss—almost 2 inches lower than group *b*.

For soil-moisture change:

Group *a* $Y_S = -4.81 + 0.58x, \quad r = 0.81^{**}$
Group *b* $Y_S = -5.93 + 0.39x, \quad r = 0.44^{**}$

Only with above-normal rainfall in group *a* was there an average increase in soil moisture. At low levels of precipitation, group *a* soils lost an average of 1 inch of soil moisture. At high amounts of precipitation, the average of group *a* soils was a gain while the average of group *b* soils was a loss. Although the correlation in group *b* was statistically significant, there was still considerable scattering of the data.

Late Summer—Early Fall

August. The data were not divided into groups for computing the relationship. Most locations would have been in group *a*. Average water loss in 1954 was little different for varying amounts of precipitation, and the correlation was very low.

$$Y_W = 3.81 + 0.12x, \quad r = 0.18$$

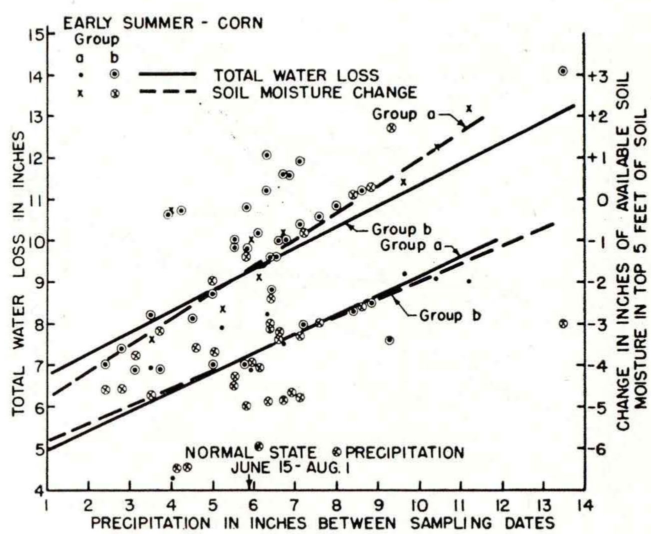

Fig. 13. Water loss and soil moisture change. Corn, late spring-early summer, 1954, 1955, 1956.

Most of the locations had 6 to 7 inches of rainfall. Ames, which had 14.7 inches, was not included in the regression equation because of the obvious difference in the relationship between precipitation and water loss. Water loss of over 9 inches occurred at Ames.

As precipitation increased, soil moisture increased.

$$Y_s = 3.81 + 0.88x, \quad r = 0.79^{**}$$

With normal precipitation soil moisture decreased slightly, on the average, but when precipitation was several inches above normal, increases of over 5 inches occurred.

September. The data were divided almost equally between group *a* and group *b*, but were analyzed without separating the groups because of the relatively few locations. The correlation between precipitation and water loss was low.

$$Y_w = -1.86 + 0.29x, \quad r = 0.53$$

Soil moisture increased as precipitation increased.

$$Y_s = -1.86 + 0.71x, \quad r = 0.83^{**}$$

Generally the locations in group *a* were above the regression line, while those in group *b* were below the line. Normal precipitation of 4 inches would be expected to give an average increase in soil moisture of about 1 inch.

Early to mid-August to November. The data were classed according to soil moisture in the 5-foot profile, as was done for the previous period.

The linear repression equations for water loss (fig. 14) were:

Group *a* $Y_w = 3.68 + 0.41x, \quad r = 0.80^{**}$
Group *b* $Y_w = 8.08 + 0.05x, \quad r = 0.13$

There was little relationship between precipitation and water loss in group *b*, but a high correlation in group *a*. However, there was a close relationship between precipitation and soil-moisture change.

Group *a* $Y_s = -3.67 + 0.60x, \quad r = 0.90^{**}$
Group *b* $Y_s = -8.07 + 0.95x, \quad r = 0.93^{**}$

At low levels of precipitation, soil moisture decreased over 3 inches more in group *b* than in group *a*. At above-normal levels of precipitation, there was little difference between the groups, both showing increases of several inches. With normal precipitation, the average increase in soil moisture in group *a* was 2½ inches; in group *b* it was 1½ inches. Above-normal precipitation in this period would be expected to give relatively large increases in soil moisture.

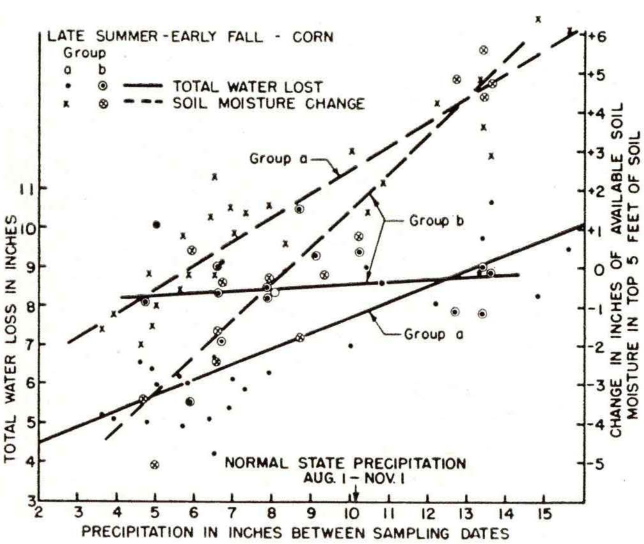

Fig. 14. Water loss and soil moisture change. Corn, late summer-early fall, 1954, 1955, 1956.

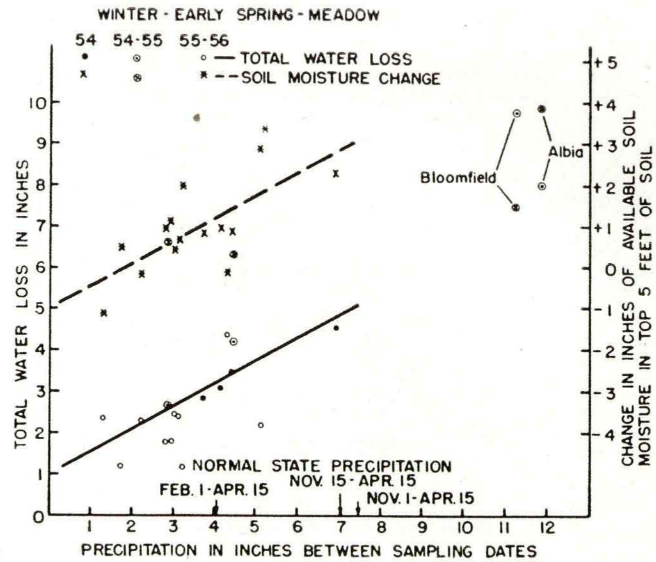

Fig. 15. Water loss and soil moisture change. Meadow, winter-early spring, 1954, 1954-55, 1955-56.

MEADOW

Winter—Early Spring

In the early stages of the study, emphasis was placed on corn land, and in several cases, only a few meadow plots were sampled. Although the combining of data for several years might be questioned on the basis of representing different soil moisture-precipitation patterns, the data for the early spring of 1954 and winter-early spring of 1955 and 1956 were all combined, except for Albia and Bloomfield, 1954-55.

For other periods where more data are available, meadow data will be divided into two groups—those with less than 4 inches of available soil moisture at the beginning of the period and those with more than 4 inches. In this case, nearly all the data fell into the class of less than 4 inches. As can be seen from fig. 15, Albia and Bloomfield were the only sampling locations having heavy rainfall for this period. The regression equations, excluding these locations were:

$$Y_w = 1.02 + 0.45x, \quad r = 0.62^{**}$$
$$Y_s = -0.99 + 0.55x, \quad r = 0.68^{**}$$

The data for Albia, where there was low soil moisture to start the period, falls close to the regression line if extended to high rainfall; the data for Bloomfield, with over 4 inches of soil moisture, deviates widely from the extended line. With soil moisture above 4 inches and above-normal rainfall, the relationship, as shown, may not apply. More data are needed to determine this relationship.

Infiltration during this time is dependent upon the distribution of precipitation, whether or not soils are frozen near the surface, the amount of water already in

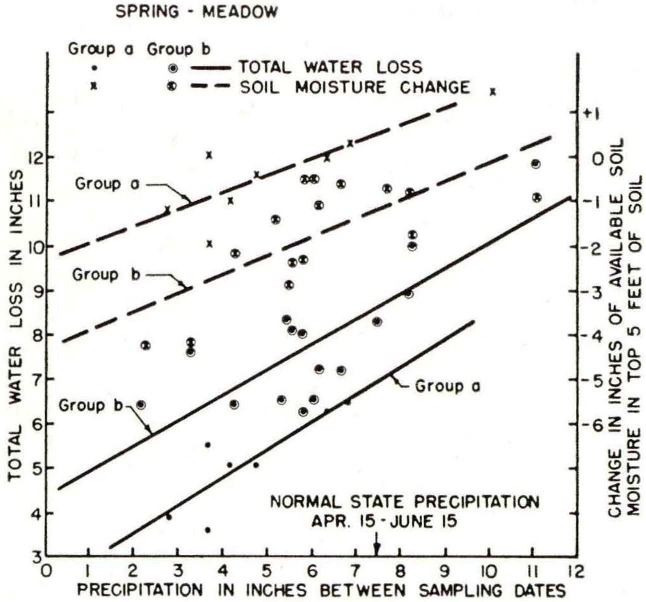

Fig. 16. Water loss and soil moisture change. Meadow, spring, 1954, 1955 and 1956.

the 0-1 to 2-foot zone, and plant cover. These data indicate an average gain of about 3 inches with normal precipitation, but considerable variation might be expected in soil moisture changes because of these factors. The gain under meadow land has been very similar to that under corn during the period of this experiment.

Spring

Both water loss and change in soil moisture will vary depending upon the available soil moisture at the start of the period. Since established meadow has a root system developed, the roots should be able to use the soil moisture wherever it is located. The same grouping, less than 4 inches of soil moisture (group *a*) and above 4 inches (group *b*), was used as previously. For this period:

Group *a* $Y_W = 2.29 + 0.63x, \quad r = 0.86^{**}$
Group *b* $Y_W = 4.37 + 0.58x, \quad r = 0.80^{**}$

Those locations with low soil moisture to start the period (fig. 16) lost about 2 inches less water than those with over 4 inches of soil moisture.

For soil moisture change:

Group *a* $Y_S = -2.33 + 0.38x, \quad r = 0.70^{*}$
Group *b* $Y_S = -4.35 + 0.42x, \quad r = 0.70^{**}$

Most plots had a decrease in soil moisture. With comparable rainfall there was about 2 inches less decrease in soil moisture where the soil started with low soil moisture. Except for very few plots classed as group *b*, all plots had below-normal rainfall.

Unless good rains fell during this period, particularly late in the period, a decrease in soil moisture would be expected, as meadow uses relatively large amounts of water at this time of year.

During this same period, with average precipitation, corn land showed gains in soil moisture ranging from slightly less than 1 inch in 1955 to 2 inches in 1954. With average rainfall, meadow would be expected to show a very small increase when soil moisture was low to start the period, but a loss of about 1 inch when the period started with over 4 inches of soil moisture. During much of this period corn land is either bare or only partially covered with vegetation, and transpiration is low. Meadow crops are growing rapidly during this period, and the heavier vegetative cover transpires larger amounts of water, except immediately after cutting.

Late Spring—Early Summer

Although meadow still uses considerable water in early summer, in the 3 years of the experiment, the use has been less than that of corn. The two groups of data, *a* and *b*, showed considerable difference in water use (fig. 17).

Group *a* $Y_W = 3.62 + 0.39x, \quad r = 0.86^{**}$
Group *b* $Y_W = 4.68 + 0.66x, \quad r = 0.72^{**}$

Those plots with over 4 inches soil moisture to start the period lost from 1 to 5 inches more water than those with less than 4 inches of moisture.

For soil moisture change:

Group *a* $Y_S = -3.63 + 0.61x, \quad r = 0.93^{**}$
Group *b* $Y_S = -4.58 + 0.33x, \quad r = 0.45$

With equal amounts of rainfall, those plots in group *a* averaged from 1 to over 4 inches smaller change in soil moisture. (At higher amounts of rainfall this was an increase.) With normal precipitation of almost 6 inches, areas starting the period with low soil moisture would be expected to show little change in soil moisture; those with over 4 inches of soil moisture to start the period would have an average loss of about 2½ inches.

Late Summer—Early Fall

Since the experiment was started in 1954, precipitation has generally been below normal during this period. No location starting the period with over 4 inches of soil moisture has had normal rainfall. The relationships found for water use were:

Group *a* $Y_W = 3.75 + 0.46x, \quad r = 0.70^{**}$
Group *b* $Y_W = 3.38 + 0.68x, \quad r = 0.68^{*}$

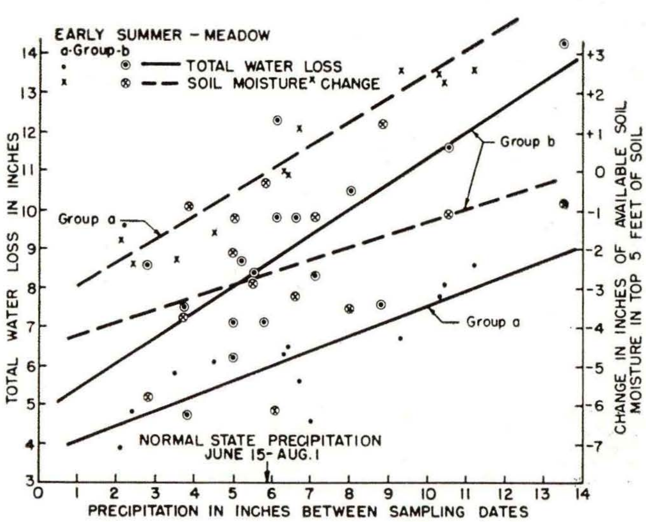

Fig. 17. Water loss and soil moisture change. Meadow, late spring-early summer, 1954, 1955 and 1956.

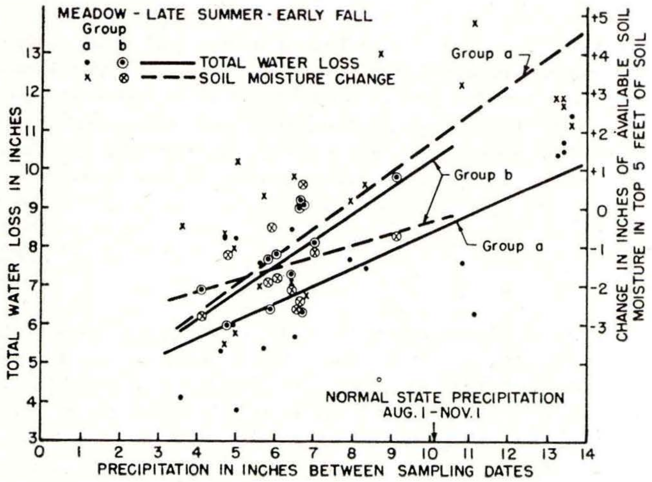

Fig. 18. Water loss and soil moisture change. Meadow, late summer-early fall, 1954, 1955, 1956.

Water use in group *b* (fig. 18) was ½ inch to over 2 inches greater.

Soil moisture increase was greater for group *a* than for group *b*.

Group *a* $Y_S = -3.76 + 0.54x, \quad r = 0.83^{**}$

Group *b* $Y_S = -3.43 + 0.31x, \quad r = 0.55$

With normal precipitation, plots in group *a* would be expected to show an increase in soil moisture of almost 2 inches; those in group *b*, little change.

OATS

For the spring period the oat locations were classed in the same manner as corn. Only four locations were in the dry group; all other locations were in the wet group. The relationship between precipitation and water loss was:

Group *b* $Y_W = 1.37 + 0.89x, \quad r = 0.56^{*}$

There was little relation between precipitation and soil moisture change. The linear regression was:

Group *b* $Y_S = -1.42 + 0.12x, \quad r = 0.09$

The only two locations in this group in 1955 and two of the locations in 1956, had a very high soil moisture loss. Three of these four locations had periods with no appreciable rain for 2 to 3 weeks just before sampling. Other stations had appreciable rain a short time before sampling. Locations with no appreciable rainfall for 2 to 3 weeks just prior to sampling would be expected to show a loss of several inches in soil moisture. Apparently locations with rainfall more evenly distributed between the sampling dates will show little change in soil moisture. More data are needed to evaluate this period.

TABLE 9. YIELD DATA, SOIL MOISTURE PLOTS (BU./ACRE).

Location	1954		1955		1956	
	Actual	Adjusted	Actual	Adjusted	Actual	Adjusted
Northwest						
Doon	....	....	....	....	35	38
Primghar	108	96	65	58	30	27
Moville	72	64	....	....	....	....
North-central						
Clarion	....	....	....	....	30	28
Kanawha	112	102	92	84	78	71
Northeast						
Elkader	....	....	....	....	55	53
Independence	72	73	51	52	85	86
Saratoga	54	74	26	35	55	75
West-central						
Castana	100	113	30†	34	35	39
Denison	68	68	....	....	....	....
Central						
Ames	71	65	53	48	28	25
Marshalltown	126	100	85	68	85	68
East-central						
Cedar Rapids	91	86	78	73	69‡	76§
Iowa City	99	85	....	....	....	....
Maquoketa	....	....	....	....	93	85
Tipton	....	....	....	....	100	89
Southwest						
Clarinda	49	53	40	43	40	43
South-central						
Albia	12	14	67††	81	60	72
Beaconsfield	35	43	43	53	67	83
Southeast						
Bloomfield	85	91	107	115	83	89
Burlington	....	....	....	....	89	87
Mt. Pleasant	65	64	....	....	....	....
Washington	62	61	....	....	....	....

† Plot cut for silage. Yield estimated from nearby corn.
‡ Serious rootworm injury.
§ Yield raised 15 percent to account for rootworm injury, then adjusted.
†† Second-year corn. First-year corn, 12 bu.

YIELD DATA

The soils of the sampling locations have different yield potentials. Any yield comparison will involve differences due to yield potential and varying weather conditions. Considerable variability must be expected because of this.

Yield estimates were obtained in two ways. In most cases an area of 4 rows x 25 feet was harvested from the actual soil moisture plot. Where this was not possible the yield of the bulk area in which the plot was located was used as the yield estimate. The yields obtained are summarized in table 9.

To place these yields on a comparable basis, the period 1940-44 was used as a reference. Township yield data[15] were readily available for this period. The average state yield for the period was 54 bushels per acre. For each location, the yield for the township in which it was located was determined for the 5-year period. The adjusted yield was:

$$\text{Adj. yield} = \frac{\text{av. state yield (1940-44)} \quad \text{X plot yield.}}{\text{av. twp. yield (1940-44)}}$$

The adjusted yields are also given in table 9.

The water-use figures, as determined, include runoff, evapo-transpiration and percolation. In some cases it was known that excessive runoff occurred. Whenever over 2 inches of rainfall was reported for a day in the climatological data for Iowa, the amount over 2 inches was considered as runoff and was deducted from the water-use figure for that location. The following stations had adjustments made for excessive runoff in 1954: Kanawha, Saratoga, Ames, Clarinda, Beaconsfield and Mt. Pleasant. Except for Kanawha and Ames, these adjustments were less than 1 inch. This was a quick pro-

[15] Iowa Department of Agriculture. Division of Agricultural Statistics. A graphic summary of crop yields and land productivity by townships, 1940-44. Bul. 925. 1947.

TABLE 10. WATER USE AND ADJUSTED YIELD, APRIL 15-NOV. 1.

Water use (inches)	Yield (bu./acre)
< 17.5	30
17.5-20.0	48
20.0-22.5	64
22.5-25.0	75
> 25.0	88

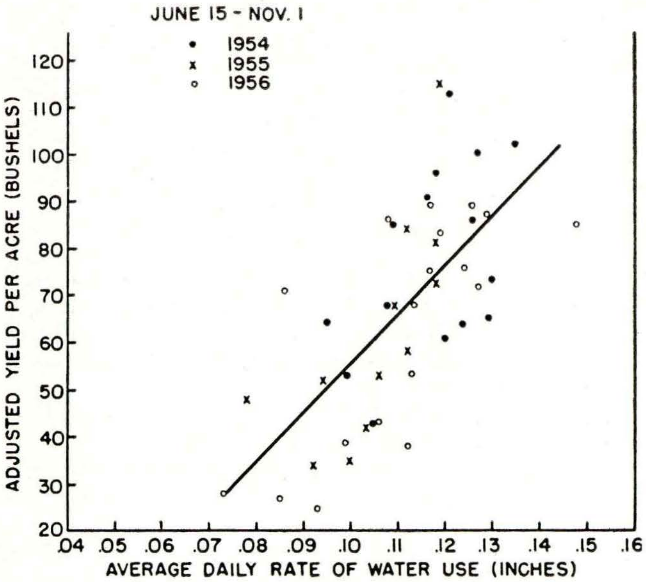

Fig. 19. Daily rate of water use. June 15-Nov. 1 and corn yield.

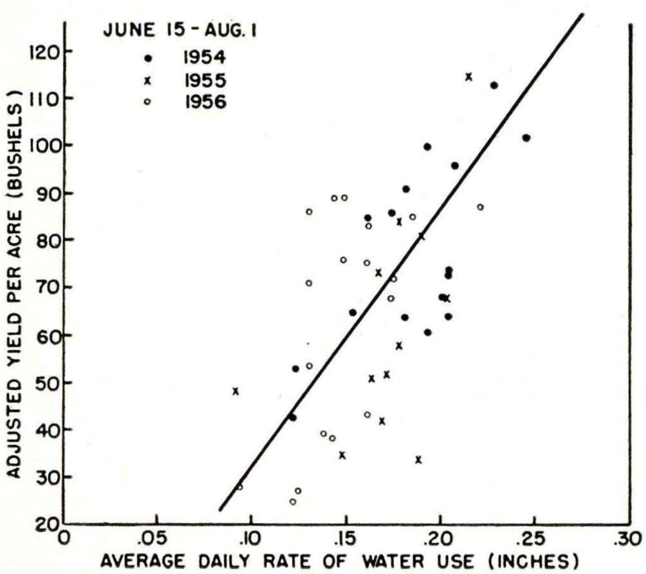

Fig. 20. Daily rate of water use. June 15-Aug. 1 and corn yield.

cedure to account for some of the excessive runoff. The water-use-yield data are given in table 10 for the period April 15-Nov. 1. Yield increased with water use during this period. There was considerable variability within groups. For a mean of 10 plots the LSD_{10} was 13 bushels. As water use increased, water was no longer the principal limiting growth factor. At high levels of water use, yield was influenced by management to a greater degree than at the lower levels.

For shorter periods water use was computed on a daily basis. The relationship for the period June 15 to Nov. 1 is given in fig. 19. The linear regression was:

$$Y = -48.4 + 1035.6x, \quad r = 0.69^{**}$$

where x = water use for period.

For the shorter period, June 15 to Aug. 1 (fig. 20) the relationship was considerably closer. The linear regression was:

$$Y = -22.3 + 543.1x, \quad r = 0.81^{**}$$

Yield increased rapidly with increased water use. Many weather factors are not considered when relating water-use values of this type to yield. Distribution of rainfall and temperatures would be particularly important in influencing yield. Also management practices would have an influence on the yield with a given amount of water use. The correlation within years was low, except for 1954. In 1954 nearly all locations had good to very good soil moisture in June. July was generally dry, but good rains fell in August. Water was available to some extent in all areas for the period June 15 to Aug. 1, but some areas were quite dry by Aug. 1. Water use was closely related to yield. This was probably because low soil moisture was not serious enough to drastically reduce yields, yet was low enough to cause some limitation on yields.

In 1955 the locations represented by X's to the right and below the regression line in fig. 20 largely fell into one group—dry at silking with not enough rain later. Water available early in the season produced a corn plant, but later shortage of moisture reduced yield. Other points in 1955 did not differ much from the regression line.

In 1956 locations represented by circles to the right of the regression line were generally low in soil moisture, which limited water use early in the season, and had low rainfall later which seriously limited yield. Clarinda (coordinates, 0.161, 43.0) had good rains before Aug. 1 but accumulated very little soil moisture. There may have been temperature injury also. Locations above and to the left of the line (6 out of 8) generally had good moisture throughout the season. In certain cases, these locations were relatively dry at silking time but had good rains generally before and after silking. The availability of water after silking resulted in high yields for the amount of water used from June 15 to Aug. 1. July was a cool month, and water use during this period for these plots was limited by the weather, not by the availability of moisture.

As more data become available it may be necessary to represent the relationship between yield and water use by a curve rather than a straight line, or possibly by a series of lines representing different conditions. However, considerably more data will be necessary before this can be done.

DISCUSSION

These data cover a relatively short period of time, much of it drier than usual. The statements which can be made are limited because of these conditions. Much of this information, however, can be of immediate use.

The amount of water used each day at any particular time of the year was about the same in all of the years studied. These amounts are summarized in table 11.

TABLE 11. WATER USE IN INCHES PER DAY (RUNOFF, PERCOLATION, EVAPO-TRANSPIRATION).

Year	Winter—early spring		Spring		Late spring—early summer		Late summer—early fall	
	Corn	Meadow	Corn	Meadow	Corn	Meadow	Corn	Meadow
1954	0.04†	......	0.10	0.15	0.18	0.17	0.09	0.09
1955	0.02	0.01	0.10	0.13	0.19	0.15	0.07	0.07
1956	0.02	0.02	0.09	0.11	0.15	0.13	0.09	0.09

† Winter season beginning February of 1954.

Water use consisted of runoff, percolation and evapo-transpiration. Except for a few locations and times, runoff and percolation were low. During periods of normal rainfall, water use would be higher because of more runoff or percolation. The summer water-use figures are probably lower than would occur in many favorable crop seasons when soil moisture is more available. This was believed to be particularly true in many areas in 1956 when midsummer daily use was only 0.15 inch. At the Agronomy Farm in July and August 1954, evapo-transpiration losses of 0.16 and 0.17 inch per day were measured over short periods with the soil surface being dry much of that time.

Water use during the cold seasons of the year is low, because of seasonally low radiation, little if any transpiration, and for the particular years being considered, below-normal precipitation. Water is lost, though, by evaporation and sublimation if present in or on the soil surface.

The relationship between water lost by transpiration and evaporation is not constant. During periods when the soil surface is wet, evaporation losses may be quite high. During the period, July-August 1954, daily evaporation from a fallow area was 0.05 and 0.07 inch for two different periods. The soil surface was quite dry much of this time. For almost identical periods, evapo-transpiration from a corn plot was 0.17 and 0.16 inch. If we assume the same rate of evaporation from the fallow and corn plots, surface evaporation was 29 and 44 percent of the total daily water loss from corn. Since there is considerable shading of the ground in the corn plot, this probably overestimates the evaporation from this plot. Soil surface evaporation under corn then was somewhat less than 29 and 44 percent of the total loss in these two cases.

The possibility of replenishment of subsoil moisture will vary with the season. Information obtained on this factor is summarized in table 12.

The change in soil moisture during a period is related to the amount of moisture in the soil at the start of the period. More soil moisture is gained when the soil is dry to start the period. With normal precipitation, corn land would be expected to show some gains in soil moisture, except in mid-June to August when normal rainfall does not supply the moisture requirement. August would be expected to fall in this period, though data are not available to verify this.

TABLE 12. ESTIMATED AVERAGE CHANGE IN SOIL MOISTURE WITH NORMAL PRECIPITATION.

Period	Initial soil condition	Normal state rainfall	Estimated change in soil moisture with normal rainfall†	
			Corn	Meadow
Feb. 15-mid-April		4.1	+1.2	
Nov.-mid-April	Dry	7.1	+3.3‡	+1.3§
	Wet	7.1	+1.5	
Mid-Apr.-mid-June	Dry	7.6	+2.5‡	+0.6§
	Wet	7.6	+0.2	—1.1
Mid-June-early August	Dry	5.8	—2.4§	—0.1§
	Wet	5.8	—3.7	—2.7
Early August-November	Dry	10.2	+2.4§	+1.8§
	Wet	10.2	+1.6	—0.2

† Estimated from linear regression equation for each set of data.
‡ Dry—less than 1 inch available moisture in each of top 2 feet or over 1 inch in 1 foot but a total of less than 2½ inches in the top 2 feet. Wet—more than 1 inch available moisture in each of the top 2 feet or total of more than 2½ inches in the top 2 feet.
§ Dry—total available moisture less than 4 inches. Wet—total available moisture more than 4 inches.

TABLE 13. ESTIMATED WATER USE BALANCE FOR CORN IN IOWA, USE = EVAPO-TRANSPIRATION, RUNOFF AND PERCOLATION.

Period	Normal precipitation	Average use
April 15-30	1.4	1.2
May	4.0	2.8
June	4.5	4.5
July	3.6	6.0
August	3.8	5.5
September	4.0	3.0
October	2.3	2.1
	23.6	25.1

The only period where the correlation between precipitation and soil moisture change was not significant for corn land was from mid-April to mid-June, when the soil started the period wet.

During the winter period, meadow land would be expected to show a small average gain in soil moisture with normal precipitation. Meadow land had a smaller average gain in soil moisture than corn land during this period. In the few cases where heavy rains fell, the meadow showed a larger gain. During the spring period, when meadow land is covered with an extensive, transpiring crop surface, water use is greater than for corn land. Where corn land would be expected to show a good gain in soil moisture with normal precipitation, especially when the soil was dry to start the period, meadow would be expected to have a small gain or a loss in soil moisture.

In the mid-June to August period, meadow land apparently is not transpiring as much as corn land, possibly because of cutting and previous use limiting water availability, and the decrease in soil moisture was less. From August to November, meadow would still be actively transpiring while corn land would be transpiring water only a limited amount in the latter part of the period. Meadow areas starting this fall period with low soil moisture would be expected to have a smaller gain than corn land, while those starting the period with several inches of soil moisture would be expected to show little change.

These data indicate that soil moisture would most likely be replenished under corn land during the fall and spring periods. Precipitation is low during the winter period, and much of this time the ground is frozen. Soil moisture would be reduced during the summer months, even with normal rainfall. Moisture under meadow land would most likely be replenished during late fall and early spring and, if soil moisture was low, in late spring and early fall. Replenishment would not be expected to be as much as for corn land.

Water use during different periods was related to yields, although considerable variability in yields was found. This should be expected, since the plots represented a wide range of soils and fertility conditions. Average yield increased with increased water use. Water use under 20 inches from April 15 to Nov. 1 produced average yields less than 50 bushels. The highest correlation with yield was obtained for use during the period June 15 to Aug. 1. Distribution of available moisture during the year is very important in influencing the final yield.

An estimated water use balance for corn for the period April 15 to Nov. 1 is given in table 13. This would represent average to above-average yields with good spring moisture but not excessive runoff.

SUMMARY

A series of soil moisture samples from 0 to 5 feet were collected at some 20 different locations in Iowa over a period of 3 years.

Average daily water use for 1954, 1955 and 1956 from corn land for the period mid-April to mid-June was 0.10, 0.09 and 0.08 inch; for mid-June to mid-August, 0.18, 0.18 and 0.15 inch; and for mid-August to November, 0.09, 0.07 and 0.08 inch, respectively. Daily water use consisted of runoff, evapo-transpiration and percolation.

At Ames in 1954 for a 19-day period in July, an average evapo-transpiration rate of 0.16 to 0.17 inch was measured. Soil moisture was probably limiting the rate of water use.

Soil moisture change was measured for different times of the year. With normal precipitation, some increase in soil moisture occurred under corn plots, except during the summer period when, even with normal rainfall, soil moisture was reduced. In all periods, except the summer, soil moisture gains averaged less under meadow than corn, or actual losses occurred.

Yield of corn increased with increased water use. The highest correlation between yield and water use was found for the period mid-June to early August.