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G. W. MARTIN, Editor

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1938

THE EFFICIENCY OF MONOCOTYLEDON ROOTS IN SOIL CONSERVATION

Howard J. Dittmer

The plant cover is of primary importance in soil conservation. It not only lessens the effects of rainfall but also greatly facilitates percolation of water since it increases soil porosity. Surface accumulations of humus also favor the retention and absorption of water. The importance of plants in soil conservation, however, is mainly due to the effects of roots and root hairs in binding soil.

Grasses are a dominant element in the natural plant associations which have for ages held and built up the soil. These indigenous plants covered the land twelve months of the year. Today, in middle western states as in many other regions, cultivation has destroyed the natural plant cover over vast areas, increasing the problems of soil erosion. Perennials have been replaced by annual crop plants which, while efficient soil binders for a few months of the year, do not present a plant cover at all comparable to the indigenous climax associations.

Since grasses have compact fibrous root systems in upper soil levels they have occupied a particularly prominent place in erosion control. Monocotyledon roots are exceedingly numerous, branch freely and retain their roots hairs. They lack cambium and are consequently small in diameter. The lack of secondary thickening is undoubtedly a factor in this multiplicity of roots for such plants and furthermore it favors the persistence of root hairs on older portions since the epidermis and cortex do not slough off.

Although some grasses send roots several feet into the ground their more abundant growth is in the upper foot of soil and in many cases within six inches of the surface. (Graber, 2; Harrison, 3). This massing of roots in upper soil levels favors soil conservation, for there is a close correlation between the number of roots and root hairs per unit-volume and the amount of soil bound by their surfaces.

Quantitative studies of roots and root hairs are valuable in giving definite information concerning the numbers and distribution of subterranean plant parts. Weaver (5), (6) and his associates (7) have published data on the lateral and vertical distribution of roots for many pasture, weed and crop plants of the prairie and plains areas. However there are few published records involving entire root systems of mature or large plants. In his quantitative study of wild oats, Marquis wheat and Prolific spring rye Pavylechenko (4) included estimates of the number and length of roots for these grasses both when grown in competition and also when grown separately. When grown apart these plants were found to have root systems one hundred times greater than when in competition under field conditions. His data included measurements of the main, secondary and tertiary divisions of roots but made no mention of root hairs.

In a previous paper the writer (1) recorded his measurements of both roots and root hairs on a single winter rye plant grown in a plant house. From careful counts of extensive samplings it was determined that this plant had approximately 13,800,000 roots with a total length of over 385 miles. These roots had a surface area of about 2,550 square feet, exposed chiefly by the smaller members. More significant were the figures for the root hairs of this single rye plant which numbered approximately 14,300,000,000. These hairs had a total length of over 6,600 miles and a surface area of about 4,320 square feet.

Similar observations have since been made on the roots and root hairs of oats, winter rye and Kentucky bluegrass growing under field conditions. Samples of soil 3 inches in diameter and 6 inches deep (42 cubic inches) were used as units in these studies. Such soil samples were taken in the field by means of a cutting tube, washed to remove the soil and the roots preserved for study. Averages were employed to determine the statistical data for counts, measurements and surface computations. Counts were made of all attached roots in the soil samples and also cut-off portions from adjacent plants. Included too, in the case of bluegrass, were roots arising from rhizomes.

Fifty main roots in each sample were used to determine the average number of secondaries per main root and also the average number of tertiary members arising from a secondary root. Root hair counts and measurements were subsequently made for all root categories. Calculations based on these figures, which included about one-third of the roots, were applied to the remaining units of each soil sample.

Avena sativa had approximately 4,700 roots of all categories in the sample soil volume (42 cubic inches). The total root length was about 150 feet with an exposed surface area of nearly 50 square inches. There were approximately 6,370,000 root hairs on these roots with a total length of about 5 miles and a surface area of nearly 535 square inches or 3.7 square feet.

Roots of winter rye in a similar sample volume of soil numbered over 6,400 with a total length of nearly 210 feet and having a surface area of about 78 square inches. Root hairs which numbered approximately 12,500,000 had a total length of about 10 miles and a total surface of nearly 1190 square inches or 8.2 square feet.

The subterranean members of *Poa pratensis* were far more numerous. There were approximately 84,500 roots per sample soil volume with a total length of nearly 1,260 feet and having a surface area of about 330 square inches. There were approximately 51,600,000 root hairs with a total length of over 30 miles and having a surface area of nearly 2,450 square inches or 17 square feet. The 24 inches of rhizomes in this soil sample gave rise to 14 percent of the total number of roots. The lateral distribution of the plants was greatly increased by these stems, which aid considerably in the formation of a compact sod.

There are obvious differences in the soil binding capacity of these plants. Oats would be least efficient since the secondary roots are farther apart and therefore fewer in number. As it is an annual, sowed in spring and harvested in late summer, it is actively growing a comparatively short time.

Winter rye is, in general, superior to other cereals in its efficiency in retarding erosion. Although an annual, it is alive three-fourths of the year and tillers readily, giving rise to numerous adventitious main roots which in turn branch freely and tend to thoroughly permeate the soil near the plant. Rye is sowed in the fall and is well established by winter; it thus binds the soil, retarding surface runoff both autumn and spring.

Poa pratensis is superior to the other grasses in retarding erosion. Because of its hardiness, abundant roots, and ready propogation by rhizomes it forms a very compact vegetative cover. Since this grass is a perennial it protects the soil twelve months of the year and throughout most of that time is growing new plants, new roots and new rhizomes. A grass which possesses this sod-forming habit of growth is better adapted to retard erosion than annuals or perennial bunch grasses. Kentucky bluegrass, within its areas of favorable growth, is the soil binder *par excellence*.

These three grasses have long been recognized as of unequal value in soil conservation. This survey, with its comparative data on the subterranean plant parts of all three, shows why winter rye is much more efficient than oats, and why Kentucky bluegrass is far superior to either of the others in retarding erosion.

Acknowledgment

The writer wishes to express his thanks to Professor R. B. Wylie, under whose direction the work was carried on, and for his continued interest and helpful criticisms.

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ADDITIONAL MYXOMYCETES FROM PANAMÁ

G. W. Martin

In a previous paper (Trans. Amer. Microscop. Soc. 55: 277-280. 1936) I reported sixty-six species of Myxomycetes collected in Panamá during the summer of 1935. Eleven species had previously been reported from Barro Colorado Island, of which nine were included in my list, making the total number of species known for the Republic, including the Canal Zone, sixty-eight. During the summer of 1937, additional collections were made in the Canal Zone and in the Province of Chiriquí, a considerable proportion of which were unfortunately destroyed by fire. Of those that survived, many were species included in the previous list, but in a number of instances from different localities, and seven species are to be added.

The localities in which collections were made in 1937 included Balboa, in the vicinity of the Missouri Botanical Garden Tropical Station at the base of Ancon Hill, the Plant Introduction Gardens at Summit, and Barro Colorado Island, all in the Canal Zone, and all visited in 1935. An additional locality in the Zone which appears to be unusually rich mycologically, and would undoubtedly reward more extensive collecting, is the low forest north of the road between Thatcher Ferry and Arraiján and about three kilometers east of that village. Some time was spent in Chiriquí, this time on the east side of the mountain, and collections were made near the town of Boquete (1040-1100 m.), at the Finca Lerida above the town (1600 m.), and particularly in the vicinity of Casita Alta, a small cabin on the trial between Finca Lerida and the summit (2000-2200 m.).

To Mr. A. M. Monniche, owner of Finca Lerida and Casita Alta, cordial acknowledgment is due for the courtesies extended to our party, which included, besides myself, Dr. R. E. Woodson, Mr. Russell E. Seibert and Mr. Robert Simon of the Missouri Botanical Garden.

As in the previous note, an asterisk indicates that the species so designated is reported upon the basis of fructifications developed in a sterile moist chamber after return to Iowa City upon substrata collected in the region indicated. Distribution is shown by the same symbols; CZ, Canal Zone, except Barro Colorado Island; BC, Barro Colorado; P, Province of Panama; Chi, Province of Chiriquí.

SPECIES HITHERTO UNREPORTED FROM PANAMA.

Badhamia affinis Rost. Chi. Spores globose, 15-16.5μ, or broadly oval, 16-18 x 14.5μ, deep violet, closely and evenly warted.

Badhamia orbiculata Rex. Chi.

Didymium intermedium Schröt. CZ. This species, originally described from Brazil on the basis of one of Ule's collections (Hedwigia 35: 209. 1896) was also found there by A. Möller, whose specimen was described by Jahn (Ber. d. d. bot. Gesell. 20: 275. 1902) as *Didymium excelsum*. Both collections were on decaying leaves. Lister (Mycetozoa ed. 3: 122. 1925) notes a report of its occurrence on Mt. Nikko, Japan, but Emoto (Jour. Jap. Bot. 10: 758-768. 1934) does not include it in his list of myxomycetes from that locality. Two California specimens in the University of Iowa collection are under this name. One of them is a portion of the collection identified by Miss Lister and reported by Plunkett (Pub. Univ. Cal. L. A. Biol. 1: 40. 1934), with very dark, coarsely spinulose to subreticulate spores, 12-16μ in diameter. An earlier collection by E. Bethel is on cow dung and was determined by him as *D. squamulosum*, which both specimens suggest in external appearance. It has spores almost exactly like those of the Plunkett specimen, and I am now inclined to believe that both represent either imperfectly matured fruitings of *D. squamulosum*, or, less probably, a distinct but closely allied species. I do not regard them as properly referred to *intermedium*.

The collection here reported was found on a fallen, partly decayed, moss-covered log at the Arraiján locality referred to previously. The fructification was a foot or more in length and at least half as broad. The luxuriantly branched clusters seemed to suggest an undescribed species, but reference to Schroeter's original description and especially to Jahn's excellent description and figures seem to make it clear that the Panamá gathering is simply a more luxuriant and perhaps more typical representation of the form previously described from Brazil. On the basis of this material a revised description may be in order, as follows:

Gregarious, sporangiate, stalked, solitary or united in simple or compound corymbose clusters, sporangia white or grayish, externally globose or somewhat irregular, 0.4-0.7 mm. broad, in reality discoid

and deeply reflexed so that the center is hollow and traversed by the limy stalk which simulates a columella; peridium thin, fragile, translucent, densely covered with a powdery, white layer of stellate crystals; stalk yellowish white, smooth, subulate, 1-1.3 mm. long, with a hyaline cortex, the core opaque and filled with rounded crystalline concretions, arising from a concolorous branch of the hypothallus, which elsewhere is colorless or somewhat crystalline on the substratum; columella small, dome-shaped, inconspicuous; capillitium

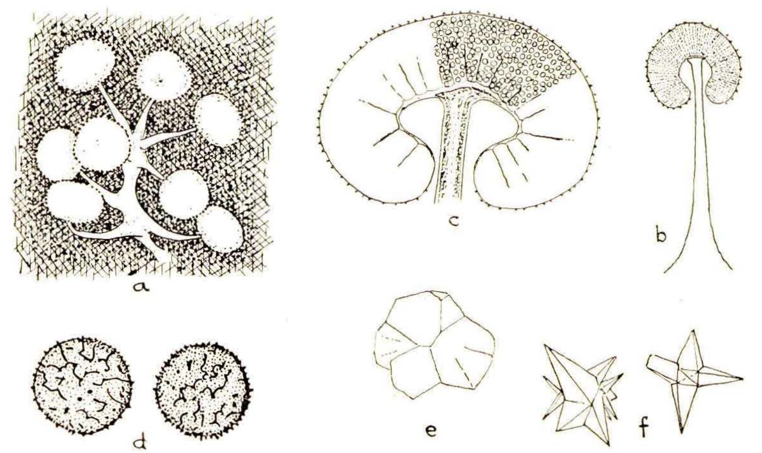

Figure 1. *Didymium intermedium* Schröt. a. cluster of sporangia, ×15; b. free-hand section of sporangium, ×25; c. microtome section of sporangium, ×60; d. two spores, ×1200; e. crystal from stalk, ×1200; f. two crystals from peridium, ×1200. Figs. c-f outlined with aid of camera lucida and reduced in reproduction to magnifications given.

delicate, colorless, profuse, branching and anastomosing freely; spores black in mass, dark brown by transmitted light, densely covered with long dark spines and by a partial and irregular reticulum, 10-12μ.

Diderma spumarioides Fries. CZ. This is the tropical form with areolate dehiscence reported from Ceylon by Petch (Ann. Royal Bot. Gard. Peradeniya 4: 343. 1910) and recorded by Lister (Mycetozoa ed. 3: 87. 1925) from Venezuela. Petch notes much variability in spore characters. The spores of the collection here recorded are very uniform, strongly but sparsely warted, 9-10μ.

**Licea minima* Fries. Chi.

Lycogala conicum Pers. BC. Collected by M. L. Shields.

**Hemitrichia leiocarpa* (Cke.) List. P.

ADDITIONS TO RANGE OF SPECIES PREVIOUSLY REPORTED

**Clastoderma Debaryanum* Blytt. CZ, BC.
Cribraria dictydioides Cke. & Balf. CZ.
**Cribraria violacea* Rex. CZ.
Fuligo septica (L.) Wiggers. Chi.
Hemitrichia Serpula (Scop.) Rost. CZ.
Hemitrichia stipitata (Massee) Macbr. CZ, BC.
Hemitrichia Vesparium (Batsch) Macbr. CZ.
**Ophiotheca chrysosperma* Currey. CZ, BC.
Physarum bogoriense Racib. CZ.
Physarum tenerum Rex. CZ.
Physarum Wingatense Macbr. CZ, BC.

In the earlier note I stated that the species previously reported from Barro Colorado Island as *Hemitrichia clavata* was in all probability *H. stipitata*. Several specimens of *stipitata* were collected on Barro Colorado on August 30. All were destroyed by fire, but the species is usually recognizable by the naked eye and unmistakably so with a hand lens. Identical specimens collected near Arraiján were preserved. I have yet to see a collection of *H. clavata* from the tropics.

HYMENIAL ORGANIZATION OF SEBACINA CALCEA

E. B. Wittlake

The genus *Sebacina* as established by the Tulasnes (9) included two species previously assigned to *Corticium* but found by them to possess cruciate-septate basidia. One of these, *S. incrustans* (Pers.) Tul., to be regarded as the type, has a semi-gelatinous hymenium borne on a tough-fibrous basal portion. The other, *S. caesia* (Pers.) Tul. is completely gelatinous. Since then a number of other species have been added to the genus, including some that are arid and even arachnoid. Many of them have little in common with *S. incrustans* except the possession of cruciate-septate basidia and a resupinate habit. Various attempts have been made to segregate certain groups of species. *Eichleriella* Bres., including forms with dry, fleshy basidiocarps and free edges, as in *Stereum*, has met with general acceptance. *Bourdotia*, characterized by the possession of gloeocystidia, and *Heterochaetella*, with cystidia, have both been adopted by a number of students of the group. Rogers (7) believes that neither of these characters is alone sufficient to justify more than subgeneric segregation. This may be granted, but the question still arises whether the curious racemose arrangement of the basidia in certain species assigned to *Bourdotia*, well illustrated by Rogers (l. c. pl. 1, fig. 13; also vol. 17: pl. 3, fig. 18b), do not constitute a basis for generic recognition. In any event *Sebacina*, as reflected in current usage, as Martin (5) has pointed out, includes a group of heterogeneous forms which must sooner or later be redistributed on more fundamental characters than those at present used to delimit the genus. The present study of one of the more aberrant species of the genus is intended as a step toward such needed clarification.

Maire (4) studied two species of *Sebacina* cytologically with reference to the nuclear phenomena of the basidium and found that the spindles of the two divisions were arranged transversely. He believed the chromosome number in both species to be two. Neuhoff (6) gives a brief but careful study of basidial development in *S. calcea* (Pers.) Bres., the species here discussed, and also adds observations on *S. effusa* (Bref.) Pat., one of the species studied by Maire, finding the chromosome number to be apparently four. Kühner (3) working on what he refers to as *S. gloeocystidiata*, described as a new species, but which Bourdot and Galzin (1) cite as a synonym of their *Bourdotia cinerea*, was the first to study the development of accessory hymenial structures. He states that the chromosomes are probably two in number, although some of his figures seem to indicate a larger number.

Whelden has published an important series of cytological studies on tremellaceous fungi, including four species of *Sebacina* (10), all gelatinous forms. He found the diploid chromosome number to be six in *S. deminuta* Bourd., *S. fugacissima* Bourd. and Galzin, and *S. epigaea* (Berk. and Br.) Bourd. and Galz., and eight in *Protodontia uda* v. Höhn., *Tremellodendron candidum* (Schw.) Atk. (12), *S. globospora* Whelden (11) and in the species of *Tremella* and *Exidia* studied. He paid particular attention to sterile hymenial structures and found that the paraphyses branched off from the same hyphae that bore basidia, while cystidia, gloeocystidia, and dendrophyses originate from separate branches; all are binucleate and look much like young basidia in their early stages.

More information is needed as to the origin and development of the non-basidial elements in these forms and since *Sebacina calcea* is a species in which the hymenium is largely composed of such elements, and since it represents the arid forms which have been included in the genus, a reexamination seemed desirable. In the course of the study certain cytological phenomena in the basidia proved to differ from those noted in previous accounts and these findings are also reported.

Sebacina calcea is not uncommon in the bottomlands in eastern Iowa and western Illinois, where it occurs chiefly on the bark of living *Salix*. It is dry, crustaceous, becoming waxy when wet, and varies in color from chalky white to light brown, the color in older fructifications differing only slightly from the exposed inner bark of the willow upon which it is growing, making it distinctly inconspicuous. The material studied was collected by G. W. Martin on the banks of the Iowa River near Iowa City, killed in formal-acetic-alcohol, Flemming's weaker solution and Allen's modification of Bouins solution known as PFA_3. Of these, the last-named proved most satisfactory. Various stains were used, but all cytological drawings were made from sections 4-15μ thick, stained with Haidenhain's iron Haematoxylin and counterstained with fast green.

Morphological studies were based on thin, free-hand sections cut from dried material soaked in weak alcohol and mounted either in KOH and Phloxine or lactic acid and acid fuchsin, the latter method serving to preserve the crystalline structures which constitute so important an element of the fructification. The general arrangement was determined from uncrushed sections. The same sections, crushed, permitted detailed study of the various hymenial elements.

In section the basidiocarp consists of a layer of closely woven septate hyphae parallel with the substratum and occupying about a third of the total thickness, which varies from 50-190μ. The hyphae adjacent to the dead host cells extend regularly into the host cells with their woven pattern looser, but essentially unaltered. Frequently partly broken down fragments of the host cell walls are found embedded in hyphae but are readily distinguished from concretions by their characteristic color and outline (Fig. 24).

A second layer of loosely woven hyphae extends from the basal layer into the matrix of the fructification. The basidia and the numerous sterile structures, the paraphyses, cystidia and gloeocystidia originate from the many hyphal tips that occur in this layer. Near the external surface of the matrix is a narrow delimited zone of crystals. With the exception perhaps of concretions found near the substratum, the basidia are the most conspicuous structures in the hymenium. Mature basidia are widely spaced. Sterile structures that approach the size of mature basidia proliferate into paraphyses. Adhering to the external surface of the matrix are numerous crystals and primary spores, the latter germinating by repetition.

The localization of the cytoplasm at the distal end of the basidium initial is precedent to the fusion of two small nuclei lying diagonally within the hypha (Fig. 1, 2). Both basidium and fusion nucleus rapidly enlarge. Following disappearance of the linin network, a spireme is formed, bearing about sixteen deeply staining, spherical bodies, each approximately 0.7μ in diameter (Fig. 3, 4, 5). The spireme is barely visible and the deeply staining bodies regarded as chromosomes become arranged in eight pairs. The observation of many fusion nuclei suggests that the chromatin draws apart on the spireme toward localized places along the thread where the chromosomes take form. The nucleolus is a well defined body approximately

1.5μ in diameter. The persistent clumping of the chromosomes in groups of four and six, or with the nucleolus, is a condition that makes an accurate count very difficult. Fortunately, the spireme on which the paired chromosomes are arranged is visible at high magnifications of the fusion nuclei.

As successive stages of mitotic division take place, the basidium tends to become irregularly ellipsoid in shape (Fig. 9). The centrosomes are very small, not over 0.3μ in diameter. In most cases, the spindle fibers can not be seen, but the arrangement of migrating chromosomes indicates their presence and position (Fig. 6). Around the spindle a less dense cytoplasmic area developes producing the effect of a halo. The number of chromosomes in the second mitosis in the basidium is definitely less than that seen in the first division and is approximately eight, never more. The two nuclei of the first division (Fig. 8) are intermediate in size between the fusion nucleus and the four nuclei of the second division (Fig. 11). The spindles of the second division are usually situated end to end, or if tilted slightly, are parallel (Fig. 9, 10). All spindles observed in basidia were oriented transversely.

After the formation of the four monoploid nuclei resulting from the second division, septa develop cutting off the basidium from the parent hypha and isolating each nucleus in its respective cell (Fig. 12). The elongation of the epibasidia and the irregular migration of nuclei toward the sterigmata is essentially the same as found in other tremellaceous fungi. Occasionally, a basidium is found in which one nucleus migrates in advance of the others (Fig. 14). The sterigmata are short and acute in contrast with the sterigmata of other species (Fig. 37). The nucleus migrating toward the sterigma gradually changes its outline from globose to narrowly fusiform (Fig. 16, 20).

A wide diversity of sterile elements is apparent throughout the basidiocarp. In addition to two types of concretions, there may be found gloeocystidia and paraphyses of three sorts, namely, slender, branched, incrusted paraphyses, thicker, unbranched or branched, unincrusted threads originating from the same hyphae as the basidia, and similar branched threads apparently representing proliferating probasidia.

Very conspicuous are the concretions embedded in the hyphae next to the substratum. Observation indicates there is a correlation between the thickness of the fructification and the number of concretions but not as to their size. In many specimens studied the concretions are situated in two regular lines while in others a much thicker, irregular zone exists (Fig. 24). Close to the external surface of the matrix is a rather evenly distributed zone of small crystals (Fig. 24).

Gloeocystidia adjacent to basidia are colorless and contain two nuclei in the younger stages, one usually larger than the other, which migrate toward the denser cytoplasm at the distal end of the structure (Fig. 10). Later stages of the gloeocystidia show no evidence of cytoplasmic or nuclear content.

The most numerous paraphyses throughout the entire hymenium are the long, slender and branched structures which Burt (2) illustrates in his taxonomic treatment of the genus *Sebacina* (Fig. 30, 31, 32). Observation suggests that this type of paraphysis produces by secretion the many crystals on nodular projections along its axis.

Many paraphyses proliferate from the same hyphae which bear the basidia. These elements are much stouter than those of the preceding type. They not only possess a variety of contours but exhibit in many cases two or three consecutive clamp connections (Fig. 33). The loops of the clamp connections are long and form a large eyelet by the time the hyphal tip fuses with the "peg" (Fig. 25, 29).

Another noteworthy type of paraphysis, much less numerous than other types, develops from a smaller hyphal tip which in all of its physical characteristics resembles a young basidium about to produce epibasidia. Instead, a stout apical paraphysis possessing several branches takes form (Fig. 27).

This work was done under the direction of Professor G. W. Martin in the mycological laboratory of the State University of Iowa.

Summary

1. *Sebacina calcea* is characterized by a hymenium in which the widely spaced basidia are interspersed between gloeocystidia and three kinds of paraphyses, many of which originate from the same hyphae which bear basidia.

2. In addition to the small crystals produced by the slender paraphyses, larger concretions form one or more irregular layers near the base of the fructification.

3. Nuclear fusion and division follows the usual sequence of events as previously described for this and related species. The monoploid number of chromosomes is believed to be eight.

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EXPLANATION OF FIGURES

Plate XX

All figures drawn from slides stained with iron alum haematoxylin with the aid of camera lucida at a magnification of ×2570 and reduced to ×1000 in reproduction.

Fig. 1, basidium initial; 2, young fusion nucleus in hypobasidium; 3-5, spireme stages showing sixteen chromosomes; 6, first anaphase; 7, late anaphase of first division; 8, daughter nuclei of first division; 9, anaphase of second division; 10, metaphase of second division and binucleate gloeocystidium; 11, four monoploid nuclei and gloeocystidium with basal clamp connection; 12, 13, basidia with monoploid nuclei, each with nucleolus and eight chromosomes; 14, nearly mature basidium showing migration of nucleus into epibasidium, upper nucleus in cell behind the former; 15, basidium with two nuclei beginning migration; 16, nucleus about to pass into developing primary spore; 17, 18, nuclei within young primary spores; 19, primary spore beginning germination by repetition; 20, passage of nucleus from primary spore into developing secondary spore; 21-23, basidiospores.

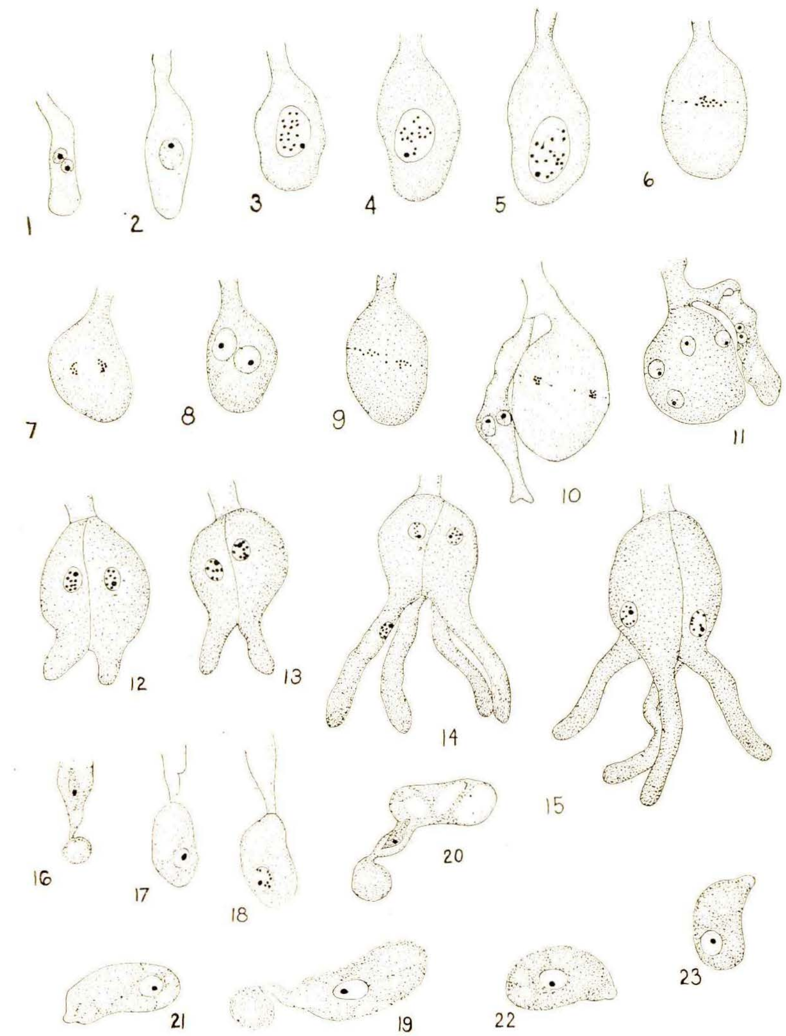
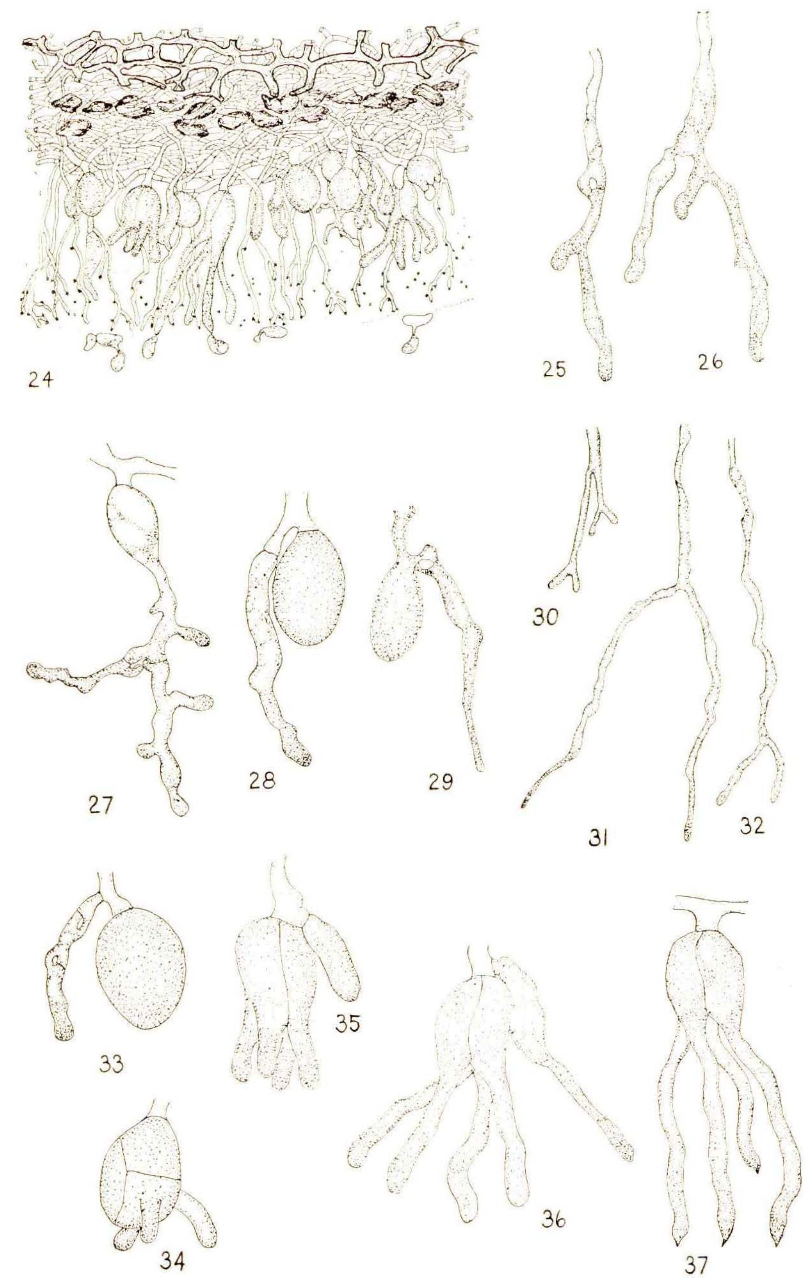


PLATE XXI

All figures drawn from mounts of hand-sectioned, crushed material with the aid of camera lucida at a magnification of × 1980 and reduced in reproduction to × 800 with the exception of Fig. 24, drawn at a magnification of × 950 and reduced to × 400 in reproduction.

Fig. 24, diagramatic cross-section of fructification attached to substratum showing the two hyphal layers and the relation of sterile and fertile structures to each other; 25, 26, two paraphyses, one with a clamp connection at its base; 27, paraphysis which has apparently developed from a basidial initial; 28, 29, basidia with gloeocystidia at their bases; 30-32, slender paraphyses; 33, basidium with paraphysis possessing two successive clamp connections; 34, basidium with unusual septation; 35, 36, basidia with young and mature gloeocystidia respectively; 37, mature basidium with epibasidia developing sterigmata.



STUDIES IN EVAPORATION: I
EVAPORATION FROM AN EASTWARD FACING SLOPE

W. A. Anderson

In 1915 the late Professor Bohumil Shimek outlined certain features of the distribution of plant associations in the region of Lake Okoboji, Dickinson County, Iowa, and offered evidence in support of the theory that distribution of forest and grassland in this district is conditioned by exposure to evaporation. Evaporation in turn is conditioned by the combined factors of temperature, relative humidity and topography as the latter modifies wind-flow. He states that groves are found only on slopes which are protected from the full effect of the hot, dry, southwest wind, that is to say, on east or north slopes, or on steep bluffs which face the lake in any direction. The latter, according to Shimek, retard air flow to such an extent that moisture from the lake accumulates there, and this permits the development of a forest. Once started, the forest may expand beyond the original bluff as the trees afford some mutual protection. On gentle slopes, even on those which lead toward the north or the east, the wind will follow close to the surface and will produce sufficient evaporation to prevent the growth of trees.

In 1934 Professor Shimek induced the writer to take up the problem of evaporation as a factor in plant distribution with the expectation of obtaining more detailed data on this problem. At that time he identified several of his old evaporation stations to the writer so that data presented here is a fairly close check on his previous findings.

Evaporation records have been kept at the Iowa Lakeside Laboratory for several summers. Some of these have been in Shimek's stations; other series have been taken in other localities. The instruments used have been for the most part Livingston porous cup atmometers. In some cases Piche evaporimeters were used. Open pans were tried one summer but with indifferent results. The value and limitations of these different instruments has been well discussed by Livingston in 1935, and in numerous earlier papers.

During the summer of 1934 data obtained with the Piche evaporimeters seemed more reliable than that from other instruments. For a period of seventeen days, from July 24th to August 9th, a comparison was made of evaporations from the line of stations on the Laboratory campus, beginning with the Lookout hill across the road to the west and ending on the lake bank. The data presented here refers to Shimek's stations 2, 3 and 5.

Station 2 is located in open ground about seventy-five feet above the level of the lake and five hundred feet west of the shore; station 3 is at the top of the 30 foot bank of the lake near the laboratory boat house and station 5 is down under the bank about 10 to 12 feet above the level of the lake. The slope from station 2 to station 3 is toward the east and averages 10 percent.

Chart 1 shows evaporation rates per hour from Livingston atmometers over a period of 24 days. The results are such as would

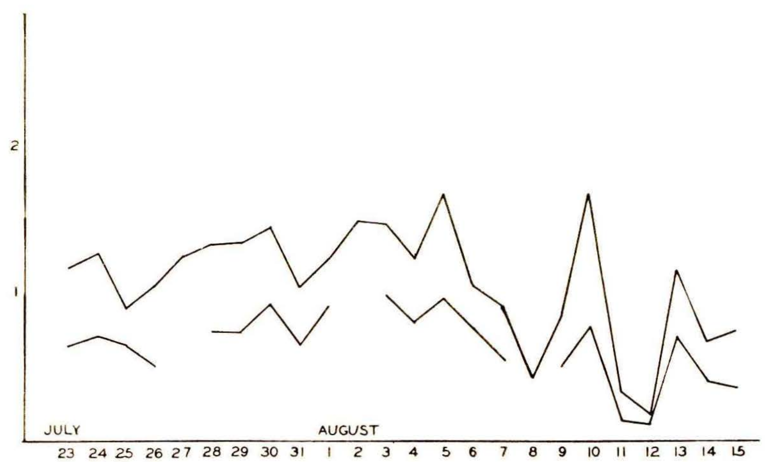


Chart 1—Average losses per hour (day and night) from Livingston atmometers. Upper line, Station 2. Lower Line, Station 3.

ordinarily be expected, with the instrument on the prairie showing consistently higher evaporation than that on the bluff under the trees. However, the rate of 1.67 cc. per hour (40.2 cc. for 24 hours) does not seem particularly high, and this was the maximum obtained for any twenty-four hours in the period during which the observations were in progress. The average daily evaporation from this

station for the twenty-four days was only 25.9 cc. while Gates (1926) reports seasonal averages of from 23.1 to 33.1 cc. at Douglas Lake, Cheboygan County, Michigan. If prairies are kept treeless by the action of drying summer winds we should surely expect a higher evaporation rate in northwestern Iowa than in the Great Lakes forest region in northern Michigan.

Piche evaporimeters were read twice a day. Chart 2 shows the day and night rates per hour for the three stations. It is at once evident that the rates of evaporation at night are remarkably uniform and low; in fact the prairie station (number 2) shows a lower night evaporation than the others. This is undoubtedly due to more rapid cooling caused by greater exposure, but the precise time in the evening at which the dew point is reached remains yet to be determined. It is true that station 2 showed consistently higher daytime

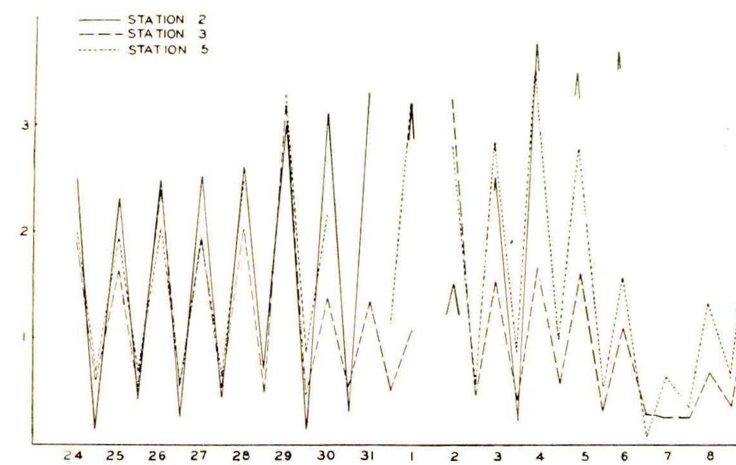


Chart 2—Average losses per hour from Piche evaporimeters at three stations, day and night computed separately.

evaporation than either of the others. Shimek (1911) stresses the point that it is not the average but the occasional unusually high rates which cause the death of forest plants. On this basis, days like July 29th and August 4th, 1934, when woodland stations show equal evaporation to that of station 2, destroy the advantage which the lake bank has as a place for forest to grow. The unexpectedly low evaporation at station 3 as shown on this chart is undoubtedly due to the shelter of a colony of sumac (*Rhus glabra* L.) which had grown up since Shimek's investigations in 1909.

As a part of the new building program at the Laboratory the bank at stations 3 and 5 was cut back early in 1937, all the trees and shrubs removed and the upper part reduced to a steep, sodded slope which drops at a pitch of about 60° to the roof of the new pump house. Comparison of evaporation on this denuded bluff with that on the prairie as well as that of former records is made possible by this development.

In 1937 Piche evaporimeters were set up at evaporation stations 2, 3 and 5, with the single change that a new station 5 was established at the foot of the steep grass bank just above the roof of the pump house. This is only a short distance from old station 5, and is like it except that it is not sheltered by trees and shrubs. Station 2 now receives direct sunlight for a longer period every day than either of the others but as to the shelter of vegetation the three stations are much alike. Care was taken that the instrument set in station 2 would not be cut off from the wind by new buildings located near it.

Chart 3 shows total evaporation in cubic centimeters from these three stations for three consecutive days, taken at intervals of one

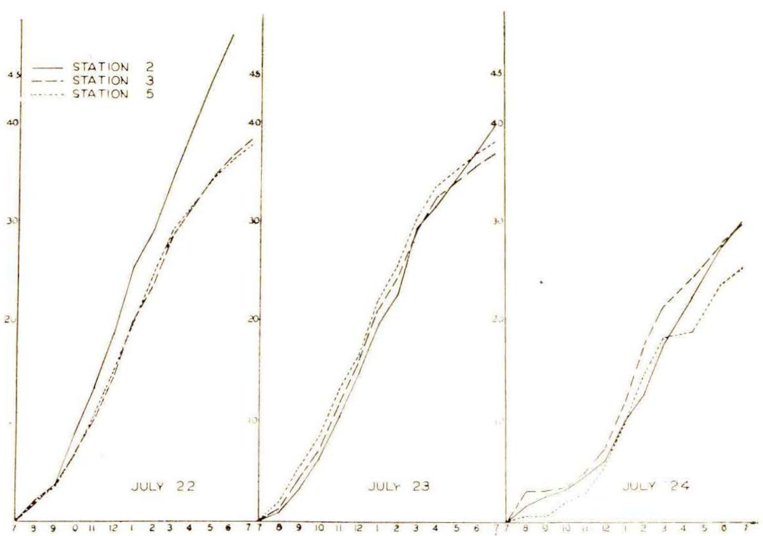


Chart 3—Total losses from Piche evaporimeters for each of three days. Readings taken every hour.

hour. On the first of these days, July 22nd, the wind was from the southwest all day. The prairie station showed 36% greater total evaporation than either of the others, but this is due to a steady high rate which began about 9 A.M. and continued through the day rather than to any afternoon "peak" as described by Shimek (1911). The other two instruments show a decrease in rate of evaporation between two and three o'clock, at the time when they begin to be shaded.

On July 23rd the wind was from the southwest all day with an average of 14.8 miles per hour from noon until 7 P.M. Here the evaporation from the three stations is about equal, with the prairie station indeed running behind both the others until after 4 P.M. at which time their rates of loss slackened. This is entirely at variance with Shimek's findings. He emphasizes the fact that the critical period of the day is between 2 and 4 in the afternoon, and that it is the evaporation stress of this peak hour which is inimical to the growth of forest mesophytes.

The third day, July 24th, the wind was in the east in the forenoon, shifting to the west in the afternoon. On this day the station on the bank of the lake (number 3) took such a lead in the morning that it was not surpassed by the others all day, though station 2 as before showed a rate for the last two hours which exceeded both 3 and 5. This is in perfect accordance with the writer's findings in 1934 (chart 2) when station 5, at the base of relatively large trees often showed higher evaporation than did station 3, which, though on a more exposed part of the bank, was partly sheltered by a low growth of grasses and sumac.

In reality these results are not at variance with Shimek's data (1915, p. 23) but the interpretation is quite different. He says of station 5, "When the wind was from the southwest evaporation was greatest, as on the 9th, 10th and 11th of August; when the wind was from the south or southeast and banked the vapors around this station evaporation was much reduced." What actually happens is that south winds run parallel with the shore, which is heavily wooded for a quarter of a mile to the south, and gives excellent shelter to station 5. Under this condition, as on August 6th in Shimek's report, there is the greatest difference between this and the prairie stations. East winds, which blow directly off the lake, are generally accompanied with falling barometer, increasing cloudiness and humidity, which results in lowered evaporation all over the region. (See last day, chart 3). At this level (about 15 feet) there is no evidence of effective banking of vapors from the lake.

As related to plant communities, the significant feature of these results is that stations 3 and 5 are in a wooded area, and, though bare at present, can support a growth of shrubs and trees. They did support such a growth for part of the years between 1915 and 1937. Station 2 is in the "trough" described by Shimek, which, according to him, affords such a good channel for the sweep of the southwest wind that it can never be populated with trees.

In order to test the comparative value of topographic shelter and shelter by vegetation two colonies of sumac were selected. One of these is on top of the "Lookout," a high hill about ⅜ of a mile west of the lake shore and 152 feet above its surface. The second colony is on the top of the lake bluff, near the site of the old Laboratory building, and partly sheltered by an open growth of bur oak trees. Both these colonies are near buildings but not sheltered by them. Three Piche evaporimeters were set up in each sumac colony; one at the top, unprotected, one amidst the foliage and one at the ground level amongst the stems. These were read at the end of the day and

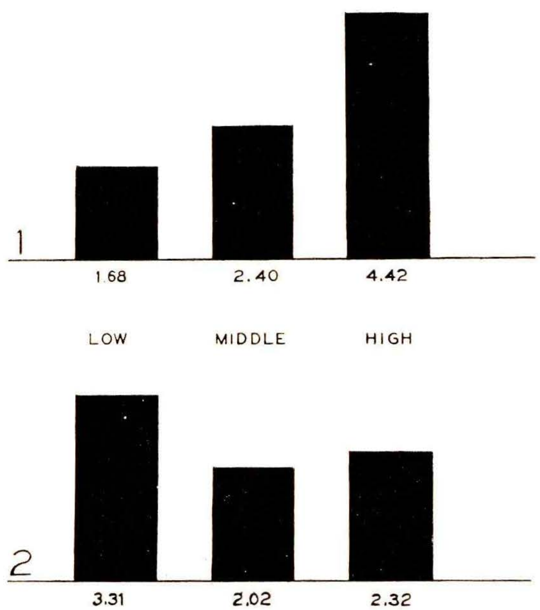


Chart 4—Average losses per hour from Piche evaporimeters at top, middle and ground level of two sumac colonies.

the hourly loss computed (chart 4). As is to be expected, the highest instrument on the Lookout, exposed to both sun and wind, lost more water than any of the others. The middle instruments were much closer together, that on the Lookout showing about 19% more evaporation than the one on the lake bank, where in the unprotected instruments that on the high point lost double the amount of the other. The real surprise came in the evaporation rates close to the ground. That on the lake bank ran higher than any of the other protected instruments, 75% of the most exposed of all! This result was so disturbing that the entire set of evaporimeters was taken down, reassembled and the experiment tried a second day. The results were essentially the same. It was then realized that the hilltop sumac was growing among tall prairie plants: *Andropogon scoparius*, *A. provincialis*, *Helianthus scaberrimus*, *Silphium laciniatum*, etc., while the one on the lake bank had only grasses such as *Poa pratensis* around it. One is forced to the conclusion that if evaporation is the critical factor which retards or inhibits the growth of seedlings, they would be in a more favorable position on the highest knob in the region, if sheltered by tall prairie grasses and a few sumac bushes, than they would in an open oak grove with all the undergrowth but sumac removed.

Conclusions

The effect of drying winds and strong insolation on vegetation is too well known to need discussion here. At the same time it is well to remember that in the study of concomitant factors it is sometimes difficult to recognize which is cause and which effect. The data presented here seem to indicate that on this eastward facing slope near Lake Okoboji differences in evaporation are dependent on plant cover rather than on contour of the hill. The development of shrub and tree growth is a cause of reduced evaporation rather than an effect.

Whatever may be the factors which induce the growth of woody plants in this particular area, evaporation stress as measured in actual evaporation during hot summer days does not seem sufficiently different to account for the present distribution of woodland.

SUMMARY

1. This paper presents records of evaporation from three points on an eastward sloping hill, leading down to West Lake Okoboji, Dickinson County, Iowa.

2. Average evaporation, day and night, from Livingston atmometers shows marked difference in losses between a station on the prairie and one on the lake bluff. The average of the prairie station is well within averages at Douglas Lake, Michigan, as reported by Gates.

3. Rates of evaporation from Piche evaporimeters, day and night read separately, show less difference among the three stations than their positions would indicate. While the prairie station ran consistently higher than the others, an occasional high day on any of them makes them essentially alike if we accept Shimek's theory that the days of greatest stress and not averages are significant in the distribution of forest.

4. Evaporation from the three stations after shrubs and trees had been removed shows close correlation among all of them. The prairie station ran at a continuous high rate all afternoon. This and not a maximum peak between two and four P.M. accounts for higher total evaporation at this point, when it does occur.

5. Evaporimeters placed in two sumac colonies indicate that evaporation rates are more modified by plant cover than by position on this slope.

6. There is no indication in the data obtained that evaporation rates on this slope are sufficiently high to inhibit invasion and growth of woodland on any part of it.

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