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HARROLD, L.L., DREIBELBIS, F.R. 1 OF 2

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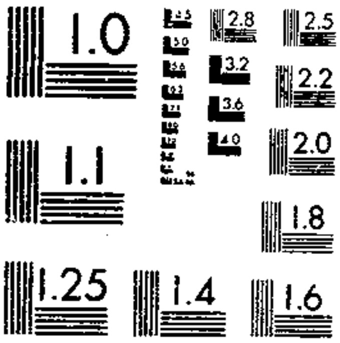

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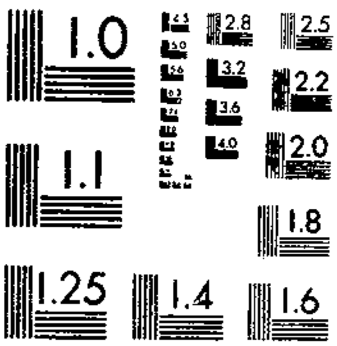

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Agricultural Hydrology as Evaluated by Monolith Lysimeters[1]

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The United States Department of Agriculture, Soil Conservation Service, in cooperation with the Ohio Agricultural Experiment Station

CONTENTS

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[2] The work on this experimental watershed project was done at the North Appalachian Experimental Watershed near Coshocton, Ohio, by the Research Division of Drainage and Water Control, Soil Conservation Service in cooperation with the Ohio Agricultural Experiment Station. The data presented in this bulletin were collected by the project staff of the experimental watershed. Much of the work of operating the lysimeters and tabulating the basic data was performed by William W. Bentz. Robert E. Youker and Walter Pomerene contributed in the tabulation and summarization of climatic and evaporation data. Some of the techniques for the tabulation and computation of data were devised by Howard Alexander, CPS Camp 23. Joe Schelling, CPS Camp 23, J. H. Wilson and C. E. Evans, Ohio Agricultural Experiment Station, Wooster, Ohio, assisted in the chemical analyses of percolation water.

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The actual construction of the lysimeters was made possible through the cooperation of the Works Progress Administration and the Civilian Conservation Corps. Special recognition is extended to H. S. Riesbol, George Sherman, H. Kohnke, and W. H. Pomerene of the North Appalachian Experimental Watershed for their collaboration in the technical development of detailed plans and designs.

SUMMARY

This bulletin is in the nature of a progress report on the lysimeter investigations carried on at the North Appalachian Experimental Watershed near Coshocton, Ohio, to 1949.

The hydrologic data were obtained from eleven monolith lysimeters, each 0.002 acre in area and 8 feet deep, three of which were weighed automatically. The features of the installations, some of which are unique, are described. Records of precipitation, runoff, and percolation are presented for each lysimeter. Weight records provided data for determination of condensation-absorption of moisture from the atmosphere, evapo-transpiration of soil moisture, and changes in storage of soil moisture.

The amount of moisture condensed and absorbed from the atmosphere was fairly large, amounting to over 6 inches of water annually. Of the water added to the soil, precipitation accounted for 81 percent and condensation-absorption 19 percent. From 80 to 85 percent of the soil-moisture depletion was due to evapo-transpiration. Percolation accounted for the remainder. Different crops had strikingly different effects on seasonal evapo-transpiration rates. Wheat and meadow crops depleted soil moisture most rapidly in May and June. Corn used water at high rates in July and August. Cultivating the cornland had a noticeable effect on evapo-transpiration, and the effect of hay cutting was still more marked.

Attempts were made to compare evapo-transpiration with evaporation from a sunken evaporation pan 6 feet in diameter, but the presence of crops sheltering the evaporation pan made it impractical to obtain accurate correlation of pan evaporation with evapo-transpiration data.

A method was devised for adapting evapo-transpiration data obtained from the lysimeters to studies of the hydrologic balance in drainage basins for which precipitation-gage data but not condensation-absorption records are available. Briefly, as an example, the value of 42.2 inches for average annual evapo-transpiration is modified by subtracting the average annual value of condensation-absorption of 10.3 inches and by further subtracting a precipitation adjustment factor of 4.0 inches. This results in a modified annual evapo-transpiration value of 27.9 inches for comparison with gage precipitation and basin runoff data.

The rainfall amounts measured by the weighing lysimeters differed from the amounts caught in the recording rain gages. The average annual rainfall on the basis of 6 years of data, as determined from the lysimeter measurements, exceeded the rain-gage catch by about 4 inches. A study of daily rainfall amounts over a 3-year period showed that storms of less than 0.6-inch rainfall accounted for a large part of this difference.

Monthly and annual amounts of percolation from each lysimeter have been summarized for the different soil types. Cumulative curves were prepared to facilitate comparison. A special study was made of the maximum percolation rates and the time lag following

rain on both wet and dry soil. Plant nutrients in percolation water were determined for each lysimeter and are presented on an annual basis. Comparisons were made of nutrient losses for different soil types and land treatments.

A brief review of the literature on lysimeter investigations which has appeared since 1939 is included.

INTRODUCTION

Agricultural hydrology in recent years has become a subject of major interest in many fields of activity. From the large-scale governmental flood-control, land-reclamation, and irrigation projects down to the individual farm operation, consideration of water movement across, into, and through soils is becoming increasingly important. Industries and municipalities the country over are conscious of the need for water conservation. Thus much attention is being given to the need for better control of water and reduction of water waste. One of the best places to begin control is the land surface where the raindrops fall.

A knowledge of water movement on the land surface, movement into and through the soil, condensation and absorption of water, evaporation, and use of water by crops is necessary for a comprehensive approach to water control. Soil moisture is either increasing or decreasing. It may be reduced through crop use, evaporation, or percolation downwards to ground-water reservoirs. Precipitation absorbed by the soil replenishes soil-water supplies. These processes result in a continuously changing soil-water supply. Even frozen soil may vary in soil-moisture content from day to day.

The lysimeter studies at Coshocton were planned to obtain measurements of the various water-cycle factors under different seasonal, vegetal, and soil-type conditions. This report, based on about 10 years of data, summarizes and discusses the results of the studies. Analyses of the lysimeter data will help to establish bases for the design of water-conservation, water-utilization, and other hydrologic and hydraulic programs.

Lysimeters in general may be defined as structures containing a mass of soil, and so designed as to permit the measurement of water draining through the soil. Three general types used in the past are as follows:

1. *The filled-in type*—where the containing unit with vertical walls, open top, and perforated bottom is filled with soil removed from its original location. Usually this soil is screened and mixed in order to make it uniform. Since the natural soil profile cannot be retained in this type of lysimeter, the soil-moisture relationships do not represent natural conditions.

2. *The Ebermayer type*—where a shallow pan or funnel is inserted at desired depths under undisturbed soil horizons. Since there are no side walls the soil of the lysimeter is not separated from the adjoining soil. The pan funnels the percolation water to a measuring tank. This type allows unrestricted lateral movement of soil water and surface runoff.

3. *The monolith or undisturbed-soil-block type*—where a casing of vertical walls is built around a block of soil *in situ.* A perforated pan is inserted beneath the soil block to collect percolation water.

There has been much criticism of the different lysimeters. Some lysimeters do not permit runoff, all the precipitation being held on the ground surface until it is absorbed. Others permit runoff but do not measure it. All have artificial bottoms that do not allow capillary movement of water upwards. In many lysimeters the floor of the metal collector interrupts the natural drainage and causes unnatural wet layers at the bottom. Some permit the lateral movement of soil water, others restrict it.

The Coshocton lysimeters were specifically planned as water-cycle instruments. Therefore, detailed attention in the design was given to soil-water relationships which would affect their performance. Every effort was made to eliminate the objectionable features of previous lysimeter installations.

The Coshocton lysimeters differ from most installations of this nature in several respects *(14, 40)*.[3] Some of the more important features of their construction and operation are as follows:

1. Side walls prevent lateral movement of water.
2. A large rectangular surface area, 6.22 × 14 feet, permits cropping with a field spacing of four corn rows, 42 inches apart.
3. The large surface area minimizes the artificial border effect along sides of casing.
4. Four side-wall baffles inserted on each of the four sides after the lysimeter casing has been sunk reduces water seepage down these unnatural planes. These baffles function like piston rings.
5. Preserving the natural soil profile of topsoil, subsoil, and geologic parent material provides an opportunity to observe soil-water relations approximating natural conditions.
6. Parent-material rock (shale or sandstone) about 3 feet thick at the bottom provides a natural means of transmitting percolation water from the overlying soils to free gravity water draining off into observation tanks. Fissures and crevices in the rock layer also naturally break the capillary columns through which ground-water might otherwise rise. The presence of this rock layer permits the insertion of percolation pans and the removal of the underlying rock without interfering with the normal downward or upward movement of the water.
7. Multiple percolation-pan bottoms in the lysimeters permit observation of percolation at eight sections of the 14-foot length.
8. Automatic weighing devices, developed expressly for this study, record weight changes in the 65-ton soil mass to a 5-pound accuracy. This is equivalent to about 0.01 inch of water over the lysimeter surface area. From these weight records it was possible to derive data on precipitation, condensation-absorption of water, and evapo-transpiration for various periods of the day.

A more complete description of these features along with the construction and installation history is given further on.

[3] Italic numbers in parentheses refer to Literature Cited.

REVIEW OF RECENT LITERATURE

The literature reviewed here covers, in general, the period from 1939 to the present. An extensive review of the previous literature by Kohnke et al. (*26*) covered two and a half centuries of research in lysimetry. No repetition of this excellent review will be made.

The purpose of most lysimeter investigations has been to study either the hydrologic balance of the soil or soil fertility. In some, the aim was to study both. A few investigations such as those of Wallihan (*51*) and Colman (*4*) were concerned primarily with lysimeter design. Wallihan pointed out that with shallow lysimeters of 30-inch depth and 12-inch diameter it was necessary to use a tension of 10 cms. mercury to provide drainage corresponding to the normal drainage of the soil. Colman used various drainage tensions to determine water outflow under each tension. It appears from these data that for shallow lysimeters where true soil rests directly above the percolation pans some tension is needed to simulate natural soil drainage. The Coshocton lysimeters were designed to overcome this objection by including in the lysimeter soil profile about 3 feet of bedrock which would rest directly above the percolation pans. The relatively natural soil-moisture conditions of these lysimeters have been pointed out by Harrold and Dreibelbis (*9, 10*).

Studies on moisture condition in lysimeters by the use of tensiometers were made by Richards et al. (*39*). Among recent hydrologic studies made with lysimeters in this country, the most noteworthy are those of Martin and Rich (*32*) in Arizona, Colman and Hamilton (*5*) in California, Stauffer (*45*) in Illinois, and Kilmer et al. (*24*) in Wisconsin. The last two investigations also included studies on nutrient losses in the percolate.

A number of lysimeter investigations in forest cover are being carried on by the U. S. Forest Service at San Dimas, Calif., (*5*); Tucson, Ariz., (*32*); and elsewhere. The extensive work done by Lunt (*28*) with lysimeters on forest cover in Connecticut was concerned primarily with the composition of the percolate. Other studies reported since 1939 on the composition of the percolate include those of Bizzell (*1, 2*) in New York, Volk and Bell (*49, 50*) in Florida, MacIntire et al. (*30, 31*) in Tennessee, Roller and Bowen (*42*) in South Carolina, Plice (*37*) in Oklahoma, Smith (*44*) in Arizona, and Kardos (*23*) in Washington. Filled-in lysimeters were used in all these investigations excepting that of Kardos who used the Ebermayer type. Neller and Forsee (*35*) of Florida report the use of a lysimeter for organic soils. Because of the high water table in organic soils, a special filled-in type of lysimeter was used in which the lysimeter soil surface was 4 feet above that of the adjacent fields. Joffe (*21, 22*) in New Jersey reports a study of the movement of cations and anions through the soil profile by the use of the Ebermayer type of lysimeter. Lowdermilk and Sundling (*27*) have used lysimeters in their study of the formation and significance of erosion pavements.

Relatively few lysimeter investigations outside the United States have been reported since 1939, due mainly to the occurrence of World War II. The literature covered is admittedly incomplete. Among the hydrologic studies reported are those of Theron (*46*) in South Africa. He found that the 15-year average percolate amounted to 11.7 percent of the rainfall under fallow conditions and 3.1 percent for soils cropped to corn. Studies on the composition of the percolate were also made. Other studies reported are those of Demolon and Bastisse (*6, 7*) in France, Geering (*15*) in Switzerland, and Maschhaupt (*33*) in Germany and Holland. Roseau (*43*) in Algeria showed by means of lysimeter measurements that drainage sometimes increased when there was no precipitation with an increase in air temperature. He attributed this to the fact that the soil water was vaporized and distilled downwards to cooler layers beneath, thereby increasing percolation.

Haouet (*16*) reported results of lysimeter experiments on calcareous clay in Tunis. Data for a 6-year period showed that the amount evaporated annually from continuous fallow is constant and averaged 316 mm., which was 50 to 70 percent of the annual rainfall. He stated that this loss, to which must be added the loss by drainage, is important, and that a crop which does not consume more water than that lost by bare soil should replace the fallow in the rotation.

Odelien and Vidme (*36*) reported an investigation in which potatoes were grown on the lysimeters. They determined N, P, K, Ca, S, and Cl in the drainage water and crops.

Data obtained from the Coshocton lysimeters have been presented in hydrologic data bulletins (*47, 48*), and in the papers of Dreibelbis and Post (*12, 13*), Harrold and Dreibelbis (*19, 20*), Dreibelbis and Harrold (*11*), Harrold (*17, 18*), and Dreibelbis (*8, 9, 10*).

DESCRIPTION AND HISTORY OF INSTALLATIONS

The research plan for the North Appalachian Experimental Watershed developed in 1935 provided for a study of all the factors affecting the disposal of precipitation as part of a comprehensive study designed to uncover the basic laws governing agricultural hydrology. Precipitation and surface-runoff measurements from agricultural fields were to provide data basic to the determination of the rates and amounts of water absorbed by the soil. In order to evaluate the extent to which land use practices affect water absorption and conservation of water and soil, and to obtain complete data on the precipitation-disposal system, the studies also included measurements of the disposal of soil water by evapotranspiration and percolation below the root zone. For this purpose, the Soil Conservation Service built at Coshocton, Ohio, in the period 1937-40, a number of monolith lysimeters equipped with self-recording weighing mechanism—the first in the history of lysimeter investigations.

Since a major purpose of the lysimeters was to provide data needed in the analysis and interpretation of watershed data, the lysimeters were established in areas representative of different watershed conditions. In order to avoid disturbing the natural conditions of the watershed areas unduly, the lysimeters were actually installed on sites adjacent to the watersheds where the slope, aspect, and soil profile were typical of the watershed. Owing to the high estimated cost of the desirable type of lysimeter, the lysimeter installations were limited to three sites as follows:

1. Permanent grassland on steep (23.2 percent), well-drained soil (Muskingum silt loam); site Y101.
2. Rotation cropland on rolling (12.0 percent), well-drained soil (Muskingum silt loam); site Y102.
3. Rotation cropland on rolling (6.0 percent), slowly permeable soil (Keene silt loam); site Y103.

The location of the lysimeter sites and other hydrologic installations is shown on a map of the experiment station (fig. 1). At each site it was planned to construct three lysimeters. This unit at each site is referred to as a "lysimeter battery." Some of the important physical and agronomic features of the watersheds used for hydrologic observation are shown in table 1.

All lysimeters in the same battery were to be operated the same so as to disclose any discrepancies which might result from differences inherent in the soil blocks. A fourth lysimeter was subsequently added to the batteries at Y101 and Y103. At Y101 the additional lysimeter provided a means of measuring the hydrologic effect of different grass mixtures. At Y103 the additional lysimeter made it possible to operate two units according to a conservation plan and to keep two as a check. One lysimeter in each of the three batteries was equipped with an automatic weight recording mechanism.

Lysimeter Sites

The physiography and soils at the three lysimeter sites vary in important respects.

Physiographic characteristics (all elevations are for height above mean sea level):

Y101; land slope, 23.2 percent; aspect east; elevation of lysimeter surface about 1,185 feet; elevation of crown of hill above lysimeter site, 1,245 feet.

Y102; land slope, 12.9 percent; aspect east; elevation of lysimeter surface about 1,185 feet; elevation of crown of hill above lysimeter site, 1,200 feet.

Y103; land slope, 6.0 percent; aspect south; elevation of lysimeter surface about 1,128 feet; elevation of crown of hill above lysimeter site, 1,130 feet.

Soil types:

Y101, Muskingum silt loam (sandstone origin).—This soil type belongs to the Gray-Brown Podzolic group and is residual in origin. The entire profile is quite permeable and has good drainage. A description of the profile near lysimeter Y101 follows:

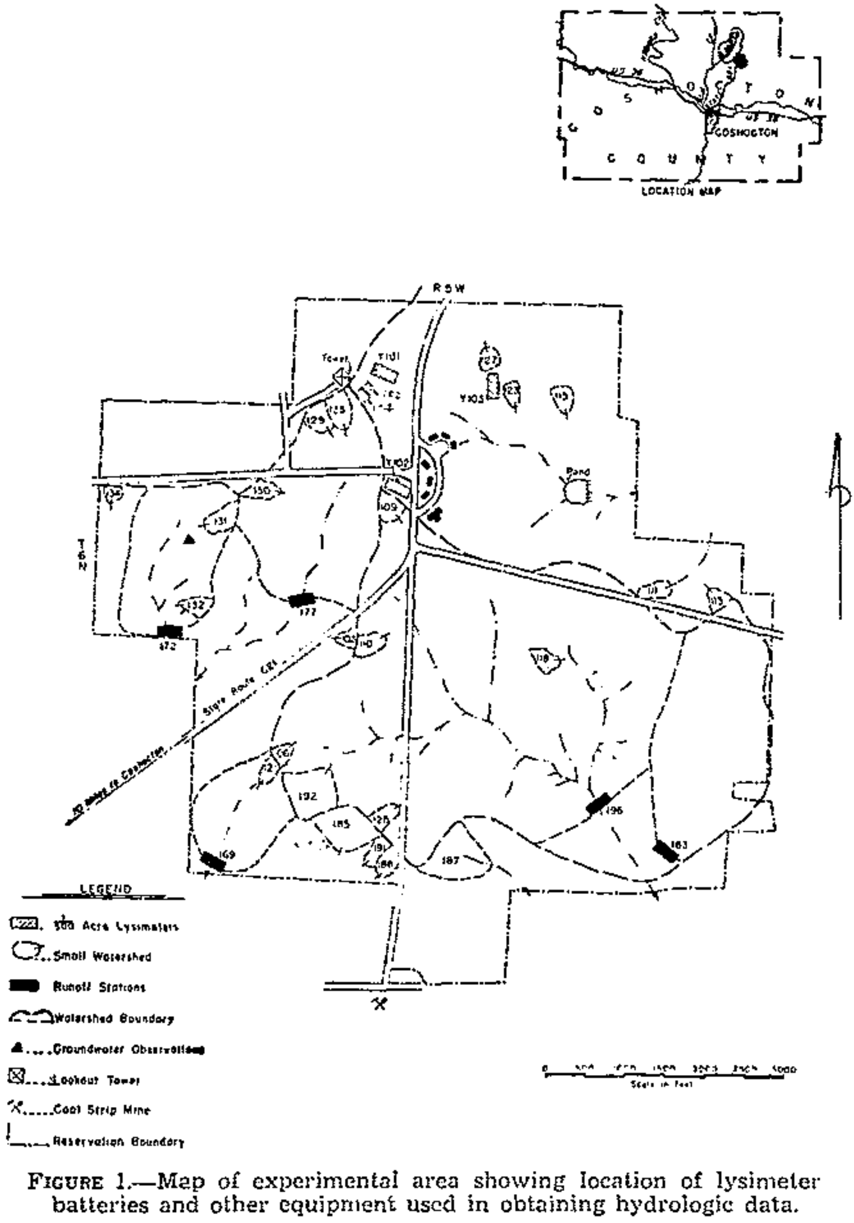

FIGURE 1.—Map of experimental area showing location of lysimeter batteries and other equipment used in obtaining hydrologic data.

Depth (Inches)	
0– 8 . . .	Dark brown silt loam with texture approaching a loam.
8–16 . . .	Brown to yellowish-brown silt loam to loam with some sandstone fragments.
16–33 . . .	Brown to yellowish-brown loam with sandstone fragments.
33–51 . . .	Decomposed sandstone with sandstone fragments.
51–96 . . .	Slightly decomposed sandstone rock with few sandstone fragments.

TABLE 1.—*Some important physical and agronomic features of watersheds on Government land used for hydrologic observation*

Watershed No. [1]	Land use	Drainage area	Cover and rotation [2]	Practice [3]	Predominant soil type
		Acres			
131	Woods	2.21	Hardwoods	Conservation	Muskingum loam.
132	do	.59	do	do	Keene silt loam.
134	Reforested	.916	Pines	do	Muskingum silt loam.
130	Meadow	1.63	Alfalfa-timothy	do	Do.
129	Pasture	2.71	Alfalfa, ladino clover, bromegrass	do	Do.
135	do	2.69	Poverty grass, briars	Poor	Do.
102	do	1.26	Alfalfa, ladino clover, bromegrass	Conservation	Do.
104	do	1.33	Bluegrass	do	Do.
109	Cultivated	1.69	C-W-M-M	do	Do.
115	do	1.61	do	Poor	Muskingum and Keene silt loam.
123	do	1.37	do	Conservation	Keene silt loam.
127	do	1 65	do	Mulch	Do.
103	do	65	M-C-W-M	Conservation	Do.
110	do	1.27	do	Poor	Do.
128	do	2.68	do	Mulch	Muskingum loam.
111	do	1.18	M-M-C-W	do	Coshocton silt loam.
113	do	1 45	do	Conservation	Do.
118	do	1 96	do	Poor	Do.
106	do	1.56	W-M-M-C	do	Muskingum loam.
121	do	1.42	do	Conservation	Do.
188	do	2 05	do	Mulch	Muskingum silt loam.
192	do	7.59	M-C-W-M	Poor	Do.
185	do	7.40	Contour strip cropped	Conservation	Do.
187	do	7.20	do	do	Keene silt loam.
169	Mixed	29.0	Mixed	do	Mixed.
172	Woods	43.6	Woods	do	Do.
177	Mixed	75.6	Mixed	do	Do.
183	do	74.2	do	Poor	Do.
196	do	303	do	do	Do.

[1] See figure 1 for location in relation to lysimeter batteries Y101, Y102, and Y103.

[2] C—corn, W—wheat, M—meadow.

[3] "Conservation" practice means contour cultivation, high fertility level, and soils with pH of 7.0. "Poor" practice means straight rows, low fertility level, and soils with pH of 5.4.

Y102, Muskingum silt loam (shale origin).—This soil type belongs to the Gray-Brown Podzolic group, is residual in origin, and occurs extensively in the North Appalachian Region. There is no mottling in the profile and the drainage is good. A description of the profile located near lysimeter Y102 follows:

Depth
(Inches)
0- 7 . . . Brown to yellowish-brown silt loam (plow layer).
7-14 . . . Yellowish-brown silt loam, slightly heavier than surface soil; occasional shale fragments.
17-24 . . . Yellowish-brown silt loam to fine sandy loam containing many sandy shale fragments.
24-39 . . . Partly decomposed shale in various stages of decomposition; fragments increasing in size with depth.
39-60 . . . Layer of shale in various stages of decomposition containing layers of ferruginous material; mostly undecomposed.
60-96 . . . Bedrock consisting of undecomposed shale with some shale in first stages of decomposition.

Y103, Keene silt loam.—This soil type occurs extensively in the vicinity of the experiment station. It belongs to the same group of upland soils as the Muskingum series but differs distinctly from the latter in its hydrologic characteristics. The subsoil is characterized by a heavy, relatively impermeable, silty clay whereas the Muskingum silt loam subsoil is a rather pervious loam or silt loam. A description of the profile near lysimeter Y103 follows:

Depth
(Inches)
0- 7 . . . Gray-brown silt loam (plow layer).
7-15 . . . Yellowish-brown silt loam; unmottled; slightly heavier than surface soil.
15-27 . . . Yellowish-brown silt loam to silty clay loam; slightly mottled with gray.
27-41 . . . Mottled gray, yellowish-brown and rust-brown heavy silty clay, gray color predominating.
41-76 . . . Gray heavy silty clay containing shale fragments.
76-96 . . . Partially decomposed clay shale to decomposed clay shale.

The mechanical analysis of these soils is given in table 2 and the chemical analysis of typical soil profiles adjacent to the lysimeters in table 3. These analyses, which are based on samples taken at the time the lysimeter casings were being sunk, include a complete profile to a depth of 8 feet.

Lysimeter Construction

A careful study of the literature and an inspection of conventional types of lysimeters revealed that none were adequate for the purposes of this study. The Coshocton lysimeters were a distinct departure from previous installations in the broad scope of information obtainable and in details of design.

The plan and typical cross section of a battery of lysimeters (*14, 40*) appears in figure 2. The three lysimeters of each set were constructed close together in order to keep the length of the shelter tunnels to a minimum. A space of 6 feet between adjoining soil blocks was required to permit enclosing each block without disturbing any of the others.

The soil block was enclosed by building a reinforced concrete casing with vertical walls in location on the ground surface and then lowering it by removing the soil from beneath the bottom edge. The lower edge of the casing was beveled and a steel cutting edge attached to facilitate lowering. The casing was 8 feet high with inside dimensions of 6.22 feet wide across the land slope and 14 feet long to provide an enclosed area of 0.002 acre. The top and bottom edges of the walls were parallel to the ground surface. To prevent seepage of water through the casing, the inside walls were

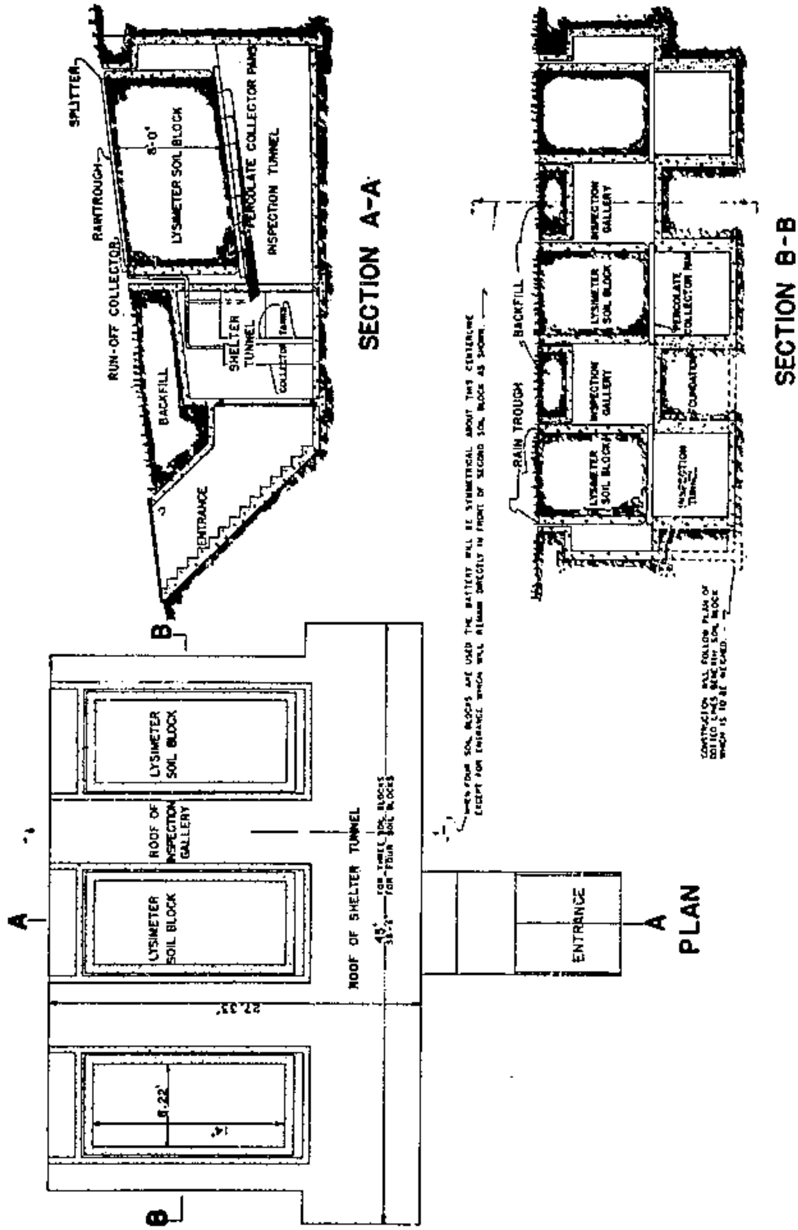

FIGURE 2.—Plan and typical cross section of a battery of water-cycle lysimeters.

TABLE 2.—*Mechanical analysis of soil profiles adjacent to lysimeters*[1]

LYSIMETER Y101, MUSKINGUM SILT LOAM (SANDSTONE)

Soil depth represented (*Inches*)	Description	Analysis of total materials		Analysis of particles <2 mm.		
		>2 mm.	<2 mm.	Total sand 2–0.05 mm.	Total silt 0.05–0.002 mm.	Total clay <0.002 mm.
		Percent	*Percent*	*Percent*	*Percent*	*Percent*
0–8	Dark brown silt loam	10.1	89.9	38.1	54.3	7.6
8–16	Brown silt loam to loam	39.8	60.2	29.6	52.6	17.8
16–33	Brown loam with sandstone fragments	27.4	72.6	45.0	36.0	19.0
33–51	Decomposed sandstone with sandstone fragments	40.2	59.8	70.8	16.1	13.1
51–96	Slightly decomposed sandstone with few fragments	4.8	95.2	75.4	13.4	11.2
	LYSIMETER Y102, MUSKINGUM SILT LOAM (SHALE)					
0–7	Brown to yellowish-brown silt loam	8.2	91.8	28.9	63.4	7.7
7–14	Yellowish-brown silt loam slightly heavier than surface soil	3.2	96.8	27.1	54.7	18.2
14–24	Yellowish-brown silt loam to fine sandy loam	6.2	93.8	54.9	27.3	17.7
24–39	Decomposed sandy shale	1.1	98.9	61.0	24.8	14.2
39–46	Mottled gray and rust-brown clay shale	24.8	75.2	48.8	33.9	17.3
46–60	Decomposed silty shale	53.3	46.7	57.9	28.7	13.4
60–74	Shale in first stages of decomposition	(2)				
74–96	Bedrock (shale)	(2)				
	LYSIMETER Y103, KEENE SILT LOAM					
0–8	Gray-brown silt loam	1.1	93.9	10.6	78.4	11.0
8–15	Yellowish-brown silt loam, unmottled	5.2	94.8	8.1	77.8	14.1
15–27	Yellowish-brown silt loam to silty clay loam slightly mottled with gray	2.4	97.6	9.1	63.4	27.5
27–41	Mottled gray, yellowish-brown, and rust-brown silty clay; gray predominant	0.5	99.5	9.3	53.1	37.6
41–60	Gray heavy silty clay containing shale fragments	2.2	97.8	8.2	54.2	37.6
60–83	Mostly decomposed clay shale	74.3	25.7	8.8	62.4	28.8
83–96	Partially decomposed clay shale	76.8	23.2	14.2	62.1	23.7

[1] Analyses by F. R. Dreibelbis and F. A. Post.
[2] No data.

TABLE 3.—*Chemical analysis of typical profiles of soils adjacent to lysimeters Y101, Y102, and Y103*[1]

Soil depth (Inches)	SiO_2	TiO_2	Fe_2O_3	Al_2O_3	MnO	CaO	MgO	K_2O	Na_2O	P_2O_5	SO_3	Loss on ignition	Total	N	Organic matter	Ratio of OM to N	Base exchange capacity M.E.[3]	pH[2]
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*			
LYSIMETER Y101. MUSKINGUM SILT LOAM (SANDSTONE ORIGIN)																		
0–8....	72.56	1.12	4.26	11.46	0.40	0.34	0.86	1.98	0.50	0.16	0.16	6.33	100.13	0.13	2.650	20.4	6.15	5.10
8–16...	75.45	1.03	4.19	12.31	.07	.16	.82	2.15	.47	.09	.09	3.78	100.51	.03	.333	11.1	3.34	4.70
16–27...	72.70	.95	5.21	13.71	.03	.12	.80	2.06	.68	.09	.05	4.15	100.47	.03	.206	6.9	5.36	4.55
27–40...	74.50	.81	4.28	12.81	.06	.12	.90	2.50	.71	.05	.08	3.23	100.05	.02	.186	9.3	3.94	4.60
40–54...	70.07	1.01	4.37	15.99	.04	.13	.95	2.75	.48	.05	.02	4.02	99.88	.02	.146	7.3	5.21	4.40
54–96...	85.53	.38	4.36	6.02	.07	.04	.34	1.56	.34	.07	.16	1.58	100.45	.01	.062	6.2	1.41	5.20
LYSIMETER Y102. MUSKINGUM SILT LOAM (SHALE ORIGIN)																		
0–7....	75.34	1.13	3.81	11.17	0.18	0.29	0.88	2.07	0.48	0.12	0.23	5.08	100.78	0.10	2.130	21.3	5.70	5.15
7–14...	73.19	1.08	4.43	12.83	.05	.19	.94	2.26	1.06	.08	.04	4.32	100.47	.04	.380	9.5	4.76	4.75
14–24...	69.01	.99	5.54	15.55	.06	.08	1.08	2.35	.45	.08	.01	4.83	100.03	.03	.241	8.0	5.74	4.70
24–39...	67.48	1.21	5.35	16.71	.06	.04	1.20	2.64	.97	.09	.12	4.70	100.57	.03	.324	10.8	4.39	4.30
39–60...	63.98	1.22	6.93	18.66	.06	.17	1.57	3.03	.54	.12	13	6.40	99.81	.03	.369	12.3	5.76	4.40
60–96...	65.63	1.17	7.52	15.76	.06	.11	1.46	2.85	.74	15	.15	4.97	100.57	.03	.353	11.8	5.92	4.60
LYSIMETER Y103. KEENE SILT LOAM																		
0–7....	75.20	1.12	4.88	10.00	0.30	0.33	0.68	1.91	0.18	0.10	0.06	5.65	100.41	0.12	2.260	18.8	9.32	5.60
7–15...	70.46	1.12	5.02	12.76	.10	.32	.92	2.27	.83	.08	.03	5.88	99.79	.05	.508	10.2	9.03	5.50
15–27...	70.00	1.11	6.54	13.39	.05	.26	.81	2.13	.48	.08	.04	5.79	100.68	.04	.333	8.8	9.49	4.90
27–36...	63.56	1.20	5.36	18.87	.02	.08	1.08	2.73	.53	.07	.02	6.85	100.37	.04	.204	5.1	8.43	4.65
36–41...	62.71	1.02	12.44	14.48	.13	.08	.70	2.15	.34	.33	.03	6.27	100.68	.03	.153	5.1	8.65	4.80
41–76...	67.13	1.33	3.94	17.99	.04	.03	.84	2.99	.21	.08	.03	5.86	100.47	.04	.255	6.4	8.92	5.10
76–96...	58.70	1.22	7.60	19.24	.14	.14	1.11	3.10	.91	.12	.02	7.44	99.74	.04	.292	7.3	11.47	5.50

[1] Analyses by Joe Schelling and F. R. Dreibelbis.
[2] Determined electrometrically on air-dry samples using the glass electrode.
[3] M. E. = milligram equivalents.

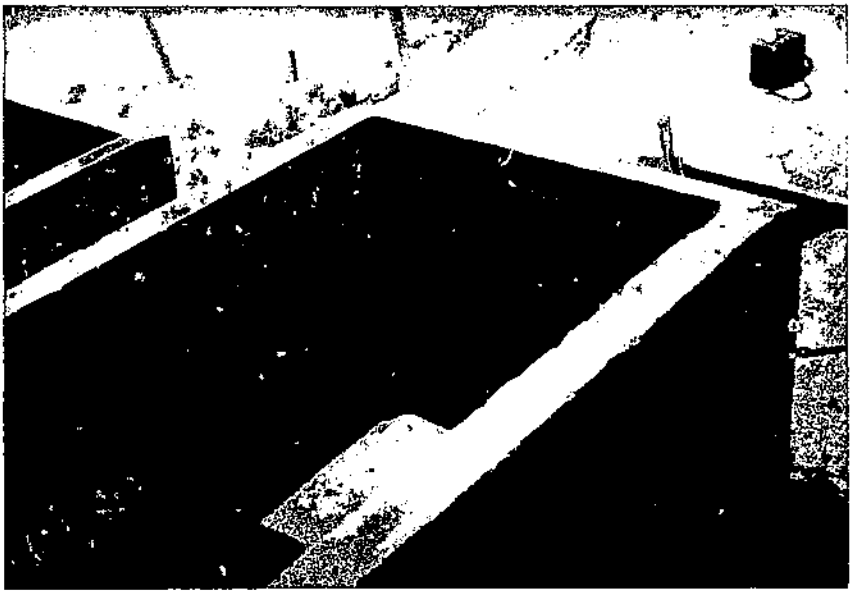

FIGURE 3.—Lysimeter casing showing waterproofed interior walls and slots for horizontal baffle plates.

first coated with creosote, which penetrated into the pores of the concrete, and then covered with hot asphalt.

An important feature of the casing was a device to eliminate the vertical seepage which normally occurs between the earth and the walls of a sunken casing. When pouring the concrete walls, four horizontal grooves 1½ inches deep were left in each inside wall. These and the waterproofed interior walls of a lysimeter casing are shown in figure 3. The ends of the slots extended through the wall so that ⅛ × 3-inch steel cut-off strips could be driven into place after the casing unit had been lowered into final position. Each lysimeter was thereby equipped with four "piston rings" to assure more nearly natural percolation of water through the soil profile. The most satisfactory method of isolating the soil block was to first sink the concrete casing to within ½ inch of its final position. The percolation pans were then jacked beneath the soil block from the downhill side and the concrete supporting walls were built below the percolation pans.

The casing was lowered by removing the soil from beneath the casing walls using screw jacks at each corner to govern the rate of lowering. Simultaneous lowering of the jacks allowed the casing to settle evenly as excavation proceeded. Smooth surfaces were cut on the sides of the soil block by the knife-edge bottom of the casing. All work was performed from outside the soil block. When necessary, the casing was weighted with sand bags to help the lowering process. Figures 4 and 5 illustrate various steps in the lowering of the casings. The lowering was stopped when the bottom of the casing wall was almost 8 feet below the original ground surface. At this point the knife edge was removed.

Concrete supporting walls, 1 foot thick, were poured so that their top was 3 feet, 5 inches below the ground surface. The inner face of each pair of walls was parallel to the long axis of the

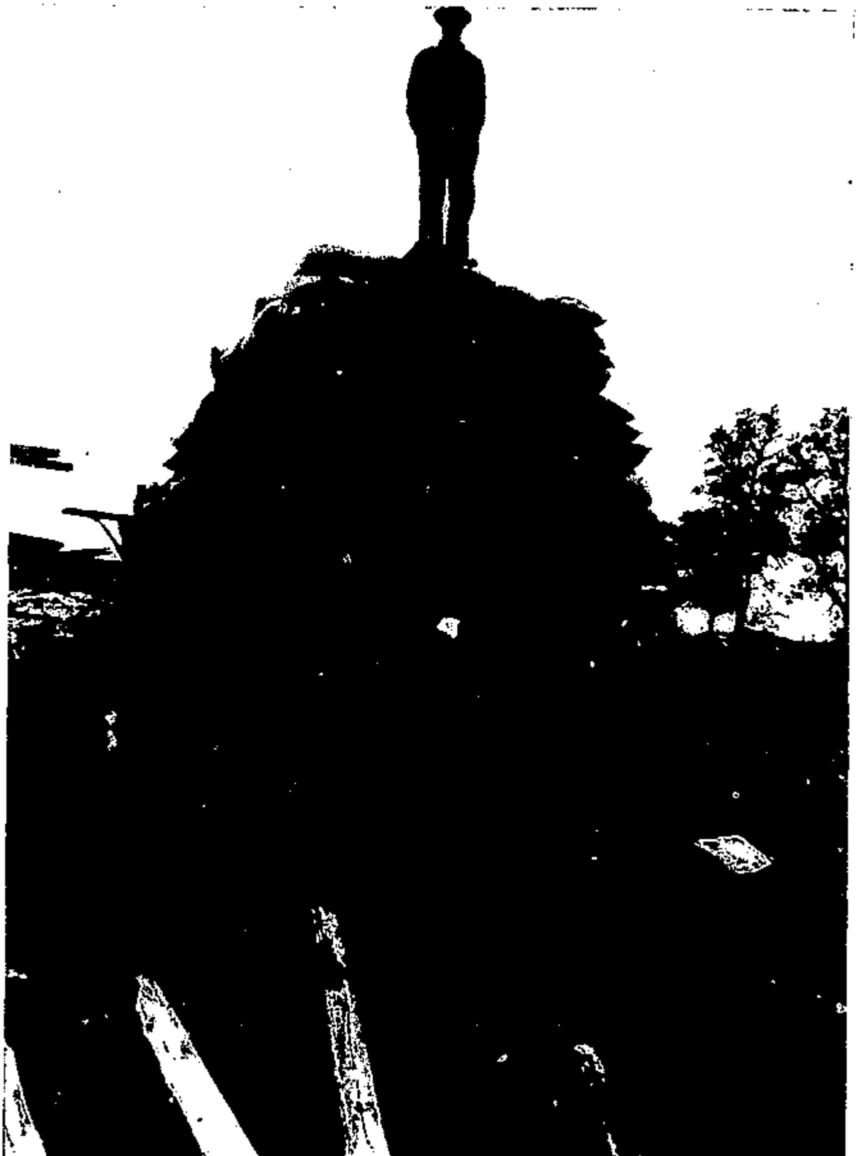

FIGURE 4.—Casing weighted with sand bags to facilitate lowering in partly excavated trench.

lysimeter and 3 feet from its center line. Excavation for one of these supporting walls is shown in figure 6.

Eight separate steel pans 5 inches deep, 2 feet wide, and 7 feet 7 inches long were constructed to support each soil block and to collect the percolation water. Holes one-half inch in diameter and spaced at 2-inch centers were provided to allow percolation water

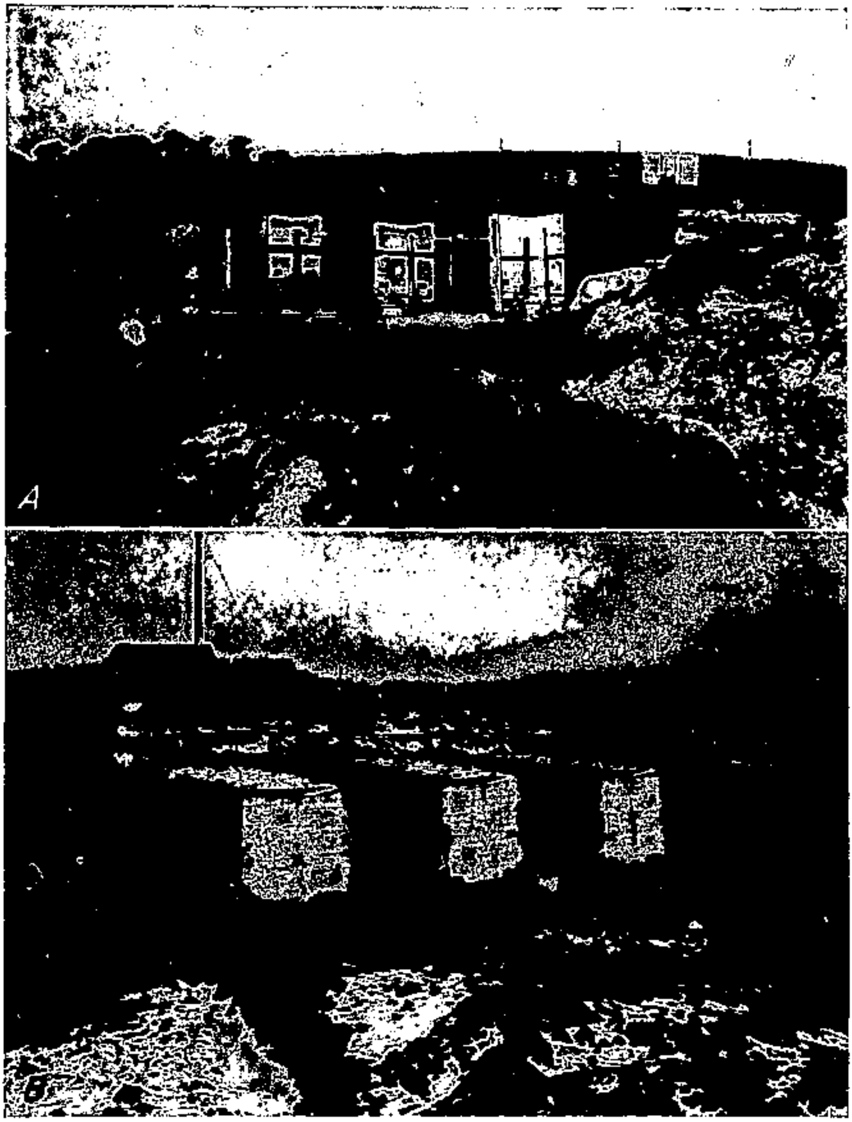

FIGURE 5.—Stages in the installation of lysimeter batteries: *A*, Lysimeters of battery Y101 partly lowered; *B*, lysimeters of battery Y103 in final position.

to drain from the overlying rock. Each steel pan was jacked beneath the soil block from the open pit on the downhill side of the lysimeter and slid along on top of the concrete supporting walls. A

FIGURE 6.—Profile in parent shale material below 8-foot depth, lysimeter battery Y103.

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FIGURE 7.—Percolation pans being jacked beneath soil block.

knife-edged bar attached to the first pan cut a smooth surface on the bottom of the soil block. The pans were bolted together after asphalt roof cement had been applied to the joints. Figure 7 shows one pan partly beneath the soil block, the asphalt cement in the joint, another pan about to be joined, and the ½-inch holes in the top surface of the pans.

Just before the lowering operation was completed, asphalt

FIGURE 8.—Surface of lysimeter battery Y102 after construction was completed.

cement was applied between the percolation pans and the bottom of the casing walls to provide a water-tight seal. When the casings were in the final position, the steel cut-off or "piston ring" strips were driven into the wall slots, protruding 1½ inches into the soil block. The holes around the strips in the casing were sealed with roof cement and concrete.

Upon completion of the shelter and inspection tunnels the excavation was backfilled to original land surface leaving no evidence above ground of the presence of underground tunnels and instruments (fig. 8).

All lysimeters were equipped for measuring separately the rainfall from collector troughs, surface runoff, and percolation. Only one lysimeter in each battery was equipped to measure weight changes.

Recording Features

Each lysimeter was equipped to record the rates and amounts of both surface runoff and percolation. From runoff, precipitation and other data, it would be possible to determine accurate values of infiltration. However, evapo-transpiration and condensation-absorption values could be obtained only by mathematical calculations of differences over long periods of time. Changes in moisture stored in the soil block could not be definitely determined from rainfall, runoff, and percolation records. Therefore, a weighing mechanism which would continuously record the change in weight of the lysimeter was devised. Detailed descriptions of the recording features are presented below:

1. *Surface runoff* is collected in a trough at the downhill end of each lysimeter. This water drains through a pipe into a metal tank in the shelter tunnel, where it is accumulated and measured. The surface area of the cylindrical tank is one-tenth that of the lysimeter. A Friez FW-1 water-stage recorder makes a continuous record of the depth of water in the tank. Water depth can be determined from the graphic record to the nearest 0.005 foot. This is equivalent to a depth of $0.005 \times \frac{12}{10}$, or 0.006 inch of water over the lysimeter surface. The recorder clock is geared to one revolution in 12 hours and permits time observations to the nearest minute.

2. *Percolation* water is drained through an airtight pipe system into a cylindrical metal tank where the percolate is accumulated and measured. The surface area of the tank is one-tenth that of the lysimeter. A Friez FW-1 water-stage recorder makes a continuous graph of the depth of water in the tank. Depth accuracy is the same as that for runoff measurements. The recorder clock is geared to one revolution in 8 days, thus permitting time observations to the nearest one-half hour. Changes in percolation rates are slow. Whenever the depth of water in the percolation tank reaches 2 feet, samples are taken and the tank is drained. The

samples are used to determine the chemical content of the percolation water.

3. *The weighing mechanism* consists of scales operating on the lever and pendulum principles. They were installed by jacking up the complete lysimeter, rolling the scale frame into place beneath it, and then lowering the lysimeter until the scale frame carried the entire load of about 65 tons. Dead weight below the expected range in weight variance was eliminated by counterbalances. After installation, the scales were tested over a 20,000-pound range by the U. S. National Bureau of Standards. The mechanism was found to measure weight changes to the nearest 5 pounds, which is slightly more than the weight of 0.01 inch of water on the lysimeter area. The weight was printed every 10 minutes on a paper tape. Storage batteries were used to operate the printing mechanism.

Grease placed in the narrow cup-shaped gap separating the movable lysimeter from the surrounding soil at the ground surface permitted the weighing lysimeters to move freely and at the same time prevented air and water from entering the shelter tunnel. The grease allowed the lysimeter to move with very little friction as evidenced by the sensitivity of the scale needle during periods of gusty winds. The seal also helped to keep the temperature in the shelter tunnels and lysimeter soils the same as in the soil of adjacent crop fields.

EXPERIMENTAL PROCEDURE

Agricultural Operations on Lysimeters

Cultural treatments on the lysimeters were designed to provide measurements needed to evaluate the hydrology of: (1) Permanent grasses and legumes on well-drained soil; (2) a crop rotation of corn, wheat, and 2 years of meadow on well-drained soil; and (3) a similar rotation on slowly permeable soil. Agricultural operations were carried on at the same time and at the same intensity as in the adjacent farm fields. Hand tools were used in working the lysimeter soil. The abnormal border effect common to many lysimeters was overcome by extending the cropping area around each battery a distance of at least 25 feet in all directions. For example, corn rows on the lysimeters were extended into the bordering area for at least 25 feet, and parallel rows were planted on the contour above and below the lysimeters.

The entire crop on each lysimeter was removed at the regular harvest time and yield determinations made. A complete history of land use operations and yields for each lysimeter battery during the 1936-49 period, by years, appears in appendix A.

Lysimeter Recording Apparatus

Percolation recorders were kept in continuous operation. Charts were removed from the water-stage recorders weekly. Data from the charts were tabulated for use in the analyses and other lysimeter data determinations. Samples of charts and tabulation sheets appear in appendixes B.1 and B.2. The percolation graph generally was a straight line—either flat or sloping. If sloping, the percolation rate was constant. Deviations from a straight line indicated that the rate was changing. During these periods, tabulations of time and depth were made at frequent intervals in order to derive adequate percolation-rate data.

Chemical analysis was made of percolate samples taken from the percolation tank each time it was drained. Nitrates were determined soon after sampling. Concentrations of other solutes were determined from composites of several samples from the same percolation tank.

Runoff recorders were likewise operated continuously. The recorder charts were changed after each runoff period and the data from the charts were tabulated for use in analyses. Samples of charts and tabulation sheets appear in appendixes C.1 and C.2. A horizontal line on the chart record indicated there was no change in the water depth in the runoff tank, hence no runoff. A sloping line indicated runoff; the steeper the slope, the greater was the runoff rate. Whenever the slope of the line indicated runoff, the time and depth of enough points on the line were tabulated to provide adequate runoff-rate data.

Weight recorder tapes were removed weekly. On these paper tapes the date, time, and part of the weight dial were printed at 10-minute intervals. The complete weight record for each day was transcribed from the dial printing to a lysimeter weight record sheet, a sample of which appears in appendix D. Average hourly weights were obtained by averaging the six consecutive 10-minute weights beginning at 30 minutes before each hour and ending at 20 minutes after the hour. This averaging process removed some of the irregularities of weight records caused by wind and provided convenient data for the study of trends and variations.

The hourly average values were summarized on sheets entitled "Semimonthly Lysimeter Record, Weighing Box," a sample of which appears in appendix E. The daily storage changes were obtained by subtracting the initial midnight weight reading from the final midnight weight reading and converting pounds into inches of water by multiplying by 0.002207. Values of daily rainfall were taken from the recording rain gage adjacent to the lysimeter battery. These differed from the rainfall amounts measured by the lysimeter. The latter were used in all lysimeter calculations. The procedure for determining lysimeter rainfall is presented in a following section.

Daily percolation and runoff values were transferred to the semimonthly lysimeter record sheets from the respective tabulation-computation sheets. Daily ET — CA values were computed, using the following relationship:

ET — CA = Lysimeter precipitation — Runoff — Percolation — Storage change. Separate ET and CA values were obtained from the hourly summaries. Weight change for the period of the day when the lysimeter was consistently losing weight was converted to inches and labeled daily ET. Likewise, consistent gains in weight were labeled CA. With few exceptions ET values represented the over-all soil-moisture change from the greatest to the least weight figure for each day, and CA values represented the over-all weight increase from the daily minimum to the subsequent maximum weight value. Minor fluctuations in weight between these daily extremes were not used in the computations. During periods of rainfall CA and ET were assumed to be zero. Percolation rates were considered in the computation of separate ET and CA values.

Values of lysimeter rainfall used in the computation of ET — CA were computed from lysimeter weight increases during periods of rainfall. A sample sheet (Calculation of Rainfall from Weight Record) appears in appendix F. The beginning and ending time of the rain period was taken from the recording rain-gage charts. These times and corresponding weight readings for each day were listed in a series of columns in the middle of the calculation form. The daily runoff and percolation for all lysimeters in the battery were tabulated to the left of these columns. The hours of rainfall for each day were totaled and these values placed in the column headed "Hours Rain." In the next two columns appear those portions of the day's percolation attributed to the rainfall periods ("Rain" column) and those for the remainder of the day ("ET" column). Throughout most rainy days, percolation rates were usually constant, and percolation amounts for the rain period could be calculated by a simple time ratio:

$$\text{Percolation in rain period} = \text{Percolation (24 hours)} \times \frac{\text{Hours rainfall}}{\text{24 hours}}.$$

Whenever the percolation rates varied materially during the 24-hour period, percolation amounts for rain periods were taken directly from the percolation recorder chart.

The increase in lysimeter weight during all the precipitation periods of the day was calculated from the "Weight Record" figures on this same form. This weight value was converted to inches of water and tabulated in the column headed "Wt. Incr." The amount of this weight increase accounted for by actual precipitation was determined by the following formula:

$$\text{Lysimeter precipitation} = \underset{\text{(all during periods of precipitation)}}{\text{Runoff} + \text{percolation} + \text{weight increase.}}$$

Data for the remaining columns of this form were determined by methods previously explained.

The dates on which the runoff, percolation and scale weight records for each lysimeter began are given in table 4.

Thermograph recorders provided continuous data on air and soil temperatures. Air-temperature recorders housed in louvered shelters were set at a height of 30 inches above the ground surface. The temperature-sensitive air thermograph, a phosphor-

TABLE 4.—*Date on which records for each lysimeter began*

Lysimeter	Runoff	Percolation	Scale weights
Y101A	Jan. 17 1938	Dec. 31, 1937	None.
Y101B	Jan. 10, 1938	do	June 1, 1939.[1]
Y101C	do	do	None.
Y101D	Dec. 31, 1942	Dec. 31, 1942	June 3, 1943.
Y102A	Jan. 6, 1938	Dec. 31, 1937	None.
Y102B	do	do	Do.
Y102C	do	Dec. 30, 1937	May, 1937.
Y103A	Apr. 23, 1940	Apr. 26, 1940	May 11, 1939.
Y103B	Mar. 11, 1940	Mar. 11, 1940	None.
Y103C	do	do	Do.
Y103D	Mar. 19, 1940	Mar. 20, 1940	Do.

[1] Scales transferred from Y101B to Y101D in June 1943.

bronze bourdon tube filled with alcohol, has an accuracy usually within 1 or 2 degrees of the mercurial thermometer. Air temperature at 2 inches above ground and at soil depths of ½, 3, 6, 12, and 24 inches were obtained by Friez Distance recorders also housed in louvered shelters. Each instrument was equipped to record temperatures at three different levels by means of small thermal bulbs which transmitted vapor pressure through flexible airtight tubes. Accuracy to about ±2 degrees was usually obtained with these instruments. Air- and soil-temperature records were gathered at each of the three lysimeter sites until 1946. At that time it was necessary to discontinue the operation of the temperature recording apparatus at lysimeters Y101 and Y103.

The recorder-clock drums revolved once in 8 days permitting observations to the nearest hour. Charts were changed weekly. The maximum, minimum, and mercurial thermometer readings were recorded each day, Monday through Friday, at about 8 a. m. The daily maximum and minimum air and soil temperatures were read from the recorder charts and tabulated. (See sample tabulation, appendix G.) The daily fluctuation in temperature, average of daily maximum and minimum temperatures, and weekly average were calculated and entered on this form.

The land treatment on the soil- and air-temperature recording sites was the same as on the lysimeters. For example, when corn was growing on the lysimeter it was also growing in the temperature-recording area. When the lysimeter crop was harvested, the crop on the temperature units was also harvested. The data therefore were representative of crop and soil conditions prevailing on the lysimeters.

Atmospheric moisture at the 30-inch level was recorded on Friez Model 594 hygrothermographs housed in the same louvered shelters containing the temperature recorders. This instrument provided direct measurements of changes in relative humidity. Its chief defect is the possibility of inaccuracy where very high or very low relative humidities are involved. Checks with the sling psychrometer showed that errors may range from +8 to —12 percent within a period of 3 days, whereas at other times the recorder values were fairly accurate, differing from the psychrometer observations by only 2 percent. Despite its defects, the hair hygrometer was found to be the most satisfactory instrument for ordinary field observations of atmospheric moisture changes.

Hygrometer charts were changed weekly. The time scale was such that hourly values of relative humidity could be read easily to the nearest percent. Psychrometer readings were obtained at about 8 a. m. daily from 1938 to 1942, inclusive, and on week days thereafter.

During the period 1938-42, barometric pressures were obtained from mercurial barometer readings and from a microbarograph Friez Model 790. Hours-of-sunshine data from a Friez Model 380 transmitter were also obtained for this period. During the summers of 1938 and 1939, daily atmometer readings were taken and evaporation of water was measured from a pan on a recording rain gage. Data of this type were gathered only during the trial period of lysimeter operations.

Evaporation records for most of the period of lysimeter record were obtained from a Bureau of Plant Industry sunken evaporation pan. This pan, which is 6 feet in diameter and 2 feet deep, was sunk in the ground so that the rim projected 4 inches above the ground surface. Water surface was maintained at about ground level. A micrometer point gage was used to measure the water-surface elevation in a stilling well attached to the outside of the pan. This pan, along with a U. S. Weather Bureau Class A pan and the Colorado sunken pan, was set in operation at the meteorological station in May 1938. All evaporation records at this site were discontinued in August 1942. The Bureau of Plant Industry (BPI) pan was placed in operation at lysimeter Y102 site in May 1944. The BPI-pan records are used in this report since evaporation from such pans is comparable with that from large water surfaces (*41*).

The initial plan of obtaining water-level readings in the various pans twice daily—8 a. m. and 5 p. m.—throughout the nonfreezing period, April-October, was continued until the close of the meteorologic study in August 1942. From 1944 through 1945 the BPI-pan water level was read once daily. After 1945 the readings on Saturdays, Sundays, and holidays were discontinued. Water-temperature and wind-movement data were obtained at each reading of the water level in the evaporation pan. A Friez Model 349, 3-cup, direct-reading anemometer was used for measuring wind movement. Numerals on the odometer dial indicated miles of wind passage over the evaporation pan. A sample of the tabulation sheet for evaporation, water temperature, and wind movement appears in appendix H.

Soil moisture observations in areas adjacent to the lysimeters were made periodically. No instrument was available for automatically recording soil-moisture changes accurately in the range from wilting point to saturation. The first and perhaps the most reliable method used for determining field moisture at various depths in the soil profile was a combination of field sampling and laboratory analysis. In order to avoid destroying the natural soil structure through frequent sampling within the lysimeter, the soil-moisture determinations were based on undisturbed field profiles adjacent to the lysimeter batteries. From four to six locations in each area were sampled to obtain reliable average values.

In order to evaluate properly the basic factors affecting water conservation and utilization, it was necessary to obtain soil-moisture data for several different layers of the soil profile and to make frequent determinations of soil moisture during periods of rapid accretion or depletion. Moisture observations were made at the following depths in the different soils throughout the study:

Muskingum silt loam (near Y101) at 0-8, 8-16, 16-24, and 24-40 inches; Muskingum silt loam (near Y102) at 0-7, 7-12, 12-22, and 22-40 inches; and Keene silt loam (near Y103) at 0-7, 7-14, 14-24, and 24-40 inches.

In addition, since 1946, soil-moisture observations have been made at other levels in the topsoil and subsoil to a depth of 10 inches. It was in this range of depth where the most rapid fluctuations of soil moisture occurred.

Field sampling for gravimetric determinations of soil moisture not only required much time but cut up the field unduly. This method was therefore replaced by the use of electrical resistance blocks installed in the field at the required depths. These units were made up and were operated according to Bouyoucus and Mick (*3*). In 1949, improvements in the blocks greatly increased their sensitivity and made it possible to determine soil moisture with greater accuracy in the range from field capacity to saturation.

Water-plant relationships are of greatest importance in the 0-40-inch part of the soil profile. Daily soil-moisture values could be obtained for this profile by direct interpolation from the periodic soil-moisture measurements, but only for periods lacking precipitation. For rainy periods the daily soil-moisture values were obtained by correlating the lysimeter-weight records with the moisture data obtained from periodic sampling of the 40-inch profile in the adjacent watersheds. From this it was possible to construct a soil-moisture graph for the 0- to 40-inch depth of soil showing probable daily changes throughout the year.

In the construction of this graph, which was based primarily on the correlation mentioned, certain assumptions were necessary relative to accretion and depletion. These assumptions, with some flexibility in their application, are as follows:

1. ET was assumed to come from the 0- to 40-inch depth of soil, regardless of season.

2. All percolation was assumed to come from below the 40-inch depth when the daily percolation did not exceed 0.2 inch. When greater than this value, one-third of the percolation was assumed to come from the 0- to 40-inch zone.

3. In winter when the soil was frozen, all precipitation which did not run off was assumed to be contained within the 0- to 40-inch depth. During the remainder of the year, when precipitation did not exceed 0.25 inch that part not running off was attributed to moisture accretion in the 0- to 40-inch depth. When precipitation exceeded this amount the allocation of the precipitation retained on the plot was dependent on season, soil-moisture content, and frequency of rainfall.

4. In the spring, when the soil was nearly saturated, only one-fifth of the nonrunoff precipitation exceeding 0.25 inch, plus 0.25 inch, was attributed to the 0- to 40-inch depth and the remainder was assumed to contribute to the lower zone. In the summer, when transpiration was high and the soils much dryer, a greater portion of the precipitation, often all of it, was considered as being held in this top zone. The resulting soil-moisture curve is believed to be accurate within ± 0.5 inch with few exceptions, and often closer than ± 0.2 inch. Some values on the calculated graph of soil moisture appeared to be more reliable than the sampled points.

The observations made in conjunction with the lysimeter operations at Y102 are listed below. All records began October 1941.

Temperature:

- Air at 30, 18 (discontinued January 1948), and 2 inches above ground.
- Soil at ½, 3, 6, 9 (discontinued August 1944), 12 and 24 (started August 1944) inch depth.

Moisture:

- Air at 30 inches above ground.
- Soil moisture, as previously noted.

Evaporation from BPI pan (began 1944).

Water temperature.

Wind movement at ground level beside evaporation pan.

Miscellaneous meteorological observations, 1939 through 1942:

- Barometric pressure.
- Sunshine duration.

Similar, but less extensive, data were obtained for a period at Y101, January 1942-January 1946, and at Y103, April 1942-April 1946, as follows:

Temperature:

- Air at 30 and 2 inches above ground.
- Soil at ½- and 3-inch depths.

LIMITATIONS OF THE LYSIMETERS

The cultural operations on the lysimeters were necessarily limited to one standard crop rotation of 4 years on two of the lysimeter batteries and a permanent grass cover on the third. The facilities available did not permit making a study of the hydrology of mature woodland or the hydrologic effects of such conservation measures as reforestation, different cropping systems, and mulching. The permanent grass lysimeters, representing pasture areas, were clipped to correspond with pasturing periods, but since actual grazing of the lysimeters was impractical, the effect of stock trampling on the soil surface could not be obtained.

Every effort was made to work the surface of the lysimeter soils in such a way that their physical condition would correspond to that of the adjacent watersheds. However, the heavy implements used in the cultivation of adjacent farm fields could not be used on the crop-rotation lysimeters. Cultivation with hand tools and the weight of a workman probably had less effect than mechanized farm equipment on soil compaction.

Prior to 1944 the precipitation data from the Fergusson rain gage within 25 feet of the lysimeters were used to represent lysimeter precipitation. These rain-gage values were found to differ noticeably from the lysimeter weight increases during storm periods. Using them in the lysimeter computations of moisture storage and ET resulted in erroneous values. Beginning in 1944 lysimeter precipitation (weight record) was used to derive moisture and ET values.

The lysimeters used in this study were not designed to measure surface runoff other than that from the lysimeters. Runoff from upperlying areas was diverted around the lysimeter. All crops were planted on the contour. No waterways were provided to carry runoff water down hill to the collecting trough. Runoff occurred in the form of sheet flow or in small rills. All these limitations in the lysimeters are common to plot studies. The concentration and development of surface flow on plots or lysimeters, therefore, is not truly representative of natural field flows. The runoff data were needed, however, for complete evaluation of all the hydrologic factors affecting disposal of precipitation. The only lysimeter runoff data presented herein are monthly totals appearing in tables 5, 6, and 7, and annual totals shown in figures 9 to 14.

The walls of the lysimeter casings prevented the lateral movement of water from or to the surrounding area. This was no serious limitation for lysimeter batteries Y101 and Y102 as the soil profiles are well drained, at least to the 8-foot depth. It is unlikely, therefore, that water moved laterally in these lysimeters or even in the surrounding area. Spring or seep spots were found only at lower elevations along the hillside. For the heavier soils represented by Y103, lateral movement of water may have occurred naturally in the unconfined areas outside the lysimeters during the temporary periods of perched water tables. The effect of the lysimeter walls in preventing lateral movement of water on percolation and soil-moisture values is believed to be small. Except in periods of perched water tables, the walls would have no effect on the Y103 lysimeter functions.

Percolation of water through the 8-foot profile was measured by water-level recorders in tanks. A few times during the period of operation the pipes for transporting percolate from the lysimeter collector pans to the tanks became clogged. This condition was evident from a comparison of all concurrent percolation charts in the lysimeter battery. Clearing the clogged pipes with compressed air allowed the stored-up water to flow out. The flow thus released was measured and the total value distributed throughout the "clogged" period according to the percolation rates of other lysimeters in the same battery. Samples of the released water were taken for chemical analyses. Whenever one lysimeter was found clogged, all eleven were blown out the same day. Clogging occurred not more than four times during the period of operation.

Samples of percolation water for chemical analysis were obtained whenever the tanks were drained; that is, when the water depth reached 2 feet. During periods of rapid percolation, it was necessary to drain the tanks several times a month. At other times, the tanks did not need to be drained for several months. Thus samples were collected at irregular intervals. Nitrates were determined for each sample within a few days after it was taken. A uniform aliquot of each sample was composited with identical aliquots of other samples from the respective lysimeters for the calendar year. This composite was then used for further chemical analysis. The nitrate determination provided data on the distribution of leaching throughout the year. Otherwise, only annual values of the chemical losses were available.

The accuracy of the weight records used for determination of storage changes depended on maintaining sufficient clearance between the weighing lysimeters and the stationary walls or other objects to permit free movement of the lysimeter. Because of the jamming of the weighing apparatus in the early years of lysimeter operation, the hourly weight readings prior to 1944 were of doubtful value. As the midnight values were unaffected, they were used without reservation in determining reliable daily ET — CA values. Separate ET and CA values were not derived.

The net daily loss in weight of the lysimeters unaccounted for by runoff or percolation was designated evapo-transpiration (ET). Beginning in 1945, these daily changes in weight were divided into periods of increase (CA) and decrease (ET). The net change for the day was designated ET minus CA. After January 1944, all daily changes in storage were calculated for the items ET, CA, and ET — CA. This permitted an evaluation of the importance of periods of soil-moisture increases and decreases separately. Snow drifting on or off the lysimeters gave abnormal weight readings.

ET values, as derived from lysimeter weight records by the methods presented herein, can be used in many hydrologic evaluations. They may be used in conjunction with precipitation data to derive values of runoff. For runoff determinations, however, some adjustment must be made to account for differences between values of rain-gage and lysimeter-measured rainfall, and to account for CA which is not measured. These adjustments can be applied either to the precipitation data in the area under study or to the ET values contained in this report. The latter procedure, which is probably the simpler, is as follows:

Annual ET minus CA minus 4 inches (precipitation-gage-data correction) equals an adjusted evapo-transpiration value which can be used with precipitation-gage data. For example, with an average annual ET value of 42.2 inches, CA of 10.3 inches, and a gage correction of 4 inches, the usable evapo-transpiration value would be 27.9 inches. Thus, if the precipitation-gage records in the study area showed an annual value of 40 inches, the precipitation—minus—evapo-transpiration value would be 40 — 27.9 or about 12 inches. This remainder is commonly attributed to runoff.

Fluctuations in the weight records due to gusty wind were observed early in the study, and many devices were tried in an attempt to evaluate and reduce this effect. These included shielding the weighing lysimeter from the wind by tarpaulins, and installing a switch which would restrict the printing of lysimeter weights to periods of little or no wind movement. None of these devices was satisfactory.

During high winds, the scale reading of the weighing lysimeter oscillated almost continuously. Oscillations varying from 5 to 10 pounds for a light wind to 150 to 200 pounds for a gusty wind of high velocity indicated the sensitivity of the weighing mechanism. An elaborate statistical study in 1942 showed that the true weight could not be obtained from the magnitude of the oscillations and the recorded wind velocity.

A detailed study of the weight readings for the year 1942 showed that wind pressure had no serious effect on the accuracy of the lysimeter weights. All weight deviations between consecutive 10-minute weight recordings greater than 15 pounds were tabulated. The largest deviation was 81 pounds. Deviations exceeded 50 pounds on only 7 occasions. Also there were only 4 days in which there were more than 10 deviations exceeding 15 pounds. As the 10-minute weight recordings were averaged for each hour, reasonably accurate values were obtained except perhaps for the 4 days mentioned.

In order to determine whether moisture condensation on the sides of the weighing lysimeters would cause appreciable errors in weighing, a lysimeter was weighed with wet walls and again after the walls had been wiped dry. The difference in weight was less than 5 pounds. Furthermore, hygrothermograph records in the observation tunnels for a period indicated practically no humidity or temperature change. Relative humidity remained at 100 percent. Since the walls were constantly moist, there was no condensation on or evaporation from them.

Evaporation-pan data were not continuous and were at times affected by shading of tall crops. Equipping the evaporation pan with an automatic recorder and moving it to an unsheltered location would permit obtaining evapo-transpiration and evaporation records which could properly be compared. Atmometers operated during the nonfreezing period would provide data which could be compared with evapo-transpiration records.

The limitations mentioned above illustrate some of the difficulties involved in obtaining accurate lysimeter and necessary related data. In spite of the limitations, these hydrologic data are believed to be the most reliable of their kind that have been obtained, either by actual measurement or by the use of theoretical formulas *(20, 34)*.

ANALYSIS OF RECORDS

The records obtained by means of the three automatic weighing lysimeters furnished basic data for analyses applicable to a wide field of agricultural hydrology. Results were derived in terms of soil-moisture storage changes, saturation deficiencies, rates of soil-moisture depletion by crops, evapo-transpiration, condensation and absorption of atmospheric moisture, amounts and rates of percolation, and plant-nutrient losses in percolation. As the data available for these analyses represent a period of only 6 to 12 years, the results and conclusions must be considered subject to modification as additional data are obtained.

The Lysimeter as a Device for Measuring the Accretion and Depletion of Soil Moisture

The lysimeters provided a means of measuring the accretion of moisture to the soil, depletion from the soil, and water-storage changes within the soil block. Monthly and annual summaries of these data for Y101D, Y102C, and Y103A during the period 1944-49 are given in tables 5, 6, and 7. The daily fluctuations of soil moisture, when summarized separately in terms of CA and ET, provide an evaluation of each of these moisture changes. The net soil moisture change (ET — CA), however, will probably prove to be a more useful value in the general field of agricultural hydrology.

ACCRETION

The weighing lysimeters acquired moisture through precipitation, condensation, and absorption. Precipitation was mainly in the form of rain, but snow, sleet, and hail were also included in the measurements. The precipitation data derived from lysimeter weight records represent the amounts falling to the earth's surface as contrasted with that collected by the ordinary rain and snow gages.

Condensation was mainly the water converted from vapor form in the atmosphere to liquid on the vegetation or soil surface. It includes also the moisture absorbed by the soil from vapor in the air layers near the ground surface and the water condensed from vapor in the soil pores. Condensation within the soil accounted for only a very small part of the total condensation—less than 1 percent. As soon as the vapor became liquid on the vegetation or in the soil of the lysimeters, its weight was recorded. Well-defined weight increases during periods of no precipitation were attributed to condensation-absorption.

Over-all weight increases were tabulated for each daily accretion period and converted to inches of water. Plus and minus variations in weight within periods of general weight increase were omitted in the calculations. Thus the CA values are only net increases and, therefore, are minimum values. If all the minor increases were totaled for each day, the resultant CA values would be greater than those given herein. Furthermore, whenever transpiration occurs during the CA period, only the net weight change can be measured. If it were possible to evaluate these two separately, the resultant values of ET and CA would be greater than those presented herein. These records made it possible to determine the hours of condensation-absorption and its fluctuation by seasons with different vegetal covers. The effect of climatic factors on atmospheric moisture condensation is discussed on pages 62 to 75 of this report. Only monthly and annual values are given in tables 5, 6, and 7.

Precipitation was by far a greater accretion factor than condensation and absorption combined, amounting to from 76 to 86 percent of the total accretion and averaging 81 percent. However. an appreciable amount of moisture other than precipitation was supplied to the soil and its plant cover through condensation-absorption. This ranged from 14 to 24 percent of the total accretion and averaged 19 percent. Actual amounts ranged from about 6 to 9 inches of water annually. Values greater than these appearing in tables 5, 6, and 7, are somewhat abnormal because of drifting snow. Drifting of snow off and on the lysimeters during the winter is quite variable, and the values for evapo-transpiration and condensation-absorption, which are based on actual lysimeter weights, are necessarily incorrect for days of drifting snow.

Monthly condensation-absorption was seldom less than 0.5 inch of water and then only occasionally in the summer months. Although much of this water was removed by evaporation after a few hours of sunshine, it is believed to have some moisture-conservation value, as explained later.

Condensation in all years was greater on Y102C than on Y103A, due possibly to differences in soil moisture, porosity, or air drainage. The Muskingum silt loam of Y102C was always drier than the Keene silt loam of Y103A, thus creating a greater moisture gradient between the moisture content of the atmosphere and that of the soil. Differences in soil moisture between these two soil types are illustrated by the top graphs of figures 9 to 14. It is believed that since the Muskingum soil was more porous than the Keene, water vapor in the atmosphere may have moved into it more readily, thus providing a greater opportunity for condensation.

Differences in condensation may have been due also to differences in air drainage. Y103, being within a few feet of the ridge, would have very little air draining down across its surface. Y102, on the other hand, lies on a 12-percent slope 200 feet downhill from the ridge, making it possible for moist air to drain down the slope and replenish the air supply available for condensation. The individual influence of soil moisture, porosity, or air drainage was not evaluated because of insufficient data.

TABLE 5.—*Monthly summary of the accretion, depletion and storage of soil water as determined by the weighing monolith lysimeter Y101D, 1944–49*

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
1944—Poverty grass:	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January	0.92	0.51	1.43	0	0.77	0.07	0.84	0.59	....
February	1.97	.88	2.85	0	1.55	.11	1.66	1.19	....
March	5.71	.95	6.66	.02	2.70	2.37	5.09	1.57	....
April	3.71	.46	4.17	.01	2.27	2.74	5.02	....	0.85
May	2.16	.22	2.38	.04	3.73	1.04	4.81	....	2.43
June	3.09	.23	3.32	.22	4.42	.55	5.19	....	1.87
July	2.42	.22	2.64	.14	4.70	.22	5.06	....	2.42
August	4.27	.27	4.54	.48	3.81	.01	4.30	.24	....
September	1.82	.44	2.26	.10	2.41	0	2.51	....	.25
October	1.83	.66	2.49	.11	2.01	0	2.12	.37	....
November	1.23	.43	1.66	0	1.03	0	1.03	.63	....
December	2.83	[1]1.87	4.70	0	[1]1.82	0	1.82	2.88	....
Total	31.96	7.14	39.10	1.12	31.22	7.11	39.45	7.47	7.82
Percent of total accretion or depletion	81.74	18.26	100.00	2.84	79.14	18.02	100.00	....	....
1945—Bluegrass:									
January	1.68	[1]4.29	5.97	0	[1]3.69	0	3.69	2.28	....
February	2.60	[1]3.71	6.31	0	[1]4.27	.64	4.91	1.40	....
March	7.87	.86	8.73	.01	3.12	5.74	8.87	....	.14
April	4.48	.51	4.99	.02	2.94	1.97	4.93	.06	....
May	4.67	.46	5.13	.04	3.68	2.44	6.16	....	1.03
June	3.51	.35	3.86	.02	4.81	1.01	5.84	....	1.98

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July	2.66	.49	3.15	.01	5.78	.47	6.26	....	3.11
August	.94	.56	1.50	.01	3.75	.20	3.96	....	2.46
September	9.67	.44	10.11	.02	2.85	.02	2.89	7.22	....
October	2.91	.61	3.52	.01	3.13	.81	3.95	....	.43
November	3.90	.88	4.78	0	1.81	.70	2.51	2.27	....
December	2.17	1.13	3.30	.09	1.63	1.35	3.07	.23	....
Total	47.06	14.29	61.35	.23	41.46	15.35	57.04	13.46	9.15
Percent of total accretion or depletion	76.71	23.29	100.00	.41	72.68	26.91	100.00	....	....
1946—Bluegrass:									
January	1.06	[1]1.76	2.82	0	[1]2.40	1.12	3.52	....	0.70
February	4.48	[1]1.45	5.93	.03	2.45	1.88	4.36	1.57	....
March	2.61	.92	3.53	0	3.55	2.11	5.66	....	2.13
April	1.84	.76	2.60	0	4.37	.80	5.17	....	2.57
May	6.27	.52	6.79	.02	4.49	.42	4.93	1.86	....
June	7.20	.33	7.53	.05	6.72	1.49	8.26	....	.73
July	5.81	.33	6.14	.02	6.21	.86	7.09	....	.95
August	2.67	.67	3.34	.01	4.70	.24	4.95	....	1.61
September	.99	.90	1.89	0	3.12	.10	3.22	....	1.33
October	4.62	.77	5.39	.01	2.50	.02	2.53	2.86	....
November	2.66	.83	3.49	0	1.88	.09	1.97	1.52	....
December	2.77	[1]1.32	4.09	0	[1]1.92	.67	2.59	1.50	....
Total	42.98	10.56	53.54	.14	44.31	9.80	54.25	9.31	10.02
Percent of total accretion or depletion	80.28	19.72	100.00	.26	81.68	18.06	100.00	....	....
1947—Brome-alfalfa:									
January	5.39	1.49	6.88	0	2.08	3.26	5.34	1.54	....
February	1.11	[1]2.40	3.51	0	[1]2.79	1.93	4.72	....	1.21
March	2.45	[1]1.65	4.10	.10	[1]3.01	1.01	4.12	....	.02
April	4.47	.86	5.33	0	3.65	1.65	5.30	.03	....

See footnote at end of table.

TABLE 5.—*Monthly summary of the accretion, depletion, and storage of soil water as determined by the weighing monolith lysimeter Y101D, 1944–49*—Continued

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
1947—Brome-alfalfa—Continued	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
May	6.49	0.85	7.34	0.03	4.08	3.10	7.21	0.13	....
June	5.61	.51	6.12	.02	5.98	2.85	8.85	....	2.73
July	2.78	.65	3.43	0	5.76	.73	6.49	....	3.06
August	3.60	.66	4.26	.01	4.28	.28	4.57	....	.31
September	3.10	.69	3.79	0	4.96	.04	5.00	....	1.21
October	.94	.86	1.80	0	2.84	0	2.84	....	1.04
November	2.32	.73	3.05	0	.95	0	.95	2.10	....
December	1.19	.81	2.00	0	.89	0	.89	1.11	....
Total	39.45	12.16	51.61	.16	41.27	14.85	56.28	4.91	9.58
Percent of total accretion or depletion	76.44	23.56	100.00	.28	73.33	26.39	100.00	....	....
1948—Brome-alfalfa:									
January	2.85	[1]1.67	4.52	0	[1]1.74	0	1.74	2.78	....
February	3.49	1.46	4.95	0	2.32	.66	2.98	1.97	....
March	4.76	1.33	6.09	.01	3.45	1.59	5.05	1.04	....
April	4.95	.57	5.52	.01	4.66	3.26	7.93	....	2.41
May	3.25	.26	3.51	0	5.63	.08	5.71	....	2.20
June	3.09	.22	3.31	.01	4.30	.01	4.32	....	1.01
July	3.56	.37	3.93	0	5.89	0	5.89	....	1.96
August	1.04	.55	1.59	0	4.70	.01	4.71	....	3.12
September	3.15	.38	3.53	0	3.04	0	3.04	.49	....
October	2.83	.75	3.58	0	2.63	0	2.63	.95	....

November	3.22	.79	4.01	0	2.14	0	2.14	1.87	....
December	2.35	[1]1.23	3.58	0	[1]1.62	0	1.62	1.96	....
Total	38.54	9.58	48.12	.03	42.12	5.61	47.76	11.06	10.70
Percent of total accretion or depletion	80.09	19.91	100.00	.06	88.19	11.75	100.00	....	....
1949—Brome-alfalfa:									
January	5.40	[1]1.08	6.48	0	[1]1.61	0.69	2.30	4.18	....
February	2.90	[1]1.34	4.24	0	[1]2.06	1.15	3.21	1.03	....
March	4.17	1.41	5.58	0	3.18	1.72	4.90	.68	....
April	3.04	.89	3.93	0	4.81	1.38	6.19	....	2.26
May	2.60	.35	2.95	.01	6.84	.60	7.45	....	4.50
June	3.43	.59	4.02	.01	6.08	.04	6.13	....	2.11
July	8.24	.37	8.61	.02	6.89	0	6.91	1.70	....
August	2.74	.71	3.45	.01	5.34	0	5.35	....	1.90
September	3.38	.74	4.12	.01	4.26	0	4.27	....	.15
October	1.01	.80	1.81	0	3.47	0	3.47	....	1.66
November	1.49	.91	2.40	0	1.83	0	1.83	.57	....
December	2.81	1.54	4.35	0	1.72	0	1.72	2.63	....
Total	41.21	10.73	51.94	.06	48.09	5.58	53.73	10.79	12.58
Percent of total accretion or depletion	79.34	20.66	100.00	.12	89.50	10.38	100.00	....	....

[1]Abnormally high values due to drifting snow.

TABLE 6.—*Monthly summary of the accretion, depletion and storage of soil water as determined by the weighing monolith lysimeter Y102C, 1944–49*

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1944—Meadow:									
January	1 13	1.10	2 23	0	1 52	0	1.52	0.71	....
February	1 97	66	2 63	.02	1.28	.01	1.31	1.32	....
March	6 98	39	7 37	.02	2 01	3.46	5.49	1.88	....
April	4 30	.32	4 62	.01	2.28	3.22	5.51	....	0.89
May	2 49	11	2 60	0	4 53	.50	5.03	....	2 43
June	3 80	12	3 92	.05	4.52	.10	4.67	....	.75
July	2 72	.20	2 92	.06	4.25	.02	4.33	....	1.41
August	4 72	19	4 91	.16	4 38	0	4.54	.37	....
September	2 07	.43	2 50	.04	3 16	0	3.20	....	.70
October	1 90	.76	2.66	.01	2.26	0	2.27	.39	....
November	1 48	.81	2.29	0	1.69	0	1.69	.60	....
December	4 55	[1]1.44	5 99	.06	[1]2.61	.02	2.69	3.30	....
Total	38 11	6.53	44 64	.43	34 49	7 33	42.25	8.57	6.18
Percent of total accretion or depletion	85 37	14 63	100 00	1.02	81.63	17.35	100.00	....	....
1945—Corn:									
January	1.93	[1]2.23	4.16	0.08	[1]2.15	0.26	2.49	1.67	....
February	3.10	[1]1.82	4.92	.01	[1]2.64	2.22	4.87	.05	....
March	9.03	.80	9.83	.19	2.79	7.74	10.72	....	0.89
April	4.88	.54	5.42	.05	3.48	1.82	5.35	.07	....
May	5.32	.66	5.98	.20	4.85	1.83	6.88	....	.90
June	4.34	.57	4.91	1.09	3.97	.34	5.40	....	.49

July	2.88	.22	3.10	.08	4.72	.13	4.93	....	1.83
August	1.23	.47	1.70	.05	4.18	.04	4.27	....	2.57
September	9.66	.44	10.10	2.03	3.40	0	5.43	4.79	....
October	2.79	.91	3.70	.39	3.24	.25	3.88	....	.18
November	3.85	.99	4.84	.05	2.32	.67	3.04	1.80	....
December	2.40	[1]1.13	3.53	.40	[1]1.87	.93	3.20	.33	....
Total	51.41	10.78	62.19	4.62	39.61	16.23	60.46	8.71	6.86
Percent of total accretion or depletion	82.67	17.33	100.00	7.64	65.51	26.85	100.00	....	....
1946—Wheat:									
January	1.09	[1]1.58	2.67	0.05	[1]2.44	1.08	3.57	....	0.90
February	4.63	1.16	5.79	.11	[1]2.32	2.46	4.89	0.90	....
March	2.62	1.05	3.67	.01	3.84	1.66	5.51	....	1.84
April	1.87	.68	2.55	0	5.11	.24	5.35	....	2.80
May	5.98	.36	6.34	.07	5.20	.08	5.35	.99	....
June	6.72	.17	6.89	.02	5.63	.07	5.72	1.17	....
July	5.33	.37	5.70	.04	5.59	.10	5.73	....	.03
August	2.40	.52	2.92	0	5.21	.12	5.33	....	2.41
September	.88	.77	1.65	0	3.22	.02	3.24	....	1.59
October	4.38	.89	5.27	.02	2.29	.03	2.34	2.93	....
November	2.74	1.11	3.85	.01	2.18	.04	2.23	1.62	....
December	2.83	[1]1.26	4.09	.01	[1]2.06	.15	2.22	1.87	....
Total	41.47	9.92	51.39	.34	45.09	6.05	51.48	9.48	9.57
Percent of total accretion or depletion	80.70	19.30	100.00	.66	87.59	11.75	100.00	....	....
1947—Meadow:									
January	5.35	[1]1.49	6.84	0.02	[1]2.03	4.16	6.21	0.63	....
February	1.15	[1]1.77	2.92	.06	[1]2.51	1.16	3.73	....	0.81
March	2.33	1.17	3.50	.11	2.76	.42	3.29	.21	....
April	4.28	.94	5.22	.01	3.13	2.01	5.15	.07	....

See footnote at end of table.

TABLE 6.—*Monthly summary of the accretion, depletion and storage of soil water as determined by the weighing monolith lysimeter Y102C, 1944–49*—Continued

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
1947—Meadow—Continued	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
May	6.43	.74	7.17	.03	4.64	3.00	7.67	....	.50
June	5.65	.44	6.09	.04	6.62	1.46	8.12	....	2.03
July	2.84	.45	3.29	.01	5.81	.08	5.90	....	2.61
August	3.76	.73	4.49	.01	4.78	.02	4.81	....	.32
September	3.13	.50	3.63	0	5.42	.01	5.43	....	1.80
October	1.04	.80	1.84	0	3.37	0	3.37	....	1.53
November	2.67	1.03	3.70	0	1.76	.01	1.77	1.93	....
December	1.49	1.22	2.71	0	1.69	.01	1.70	1.01	....
Total	40.12	11.28	51.40	.29	44.52	12.34	57.15	3.85	9.60
Percent of total accretion or depletion	78.05	21.95	100.00	.51	77.90	21.59	100.00	....	....
1948—Meadow:									
January	3.41	1.58	4.99	0	1.94	0.01	1.95	3.04	....
February	3.14	2.10	5.24	...	2.54	.14	2.69	2.55	....
March	4.80	1.34	6.14	.08	3.00	2.33	5.41	.73	....
April	5.17	.88	6.05	.02	4.35	3.88	8.25	....	2.20
May	3.65	.37	4.02	0	7.05	.10	7.15	....	3.13
June	5.05	.26	5.31	.01	7.02	.01	7.04	....	1.73
July	3.57	.36	3.93	.01	6.09	.01	6.11	....	2.18
August	1.12	.83	1.95	0	3.93	0	3.93	....	1.98
September	3.74	.63	4.37	.01	3.66	0	3.67	.70	....
October	2.85	.84	3.69	.01	2.77	.01	2.79	.90	....

November	3.23	1.01	4.24	0	2.26	.01	2.27	1.97	....
December	2.31	1.48	3.79	0	1.91	.01	1.92	1.87	....
Total	42.04	11.68	53.72	.15	46.52	6.51	53.18	11.76	11.22
Percent of total accretion or depletion	78.26	21.74	100.00	.28	87.48	12.24	100.00	....	....
1949—Corn:									
January	5.54	1.19	6.73	0.01	1.75	0.14	1.90	4.83	....
February	2.85	1.19	4.04	.01	2.09	1.35	3.45	.59	....
March	3.89	1.34	5.23	.01	2.90	2.02	4.93	.30	....
April	2.93	.83	3.76	.01	4.02	.94	4.97	....	1.21
May	3.01	1.17	4.18	.06	4.07	.46	4.59	....	.41
June	3.40	.78	4.18	.05	5.19	.32	5.56	....	1.38
July	6.71	.33	7.04	.16	7.54	.18	7.88	....	.84
August	2.68	.69	3.37	0	5.53	.06	5.59	....	2.22
September	3.45	.90	4.35	.01	3.13	0	3.14	1.21	....
October	1.03	1.19	2.22	0	2.81	.01	2.82	....	.60
November	1.55	.97	2.52	0	2.28	.02	2.30	.22	....
December	2.94	1.19	4.13	0	1.96	0	1.96	2.17	....
Total	39.98	11.77	51.75	.32	43.27	5.50	49.09	9.32	6.66
Percent of total accretion or depletion	77.26	22.74	100.00	.65	88.14	11.21	100.00	....	....

[1]Abnormally high values due largely to drifting of snow.

TABLE 7.—*Monthly summary of the accretion, depletion, and storage of soil water as determined by the weighing monolith lysimeter Y103A, 1944–49*

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1944—Meadow:									
January	1.15	0.73	1.88	0	1.14	0.04	1.18	0.70	....
February	2.14	.88	3.02	0	1.88	.25	2.13	.89	....
March	6.10	.62	6.72	0	3.28	2.92	6.20	.52	....
April	3.83	.49	4.32	0	3.05	1.67	4.72	....	0.40
May	2.40	.17	2.57	0	3.97	.07	4.04	....	1.47
June	3.15	.17	3.32	.01	5.35	.04	5.40	....	2.08
July	2.46	.07	2.53	.01	4.68	.02	4.71	....	2.18
August	4.39	.07	4.46	.02	4.27	.02	4.31	.15	....
September	1.84	.20	2.04	.01	2.89	.01	2.91	....	.87
October	1.81	.45	2.26	0	1.70	.01	1.71	.55	....
November	1.25	.39	1.64	0	1.01	0	1.01	.63	....
December	4.54	[1]1.56	6.10	.01	[1]2.95	0	2.96	3.14	....
Total	35.06	5.80	40.86	.06	36.17	5.05	41.28	6.58	7.00
Percent of total accretion or depletion	85.81	14.19	100.00	.15	87.62	12.23	100.00	....	....
1945—Corn:									
January	2.04	[1]2.11	4.15	0.04	[1]2.70	0	2.74	1.41	....
February	2.66	[1]1.53	4.19	.01	[1]2.36	1.37	3.74	.45	....
March	8.11	.56	8.67	.07	2.79	5.47	8.33	.34	....
April	4.89	.26	5.15	0	3.72	1.37	5.09	.06	....
May	4.82	.29	5.11	.01	5.25	.78	6.04	....	0.93
June	4.37	.42	4.79	.24	4.53	.06	4.83	....	.04

July	2.71	.26	2.97	.02	5.93	.02	6.02	....	3.05
August	1.04	.38	1.42	0	4.59	.01	4.60	....	3.18
September	9.42	.41	9.83	.01	2.69	.55	3.25	6.58	....
October	2.78	.76	3.54	.01	3.21	.43	3.65	....	.11
November	3.61	.67	4.28	0	2.21	.76	2.97	1.31	....
December	2.15	.82	2.97	.01	1.93	.18	2.12	.85	....
Total	48.60	8.47	57.07	.42	41.96	11.00	53.38	11.00	7.31
Percent of total accretion or depletion	85.16	14.84	100.00	.78	78.61	20.61	100.00	....	....
1946—Wheat:									
January	0.89	[1]1.35	2.24	0	[1]2.23	0.80	3.03	....	0.79
February	4.11	[1].96	5.07	.01	[1]2.34	2.19	4.54	0.53	....
March	2.46	.82	3.28	0	3.65	1.03	4.68	....	1.40
April	1.59	.40	1.99	0	4.53	.06	4.59	....	2.60
May	5.92	.33	6.25	0	5.32	.03	5.35	.90	....
June	7.16	.29	7.45	.01	6.26	.50	6.77	.68	....
July	5.16	.38	5.54	.01	6.77	.04	6.82	....	1.28
August	2.47	.52	2.99	0	5.61	.02	5.63	....	2.64
September	.90	.85	1.75	0	3.43	.01	3.44	....	1.69
October	4.42	.86	5.28	.01	2.53	.01	2.55	2.73	....
November	2.77	.75	3.52	0	1.66	.01	1.67	1.85	....
December	2.80	.82	3.62	0	1.62	.28	1.90	1.72	....
Total	40.65	8.33	48.98	.04	45.95	4.98	50.97	8.41	10.40
Percent of total accretion or depletion	82.99	17.01	100.00	.08	90.15	9.77	100.00	....	....
1947—Meadow:									
January	5.28	[1]1.05	6.33	0	[1]2.07	3.32	5.39	0.94	....
February	1.12	[1]1.53	2.65	.02	[1]2.19	.28	2.49	.16	....
March	2.30	1.07	3.37	.03	2.93	.58	3.54	....	0.17
April	4.43	.82	5.25	0	3.20	1.90	5.10	.15	....

See footnote at end of table.

TABLE 7.—*Monthly summary of the accretion, depletion and storage of soil water as determined by the weighing monolith lysimeter Y103A, 1944–49*—Continued

Year, month, and crop grown	Accretion			Depletion				Storage in 8-foot profile	
	Precipitation	Condensation	Total	Runoff	Evapotranspiration	Percolation	Total	Net increase	Net decrease
1947—Meadow—Continued	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
May	6.44	.65	7.09	.01	4.76	2.66	7.43	....	.34
June	5.79	.45	6.24	.02	6.90	1.11	8.03	....	1.79
July	3.03	.45	3.48	.01	5.60	.05	5.66	....	2.18
August	3.70	.63	4.33	.02	4.69	.03	4.74	....	.41
September	3.18	.45	3.63	0	5.13	.02	5.15	....	1.52
October	1.21	.76	1.97	0	3.07	.01	3.08	....	1.11
November	2.74	.76	3.50	0	1.49	.01	1.50	2.00	....
December	1.52	.99	2.51	0	1.37	0	1.37	1.14	....
Total	40.74	9.61	50.35	.11	43.40	9.97	53.48	4.39	7.52
Percent of total accretion or depletion	80.91	19.09	100.00	.21	81.15	18.64	100.00	....	....
1948—Meadow:									
January	3.12	[1]1.27	4.39	0	[1]1.58	0.01	1.59	2.80	....
February	3.23	[1]1.43	4.66	0	[1]2.31	1.54	3.85	.81	....
March	4.96	1.26	6.22	.02	3.24	2.19	5.45	.77	....
April	4.89	.54	5.43	.02	4.57	2.42	7.01	....	1.58
May	3.81	.34	4.15	.01	6.88	.10	6.99	....	2.84
June	5.39	.31	5.70	.02	7.57	.02	7.61	....	1.91
July	3.56	.44	4.00	.01	6.09	.01	6.11	....	2.11
August	.99	.51	1.50	0	3.65	.01	3.66	....	2.16
September	3.91	.45	4.36	.01	3.28	0	3.29	1.07	....
October	2.72	.63	3.35	.01	2.34	0	2.35	1.00	....

November	3.00	.83	3.83	0	1.71	0	1.71	2.12	
December	2.37	1.04	3.41	0	1.45	0	1.45	1.96	....
Total	41.95	9.05	51.00	.10	44.67	6.30	51.07	10.53	10.60
Percent of total accretion or depletion	82.25	17.75	100.00	.19	87.47	12.34	100.00	....	....
1949—Corn:									
January	5.49	[1]1.05	6.54	0	1.84	1.96	3.80	2.74	....
February	2.87	[1]1.15	4.02	.01	2.20	1.59	3.80	.22	....
March	3.95	1.41	5.36	0	3.30	1.42	4.72	.64	....
April	2.98	.64	3.62	0	3.88	.37	4.25	....	0.63
May	3.04	.85	3.89	.02	4.62	.14	4.78	....	.89
June	3.40	.69	4.09	.01	5.92	.01	5.94	....	1.85
July	8.90	.28	9.18	.19	8.83	.05	9.07	.11	....
August	2.75	.70	3.45	.01	5.82	0	5.83	....	2.38
September	3.43	1.13	4.56	0	3.25	0	3.25	1.31	....
October	1.04	1.27	2.31	0	2.68	0	2.68	....	.37
November	1.59	.97	2.56	0	2.10	0	2.10	.46	....
December	3.01	1.70	4.71	.01	2.35	0	2.36	2.35	....
Total	42.45	11.84	54.29	.25	46.79	5.54	52.58	7.83	6 12
Percent of total accretion or depletion	78.19	21.81	100.00	.47	88.99	10.54	100.00	....	....

[1]Abnormally high values due to drifting of snow.

DEPLETION

Of the three depletion factors—evapo-transpiration, percolation, and runoff—annual evapo-transpiration was the most important and annual runoff the least. The monthly evapo-transpiration in many of the summer months was greater than the corresponding rainfall. Often in the months of March and April, percolation values exceeded those of evapo-transpiration. ET values given herein do not represent the daily, monthly, or annual rate of soil-moisture depletion. If such data are desired, ET — CA values should be used.

Annual evapo-transpiration values ranged from 31.22 to 48.09 inches on Y101; from 34.49 to 46.52 inches on Y102; and from 36.17 to 45.95 inches on Y103. In the dry year 1944, evapo-transpiration was much lower than in other years of high precipitation. It constituted about 80 percent of the total annual depletion on the Muskingum soils and about 85 percent on the Keene silt loam, a heavier soil. As percolation in the Keene soil was less, more soil water was available for evapo-transpiration. More water was removed from the soil by evapo-transpiration in the months of May, June, July, and August than in other months. Higher temperatures and longer days furnished better opportunities for this process.

Conditions favorable to vegetative growth obviously increased evapo-transpiration. The stage of growth of a crop as well as the type of crop itself, also greatly influenced evapo-transpiration. For example, in the corn year 1949, the evapo-transpiration values for May were 2 to 3 inches lower than for meadow in May 1948. The May rainfall was nearly the same in both years. The small corn plants removed very little water by transpiration. Water loss was mainly in the form of evaporation. Evaporation from the bare soil of cornland in May was much less than the May evapo-transpiration from meadow. Both corn and wheat crops, as they approached maturity, consumed large quantities of water.

The net loss to soil moisture is properly represented by evapo-transpiration minus condensation-absorption. This is referred to as ET — CA, curves of which for various lysimeter crops are shown in figures 9 to 14. No effort has been made to separate evapo-transpiration into its component parts since information on evaporation and transpiration separately is considered to be less useful in hydrologic studies than the combined value.

SOIL-MOISTURE STORAGE CHANGES

The weighing lysimeter, by automatically recording the weights at 10-minute intervals, indicated for any period of the day whether soil moisture was accumulating or being depleted. As shown in tables 5, 6, and 7, the lysimeters gained weight through increases in soil moisture in some seasons, and lost moisture more rapidly than it was received in other seasons. The monthly values in May, June, July, August, and often April and September generally showed losses of moisture in storage. When precipitation for any of these months was unusually high, a gain in storage resulted. The other months generally showed a gain in storage unless precipitation was well below normal.

The net annual storage values varied from year to year. In the wet year of 1945 there was a net increase in storage for the year. High monthly rainfall did not always result in an increase of moisture storage. For example, in March 1945 more than 9 inches

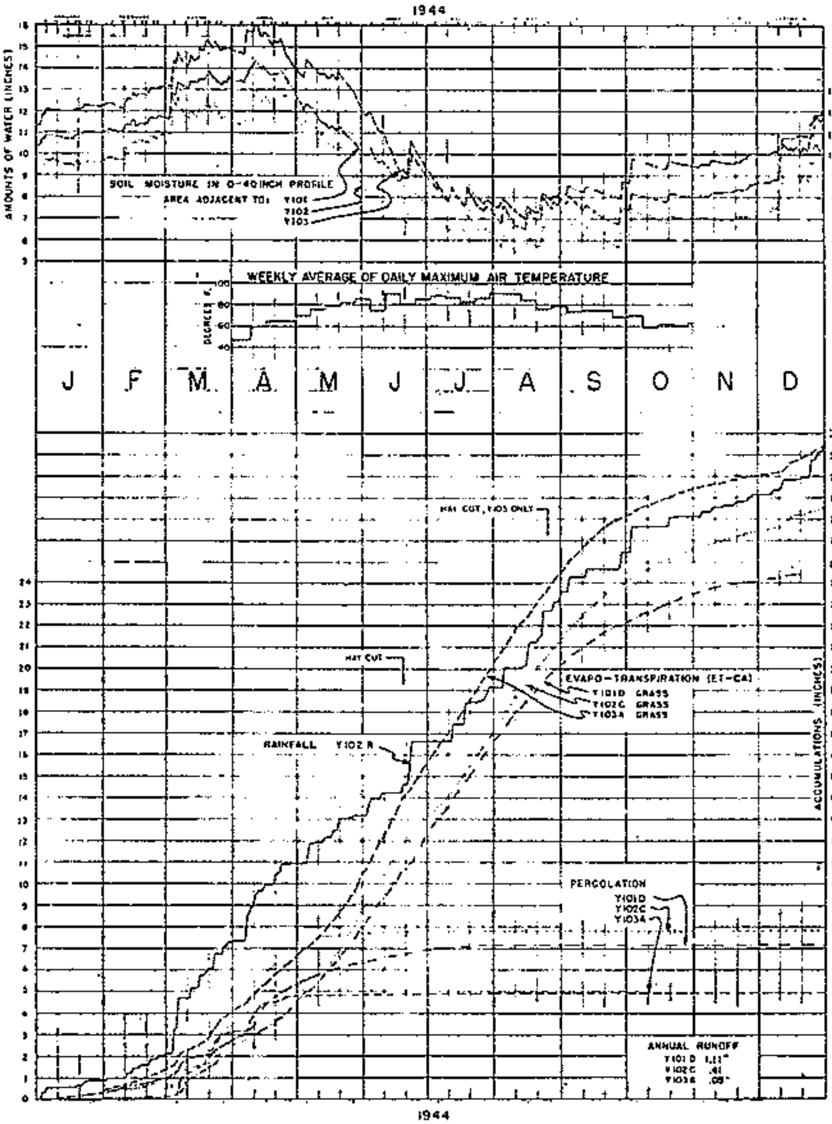

FIGURE 9.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1944.

of rain fell on the very wet soil of Y102C, yet the monthly net storage change was a decrease of 0.89 inch, due principally to excessive percolation.

In September of the same year over 9 inches of rain fell on the same lysimeter, but the soil was dry. There was no percolation. Although runoff of 2.03 inches reduced the accretion value of the

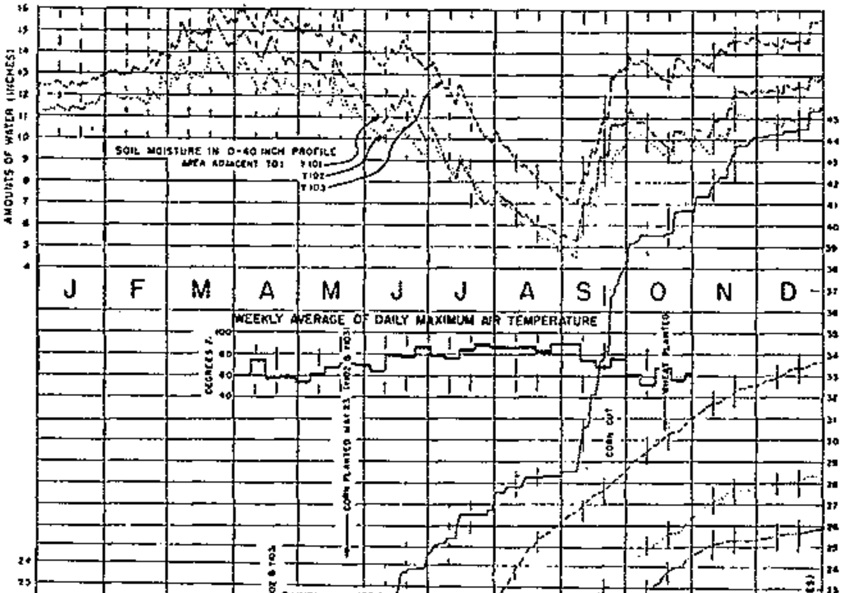

FIGURE 10.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1945.

rain, the net storage increased 4.79 inches. On lysimeter Y103A, on the other hand, because there was practically no runoff the storage change was greater, amounting to 6.58 inches. Figure 10 shows the daily changes in storage of the 0- to 40-inch profile, rainfall, runoff, and ET — CA for September 1945.

The daily fluctuations of moisture in the upper 40-inch layer of soil are represented by graphs in figures 9 to 14. This layer in-

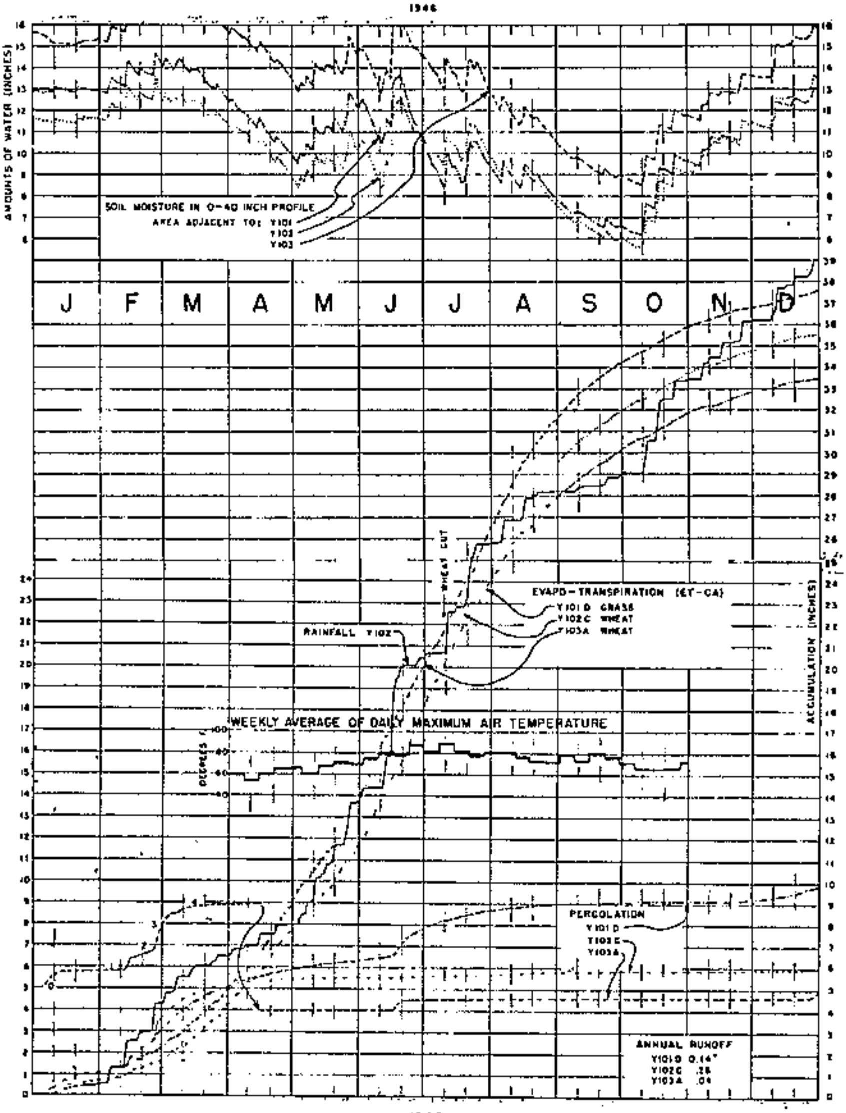

FIGURE 11.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1946.

cluded practically all the roots of plants grown in a crop-rotation system. Daily fluctuations of soil moisture differed with depth of soil (fig. 15). Most of the water changes occurred in the top 7 inches of soil. Accretions and depletions took place most rapidly in this layer, the fluctuations becoming less violent with increasing depth of soil. The curves of daily July and August soil-moisture fluctuations for the years 1946-49 (fig. 15) indicate that pores in the 0- to

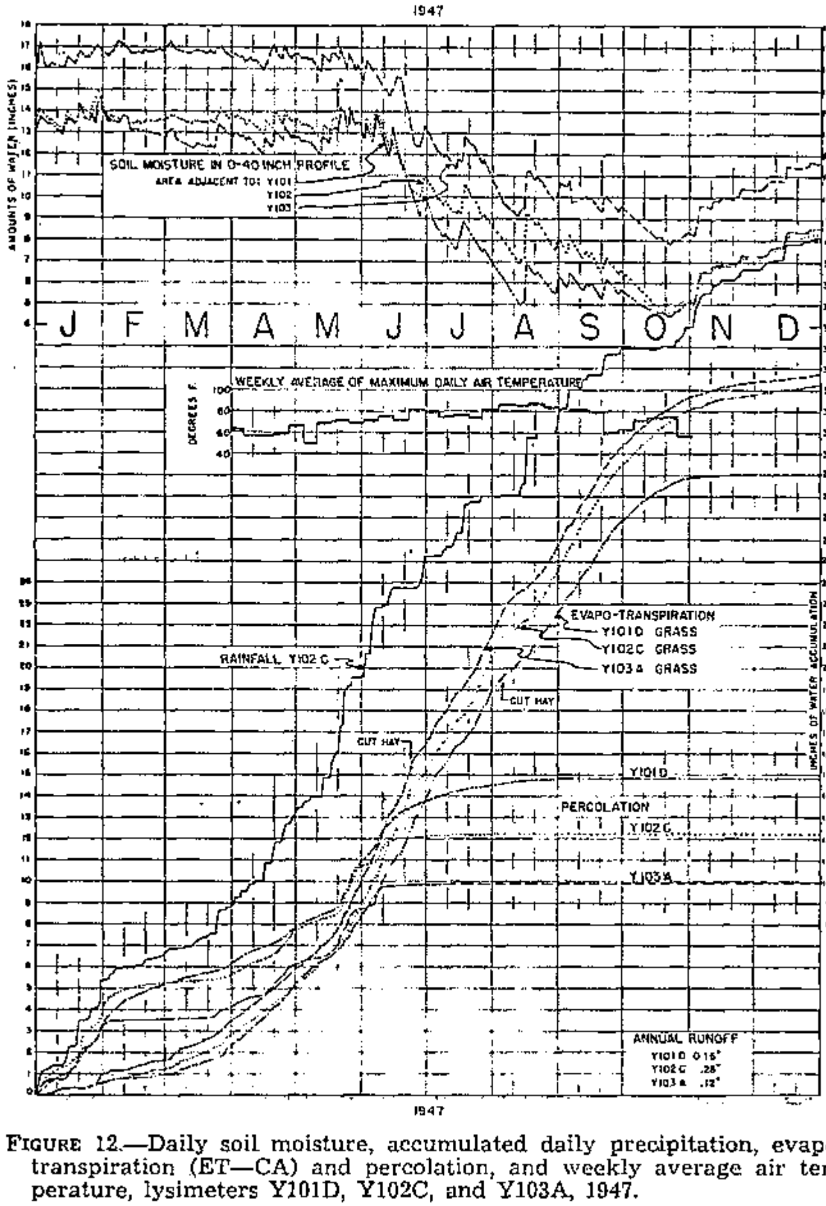

FIGURE 12.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1947.

7-inch profile were used many times to take up storm rainfall. The pores at soil depths below 7 inches were used only a few times. For example, on August 16, 1946, moisture in the 0- to 7-inch profile increased greatly, approaching saturation. Moisture in the 7- to 14-inch depth increased only slightly. There was no apparent increase in moisture below 14 inches.

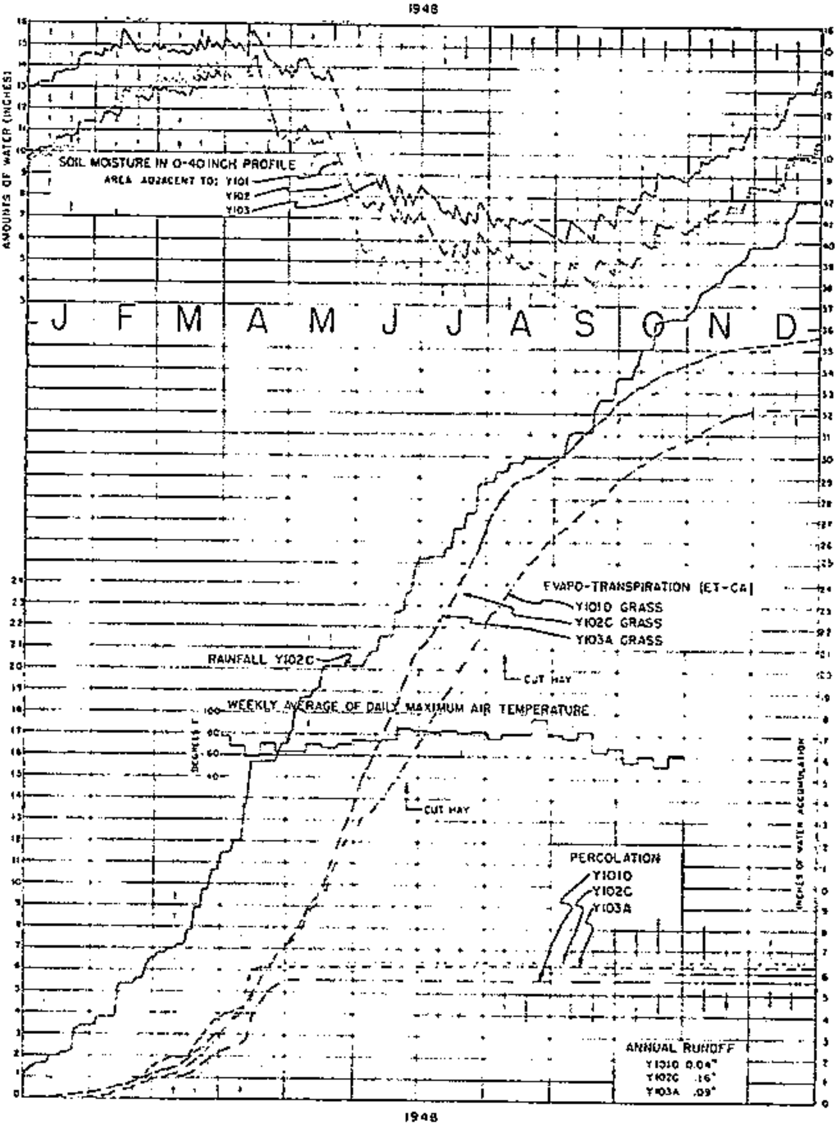

FIGURE 13.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1948.

The Lysimeter as a Rain Gage

It has long been desired to improve the accuracy of records of the amount of rainfall reaching the earth (including vegetation and ground surface). The U. S. Weather Bureau has used a stand-

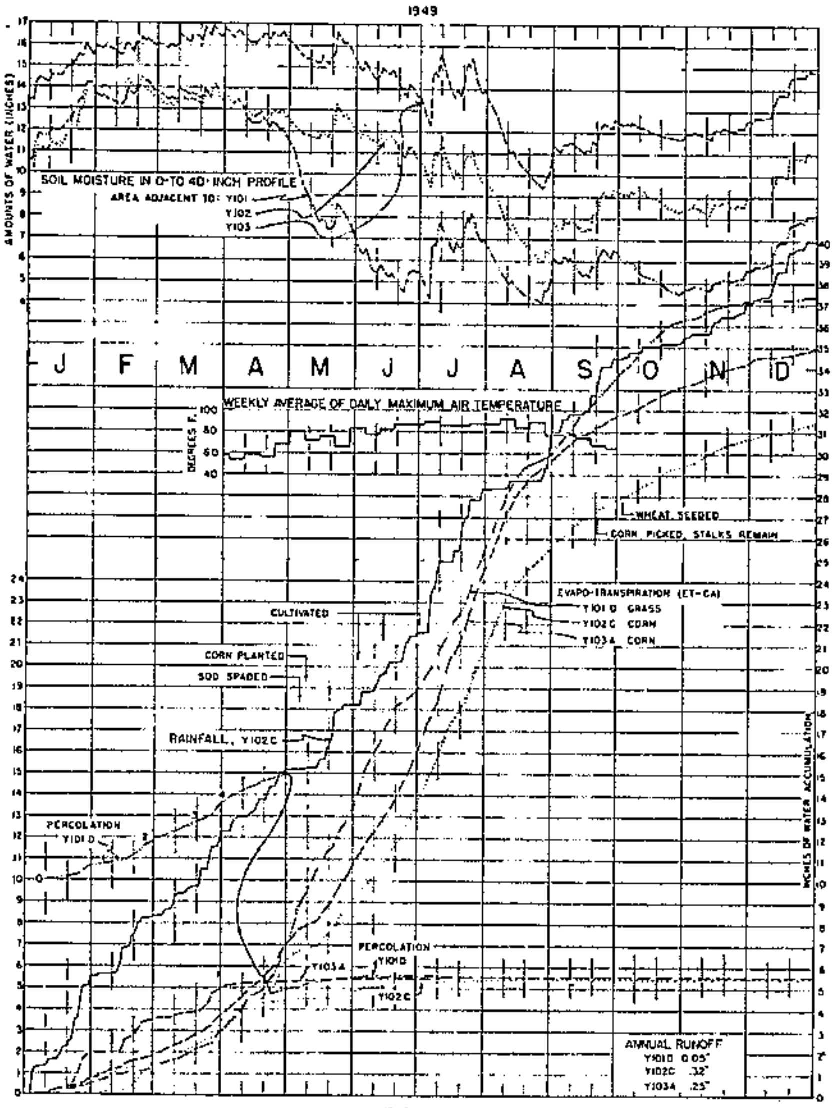

Figure 14.—Daily soil moisture, accumulated daily precipitation, evapotranspiration (ET—CA) and percolation, and weekly average air temperature, lysimeters Y101D, Y102C, and Y103A, 1949.

ard sampling area of 50 square inches (8-inch diameter) for its gages. The weighing lysimeter provided a means of measuring rainfall on an area of 12,540 square inches (6.22 × 14-foot rectangle).

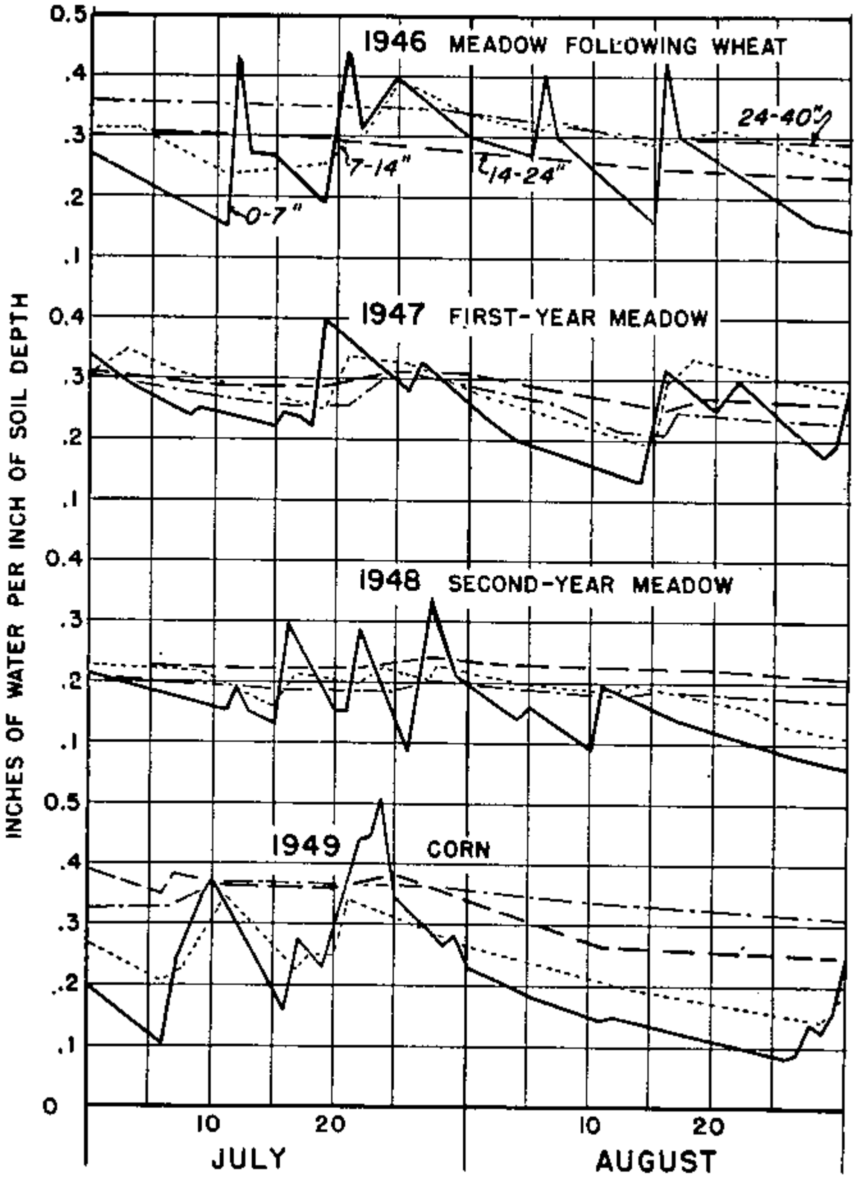

FIGURE 15.—Typical July and August soil-moisture fluctuations at different depths and for different crops, 1946-49.

The rainfall during any given rainfall period was calculated from the weighing-lysimeter records by means of the formula:

$Ra = 0.0022W + Per + Ro$, in which

Ra = rainfall on lysimeter, in inches;

W = weight change of lysimeter for the period, in pounds;

$0.0022W$ = weight change of lysimeter for the period, in inches of water;

Per = percolation water for period of rain drained from bottom of lysimeter, in inches of depth; and

Ro = runoff water for period of rain from surface of lysimeter, in inches of depth.

The period of rainfall was determined by noting the time of beginning and end of the rainfall period as shown by the recording rain gage adjacent to the lysimeter.

Monthly and annual values of precipitation (snow and rain) during a 6-year period, 1944-49, as obtained by means of the lysimeters, were compared with those from the Fergusson rain gage at two locations, Y102 and Y103 (tables 8 and 9). The recording-gage data were not the values shown on the chart but are actual measurements of depth obtained by pouring the captured water into a calibrated measuring tube.

The monthly values of precipitation obtained by the two methods had a wide range of differences. Basing comparisons on the lysimeter records as the more accurate, the Fergusson gage data with few exceptions were found to be either greater or less than the lysimeter data. At Y102 (table 8), the monthly rain catch in the Fergusson gage was as much as 1.59 inches less than that on the lysimeter. At the other extreme for 1 month, the Fergusson gage caught 0.85 inch more water. Out of 60 months, there were 56 when the Fergusson catch was less than that shown by the lysimeter. The average monthly difference for the 5-year record was 0.34 inch.

At Y103A (table 9), the maximum difference between the two records was — 1.59 inches. The other extreme was + 0.15 inch. Out of 72 months, there were 69 when the Fergusson catch was less than that for the lysimeter. The average monthly difference for the 6-year period was 0.32 inch.

It is apparent that the greatest differences occurred in the months of January, February, and March. The records for the first two were complicated by snow. It is generally agreed that the unshielded Fergusson gage is not at all satisfactory for snowfall measurements. Drifting snow often makes the lysimeter precipitation records unreliable. In March, a month of very little snow, high winds may be expected to affect the accuracy of the Fergusson gage; but the March lysimeter data for the period covered, as well as the data for any other month without snow, are considered satisfactory.

A clearer concept of the differences was obtained by tabulating the daily rainfall values from the Fergusson gages and lysimeters in four rainfall groups, as follows: 0.1 to 0.3 inch; 0.3 to 0.6 inch;

0.6 to 1.0 inch; and over 1.0 inch. Days of snow and those of less than 0.1 inch of rain were not included. A sample of the grouping for Y102C in 1946 (table 10) indicates the relative accuracy of the two methods of measuring rainfall and provides a basis for seasonal as well as annual comparisons. The greatest number of days falls in the low-rainfall groups—less than 0.6 inch. Of 69 rain days tabulated, 50 were in these groups. Of this 50, there were 9 days in which the rainfall catch under both methods was identical, 4 when the Fergusson values were greater, and 37 when the Fergusson values were less. A sample plotting of a similar comparison for Y103A, 1948, appears in figure 16.

Tabulations similar to that for Y102, 1946 (table 10), were made for Y102 for 1947 and 1948, and for Y103 for 1946, 1947, and 1948. Summaries of the data from these tabulations appear in table 11. These show that the Fergusson catch is consistently less than that shown by the lysimeters.

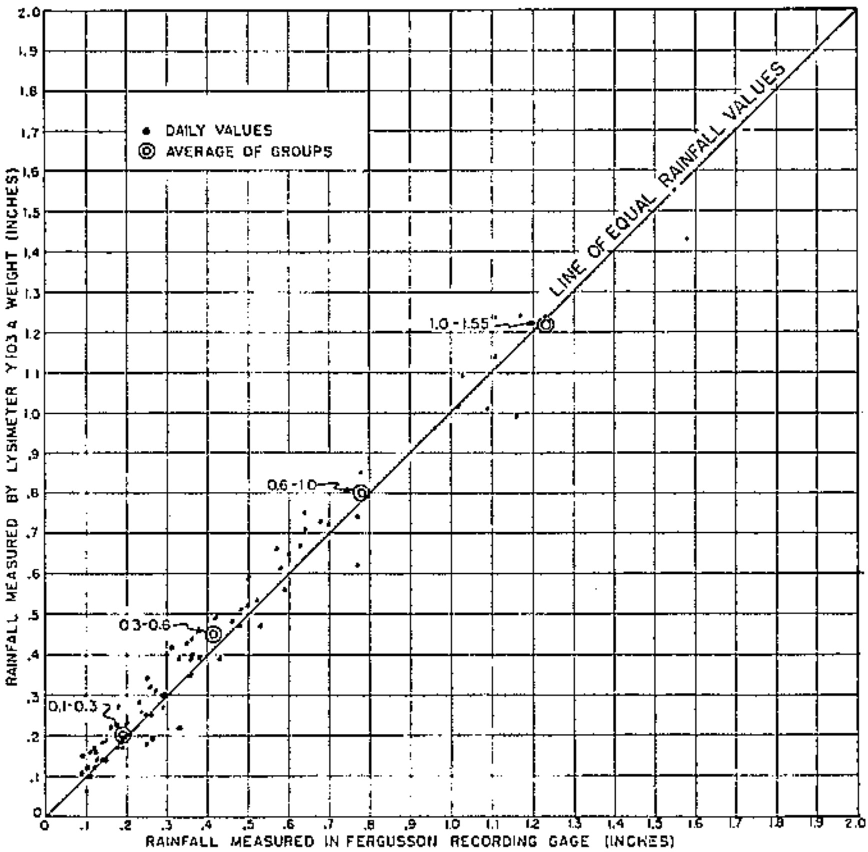

FIGURE 16.—Comparison of rainfall data from Fergusson recording gage and from lysimeter Y103A weight record, 1948.

TABLE 8.—*Monthly precipitation in recording rain gage Y102R and on ground surface of lysimeter Y102C, 1945–49*[1]

Year	Gage	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1945	Recorder	1.04	2.36	8.06	4.40	4.70	3.93	2.72	1.12	9.68	2.63	3.45	1.35	45.49
	Lysimeter	1.63	2.93	9.03	4.88	5.32	4.34	2.85	1.23	9.66	2.74	3.85	2.40	50.86
1946	Recorder	.58	3.72	2.21	1.50	5.53	6.44	5.21	2.40	.68	4.26	2.56	2.32	37.41
	Lysimeter	1.09	4.63	2.61	1.87	5.98	6.72	5.33	2.40	.88	4.38	2.74	2.83	41.46
1947	Recorder	4.84	.36	.74	3.96	6.29	5.72	2.72	3.65	3.02	.97	2.34	1.18	35.79
	Lysimeter	5.35	1.15	2.33	4.28	6.43	5.65	2.84	3.76	3.13	1.04	2.67	1.49	40.12
1948	Recorder	1.91	2.78	4.43	5.04	3.42	4.81	3.49	.92	3.33	2.69	2.83	2.02	37.67
	Lysimeter	3.42	3.14	4.80	5.17	3.65	5.05	3.57	1.12	3.74	2.85	3.23	2.31	42.05
1949	Recorder	4.79	2.61	3.42	2.68	2.86	2.91	7.56	2.57	3.44	.90	1.28	2.42	37.44
	Lysimeter	5.54	2.85	3.89	2.93	3.01	3.40	6.71	2.68	3.45	1.03	1.55	2.94	39.98
Average	Recorder	2.63	2.37	3.77	3.52	4.56	4.76	4.34	2.13	4.03	2.30	2.49	1.86	38.76
	Lysimeter	3.41	2.94	4.53	3.83	4.88	5.03	4.26	2.24	4.17	2.41	2.81	2.39	42.89
Difference:														
Average		−.78	−.57	−.76	−.31	−.32	−.27	+.08	−.11	−.14	−.11	−.32	−.53	−4.13
Extremes		−1.51	−.91	−1.59	−.48	−.62	−.49	−.13	−.20	−.41	−.16	−.40	−1.05	−5.37
		−.51	−.24	−.37	−.13	−.14	+.07	+.85	0	+.02	−.06	−.18	−.29	−2.54
Number of months Fergusson catch greater ... months		0	0	0	0	0	1	1	0	1	0	0	0	0
Number of months Fergusson catch less ... months		5	5	5	5	5	4	4	4	4	5	5	5	5

[1] Rain gage and lysimeter on a 12-percent slope to the east. Prevailing winds from the southwest.

The average differences in daily rainfall range from 0.01 to 0.06 inch. This amount is small when consideration is given to the areal variation of storm rainfall and the area of application for the rainfall data. At this research station the rain gages are as close to the experiments as they are anywhere in the country. Yet, the 8-inch diameter catchment area must be used to represent the rainfall on watersheds 1 to 8 acres in size. Parts of these drainage areas are from 1 to 500 feet away from the gage. Cumulatively, the annual differences in rainfall amounted to more than an inch of rainfall in 5 out of the 6 station-years given in table 11. These values include only rain days of 0.1 inch or more. When the days of less rainfall and all snow days are included, the precipitation differences amounted to more than 4 inches for the same period (tables 8 and 9).

The weighing lysimeters also give a measure of the amount of moisture coming from the atmosphere in the form of condensation, which rain gages cannot measure. The annual total condensation may be more than 5 inches of water. When this amount and the differences in precipitation are added to the rainfall shown by recording rain-gage records, the result is a figure for water acquired which is over 9 inches more than the amount of annual rainfall recorded by rain gage. The larger total represents all the moisture coming to the earth (soil and vegetation) from the atmosphere.

The Lysimeter for Measuring Evapo-Transpiration and Condensation-Absorption

The self-recording mechanism of the weighing lysimeters provided records from which were calculated the moisture transferred from the earth to the atmosphere and that going in the opposite direction. On days of no precipitation, weight increases plus percolation were attributed to condensation and absorption of moisture from the atmosphere. This phenomenon is labeled CA in this report. Also, on days of no precipitation, weight decreases were attributed to evapo-transpiration and percolation. The latter is measured separately, thus a means was provided for evaluating the former. Evapo-transpiration is labeled ET in this report.

ET is a combination of (1) evaporation of moisture from the ground surface, including the surface of vegetation; and (2) transpiration, the removal of water by crops. The two phenomena operate in nature together to deplete soil moisture. The amount of soil-moisture depletion caused by evaporation and transpiration may be compensated in whole or in part by water added to the soil through condensation and absorption. The net soil-moisture depletion resulting from these processes may be conveniently designated ET — CA. For drainage-basin studies involving the hydrologic cycle, ET — CA values should be used instead of ET alone, as explained in a previous section.

TABLE 9.—*Monthly precipitation in recording rain gage Y103R and on ground surface of lysimeter Y103A, 1944–49*[1]

Year	Gage	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1944	Recorder	0.97	1.46	5.04	3.75	2.14	3.04	2.34	4.12	1.73	1.61	0.98	2.42	29.60
	Lysimeter	1.14	2.12	5.34	3.83	2.40	3.14	2.46	4.39	1.81	1.82	1.25	3.46	33.16
1945	Recorder	1.10	2.47	7.99	4.33	4.72	4.03	2.63	1.01	9.29	2.78	3.45	1.56	45.36
	Lysimeter	2.04	2.62	8.11	4.89	4.81	4.37	2.71	1.04	9.42	2.78	3.62	2.15	48.56
1946	Recorder	.59	3.86	2.24	1.46	5.64	6.84	5.23	2.45	.71	4.27	2.59	2.29	38.17
	Lysimeter	.89	4.11	2.46	1.59	5.92	7.15	5.17	2.47	.90	4.42	2.78	2.80	40.66
1947	Recorder	4.99	.37	.71	4.12	6.26	5.75	2.82	3.52	2.93	.98	2.46	1.37	36.28
	Lysimeter	5.28	1.12	2.30	4.43	6.45	5.79	3.03	3.70	3.18	1.21	2.74	1.52	40.75
1948	Recorder	1.76	2.92	4.30	5.04	3.43	4.69	3.12	.97	3.80	2.70	2.84	2.14	37.71
	Lysimeter	3.12	3.23	4.96	4.89	3.81	5.39	3.56	.99	3.91	2.72	3.00	2.37	41.95
1949	Recorder	4.89	2.54	3.36	2.63	2.80	2.96	7.85	2.60	3.22	.93	1.29	2.57	37.64
	Lysimeter	5.49	2.87	3.95	2.98	3.04	3.40	8.90	2.75	3.42	1.04	1.59	3.01	42.44
Average	Recorder	2.39	2.27	3.94	3.56	4.17	4.55	4.00	2.45	3.61	2.21	2.27	2.06	37.46
	Lysimeter	2.99	2.68	4.52	3.77	4.41	4.87	4.31	2.56	3.77	2.33	2.50	2.55	41.26
Difference:														
Average		−.61	−.41	−.58	−.21	−.24	−.32	−.31	−.11	−.16	−.12	−.23	−.49	−3.79
Extremes		−1.36	−.75	−1.59	−.56	−.38	−.70	−1.05	−.27	−.25	−.23	−.30	−1.04	−4.80
		−.17	−.15	−.12	+.15	−.09	−.04	+.06	−.02	−.08	0	−.16	−.15	−2.49
Number of months Fergusson catch greater ... months		0	0	0	1	0	0	1	0	0	0	0	0	0
Number of months Fergusson catch less ... months		6	6	6	5	6	6	5	6	6	5	6	6	6

[1] Rain gage on an east-west ridge. Lysimeter on a 6-percent slope to the south, 30 feet from the rain gage. Prevailing winds from the southwest.

TABLE 10.—*Comparison of rainfall catch as determined by lysimeter Y102C and Fergusson recording gage, by size of rain, 1946*

Period	0.1– to 0.3–inch rains		0.3– to 0.6–inch rains		0.6– to 1.0–inch rains		Rains over 1.0 inch	
	Fergusson gage	Lysimeter Y102C	Fergusson gage	Lysimeter Y102C	Fergusson gage	Lysimeter Y102C	Fergusson gage	Lysimeter Y102C
	Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
January–April	0.20	0.26	0.57	0.61	......	......	1.14	1.35
	.10	.19	.40	.50	......	......	1.25	1.33
	.16	.30	.49	.51	......	......	......	......
	.20	.29	.48	.49	......	......	......	......
	.12	.17	.32	.41	......	......	......	......
	.16	.19	.28	.36	......	......	......	......
	.28	.29	.54	.59	......	......	......	......
	.13	.15	.39	.45	......	......	......	......
May–September	.10	.13	.45	.59	0.72	0.76	.99	1.06
	.18	.18	.54	.51	.71	.70	.95	1.03
	.16	.16	.43	.44	.73	.75	2.77	2.97
	.17	.17	.47	.53	.73	.71	1.94	1.92
	.15	.16	.36	.37	......	......	1.35	1.31
	.20	.19	.41	.43	......	......	1.06	.99
	.15	.19	.63	.59	......	......	......	......
	.23	.23	.39	.42	......	......	......	......
	.15	.16	.36	.41	......	......	......	......
	.14	.14	.47	.47	......	......	......	......
	.11	.13	.52	.52	......	......	......	......
	.27	.33	.30	.33	......	......	......	......
	.12	.13	......	......	......	......	......	......
October–December	.18	.19	.43	.45	.88	.85	1.05	1.00
	.18	.18	.44	.48	.83	.86	.98	1.07
	.27	.26	.45	.47	.67	.72	.98	1.07
	.30	.30	......	......	.70	.68	......	......
	.14	.29	......	......	......	......	......	......
	.15	.17	......	......	......	......	......	......
Days of record....No...	27		23		8		11	
Days of equal catch..........No...	7		2		0		0	
Days Fergusson catch greater...No...	2		2		4		4	
Days Fergusson catch less......No...	18		19		4		7	
Rainfall difference for all days......inches..	–.83		–.81		–.06		–.64	
Average rainfall difference per day.........inches..	–.030		–.035		–.008		–.058	

Total difference for the year = 2.34 inches.

In flood control and soil and water conservation the volume of air space in the soil and the possibility of increasing it are important. The soil pores may be needed to store all or part of the storm rainfall. Not only the volume of air space, but the size and arrangement of pores and other factors govern the capacity of the soil to transmit rainfall; in other words, its permeability rate, including capacity. When the water in pores is replaced by air, oxygen and other gases are made available for plant use. When air replaces water in too many pores, however, crop failure may result because of insufficient moisture.

CONDENSATION-ABSORPTION (CA)

The average daily CA on all three weighing lysimeters is given by months and years for the period 1944-49 in table 12. The greatest average daily CA for any month except for those affected by drifting snow was almost 0.05 inch. Months in which the average daily CA was more than 0.02 inch were March, April, September, October, November, and December. On the basis of a 30-day month the total CA for these months averaged over 0.6 inch of water.

Y102C and Y103A had the same crop treatment. Hence, the CA values for these lysimeters provide a means of evaluating the over-all effect of soil type and topography, uncomplicated by the crop factor. CA values for the slowly permeable soil of Y103A for the period April-November were generally less than those for the well-drained soil of Y102C. The slowly permeable soils of Y103 were wetter than those of Y102 throughout this entire period. Without doubt, this greatly affected CA.

The greater volume of large pores and more total air space in the soil of Y102C may have allowed freer movement of moist air into this soil, resulting in greater CA. Hourly records of soil-moisture changes (figs. 17 to 19 and 21 to 26) show that CA generally occurred about sundown when the ground began to cool. Diurnal cooling of the soil block not only caused condensation of vapor within the soil pores but also contraction of air in the soil pores and the drawing in of air from outside. Total daily condensation resulting from these processes, as computed from vapor pressure, temperature changes, and volume of air in soil pores, was less than 0.01 pound—an amount too small to register on the weighing mechanism of the lysimeter. There was generally very little CA after midnight.

The CA on these two lysimeters may also have been influenced by the topography. Y102C lies on a 12-percent easterly slope about 200 feet from the hilltop. Cool, moist air from the upper area may have flowed downhill across the lysimeter surface in the form of a density current. Such a continuous stream of moist air passing through the vegetation of the lysimeter might have resulted in high CA values. Y103A is located about 30 feet down from the ridge on a 6-percent south slope. There was little opportunity for air drainage at this site.

The effect of crop on the average daily CA is indicated by the records for Y101D and Y102C (table 12). The soil types on these two lysimeters are nearly similar. In the May-September period of 1945 and 1949, Y101D was in grass, Y102C in corn. No consistent CA difference was apparent. Likewise, no significant differences were noticeable for the years when the lysimeters were in wheat and meadow.

TABLE 11.—*Summary of rainfall measured in Fergusson recording gage and on lysimeter ground surface, by storm magnitude, Y102C and Y103A, 1946–48*

Range in rainfall (inches)	Item	Lysimeter Y102C [1]			Lysimeter Y103A [2]		
		1946	1947	1948	1946	1947	1948
0.1 to 0.3	Days of rainfall of 0.1 inch or greater ... number	27	33	27	22	34	27
0.3 to 0.6		23	15	22	18	16	23
0.6 to 1.0		8	3	15	6	12	13
Over 1.0		11	8	9	8	8	8
0.1 to 0.3	Days of equal catch by both gages ... number	7	6	6	3	4	3
0.3 to 0.6		2	2	5	2	2	0
0.6 to 1.0		0	3	1	0	1	1
Over 1.0		0	0	0	1	2	2
0.1 to 0.3	Days with rain catch greater by Fergusson gage than by lysimeter ... number	2	10	3	3	9	9
0.3 to 0.6		2	4	1	4	1	5
0.6 to 1.0		4	[illegible]	3	3	3	3
Over 1.0		4	6	4	4	3	1
0.1 to 0.3	Days with rain catch less by Fergusson gage than by lysimeter ... number	18	17	18	16	21	15
0.3 to 0.6		19	9	16	12	13	18
0.6 to 1.0		4	7	11	3	8	9
Over 1.0		7	2	5	3	3	5
0.1 to 0.3	Amount Fergusson gage catch differed from lysimeter catch ... inch	−.82	−.45	−.52	−.51	−.46	−.28
0.3 to 0.6		−.81	−.20	−.94	−.29	−.66	−.82
0.6 to 1.0		−.06	−.13	−.26	−.14	−.28	−.26
Over 1.0		−.64	+.06	−.12	−.14	+.05	+.06
0.1 to 0.3	Average rainfall difference per day ... inch	−.030	−.014	−.019	−.023	−.013	−.010
0.3 to 6		−.035	−.013	−.043	−.016	−.041	−.036
0.6 to 1.0		−.008	−.010	−.017	−.023	−.023	−.020
Over 1.0		−.058	+.008	−.013	−.017	+.006	+.008
	Total difference for the year ... inches	−2.33	−.72	−1.84	−1.08	−1.35	−1.40

[1] Lysimeter Y102C and Fergusson recording rain gage located on a 12-percent east slope about 200 feet from ridge.

[2] Lysimeter Y103A and Fergusson recording rain gage located on a flat ridge. Slope to the south, 6 percent; to the north, 12 percent.

A detailed study of the daily and hourly CA values for hay meadow revealed that CA values were noticeably different after cutting hay than before. The effect of hay cutting on ET and CA is discussed further on.

The value of CA in conserving soil moisture is described on page 75. The amount of moisture accumulated during the night was small and evaporated completely before noon the next day. ET following heavy dew was about the same as that following little or no dew. Without any dew, soil moisture day by day decreased at a faster rate than for periods of large CA.

EVAPO-TRANSPIRATION (ET)

The average daily ET from all three weighing lysimeters is given by months and years for the period 1944-49 in table 13. As expected, the growing season had the greatest ET. June and July were the months of highest water demand by plants. The 6-year average daily ET for June ranged from 0.179 to 0.203 inch, and the July range of ET values was not materially different. The variation between the 6-year average ET values for the three lysimeters for the different months is small. Average ET values for all lysimeters, however, had a definite trend throughout the year similar to that for air temperature. Average ET for the warm months was from three to four times as much as that for the cooler months. This difference reached a ratio as high as six to one in some years.

Average values of ET provide a reliable basis for estimating the amount and frequency of irrigation requirements for this region. In the month of July, for example, when soil water is used up at an average rate of about 0.18 inch per day, 1.80 inches would be used in 10 days. Almost all of this depletion would occur in the 0- to 14-inch depth. If the following 10-day period should be dry, the moisture in this depth would have almost reached the wilting point. An irrigation application of 1.80 inches of water would delay the wilting period for about 10 days. This calculation is based on the assumption that no moisture would be added to the soil by CA and none would be lost by percolation to depths below the root zone. Actual daily soil-moisture-depletion rates for certain crops exceed this average value for critical periods, as brought out in more detail further on under the section "Water use by crops." Irrigation requirements should, therefore, be established separately for different crops.

Different crops use water at different rates. Data in table 13 show that wheat in May 1946 used about 0.17 inch of water per day. This May rate was exceeded only by that for good legume-grass sod—0.23 inch per day for Y102C in 1948, 0.22 inch for Y103A in 1948, and 0.22 inch for Y101D in 1949. ET in May was lowest from poor sod and cornland. Water removal from soil pores was more rapid when the land was in good sod and wheat than when it was in poor sod or corn. Consequently, poor sod and cornland were less capable of absorbing storm rainfall at this season. In

TABLE 12.—*Average daily condensation and absorption (CA) on lysimeters Y101D, Y102C, and Y103A by months, 1944–49, expressed in inches of water*

Year	Lysimeter[1]	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1944	Y101D	0.016	0.030	0.031	0.015	0.007	0.008	0.007	0.009	0.015	0.021	0.014	[2] 0.060	0.019
	Y102C	.035	.023	.013	.011	.004	.004	.006	.006	.014	.025	.027	[2] .046	.018
	Y103A	.024	.030	.020	.016	.005	.006	.002	.002	.007	.015	.013	[2] .050	.016
1945	Y101D	[2] .138	[2] .120	.028	.017	.015	.012	.016	.018	.015	.020	.029	.036	.039
	Y102C	[2] .072	[2] .065	.026	.018	.021	.019	.007	.015	.015	.029	.033	.036	.030
	Y103A	[2] .068	[2] .055	.018	.009	.009	.014	.008	.012	.014	.025	.032	.026	.064
1946	Y101D	[2] .057	[2] .052	[2] .030	.025	.017	.011	.011	.022	.030	.025	.028	[2] .043	.029
	Y102C	[2] .051	[2] .041	.034	.023	.012	.006	.012	.017	.026	.029	.037	.041	.027
	Y103A	[2] .044	[2] .034	.026	.013	.011	.010	.012	.017	.028	.028	.025	.026	.023
1947	Y101D	[2] .048	[2] .086	[2] .053	.029	.027	.017	.021	.021	.023	.028	.024	.026	.034
	Y102C	[2] .048	[2] .063	.038	.031	.024	.015	.015	.024	.017	.026	.034	.039	.031
	Y103A	[2] .034	[2] .049	.035	.027	.021	.015	.015	.020	.015	.025	.025	.032	.026
1948	Y101D	[2] .054	[2] .050	.043	.019	.008	.007	.012	.018	.013	.024	.026	[2] .040	.026
	Y102C	[2] .051	[2] .072	.043	.029	.012	.009	.012	.027	.021	.027	.034	[2] .048	.032
	Y103A	[2] .041	[2] .050	.041	.018	.011	.010	.014	.016	.015	.020	.028	[2] .034	.025
1949	Y101D	[2] .035	[2] .048	.045	.030	.011	.020	.012	.023	.025	.026	.030	.050	.030
	Y102C	.038	[2] .042	.043	.028	.038	.026	.011	.022	.030	.038	.032	.039	.032
	Y103A	[2] .034	[2] .041	.045	.021	.027	.023	.009	.023	.038	.041	.032	.055	.032
Average 1944–49	Y101D	[2] .058	[2] .064	.038	.023	.014	.013	.013	.019	.020	.024	.025	.042	.029
	Y102C	[2] .049	[2] .051	.033	.023	.019	.013	.011	.019	.021	.029	.033	.042	.029
	Y103A	[2] .041	[2] .043	.031	.017	.016	.013	.010	.015	.020	.026	.026	.037	.025

[1] For cropping history see Appendix A.

[2] Abnormally high values due to drifting of snow.

July and August, however, ET from cornland was very great, especially in 1949, and the rate of soil-moisture depletion was high. The volume of air space in soils of cornland for this period was also high (fig. 14). In August 1949, there was a maximum saturation deficiency of about 11 inches of water for the 40-inch root zone of cornland. The difficulty of using much of this available pore space for storage of storm rainfall has been due to the low infiltration capacity rate characteristic of sealed soil surfaces when the land was used for corn.

Average daily values of ET for the various crops (table 13) show general seasonal trends and differences. The effects on ET of crop maturing, stage of growth, and harvesting are more readily compared by using semimonthly values for ET — CA (figs. 28 to 31) as such data more nearly represent the rate of soil-moisture depletion in areas where CA is significant. These values represent the total ET — CA for both rain and rainless days. For some hydrologic studies ET — CA values for only rainless days may be needed. A knowledge of the rate of net soil-moisture depletion, ET — CA, for rainless days by crops and seasons will assist in estimating soil moisture data for periods following irrigation or rainfall or before rainstorms. Table 14 presents such information compiled from weighing lysimeter Y102C.

HOURLY ET AND CA

Hourly lysimeter weights during periods in which there was no rainfall and little or no percolation revealed periods of gain and loss in moisture. Hourly moisture changes for nine representative 3-day periods of no rainfall in 1946, 1948, and 1949 are shown graphically in the three upper diagrams of figures 17 to 19 and 21 to 26. Weight gains were called CA; weight losses, ET. The selected periods illustrate weight changes in soils under different crop treatments and on days of both large and small CA values. Hourly CA is shown by solid blocks above the zero line; hourly ET by open blocks below the line. The daily totals of CA and ET are shown below each graph of hourly moisture changes—CA (plus values) at the left, ET (minus values) at the right.

The diurnal weight fluctuations shown in these examples are typical for all the years of record. Daytime losses in weight (ET) and evening and night gains in weight (CA) were usual and somewhat regular in their occurrence. Such changes are normal with diurnal variations of sunshine and temperatures.

Figures 17, 18, and 19 show moisture changes for 3 days each in July, September, and October 1946. The vegetal cover on lysimeter Y101D throughout the year was bluegrass and white clover. The cover on Y102C and Y103A was wheat until July 9, and a new clover-alfalfa-timothy meadow thereafter.

The data for July 7, 9, and 10, 1946 (values for July 8 omitted because of rain on that day) show large daily and hourly ET values (fig. 17). On each of these days the vegetation on Y101D used water at a rate greater than 0.02 inch of water per hour for

TABLE 13.—*Average daily evapo-transpiration (ET) from lysimeters Y101D, Y102C, and Y103A by months, 1944–49, expressed in inches of water*

Year	Lysimeter [1]	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
1944	Y101D	0.025	0.053	0.087	0.076	0.120	0.147	0.152	0.123	0.080	0.065	0.034	[2] 0.059	0.085
	Y102C	.049	.044	.065	.076	.146	.151	.137	.141	.105	.073	.056	[2] .084	.094
	Y103A	.037	.065	.104	.102	.128	.178	.151	.138	.096	.055	.034	[2] .095	.099
1945	Y101D	[2] .119	[2] .152	.100	.098	.119	.160	.187	.121	.095	.100	.060	.053	.114
	Y102C	[2] .069	[2] .094	.090	.116	.156	.132	.153	.135	.113	.104	.077	.060	.108
	Y103A	[2] .087	[2] .084	.090	.124	.169	.151	.193	.148	.090	.104	.074	.062	.115
1946	Y101D	[2] .077	[2] .087	.115	.146	.145	.224	.200	.152	.104	.081	.063	.062	.121
	Y102C	[2] .079	[2] .080	.124	.170	.168	.188	.180	.168	.107	.074	.073	.066	.123
	Y103A	[2] .072	[2] .084	.118	.151	.172	.209	.218	.181	.114	.082	.055	.052	.126
1947	Y101D	.067	[2] .100	.097	.122	.132	.199	.186	.138	.165	.092	.032	.029	.113
	Y102C	.065	[2] .090	.089	.104	.150	.221	.188	.154	.181	.109	.059	.054	.122
	Y103A	.067	[2] .078	.095	.107	.154	.230	.181	.151	.171	.099	.050	.044	.119
1948	Y101D	[2] .056	[2] .083	.111	.155	.182	.143	.190	.152	.101	.085	.071	.052	.115
	Y102C	[2] .063	[2] .088	.097	.145	.228	.234	.197	.127	.122	.089	.075	.062	.127
	Y103A	[2] .051	[2] .080	.104	.152	.222	.252	.197	.118	.109	.076	.057	.047	.122
1949	Y101D	[2] .052	.071	.103	.206	.220	.204	.222	.172	.142	.112	.061	.055	.135
	Y102C	.057	.075	.094	.134	.131	.173	.243	.179	104	.091	.076	.063	.118
	Y103A	.059	.079	.106	.129	.149	.197	.284	.188	.108	.086	.070	.076	.128
Average 1944–49	Y101D	[2] .066	[2] .091	.102	.134	.153	.179	.189	.143	.115	.089	.054	.052	.113
	Y102C	[2] .064	[2] .079	.093	.124	.163	.183	.183	.151	.122	.090	.069	.065	.115
	Y103A	[2] .062	[2] .078	.103	.127	.166	.203	.204	.154	.115	.084	.057	.063	.118

[1] For cropping history see Appendix A.

[2] Abnormally high values due to drifting of snow.

TABLE 14.—*Average daily rate of soil-moisture depletion by evapo-transpiration (ET—CA) for rainless days by months and crops, 1944–49 (inches of water)*

LYSIMETER Y102C

Crop	Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Crop yield per acre
Corn	1945	0.04	0.03	0.08	0.10	0.15	[1]0.11	0.16	0.12	0.10	0.09	0.07	0.02	34 bushels.
	1949	.04	.06	.06	.11	.09	[2] .15	.26	.16	.08	.06	.06	.04	144 bushels.
Wheat	1946	.04	.04	.11	.16	.22	[3] .21	.19	.16	.09	.07	.04	.03	38 bushels.
Meadow 1	1947	04	.05	.06	.09	.15	.25	.20	.14	.17	.09	.03	.02	2.4 tons.
Meadow 2	1944	.02	.02	.06	.08	.16	.14	.12	.14	.10	.05	.03	.02	1.5 tons.
	1948	.03	.04	.06	.15	.26	.26	.21	.09	.11	.07	.04	.02	3.1 tons.
							LYSIMETER Y101D							
Bluegrass	1944	.02	.02	06	.09	.12	.16	.14	.12	.07	.04	.02	.02	1.5 tons.

[1] First half of month, 0.11 inch; last half, 0.12 inch.
[2] First half of month, 0.12 inch; last half, 0.19 inch.
[3] First half of month, 0.24 inch; last half, 0.18 inch.

at least 6 consecutive hours beginning about 9 a. m. Some ET began as early as 5 a. m., but ET prior to 8 a. m. was very small. After 4 or 5 p. m. the lysimeters showed practically no further ET. They also showed very little evidence of CA for this July period, and most of the small amount recorded came soon after ET ceased. For example, on July 7, 9, and 10 the CA on Y102C started after 5 p. m. and very little occurred after midnight.

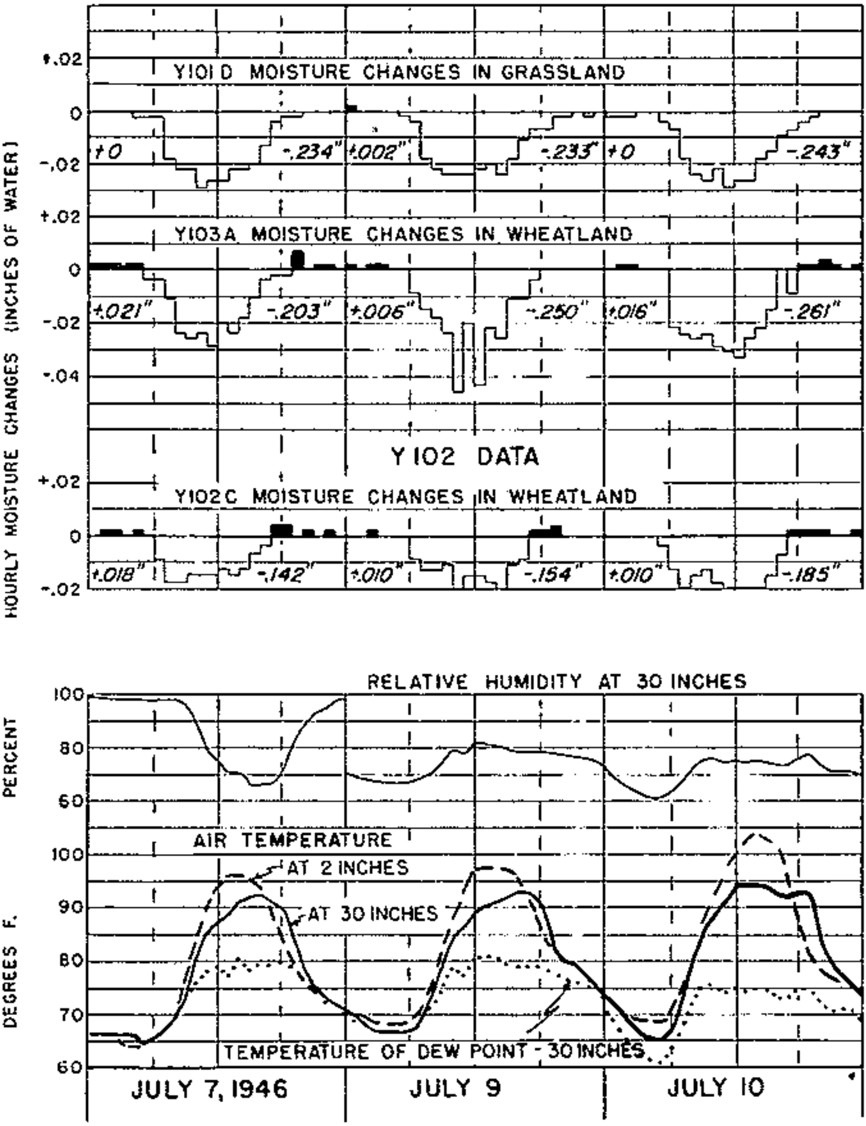

FIGURE 17.—Hourly moisture changes in grassland and wheatland lysimeters and related temperature and humidity data, July 7, 9, and 10, 1946.

ET noticeably diminished as soon as the air temperature 2 inches above the ground began to cool. CA in wheatland appeared to begin at a time when the temperature at the 2-inch level dropped below that at the 30-inch level. The lysimeter records showed practically no condensation or absorption on grassland. Soil temperature at the ½-inch depth generally showed a definite drop about 4 p. m. daily.

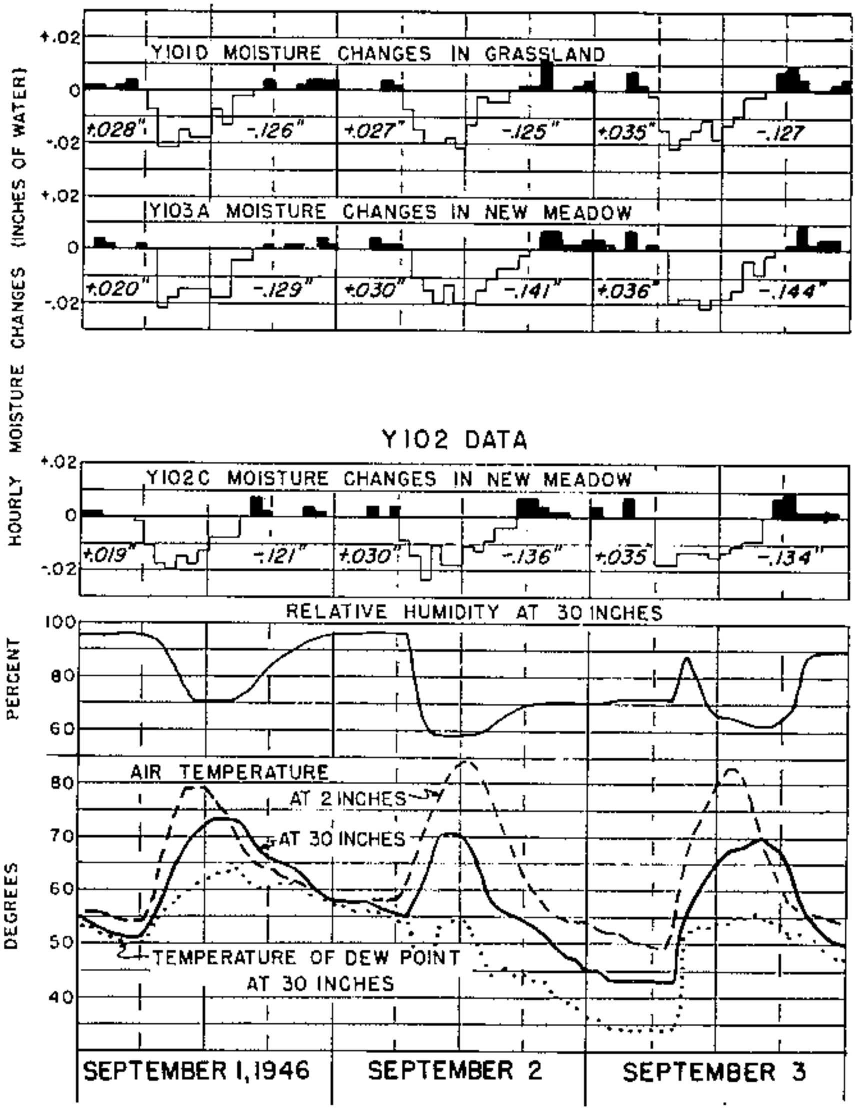

FIGURE 18.—Hourly moisture changes in grass and new-meadow lysimeters and related temperature and humidity data, September 1-3, 1946.

The curves of relative humidity shown on these figures were plotted from hygrothermograph recorder charts. The humidity-sensitive element of this instrument is a banjo-spread of human hairs. The humidity data and the computed dew-point temperature data appear to give general trends but not absolutely accurate quantitative values. For CA periods, lysimeter weight records indicated that dew was forming on the vegetation or soil surface when the air temperature at 30 inches was greater than the dew-

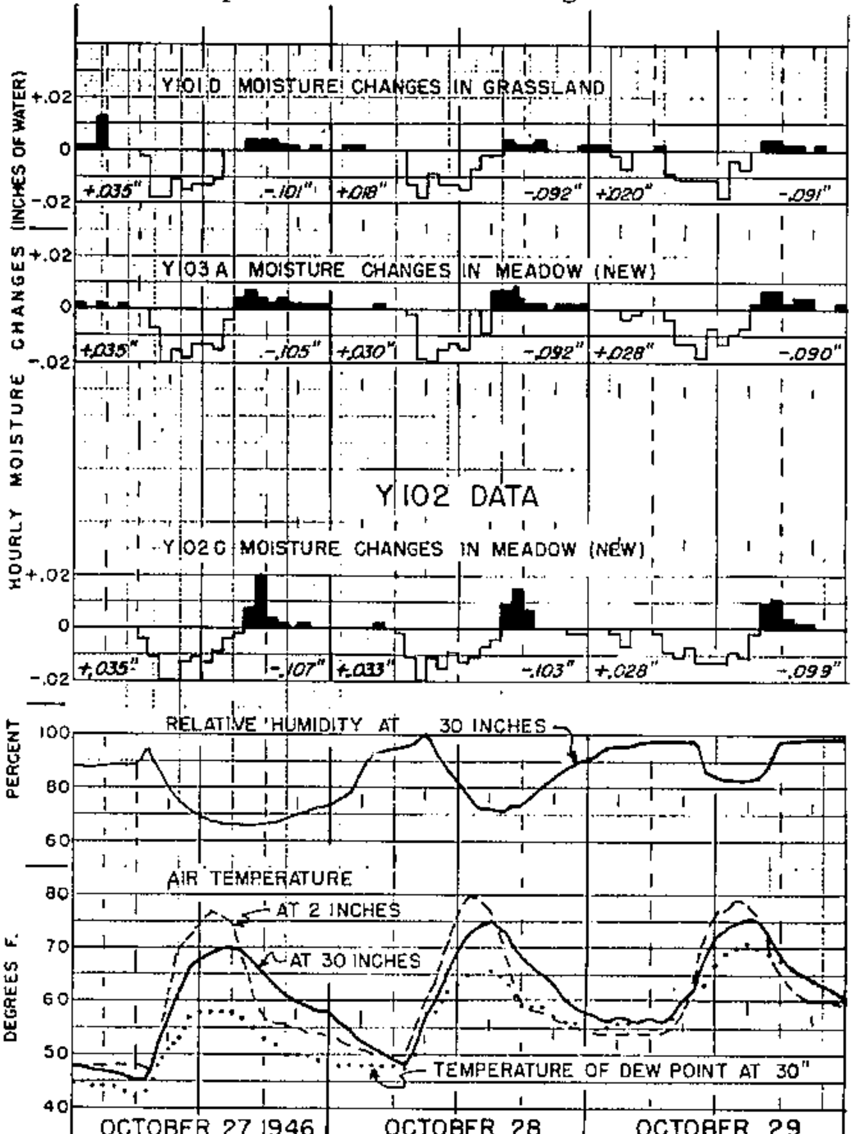

FIGURE 19.—Hourly moisture changes in grass and new-meadow lysimeters and related temperature and humidity data, October 27-29, 1946.

point temperature at this level. For example, all three weighing lysimeters showed increases in weight (CA) throughout most of the night of September 2-3 (fig. 18). Relative humidity, air temperature, and temperature of dew point all indicated that moisture should not be condensing. Possible differences between recorded humidity values and psychrometer readings, which may be as much as 10 to 15 percent, may account for this apparent discrepancy.

In the period September 1-3, 1946 (fig. 18), CA was greater and ET less than in July. October 27-29, 1946 values of CA (fig. 19) were about the largest for the year. ET was less than for either

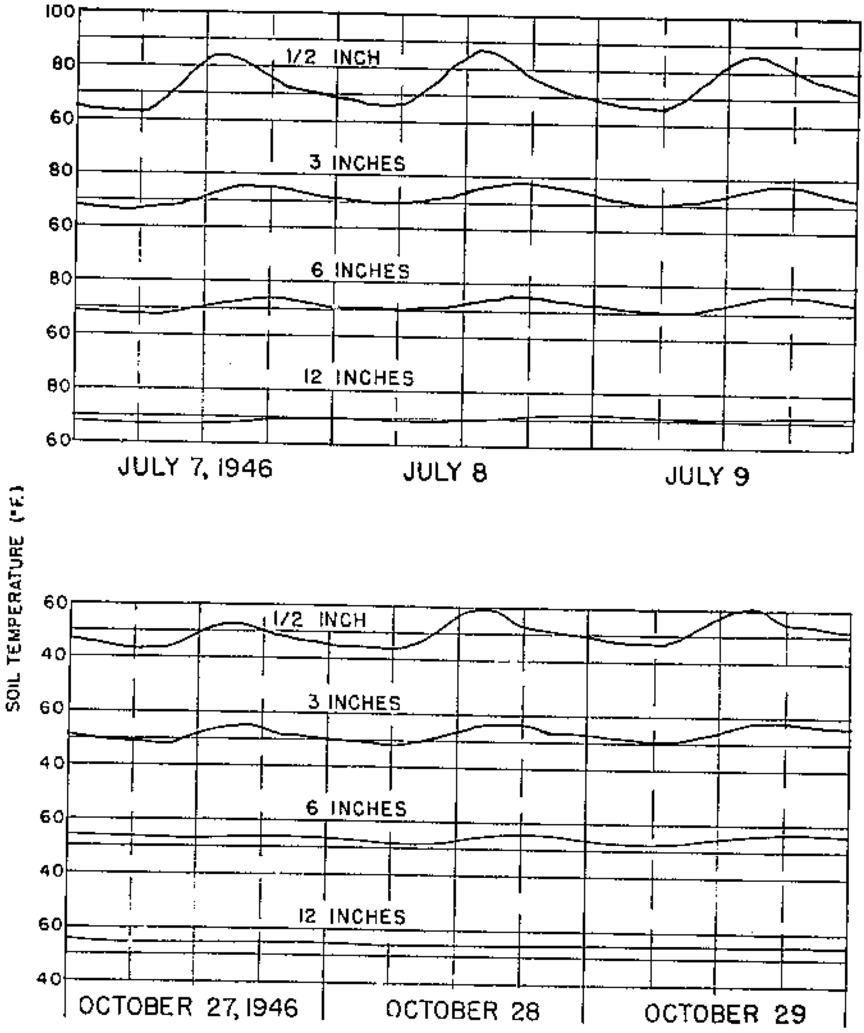

FIGURE 20.—Typical diurnal fluctuation of soil temperature at depths of ½, 3, 6, and 12 inches at Y102, July and October, 1946.

the July or September values. Marked ET on October 29 began about 7 a. m., yet the humidity graph remained close to 100 percent until 10 a. m. CA for that day ranged from 0.020 to 0.028 inch. Practically all of it occurred between 4 and 10 p. m. Soil-

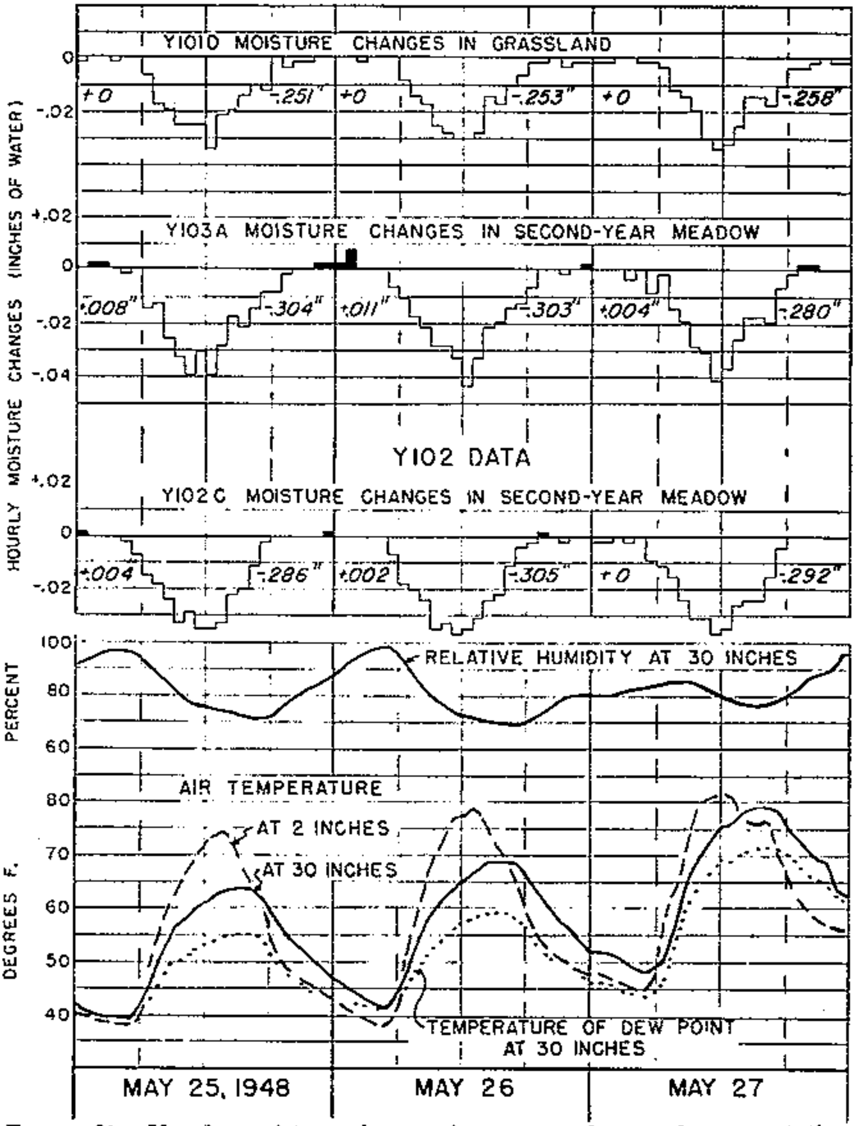

FIGURE 21.—Hourly moisture changes in grass and second-year rotation meadow lysimeters, May 25–27, 1948.

temperature data for the October period (fig. 20) show that most of the daily fluctuations occurred in the upper 6 inches of soil. Computations based on vapor pressure, temperature fluctuations, and pore space indicated that the condensation of vapor within the soil pores plus that from the air that was drawn in amounted to less than 0.01 pound daily on the lysimeter. CA, therefore, was a soil-surface phenomenon of the condensation and absorption of atmospheric moisture.

Similar comparisons can be made for the May, August, and October periods in 1948, a year in which the vegetation on all lysimeters was a good alfalfa-grass sod (figs. 21, 22, and 23). The data for May 25-27 (fig. 21) showed that this legume-grass mixture depleted soil moisture at a high rate. ET amounted to about 0.3

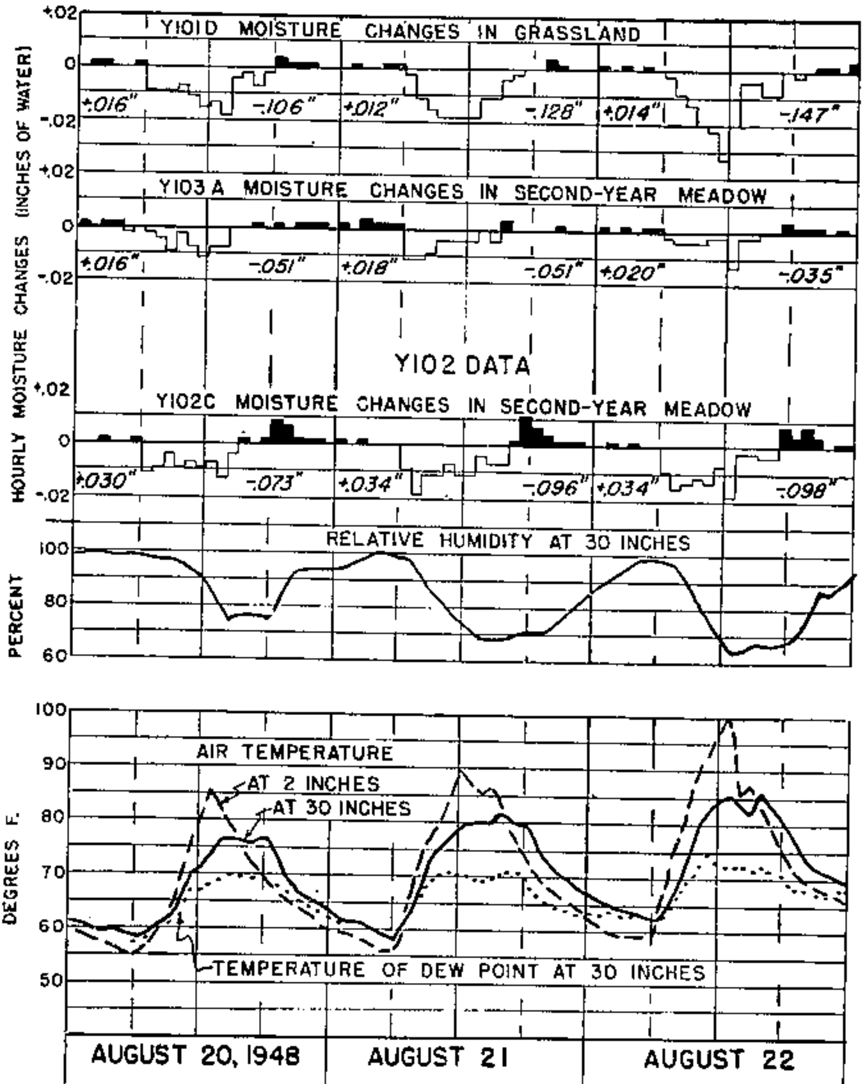

FIGURE 22.—Hourly moisture changes in grass and second-year rotation meadow lysimeters, August 20-22, 1948.

inch of water per day. It started before 6 a. m. and continued until 6 p. m. The maximum rates occurred about noon and ranged from 0.03 to 0.04 inch per hour. ET continued after soil temperatures began to cool; that is, after the soil air contracted and began to draw in moist air from above. The soil was probably absorbing moisture, yet the increase in lysimeter weights was negligible in these May evening and night periods. Possibly, the vegetation continued to transpire throughout the evening and night and the water loss about balanced the water gained through CA.

In August 1948, there was less vegetation and, consequently, less ET. CA exceeded night transpiration as indicated by the solid

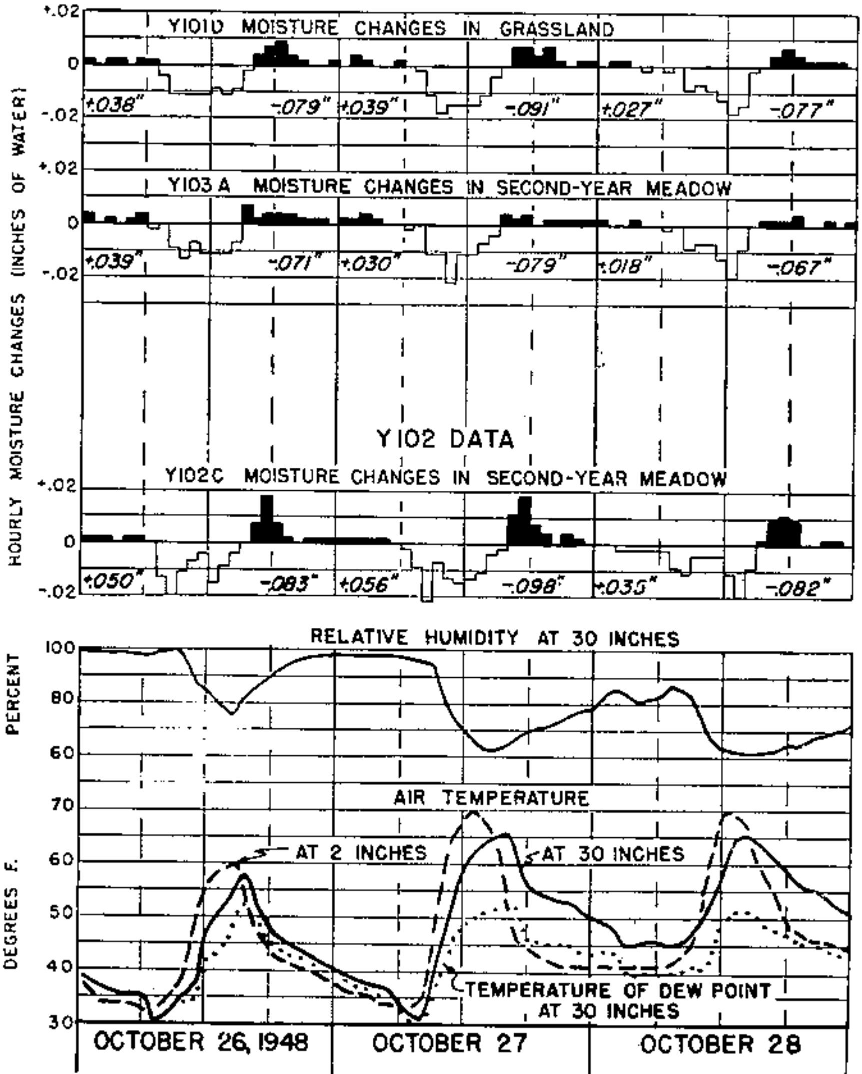

FIGURE 23.—Hourly moisture changes in grass and second-year rotation meadow lysimeters, October 26-28, 1948.

blocks above zero in figure 22. In October (fig. 23) the CA periods were also quite distinct.

The May 1949 moisture changes (fig. 24) are for grass-legume cover (Y101D) and for bare land planted to corn (Y102C and Y103A). At this period of growth the ET on land with legumes and grass was from two to about four times as much as the water evaporated from the bare soil of the cornland (Y102C and Y103A). Weight increases on May 11 were about 0.05 inch on the bare soil and only a trace on grassland, which may indicate that transpiration continued during the night. There was equal opportunity for

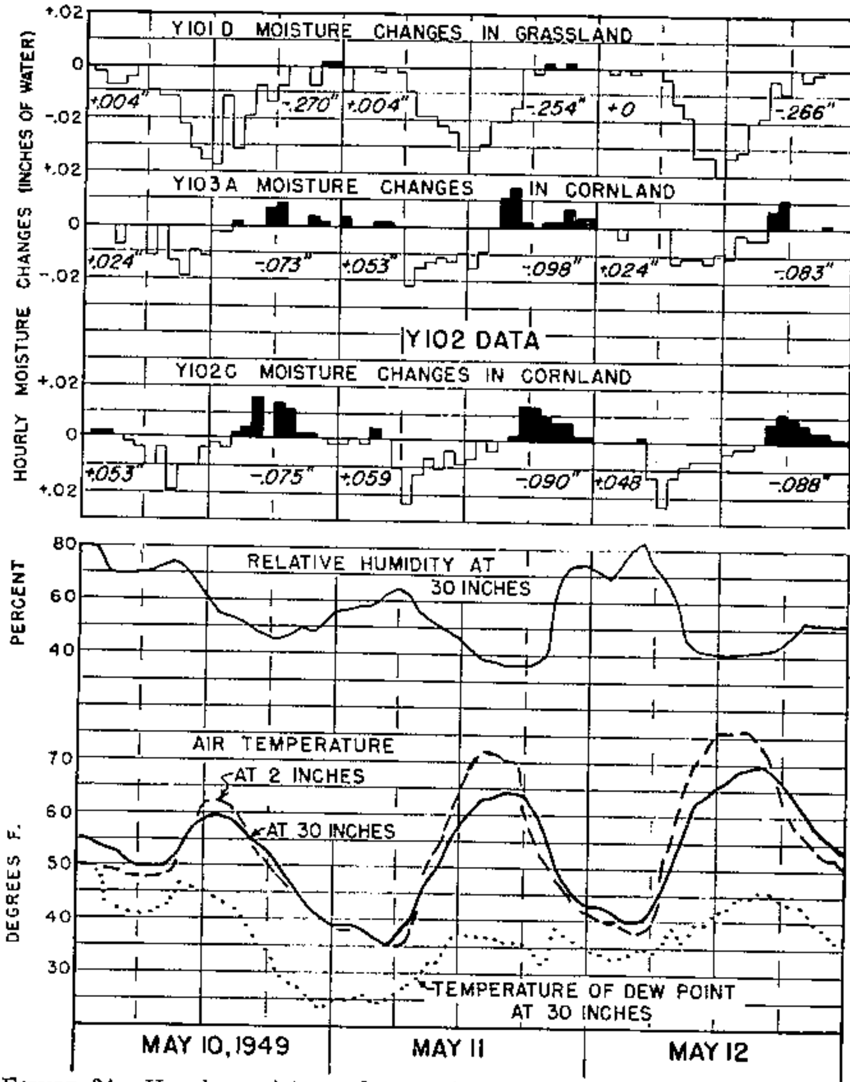

FIGURE 24.—Hourly moisture changes in grass and corn lysimeters and related temperature and humidity data, May 10–12, 1949.

condensation and absorption on Y101D and Y102C, yet only Y102C showed weight increases (gains in moisture from moisture absorption). The soil in Y101D might have absorbed as much moisture as that in Y102C, but loss of soil moisture from transpiration during this same period (weight decreases) may have counterbalanced the CA (weight increases) and resulted in practically no weight change for Y101D in the evening and night period. With no transpiration from the bare soil of Y102C there was little opportunity for losses in weight during the CA period. Consequently, the net weight increases were large.

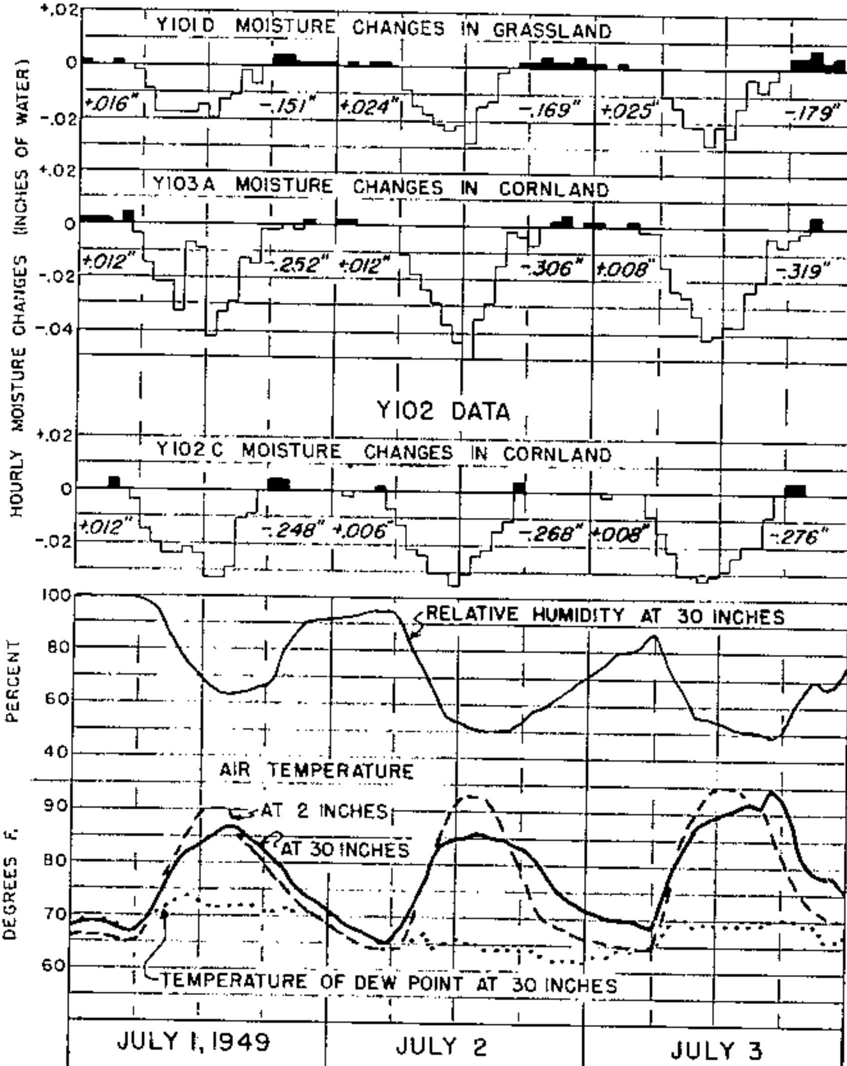

FIGURE 25.—Hourly moisture changes in grass and corn lysimeters and related temperature and humidity data, July 1-3, 1949.

Hourly moisture changes in grassland (Y101D) and cornland (Y102C and Y103A) for July 1, 2, and 3, 1949, are illustrated in figure 25. July ET for the cornland lysimeters was greater than that for the grass lysimeter. Weight increases for grass lysimeters during night periods were greater than for cornland at this season. It is likely that the corn as well as the grass plants continued some transpiration during night periods at the same time that the soil was absorbing moisture. The net result was that hourly CA

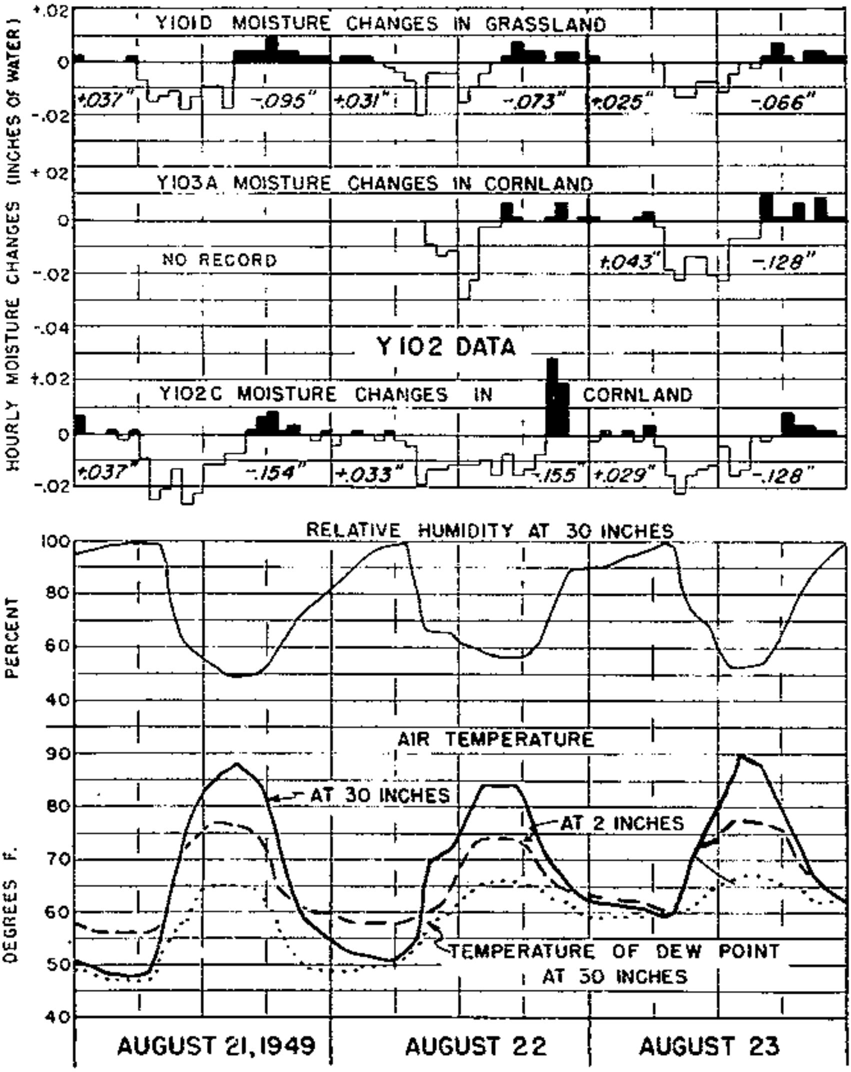

FIGURE 26.—Hourly moisture changes in grass and corn lysimeters and related temperature and humidity data, August 21-23, 1949.

during the evening and night period was generally equal to or greater than ET. As the transpiration rate for corn was greater than that for grass during the CA period, the net CA values for the latter appeared to be greater.

By late August, ET on both grass and cornland (fig. 26) was small—about half of that in early July. CA had increased from about 0.01 inch in July to 0.04 inch in August. With a lower ET rate in August, there was less tendency for the CA to be counterbalanced than in the CA periods of July. Furthermore, since the soil was much drier in August than in July, absorption of atmospheric moisture could reasonably have been greater.

EVAPO-TRANSPIRATION FOLLOWING NIGHT RAINFALL OR HEAVY DEW

The effect on evapo-transpiration of dew or rain water on the vegetation or soil was determined by comparing the evapo-transpiration values for wet plant and soil surfaces with those from dry surfaces. For ET from wet surfaces, ET values were selected for days following either night rainfall or periods of large CA. For dry surfaces, ET values were selected for days following night periods of little or no condensation. These data for lysimeters Y101D and Y102C are given in tables 15, 16, and 17 for 1947, 1948, and 1949, respectively.

In all 3 years very few values for comparative purposes were found. The criterion for selecting the data was to have 3 days

TABLE 15.- *Effect of either night rainfall or dew on next day's evapo-transpiration, 1947*

Date	Lysimeter [1]	Evapo-transpiration following—		
		Night rainfall [2]	Heavy dew [3]	Little or no dew
		Inch	*Inch*	*Inch*
May 6	Y101D			0.12
	Y102C			.11
May 7	Y101D	0.15		
	Y102C	.11		
May 9	Y101D		0.13	
	Y102C		.10	
Aug. 27–29	Y101D		.20	
	Y102C		.21	
Aug. 31	Y101D	.13		
	Y102C	.15		
Sept. 3–4	Y101D			.20
	Y102C			.25

[1] Lysimeter Y101D in grass and Y102C in first-year meadow, legume-grass sod.

[2] Night rainfall preceding evapo-transpiration period, May 7=0.20 inch, and August 31 = 0.74 inch.

[3] Dew preceding evapo-transpiration period = 0.03 to 0.06 inch.

TABLE 16.—*Effect of either night rainfall or dew on next day's evapo-transpiration, 1948*

Date	Lysimeter [1]	Evapo-transpiration following —		
		Night rainfall [2]	Heavy dew [3]	Little or no dew
		Inch	*Inch*	*Inch*
July 11	Y101D			0.16
	Y102C			.19
July 13	Y101D	0.15		
	Y102C	.15		
Oct. 4	Y101D			.12
	Y102C			.12
Oct. 14	Y101D		0.12	
	Y102C		.13	
Oct. 18	Y101D	.10		
	Y102C	.11		

[1] Lysimeter Y101D and Y102C in second-year meadow, legume-grass sod.
[2] Night rainfall preceding evapo-transpiration period, October 18 = 1.04 inch.
[3] Dew preceding evapo-transpiration period = 0.03 to 0.05 inch.

within a period of very little change of vegetation—one of night rainfall, one of heavy dew, and one of little or no dew. The days were not always consecutive.

The general conclusion of the study was that moisture on vegetation from the preceding night, whether from rain or dew, had no noticeable effect on evapo-transpiration. Evapo-transpiration was no greater from wet vegetation than from dry. For example, in the period May 6-9, 1947 (table 15), the Y102C values of ET for each of the 3 days were almost identical. The total ET of 0.10 inch for May 9 was probably made up of 0.06 inch of evaporated dew early in the day and 0.04 inch of evapo-transpiration from soil moisture. With no dew, as on May 6, all of the ET had to come from the soil water. Dew, therefore, had conserved some soil moisture. When there was little or no dew, larger quantities of soil water were used in the ET process. In other words, the evapo-transpiration from vegetated land following nights of little or no dew was mostly transpiration. Furthermore, sizeable quantities of the ET from land moistened by CA must have been evaporation. Dew fall, or absorption of water by the soil, or both, have, therefore, a soil-moisture conservation value.

Dew or rain was found to have a noticeable effect on evaporation from bare soils. The 1949 data showed that the quantity of evapo-transpiration (mostly evaporation) from cornland lysimeter Y102C on June 3 was 0.11 inch. The soil was dry and practically bare. On June 5, following a rainfall of 0.53 inch, the evapo-transpiration (mostly evaporation) was 0.25 inch—more than double that of June 3. This same rainstorm on grass lysimeter Y101D had no effect on evapo-transpiration, as indicated by the identical ET values for June 3 and June 5. Much of the ET from grassland was transpiration by plants.

The hourly moisture changes on grassland lysimeter Y101D and on cornland lysimeter Y102C before and after this rain are shown in figure 27. As the vegetal cover on cornland Y102C increased during July and August, the effect of rain on evapo-transpiration became negligible.

TABLE 17.—*Effect of either night rainfall or dew on next day's evapo-transpiration, 1949*

Date	Lysimeter [1]	Evapo-transpiration following —		
		Night rainfall [2]	Heavy dew [3]	Little or no dew
		Inch	*Inch*	*Inch*
June 3	Y101D			0.32
	Y102C			.11
June 5	Y101D	0.32		
	Y102C	.25		
June 18	Y101D	.31		
	Y102C	.24		
June 19	Y101D			28
	Y102C			.21
July 4	Y101D		0 20	
	Y102C		27	
July 25	Y101D	32		
	Y102C	32		
July 26	Y101D			.31
	Y102C			.32
July 27	Y101D			.33
	Y102C			.32
Aug. 7	Y101D		.28	
	Y102C		.26	

[1] Lysimeter Y101D in grass and Y102C in corn.

[2] Night rainfall preceding evapo-transpiration period, June 5=0.53 inch, June 18=0.20 inch, July 25=0.74 inch.

[3] Dew preceding evapo-transpiration peri[illegible] about 0.02 inch.

Evaporation from wet soil in 1945 also exceeded that from dry soil. Furthermore, soil-water evaporation was greater than free-water surface evaporation at least for the first day following rainfall. Before the rain of May 26, 1945, ET from bare soil averaged 0.13 inch of water per day. Water-surface evaporation was 0.15 inch per day. For the day following the rain, ET was 0.19 inch and water-surface evaporation, 0.10 inch. Likewise, after the rain period of June 10-13, 1945, evapo-transpiration from the nearly bare soil was 0.23 inch and water-surface evaporation was 0.18 inch.

WATER USE BY CROPS

The amount of water required for crop growth has been the subject of much experimentation, especially in the arid and semiarid sections of the country where irrigation of much of the cropland is a necessity. The scarcity of water supplies and the costliness of transporting water to the crops have created a demand for sound technical information on the use of water by crops.

The availability of adequate water supplies for agricultural purposes is now becoming a problem also in the humid region of the country. Some crop fields in this region are irrigated frequently throughout the growing season. Generally water is supplied when needed to supplement the rainfall. The Coshocton lysimeters provide data on water use for some of the crops commonly raised in the eastern regions. Such information can be used for planning general irrigation programs. More specific data may be required for special problems. These water-use values show the rate at which water was removed from the soil pores. Soil moisture has a bearing on the ability of the soil to absorb storm rainfall, an important factor in the solution of many flood-control problems.

Weight records obtained for lysimeters Y102C and Y103A during the 1941-49 period provided data on the amount of water used by different crops in a crop rotation in their respective periods of growth (table 18). These data are for 3 corn years and 2 years each of wheat and first- and second-year meadow. They show, for each year and for each crop, the amount of water taken from the soil in the crop period; i. e., ET — CA. For periods of no rainfall, ET — CA is the rate of soil-moisture depletion. Values of

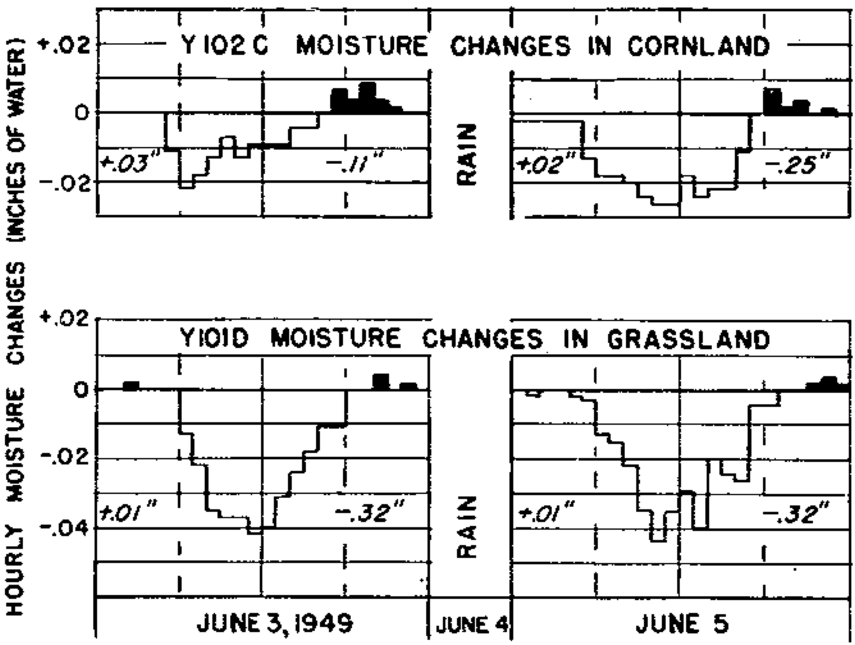

Figure 27.—Effect of night rainfall on the following day's evapotranspiration from grassland and cornland, June 1949.

ET alone, without CA, are greater than ET — CA values and do not truly represent the net quantity of soil-water depletion. No effort was made to separate evaporation and transpiration as these processes often act together to deplete soil moisture. Much of the previous work of others on this problem has reported only transpiration, omitting evaporation and CA.

The amount of water transpired and evaporated in the production of corn crops, computed on an acre basis, ranged from 17.4 to 24.6 inches; that for wheat, 12.0 to 14.2 inches; that for first-year meadow hay, 19.4 to 21.7 inches; and that for second-year meadow hay, 18.7 to 26.3 inches. Crop yields are given in busheis of grain and tons of hay. Corn-stover and wheat-straw weights were added to the respective grain weights to arrive at the total weight of plant produced above ground. These values divided by the pounds of water used in the growth period, provide data on the ratio of water transpired and evaporated to the weight of plant grown.

The amount of water used to produce 1 pound of corn crop ranged from 334 to 586 pounds, whereas the amount used to produce 1 pound of wheat crop ranged from 660 to 762 pounds and averaged 710 pounds.[4] Water used to produce 1 pound of first-year meadow hay ranged from 932 to 1,377 pounds, averaging 1,136 pounds. Water used to produce 1 pound of second-year meadow hay ranged from 784 to 1,550 pounds, averaging 1,169 pounds. In 1944 the meadow was poor, yielding only 1.5 tons of hay. For that growth season the average amount of water used per acre was 19.6 inches, or 1,480 pounds of water per pound of hay. In 1948 the weight of hay increased to an average of 3.45 tons. During this growth season the amount of water used per acre increased to an average of 26.1 inches. The amount of water used, however, dropped to an average of only 866. In 1948 the hay yield was more than double that of 1944 and the amount of water used per acre increased about 6.5 inches. The water used per pound of crop was reduced by about 41 percent; that is, the efficiency of water use was greater. A million pounds of water in 1944 produced about 700 pounds of hay, whereas in 1948 the same amount of water produced about 1,160 pounds of hay.

A study of the crop use of water by semimonthly periods (figs. 28, 29, 30, and 31) shows that the rate of water consumption varies during the growing period. Depletion of soil-water supplies by corn, for example, was greatest in July (fig. 28). The usage exceeded the normal rainfall in both the first and second half of this month 9 out of 10 times. For Y103A, the usage in 1949 was over 2 inches more than the normal rainfall, or about twice the normal rainfall, for both halves of July. Values of semimonthly use of water for each of the three corn years along with air-temperature data are given in table 19.

Without conservation practices on cornland, a considerable portion of the July rainfall was lost in runoff water. For example,

[4] The term "water use," as used in this bulletin, denotes both transpired and evaporated water unless otherwise specified.

TABLE 18.—*Water used by crops; evapo-transpiration (ET—CA) during season of growth, 1941–49*

Crop	Year	Lysimeter	Water used per acre[1]			Crop yield per acre[1]	Dry weight of crop per acre, including straw or stover[1]	Weight of water used to produce 1 pound of crop
			Period	Amount				
				Inches	*Millions of pounds*		*Pounds*	*Pounds*
Corn	1941	Y102C	May–Sept	17.4	3.94	80 bushels	10,000	394
	1945	Y102C	do	18.9	4.28	34 bushels	7,300	586
	1945	Y103A	do	20.7	4.69	61 bushels	10,500	447
	1949	Y102C	do	21.5	4.87	144 bushels	14,600	334
	1949	Y103A	do	24.6	5.57	139 bushels	14,100	395
Wheat	1942	Y102C	Apr.–June	12.4	2.81	32 bushels	3,720	755
	1942	Y103A	do	12.0	2.72	35 bushels	4,100	663
	1946	Y102C	do	14.2	3.22	38 bushels	4,880	660
	1946	Y103A	do	14.0	3.17	36 bushels	4,160	762
Meadow, first year	1943	Y102C	Apr.–Aug.	19.4	4.40	2.36 tons	4,720	932
	1943	Y103A	do	20.3	4.60	1.67 tons	3,340	1,377
	1947	Y102C	do	21.7	4.91	2.44 tons	4,880	1,006
	1947	Y103A	do	21.2	4.80	1.95 tons	3,900	1,231
Meadow, second year	1944	Y102C	Apr.–Aug.	18.7	4.23	1.50 tons	3,000	1,410
	1944	Y103A	do	20.5	4.65	1.50 tons	3,000	1,550
	1948	Y102C	do	25.9	5.87	3.10 tons	6,200	947
	1948	Y103A	do	26.3	5.96	3.80 tons	7,600	784

[1]Computed on an acre basis from the lysimeter data.

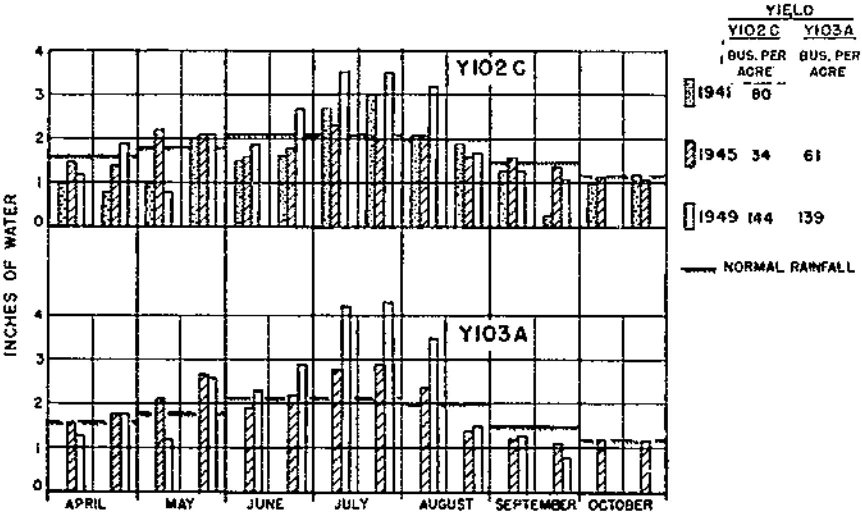

FIGURE 28.—Semimonthly evapo-transpiration (ET—CA) from cornland (lysimeters Y102C and Y103A), 1941, 1945, and 1949.

more than half the July 1941 rainfall ran off the corn field adjacent to lysimeter Y102C. Only a part of the rainfall went towards the replenishment of soil moisture. As the result of continued heavy use of soil water in the first half of August 1949, the corn plants suffered from lack of moisture in late August and early September. Soil-moisture curves for the 0- to 40-inch profile (fig. 14) show the extent of soil-moisture depletion in 1949. In this year, the corn plants on Y102C wilted before reaching full growth.

ET — CA values for May and October (fig. 28) represent evaporation from bare soil surfaces. In this case, corn was harvested in September and wheat was planted early in October. (ET — CA values from plowing time until the middle of June could logically be put in this same group as there is little transpiration from small corn plants.)

Wheat used water most heavily in late May and early June (fig. 29). Use exceeded normal rainfall from the middle of April through the first half of June. Wheat usually removed water from soil pores by evapo-transpiration faster than cornland prior to June 15. Water needs for wheat diminished after June 15. This is the ripening period. Following wheat harvest and the removal of straw, the new meadow of timothy, red clover, and alfalfa put on rapid growth. Water consumption increased somewhat in late July and early August.

Water use by first-year meadow is shown on figure 30. Vegetation was mostly red clover, timothy grass, and small alfalfa plants. Water consumption was greatest in the first half of June. Hay cutting in the last half of June decreased the demand for water. The second cutting of hay early in August 1947 had no noticeable effect on the semimonthly ET — CA. The cutting of

August 1943 was effective in reducing ET—CA water usage. Hay cutting may result in striking changes in daily evapo-transpiration and condensation-absorption, as explained further on.

Water use by second-year meadow is shown in figure 31. In 1944 the meadow consisted mostly of timothy and only a few alfalfa plants. In 1948 there was a vigorous stand of alfalfa and timothy. Water use in the latter half of May was very great—

TABLE 19.—*Water use by corn crop, and air temperatures, lysimeter Y102C by semimonthly periods, 1941, 1945, and 1949*

Month	Water used			Average of daily maximum air temperature at 30 inches (Fahrenheit)		
	1941	1945	1949	1941	1945	1949
	Inches	*Inches*	*Inches*	*Degrees*	*Degrees*	*Degrees*
May 1–15	1.0	2.2	0.8	68.8	61.0	75.9
May 16–31	2.0	2.1	2.1	77.6	69.0	72.0
June 1–15	1.5	1.6	1.9	75.9	71.6	81.9
June 16–30	1.6	1.8	2.7	87.3	81.9	85.5
July 1–15	2.7	2.3	3.5	81.9	78.8	89.6
July 16–31	3.0	2.0	3.5	89.7	87.4	86.3
Aug. 1–15	2.1	2.1	3.2	85.5	87.5	89.9
Aug. 16–31	1.9	1.6	1.7	80.4	86.2	86.6
Sept. 1–15	1.3	1.6	1.3	82.7	84.3	76.7
Sept. 16–30	3	1.4	.8	79.6	72.3	68.1
Total	17.4	18.9	21.5			
Crop yield bushels per acre	80	34	144			
Water used per pound of crop pounds	394	586	334			

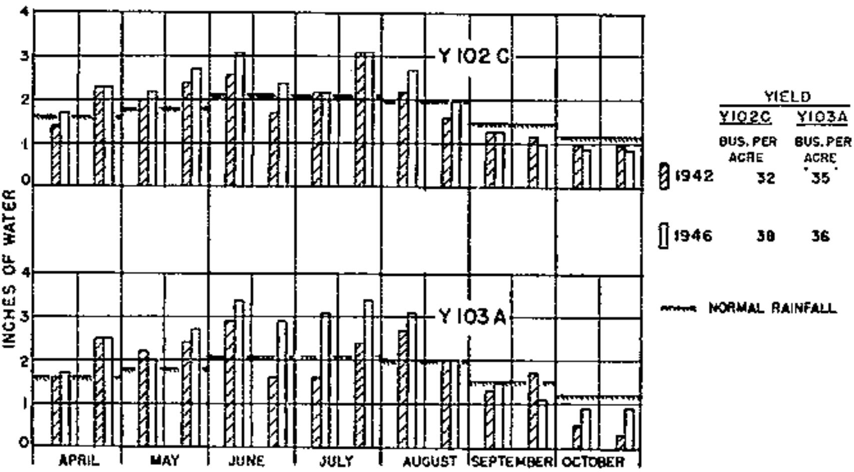

FIGURE 29.—Semimonthly evapo-transpiration (ET—CA) from wheatland (lysimeters Y102C and Y103A), 1942 and 1946.

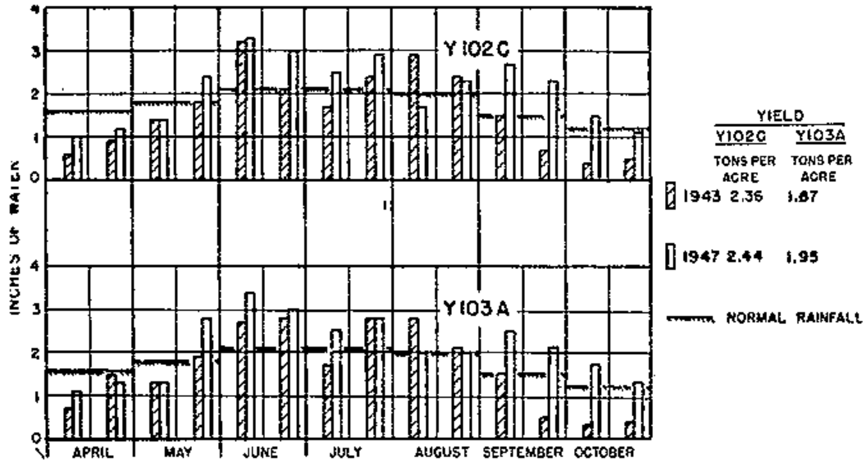

FIGURE 30.—Semimonthly evapo-transpiration (ET—CA) from first-year meadow (lysimeters Y102C and Y103A), 1943 and 1947.

about 2.5 inches in excess of the normal rainfall. The 9-year study showed no greater demand for water than that made by the good alfalfa-timothy meadow in 1948. Hay harvest late in June caused a reduction in evapo-transpiration, but in the latter half of July 1948 the alfalfa plants had recovered enough to increase plant use of water materially. Harvest of alfalfa early in August 1948 again reduced evapo-transpiration.

As there was very little runoff from these first- and second-year meadows, all the rainfall except that retained on the vegetation went towards replenishment of soil moisture. Normally a good alfalfa-grass meadow will use much more water than is supplied

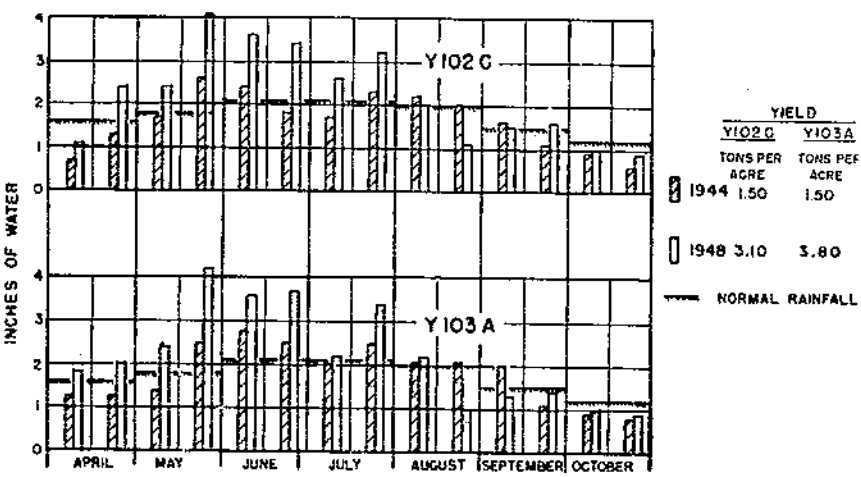

FIGURE 31.—Semimonthly evapo-transpiration (ET—CA) from second-year meadow (lysimeters Y102C and Y103A), 1944 and 1948.

by rainfall during the period April 15 to July 31. The excess of ET — CA over normal rainfall (fig. 31) gives an idea of how fast the soil moisture will be depleted in this period. In 1948 this depletion amounted to 8 inches of water.

The maximum daily consumptive use of water by corn, meadow, and wheat, based on the data obtained in this study, is given in table 20.

TABLE 20.—*Maximum daily rate of soil—moisture depletion (ET—CA) by corn, meadow, and wheat (inches of water)*

Crop	May	June	July	August	September	October
Corn	0.20	0.23	0.34	0.28	0.09	[1] 0.06
Meadow	.34	.30	.30	.27	.16	.12
Wheat-meadow	.28	.26	[2] .25	[2] .22	[2] .12	[2] .06

[1] Cornland planted to wheat in early October.
[2] Wheat harvested in early July. New meadow cover in following months.

EFFECT OF HAY CUTTING ON CONDENSATION-ABSORPTION AND EVAPO-TRANSPIRATION

A decided change was observed in the ET — CA curve (fig. 13) for second-year meadow lysimeters Y102C and Y103A, which occurred at the time hay was cut. Yet there was no perceptible change in the rate of evaporation (discussed on page 87). The reduction in ET — CA, or rate of net soil-moisture depletion, was first believed to be entirely a lessening of the transpiration rate due to a reduction of leaf area. However, a study of both evapo-transpiration and condensation-absorption data for periods before and after hay cutting, including the plotting of hourly moisture changes on all three weighing lysimeters (fig. 32), showed that the cutting and removal of hay not only reduced the evapo-transpiration but also increased the values of condensation-absorption perceptibly. Of all the hay-cutting operations on the lysimeters over the period of record, only three were acceptable for comparison. Records for all others were affected by rainfall.

In both 1947 and 1948, the evapo-transpiration and condensation-absorption changes on Y102C and Y103A before and after hay cutting were compared with the corresponding values for lysimeter Y101D, on which the grass remained uncut (table 21). This table shows that in June 1947 the evapo-transpiration from Y102C after hay cutting was 0.262 inch of water per day less than that before cutting. Some of this difference—perhaps a third—may be attributed to the change in climatic conditions during the period of comparison. Records for Y101D, where the grass was not cut, show that the "after" period had 0.096 inch less evapo-transpiration than the "before" period. This is an indication that the

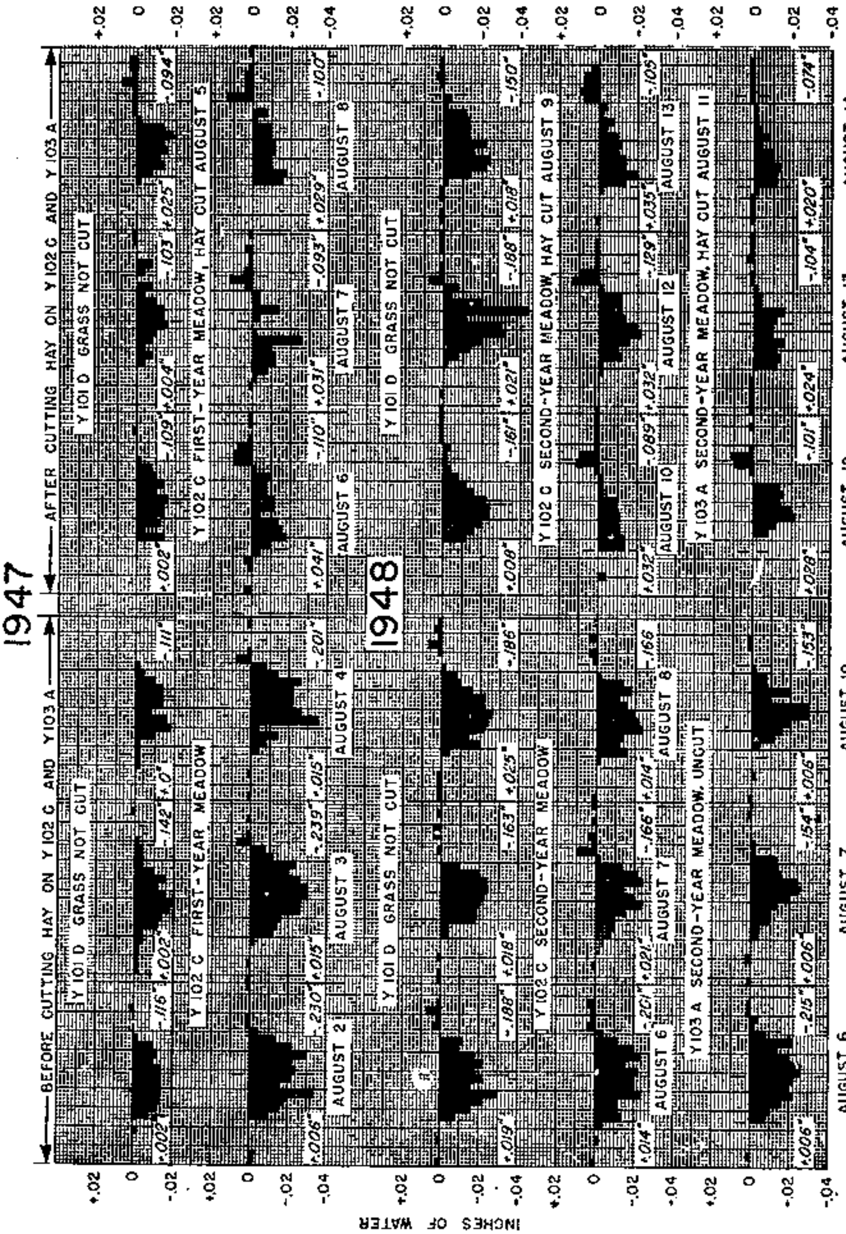

FIGURE 32.—Hourly moisture changes in uncut grass lysimeter Y101D and in Y102C and Y103A before and after cutting hay, August 1947 and August 1948.

evaporation potential of the later period was less than the earlier one. Evaporation-pan records are not complete enough to evaluate this potential. It can be stated, however, that the June cutting of first-year meadow (timothy, red clover, and alfalfa) reduced evapo-transpiration by 0.166 (0.262-.096) inch of water per day. This reduced rate of water loss prevailed for about a week, after which the vegetation recovered and the evapo-transpiration rate increased. However, the full rate that prevailed prior to cutting was not attained again the same year.

TABLE 21.—*Moisture changes (ET and CA) before and after cutting hay,*[1] *1947 and 1948*

Year	Period [2]	Average daily ET from lysimeters			Average daily CA on lysimeters		
		Y101D [3]	Y102C [4]	Y103A [4]	Y101D [3]	Y102C [4]	Y103A [4]
		Inch	*Inch*	*Inch*	*Inch*	*Inch*	*Inch*
1947.	June:						
	Before cutting..	0.324	0.378	([5])	0.006	0	([5])
	After cutting...	.228	.116	([5])	.021	.024	([5])
	Change.....	.096	.262	....	−.015	−.024	....
	August:						
	Before cutting..	.123	.223	([5])	.001	.012	([5])
	After cutting...	.102	.101	([5])	.010	.034	([5])
	Change.....	.021	.122	....	−.009	−.022	....
1948.	August:						
	Before cutting..	.179	.178	0.174	.021	.016	0.006
	After cutting...	.166	.108	.093	.016	.033	.024
	Change.....	.013	.070	.081	.005	−.017	−.018

[1] Hay removed from lysimeter same day as cut.

[2] Usually 3 days before and 3 days after the date of hay cutting.

[3] Grass on lysimeter Y101D not cut; bromegrass, alfalfa, and ladino clover seeded May 8, 1947.

[4] 1947 crop: first-year meadow of timothy, red clover, alfalfa;
1948 crop: second-year meadow of timothy and alfalfa.

[5] No record.

A similar comparison of condensation-absorption values at the June 1947 hay-cutting period shows that the CA rate on Y102C increased by 0.024 inch per day following the cutting of hay. Atmospheric conditions in the latter period must have been more favorable for condensation-absorption since records for Y101D show an increase of 0.015 inch per day for the same period. It appears that the removal of hay increased the condensation-absorption by about 0.01 inch (0.024-0.015) per day.

The increase in CA after hay cutting is believed to be due mainly to reduction in transpiration during the CA periods of the day. It is true that the range in soil-temperature fluctuations was greater following hay cutting and that more air moved into and out of the soil daily. Computations based on the soil-temperature changes (fig. 20), vapor pressure, and volume of air in soil pores indicated that the moisture condensed by cooling the air in soil pores plus the moisture condensed from air drawn into the soil during the cooling period was extremely small. The daily total was less than 0.01 pound (about 0.00002 inch of water) for the lysimeter. Before hay cutting, the transpiration during the CA period of the day was large enough to almost balance the CA amounts. This transpiration practically ceased for a few days after hay cutting, thus allowing the CA values to more nearly reflect the actual CA. Lysimeter weight records after hay harvest, or in the seasons of little or no transpiration, yield reliable values of CA. All other CA values are affected by night transpiration.

Perhaps the greater CA after hay cutting can be attributed to both the cooling of air in the soil pores and the lack of night transpiration. Neither the relative nor the quantitative influence of either factor can be evaluated from the data available.

The 1948 graphs of hourly moisture changes on Y102C and Y103A after hay cutting show that high rates of evapo-transpiration prevailed early in the day (fig. 32). They began to decrease about noon. The water that was evaporated early in the day may have been mainly water absorbed by the soil surface during the preceding night. The amount of morning transpiration of the meadow stubble was probably small. Before cutting, much water in the form of dew could be held by the rank growth of meadow. As the vegetation was usually dry by noon, the evaporation of dew from the large area of leaf surface must have taken place early in the day. Subsequent losses in weight during the day consisted mainly of transpiration of soil moisture.

In 1948, the evapo-transpiration on both Y102C and Y103A decreased noticeably after the August cutting of second-year alfalfa-timothy hay. This decrease amounted to about 0.06 inch (0.070-0.013) of water per day. The increase of condensation-absorption after hay cutting amounted to about 0.02 inch per day. The reduction in evapo-transpiration persisted for almost 2 weeks after hay cutting. The recovery in its daily rate was only slight thereafter. Soil-moisture-depletion rates (ET — CA) on Y102C before cutting hay, August 1948, were about 0.16 inch per day. Those for about 2 weeks after cutting were about 0.07 and those thereafter about 0.10 per day (fig. 13).

These data show that the net soil-moisture depletion (ET — CA) is fairly rapid on land with a good meadow crop like that on Y102C, ranging from 0.16 to 0.38 inch per day for a vigorous and full-grown legume-grass meadow. The removal of most of this growth decreased the daily loss of soil moisture by at least one-half. The reduction may reach two-thirds, as in June 1947.

Soil-moisture-depletion rates might be reduced further by cutting hay once or twice more each year, thus preventing the vegetal

TABLE 22.—*Effect of cultivation of cornland on evapo—transpiration, 1941 and 1949*

Date	Evapo-transpiration			Evaporation (BPI pan)	Ratio of evapo-transpiration from —			
	Cornland		Grass		Lysimeter Y102C to —		Lysimeter Y103A to —	
	Y102C	Y103A	Y101D		Evaporation from BPI pan	Evapo-transpiration Y101D	Evaporation from BPI pan	Evapo-transpiration Y101D
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1941	*Inch*	*Inch*	*Inch*	*Inch*	*Percent*	*Percent*	*Percent*	*Percent*
June 17[1]	0.22			0.09				
June 18	.25		0.20	.10				
June 19	.31		.20					
June 20	.32		.20					
Daily average	.28		.20	.10	280	140		
June 23[2]								
June 24	.19		.22	.22				
June 25	.16		.22	.27				
June 26	.24		.11	.16				
June 27	.15		.15	.15				
Daily average	.19		.18	.20	95	105		
1949								
June 28[3]	.20	.21	.09	.10				
June 29	.26	.29	.12	.12				

June 30	.22	.22	.14	.12	....	....	....	....
Daily average	.23	.24	.12	.11	210	190	220	200
July 1 [2]	....	....	....	....	....	....	....	....
July 2	.27	.30	.17	.20	....	....	....	....
July 3	.27	.31	.19	.20	....	....	....	....
July 4	.27	.31	.20	.18	....	....	....	....
July 5	.27	.32	.21	.20	....	....	....	....
Daily average	.27	.31	.19	.19	142	153	142	153

[1] 1.54 inches of rain in preceding 4 days.
[2] Corn cultivated this date.
[3] 1.07 inches of rain in preceding 4 days.

leaf area from reaching its maximum. This could result in decreasing drought damage and increasing ground-water recharge. The maintenance of greater supplies of soil moisture, on the other hand, would cause the soil to lose some of its flood-control ability.

EVAPO-TRANSPIRATION FROM CORNLAND BEFORE AND AFTER CULTIVATION

The effect of cultivation in reducing losses of soil moisture caused by evaporation is a subject which has been widely discussed. An examination of the lysimeter records for the corn years 1941, 1945, and 1949, particularly evapo-transpiration data for several days before and after cultivation, throws some light on this matter. Although there were a total of more than six cultivations in these 3 years, only two periods—June 1941 and June-July 1949—were suitable for comparison. The other periods were affected by rain and other factors which prevented their use for this purpose.

The daily rate of evapo-transpiration from cornland several days before and after these two cultivation periods is given in table 22. In both cases, over 1 inch of rain preceded the initial period prior to cultivation. The ground was moist and the evapo-transpiration rate high, averaging about 0.25 inch per day. After cultivation on June 23, 1941, the daily evapo-transpiration was less than it was before this operation. Conversely, in 1949, evapo-transpiration following cultivation was greater.

The apparent reason for this reversal was the difference in meteorological conditions such as air temperature, moisture, and wind. The integrated effect of these factors as measured by evaporation from the BPI pan is given in column 5 of table 22. It is evident that in the period following cultivation on June 23, 1941, there was a greater meteorological potential for evapo-transpiration than before cultivation. In spite of this greater potential, the cornland evapo-transpiration following cultivation was less. Before cultivation, evapo-transpiration from lysimeter Y102C was 280 percent of the BPI-pan evaporation. After this date the ratio was 95 percent. Likewise, before cultivation on July 1, 1949, the ratio was 210 percent, and 142 percent after. Y103A data show similar trends for 1949. There are no data from this lysimeter for the 1941 cultivation period.

For both of these cultivations, it can be said that cultivation reduced evapo-transpiration. Possibly all the saving was in evaporation. Cultivation might slow up transpiration slightly if many of the plant roots were destroyed by mechanical stirring of the soil.

A comparison between evapo-transpiration data from the undisturbed grassland of lysimeter Y101D on one hand and cornland lysimeters Y102C and Y103A on the other furnished an additional basis for judging the effect of cultivation on moisture conservation. Data in columns 7 and 9 of table 22 show the magnitude of this moisture saving.

Lysimeter weight records were also examined to determine if cultivation had any effect on condensation-absorption. Data for the only period acceptable for comparison (table 23) show that CA after cultivation was less than that before. Using the records for Y101D, which had no change, as a comparison, CA following cultivation was about one-third less.

TABLE 23.—*Effect of cultivation*[1] *of cornland on condensation-absorption, 1949*

Date	Condensation-absorption (CA) on lysimeters—			Ratio of CA on—	
	Y101D [2]	Y102C	Y103A	Y102C to Y101D	Y103A to Y101D
	Inch	*Inch*	*Inch*	*Percent*	*Percent*
June 28	0.026	0.015	0.009		
June 29	.023	.025	.023		
June 30	.017	.010	.025		
Average	.022	.017	.019	78	8[illegible]
July 1	.022	.014	.011		
July 2	.028	.007	.013		
July 3	.023	.010	.009		
July 4	.013	.006	.013		
July 5	.014	.007	.016		
Average	.020	.009	.012	45	6[illegible]

[1] Y102C and Y103A cultivated on July 1.
[2] Legume-grass sod not cultivated.

EVAPO-TRANSPIRATION (ET—CA) COMPARED TO WATER-SURFACE EVAPORATION

The lysimeter studies provided an opportunity to compare evapo-transpiration from the lysimeters with water-surface evaporation and the meteorologic factors influencing the potential rate of such water losses. These factors, which were measured at the site of lysimeter Y102 for the period 1944-49, are given by months in table 24. Evaporation from the BPI pan is a measure of the combined effect of wind movement and turbulence, air temperature, moisture in the air, barometric pressure, and solar energy. As long as this evaporation pan was exposed to free movement of air, its records represented the full evaporation potential of the atmosphere. In periods when corn and wheat plants in the surrounding area restricted such air movement and shaded the water surface, the vegetal canopy influenced the evaporation values. The higher vegetal canopies had a greater effect than the lower growing plants on wind movement, and on air and soil temperatures.

Prior to 1943, evaporation and meteorological observations were made about 600 feet southeast of lysimeter Y102 in an area unobstructed by vegetation. Although evaporation, humidity, wind

TABLE 24.—*Average daily evaporation, relative humidity, wind movement, and air and soil temperatures near lysimeter battery Y102, by months, 1944–49*

Month	Average daily evaporation from BPI pan [1]	Average relative humidity [2]	Average daily wind movement [1]	Average air temperature				Soil temperature [4] at a depth of —				
				30-inch height [3]		2-inch height [4]						
				Maximum	Minimum	Maximum	Minimum	0.5 inch	3 inches	6 inches	12 inches	24 inches
1944	*Inches*	*Percent*	*Miles*	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
January	...	84	...	38.7	23.5	43.0	25.8	34.4	31.0	31.0	...	...
February	...	78	...	40.9	22.7	43.4	26.2	36.6	32.5	32.1	31.3	...
March	...	76	...	45.2	25.6	46.9	30.9	37.8	35.6	35.7	35.7	...
April	...	74	...	58.9	38.3	64.0	39.4	52.6	45.3	45.3	44.4	...
May	[5] .14	76	[5] 58	77.1	55.3	86.9	55.9	70.7	62.4	60.4	56.9	...
June	.19	81	57	83.6	59.6	94.7	61.9	78.2	70.3	70.0	67.0	...
July	.22	73	51	86.2	62.2	105.8	61.8	83.1	72.1	72.8	72.4	...
August	.18	79	45	84.4	61.4	100.3	62.3	80.2	73.6	71.9	72.1	69.2
September	.11	81	48	73.4	52.2	89.2	55.6	73.4	64.8	64.9	66.6	64.2
October	.07	80	57	63.0	42.6	73.8	47.0	58.7	54.0	56.3	57.8	57.1
November	.03	85	55	48.1	33.3	53.7	37.1	45.0	41.4	42.7	47.8	47.8
December	...	83	...	32.8	18.2	34.4	27.8	34.0	31.2	32.2	37.8	37.1
1945												
January	...	82	...	28.2	13.8	30.4	28.0	31.8	30.2	29.8	32.6	33.8
February	...	81	...	35.6	20.4	37.3	29.1	34.4	31.7	30.1	31.3	32.8
March	...	78	...	57.0	36.2	65.0	36.6	50.4	44.9	41.8	37.6	41.5
April	.12	74	97	63.3	43.5	75.3	42.9	57.9	52.4	51.1	48.4	50.6
May	.13	78	102	65.5	43.7	...	...	...	...	...	...	...
June	.13	82	79	77.6	58.4	...	...	...	...	...	...	...
July	.13	81	21	82.8	60.8	...	...	...	...	...	...	...
August	.12	80	18	87.1	60.5	91.0	63.6	77.1	73.3	72.8	72.0	70.1
September	.09	85	34	77.8	56.4	80.4	58.2	67.2	66.4	66.4	65.7	66.6
October	.07	75	82	59.9	39.3	61.8	44.2	50.8	51.0	52.8	55.2	55.2
November	[6] .08	81	[6] 126	50.3	34.5	49.9	39.3	38.7	41.6	42.0	44.2	47.7
December	...	84	...	28.9	18.3	31.1	26.1	24.8	30.7	31.1	33.9	36.2

1946												
January	...	79	...	36.2	18.0	35.7	23.7	26.3	31.4	31.2	32.3	34.4
February	...	78	...	42.4	29.0	39.7	27.1	28.9	30.8	31.0	32.6	32.4
March	...	77	...	62.0	40.4	63.4	43.0	45.4	44.4	45.1	43.8	42.8
April	[7].12	68	[7]99	59.3	35.9	64.3	40.5	46.6	46.2	47.8	48.0	47.3
May	.09	82	40	67.3	48.1	67.6	49.0	55.2	56.0	54.4	52.6	51.4
June	.13	84	12	80.8	53.0	84.0	58.8	65.4	66.2	64.9	62.5	61.1
July	.19	82	36	83.2	60.4	90.5	61.7	71.2	70.2	70.8	69.6	66.6
August	.14	82	64	77.4	56.6	81.8	58.8	64.1	66.6	66.0	66.1	64.9
September	.11	77	60	78.0	55.0	87.1	56.1	62.8	64.6	63.9	63.3	62.2
October	.07	82	70	68.6	46.0	73.9	47.9	53.0	55.8	57.7	57.0	57.5
November	[8].05	79	[8]79	51.4	32.0	54.4	37.4	39.9	43.3	45.1	48.6	49.6
December	...	75	...	43.2	21.6	42.5	30.7	32.4	35.5	36.3	39.9	40.6
1947												
January	...	82	...	41.6	25.0	40.2	30.2	29.6	33.3	34.0	36.6	36.2
February	...	76	...	30.6	16.6	28.8	19.2	24.6	30.0	30.5	34.2	33.7
March	...	79	...	38.4	24.2	42.0	28.8	27.8	31.6	31.0	33.4	32.7
April	[7].13	76	[7]160	59.0	42.6	61.0	37.8	43.9	43.6	44.1	45.8	42.5
May	.11	81	83	65.6	46.4	66.4	42.4	52.2	53.0	54.6	53.1	51.7
June	.15	85	54	76.0	57.8	78.0	52.4	64.0	63.7	64.3	63.6	59.6
July	.13	88	55	77.9	59.7	78.9	53.9	65.4	66.1	66.8	67.6	63.0
August	.14	93	58	86.3	68.9	89.8	65.0	74.8	72.6	73.2	74.2	68.2
September	.13	86	65	76.0	57.2	76.0	54.6	65.7	65.8	67.7	70.4	66.3
October	.08	84	50	68.1	48.3	70.2	48.6	55.8	58.5	58.8	61.4	59.1
November	[9].05	82	[9]62	41.4	30.0	42.0	32.6	35.8	40.5	43.2	51.2	48.5
December	...	81	...	36.7	23.1	35.4	25.4	28.6	32.3	34.9	40.4	37.8
1948												
January	...	78	...	27.5	13.5	26.3	18.7	25.4	30.8	30.8	33.8	33.9
February	...	78	...	39.3	21.9	37.7	24.7	28.9	32.2	31.6	34.2	32.8
March	...	78	...	50.2	30.0	52.8	23.6	37.0	38.3	39.8	42.0	38.1
April	.12	76	105	64.3	43.1	67.8	38.6	47.9	48.8	51.7	51.9	48.6
May	.13	80	47	68.4	45.4	73.6	43.2	54.6	55.8	57.8	57.3	54.4
June	.15	82	74	78.1	55.1	85.6	52.4	64.3	63.5	65.0	64.6	59.9
July	.14	89	36	83.3	62.1	89.4	57.8	68.5	69.7	69.9	67.5	65.8
August	.16	83	52	84.4	59.6	94.4	56.4	67.6	68.0	68.4	66.9	65.7
September	.12	84	73	75.5	53.9	82.6	51.4	61.9	64.4	66.6	66.1	65.0
October	.06	86	72	58.3	37.7	61.6	38.6	44.0	49.0	54.1	51.7	54.5
November	.04	83	97	54.6	35.8	54.5	36.3	40.7	45.3	48.7	47.8	50.2
December	...	85	...	40.9	25.3	40.3	25.9	30.6	35.3	39.5	38.6	40.7

See footnotes at end of table.

TABLE 24.—*Average daily evaporation, relative humidity, wind movement and air and soil temperatures near lysimeter battery Y102 by months, 1944–49*—Continued

Month	Average daily evaporation from BPI pan [1]	Average relative humidity [2]	Average daily wind movement [1]	Average air temperature				Soil temperature [4] at a depth of —				
				30-inch height [3]		2-inch height [4]						
				Maximum	Minimum	Maximum	Minimum	0.5 inch	3 inches	6 inches	12 inches	24 inches
1949	*Inches*	*Percent*	*Miles*	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.	°F.
January	....	83	....	43.6	27.9	39.7	28.4	31.5	34.7	35.6	35.2	37.3
February	....	80	....	43.5	25.0	42.3	25.5	30.5	34.4	34.9	35.1	37.0
March	....	83	....	46.9	29.0	47.0	28.8	34.1	37.7	38.0	38.2	39.1
April	[7].07	79	[7]98	59.8	38.9	60.6	37.6	43.3	45.1	44.2	43.8	46.0
May	.14	76	90	73.8	50.2	77.0	46.1	55.4	57.8	57.5	56.8	55.7
June	.14	80	56	83.8	62.8	87.0	58.9	67.2	69.3	67.8	66.3	63.8
July	.13	88	35	87.8	66.6	83.8	66.0	71.4	72.8	72.2	71.2	69.4
August	.09	87	5	88.8	61.6	78.0	63.1	68.3	69.3	71.2	69.0	67.4
September	[10].09	84	[10]21	73.0	49.9	67.4	52.4	57.0	59.5	61.6	61.9	61.7
October	....	78	....	65.8	49.9	69.8	49.8	55.6	56.0	....	59.2	58.5
November	....	84	....	50.0	32.8	46.7	34.2	36.6	40.8	46.4	47.2	48.6
December	....	80	....	43.6	25.4	37.4	26.8	31.4	34.9	....	41.2	39.2

[1] Bureau of Plant Industry type pan 6-foot diameter, 3-foot depth, sunken with top of pan 2 inches above ground; water level in pan maintained at about ground surface. Evaporation and wind-movement records affected by shielding from tall corn and wheat plants in 1945, 1946, and 1949.

[2] Average of daily 8 a. m. hygrometer readings.

[3] Average of daily values taken from chart of a model 594 Friez hygrothermograph having an alcohol-filled bourdon tube for temperature recording.

[4] Average of daily values taken from charts of distance thermographs, Friez Model 1160, using thermal bulbs and vapor-pressure transmission to recorder.

[5] 16-day record only.

[6] 8-day records.

[7] 27 days record.

[8] 14 days record.

[9] 12 days record.

[10] 29 days record.

movement, and temperature records were reliable for this period, they may not be representative of conditions at Y102.

The cumulative values of ET — CA for corn lysimeter Y102C and BPI-pan evaporation for 1941 are shown graphically in figure 33. The pan-evaporation curve indicates that the rate of evapora-

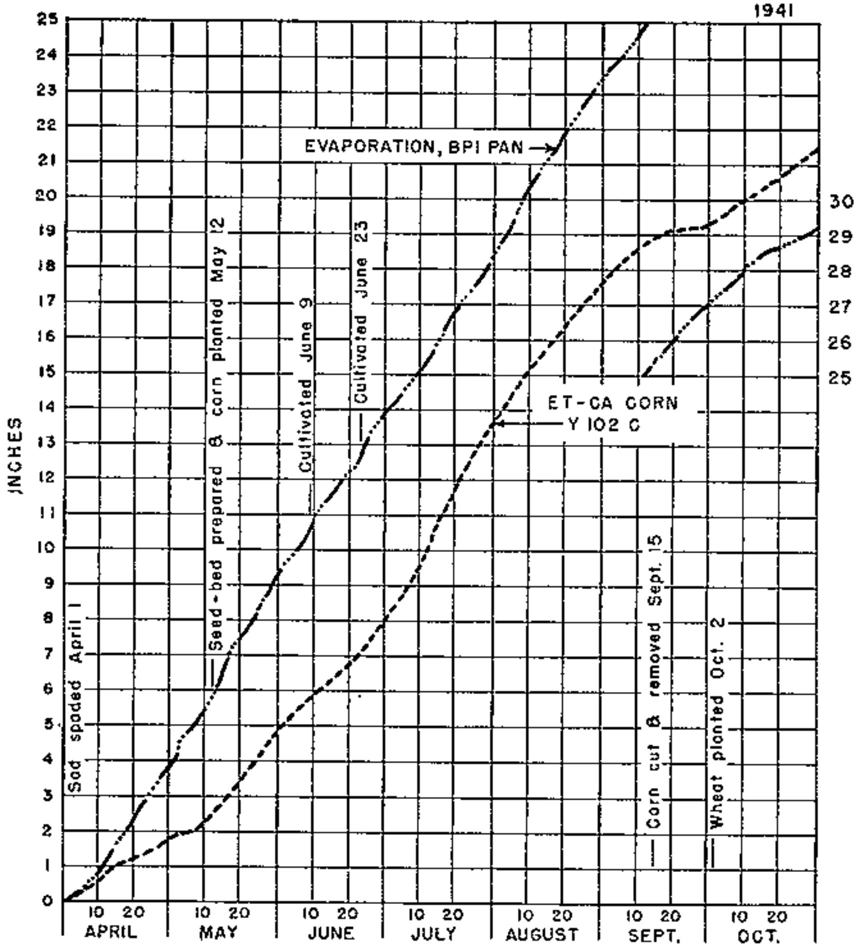

FIGURE 33—Comparison of evapo-transpiration from cornland contrasted to evaporation from a water surface (BPI pan), 1941.

tion from April into early September was fairly constant. The slope of the ET—CA line for Y102C corn, on the other hand, varied noticeably. For about 40 days after the sod was turned, ET — CA increased only about half as fast as evaporation. As long as the soil was wet it lost water as fast as the evaporation pan. In the period April 10-May 5, during which the soil surface became unseasonably dry, ET — CA was only one-third the evaporation from the pan. From corn-planting time to July 1, ET — CA accumulated about two-thirds as fast as evaporation. During July, ET — CA was 30 percent greater than evaporation; in August it was 20 percent less; and in September, 50 percent less. It is obvious that ET — CA rates differed materially from the evaporation rates throughout this season. This was expected in view of the influence of area of leaf surface on the rate of water use by plants.

In 1945, also a corn year, ET — CA values for Y102C and Y103A (fig. 34) were greater than those for 1941. ET — CA and evaporation curves in 1945 were almost identical through June. The relation between ET — CA and evaporation after July 1 cannot be accurately determined since evaporation records were affected by corn plants shielding the pan. The extent of shielding is indicated by the reduction of wind movement in July, August, and September (table 24). ET — CA was greater for Y103A than for Y102C. Soil moisture of the former lysimeter was consistently greater than that of the latter.

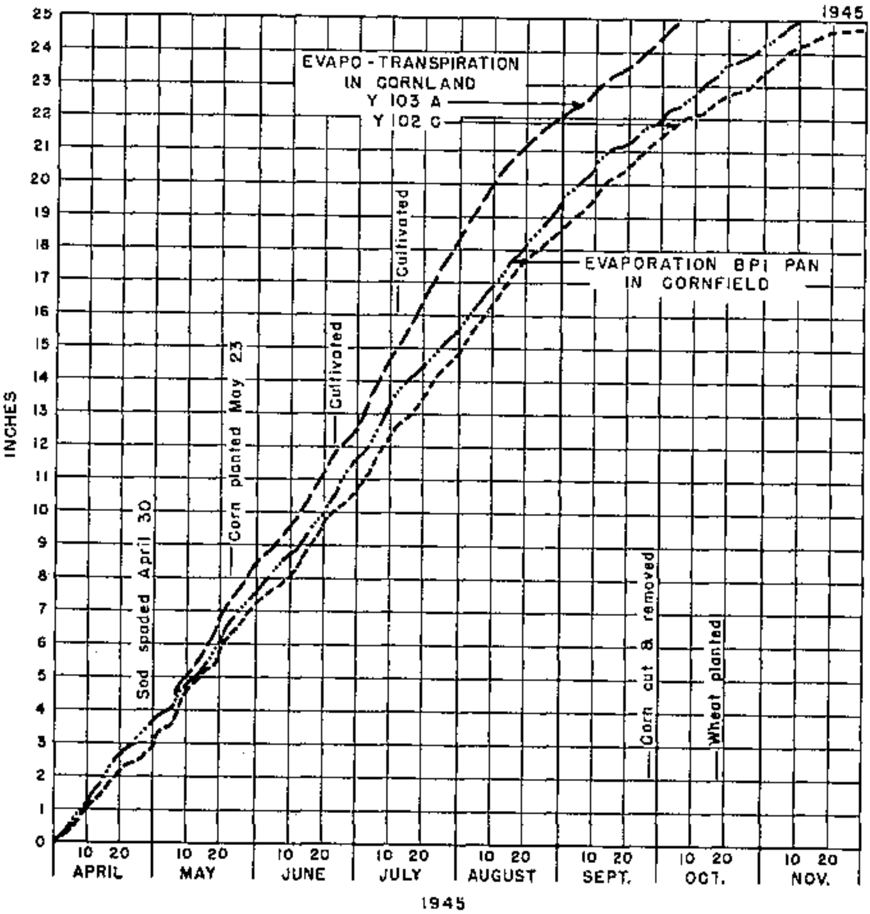

FIGURE 34.—Comparison of evapo-transpiration from cornland contrasted to evaporation from a water surface (BPI pan), 1945.

In 1949, the third year of corn on the lysimeters, ET — CA for the period April through June was about the same as the BPI-pan evaporation. No comparison can truly be made for the period July through September due to the corn plants shielding the evaporation pan. Wind movement across the evaporation pan in August amounted to only 5 miles per day (table 24). Normally, this value would be somewhere between 40 and 60 miles per day.

The curves for 1946 indicate that during the growing period the amount of water used by wheat was greater than the amount evaporated from the pan (fig. 35). ET — CA in the April-June period probably also exceeded the amount of evaporation that

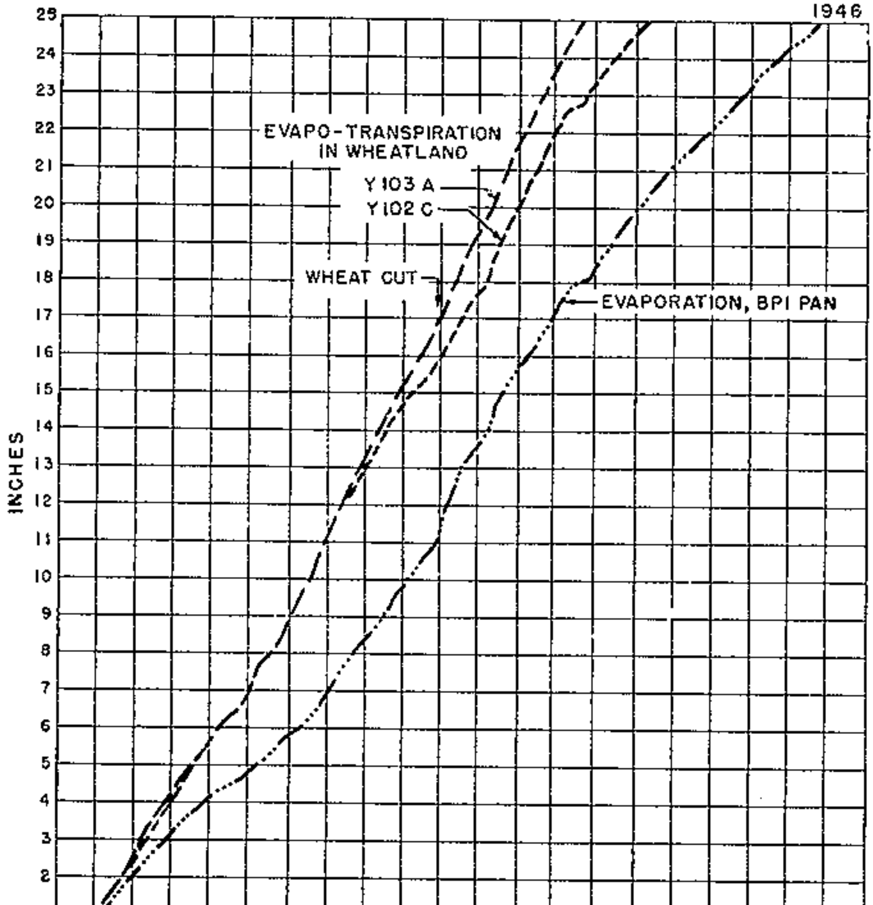

FIGURE 35.—Comparison of evapo-transpiration from wheatland contrasted to evaporation from water surface (BPI pan), 1946.

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would occur from a free water surface. This could not be determined positively from the data, since the wheat plants partly shielded the evaporation pan from the wind, especially in May and June. The new meadow following wheat on Y102C appeared to use about as much water as evaporated from the BPI pan. ET — CA for Y103A was greater than that for Y102C. The former has a heavier soil and a consistently higher moisture content than the latter.

Comparisons of ET — CA and BPI-pan evaporation were possible for meadow throughout the entire growing season because there was little shielding of the pan by vegetation. The comparison

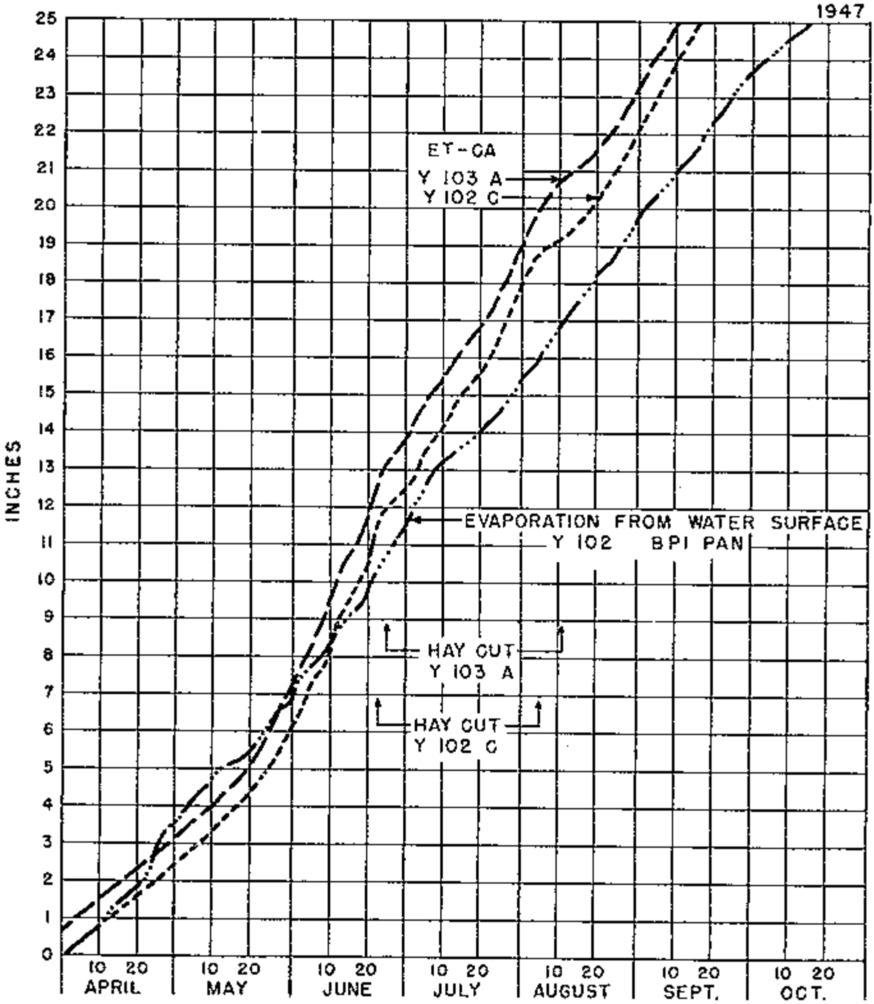

FIGURE 36.—Comparison of evapo-transpiration from first-year meadow contrasted to evaporation from a water surface (BPI pan), 1947.

for first-year meadow (1947) appears in figure 36. Prior to July 1, ET — CA did not differ greatly from pan evaporation; thereafter, ET — CA was about 20 to 25 percent greater than the pan evaporation. The differences can be expected to vary according to the proportion of the surface covered by vegetation and the amount of plant cover.

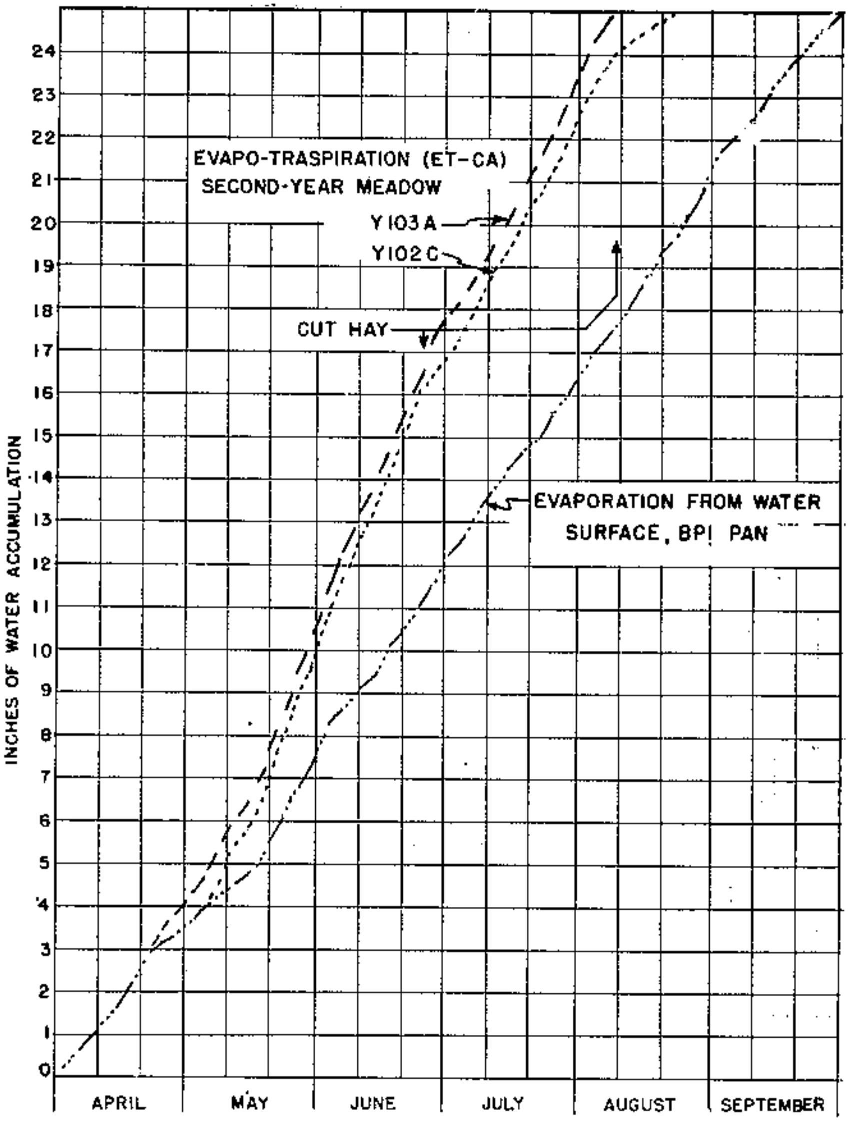

FIGURE 37.—Comparison of evapo-transpiration from a second-year meadow contrasted to evaporation from a water surface (BPI pan), 1948.

TABLE 25.—*Average daily evapo-transpiration minus condensation-absorption (ET—CA) for Y102C and pan water-surface evaporation, by months, in inches of water, 1941–49*

Crop	Year	April		May		June		July		August		September	
		ET—CA	Evaporation	ET—CA	Evaporation	ET—CA	Evaporation	ET—CA	Evaporation	ET—CA	Evaporation	ET—CA	Evaporation
Corn	1941	0.06	0.13	0.10	0.18	0.11	0.15	0.18	0.14	0.13	0.16	0.05	0.12
	1945	.10	.12	.14	.13	.12	.13	.13	[1] .13	.13	[1] .12	.09	[1] .09
	1949	.10	.07	.10	.14	.15	.14	.24	[1] .13	.16	[1] .09	.07	[1] .09
Wheat	1942	.13	.10	.14	.10	.14	.14	.17	([2])	.13	([2])	.09	([2])
	1946	.15	.12	.16	[1] .09	.18	[1] .13	.17	.19	.15	.14	.08	.11
Meadow 1	1943	.05	([2])	.11	([2])	.18	([2])	.13	([2])	.17	([2])	.07	([2])
	1947	.07	.13	.13	.11	.20	.15	.17	.13	.13	.14	.16	.13
Meadow 2	1944	.06	([2])	.14	([2])	.14	.19	.14	.22	.14	.18	.09	.11
	1948	.12	.12	.22	.13	.23	.15	.18	.14	.10	.16	.10	.12

[1] Evaporation affected by shielding of crops.

[2] No record.

A similar comparison for second-year meadow (1948) appears in figure 37. There is no noticeable difference in the curves until early May. From then until the first hay harvest, ET — CA was over 50 percent greater than the pan evaporation. From late June until the second cutting of hay, ET — CA was over 20 percent greater than pan evaporation, indicating again the effect of crop quantity and quality on ET — CA.

The above comparisons of ET — CA at Y102 and BPI-pan evaporation are summarized in table 25, which also contains additional data for earlier years. Average daily values of ET — CA for the various months reflect the condition of the crop. For example, the second-year meadow in 1948 was much better in quality and quantity than that of 1944. Consequently, ET — CA was noticeably greater in 1948 for every month except August. Extremely dry weather in August 1948 affected the ET — CA value. In 1944, August had over 4 inches of rainfall, whereas the August 1948 rainfall was less than 1 inch. Apparently, great excesses or deficiencies of soil moisture also affect ET — CA.

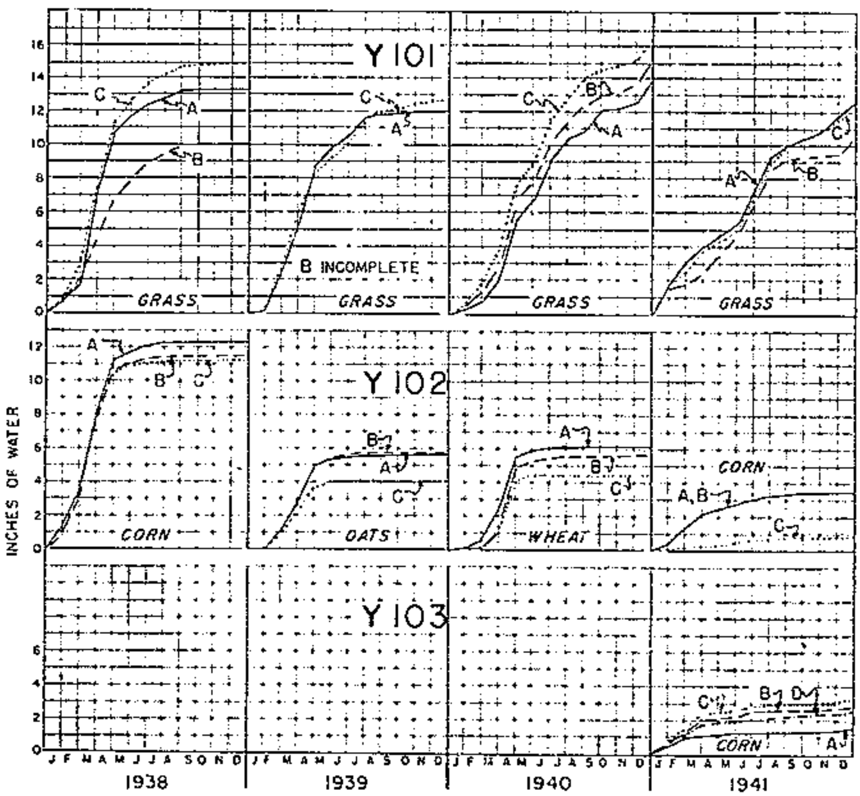

FIGURE 38.—Accumulated monthly percolation for all lysimeters, by years, 1938–41.

The Lysimeter for Measuring Percolation

Percolation data from the lysimeters are presented in two parts: (1) Amounts and rates of percolation water, and (2) chemical analysis of the percolates. Amount and rate of percolation affect the chemical content.

AMOUNTS AND RATES

Percolation water, the water which had seeped downward beyond the root zone of the soil into the underlying sandstone or shale rock, was measured by all 11 lysimeters. Under natural conditions this water contributes to the ground-water supply and thereby replenishes the water in springs, wells, and streams.

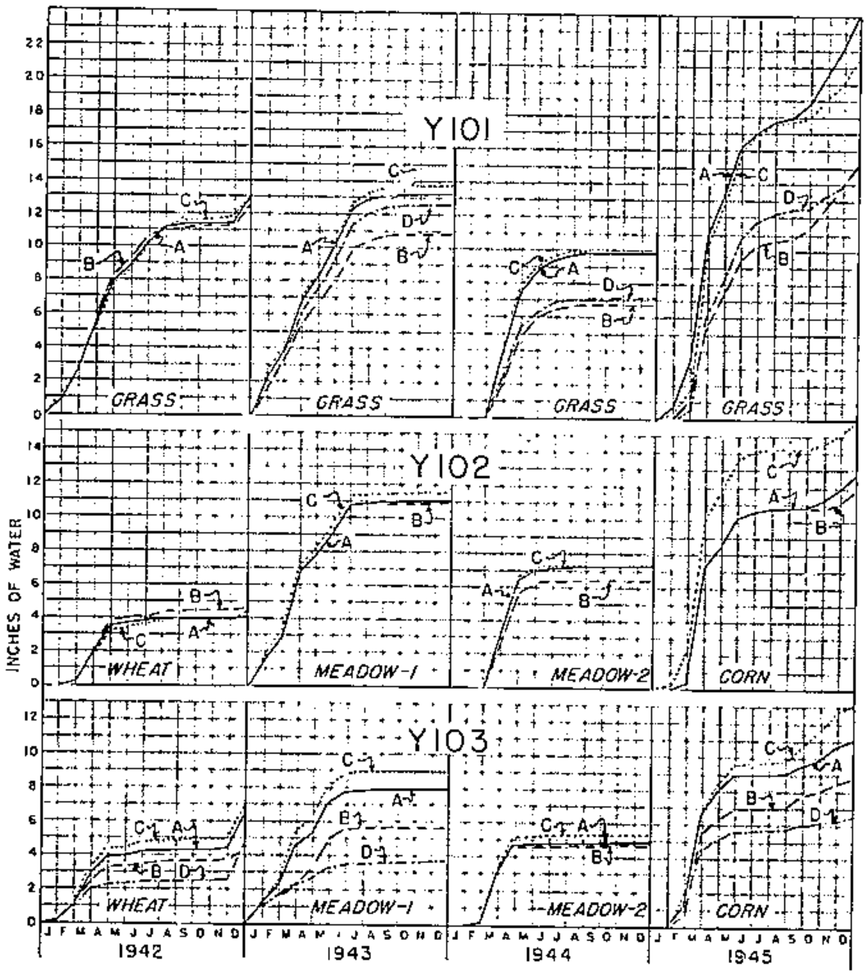

FIGURE 39.—Accumulated monthly percolation for all lysimeters, by years, 1942–45.

Most of the percolation through the soil profile occurred during late winter and early spring. This is the period when soil moisture was at or near saturation following several months of almost continuous accretion with very little depletion by evapo-transpiration. The low point of soil moisture was usually reached sometime in the period August to October. Percolation usually had stopped early in the summer. From October until spring, accretion usually exceeded depletion. The peaks of percolation rates paralleled peaks of high soil-moisture content of the soil profile.

Monthly values of percolation from all lysimeters are given in tables 26, 27, and 28. Curves of accumulated monthly percolation by years appear in figures 38, 39, and 40. Precipitation, especially during the winter and spring months, exerted the greatest effect on percolation. Soil type, soil moisture, land use, and freezing were also major influences. Factors which affect soil-water supplies, such as surface runoff and evapo-transpiration, tend to affect the amount of water available for percolation. A reduction in either surface runoff or evapo-transpiration may increase percolation.

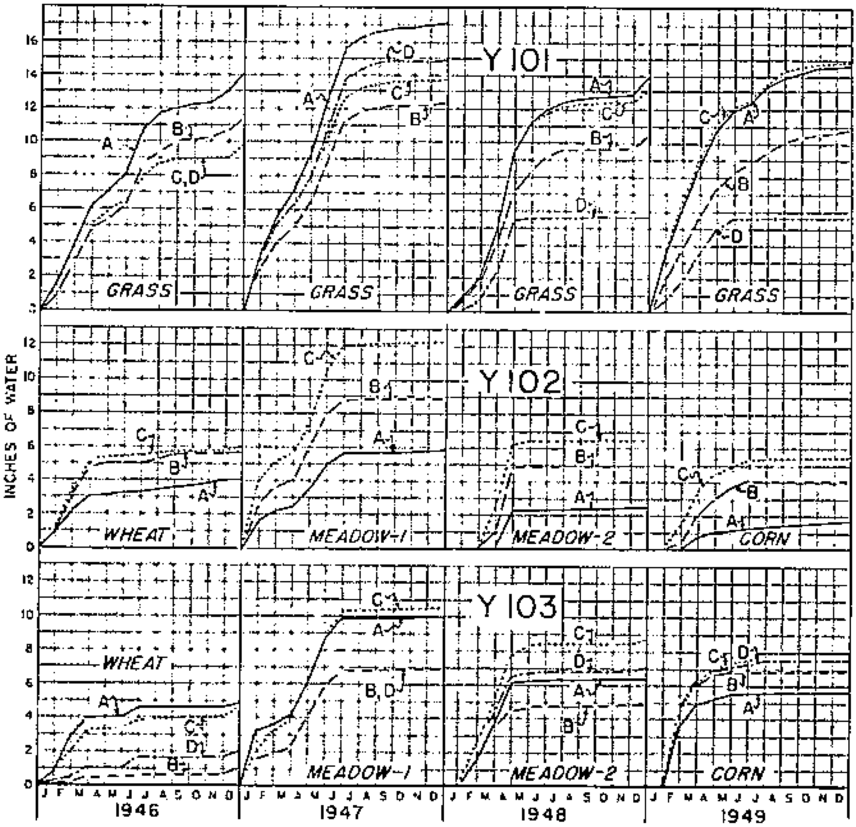

FIGURE 40.—Accumulated monthly percolation for all lysimeters, by years, 1946–49.

TABLE 26.—*Monthly percolation data, lysimeter battery Y101, 1938–49*

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inche*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1938 ..	A ..	0.876	1.848	4.548	3.516	0.936	0.708	0.348	0.420	.060	0	0	0	13.260
	B ..	.804	1.200	2.568	2.244	1.152	1.008	.444	.492	.108	0	.012	T	10.032
	Average:	.840	1.524	3.558	2.880	1.044	.858	.396	.456	.084	0	.006	T	11.646
	C ..	.996	2.028	4.764	3.528	1.356	1.044	.444	.456	.180	0	.024	T	14.820
1939	A	.216	[1]2.204	2.832	3.500	1.060	.706	1.078	.298	.036	.024	.057	.046	12.057
	B	.240	[1]0.942	[1]1.344	[1]0.366	.904	.628	.994	.271	.022	.239	.030	.057	6.037
	Average:	.228	1.573	2.088	1.933	.982	.667	1.036	.285	.029	.131	.044	.051	9.047
	C	.384	[1]2.462	3.210	[1]2.332	[1].850	.970	1.468	.400	.072	.330	.160	.126	12.764
1940	A	.359	.429	1.277	3.572	1.145	2.531	1.210	.426	1.234	.042	.300	1.522	14.047
	B	.550	.868	1.462	3.872	1.240	2.334	1.300	.846	.550	.204	.444	1.588	15.258
	Average:	.455	.648	1.369	3.722	1.193	2.432	1.255	.636	.892	.123	.372	1.555	14.652
	C	.726	1.102	2.056	3.842	1.240	2.514	1.324	1.284	.490	.102	.474	1.642	16.796
1941	A	1.884	1.368	.828	.672	.636	1.908	2.184	.708	.276	.396	.960	.846	12.666
	B ..	1.536	.299	.678	1.217	.990	1.931	1.951	.660	.102	.114	.034	1.183	10.695
	Average:	1.710	.834	.753	.944	.813	1.920	2.068	.684	.189	.255	.497	1.015	11.682
	C	1.872	.828	1.200	.516	.648	2.112	2.016	.936	.264	.528	.732	.708	12.360

1942...	A	1.104	1.596	2.838	2.466	.918	1.338	.912	.174	.024	.018	.018	1.560	12.966
	B	.960	1.858	3.024	2.472	1.032	1.266	.378	.174	.036	0	.078	1.302	12.580
	Average:	1.032	1.727	2.931	2.469	.975	1.302	.645	.174	.030	.009	.048	1.431	12.773
	C	1.362	1.314	2.670	2.364	1.080	1.428	.888	.396	.114	.048	.288	1.188	13.140
1943...	A	2.436	1.512	3.024	1.308	1.788	2.364	.528	.180	.048	.012	.012	0	13.212
	B	2.100	1.464	2.004	1.164	1.416	1.884	.492	.276	.048	.012	0	0	10.860
	Average:	2.268	1.488	2.514	1.236	1.602	2.124	.510	.228	.048	.012	.006	0	12.036
	C	2.796	1.428	2.928	1.176	1.824	2.580	.600	.312	.060	.012	0	0	13.716
	D	1.968	1.440	2.892	1.272	1.668	2.196	.612	.408	.120	.024	0	0	12.600
	Average:	2.382	1.434	2.910	1.224	1.746	2.388	.606	.360	.090	.018	0	0	13.158
1944...	A	.012	.180	3.900	3.474	1.278	.612	.276	.087	.006	.012	.003	.036	9.876
	B	0	.180	2.058	2.706	1.122	.486	.186	.018	.003	.003	0	.003	6.765
	Average:	.006	.180	2.979	3.090	1.200	.549	.231	.052	.005	.007	.002	.020	8.321
	C	.024	.240	4.068	3.468	1.278	.540	.198	.035	.007	.004	0	.023	9.884
	D	.072	.108	2.370	2.742	1.044	.546	.222	.012	0	0	0	0	7.116
	Average:	.048	.174	3.219	3.105	1.161	.543	.210	.024	.003	.002	0	.011	8.500
1945...	A	.750	2.841	7.437	2.471	2.660	.976	.486	.176	.886	1.829	1.667	2.076	24.255
	B	.018	1.098	4.516	1.841	2.029	.792	.357	.124	.520	1.317	1.313	1.461	15.386
	Average:	.384	1.969	5.977	2.156	2.345	.884	.421	.150	.703	1.573	1.490	1.769	19.821
	C	.357	2.435	7.518	2.487	3.180	1.044	.544	.133	.270	1.191	.826	1.674	21.659
	D	0	.636	5.740	1.968	2.441	1.011	.471	.204	.024	.807	.697	1.350	15.349
	Average:	.179	1.535	6.629	2.228	2.810	1.027	.508	.168	.147	.999	.762	1.512	18.504

See footnotes at end of table.

TABLE 26.—*Monthly percolation data, lysimeter battery Y101, 1938–49*—Continued

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1946	A	1.698	2.119	2.436	0.894	0.963	2.649	0.930	0.384	0.192	0.090	0.591	1.242	14.188
	B	1.231	1.532	2.199	.792	.840	2.310	.849	.339	.120	.081	.438	.954	11.685
	B	1.465	1.825	2.318	.843	.902	2.479	.890	.361	.156	.085	.514	1.098	12.936
	C	1.156	1.783	2.265	.801	.444	1.510	.864	.198	.042	.012	.099	.648	9.822
	D	1.123	1.876	2.106	.801	.423	1.492	.861	.242	.102	.020	.088	.669	9.803
	Average:	1.140	1.829	2.186	.801	.433	1.501	.862	.220	.072	.016	.094	.658	9.812
1947	A	3.562	2.181	1.287	2.313	3.416	2.901	.702	.294	.159	.065	.034	.165	17.079
	B	2.517	1.641	.852	1.557	2.484	2.247	.600	.216	.086	.037	.014	.139	12.390
	Average:	3.040	1.911	1.070	1.935	2.950	2.574	.651	.255	.122	.051	.024	.152	14.735
	C	3.282	2.038	1.029	1.635	2.349	2.361	.639	.231	.104	.052	.032	.031	13.783
	D	3.258	1.928	1.005	1.653	3.096	2.850	.735	.282	.045	0	0	0	14.852
	Average:	3.270	1.983	1.017	1.644	2.722	2.606	.687	.256	.074	.026	.016	.016	14.318
1948	A	.909	1.125	2.757	4.644	1.830	.765	.390	.204	.070	.008	.126	1.098	13.926
	B	.861	1.023	2.160	2.979	1.548	.714	.303	.087	.015	.003	.021	.777	10.491
	Average:	.885	1.074	2.458	3.812	1.689	.740	.346	.145	.043	.005	.074	.938	12.209
	C	.561	1.599	2.709	4.755	1.518	.723	.339	.171	.060	.008	.028	.639	13.110
	D	0	.660	1.587	3.264	.083	.007	.004	.008	0	0	0	0	5.613
	Average:	.280	1.130	2.148	4.009	.801	.365	.171	.090	.030	.004	.014	.320	9.362

1949...	A.......	3.429	2.682	2.577	2.058	1.161	0.498	0.963	0.693	0.243	0.225	0.075	0.471	15.075
	B.......	1.950	1.848	1.890	1.608	1.047	.444	.720	.693	.225	.198	.120	.498	11.241
	Average:	2.689	2.265	2.234	1.833	1.104	.471	.842	.693	.234	.211	.098	.484	13.158
	C.......	3.651	2.868	2.655	1.884	1.002	.426	1.059	.849	.261	.111	.077	.178	15.021
	D.......	.690	1.149	1.719	1.380	.603	.036	.003	0	0	0	0	0	5.580
	Average:	2.171	2.009	2.187	1.632	.803	.231	.531	.424	.130	.055	.039	.089	10.301
	12-year Average:													
	A....	1.436	1.674	2.978	2.574	1.483	1.496	.834	.337	.269	.227	.320	.755	14.383
	B....	1.064	1.163	2.063	1.902	1.317	1.337	.715	.349	.153	.184	.209	.664	11.120
	A & B	1.250	1.419	2.521	2.238	1.400	1.417	.774	.343	.211	.206	.264	.710	12.752
	C....	1.431	1.677	3.089	2.399	1.397	1.438	.865	.450	.160	.199	.228	.572	13.902
	[2]D....	1.016	1.114	2.488	1.869	1.337	1.163	.415	.165	.042	.122	.112	.288	10.131

[1]Record incomplete. [2]7-year average.

TABLE 27.—*Monthly percolation data, lysimeter battery Y102, 1938–49*

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1938...	A........	1.224	2.268	4.848	3.012	0.408	0.432	0.132	0.024	0	0	0	0	12.348
	B....	.840	2.232	4.668	2.868	.408	.324	.096	.024	0	0	0	0	11.460
	C........	[1] .972	2.340	[1]4.308	2.868	.360	.324	.072	.012	0	0	0	0	[1]11.256
	Average:	[2]1.032	2.280	[2]4.758	2.916	.392	.360	.100	.020	0	0	0	0	11.858
1939...	A........	0	1.164	1.579	2.288	.387	.150	[1] .061	[1]0	0	0	0	0	[1]5.629
	B........	0	.962	1.706	2.275	.463	.234	.127	[1]0	0	.043	0	0	[1]5.810
	C........	0	.976	1.340	[1]1.441	323	.078	.023	.004	0	.009	0	0	[1]4.194
	Average:	0	1.034	1.542	[2]2.282	.391	.154	[2] .070	[2] .004	0	.017	0	0	5.211
1940...	A........	.123	.453	1.779	3.276	.360	.132	.052	.012	0	0	0	0	6.187
	B........	.044	.130	1.263	3.542	.432	.150	.085	.024	.012	0	0	0.091	5.773
	C........	.020	.128	1.019	2.980	.354	.066	.015	.004	.004	.003	0	0	4.593
	Average:	.062	.237	1.354	3.266	.382	.116	.051	.013	.005	.001	0	.030	5.517
1941...	A........	.420	.960	.816	.384	.156	.336	.228	.108	.012	0	0	0	3.420
	B........	.468	.960	.780	.348	.312	.348	.192	.132	0	0	0	0	3.540
	C........	.119	.114	.064	.042	.187	.156	.090	.051	.002	.004	.031	0	.860
	Average:	.336	.678	.553	.258	.218	.280	.170	.097	.005	.001	.010	0	2.606
1942...	A........	0	.276	1.818	1.476	.174	.048	.084	.060	.006	.006	0	.204	4.152
	B........	0	.220	2.012	1.608	.204	.084	.276	.066	.012	.018	0	.150	4.650
	C........	.006	.222	1.620	1.536	.138	.234	.150	.024	.036	.018	.018	.402	4.404
	Average:	.002	.239	1.817	1.540	.172	.122	.170	.050	.018	.014	.006	.252	4.402

1943	A	1.608	1.248	3.936	1.092	1.248	1.656	.144	.060	.048	.024	.024	.012	11.100
	B	1.512	1.392	3.816	1.140	1.272	1.692	.084	.036	0	.012	0	0	10.956
	C	1.956	1.536	3.636	1.104	1.428	1.668	.096	.072	.024	.036	.024	.012	11.592
	Average:	1.692	1.392	3.796	1.112	1.316	1.672	.108	.056	.024	.024	.016	.008	11.216
1944	A	.012	0	3.342	3.150	.540	.132	.030	.006	0	.003	0	.009	7.224
	B	0	0	2.658	3.126	.510	.114	.030	.003	0	0	0	0	6.441
	C	0	.012	3.432	3.222	.504	.102	.024	0	0	0	0	.021	7.317
	Average:	.004	.004	3.144	3.166	.518	.116	.028	.003	0	.001	0	.010	6.994
1945	A	.021	.390	6.903	1.275	1.628	.372	.171	.054	.014	.484	.642	.921	12.875
	B	0	.123	6.939	1.486	1.614	.387	.159	.052	.011	.081	.030	.996	11.878
	C	.258	2.215	7.735	1.817	1.827	.342	.129	.036	.003	.246	.675	.927	16.210
	Average:	.093	.909	7.192	1.526	1.690	.367	.153	.047	.009	.270	.449	.948	13.654
1946	A	1.102	1.197	.777	.141	.090	.084	.126	.123	.117	.165	.134	.043	4.099
	B	1.050	2.287	1.445	.249	.070	.019	.166	.342	.051	.013	.002	0	5.694
	C	1.083	2.456	1.659	.242	.080	.071	.105	.125	.019	.027	.044	.151	6.062
	Average:	1.078	1.980	1.294	.211	.080	.058	.132	.197	.062	.068	.060	.065	5.285
1947	A	1.635	.649	.168	1.167	1.485	.588	.054	.044	.038	.036	.029	.018	5.911
	B	2.717	1.054	.363	2.067	1.845	.777	.068	.039	.023	.018	.015	.012	8.998
	C	4.156	1.163	.423	2.007	3.000	1.457	.076	.016	.004	.003	.011	.004	12.320
	Average:	2.836	.955	.318	1.747	2.110	.941	.066	.033	.032	.019	.018	.011	9.086
1948	A	.021	.016	.158	2.079	.038	.031	.035	.025	.025	.019	.019	.016	2.482
	B	.007	.016	.847	3.969	.098	.022	.016	.011	.007	.005	.009	.006	5.013
	C	.010	.143	2.331	3.884	.104	.004	.006	.003	0	.011	.013	.012	6.521
	Average:	.013	.058	1.112	3.311	.080	.019	.019	.013	.010	.012	.014	.011	4.672

See footnotes at end of table.

TABLE 27.—*Monthly percolation data, lysimeter battery Y102, 1938–49*—Continued

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1949...	A........	0.081	0.790	1.182	0.551	0.271	0.186	0.104	0.033	0.002	0.002	0.009	0	3.212
	B........	0	.344	2.016	1.001	.336	.315	.129	.044	.018	.013	.007	.006	4.229
	C......	.138	1.347	2.018	.939	.462	.318	.177	.057	.003	.005	.016	0	5.480
	Average:	.073	.827	1.739	.830	.356	.273	.137	.045	.008	.007	.011	.002	4.307
	12-year Average:													
	A	.521	.784	2.275	1.658	.566	.345	.102	.045	.022	.062	.071	.102	6.553
	B	.553	.810	2.376	1.973	.630	.372	.119	.064	.011	.017	.005	.105	7.035
	C	.726	1.054	2.465	1.840	.731	.402	.080	.034	.008	.030	.069	.127	7.566
	A,B,C	.600	.883	2.372	1.824	.643	.373	.100	.048	.014	.036	.048	.111	7.052

[1] Record incomplete.

[2] Average includes complete records only.

The greatest amount of percolation came from the Muskingum silt loam of sandstone origin (battery Y101). The maximum annual amount of 24.25 inches was obtained from lysimeter Y101A in 1945. The annual rainfall that year was over 45 inches. The minimum annual amount from the lysimeters of battery Y101 was about 6 inches in 1939, 1948, and 1949. The annual variation is due largely to precipitation and to a lesser extent to other meteorological and biological factors. The highest monthly percolation values were obtained in March, April, and February for all lysimeters. Percolation in appreciable quantities occurred also in May, June, and January. In the last half of the year it was negligible except for periods of excessive rainfall.

The vegetation on all lysimeters of battery Y101 was the same up through 1944 except for lysimeter Y101D which was practically bare in 1943, the first year of its operation. Percolation values for lysimeters Y101A, Y101B, and Y101C (fig. 38) from 1939-42 were almost identical. After 1942, percolation from lysimeter Y101B for some unknown reason was less than from Y101A and Y101C. Percolation values from Y101D appear to correspond closely with those from Y101B from 1944 through 1946. In 1945, percolation from Y101D was greater than from Y101B. In 1948 and 1949, however, the reverse was the case, percolation from Y101D being much less.

Transpiration was probably an important factor in causing the 1948 and 1949 percolation from Y101D to differ so greatly from that of the other lysimeters in battery Y101. The variation of percolation along with vegetal changes for lysimeters Y101B, Y101C, and Y101D in 1944-49 are given in table 29 (data from Y101A omitted because of soil slumping during the construction operations). Evapo-transpiration values for Y101D (April-August) in this table are low for 1944. Poverty grass was the predominant cover on all three lysimeters. Percolation from Y101B and Y101D was about the same.

In 1945 the new seeding on Y101C and Y101D made little growth, evapo-transpiration was the same as in 1944, and there was practically no difference between the percolation from Y101B and Y101D. In 1946 the bluegrass and clover made good growth. Evapo-transpiration from Y101D increased by several inches of water. Percolation from Y101D was less than that for Y101B. The relatively small amount of soil moisture used by the poverty grass on the latter probably resulted in leaving more water available for percolation.

In 1947 the vegetation on Y101D was torn up and a seeding of brome grass, ladino clover, and alfalfa made. In that year the evapo-transpiration was lower than in 1946 as the new seeding made very little growth and drew little moisture from the soil. Percolation from Y101D in 1947 increased greatly and exceeded that from Y101B. In 1948 and 1949 the legume-grass mixture on Y101D apparently made heavy use of water. Evapo-transpiration on that lysimeter took so much soil water that less was available for percolation. Less than 6 inches of water drained from Y101D,

TABLE 28.—*Monthly percolation data, lysimeter battery Y103, 1940–49*

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
1940...	A........	....	....	([1])	([1])	([1])	0.067	0.024	0.124	0.018	0.018	0.030	0.732	[1]1.013
	B........	....	....	[1]0.304	1.925	0.063	.042	.077	.185	.018	.006	.132	.984	[1]3.736
	Average:	....	....	[1] .152	[1] .962	[1] .032	0.055	.050	.155	.018	.012	.081	.858	[1]2.375
	C........	....	....	[1] .094	1.797	.053	.018	.030	.035	.011	.006	.012	.816	[1]2.872
	D........	....	....	[1] .136	1.328	.054	.042	.136	.180	.018	.006	.024	.744	[1]2.668
	Average:	....	....	[1] .115	1.562	.054	.030	.083	.107	.015	.006	.018	.780	[1]2.770
1941...	A........	0.624	0.306	.186	.052	.042	.042	.018	.024	.054	.036	.054	.096	1.533
	B........	.708	.672	.672	.144	.072	.312	.024	.048	0	0	.048	.120	2.820
	Average:	.666	.489	.429	.098	.057	.177	.021	.036	.027	.018	.051	.108	2.177
	C........	.720	.876	.720	.192	.036	.360	.048	.048	.036	0	.060	.228	3.324
	D........	.576	.732	.348	.228	.048	.132	.024	.144	.108	.036	.036	.192	2.604
	Average:	.648	.804	.534	.210	.042	.246	.036	.096	.072	.018	.048	.210	2.964
1942...	A........	.138	.900	1.962	.948	.042	.246	.090	.018	.018	.006	.162	1.992	6.522
	B........	.108	.870	1.608	.804	.042	.156	.126	.018	.012	.012	.048	.612	4.416
	Average:	.123	.885	1.785	.876	.042	.201	.108	.018	.015	.009	.105	1.302	5.469
	C........	.234	1.050	2.094	1.080	.054	.360	.102	.030	.024	.006	.048	1.926	7.008
	D........	.162	.978	.912	.252	.102	.090	.036	.024	.012	.024	.024	2.046	4.662
	Average:	.198	1.014	1.503	.666	.078	.225	.069	.027	.018	.015	.036	1.986	5.835

1943...	A.......	1.176	1.212	2.316	.660	1.908	.528	.048	.060	.024	.024	.012	0	7.968
	B.......	.948	.600	.720	.996	1.800	.564	.036	.024	0	0	.024	.012	5.724
	Average:	1.062	.906	1.518	.828	1.854	.546	.042	.042	.012	.012	.018	.006	6.846
	C.......	1.188	1.512	2.868	.792	1.836	.756	.048	.024	.024	.012	0	.024	9.084
	D.......	1.056	.636	.672	.312	.636	.240	.036	.024	.024	0	.012	.036	3.684
	Average:	1.122	1.074	1.770	.552	1.236	.498	.042	.024	.024	.006	.006	.030	6.384
1944...	A.......	.036	.252	2.838	1.674	.072	.036	.024	.015	.012	.003	0	0	4.962
	B.......	.048	.072	2.436	2.088	.048	.012	.015	.015	0	0	0	.018	4.752
	Average:	.042	.162	2.637	1.881	.060	.024	.020	.015	.006	.002	0	.009	4.852
	C.......	.036	.036	3.042	2.142	.108	.036	.033	.021	.009	.009	.006	.014	5.492
	D.......	.036	.024	2.226	1.716	.078	.030	.012	.009	.003	.006	0	.005	4.145
	Average:	.036	.030	2.634	1.929	.093	.033	.023	.015	.006	.008	.003	.009	4.819
1945...	A.......	0	1.371	5.468	1.368	.780	.060	.028	.014	.546	.431	.765	.183	11.014
	B.......	.014	1.387	3.220	.693	.363	.087	.020	.007	.309	.153	.163	.105	6.521
	Average:	.007	1.379	4.344	1.031	.571	.073	.024	.010	.428	.292	.464	.144	8.767
	C.......	.019	1.842	4.956	1.848	1.066	.096	.052	.029	.881	.864	1.141	.372	13.166
	D.......	.004	.876	4.746	.957	.471	.022	.015	.005	.840	.330	.381	.216	8.863
	Average:	.011	1.359	4.851	1.402	.769	.059	.034	.017	.860	.597	.761	.294	11.014
1946...	A.......	.797	2.195	1.034	.062	.029	.497	.040	.017	.013	.011	.006	.280	4.981
	B.......	.097	.095	.273	.062	.028	.080	.065	.020	0	.021	.035	.304	1.080
	Average:	.447	1.145	.654	.062	.028	.289	.053	.018	.006	.016	.020	.292	3.030

See footnote at end of table.

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TABLE 28.—*Monthly percolation data, lysimeter battery Y103, 1940–49*—Continued

Year	Lysimeter	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual total
		Inches	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*	*Inches*
	C........	1.019	0.984	1.386	0.068	0.041	0.470	0.084	0.034	0.020	0.016	0.019	0.574	4.715
	D........	.293	.241	.484	.055	.029	.566	.047	.018	.013	.007	.010	.457	2.220
	Average:	.656	.612	.935	.062	.035	.518	.066	.026	.017	.011	.014	.516	3.468
1947...	A........	3.319	.282	.576	1.896	2.658	1.114	.045	.032	.016	.010	.005	.003	9.956
	B........	1.578	.432	.327	1.962	1.793	.786	.040	.028	.019	.004	.032	.038	7.039
	Average:	2.448	.357	.452	1.929	2.225	.950	.042	.030	.018	.007	.018	.020	8.496
	C........	2.809	.507	.681	2.199	2.871	1.374	.053	.030	.022	.012	.014	.013	10.585
	D........	1.620	.372	.411	1.479	2.139	.744	.050	.030	.019	.009	.012	.006	6.891
	Average:	2.214	.440	.546	1.839	2.505	1.059	.052	.030	.020	.010	.013	.010	8.738
1948...	A........	.007	1.544	2.188	2.420	.101	.022	.012	.009	0	.003	0	.003	6.309
	B........	.029	1.544	1.935	1.005	.203	.052	.038	.004	.030	.026	.058	.043	4.967
	Average:	.018	1.544	2.062	1.713	.152	.037	.025	.006	.015	.014	.029	.023	5.638
	C........	.240	2.400	2.487	2.695	.608	.045	.033	.018	.009	0	.003	.246	8.784
	D........	.073	2.219	2.064	2.049	.367	.032	.029	.010	.040	.026	.012	.150	7.071
	Average:	.157	2.310	2.276	2.372	.487	.038	.031	.014	.025	.013	.007	.198	7.928
1949...	A........	1.959	1.585	1.422	.366	.138	.012	.050	.001	.003	.003			5.539
	B........	2.569	1.920	1.563	.624	.180	.022	.088	.010	.033	.006	.012	.033	7.060
	Average:	2.264	1.753	1.493	.495	.159	.017	.069	.005	.018	.004	.006	.017	6.300

C	2.499	1.839	1.848	.813	.441	.084	.483	.057	.022	.013	.013	.087	8.199
D	2.787	1.864	1.665	.558	.360	.055	.133	.031	.022	.005	.006	.108	7.594
Average:	2.643	1.852	1.757	.685	.401	.069	.308	.044	.022	.009	.009	.098	7.897
10-year Average:													
A	.806	.965	1.799	.945	.577	.262	.038	.031	.070	.055	.103	.329	5.980
B	.610	.759	1.306	1.030	.459	.211	.053	.036	.042	.023	.055	.227	4.811
A & B	.708	.862	1.553	.987	.518	.236	.046	.033	.056	.039	.079	.278	5.395
C	.876	.794	2.018	1.363	.711	.360	.097	.033	.106	.094	.132	.430	7.014
D	.661	1.105	1.366	.893	.428	.195	.052	.048	.110	.045	.052	.396	5.351
C & D	.769	.949	1.692	1.128	.570	.277	.075	.040	.108	.069	.092	.413	6.182

[1]Record incomplete.

TABLE 29.—*Percolation, evapo-transpiration and vegetal cover for lysimeters Y101B, Y101C, and Y101D, 1944–49*

Year	Lysimeter	Cover	Percolation for the year	April – August evapo-transpiration (ET – CA)
			Inches	*Inches*
1944..	Y101B	Poverty grass	6.8	
	Y101C	....do	9.9	
	Y101D	....do	7.1	18.4
1945..	Y101B	Poverty grass	15.4	
	Y101C	New seeding of bluegrass and clover	21.7	
	Y101D	....do	15.3	18.4
1946..	Y101B	Poverty grass	11.7	
	Y101C	Bluegrass and clover	9.8	
	Y101D	....do	9.9	23.7
1947..	Y101B	Poverty grass	12.4	
	Y101C	Bluegrass	13.8	
	Y101D	New seeding of bromegrass, ladino clover, and alfalfa	14.9	20.2
1948..	Y101B	Poverty grass	10.5	
	Y101C	Bluegrass	13.1	
	Y101D	Bromegrass, ladino clover, and alfalfa	5.6	23.2
1949..	Y101B	Poverty grass	11.2	
	Y101C	Bluegrass	15.0	
	Y101D	Bromegrass, and alfalfa	5.6	27.0

whereas twice that much came from Y101B (poverty grass). In both 1948 and 1949, percolation stopped about 3 months earlier from Y101D than from Y101B.

Although there may be several reasons why the 1948 and 1949 percolation from lysimeter Y101D was much less than from the other lysimeters in battery Y101, it appears that evapo-transpiration was by far the most influential factor. The deeply rooted grass (brome) and legume (alfalfa) apparently used water in large enough quantities to significantly reduce the percolation. Seasonal water requirements may also account for large differences in evapo-transpiration for the various crops in different seasons.

Although lysimeter batteries Y101 and Y102 are both on Muskingum silt loam, the sandstone bedrock on battery Y101 has produced a very permeable soil through which soil water percolates freely. The influence of shale on Y102 has produced a heavier soil resulting in a lower permeability and, therefore, lower percolation values. The maximum annual percolation from battery Y102 came from Y102C, 16.2 inches in 1945. The minimum was less than 1 inch from Y102C in 1941. For all but the last 3 years of record, the annual percolation values from all three lysimeters were not greatly different. Variation in the 1947-49 period appears to be consistent but the cause has not been ascertained.

The highest monthly percolation from lysimeters in battery Y102 occurred in March 1945 when 7.73 inches was obtained from lysimeter Y102C. There were a number of years with no percolate in September, October, November, December, or January. Percolation was appreciably lower from lysimeter battery Y102 than from battery Y101. The effect of soil type on percolation is evident from a comparison of the percolation for the Keene silt loam (battery Y103) with that for Muskingum silt loam (battery Y102). Percolation rates are more erratic on the former due to the texture and structure of the various soil horizons. The subsoil of the Keene is a heavy silt loam grading into silty clay loam and then into silty clay. The high colloidal content of the latter enhances swelling and shrinking of this soil layer which directly influences percolation. When the soil is saturated or nearly so, the colloids swell to such an extent that the soil is almost impermeable. When the soil dries and shrinks, the cracks produced facilitate percolation of the soil water. Presumably, these cracks close very slowly because high percolation rates sometimes occur many times over a period of several months. The highest monthly percolation on the Keene silt loam occurred in March 1945 when lysimeter Y103A yielded 5.47 inches. The highest annual percolation on this soil was 13.17 inches in 1945; the lowest, 1.08 inches in 1946.

The differences in the amount of percolation from heavy rainfall in March and September, 1945 was extremely great as shown in figure 41. Of the 7.5 inches of rain in March, percolation averaged 6.3 inches for lysimeters in battery Y101, 7.2 inches for those in Y102, and 4.6 inches for Y103. Of the 9.5 inches of rainfall in September, percolation averaged 0.4 inch for Y101, 0.3 inch for Y102, and 0.6 inch for Y103 (fig. 42). Large differences in soil moisture (fig. 10)—very wet in March and very dry prior to the September rain—were major factors in causing such wide differences in percolation for the two periods.

A detailed study of the periods of high rainfall and percolation rates (figs. 41 and 42) shows the approximate time-lag of percolation after rainfall. Typical curves for each of the three batteries of lysimeters were selected for comparison. In figure 41, percolation is compared with rainfall for the period March 2-12, 1945. Soil moisture preceding this period was well above field capacity. Percolation was active in all lysimeters immediately prior to March 2. Percolation increased markedly after both the March 2 and March 6 storms. Percolation from Y103A on March 6 began to respond about 8 hours after a definite increase in rainfall, in 12 hours from Y102B, and in about 16 hours from Y101. This does not mean that the rain falling on the ground appeared at the 8-foot level of the soil in the lysimeters 8, 12, or 16 hours later, but that the rainfall was effective in causing an increase of water seeping from the bottom of the lysimeters 8, 12, or 16 hours after the rain began. The lag periods and maximum rates of percolation for several lysimeters are presented in table 30.

The maximum 3-hour rates of percolation are between 0.07 and 0.12 inch of water per hour for all lysimeters except Y101B. Maximum rates of percolation may be expected to occur when most of the pores, root channels and other openings are used to transmit the gravitational water. When the soil approaches saturation, percolation rates would govern infiltration rates to a large extent. It has been observed from hydrograph analysis of watershed data that the Muskingum silt loam soils had minimum infiltration rates of about 0.08 inch per hour, a value not greatly different from the maximum percolation rate obtained in these studies.

Percolation rates for unsaturated soils were less than for wet soils, as illustrated by the percolation for the period September 22-October 6, 1945 (fig. 42). Following an exceedingly dry late summer period, percolation response to the September rainfall was slow. In fact, there was no percolation from Y103A until after 5.6 inches of rain had fallen. Likewise, 9.1 inches of rain fell in September before percolation occurred in Y101D. For Y102B it took 10.2 inches of rain, the surface runoff of 1.70 inches probably preventing earlier percolation.

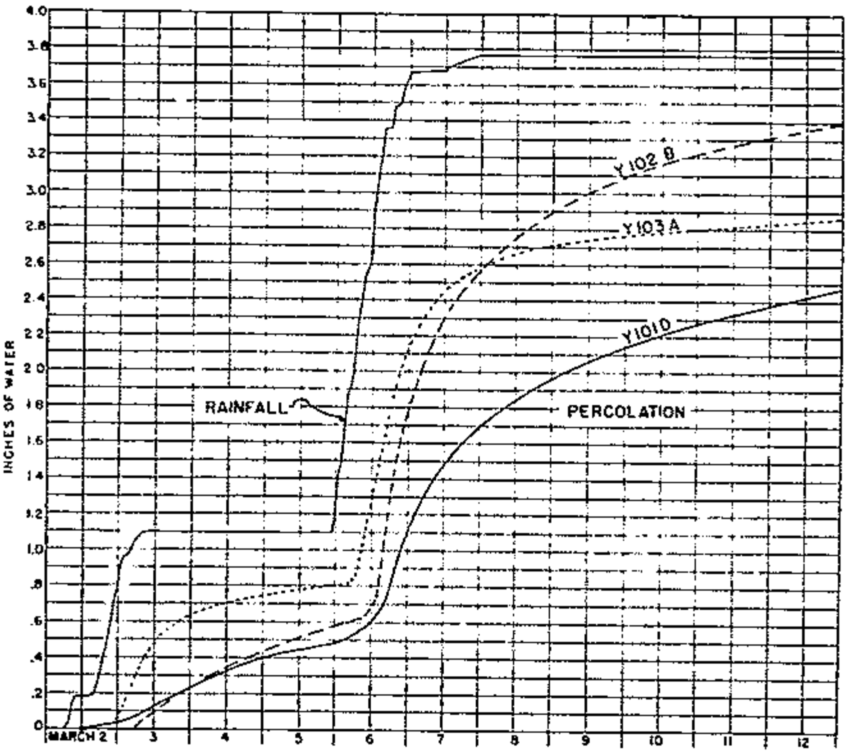

FIGURE 41.—Typical curves of accumulated percolation following rainfall on wet soil, March 2-12, 1945.

TABLE 30.—*Maximum rates of percolation and approximate time lag following rainfall on wet soil, March 1945*

Lysimeter	Maximum 3-hour rate of percolation	Approximate time lag between rainfall and increase of percolation
	Inches of water per hour	*Hours*
Y101B	0.02	18
Y101C	.08	14
Y101D	.08	16
Y102B	.11	12
Y102C	.12	12
Y103A	.10	8
Y103C	.07	8

The 12-year monthly averages of percolation on batteries Y101 and Y102 and the 10-year average on battery Y103 give a good picture of normal percolation values to be expected under average conditions. When unusual conditions of precipitation and other meteorological phenomena occur, percolation varies from the average pattern. This was evident in 1947 when high temperature and high precipitation in January resulted in unusually high per-

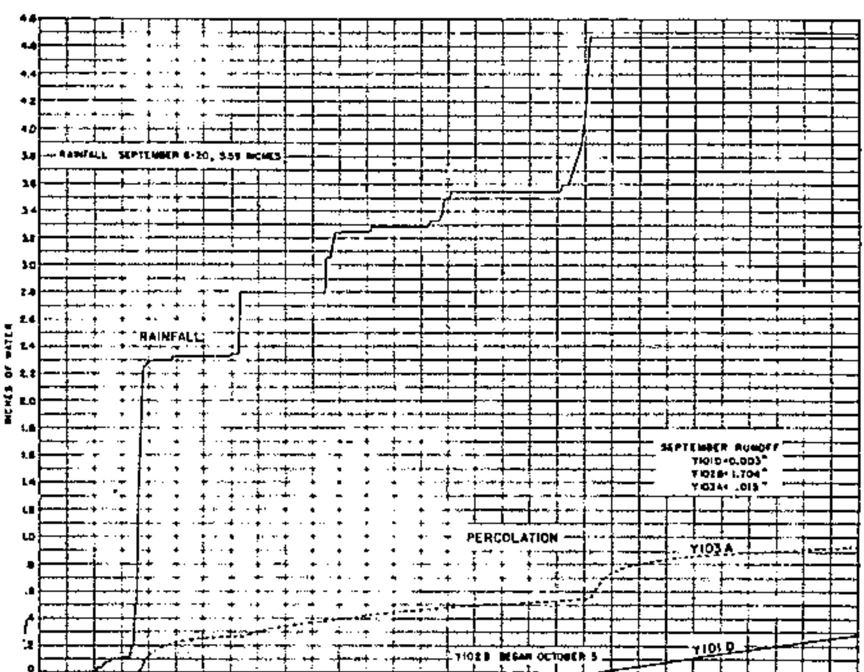

FIGURE 42.—Typical curves of accumulated percolation following a dry summer period, September 22-October 6, 1945.

TABLE 31.—*Summary of annual nutrient losses through percolation, and amounts of percolation water lost, from lysimeter batteries Y101, Y102, and Y103, 1940–49*

NUTRIENT LOSSES (pounds per acre)

Lysimeter	Land use practice [1]	Element	Year								
			1940	1941	1942	1943	1944	1945	1947	1948	1949
Y101	P	K	12.99	14.76	9.66	8.23	9.78	([2])	8.66	4.83	6.49
Y101	I		([2])	8.91	7.37	16.80	24.18	([2])	12.66	8.65	7.64
Y102	I		4.49	3.63	4.79	9.51	7.17	7.50	5.71	4.15	5.00
Y103	I		([2])	8.03	7.69	18.73	14.44	10.99	16.02	8.84	10.06
Y103	P		3.23	19.49	7.34	28.29	18.64	([2])	22.43	17.47	10.84
Y101	P	Ca	25.46	([2])	([2])	11.24	8.66	([2])	18.11	10.08	8.80
Y101	I		([2])	12.41	([2])	20.46	17.88	([2])	20.20	13.36	14.49
Y102	I		13.66	11.60	11.02	32.53	16.28	17.19	14.45	9.27	10.95
Y103	I		([2])	([2])	([2])	38.75	21.40	37.73	34.23	29.79	34.24
Y103	P		16.58	13.80	21.92	30.25	21.80	([2])	37.07	30.80	24.40
Y101	P	Mg	8.07	2.40	2.20	2.37	5.22	([2])	2.80	4.75	6.97
Y101	I		([2])	2.11	2.38	9.29	2.77	([2])	7.20	7.63	7.97
Y102	I		5.80	5.66	7.94	21.73	13.98	15.32	9.82	9.62	8.23
Y103	I		([2])	5.66	4.12	21.49	18.35	31.25	24.37	21.29	25.40
Y103	P		2.26	6.43	6.06	19.27	17.72	([2])	25.13	18.13	19.45
Y101	P	N [3]	.29	.40	.38	.30	.24	.72	.27	.33	.24
Y101	I		([2])	.40	.25	.43	.36	1.36	.50	1.13	.42
Y102	I		6.56	2.63	3.56	6.58	3.72	3.74	4.06	2.25	.84
Y103	I		([2])	.49	.62	2.45	4.02	2.75	11.82	3.38	2.47
Y103	P		4.36	.79	1.46	2.50	4.70	4.37	14.00	6.84	1.55
Y101	P	Mn	.46	.64	.73	.87	.54	([2])	.22	([2])	([2])
Y101	I		([2])	.52	.31	.57	.50	([2])	.14	([2])	([2])
Y102	I		.25	.15	.19	.76	.34	.34	.16	([2])	([2])
Y103	I		([2])	.12	.09	.48	.34	.35	.14	([2])	([2])

Y103	P		.16	.16	.32	.64	.36	([2])	.21	([2])	([2])
Y101	P	S	10.43	7.97	9.52	9.68	6.62	([2])	18.50	([2])	([2])
Y101	I		([2])	6.09	6.65	11.08	8.06	([2])	33.45	([2])	([2])
Y102	I		3.74	([2])	4.14	4.53	3.49	3.91	9.10	([2])	([2])
Y103	I		([2])	7.15	10.87	44.38	24.92	35.87	31.10	([2])	([2])
Y103	P		10.01	8.95	10.85	30.92	19.40	([2])	27.90	([2])	([2])
PERCOLATION (inches of water)											
Y101	P		14.65	11.68	12.77	12.04	8.32	19.82	14.73	12.21	13.16
Y101	I		16.80	12.36	13.14	13.16	8.50	18.50	14.32	9.36	10.30
Y102	I		5.52	2.61	4.40	11.22	6.99	13.65	9.03	4.67	4.31
Y103	I		3.52	2.18	5.47	6.85	4.86	8.77	8.50	5.64	6.30
Y103	P		2.77	2.96	5.84	6.38	4.82	11.01	8.74	7.93	7.90

[1] P—Prevailing or poor practices.
I—Improved or conservation practices. These were started on Y101C and Y101D in April 1945; on Y102 in May 1941; and on Y103A and Y103B in May 1941.

[2] No data.

[3] Nitrate.

colation rates for that month. In February and March of that year, abnormally low temperatures froze the soil, resulting in retarded percolation rates. A detailed account of this has previously been presented (*10*). Soil freezing influenced percolation only when soil moisture was sufficiently high to permit percolation. Under these conditions the density of frozen soil permitted little air to enter the soil profile, thereby retarding percolation. The porous honeycomb and stalactite types of frost structure also permitted more air to enter the soil than the dense concrete type (*38*). Greater air penetration in frozen soil permitted a greater release of water by percolation.

The large variation of percolation among lysimeters on the same soil type is mainly due to internal soil differences and in a small degree to differences in the vegetative growth of the crops on the various lysimeters. Although the improved-practice lysimeters of Y101 and Y103 show lower average percolation values than the poor-practice lysimeters, the differences in percolation cannot be attributed entirely to the agronomic and land treatment practices. There is no doubt that improved-practice lysimeters lose more water by evapo-transpiration than poor-practice lysimeters. Since most percolation occurs during the months when evapo-transpiration is low, it is not unlikely that soil differences influence percolation more than differences in practice.

The data for years in which all lysimeters were in meadow or grass (1943, 1944, 1947, and 1948) provide a good comparison of the effect of soil type on percolation. Soil-type effects on Y102 and Y103 can be compared for any year because both lysimeters are on a 4-year rotation and treatment practices are identical.

PLANT NUTRIENT LOSSES THROUGH PERCOLATION

Losses of the chemical constituents of the soil through percolation were determined by chemical analysis of the lysimeter percolates. The loss of major plant nutrients through percolation has been studied by numerous investigators, as pointed out by Kohnke and Dreibelbis (*26*). In this study, as in many others, attention has been called to the shortcomings of many lysimeters because of the unnatural conditions for percolation, the most serious being the use of filled-in lysimeters or failure to make provision for runoff.

The more natural conditions prevailing on the Coshocton lysimeters made it possible to evaluate more accurately the plant nutrient losses resulting from the leaching process. Moreover, a knowledge of the extent of plant nutrient losses in percolation is important in soil and water conservation research as well as other phases of agriculture.

Dreibelbis (*8*) reported the plant nutrient losses in percolates from the Coshocton lysimeters for the period 1940-1945. The present report brings these data up to date. The nutrient-loss data appear in table 31. The amounts of fertilizer, lime, and manure applied to each lysimeter are given in table 32.

It is evident that nutrient losses are generally lower on the Muskingum silt loam (Y102) than on other soil types. This is probably due mainly to the relative rapidity of percolation which is characteristic of Muskingum soils. On the Keene silt loam, the clay soil particles present a much greater surface area in contact with water. Consequently, the water and soil solution have more opportunity to exert their solvent effect on the soil particles and to dissolve nutrients in the Keene profile than in the more rapidly drained and granular Muskingum soils.

Calcium exceeds the other nutrients in total amount lost through percolation. The Muskingum series shows a smaller loss than the Keene. In the latter, more calcium was lost under improved practices than under prevailing practices, probably due to the addition of limestone to the soil.

Magnesium losses were also higher on the Keene. There was no appreciable difference in losses of magnesium as the result of improved or prevailing practices.

The potassium content of percolates was lower than either calcium or magnesium. The loss of potassium was greater under prevailing practices than under improved practices on the Keene silt loam. On the Muskingum silt loam over sandstone (Y101), the trend after 1943 was the reverse. This was probably due to the poor ability of the clay complex of this light-textured soil to absorb potassium, which apparently allowed the potassium to escape readily by leaching. On the heavier Keene silt loam, the opportunity for absorption and fixation was great enough to limit the amounts of potassium in the percolates. The increased vegetation on the improved-practice lysimeters probably utilized more of the available potassium leaving a lesser amount in the percolate. The repressive effect of limestone additions on the outgo of potassium also may have been a major influence (*29*).

Nitrogen occurs in the percolate mostly, if not entirely, in the form of nitrate, and in this study it was determined only as such. The nitrogen loss was generally greater each year in the prevailing-practice lysimeters than in the improved. As with potassium, this was probably due to heavier utilization of nitrogen by the larger amount of vegetation on the improved lysimeters. Nitrogen losses were generally greater under meadow than under corn or wheat on both the Keene silt loam and the Muskingum silt loam. The smallest losses of nitrogen during the period were from the lysimeters cropped to corn in 1941 and 1949. The greatest amount was lost from lysimeters in meadow.

A summary of the data on nitrates in the percolates from each lysimeter for the period 1940-49 appears in table 33. These data reveal the contrast in nitrogen loss in percolates by soil type and the variations in nitrogen loss from lysimeters on the same soil type. The concentration of nitrogen in the percolate varied considerably from year to year, although it was fairly uniform throughout most of each year. The amount of nitrates lost in percolation varied directly with the quantity of percolation.

TABLE 32.—*Application of fertilizer, lime, and manure, 1937–49*[1]

Year	Lysimeter [2]	Fertilizer		Lime per acre	Manure per acre
		Amount per acre	Kind		
		Pounds		*Tons*	*Tons*
1937	Y101	0	....	0	0
	Y102	0	....	0	8
	Y103	0	....	0	0
1938	Y101	0	....	0	0
	Y102	125	2-12-6	0	0
	Y103	175	2-12-6	0	0
1939	Y101	0	....	0	0
	Y102	100	0-20-0	0	0
		150	0-16-0	....	....
		10	20-0-0	....	....
	Y103	100	0-20-0	0	0
		150	0-16-0	....	....
		10	20-0-0	....	....
1940	Y101	0	....	0	0
	Y102	0	....	0	0
	Y103	0	....	0	0
1941	Y101	0	....	0	0
	Y102	500	2-12-6	....	8
	Y103 A, B	500	2-12-6	....	4
	Y103 C, D	200	2-12-6	....	4
1942	Y101	0	....	0	0
	Y102	0	....	0	0
	Y103 A, B	0	....	0	4
	Y103 C, D	0	....	0	0
1943	Y101	0	....	0	0
	Y102	0	....	0	0
	Y103	0	....	0	0
1944	Y101	0	....	0	0
	Y102	0	....	2.5	6
	Y103 A, B	0	....	2.5	6
	Y103 C, D	0	....	0	6
1945	Y101 A, B	0	....	0	0
	Y101 C, D	500	2-12-6	3	4
	Y102	500	2-12-6	2	0
	Y103 A, B	500	2-12-6	2	0
	Y103 C, D	200	2-12-6	0	0
1946	Y101 A, B	0	....	0	0
	Y101 C, D	400	0-20-0	2	0
	Y102	0	....	0	4
	Y103 A, B	0	....	0	4
	Y103 C, D	0	....	0	0
1947	Y101 A, B	0	....	0	0
	Y101 C, D	500	3-12-12	0	0
	Y102	200	0-12-20	0	0
	Y103 A, B	200	0-12-20	....	....
	Y103 C, D	0	....	0	0

TABLE 32.—*Application of fertilizer, lime, and manure, 1937-49*—Cont.

Year	Lysimeter [2]	Fertilizer Amount per acre	Fertilizer Kind	Lime per acre	Manure per acre
		Pounds		*Tons*	*Tons*
1948	Y101	0	....	0	0
	Y102	0	....	0	0
	Y103	0	....	0	0
1949	Y101	0	....	0	0
	Y102	600	3-12-12	0	6
	Y103 A, B	600	3-12-12	0	6
	Y103 C, D	300	2-12-6	0	6

[1] For dates of application, see appendix A.
[2] Data are for all lysimeters in the battery unless specific lysimeters are listed, such as A, B, C, or D.

The amount of manganese found in the percolates was small but appreciable. The amounts needed for plant nutrition are likewise small. The maximum amount in the percolates was found in 1943 and 1944 when the lysimeters were in meadow. Manganese losses were consistently higher under prevailing practices than under improved practices. Limestone applications may have influenced the manganese losses.

Sulfur losses were four to five times higher on the Keene soil than on the Muskingum. This may be due in part to greater sulfur contamination of the atmosphere on the Keene silt loam. The sulfur losses were greater under improved practices, which may reflect the effect of the sulfur added in fertilizers.

Under improved practices, more nutrients were removed from soil by crops because of the greater vegetative growth. Increasing the amount of fertilizer did not result in any increase of nitrogen, potassium, and manganese in the percolates. The increased amounts of calcium, magnesium, and sulfur in percolates were probably due to fertilizer and limestone applications.

The extent of plant nutrient losses in percolation did not always parallel the amount of percolate collected. Land use likewise influenced nutrient losses by percolation. In general, nutrient losses by percolation were higher under meadow and lower under corn. This may have been due to (1) the failure of quantities of fertilizer applied in the corn and wheat years of the rotation to appear in the percolate until the meadow years, and (2) the increased percolation during meadow years. When precipitation and percolation were very high as in the corn year of 1945, the nutrient losses in percolates were high as compared to other corn years.

The nutrients in drainage water were derived mainly from the applied manure, fertilizer, and limestone materials and from the soil itself. Contaminants in the atmosphere contributed a small but appreciable amount.

Although appreciable amounts of plant nutrients were lost annually through percolation, such losses were small compared to those lost through surface runoff (*25*). Data from the Coshocton lysimeters, however, indicate that nutrient losses through drainage were less than those determined on the basis of data from filled-in lysimeters.

DISCUSSION OF RESULTS

Analysis of the Coshocton lysimeter data provided a means of evaluating various factors in the hydrologic cycle in quantitative terms. The results are believed to closely approximate those which prevail under natural conditions. The unique weighing mechanism of the lysimeters made it possible to record the weight of moisture vapor transferred from the atmosphere to liquid form on the earth and vice versa. Diurnal as well as seasonal moisture movements for various crops were evaluated. Such results can be used in the solution of numerous problems of agricultural hydrology.

Precipitation, the major factor responsible for increasing soil water, was found to average only 81 percent of the total accretion. Condensation and absorption (CA) was also a sizeable factor in soil water accretion. Whenever plants transpire water during the night period, the scales of the weighing lysimeters record only the net increase in weight—CA minus T. In reality, CA was probably greater than that given herein. The cutting of a growing crop such as hay resulted in large increases in apparent CA. It is likely that there was no noticeable increase in CA after the hay was cut, but that the reduction of night transpiration permitted the entire CA to show up as increased lysimeter weight. The magnitude of, and seasonal variation in, condensation-absorption is a factor in soil moisture available for crop growth. Only a part of this water may actually be used by the plant. Its presence in the early morning and its subsequent evaporation was found to reduce the depletion of soil moisture. While the moisture of CA was being evaporated, soil-water depletion was slow and an equivalent amount of soil moisture was probably being conserved.

Soil temperature in the upper 6-inch layer showed some diurnal fluctuation. Although it was thought that during the cooling period some moisture might condense from the air in the soil pores and from the air drawn into the soil from the outside, computations involving temperature changes, vapor pressure, and volume of soil pores indicated that this phenomenon had no noticeable effect on CA. The values were less than 0.00002 inch daily.

Moisture removed from the vegetal or soil surface and converted to atmospheric vapor is termed evapo-transpiration. Lysimeter weight records made it possible to evaluate the magnitude of this removal. Variations by seasons and crops provide data useful in water utilization and other cropping programs. A corn crop of 140 bushels per acre used from 22 to 25 inches of water. A 3½-ton hay crop took 26 inches of water from the soil. Wheat

TABLE 33.—*Summary of nitrates in lysimeter percolates, 1940–49 (in pounds N per acre per year)*

Year	Lysimeter Y101				Lysimeter Y102			Lysimeter Y103			
	A	B	C	D	A	B	C	A	B	C	D
1940	0.27	0.30	([1])	([1])	6.53	6.62	5.76	([1])	([1])	4.48	4.25
1941	.44	.36	0.40	([1])	2.72	2.53	([1])	0.23	0.75	.72	.87
1942	.40	.35	.25	([1])	2.76	2.93	4.98	.29	.96	1.84	1.09
1943	.40	.19	.43	([1])	5.40	4.71	9.63	3.39	1.52	3.58	1.42
1944	.31	.17	.36	([1])	2.87	2.86	5.44	6.23	1.80	3.44	5.95
1945	1.22	.22	.62	2.09	2.25	2.03	6.93	5.04	.46	2.99	5.74
1946	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])	([1])
1947	.40	.14	.20	.81	1.52	3.07	7.58	14.85	8.79	14.53	13.46
1948	.47	.18	.39	1.86	1.26	1.91	3.57	4.55	2.22	10.44	3.23
1949	.32	.15	.41	.43	.59	.73	1.19	3.25	1.68	1.70	1.41
9-year average	.47	.23	[2] .38	[3]1.30	2.88	3.04	[2]5.64	[2]4.73	[2]2.27	4.86	4.16

[1] No data.
[2] 8-year average.
[3] 4-year average.

showed the least demand for water—less than 15 inches. In the humid and subhumid areas there is generally no serious moisture deficiency for wheat.

Periods of rapid removal of soil-water by corn or meadow plants are followed frequently by serious moisture deficiencies. In every corn year in the period of record, evapo-transpiration from corn-land lysimeters in July and the first half of August has exceeded normal rainfall. Sometimes the amount of water used exceeded normal rainfall by 50 to 100 percent. Subnormal rainfall in this period would result in even more rapid depletion of soil moisture. Soil and water conservation programs should include plans for efficient water utilization in these critical periods.

A good legume second-year meadow depletes soil moisture earlier in the growing season than corn, leaving little surplus for percolation. Percolation rates were materially reduced by extremely high ET, an important consideration in ground-water supply studies. Bluegrass and poverty grass afford good ground cover and maintain high infiltration rates. But since they deplete soil water less rapidly than a legume-grass sod, more water is made available for percolation.

The ET values presented herein should not be applied directly in studies of the hydrologic balance (precipitation, runoff, and evapo-transpiration) of entire drainage basins. The values of ET — CA should be used in such studies. Furthermore, the precipitation values based on the rain-gage records available for such studies were about 4 inches less on an annual basis than those obtained by the lysimeters. If gage data are used, they can be adjusted by adding about 4 inches to the annual amount.

The weighing lysimeters afforded an opportunity to measure precipitation on a surface 1/500 acre in area. This is over 200 times the size of the catchment area of the standard recording and nonrecording rain gages used throughout the country. As the lysimeter weights are accurate to 0.01 inch of rainfall, they served as a check on the accuracy of the rain gage. Using only rainfall amounts greater than 0.1 inch, the total measured catch of the rain gage for the year ranged from 0.72 to 2.33 inches less than that measured by lysimeter. Most of this difference occurred in storms of less than 0.6 inch rainfall. Of the days having rainfall between 0.1 and 0.6 inch, the recording rain gage catch was less than that of the lysimeter 67 percent of the time. It was greater 18 percent of the time and identical 15 percent. Of the days having rainfall greater than 0.6 inch, the recording rain gage catch was less than that of the lysimeter 59 percent of the time. It was greater 36 percent of the time and identical 5 percent. Seventy-two percent of the rainy days with over 0.1 inch had less than 0.6 inch rainfall and 28 percent had rainfall greater than 0.6 inch.

Although the rain gage is of questionable accuracy, no other instruments capable of providing the needed information as economically are available. Furthermore, areal variations in storm rainfall at times are believed to be much greater than the errors referred to above. At this station the catchment in a single rain gage is used to represent rainfall on drainage basins up to 40 acres. For some hydrologic studies, the record from a single rain gage is used to represent thousands of square miles. In applying single-gage data to large areas, the inaccuracies of the gage itself can possibly be ignored.

Percolation data from the lysimeters provided information on the amounts and rates of recharge to ground water. Differences in soil type and vegetative cover on the lysimeters furnished a basis of comparison. Seasonal variation in percolation was marked. About 80 percent of the annual percolation occurred in the 4-month period, January-April. On the average, percolation in the 4-month period, July-October, amounted to about 3 percent of the total. These proportions varied from year to year depending on the crop and the distribution of rainfall absorbed by the soil.

Rainfall on a wet soil caused increases in percolation 8 to 16 hours later. Maximum 3-hour rates of percolation usually were less than 0.12 inch per hour. These values correspond closely with minimum infiltration rates derived by hydrograph analysis of data on runoff from small watersheds. Over 2.5 inches of water percolated from the lysimeters during an 11-day wet period in March 1945. Rainfall during the same period amounted to about 3.8 inches.

Following dry periods, the soil must absorb much rainfall before percolation begins. Following the dry August of 1945, over 7 inches of rain fell before percolation water first appeared through the cracks of the Keene soil. About 9 inches of rain fell before percolation occurred from the Muskingum soils. This soil did not shrink and crack seriously. With more than 10 inches of rain, the maximum percolation amounted to about 1 inch.

Plant nutrient losses through percolation were summarized for 9 years of record. The data were grouped into prevailing (poor) and improved (conservation) practices. The largest quantities of chemical elements were lost during periods of greatest percolation. As 80 percent of the annual percolation occurred in the first 4 months of the calendar year, it can be concluded that this is the season of greatest leaching of nutrients. This information is useful in determining the proper season for chemical fertilizer application. For grain crops there is little choice in time of fertilizer application. With respect to pastures or meadows, some of the fertilizer materials applied as a top dressing after the plants become dormant may be carried through the soil profile beyond the root zone during the critical 4-month percolation period. Percolation has practically stopped before much plant growth takes place.

Greater quantities of chemicals were leached from the heavy textured Keene soil than from the lighter Muskingum soil. Of all the nutrients lost in percolation, calcium was removed in largest amount. On the lysimeters limed to a pH of about 6.8, more calcium was leached than from the lysimeters with more acid

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soil. Potassium losses on the heavy-textured Keene soil (battery Y103) did not reflect the addition of this element in chemical fertilizer. The lysimeters which received more potassium in fertilizer lost less of this element by leaching than the lower fertility lysimeters. This difference was reversed on the light-textured Muskingum soils (lysimeters Y101). This result may have some bearing on the time and frequency of fertilizer application. It would appear that the heavy-textured soils could receive heavy applications of fertilizer at infrequent intervals. On the other hand, the light-textured soils should receive fertilizer in smaller quantities rather frequently.

Most of the increased fertilizer applications appeared to favor greater crop production. Nitrate losses in percolation water were less from the lower fertility lysimeters than from those fertilized more heavily. The concentration of nitrates in the percolate varied but little throughout the seasons. In general the amount of nitrates lost varied with the quantity of percolation.

Although the lysimeter data cover only a few years, they provide the basis for a number of tentative findings which can be of material use in agricultural hydrology. Further sampling in seasons with extreme climatic variations may modify the results to some extent.

Water control and utilization problems are numerous and varied. The adequate solution of these problems requires the proper use and treatment of the land with consideration of the hydrologic balance including precipitation, condensation, absorption, runoff, percolation, evapo-transpiration, and moisture-storage changes. The data contained in this report can be used to help solve many phases of these and related water-control problems.

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APPENDIX

A.—*Summary of farming operations on all lysimeters, 1936–49*

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
1936	Cover: Pasture grass.	Cover: Meadow, poor.	Cover: Meadow, poor.
1937	Cover: Pasture grass.	Cover: Meadow, poor; burlap, Apr. 2 Oct. 11. Seeded: Oct. 15, 4 pounds rye and 2 bushels oats per acre; no fertilizer. Manure: Oct. 29, 8 tons per acre.	Cover: Meadow, poor.
1938	Cover: Pasture grass Red top. Canada blue grass. Timothy. Poverty grass. Weeds.	Crop: Corn. Spaded: May 10-13. Corn planted May 27, 125 pounds of 2-12-6 fertilizer per acre. Cultivated: June 7 9, 28–29, July 11. Harvested: Sept. 23–27, crop removed. Yield: No data.	Cover: Meadow to wheat. Spaded: Late September. Seeded: October 7, 2 bushels wheat per acre, 175 pounds 2 12–6 fertilizer per acre.
1939	Cover: Pasture grass Tame grass. Poverty grass. Weeds.	Crop: Oats to wheat. Spaded and raked: May 1 2. Oats planted: May 4, 100 pounds 0-20-0 fertilizer per acre. Oats lodged: July 13. Harvested: July 27. Yield of oats: Y102A 43 bu acre. Y102B 44 bu acre. Y102C 45 bu acre. Spaded: Sept. 1. Raked: Sept. 9. Seeded wheat: Oct. 2, 150 pounds 0-16-0 and 10 pounds 20-0-0 fertilizer per acre. 2 bushels wheat and 5 pounds timothy per acre.	Crop: Oats to wheat. Spaded and raked: Apr. 26-27. Planted oats: May 4, 100 pounds 0-20-0 fertilizer per acre. Harvested: July 24–25. Yield of oats: No record. Spaded: Sept. 1. Raked: Sept. 9. Wheat seeded: Oct. 2, 150 pounds 0–16 0 and 10 pounds 20 0 0 fertilizer per acre. 2 bushels wheat and 5 pounds timothy per acre.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49*—Continued

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
1940	Cover: Pasture grass. Yield: Y101A—0.46 ton per acre. Y101B—0.47 ton per acre. Y101C—0.45 ton per acre.	Crop: Wheat to meadow. Clover seeded: Mar. 15, 6 pounds red clover and 3 pounds alsike clover per acre. Wheat harvested: July 12. Yield: A {grain—31 bushels per acre. straw—1.2 tons per acre. B {grain—28 bushels per acre. straw—1.1 tons per acre. C {grain—24 bushels per acre. straw—0.9 ton per acre.	Crop: Wheat to meadow. Clover seeded: Mar. 15, 6 pounds red clover per acre and 3 pounds alsike clover per acre. Wheat harvested: July 12. Yield: A {grain—23 bushels per acre. straw—0.9 ton per acre. B {grain—33 bushels per acre. straw—1.3 tons per acre. C {grain—24 bushels per acre. straw—0.9 ton per acre. D {grain—26 bushels per acre. straw—1.0 ton per acre.
1941	Cover: Pasture grass. Poverty grass. Weeds. Clover.	Conservation practices on all lysimeters. Crop: Corn to wheat. Manured: Mar. 29, 4 tons per acre. Spaded: Mar. 29–Apr. 1. Raked and seeded: May 12, 200 pounds 2-12-6 fertilizer per acre. Cultivated: June 9, 23. Corn cut and removed: Sept. 15. Yield: A {grain—102 bushels per acre. fodder—2.5 tons per acre. B {grain—99 bushels per acre. fodder—2.6 tons per acre. C {grain—80 bushels per acre. fodder—2.4 tons per acre.	Conservation practices on Y103A and Y103B only. Crop: Corn to wheat. Manured: Apr. 1, 4 tons per acre. Spaded: Apr. 1–2. Raked and seeded: May 13— Lysimeters A and B—200 pounds 2-12-6 fertilizer per acre. Lysimeters C and D—75 pounds 2-12-6 fertilizer per acre. Cultivated: June 9, 23. Corn cut and removed: Sept. 15. Yield: A {grain—92 bushels per acre. fodder—2.0 tons per acre. B {grain—102 bushels per acre. fodder—2.3 tons per acre. C {grain—94 bushels per acre. fodder—2.5 tons per acre.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49*—Continued

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
		Raked and wheat seeded: Oct. 2. Seed: 2 bushels wheat, and 3 pounds timothy per acre. 300 pounds 2-12-6 fertilizer per acre. Manured: Dec. 31, 4 tons per acre.	D { grain—95 bushels per acre. fodder—2.9 tons per acre. Raked and wheat seeded: Oct. 2. Seed: 2 bushels wheat and 3 pounds timothy per acre. Lysimeters A and B: 300 pounds 2-12-6 fertilizer per acre. Lysimeters C and D: 125 pounds 2-12-6 fertilizer per acre.
1942	Cover: Pasture grass Poverty grass. Weeds. Clover.	Crop: Wheat to meadow. Clover seeded: Apr. 13, 4 pounds red clover, 6 pounds alfalfa, and 2 pounds alsike per acre. Wheat cut: June 29. Yield: A { grain—38 bushels per acre. straw—1.0 ton per acre. B { grain—30 bushels per acre. straw—0.8 ton per acre. C { grain—32 bushels per acre. straw—0.9 ton per acre. Stubble clipped: Aug. 18.	Crop: Wheat to meadow. Manured: Mar. 2, 4 tons per acre on lysimeters A and B; none on lysimeters C and D. Clover seeded: Apr. 13— Lysimeters A and B: 4 pounds red clover, 6 pounds alfalfa, and 2 pounds alsike per acre. Lysimeters C and D: 6 pounds red clover and 3 pounds alsike per acre. Wheat cut: June 30. Yield: A { grain—35 bushels per acre. straw—1.0 ton per acre. B { grain—39 bushels per acre. straw—1.2 tons per acre. C { grain—23 bushels per acre. straw—0.6 ton per acre. D { grain—30 bushels per acre. straw—0.7 ton per acre. Stubble clipped: Aug. 26, on lysimeters A and B only.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49* —Continued

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
1943	Cover: Pasture grass. Lysimeter D now in operation. Lysimeters A, B, and C: Poverty grass. Weeds. Clover. Lysimeter D: Mostly bare.	Crop: Meadow, first year. Hay cut: June 16. Hay removed: June 19. Yield: C—2.06 tons per acre, only one cutting; second growth, estimated 0.30 ton per acre.	Crop: Meadow, first year. Hay cut: June 17. Hay removed: June 19. Yield: A—1.17 tons per acre. Hay cut: Sept. 10. Yield: A—estimated 0.5 ton per acre.
1944	Cover: Pasture grass Poverty grass. Weeds. Clover.	Crop: Meadow, second year. Limed: Apr. 25, 2.5 tons per acre. Hay cut: June 19. Hay removed: June 21. Yield: C—1.25 tons per acre, only one cutting this year; second crop poor; second growth estimated at 0.25 ton per acre. Manured: Oct. 18, 6 tons per acre.	Crop: Meadow, second year. Limed: Apr. 25, lysimeters A and B only, 2.5 tons per acre. Hay cut: June 19. Hay removed: June 21. Yield: A—1.0 ton per acre. Hay cut: Aug. 25. Yield: A—estimated 0.5 ton per acre. Manured: Oct. 18, 6 tons per acre.
1945	Cover: Pasture grass Lysimeters A and B: Poverty grass. Weeds. Lysimeters C and D: improved . Sod chopped: Apr. 12, Lysimeters C and D only. Seeded: Apr. 12, C and D only. 3 tons lime, 500 pounds 2-12-6 fertilizer, and 4 tons manure per acre. 4 pounds ladino clover, 4 pounds white clover, and 100 pounds blue grass per acre. Grass cut: July 25.	Crop: Corn to wheat. Spaded: Apr. 30. Corn planted: May 23. 200 pounds 2-12-6 fertilizer per acre. Cultivated: June 23, July 12. Cut and removed: Sept. 28. Yield: A {grain—54 bushels per acre. fodder—3.6 tons per acre. B {grain—60 bushels per acre. fodder—3.7 tons per acre. C {grain—34 bushels per acre. fodder—2.7 tons per acre. Seedbed prepared: Oct. 18. Wheat seeded: Oct. 18. 300 pounds 2-12-6 fertilizer per acre. 2 bushels wheat and 6 pounds timothy per acre.	Crop: Corn to wheat. Spaded: Apr. 30. Corn planted: May 23— Lysimeters A and B: 200 pounds 2-12-6 fertilizer per acre Lysimeters C and D: 75 pounds 2-12-6 fertilizer per acre. Cultivated: June 23, July 12. Cut and removed: Oct. 2. Yield: A {grain—61 bushels per acre. fodder—3.6 tons per acre. B {grain—62 bushels per acre. fodder—3.6 tons per acre. C {grain—48 bushels per acre. fodder—3.0 tons per acre. D {grain—57 bushels per acre. fodder—3.5 tons per acre.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49* —Continued

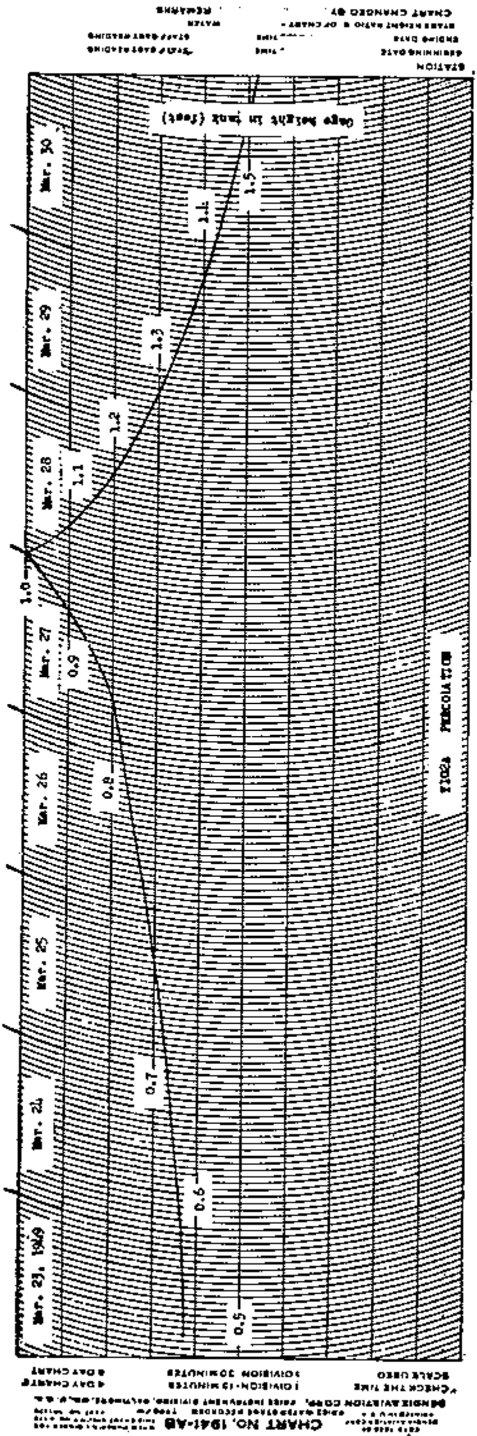
Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
		Lime: 2 tons per acre.	Seedbed prepared: Oct. 18. Wheat seeded: Oct. 18. 300 pounds 2–12–6 fertilizer per acre on lysimeters A and B; 125 pounds 2–12–6 fertilizer per acre on lysimeters C and D. 2 bushels wheat and 6 pounds timothy per acre. Lime: Lysimeters A and B, 2 tons per acre.
1946	Cover: Pasture grass— Lysimeters A and B: Poverty grass. Weeds. Lysimeters C and D: Grass. Clover. Fertilized: Sept. 4, 1946, Lysimeters C and D only, 400 pounds 0–20–0 fertilizer and 2 tons lime per acre. Yield: A—0.65 ton per acre. B—0.28 ton per acre. C—0.53 ton per acre. D—0.50 ton per acre.	Crop: Wheat to meadow. Manured: Jan. 3, 4 tons per acre. Clover seeded: Mar. 25. 4 pounds red clover, 6 pounds alfalfa, and 2 pounds alsike per acre. Wheat cut: July 9. Yield: A—grain—40 bushels per acre. B—grain—30 bushels per acre. C {grain—38 bushels per acre. straw—1.0 ton per acre.	Crop: Wheat to meadow. Manured: Jan. 3, 4 tons per acre, lysimeters A and B only. Clover seeded: Mar. 25— Lysimeters A and B: 4 pounds red clover, 6 pounds alfalfa, and 2 pounds alsike per acre. Lysimeters C and D: 6 pounds red clover and 3 pounds alsike per acre. Wheat cut: July 9. Yield: A {grain—36 bushels per acre. straw—1.0 ton per acre. B—grain—38 bushels per acre. C—grain—29 bushels per acre. D—grain—33 bushels per acre.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49*—Continued

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
1947	Cover: Pasture grass— Lysimeters A and B: Poverty grass. Weeds. Lysimeters C and D: Grass. Clover. Fertilized: Apr. 18, lysimeters C and D; 500 pounds 3-12-12 per acre. Sod chopped: Apr. 18, lysimeter D only. Seeded: May 8, lysimeter D only. 8 pounds alfalfa, 1 pound ladino clover, and 7 pounds brome grass per acre. Grass clipped: Aug. 1, clippings left on surface.	Crop: Meadow, first year. Hay cut: June 23, Aug 5. Yield (tons per acre): *June 23* *Aug. 5* A—1.47 1.18 B—1.58 1.08 C—1.65 .88 Fertilized: June 27, 200 pounds 0-12-20 per acre.	Crop: Meadow, first year. Hay cut: June 25, Aug. 11. Yield (tons per acre): *June 25* *Aug. 11* A—1.15 0.80 B—1.42 .76 C— .98 .76 D—1.03 .88 Fertilized: Lysimeters A and B only, 200 pounds 0–12–20 per acre in July.
1948	Cover: Pasture grass— Lysimeters A and B: Poverty grass. Weeds. Lysimeter C: Bluegrass. Lysimeter D: Brome grass. Alfalfa. Clover. Grass clipped: May 28. Yield: A—1.4 tons per acre. B—0.4 ton per acre. C—0.5 ton per acre. D—3.4 tons per acre.	Crop: Meadow, second year. Hay cut: June 25, Aug. 9. Yield: A—3.3 tons per acre. B—4.2 tons per acre. C—3.1 tons per acre.	Crop: Meadow, second year. Hay cut: June 28, Aug. 11. Yield: A—3.8 tons per acre. B—3.1 tons per acre. C—1.7 tons per acre. D—2.5 tons per acre.

APPENDIX A.—*Summary of farming operations on all lysimeters, 1936–49*—Continued

Year	Lysimeter battery Y101	Lysimeter battery Y102	Lysimeter battery Y103
1949	Cover: Pasture grass— Lysimeters A and B: Poverty grass. Weeds. Lysimeter C: Bluegrass. Lysimeter D: Brome grass. Alfalfa. Grass cut: June 20, Aug. 18. Yield: A—1.4 tons per acre. B—1.3 tons per acre. C—1.1 tons per acre. D—4.0 tons per acre.	Crop: Corn to wheat. Manured: Apr. 25, 6 tons per acre. Sod spaded: May 6. Corn planted: May 9. Fertilizer: 300 pounds 3-12-12 per acre. Cultivated: June 2, 14, July 1. Corn picked, stalks chopped and left: Sept. 21. Yield: A—grain—151 bushels per acre. B—grain—148 bushels per acre. C {grain—151 bushels per acre. fodder—2.75 tons per acre. Wheat seeded: Oct. 3. Fertilizer: 300 pounds 3-12-12 per acre. Seed: 2 bushels wheat and 3 pounds timothy per acre.	Crop: Corn to wheat. Manured: Apr. 25, 6 tons per acre. Sod spaded: May 6. Corn planted: May 10— Lysimeters A and B: Fertilizer: 300 pounds 3-12-12 per acre. Lysimeters C and D: Fertilizer: 100 pounds 2-12-6 per acre. Cultivated: June 3, 14, July 1. Corn picked, stalks chopped and left: Sept. 21. Yield: A {grain—148 bushels per acre. fodder—2.55 tons per acre. B—grain—154 bushels per acre. C—grain—107 bushels per acre. D—grain—120 bushels per acre. Wheat seeded: Oct. 4— Lysimeters A and B: Fertilizer: 300 pounds 3-12-12 per acre. Seed: 2 bushels wheat and 3 pounds timothy per acre. Lysimeters C and D: Fertilizer: 200 pounds 2-12-6 per acre. Seed: 2 bushels wheat and 3 pounds timothy per acre.



APPENDIX B.1—Sample percolation recorder chart, lysimeter Y102C.

APPENDIX B.2—Sample tabulation-computation sheet for percolation, lysimeter Y102C.

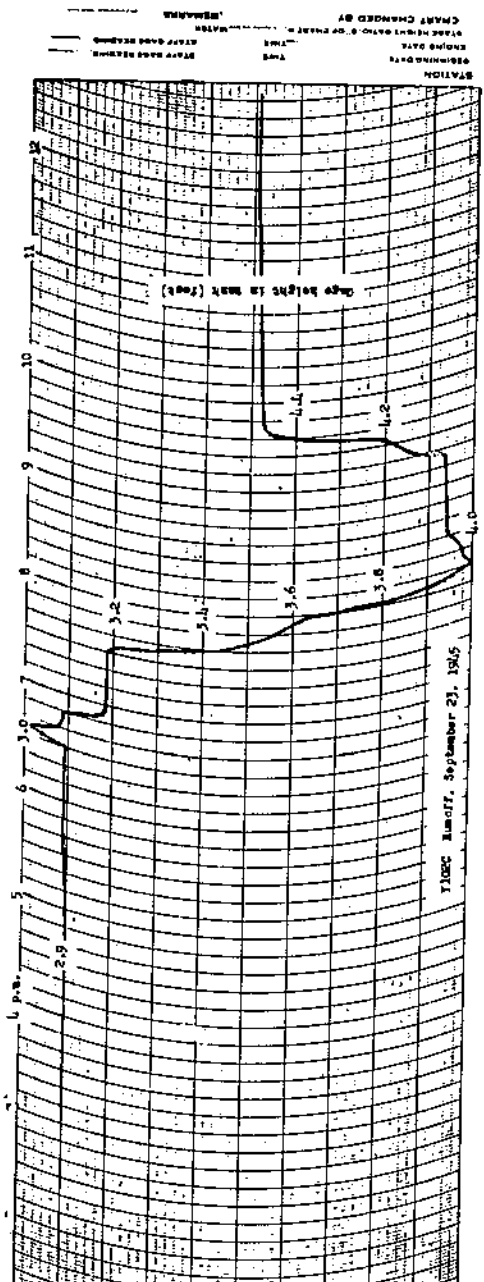
1949

PERCOLATE

Y102C

Sheet __ of __

Date	Time	Gage Height (feet)	Amount (inches)	Date	Time	Gage Height (feet)	Amount (inches)
Mar 4		0.105					
5		.140	0.042				
6		.1675	.033				
7		.195	.033				
8		.220	.030				
9		.245	.030				
10		.2725	.033				
11		.2975	.030				
12		.320	.027				
13		.350	.036				
14		.385	.042				
15		.4175	.039				
16		.455	.045				
17		.480	.030				
18		.5125	.039				
19		.540	.033				
20		.5625	.027				
21		.5875	.030				
22		.615	.033				
23		.6325	.021				
24		.670	.045				
25		.720	.060				
26		.7825	.075				
27		1.000	.261				
28		1.265	.318				
29		1.4025	.165				
30		1.4975	.114				



APPENDIX C.1—Sample runoff recorder chart, lysimeter Y102C.

APPENDIX C.2—Sample tabulation-computation sheet for runoff, lysimeter Y102C.

RUNOFF

1945

Y102 C

Sheet __ of __

Date	Time	Gage Height (feet)	Amount (inches)	Date	Time	Gage Height (feet)	Amount (inches)
Sept. 11		2.1075					
12		2.1075	0				
13		2.1125	.006				
14		2.475	.435				
15		2.475	0				
16		2.475	0				
17		2.520	.054				
18		2.715	.234				
19		2.715	0				
20		2.9025	.225				
21		2.9025	0				
22		2.9025	0				
23		4.500	1.917				
24		4.500	0				

APPENDIX D.—Sample 10-minute and hourly transcription of lysimeter print-weight record, lysimeter Y102C, November 30, 1949.

United States Department of Agriculture
Soil Conservation Service
LYSIMETER WEIGHT RECORD

Date 11-30 1949 Y10 2C

Time	Scale Weight	Hourly Average	Time	Scale Weight	Hourly Average	Time	Scale Weight	Hourly Average	Remarks
A.M.			A.M.			P.M.			
12:10	1962	61.0	8:10	1956		4:10	1935		
20	62		20	54		20	33		
30	62		30	54		30	33		
40	62		40	54		40	32		
50	62		50	55		50	32		
1:00	62	62.3	9:00	53	53.0	5:00	33	31.5	
10	63		10	53		10	37		
20	63		20	50		20	32		
30	64		30	49		30	37		
40	64		40	49		40	32		
50	63		50	41		50	33		
2:00	63	63.8	10:00	43	45.3	6:00	37	32.5	
10	65		10	45		10	29		
20	64		20	45		20	27		
30	64		30	43		30	27		
40	65		40	37		40	32		
50	65		50	41		50	30		
3:00	64	64.2	11:00	39	39.5	7:00	30	30.5	
10	64		10	39		10	32		
20	63		20	38		20	32		
30	63		30	37		30	30		
40	63		40	37		40	32		
50	63		50	35		50	31		
4:00	63	63.5	12:00	36	35.2	8:00	31	31.0	
10	64		10	33		10	32		
20	65		20	33		20	32		
30	65		30	32		30	32		
40	65		40	32		40	31		
50	65		50	31		50	31		
5:00	66	65.7	1:00	31	29.8	9:00	30	31.3	
10	67		10	28		10	33		
20	66		20	25		20	32		
30	66		30	28		30	32		
40	67		40	28		40	31		
50	67		50	27		50	31		
6:00	67	66.7	2:00	28	26.5	10:00	32	32.2	
10	67		10	23		10	35		
20	66		20	25		20	32		
30	66		30	26		30	35		
40	65		40	22		40	32		
50	66		50	24		50	33		
7:00	65	64.7	3:00	27	26.0	11:00	32	32.8	
10	63		10	28		10	33		
20	63		20	24		20	32		
30	63		30	29		30	32		
40	62		40	29		40	32		
50	62		50	30		50	32		
8:00	59	59.3	4:00	32	31.3	12:00	33	33.2	

APPENDIX E.—Sample of semimonthly summary sheet of lysimeter weights, rainfall, moisture storage change, runoff, percolation, evapo-transpiration, and condensation-absorption.

Lysimeter No. Y 102
Weighing Box C

U. S. Department of Agriculture
Soil Conservation Service
Semi-monthly Lysimeter Record
Weighing Box

From: Nov. 17, 1949 (Date)
To: Nov. 30, 1949 (Date)

	Date	17	18	19	20	21	22	23	24	25	26	27	28	29	30		Ave.	Adj. Lbs.	Rate Ins.
	Base	1700	1800	1800	1700	1700	1700	1700	1700	1700	1700	1700	1700	1900	1900				
Pounds	12:00 M	89.0	61.0	42.8	101.5	96.8	85.0	65.8	56.7	94.0	90.8	87.0	77.2	51.0	61.0				
	1:00 A	100.7	62.0	44.3	100.5	96.0	85.0	63.8	52.8	95.5	90.2	87.2	77.3	54.8	63.3				
	2:00 A	106.5	61.7	41.2	100.3	97.3	85.8	63.2	49.2	97.7	89.2	85.7	77.8	63.5	63.8				
	3:00 A	108.7	62.0	38.3	98.7	97.5	85.8	61.7	41.5	96.3	94.0	84.7	84.7	61.7	64.2				
	4:00 A	116.0	61.8	36.7	99.5	98.7	85.7	61.5	47.7	97.0	95.7	84.0	81.8	65.7	63.5				
	5:00 A	126.2	62.2	36.3	97.5	99.3	87.2	60.7	47.2	100.0	93.7	82.2	81.5	69.0	65.7				
	6:00 A	131.0	61.7	32.8	97.2	98.0	89.5	59.0	45.5	100.0	95.5	81.3	80.8	71.8	66.7				
	7:00 A	136.3	59.2	32.3	97.3	96.3	91.2	57.7	43.3	98.3	96.5	80.5	79.7	72.5	64.7				
	8:00 A	139.7	57.5	33.2	99.0	91.2	72.8	48.8	42.5	98.0	90.0	79.2	78.0	70.8	59.3				
	9:00 A	137.5	54.0	30.5	96.2	82.7	64.3	50.7	48.0	98.7	80.3	77.3	70.3	65.7	53.0				
	10:00 A	130.3	50.5	23.7	94.0	81.8	67.7	48.7	41.3	100.7	81.2	76.8	67.2	62.0	45.3				
	11:00 A	125.5	46.0	21.2	89.7	79.5	61.2	46.3	38.5	100.7	76.7	76.3	63.7	57.3	39.5				
	12:00 N	123.0	44.7	18.3	88.3	79.8	66.8	45.0	35.5	101.8	77.0	76.2	60.2	53.5	35.2				
	1:00 P	124.2	42.3	12.5	90.7	77.2	63.7	43.3	33.8	100.5	73.0	77.5	59.7	48.3	29.8				
	2:00 P	127.2	42.0	8.8	91.5	76.5	63.8	44.2	33.0	96.0	70.7	77.0	62.2	45.5	26.5				
	3:00 P	135.2	39.5	9.0	92.7	81.7	65.2	40.8	42.2	93.0	78.8	77.5	64.8	42.0	26.0				
	4:00 P	143.8	36.8	10.0	93.5	84.0	65.8	43.8	61.2	92.8	78.2	77.2	65.5	45.8	31.3				
	5:00 P.	151.3	41.2	12.5	96.0	85.7	71.8	48.5	81.2	96.7	81.3	78.8	75.5	52.0	31.5				
	6:00 P	156.7	44.7	14.5	97.3	88.8	75.5	52.5	87.8	99.2	82.8	80.0	111.3	56.6	32.5				
	7:00 P	157.5	45.7	15.2	97.3	87.5	73.5	54.5	88.7	98.0	91.3	78.8	130.2	59.0	30.5				
	8:00 P	158.5	42.7	11.0	97.5	87.0	70.8	57.7	93.3	99.7	91.7	78.8	133.0	60.5	31.0				
	9:00 P	161.2	42.7	10.0	96.5	87.7	64.3	57.8	93.2	97.7	90.5	78.2	131.5	61.7	31.3				
	10:00 P	162.0	42.3	4.8	96.8	86.5	62.8	59.3	92.7	94.5	89.3	78.0	150.0	62.7	32.2				
	11:00 P	161.0	42.2	3.0	97.0	83.2	64.7	57.8	93.3	92.5	88.2	77.7	168.7	61.6	32.8				
	12:00 M	161.0	42.8	1.5	96.8	85.0	65.8	56.2	94.0	90.8	87.0	77.2	251.0	61.0	33.7				
Inches	Stor. Chg.	+.159	-.040	-.091	-.010	-.026	-.042	-.021	+.083	-.007	-.008	-.022	+.384	+.022	-.060				
	Rain 1/	.14 R-3	Ts	T	T	Ts	0	0	.10	Ts	Ts	0	.42	.02	0				
	Runoff	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
	Perc.	.001	.031	.001	.001	.001	.001		.001		.001			.001	0				
	Ev. Trans.	.042	.063	.106	.048	.076	.095	.066	.082	.046	.073	.030	.055	.071	.094				
	Cond&Absp.	.043	.024	.016	.027	.031	.053	.045	.021	.028	.042	.008	.028	.074	.034				
	ET-CA	-.001	.039	.090	.020	.045	.041	.021	.062	.018	.031	.002	.027	-.003	.060				

1/ FROM LYSIMETER RECORD APPENDIX F

APPENDIX F.—*Calculation of rainfall from weight record, November 17-30, 1949*

Date	Gage rainfall [1]	Runoff				Percolation				Weight record (Y102C) (at time designated)						Hrs. Rain	Percolation		Wt. Incr.	Rain	Stor. Chg.	ET	C and A	ET−CA
		A	B	C	D	A	B	C	D								Rain	ET						
17	.14R+S	0	0	0	..	.003	0	.001	..	M 1789	120a 1805	310a 1808	730a 1840	230p 1828	450p 1849	$6\frac{2}{3}$	0.0003	0.0007	0.1589	0.159	+0.159	0.042	0.043	−0.001
														300p 1843	520p 1858									
18	TS	0	0	0		003	.001	.001	..															
19	T	0	0	0	..	.003		.001																
20	T	0	0	0	..	.003	.001	.001	..	830a 1793	850a 1798					$\frac{1}{3}$	0	.001	.0110	.011	−.010	.048	.027	.020
21	TS	0	0	0	..	.003	....	.001	..	210p 1773	250p 1782					$\frac{2}{3}$	0	.001	.0199	.020	−.026	.076	.031	.045
22	0	0	0	0		003	.001	.001	..															
23	0	0	0	0		002	0																	
24	.10	0	0	0	..	.002	0	.001	..	300p 1730	330p 1762	420p 1762	500p 1786	710p 1787	740p 1797	$1\frac{2}{3}$	.0001	.0009	.1457	.146	+.083	.082	.021	.062
25	TS	0	0	0	..	.002	0	....	..	930a 1798	1010a 1803					$\frac{2}{3}$	0	0	.0110	.011	−.007	.046	.028	.018
26	TS	0	0	0	..	.002	0	.001	..	600p 1782	710p 1793					$1\frac{1}{6}$	0	.001	.0243	.024	−.008	.073	.042	.031
27	0	0	0	0	..	.002	0	....																
28	.42	0	0	0	..	.001	0	....	..	410p 1766	650p 1832	1040p 1831	M 1951			4	0	0	.411	.411	+.384	.055	.028	.027
29	.02	0	0	0	..	.001	0	.001	..	M 1951	1220a 1960					$\frac{1}{3}$	0	.001	.0199	.020	+.022	.071	.074	−.003
30	0	0	0	0		.003	0	0																
Mo. Tots.	....	0	0	0	..	.072	.007	.016																

[1] R—rain; S—snow; T—less than 0.01.

OH-R-2-44

SOIL TEMPERATURE STUDIES
DATA SHEET
Soil Conservation Service
Coshocton, Ohio

Soil thermograph No. Ta + T4 Field No. 107 Land use Corn

Date	Air temp. 30" above ground				Air temp. 2" above ground				Soil temp. at 1/2" depth			
1949	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.
6/20	91	68	23	79.5	93	66	27	79.5	76	72	4	74
21	86	69	17	77.5	87	66	21	76.5	75	69	6	72
22	81	64	17	72.5	87	59	28	73	74	68	6	71
23	84	60	24	72	89	57	32	73	74	65	9	69.5
24	91	62	29	76.5	91	60	31	75.5	76	66	10	71
25	85	69	16	77	80	65	15	72.5	72	68	4	70
26	87	70	17	78.5	90	66	24	78	76	70	6	73
Weekly aver.	86.7	66.0	20.7	76.4	88.1	62.7	25.4	75.4	74.7	68.3	6.4	71.5
6/27	85	71	14	78	86	66	20	76	74	69	5	71.5
28	85	70	15	77.5	92	65	27	78.5	74	68	6	71
29	89	66	23	77.5	92	65	27	78.5	76	68	8	72
30	85	67	18	76	92	66	26	79	76	72	4	74
7/1	87	67	20	77	91	65	26	78	76	68	8	72
2	86	65	21	75.5	95	64	31	79.5	76	68	8	72
3	95	68	27	81.5	95	63	32	79	79	75	4	77
Weekly aver.	88.4	67.7	18.7	77.6	91.9	64.9	27.0	78.4	75.9	69.7	6.1	72.8
7/4	93	72	21	82.5	98	68	30	83	79	71	8	75
5	96	76	20	86	99	71	28	85	80	72	8	76
6	90	68	22	79	97	65	32	81	78	71	7	74.5
7	91	68	23	79.5	93	69	24	81	76	70	6	73
8	90	70	20	80	87	69	18	78	76	70	6	73
9	87	71	16	79	89	66	23	77.5	78	71	7	74.5
10	84	62	22	73	82	60	22	71	75	70	5	72.5
Weekly aver.	90.1	69.6	20.6	79.9	92.1	66.9	25.3	79.6	77.4	70.7	6.7	74.0

Date	Soil temp. at 3" depth				Soil temp. at 6" depth				Soil temp. at 12" depth				Soil temp. at 24" depth			
1949	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.	Max. temp.	Min. temp.	Max. fluct.	Av. of max. & min. T.
6/20	78	71	7	74.5	79	78	1	78.5	70	69	1	69.5	66	65	1	65.5
21	77	71	6	74	79	79	0	79	70	72	0	70	67	66	1	66.5
22	77	71	6	74	80	79	1	79.5	70	70	0	70	67	66	1	66.5
23	77	68	9	72.5	81	80	1	80.5	71	71	1	70.5	67	66	1	66.5
24	77	69	8	73	82	81	1	81.5	71	71	0	71	68	67	1	67.5
25	74	71	3	72.5	82	82	0	82	71	70	1	70.5	68	68	0	68
26	76	71	5	73.5	83	82	1	82.5	70	70	0	70	68	68	0	68
Weekly aver.	76.6	70.3	6.3	73.4	80.9	80.1	.7	80.5	70.4	70.0	.4	70.2	67.3	66.6	.7	67.0
6/27	76	70	6	73	83	83	0	83	70	70	0	70	68	68	0	68
28	76	71	5	73.5	83	83	0	83	70	70	0	71	68	68	0	68
29	77	71	6	74	84	83	1	83.5	70	70	0	70	68	67	1	67.5
30	77	72	5	74.5	84	84	0	84	70	70	0	70	68	68	0	68
7/1	77	71	6	74	84	84	0	84	70	70	0	70	69	68	1	68.5
2	78	71	7	74.5	84	84	0	84	70	70	0	70	69	68	1	68.5
3	78	71	7	74.5	84	84	0	84	70	70	0	70	69	69	0	69
Weekly aver.	77.0	71.0	6.0	74.0	83.7	83.6	.1	83.6	70.0	70.0	0	70.0	68.4	68.0	.4	68.2
7/4	80	72	8	76	84	84	0	84	70	73	0	70	69	69	0	69
5	77	74	5	76.5	84	84	0	84	71	70	1	70.5	70	69	1	69.5
6	77	70	7	73.5	84	84	0	84	72	71	1	71.5	70	70	0	70
7	77	72	5	74.5	84	84	0	84	72	72	1	72	70	72	0	70
8	77	72	5	74.5	84	84	0	84	73	72	1	72.5	70	70	0	70
9	78	72	6	75	84	84	0	84	74	73	1	73.5	70	70	0	70
10	75	71	4	73	84	84	0	84	74	73	1	73.5	70	72	0	72
Weekly aver.	77.6	71.9	5.7	74.8	84.0	84.0	0	84.0	72.3	71.6	.7	72.0	69.9	69.7	.1	69.8

APPENDIX G.—Sample tabulation sheet for daily maximum and minimum air and soil temperature.

APPENDIX H.—Sample tabulation sheet for daily evaporation, water temperature, and wind movement.

Form SCS-311 (Rev. [illegible])

UNITED STATES DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE—WATERSHED AND HYDROLOGIC STUDIES

EVAPORATION RECORD

Station Y102 Lysimeter
Month August 17-31, 1948

Date	U. S. W. B. Class A Pan: Gage reading, Regular	Gage reading, After filling	Evaporation	Water temperature	Colorado Type Pan: Gage reading, Regular	Gage reading, After filling	Evaporation	Water temperature	[illegible] Type Pan: Gage reading, Regular	Gage reading, After filling	Evaporation	Water temperature	Anemometer	Miles wind	Air temperature	Wind direction	Remarks
	In.	In.	In.	°F	In.	In.	In.	°F	In.	In.	In.	°F		Miles	°F		
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)
17 8A / 5P									6.782	6.840	.156	68	9576.3	30.2			0 - Rain
18 8A / 5P									6.684	6.774	.156	69	9619.7	43.4			.06
19 8A / 5P									6.660		.114	70	9658.1	38.4			.08
20 8A / 5P									6.456		.204	69	9738.6	80.5			0
21 8A / 5P																	
22 8A / 5P																	
23 8A / 5P									6.108		.348	72.5	9855.8	117.2			0
24 8A / 5P									5.964		.144	73	9880.8	25.0			0
25 8A / 5P									5.792		.172	73	9926.5	45.7			0
26 8A / 5P									5.664		.108	77	9948.4	22.9			0
27 8A / 5P									5.496		.168	77	9970.9	22.5			0
28 8A / 5P																	
29 8A / 5P																	
30 8A / 5P									4.860		.636	75.5	110.5	139.6			0
31 8A / 5P									4.620		.240	80.5	217.5	107.0			
8A / 5P																	
Total																	
Aver.																	

Entered by ———— Computed by ———— Checked by ————

CONTENTS

TABLES

END