THE RANGE OF EVAPORATION AND SOIL MOISTURE IN THE OAK-HICKORY FOREST ASSOCIATION OF ILLINOIS.

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I. EVAPORATION.

The oak-hickory forest, an association characterized by the presence of the white oak (*Quercus alba*), the red oak (*Q. rubra*) and the shag-bark hickory (*Carya ovata*) as its dominant tree members, occupies a unique position in Illinois, appearing as the climax association of much of the woodlands bordering upon the prairie region and as the association next below the climax in areas farther removed from the grasslands where the beech-maple forest association forms the climax. The composition and relationships of these associations have been fully discussed by Cowles,[1] Whitford[2] and others, but almost nothing has been known quantitatively of the physical factors (other than rainfall) that determine their character and extent. Some preliminary studies upon the evaporating power of the air in some of the associations involved have already been reported to this Academy,[3] but the oak-hickory forest was not included among the associations studied. To supply this deficiency, the evaporating power of the air and the soil moisture have been determined during the season extending from April 22 to October 28, 1911, in a fairly undisturbed forest situated upon the Valparaiso moraine, about twenty miles southwest of Chicago, near the little village of Palos Park.

In the evaporation determinations the porous cup atmometer was employed and the directions given by its inventor, Livingston,[4] for its operation were so closely followed that any extended account of its management becomes quite unnecessary. All instruments were standardized before being set up and the standardization repeated at intervals of six to eight weeks. By the coefficients thus obtained all readings were reduced to a common unit. Readings were made weekly throughout the season and the results expressed as the average daily rate of loss for the interval between the readings. These results have been graphically represented with the weekly intervals as abscissae, and the amount of daily loss by the standard atmometer, in cubic centimeters, as ordinates.

Four stations were established, three upon the upland and one in a small depression, a wedge-shaped flood-plain of a small stream, usually without water during the summer. The upland stations were upon the low sloping hills of the moraine about twelve meters above the level of Lake Michigan, where the soil was of a fine texture, being composed of boulder clay with a small admixture of sand. In the depression there was a mixture of alluvium and humus, no clay appearing at a depth of 30 cm.

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[1] Cowles, H. C. The physiographic ecology of Chicago and vicinity. Bot. Gaz., *31:* 73-108, 145-182, 1901.

[2] Whitford, H. N. The genetic development of the forests of northern Michigan. Bot. Gaz., *31:* 289-325, 1901.

[3] Fuller, Geo. D. Evaporation and plant succession. Trans. Ill. Acad. Sci., *4:* 119-125, 1911, and Bot. Gaz. *52:* 193-208, 1911.

[4] Livingston, B. E. Operation of the porous-cup atmometer. Plant World, *13:* 111-119, 1910.

The stations were numbered arbitrarily, number one being located in the depression, numbers two and three in the ungrazed forest, and number four in a portion of the forest which had been grazed. The forest is here largely composed of white oak (*Quercus alba*) and red oak (*Q. rubra*), with occasional trees of the bur oak (*Q. macrocarpa*), shag-bark hickory (*Carya ovata*) and the bitternut hickory (*C. cordiformis*). Station four was almost devoid of undergrowth, but at stations two and three there were seedlings of the trees, particularly of the white oak, together with a considerable amount of the hazel (*Corylus americana*) and a few other shrubs. The instruments were placed in spots with an average amount of shelter from both the trees and the shrubs. The forest about station one had, in addition to the species already enumerated, trees and seedlings of the white ash (*Fraxinus americana*) and of black walnut (*Juglans nigra.*)

An examination of the evaporation records shows that the evaporating power of the air was highest during the month of

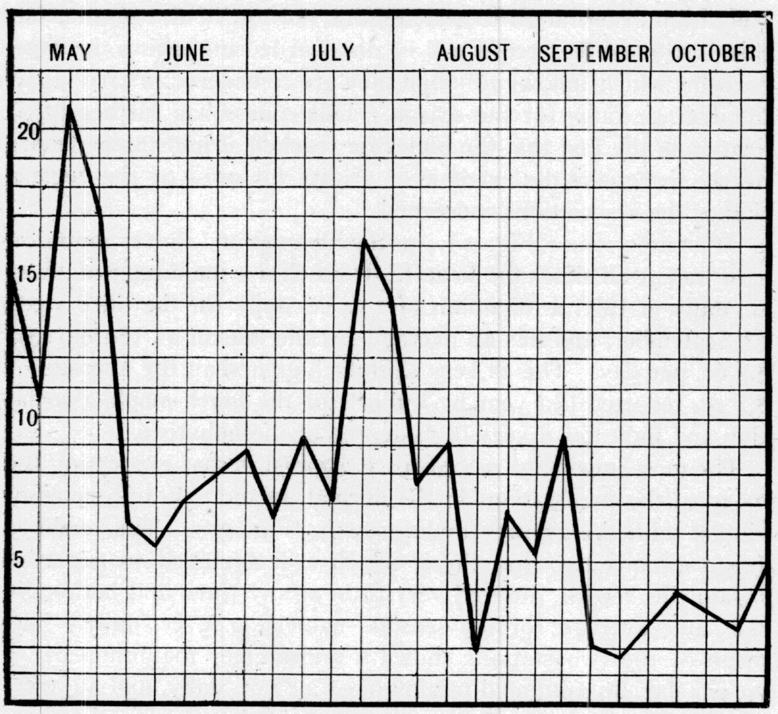

Figure 1. Graph representing the evaporating power of the air in a depression in the oak-hickory forest.

May. Doubtless this may be explained by the unusual conditions that obtained during this month. It had the highest temperature record experienced since the establishment of the Chicago Weather Bureau in 1871. The average temperature for the month was 10 degrees above the normal; for six days it reached or exceeded 90° F., and it reached 94° on the 25th, 26th and 27th of the month. The percentage of sunshine, 79 per cent, was also greater than that observed during any previous May. In contrast, during September, the period with least evaporating power, the temperature was about normal, while the relative humidity was somewhat above and the percentage of sunshine considerably below the normal mean. All these meteorological factors influence the evaporating power of the air profoundly, and their great variation gives emphasis to the necessity of records extending over more than one season before definite conclusions may be reached with safety.

The unusual conditions during May, combined with the absence of foliage during a portion of the month, gives such an excessively high evaporation record for this portion of the season that this portion of the record will be disregarded in making the comparisons which follow, although they are considered in arriving at the average rates for the season. This course has further justification in the fact that the high rate reached at midsummer more nearly represents the extreme of aridity for most of the vegetation of the associations concerned.

At station one (Fig. 1), in the depression, the evaporation rate was at all times the lowest. It reaches a maximum of 16.21 cc. daily in July, a minimum of 1.74 cc. daily for the third week of September, and has an average for the season of 189 days of 8.3 cc. per day. This is very slightly higher than the average of 8.1 cc. reported last year by Fuller[3] for the beech-maple association and indicates a very high degree of mesophytism.

The most important record for the forest is that expressing the mean of the two stations in the normal upland oak-hickory association with the average undergrowth (Fig. 2b). The readings from stations two and three, which are combined in order to obtain this record, differed very little at any time, and both gave the same average for the season—namely, 9.89 cc. daily. The mean of the two stations shows a midsummer maximum of 17 cc. per day, an autumnal minimum of 2.87 cc. daily, and an average for 189 days of 9.89 cc. The effect of the absence of undergrowth is plainly shown by the record (Fig. 2a), exhibiting the highest rate of the series, having a midsummer maximum of 22.12 cc. per day, and a daily average of 12.74 cc. The minimum, 2.77 cc. per day, almost exactly coincides with that of the ungrazed forest, 2.87 cc. daily. A comparison of the two graphs (Fig. 2) will show that the least divergence in the evaporation

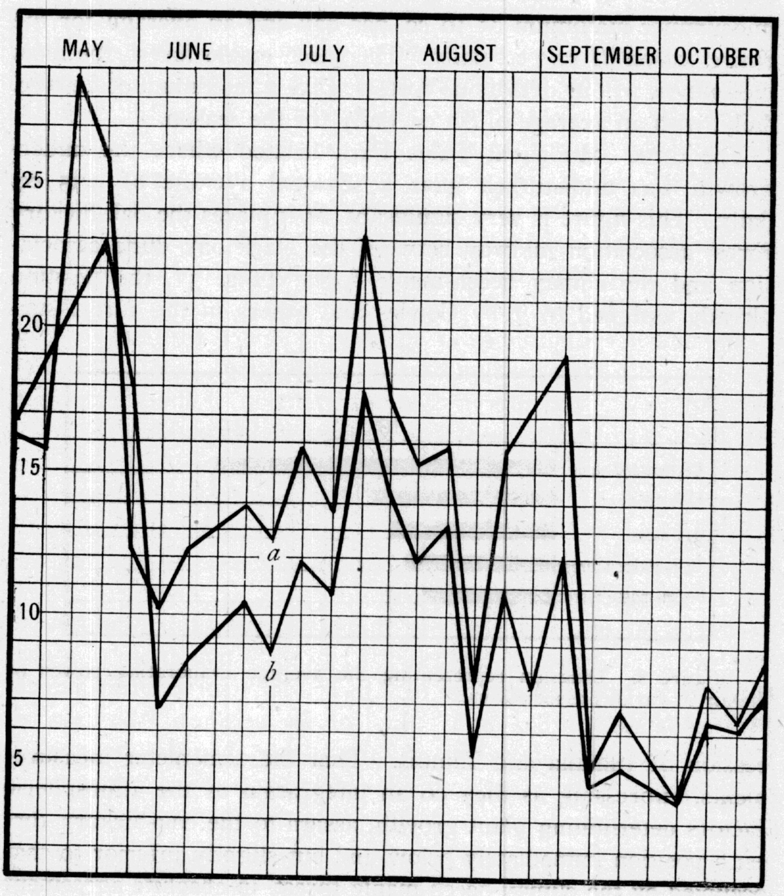

Figure 2. Graphs representing the range of the evaporating power of the air in (a) the grazed and (b) in the undisturbed portion of the oak-hickory forest.

rates of the grazed and ungrazed portions of the forest occurred in the spring and autumn, when the trees were in a more or less leafless condition.

A comparison of these records with those obtained by Fuller,[3] in 1910, in related forest associations is most interesting and instructive. The pine dune association with a maximum of 17.5 cc. per day and a daily average of 11.3 cc. for the season compares closely with the record of the grazed oak-hickory forest, with an average of 12.74 cc. daily for the season. The oak dune forest he studied, which has been regarded as less mesophytic than the one at Palos Park, gave similar evaporation rates with midsummer maximum of 16 cc. per day and an average for the entire season of 10.3 cc. daily. The beech-maple forest, the most mesophytic of our deciduous forests, gave a maximum of 12.0 cc. daily, with an average of 8.1 cc. daily for the season.

The three stations at Palos Park located where the undergrowth was undisturbed gave a seasonal average of 9.35 cc. daily. This figure is very significant, as it places the oak-hickory forest association midway between the black oak dune association and the climax beech-maple forest (Fig. 3), the position already assigned to it by Cowles and others in the forest suc-

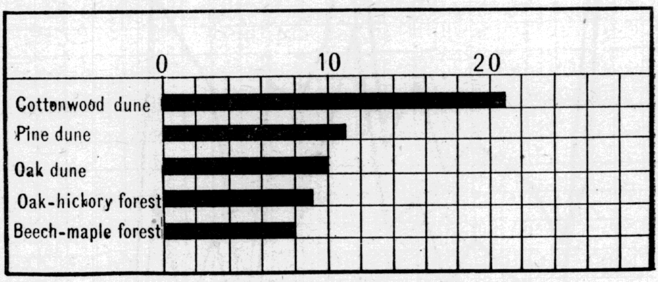

Figure 3. Diagram representing the average evaporating power of the air in various associations.

cession of Indiana and Illinois. That the atmometer measurements, expressing as they do an integration of the atmospheric factors determining plant growth, assign to the oak-hickory forest a position immediately below and but slightly inferior to that occupied by the climax beech-maple forest, in absolute agreement with the conclusion already reached by a consideration of other data, must be regarded as of the greatest importance.

Expressing the same result upon a percentage basis, with the average rate throughout the season of 1910 in the beech-maple forest as a unit,[3] the comparative evaporating power of the air in the oak-hickory forest is 115 per cent; in the oak dune association, 127 per cent; in the pine dune association, 140 per cent; and in the cottonwood dune association 260 per cent.

II. SOIL MOISTURE.

While ecologists have usually been agreed that the water of the soil is the most important single factor limiting the development of vegetation, very few quantitative determinations of this factor have been made. This has been due largely to the difficulty in obtaining a standard by which the water content could be related to plant growth. The percentage of water in one soil which would produce a luxuriant vegetation, in another of different texture, would not support any plant life whatever. Livingston[5] recognized that the water-holding capacity of soils varied and had a fairly constant relation to the relative soil moisture conditions, but only with the very recent work of Briggs and Shantz[6] has a satisfactory function of soil moisture been recognized by which to relate vegetation to the actual amount of water present in the soil. They determined the amount of water present in a particular soil when permanent wilting occurred in Kubanka wheat, the plant adopted for the standard. This amount expressed in percentage of the dry weight of the soil they have termed the *wilting coefficient,* and it represents the water content above which all growth must occur; life, however, is maintained for very considerable periods with much less water. The same workers also gave data which show that many ordinary mesophytic plants vary very little in their wilting coefficients from the standard wheat employed.

In order to determine the soil moisture conditions in the oak-hickory forest at Palos Park, weekly samples, each consisting of about 300 grams of soil, were taken at atmometer stations one, two and four, from depths of 7.5 cm. and 25 cm. below the surface. The soil was placed in tightly closed wide-mouthed jars, brought to the laboratory, weighed and dried at a temperature of 100° to 104° C. until it ceased to lose in weight. The percentage of water to the dry weight of the soil was thus obtained. Using the same soils, the wilting coefficients were obtained according to the wax seal method described by Briggs and Shantz (loc. cit.). Graphs representing the range of soil moisture have been plotted with weekly intervals as abscissae, while the ordinates represent the percentage of the soil moisture present. The wilting coefficients are represented upon the same diagrams in broken

[5] Livingston, B. E. Relation of soil moisture to desert vegetation. Bot. Gaz., *50:* 241-256, 1910.

[6] Briggs, L. J., and Shantz, H. L. The wilting coefficient for different plants and its indirect determination. U. S. Dept. of Agr., Bur. of Plant Industry, Bull. No. 230, 1912.

lines; hence the amount of water available for the purposes of growth is shown by the interval between the graphs representing the soil moisture and the line representing the wilting coefficient.

The wilting coefficient will be found to vary considerably in the different locations dependent largely upon the amount of humus present in the soil. Thus, in the depression, it is seen to be 18.9 at 7.5 cm. (Fig. 4B) below the surface, but only 12.5 at 25 cm. (Fig. 4D), due to more humus in the surface layers. The abundance of the water supply in this locality is seen by the very

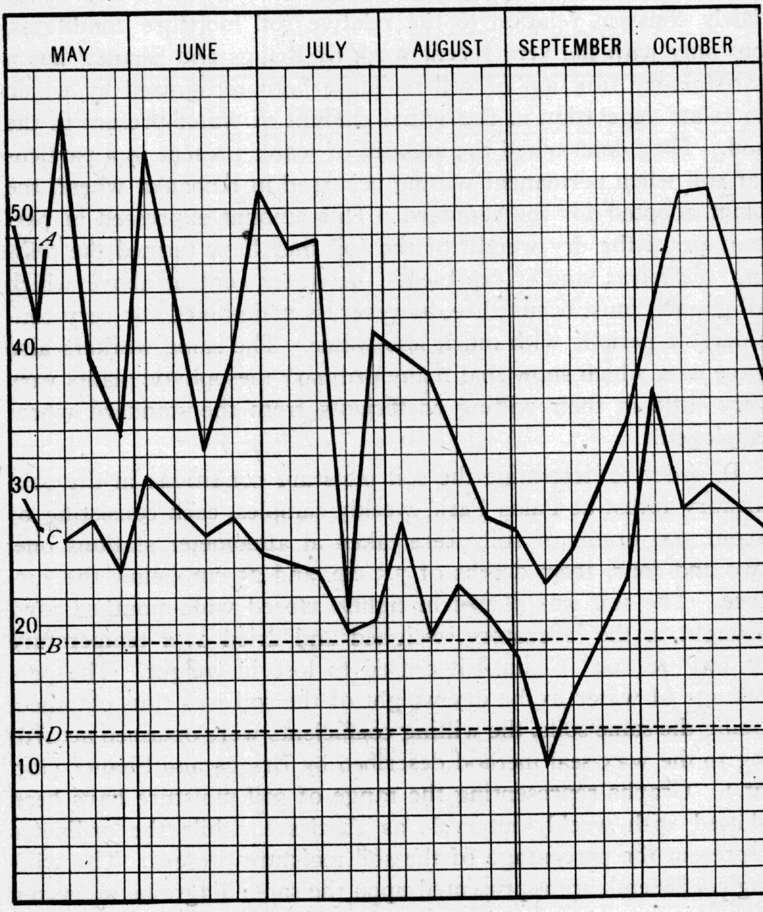

Figure 4. Graphs representing the range of soil moisture throughout the growing season, at 7.5 cm. (A) and at 25 cm. (C), below the surface, in the depression in the oak-hickory forest, and the wilting coefficients (B, D) at these depths.

large percentage in May, June and October, and the plentiful and constant supply during the critical weeks of midsummer. Only once does the supply fall below the wilting point—namely, during September, at the 25 cm. level (Fig. 4). The mesophytism of the soil may possibly best be expressed by noting the average amount by which the actual water content exceeds the wilting coefficient during the critical ten weeks beginning with July 1st. At the 7.5 cm. level there will be found to be an average of 18.3 per cent, and at 25 cm. 7.8 per cent of the dry weight of the soil in water available for growth during these midsummer weeks.

At station three, the smaller amount of humus present in the

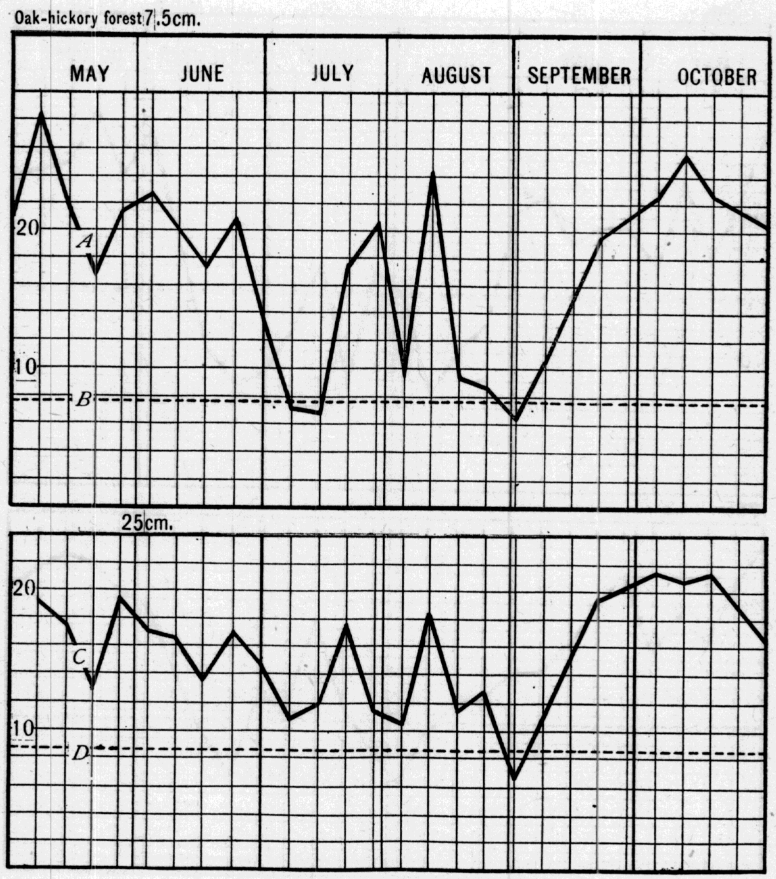

Figure 5. Graphs representing the range of soil moisture at 7.5 cm. (A) and at 25 cm. (C) below the surface in the oak-hickory forest, and the wilting coefficients (B, D) at these depths.

soil is indicated by the smaller wilting coefficients, 7.7 and 8.5 per cent (Fig. 5). The amount of water available for growth is also less, and once at 25 cm. and twice at 7.5 cm. it fails. The greater fluctuation in the supply at the higher level is very evident at this station (Fig. 5A), but is also apparent in the other localities (Figs. 4A and 6A). Here the surplus supply for the ten weeks from July 1st averages 4.6 per cent at 7.5 cm. and 4.1 per cent at 25 cm.

The soil records at the grazed station are noticeable for their great range, and for the deficiency in the supply at the 7.5 cm. level (Fig. 6). Here during the ten critical weeks of midsummer

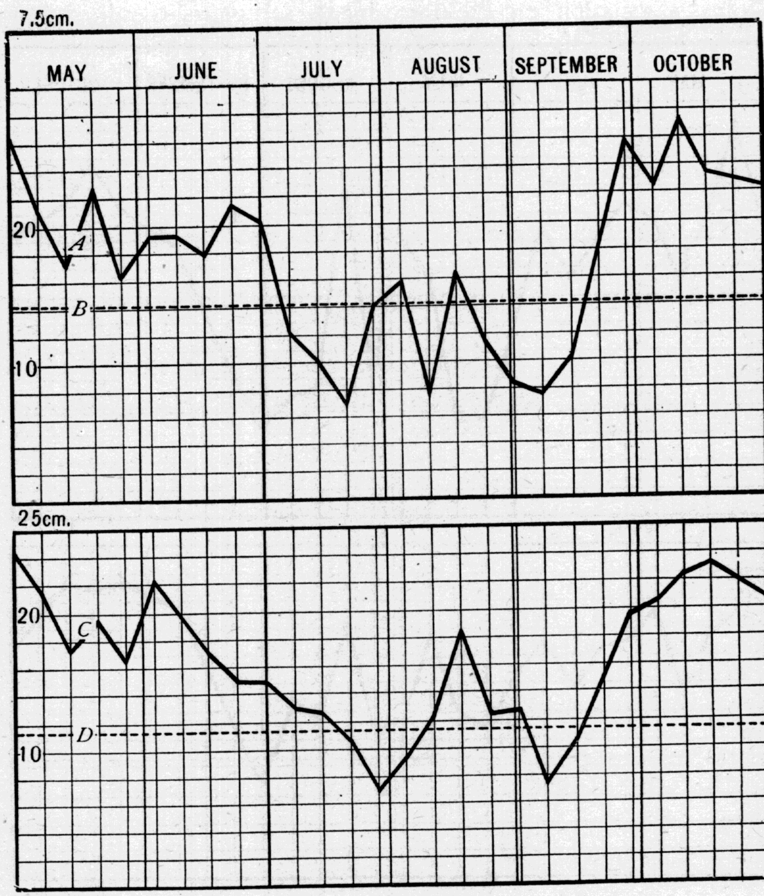

Figure 6. Graphs representing the range of soil moisture at 7.5 cm. (A) and at 25 cm. (C) below the surface, in the grazed oak-hickory forest, and the wilting coefficient (B, D) at these depths.

there is, instead of a surplus, a deficiency in the water supply amounting to an average of 3 per cent at the 7.5 cm. and 0.5 per cent at 25 cm.

The writers gratefully acknowledge their indebtedness to Miss Laura Gano for making the atmometer readings and soil moisture determinations during July and August.

SUMMARY.

The evaporating power of the air in the lowest stratum of the oak-hickory forest, as determined for the growing season of 1911, places the association midway between the black oak dune forest association and the beech-maple forest association, a position which exactly corresponds with its place in formerly observed succession.

The data on soil moisture show that the water-retaining powers and wilting coefficients of the soils studied varied considerably and appeared largely to be determined by the amount of humus present.

The soil of the depression showed the most favorable moisture conditions throughout the season.

The soil moisture determinations afford too meager data to permit any but the most tentative conclusions, but it is believed that they will tend to confirm the position assigned to the oak-hickory forest association upon the basis of its evaporation rate.

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