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STEPHEN A. FORBES, PH.D., LL.D.,
DIRECTOR

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ARTICLE I.

THE RELATION OF EVAPORATION AND SOIL MOISTURE
TO PLANT SUCCESSION IN A RAVINE

BY

FRED THEODORE ULLRICH

NATURAL HISTORY SURVEY

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ERRATA AND ADDENDA

- Page 5, first column: line 2, for *Shepcrdia* read *Shepherdia*; line 11, for *americana* read *americanus*.
- Page 9, line 5 from bottom, for *XVII* read *X*.
- Page 42, line 4 from bottom of key, for *Pyromorphidae* read *Euclididae*.
- Page 73, line 7 from bottom of key, for *or* read *and seldom*.
- Page 100, just below key, insert as follows:—
The following species were examined:
Lophoptilus cloisella Clemens
Laverna brevivittella Clemens
- Page 107, lines 8 and 9 from bottom, page 108, line 10 from bottom, and page 110, line 10, for *Cucullianac* read *Cuculliinae*.
- Page 110, line 8 from bottom, delete *Polia*.
- Page 112, line 19 from bottom, for *Mctathoracic* read *Mésothoracic*.
- Page 129, line 8, for *never* read *sometimes*.
- Page 131, at end of second line insert *Paleacrita* Riley.
- Page 158: first column, after *Paleacrita*, 127, add 131; second column, after *Polia* delete 110.
- Page 170, line 4, for *Strayiomyiidae* read *Stratiomyiidae*.
- Page 243, line 2, for *alternata* read *alternatus*.
- Page 307: line 5 from bottom, for *with* read *and*; line 16 from bottom, for *Homeodactyla* read *Homocodactyla*.
- Page 314, line 15 from bottom, for *Cccidomyiidae* read *Coenomyiidae*.
- Page 321, line 12 from bottom, for *Stratomyia* read *Stratiomyia*.
- Page 324, line 6, for *pantherina* read *pantherinus*.
- Page 370, line 18, for *Empidoidea* read *Empididoidea*.
- Page 428, line 8 from bottom, for *Mcsnotum* read *Mesonotum*.
- Page 461, line 10 from bottom, for *Aeshnide* read *Aeshnidac*.
- Page 478, line 13 from bottom, for *vigilas* read *vigilax*.
- Page 519, line 2, delete *side*.
- Page 528, line 10, for *caruncluatum* read *carunculatam*.



GLENCOE, ILLINOIS, AND VICINITY

INTRODUCTION

For some time geologists have surmised that differences in the evaporative power of the air and the soil-moisture content account for the succession of vegetation that accompanies the physiographic changes in the development of a ravine. In order to determine whether or not this surmise can be supported by experimental data, this study was made during the summer of 1913. The ravine selected for investigation was the McLeish ravine, which lies in the southeastern part of the beautiful village of Glencoe, about sixteen miles north of Chicago. It is mapped in the Chicago folio of the United States Geological Survey as a part of the Evanston-Waukegan region. The general geographic features of this region are the moraine plain or rolling upland, the present shore, and the lake plain with its associated beach ridges. The rolling upland which constitutes the larger part of this area is glacial in origin, consisting of the usual glacial drift, clay, sand, gravel, and boulders, and rises more than sixty feet above the level of the lake. Since the ice sheet retreated, some of the glacial material has been reworked by rivers, waves, and winds, and thus is stratified. The heterogeneity in the composition of the drift and the resulting differences in the resistance to the forces of corrasion, and the great elevation of the upland above the level of the lake have furnished and are furnishing excellent conditions for the development of ravines. Of the many that have been carved in this upland, the McLeish ravine, although one of the smaller, may be considered a good representative.

PHYSIOGRAPHY OF THE MCLEISH RAVINE

(Plate XVIII)

It would be foreign to this study to give a complete exposition of the geology and physiography of the ravines of this upland region. Such a presentation is given by Atwood and Goldthwait ('08). However, an intelligent appreciation of the method and results of this study requires a brief description of the location and direction of the

*Accepted by the University of Chicago for the degree of Master of Arts in Botany.

courses of the ravine and its tributaries, the probable origin of the ravine, and its present physiography. The McLeish ravine is formed by the confluence of two gullies, the heads of which, if measured in straight distance, are each about 2000 feet inland. From the junction of the two gullies the ravine has an almost easterly direction for about 1500 feet, until it reaches its main tributary from the south, when it continues in a northeasterly direction for about 800 feet to the point where it empties into the lake. From the south, in addition to the main tributary, the ravine receives a number of small gullies.

Physiographers have summarized under three heads the successive stages in the cycle of the development of such a ravine as the one here considered: the V-shaped valley, with slopes normally convex; the U-shaped valley, a stage of development where detritus descending the slopes is not all carried away by the stream, and consequently the valley is being widened faster than it is deepened; and, finally, the valley with a broad bottom, in which transformation is affected partly by erosion and partly by deposition in the ravine. The tributaries of the McLeish ravine are mostly in the first stage of the cycle, while the main course of the ravine shows that it is passing from the V-shaped stage into the U-shaped stage.

It is altogether likely that this ravine had its infant development accelerated by swampy depressions in the upland near to the lake. Such swamps or marshes within reasonable distance from the head of the cliff of the lake shore would, through seepage, make materials between them and the lake shore so mobile that the head of the gully would work inland with unusual rapidity. The influence of such depressions in ravine formation can at present be seen in the vicinity of Glencoe.

In the weekly visits to this ravine, the physiographic changes due to weathering, wash, and lateral corrasion were decidedly noticeable. Some of the records made at the time of observation read as follows: (1)—during a heavy rain—small streams of clay are flowing leisurely to the bottom of the stream; (2) it will be only a matter of a relatively short time when two large hard-maple trees will become so undermined by the streams caused by heavy rains as to fall across the channel; (3) a large slump of clay has been deposited at the bottom of the ravine during the preceding week, due to the undermining action of the stream and to the percolating of the water through the soil above the cavity; (4) in following the ravine, from the point where the main tributary enters, to its mouth, a gradation of detritus ranging from boulders and cobblestones to sand is passed (Pl. I, Fig. 1); (5) the waves of the lake usually maintain a bar of shingle and sand across the mouth of the ravine, which results in the formation

of a pool of water which gradually filters into the lake as more water is brought down the ravine; (6) after heavy rains the channel is invariably reopened by sweeping the materials which form the barrier into the lake. This gives some conception and appreciation of the force of the current as an active agent in modifying the physiography of the ravine. These statements indicate the dynamic character of the McLeish ravine.

SUCCESION OF VEGETATION

After this brief consideration of the geographical and physiological features, we may now turn our attention to the vegetation. Cowles ('01), in his "Plant Societies of Chicago and Vicinity," calls attention to the fact that the slopes of the embryonic V-shaped ravine, after they attain sufficient stability, develop a carpet of luxuriant vegetation. He says: "In a comparatively few years the vegetation leaps, as it were, by bounds through the herbaceous and shrubby stages into a mesophytic forest, and that, too, a maple forest, the highest type found in our region." This quotation describes admirably what has taken place in the greater portion of this ravine and its tributaries. A somewhat detailed examination of the summer and fall flora of the ravine showed that the slopes of the gullies leading into the ravine (Pl. I, Fig. 2) were nearly or quite devoid of vegetation, with the exception of some mosses on the north-facing slopes. A wash or gully near the mouth of the ravine, comparable to the head of a ravine working inland, had rather severe conditions for plant growth in the upper half of its slope. Owing to the extreme exposure to light, wind, and heat, and to the absence of humus in the soil, only a few of the xerophytic pioneers succeeded in establishing themselves. Near the foot of this wash a more or less stable miniature plateau (Pl. II, Fig. 3) was formed. On this, during the latter part of the summer, there was a great variety and profusion of asters,—one of the most pleasing sights in the ravine at that time. The slopes with mesophytic forest vegetation, with its usual undergrowth, constitute the most general feature of the ravine. This mesophytism in a ravine is regarded by ecologists as only temporary. After the vertical cutting has reached base-level, and as lateral cutting reduces the inclination of the slope, removing the humus and increasing the exposure, there is retrogression from mesophytism to xerophytism. This tendency towards xerophytism is checked through the development of vegetation, which finally results in the establishment of the permanent mesophytic climax of the region. In the ravine under consideration one of the strongest features showing the significance of exposure in the gradual retrogression from mesophytism to xero-

phytism was the paucity of tender mesophytic forms and the less luxuriant vegetation in general on the south-facing slopes. In the early spring the north-facing slopes of the ravine were covered more abundantly with the various plants of the vernal flora and certain mosses than the south-facing slopes.

PLANTS OF THE RAVINE AND THE OAK UPLANDS

The plants of the ravine are recorded under two more or less distinct physiographic areas; the xeromesophytic slopes of the gullies (Region 1 of the table) and the mesophytic slopes of the ravine (Region 2). Some of the plants of the oak uplands (Region 3) are listed, to emphasize the differences between it and the ravine. The vegetation of the oak uplands may be thought of as either antedating or succeeding that of the ravine. The vegetation in these three successional regions is not entirely distinct, but even a superficial examination of the following list shows striking differences. As this study covers only the period from June 21 to October 18, 1913, much of the vernal vegetation is omitted.

In the examination of this list of plants it should be borne in mind that the vegetation of the slopes of the gullies and ravine is noted much more completely than that of the oak uplands; that the individuals of certain species were generally more numerous on the slopes of the ravine than on the slopes of the gullies; and that in certain localities of the ravine such plants as *Osmorhiza longistylis* (Pl. III, Fig. 5), *Amphicarpa monoica* (Pl. II, Fig. 4), and *Aralia nudicaulis* (Pl. IV, Fig. 6) had developed pure growths to the exclusion of all other species. Furthermore, and most important of all from the standpoint of this study, the list of plants for any of the three regions must not be considered as static but as dynamic in character. As already emphasized in an earlier part of this paper, with the changes in the physiography of the ravine the vegetation of its slopes tends to assume a xerophytic aspect, but only until stability of topography favors the succession of forest types, whose climax in the Evanston-Waukegan region is essentially the same as that of the mesophytic slopes of the ravine, the hard-maple type.

An investigation which is to determine whether or not the differences in the evaporative power of the air and in the soil-moisture content account for these successions and the minor differences within each of the areas where plants have been listed, involves, as the first step, the selection of certain typical stations—stations significant from the standpoint of exposure and ravine development; as the second step, the measurement, at regular intervals, of the evaporative power

Species	Region 1	Region 2	Region 3	Species	Region 1	Region 2	Region 3
[Trees and shrubs]				<i>Saponaria officinalis</i>	XX		
<i>Juniperus communis</i>	XX			<i>Polygala Senega</i>	XX		
<i>Shepherdia canadensis</i>	XX			<i>Aster laevis</i>	XX		
<i>Thuja occidentalis</i>	XX			<i>Aster multiflorus</i>	XX		
<i>Populus grandidentata</i>	XX			<i>Gentiana quinquefolia</i>	XX		
<i>Prunus serotina</i>	XX			<i>Polytrichum commune</i>	XX		
<i>Salix glaucophylla</i>	XX			<i>Helianthus divaricatus</i>	XX		
<i>Elwagnus argentea</i>	XX			<i>Asclepias syriaca</i>	XX		
<i>Ostrya virginiana</i>	XX			<i>Desmodium rigidum</i>	XX		
<i>Lonicera Sullivantii</i>	XX			<i>Monarda fistulosa</i>	XX		X
<i>Tilia americana</i>	XX	X		<i>Catherinca undulata</i>			
<i>Ceanothus americana</i>	XX	XX		<i>Mnium sp.</i>		XX	
<i>Acer saccharum</i>		XX		<i>Ancmonella thalictroides</i>		XX	X
<i>Carpinus caroliniana</i>		XX		<i>Adiantum pedatum</i>		XX	
<i>Juniperus virginiana</i>		XX		<i>Botrychium virginianum</i>		XX	
<i>Fraxinus americana</i>		XX		<i>Asclepias phytolaccoides</i>		XX	
<i>Hamamelis virginiana</i>		XX		<i>Thalictrum dioicum</i>		XX	
<i>Fiburnum Opulus</i>		XX		<i>Urticaria grandiflora</i>		XX	
<i>Cornus alternifolia</i>		XX		<i>Mitella diphylla</i>		XX	
<i>Cornus paniculata</i>		XX		<i>Hepatica acutiloba</i>		XX	
<i>Cornus circinata</i>		XX		<i>Trillium declinatum</i>		XX	
<i>Ribes Cynosbati</i>		XX		<i>Viola cucullata</i>		XX	
<i>Psedera quinquefolia</i>		XX		<i>Galium triflorum</i>		XX	
<i>Menispermum canadense</i>		XX		<i>Ancmone virginiana</i>		XX	
<i>Celastrus scandens</i>	X	XX	X	<i>Cryptotrnia canadensis</i>		XX	
<i>Rhus toxicodendron</i>	XX	X	XX	<i>Osmorhiza longistylis</i>		XX	
<i>Quercus alba</i>			XX	<i>Amplicarpa monoica</i>		XX	
<i>Quercus rubra</i>			XX	<i>Impatiens biflora</i>		XX	
<i>Quercus velutina</i>			XX	<i>Allium tricoccum</i>		XX	
<i>Quercus macrocarpa</i>			XX	<i>Smilax herbacea</i>		XX	
<i>Carya ovata</i>			XX	<i>Aralia nudicaulis</i>		XX	
<i>Corylus americana</i>			X	<i>Aralia racemosa</i>		XX	
				<i>Desmodium grandiflorum</i>		XX	
				<i>Polygonatum commuta-</i>		XX	
				<i>tum</i>			
[Herbaceous plants]				<i>Sanicula marilandica</i>		X	
<i>Rudbeckia hirta</i>	X			<i>Heracleum lanatum</i>		XX	
<i>Franaria americana</i>	XX			<i>Solidago canadensis</i>		XX	
<i>Melilotus alba</i>	XX			<i>Convolvulus sepium</i>		XX	
<i>Equisetum arvense</i>	XX			<i>Sanguinaria canadensis</i>		X	
<i>Equisetum hyemale</i>	XX			<i>Helianthus hirsutus</i>			
<i>Pedicularis canadensis</i>	XX			<i>Eriqeron philadelphicus</i>			XX
<i>Echinocystis labata</i>	XX			<i>Eriqeron ramosus</i>			XX
<i>Krigia amplexicaulis</i>	XX						

of the air and the soil-moisture content at the stations selected; and finally, as the third and last step, the interpretation of results.

LOCATION AND DESCRIPTION OF THE STATIONS

In this study seventeen different stations were established; fifteen in the ravine, one in the oak uplands, station 16, and still another in the open uplands, station 17 (Pl. IX, Fig. 15), the vegetable garden of the McLeish estate. The fifteen stations in the ravine were located, speaking generally, as follows: Station 1 (Pl. I, Fig. 2) in an embryonic ravine; station 2, in a portion of a ravine, with lateral cutting delayed, forming a miniature clay cañon; stations 3 (Pl. I, Fig. 1), 4 (Pl. III, Fig. 5), 5 (Pl. IV, Fig. 6), 6 (Pl. V, Fig. 8), and 7 (Pl. VI, Fig. 9), in the part of the ravine with the mesophytic forest vegetation on the slopes; stations 8 (Pl. IV, Fig. 7), 9 (Pl. VII, Fig. 10), 10 (Pl. VII, Fig. 11), 11 (Pl. II, Fig. 4), and 12 (Pl. VIII, Fig. 12) in a portion slightly less mesophytic than the preceding; and stations 13 (Pl. VIII, Fig. 13), 14 (Pl. II, Fig. 3), and 15 (Pl. IX, Fig. 14), on the slopes of a wash or gully near the mouth of the ravine. The specific geographical location of each of these stations in the ravine and its tributaries and also of those in the oak and open uplands is shown on the surface map (Pl. XVIII), while the angle of slope, direction of exposure, and soil and vegetation characteristics are enumerated in the following tabular summary.

The "wilting coefficient"—a term used by Briggs and Shantz ('12:9) to represent the moisture content of a soil corresponding to the wilting point of a plant—for various soils in the McLeish ravine was correlated with the soil-moisture equivalent by an indirect method devised by these authors ('12:56-57). This coefficient indicates the limit of soil-water content above which growth must occur, although plants will live and continue to draw water below this point.

In listing the dominant vegetation of each station the emphasis was placed on the herbaceous forms and the seedlings of shrubs and trees because they are a much better index of present ecological conditions than the mature trees.

MEASUREMENT OF THE EVAPORATIVE POWER OF THE AIR

The instrument that was used to measure the evaporative power of the air in the different stations was the Livingston ('10) porous cup. The structure and operation of this simple instrument have been so well set forth by the inventor and others that have used it for scientific purposes that an explanation of its management would be

DESCRIPTIVE SUMMARY CONCERNING STATIONS

No. of station	Angle of slope	Location of slope	Exposure	General character of soil	"Wilting coefficient"	Dominant plants	Av. daily evap.
1	75°	Foot	W.	Sandy clay, mixed with pebbles. Powdery white	—	None	5.44 c.e.
2	80°	Near top	N.E.	Clay and humus, more clay than humus	15.2	Species of moss	3.27 c.e.
3	—	Foot	N.W.	Alluvium and humus, about 3 in. thick	17.9	<i>Acer saccharum</i> <i>Smilax herbacea</i> <i>Mitella diphylla</i>	4.75 c.e.
4	60°	Middle	N.W.	Black loam	18.3	<i>Osmorhiza longistylis</i>	4.28 c.e.
5	55°	Near top	N.W.	Black loam	16.4	<i>Aralia nudicaulis</i>	6.67 c.e.
6	60°	Middle	S.E.	Clay and loam	17.9	<i>Acer saccharum</i> <i>Fraxinus americana</i>	5.51 c.e.
7	—	Near top	S.E.	Principally humus	18.5	<i>Juniperus virginiana</i> <i>Quercus alba</i>	7.6 c.e.
8	Abrupt rise above sta.	Foot	N.	Soil matted by roots	21	No herbaceous vegetation	3.67 c.e.
9	65°	Middle	N.	Sandy clay mixed with pebbles	13.5	<i>Hepatica triloba</i>	6.36 c.e.
10	At foot of precipice	Near top	N.	Same as above	12.5	Mosses	6.0 c.e.
11	50°	Middle		Same as station 9	12.8	<i>Amphicarpa monoica</i>	5.74 c.e.
12	45°	Near top	S.	Same as station 9	12.7	None	7.93 c.e.
13	—	Foot	N.W.	Sandy clay	10.3	<i>Equisetum arvense</i>	8.93 c.e.
14	Small plateau	Middle	N.W.	Sandy clay	11.4	<i>Aster</i> spp.	8.31 c.e.
15	Foot of vertical wall	Near top	N.W.	Sticky clay	13.1	None	9.32 c.e.
16	Level surface	Oak woods		Boulder clay with humus	20.4	<i>Helianthus hirsutus</i>	8.78 c.e.
17	Level surface	Strawberry bed		Good garden soil	16.4	Strawberry plants	16.39 c.e.

superfluous. The writer is aware that the instrument does not register with complete accuracy the evaporative power of the air when there has been precipitation during the period for which the measurement is made. During a rain, indeed, there may be a flow of water into the bottle. Drizzling rain for a long period will cause more water to enter the cup than will the same aggregate precipitation if due to a heavy rain extending over a short period. Since the results in this study have only a comparative value, the entrance of water into the bottles does not vitiate the results. This fact was first pointed out by Brown ('10) and later emphasized by Fuller ('11). In the handling of the instruments for scientific accuracy, in the selection of the intervals of time for reading, and in plotting the results, the writer had the constant advice and suggestion of Dr. Fuller, of the Department of Botany of the University of Chicago. Without his help many of the difficulties would not have been so readily overcome. All the instruments were standardized before being placed in the respective stations, and restandardized at intervals of six to eight weeks. By the coefficients thus obtained all the readings were reduced to a common unit. The first reading was made on July 5, 1913, and weekly readings were made thereafter until October 18, when the last record was made. Thus the investigation extended over a period of 112 days. Very few of the instruments were molested during the entire season, and hence the regularity of the results for each of the stations is rarely interrupted. These results are expressed as the average daily loss for the weekly interval between the readings. These results are graphically represented with the weekly intervals as abscissæ, and the amount of daily loss by the standard atmometer in cubic centimeters as ordinates.

INTERPRETATION AND DISCUSSION OF RESULTS

1. The graphs in Figure 16 (Pl. X) show that the average daily rate of evaporation for the weekly intervals was almost uniformly greater in the embryonic ravine than in either the narrow or broad portions, and greater in the broad than in the narrow. The average amounts of evaporation per day for the entire season at stations 1, 2, and 3 were 5.44 c.c., 3.27 c.c., and 4.75 c.c. respectively; that is 2.17 c.c. per day greater in the embryonic ravine than in the narrow portion, .69 c.c. greater in the embryonic ravine than in the broad portion, and 1.48 c.c. greater in the broad than in the narrow portion. In terms of percentage the rate of evaporation was 66.3% greater in the embryonic than in the narrow portion, 14.5% greater in the embryonic than in the broad, and 45.2% greater in the broad than

in the narrow.* Since all of these stations are located near the floor and represent successional stages in ravine development, the data suggest a movement from moderate moisture conditions in the embryonic ravine to greater moisture in the narrow portion, with a reversion to slightly drier conditions as the ravine changes from the V-shaped to the U-shaped type.

2. The graphs in Figure 17 (Pl. X) show that the rate of evaporation was only about two-thirds as great at the foot of the northwest-facing slope as near the top of the same slope, and that there was little difference in the rate of evaporation for the greater part of the season between the foot and the middle of this slope. The average amounts of evaporation per day at the foot, middle, and near the top of this slope were 4.75 c.c., 4.28 c.c., and 6.67 c.c. respectively. The graphs in Figure 22 (Pl. XIII) show similar results; the amount of evaporation per day was 2.33 c.c., or 63.4%, greater near the top than at the foot of the north-facing slope. The rate of evaporation at the middle of this slope was, for about the first two-thirds of the season, nearly the same as near the top. The graphs in Figure 19 (Pl. XI) show similar results for the opposing slope, the average amount of evaporation per day being 4.75 c.c., 5.51 c.c., and 7.6 c.c. respectively for the bottom, middle, and top of the southeast-facing slope—2.85 c.c., or 60%, greater near its top than at its foot. A similar series of stations in a less mesophytic portion of the ravine exhibit a similar set of conditions to those found in the more mesophytic portion. Here the rates of evaporation at the bottom, middle, and top of the north-facing slope (Pl. XIII, Fig. 22) were respectively 3.67 c.c., 6.36 c.c., and 6.0 c.c., while for the south-facing slope (Pl. XIV, Fig. 24) they were 3.67 c.c., 5.74 c.c., and 7.93 c.c.; that is, the average amount of evaporation per day was 4.26 c.c., or 11.6% greater near the top of the south-facing slope than at its foot. The graph for the daily rate of evaporation for weekly intervals at the middle of the southeast-facing slope (Pl. XI, Fig. 19) is diagrammatically between the graphs for the evaporation at the foot of the northwest- and near the top of the southeast-facing slopes, and likewise the graph for the rate of evaporation of the middle of the south-facing slope (Pl. XIV, Fig. 24) is between the graphs for the foot of the north- and near the top of the south-facing slopes. As already pointed out, the rates of evaporation for the middle of the northwest- and north-facing slopes (Pl. XVII, Fig. 17, and Pl. XIII, Fig. 22) were not intermediary between those at the foot and near the top of these slopes; the coincidences in the

*In the computation of the percentage rates the smaller of the two numbers is always used as the base.

rates of evaporation at the middle and foot of the northwest-facing slope (Fig. 17) during the early part of the season might be attributed to the fact that the instrument at the middle of the slope was almost surrounded by a dense growth of *Osmorhiza longistylis* (Pl. III, Fig. 5); and the slightly higher rate of evaporation at the middle than at the top of the north-facing slope during the latter part of the season (Pl. XIII, Fig. 22) might have been due to the unusual exposure of the middle of the slope compared with that at the top (Pl. VII, Figs. 10 and 11). Further, the differences in evaporation on different parts of the northwest- and north-facing slopes (Figs. 17 and 22), are less than on corresponding parts on the opposite slopes, and thus a station between two other stations would give less striking differences. In summary, the graphs in figures 17, 22, 19, and 24 show that as the northwest-, southeast-, and south-facing slopes are ascended there is a graded rise in the evaporative power of the air, the southeast- and south-facing slopes showing this more decidedly than the northwest- and north-facing slopes.

3. The graphs in Figure 18 (Pl. XI) show that the rate of evaporation was generally greater near the top of the southeast-facing slope than near the top of the opposite slope, the average amount per day for the entire series being nearly 1 c.c., or 13.9%, greater; the graphs in Figure 20 (Pl. XII) show that the rate of evaporation was almost uniformly greater at the middle of the southeast-facing slope than at the middle of the northwest-facing one, the average amount of evaporation per day being 1.23 c.c., or 28.7%, greater; the graphs in Figure 23 (Pl. XIII) show that the rate of evaporation for every weekly interval was greater near the top of the south-facing slope than near the top of the opposite north-facing one, being 1.93 c.c., or 32.1%, greater; while the graphs in Figure 25 (Pl. XIV) show results at variance with those in Figure 20 (Pl. XII)—a greater rate of evaporation at the middle of the north-facing slope than at the middle of the opposite south-facing one. This was undoubtedly due, as before suggested, to the unusual exposure of the middle of the north-facing slope, which was subject to less shade than any of the other stations in the immediate vicinity excepting the one near the floor of the ravine. The results shown by figures 18, 20, and 23 indicate a greater loss of water and consequently drier conditions on the southeast-facing slope than on the northwest-facing slope, and likewise greater loss of water and drier conditions on the south-facing slope than on the north-facing one. This difference in evaporation is undoubtedly due to the fact that the incident rays of the sun strike the southeast- and south-facing slopes more nearly at right angles, which means greater absorption and radiation of energy on the southeast-

and south-facing slopes than on the northwest- and north-facing slopes. Furthermore, this difference tends to explain the presence of tender mesophytic forms on the north-facing slopes of a ravine during the early part of spring, before the development of leaves on the trees, and their absence on the south-facing slopes.

4. The graphs in Figure 21 (Pl. XII) show that the rate of evaporation was greater throughout the season in the oak uplands than near the top of the northwest- and of the southeast-facing slopes, being 2.11 c.c., or 31.6%, greater per day for the entire season in the oak uplands than near the top of the northwest-facing slope, and 1.18 c.c., or 15.5%, greater than near the top of the southeast-facing slope. The graphs in Figure 26 (Pl. XV) show similarly that the rate of evaporation in the oak uplands was generally greater than near the top of the north- and south-facing slopes, the average daily evaporation for the entire period being 2.78 c.c., or 46.3%, greater in the oak uplands than near the top of the north-facing slope, and .85 c.c. per day, or about 10%, greater than near the top of the south-facing slope. This indicates that the upper portions of the south-facing ravine slopes have an evaporation very close to that of the oak uplands. Indeed one might expect a greater evaporation near the top of the south-facing slopes than in the oak uplands, due to the influence of slope exposure. Further, the differences in the average amount of evaporation per day between the oak uplands and near the floor of portions of the ravine were 4.03 c.c. and 5.11 c.c. In summary, all of the preceding statements show greater evaporation in the oak uplands than in any part of the mesophytic portion of the ravine. These differences may account for the more xerophytic aspect of the vegetation in the oak uplands than of that in the ravine (see p. 5). The graphs in Figure 21 (Pl. XII) and Figure 26 (Pl. XV) further show that the rate of evaporation in the open uplands, the strawberry bed, was nearly twice as great as in the oak uplands or in the most xerophytic portion of the ravine, the average daily rate for the entire period near the top of the northwest- south-east-, north-, and south-facing slopes, the oak uplands, and the open uplands being 6.67 c.c., 7.6 c.c., 6 c.c., 7.93 c.c., 8.78 c.c., and 16.39 c.c. respectively. The high rate of evaporation in open uplands clearly shows the effect of shade in retarding evaporation. This gives some conception of the relatively high rate of transpiration of the plants that constitute the various crops as compared with the vegetation that springs up in the forests, it having been clearly shown by Livingston ('10) that there is a definite relation between rate of evaporation of water from a free surface and the rate of transpiration in a leaf.

5. The graphs in Figure 27 (Pl. XV) show relatively high rates of evaporation when compared with the rates in other portions of the ravine. The average amounts of evaporation per day at the foot, middle, and head of the gully, or wash, were 8.93 c.c., 8.31 c.c., and 9.32 c.c. respectively. The evaporation on the gully slope shows less gradation than on the mesophytic slopes of the ravine, the difference between the average at the foot and the head of the gully being only .39 c.c. The evaporation on the gully slope was about the same as that in the oak uplands, which was 8.78 c.c. per day for the season. There is no question that during certain parts of the day the evaporation was greater on the gully slope than in the oak uplands. These high rates of evaporation on this slope suggest a vegetation with a xerophytic aspect (see p. 5). In the early part of the summer the gully slope was nearer devoid of vegetation than during the latter part of the season. Reference has been made in an earlier part of this paper to the luxuriance of the late-summer flora of the slope (Pl. II, Fig. 3). These changes in the vegetative conditions would tend to account for the special variations in the graphs for the gully slope, the presence of abundant vegetation about the atmometer tending to check the evaporation and its absence tending to increase the evaporation relatively.

6. A comparison of all the graphs, with the exception of those for the station in the open uplands and the stations on the gully slope, shows a remarkable similarity in the variation of the average daily loss for the weekly intervals, the minimum evaporation occurring during the week preceding August 16 and the maximum during the week preceding September 12. The graphs for the station in the open uplands and the stations on the gully slope show that the lowest rate of evaporation was during the same week as for the other stations, while the highest rate for the open uplands was during the week preceding August 2, and for the stations on the gully slope high rates occurred during the weeks preceding July 12 and 26, and August 2 and 31, as well as during the week preceding September 12.

SUMMARY AND CONCLUSION

The average daily evaporation rate for any weekly period was greater in the embryonic ravine than that for the corresponding weekly period in the narrow ravine; almost always greater in any portion of the broad ravine with mesophytic slopes than in the narrow ravine; greater near the top of slopes of mesophytic portions of ravine than near the floor; generally greater at the middle of the southeast-facing slopes than at the middle of the opposite slope; al-

most uniformly greater near the top of the southeast- and south-facing slopes than near the top of the opposite northwest- and north-facing slopes; usually greater in the oak uplands than in any mesophytic portion of the ravine; and, finally, the greatest average daily evaporation for any weekly period for any of the stations was in the open and exposed upland, as noted for the strawberry bed. (Pl. XVI, Fig. 28.)

If the differences in the evaporative power of the air at the different stations are taken as an index of the relative xerophytism and mesophytism of the vegetation, the preceding summary permits the following ranking of the stations, based upon their progressive xerophytism: the embryonic ravine, the narrow ravine, the foot of the mesophytic slopes, near the top of the northwest- and north-facing slopes, near the top of the southeast- and south-facing slopes, the oak uplands, and, the most xerophytic of all, the open uplands, represented by the strawberry bed. In general the movement is from a moderate rate of evaporation in the embryonic ravine to a lower rate in the narrow portion, and then a reversion to a higher rate, which gradually increases until it reaches its climax for the ravine near the top of the southeast- and south-facing slopes, and the climax for all of the stations in the open uplands.

The average amount of evaporation for each of the stations, as shown in Figure 28 (Pl. XVI), strongly reinforces diagrammatically the preceding conclusion.

The data clearly show that the differences in the rates of evaporation at the various stations are sufficient to indicate that the atmospheric conditions are effective factors in causing plant succession in a ravine.

MEASUREMENT OF SOIL MOISTURE

Samples of soil were taken weekly at depths of 7.5 cm. and 15 cm. in the narrow ravine, station 2; at the foot of the most mesophytic slope of the broad ravine, station 3; and at the foot of the gully slope, station 13. Each sample was placed in an air-tight soil jar and weighed when brought to the laboratory, and then placed in a drying oven at a temperature of 100° C. for one week, or until it ceased to lose weight. It was then weighed to determine the loss in weight resulting from the removal of the soil moisture, and the amount of such moisture was calculated in terms of percentage of the dry weight of the soil. The results have been plotted with the weekly intervals as abscissæ and the percentages of moisture as ordinates (Pl. XVI, Fig. 29, and Pl. XVII, Fig. 30 and 31).

It had long been thought that there could be no direct relation established between the percentage of water in a soil and the amount that is available for plant growth. Recently, however, a standard has been discovered by Briggs and Shantz ('12) by which the water content of the soil may be directly related to continuity of plant vitality. They have termed this standard or constant the "wilting coefficient" of the soil, and defined it (p. 6) as "The moisture content of the soil (expressed as a percentage of the dry weight) at the time when the leaves of the plant growing in that soil first undergo a permanent reduction in their moisture content as the result of a deficiency in the soil-moisture supply." Only the soil moisture over and above the wilting coefficient is available for plant growth, and hence this surplus has been termed "growth water." In this investigation the wilting coefficients of the various soils were found by the "indirect method" devised by Briggs and Shantz ('12: 56-57) which is based on the relationship of the wilting coefficient to the moisture equivalent as determined by physical methods. These coefficients have been represented (in figures 29, 30, and 31, plates XVI and XVII) by transverse broken lines, hence the growth water, or that portion of the soil moisture available for the growth of plants, is denoted by the interval between the lines representing the total percentage of moisture present and those showing the amount of the wilting coefficients.

INTERPRETATION AND DISCUSSION OF RESULTS

1. The graphs in Figures 29 (Pl. XVI) and 30 (Pl. XVII) show that the percentage of moisture at stations 2 and 3 at a depth of 7.5 cm. was greater than at a depth of 25 cm. in each of the weekly examinations that was made. (The results are graphically represented, with the weekly intervals as abscissæ, and the percentages of soil moisture at the time of each examination as ordinates.) No such regularity in the per cent. of moisture content at the different depths was found at station 13 (Pl. XVII, Fig. 31).

2. The samples taken at a depth of 7.5 cm. show in a general way that the per cent. of moisture content in the narrow ravine at station 2 was less than in the broad ravine, station 3, and that the percentage of moisture content at the foot of the gully slope at station 13 was less than at either of the other two stations examined. The samples from a depth of 25 cm. did not show any such variations. From this we must not hastily conclude that conditions were more favorable for plant growth from the standpoint of soil moisture in the broad ravine than in the narrow ravine, or more favorable

at either of these two stations than at the foot of the gully slope, but further examine our data. What is really important in soil-moisture comparisons is the relative amount of growth water, or the difference between the actual water content of the soil and the water content not available for growth in the plant. The average percentages of moisture at a depth of 7.5 cm. for broad ravine, narrow ravine, and gully slope were, in the order named, 28.3, 24.1, and 17.7. The respective wilting coefficients for the same were 18, 15.1, and 10.2. This indicates that the average percentage of growth water in the broad ravine was 10.3, in the narrow ravine 9, and for the foot of the gully slope 7.5. Thus, from the standpoint of soil moisture, supplies were slightly more abundant in the broad than in the narrow ravine, and least abundant at the foot of the gully slope.

If the wilting coefficient may be regarded as indicating a condition in which the water supply of plants is reduced to such a degree as to cause permanent wilting, a recovery from which is only possible by an increase of the soil moisture, the graphs clearly show that at no time did the plants wilt permanently from the lack of water in the soil. One of the plants that wilted regularly during midday on sunny days was the jewel weed. This must not be attributed to the lack of water in the soil, but to a more rapid rate of evaporation from the portion of the plant above ground—a more rapid rate than that at which the water was taken in by the root of the plant. Such wilting would not be permanent wilting, which would eventually mean the death of the plant, but a temporary wilting, which would mean the restoration of the turgidity of the plant with a decrease of evaporation such as is caused by the coming of nightfall.

4. These data show in general so generous a supply of soil moisture at the various stations within the ravine that it may be safely assumed that the soil moisture is a factor contributing to the rapid advance of succession in such situations, and should have consideration in explaining the early attainment of advanced mesophytism.

5. These data also show that while the variations in soil moisture are not great at the different stations, the differences that do exist correspond in a general way to those of evaporation and may indicate a contributing factor in causing plant succession in a ravine. In order to make these soil-moisture studies more convincing, weekly examinations should have been made at the other fourteen stations.

CONCLUSION

The close relationship of evaporation and soil moisture to plant succession in a ravine is clearly evident from this study. It would have been more convincing if it had extended over a longer period;

but the writer does not believe that in case the period had been longer the general results would have been different, since the investigation extended over the most critical season of the year, namely, the part of the summer when the evaporation rates are relatively high and soil moisture relatively low; and these are the most critical conditions for the development and survival of plants.

ACKNOWLEDGMENTS

Grateful acknowledgment is here extended to Dr. H. C. Cowles, of the University of Chicago, for suggesting the problem and site for study; to Mr. and Mrs. McLeish for their kindness in permitting weekly visits to their estate, on which the ravine is located; to H. DeForest for photographs of vegetation in vicinity of stations, and to Dr. Geo. D. Fuller, also of the University of Chicago, for his helpful suggestions in overcoming the difficulties that arose in the course of the investigation.

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PLATE I



Fig. 1. Station 3, at the foot of the main ravine. Hard maple fallen across the channel as the result of lateral corrosion.



Fig. 2 Station 1, in an embryonic V-shaped ravine working its way back into the oak uplands.

PLATE II



Fig. 3. Station 14, in the gully. A miniature plateau showing a great variety and profusion of asters.



Fig. 4. Station 11, on the middle of the south-facing slope covered with an almost pure stand of the hog peanut, *Amphicarpa monoica*.

PLATE III



Fig. 5. Station 4. The lower half of the picture shows an almost pure growth of *Osmorhiza longistylis*, on northwest-facing slope.

PLATE IV



Fig. 6. Station 5, near the top of the northwest-facing slope. *Aralia nudicaulis* is the dominant plant of the undergrowth.



Fig. 7. Station 8, on the floor of the mesophytic portion of the ravine.

PLATE V



Fig. 8. Station 6, near the middle of the southeast-facing slope. Hard maple and ashes are dominant.

PLATE VI



Fig. 9. Station 7, near the top of the south-east facing slope.

PLATE VII



Fig. 10. Station 9, on the middle of the north-facing slope. Species characteristic of the vernal flora are abundant here.



Fig. 11. Station 10, in the characteristic mesophytic forest of the ravine.

PLATE VIII



Fig. 12. Station 12, near the top of the south-facing slope among red oaks and witch hazel.



Fig. 13. Station 13, at the foot of the wash near the mouth of the ravine. The only place in the ravine showing *Juniperus communis*.

PLATE IX



Fig. 14. Station 15, at the head of the wash near the mouth of the ravine.



Fig. 15. Station 17, on the open upland. The strawberry bed on the McLeish estate.

PLATE X

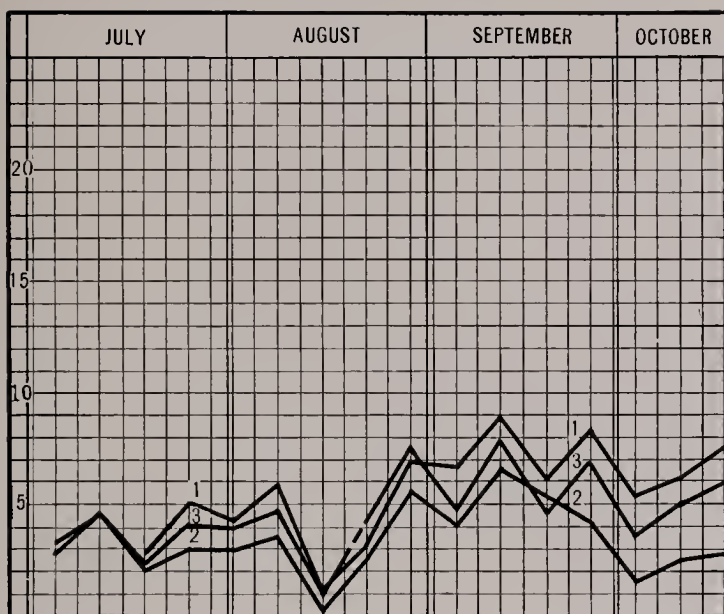


Fig. 16. Evaporation rates in an embryonic ravine (1), in a portion of ravine with lateral cutting delayed (2), and at the bottom of the most mesophytic portion of ravine (3). Stations 1, 2, and 3.

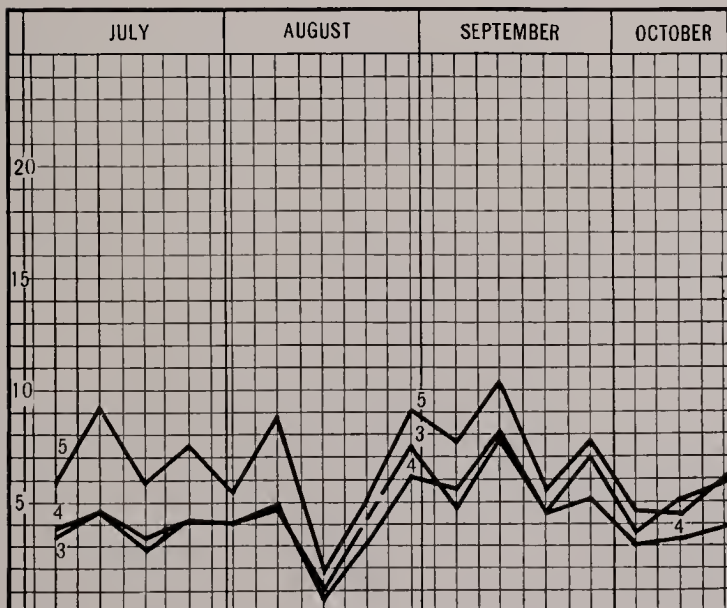


Fig. 17. Evaporation rates at the foot (3), middle (4), and top (5) of the north-west-facing slope of the most mesophytic portion of the ravine. Stations 3, 4, and 5.

PLATE XI

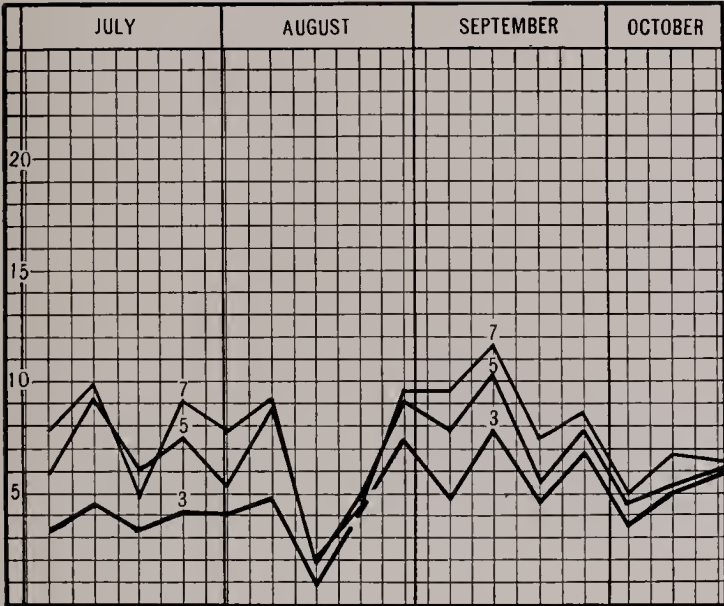


Fig. 18. Evaporation rates at bottom (3) and near the top of the northwest (5) and the southeast-facing (7) slopes of the ravine. Stations 3, 5, and 7

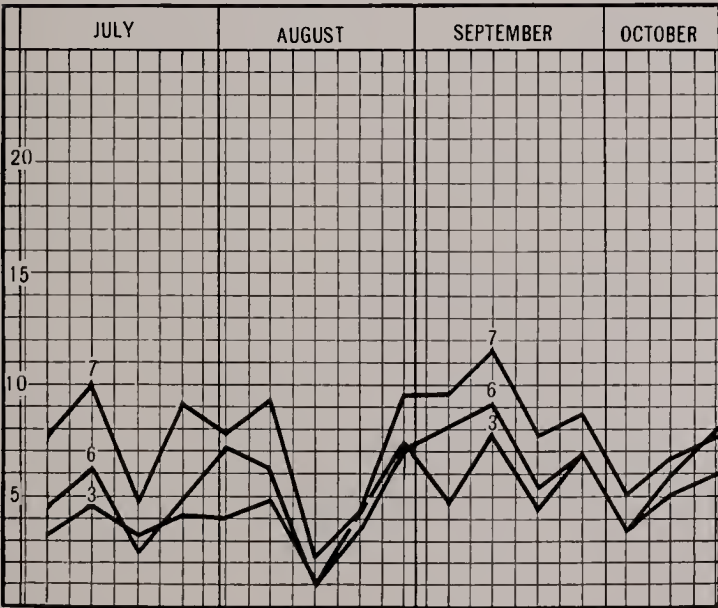


Fig. 19. Evaporation rates at foot of the northwest facing slope (3), and middle (6) and top (7) of the southeast-facing slope of the most mesophytic portion of the ravine. Stations 3, 6, and 7

PLATE XII

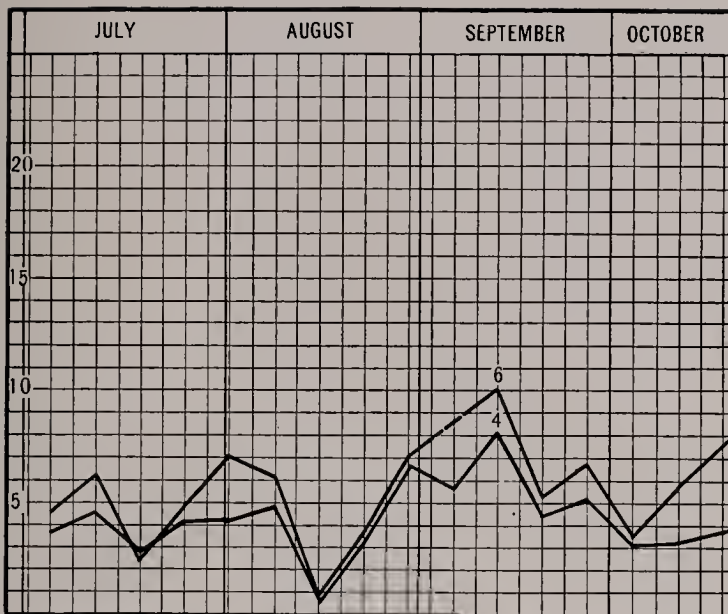


Fig. 20. Evaporation rates at the middle of both the northwest (4) and the southeast (6) facing slopes of the most mesophytic portion of the ravine. Stations 4 and 6.

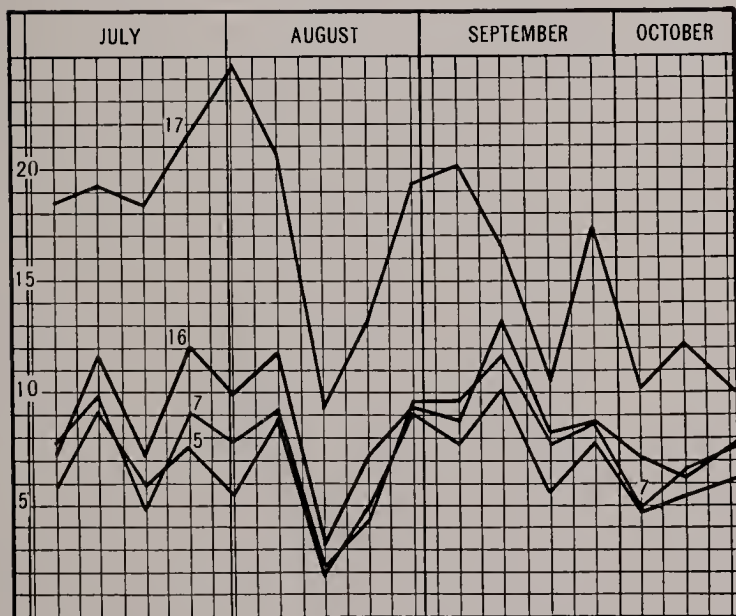


Fig. 21. Evaporation rates near the top of both northwest (5) and southeast (7) facing slopes of the ravine, the oak uplands (16), and the open uplands (17). Stations 5, 7, 16 and 17.

PLATE XIII

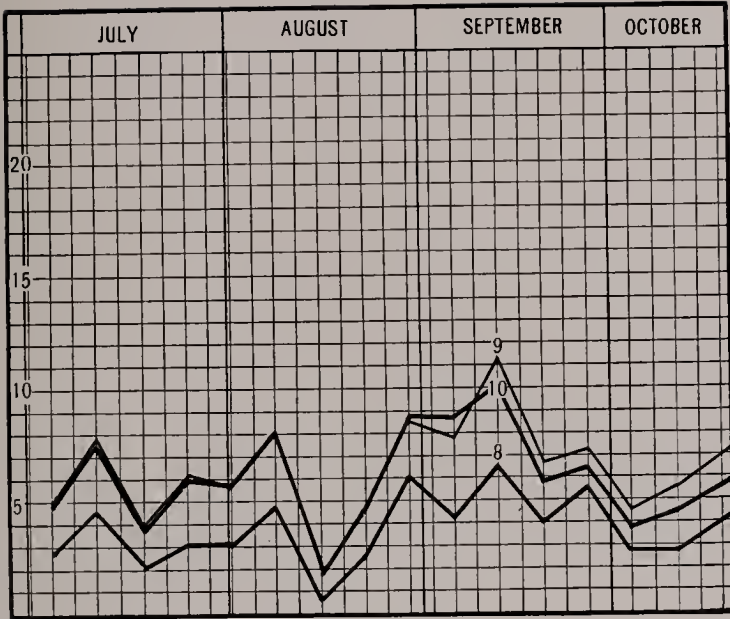


Fig. 22. Evaporation rates at the foot (8), middle (9), and near the top (10) of north-facing slope of ravine. Stations 8, 9, and 10.

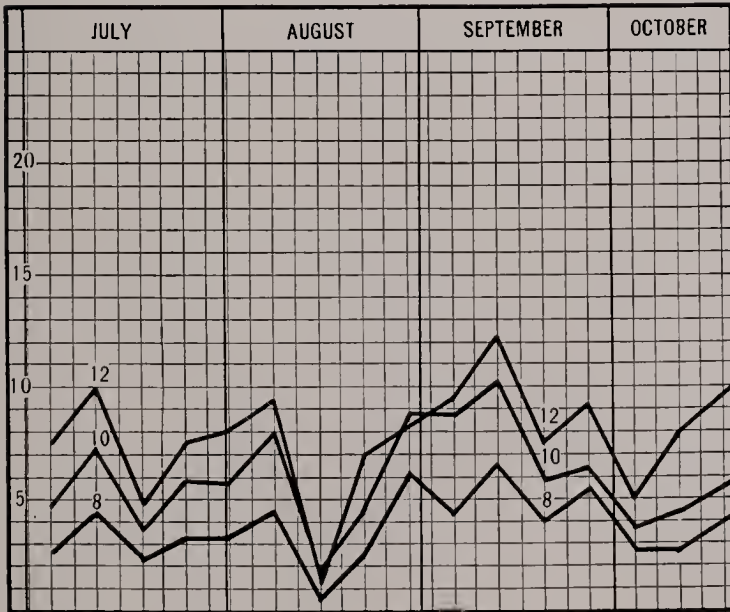


Fig. 23. Evaporation rates at the bottom (8) and near the top of the north (10) and of the south (12) facing slopes of the ravine. Stations 8, 10, and 12.

PLATE XIV

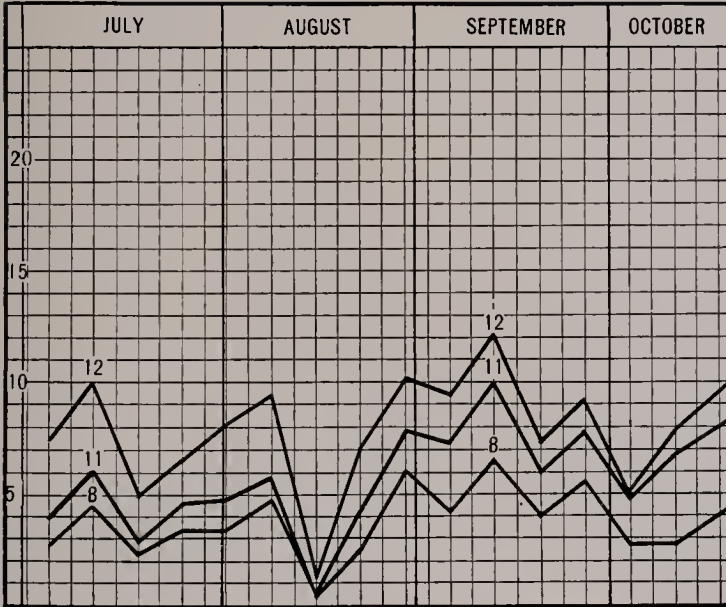


Fig. 24. Evaporation rates at the foot (8), at the middle (11), and near the top (12) of the south-facing slope. Stations 8, 11, and 12.

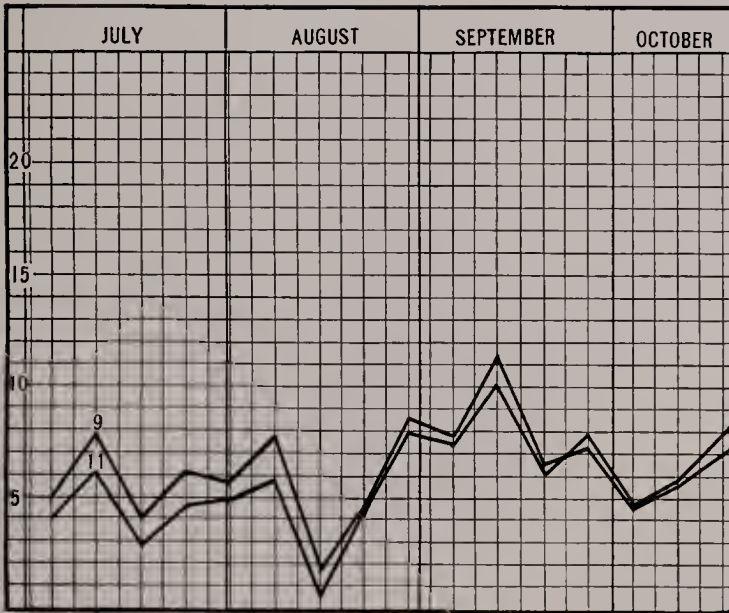


Fig. 25. Evaporation rates at the middle of both the north (9) and the south (11) facing slopes of the ravine. Stations 9 and 11.

PLATE XV

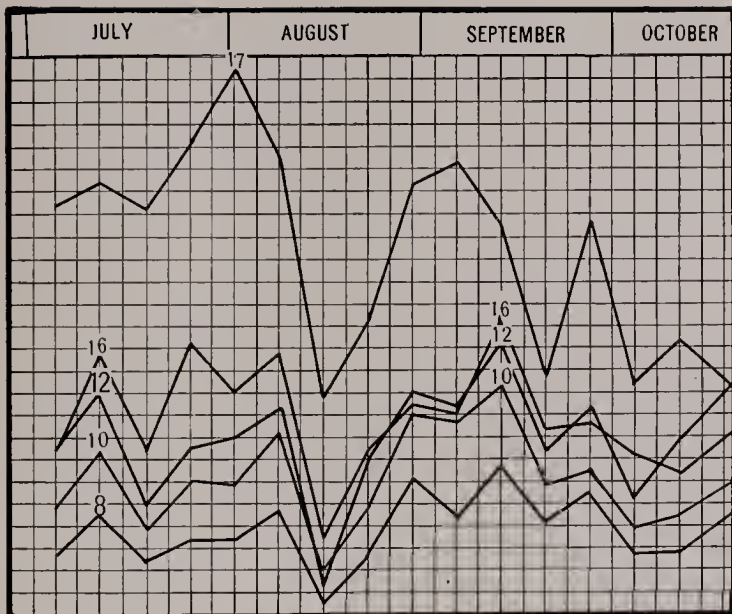


Fig. 26. Evaporation rates at the foot (8), near the top of the north (10) and of the south (12) facing slopes of the ravine, in the oak uplands (16), and in the open uplands (17). Stations 8, 10, 12, 16, and 17.

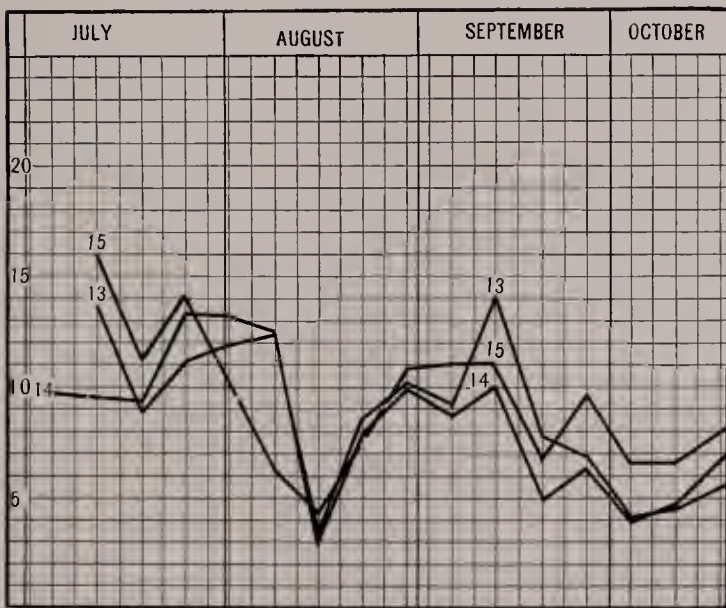


Fig. 27. Evaporation rates at the foot (13), middle (14), and top (15) of the wash or gully slope. Stations 13, 14, and 15.

PLATE XVI

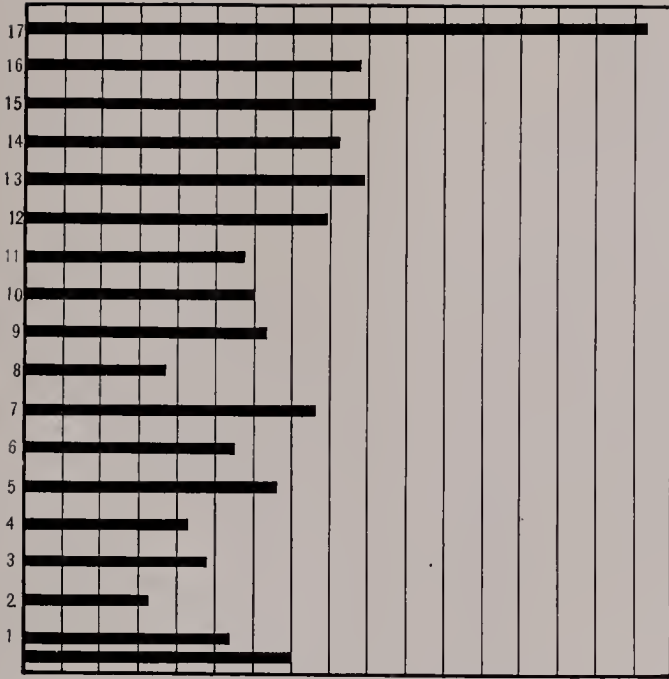


Fig. 28. Diagram showing the comparative evaporation rates at the different stations on the basis of the maximum average amount per day between July 5 and October 18, 1913.

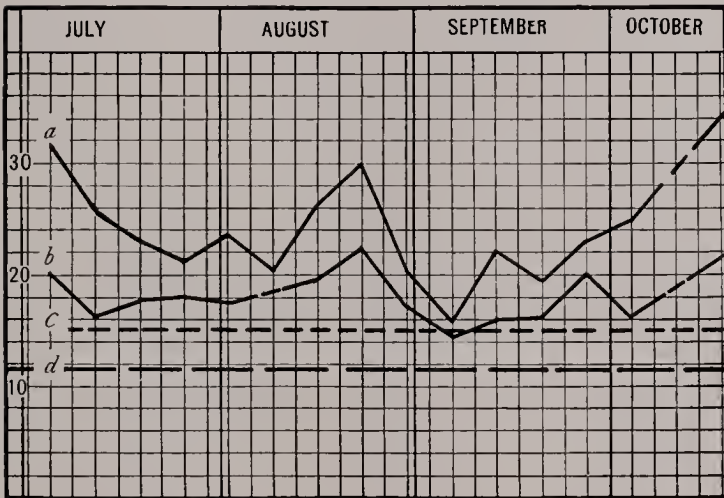


Fig. 29. Graphs showing the range of soil moisture in the narrow ravine, Station 2, at depths of 7.5 cm. (a) and 15 cm. (b). Broken lines show the wilting coefficients for the soil at depths of 7.5 cm. (c) and 15 cm. (d).

PLATE XVII

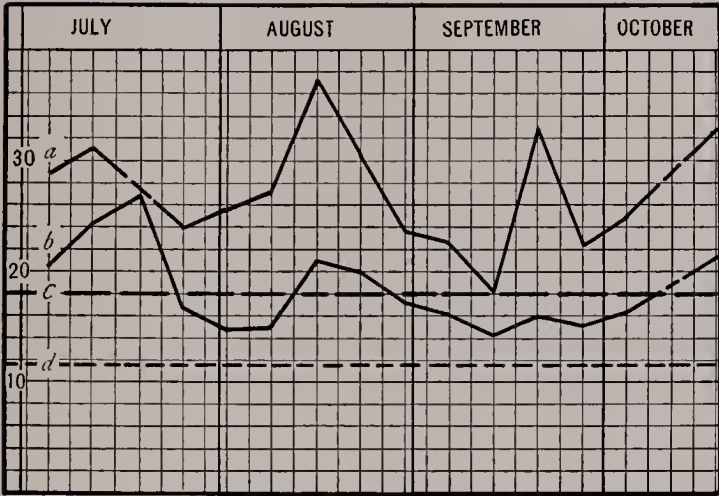


Fig. 30. Graphs showing the range of soil moisture at the bottom of the mesophytic ravine, Station 3, at depths of 7.5 cm. (a) and 15 cm. (h). Broken lines show the wilting coefficients for the soil at depths of 7.5 cm. (c) and 15 cm. (d).

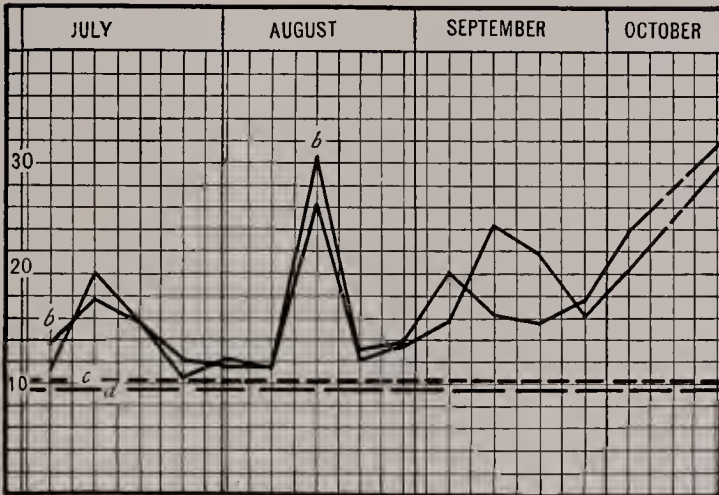
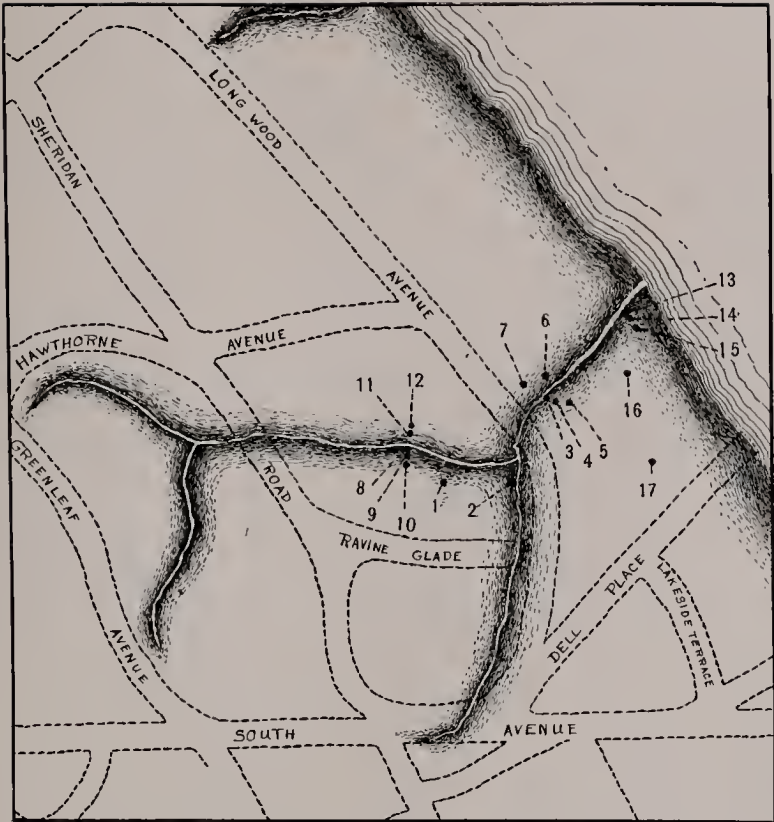


Fig. 31. Graphs showing the range of soil moisture at the foot of the wash, Station 13, at depths of 7.5 cm. (a) and 15 cm. (b). Broken lines show the wilting coefficients for the soil at depths of 7.5 cm. (c) and 15 cm. (d).

PLATE XVIII



Map of McLeish Ravine, Glencoe, Illinois. Scale about $\frac{2}{17}$ miles to the inch.