SOME OBSERVATIONS ON *PINUS VIRGINIANA* MILL. IN MONROE COUNTY, INDIANA: AN ECOLOGICAL STUDY

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The writer first became interested in *Pinus virginiana* Mill while on a geology trip through the picturesque Knobstone region of southern Indiana. Beginning near Borden, Indiana, this pine had taken possession of nearly all the slopes and uplands, and had invaded abandoned fields, pastures, and roadsides. At that time it was the intention to make a study of this locality during the summer of 1931, and the plan was suggested to the Central States Forest Experiment Staion. Mr. E. F. McCarthy, at that time director of the Experiment Station, encouraged such an ecological investigation.

Later in the autumn Professor C. A. Malott of the Indiana University Geology Department drew my attention to a grove of pine located about four miles northwest of Ellettsville in Monroe County. A visit to the place proved the grove to be a *Pinus virginiana* consocies similar to the one at Borden, Indiana, only more limited in extent, and it was at once decided to study this area as an initial work on *Pinus virginiana* in Indiana. During the spring of 1931, Dr. E. R. Cumings of the Geology Department called my attention to a similar grove about two and one-half miles west of Bloomington, along Weimer's Lake, and the area was included as part of the present study.

Physiographic Features of the Ellettsville Region. The whole region near the Ellettsville grove is one of singular beauty and scenic attraction. High ridges and hills slope gently into broad valleys. The difference in elevation is mellowed by these long sweeping slopes and rounded crests of the uplands. There is an occasional hint of Karst topography as one meets a sink, and although some of Indiana's highest elevations are close to the area, the absence of rugged declivities softens the feeling of upland topography. The climax is reached as one approaches the crest of the upland on which the pine groves are situated. The hills melt into a wide stretch of level land where farm borders farm, and the upland is crowded into the distant background. This is the famous Flatwoods Region of Monroe and Owen counties. In 1914, Professor C. A. Malott (3) published a detailed work on the region. He says, "Lying between Ellettsville, Monroe County, and Spencer, Owen County, Indiana, is a strip of territory some six miles long and averaging about two miles wide which has been the object of considerable curiosity and study. It is a low level basin nearly surrounded by higher land, yet having several openings in the surrounding periphery of the hills. The surface of the region is mainly ash-colored soil of a fine texture, containing very little sand. It is in reality a

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silt region at the surface, and its outline is clearly discernible at the margin of the basin . . . frequently a hill-like peninsula protrudes out into the region, rising high above the ash-colored silt margin . . . This region of the Flatwoods area is also exceptional in regard to the periphery . . . the hills surrounding the area rise rather suddenly above the basin."

It is on one of these peninsula-like hills, beginning at the foot and extending about one-third up the slope that the area occupied by *Pinus virginiana* is situated. Its exact location is Section 6, T. 9, N. R. 2 W. While the highest ridges of the region are capped by the Chester sandstone, the underlying rock where the study was made is the St. Genevieve

Fig. 1—Parent tree of groves "A" and "B".

limestone, its outcrops are seen at several places in the upper part of the grove, and part of the drainage of this same grove is underground through a small sink in the side of the hill. The soil is of the usual Monroe County residual type, i.e., clay, in the wooded area more or less covered by humus.

The Pennington grove near Weimer Lake is about two and one-half miles west of Bloomington, in the midst of the famous Karst region of the Mitchell Plain, the bedrock being the Salem limestone.

History and Description of the Areas Studied. The grove near Ellettsville where most of the present observations were made is located about four miles northwest of Ellettsville on the side of a high hill which slopes gently down into the Flatwoods Region. The groves are separated by a narrow country road. The upper grove is the property of Mr. Clyde Christie (referred to as Grove "A"), the lower one belongs to Mr. Charles D. Freeman (designated as Grove "B"). The problem

was doubly interesting because the owners of the land had seen the trees grow from seedlings to the present mature stage. According to their report, the grandmother of Mrs. Freeman had come to this region from North Carolina about 75 yeas ago and had planted several small white pine and one *Pinus virginiana* near the old homestead. In the course of years the home was moved to the opposite side of the road and a barn was erected on the old cabin site. The barn still stands and over it tower the pines the old pioneer had planted (See Figure 1).

In the immediate vicinity of the barn is a cultivated field, but about 200 meters to the northeast were two apple orchards separated by the

Fig. 2—The dense stand of pine in Grove "B".

before-mentioned road. It was in these orchards that *Pinus virginiana* first became established some 40 years ago. As the trees grew to maturity their seeds added to the extension of the consocies to the east. The area directly adjacent to the orchard where Grove "A" is now located was at that time under cultivation, but was later abandoned and *Pinus virginiana* at once established itself there. About 100 meters to the northwest of the parent tree is a knoll which was left as waste land and the Jersey pine at once took possession of it. No doubt this grove would have extended its limits too if the owner had not cut the trees about twenty years ago.

After approximately 40 years of establishment and growth, the pine fairly well controls the area of Grove "A" and completely in Grove "B". Figure 2. The crowns form a dense canopy which makes a semi-darkness beneath the trees even on sunny days. Nearly all ground plants are eliminated (See Table I) only the most shade-resisting, i. e. *Galium*

concinnum, species of Poa, and seedlings of such low trees as *Cornus florida,* and *Sassafras variifolium* persist. In the older part of the groves the needles form a dense ground mat. Eastward of Grove "A" is a pasture and of Grove "B" a cultivated field.

The grove near Weimer Lake was studied in a more comparative way with the Freeman-Christie groves where the main observations were carried on. The place was originally owned by Mrs. Sarah Cree. She and her husband had come to Monroe County from Pennsylvania about 85 years ago. In 1885 her son, Wm. Cree, moved here from Ohio. He does not know how or from where the original tree came to the homestead, but does know that three large trees were growing near the

Fig. 3—Parent tree of the Pennington grove.

house. One of these trees still remains near the old home-site on the ridge. (Figure 3.) About the time when he came to his mother's home the first successful seedings from the parent tree began on the slope to the south of the trees. At the present time the grove occupies about fifteen acres, and has migrated at least a quarter of a mile to the opposite ridge across an intermittent stream. The character of the grove, the age of the trees, as well as the physical characteristics of the trees are all about identical with those of the Christie-Freeman groves. At present the woods near Weimer Lake is owned by Mr. C. J. Pennington of Bloomington.

Some Notes on the Jersey Pine

Regional Distribution. *Pinus virginiana* occupies a unique position in sylvan formation. Livingston and Shreve (5) selected it as a representative type of unusual distribution, and say the following, "*Pinus virginiana* has been used as an example of a type of distribution which is somewhat unusual among the evergreen needle-leaved trees, occupy-

ing an area between the northern and southern areas of evergreen needle-leaved forest, and lying almost wholly in the deciduous region."

Its original range was approximately between 34 and 41 N. latitude, and 75 and 88 W. longitude, or from New York southwest to the southern part of Indiana, south to Tennessee, Louisiana, Alabama and Georgia. As far as Indiana is concerned Deam (1) has the following to say, "The distribution in Indiana is quite limited and has never been understood by the authors who variously give it as found throughout the southern part of Indiana. It is confined to the Knob area of Floyd, Clark, and Scott counties, and the southeastern part of Washington County. In the original forests it is confined to the tops of the Knobs

TABLE I

Species Represented in the Ground Cover on 50 Quadrats of One Meter Square. Shaded Area of Grove "B"

Species	Frequency index on 50 quadrats
Antennaria sp., Ambrosia artemisiifolia, Galium concinnum, Mitchella repens, Panicum capillare, Panicum sp., Pinus virginiana, Prunus serotina, Quercus alba, Smilacina racemosa.	1
Acalypha ostryaefolia, Carex sp., Cercis canadensis, Fragaria virginiana, Rhus toxicodendron, Tecoma radicans	2
Cornus florida, Fraxinus americana, Ulmus fulva	3
Isanthus brachiatus, Moss sp.,	4
Poa sp.	5
Sassafras variifolium	10

where it is associated with *Quercus prinus*. It propagates easily from self-sown seed, hence is soon found on the lower slopes of the cut-over lands and soon occupies fallow fields. It is now found in the open woods several miles east of the Knobs in the preceding counties, but pioneers of this section say it was not a constituent of the original forests but has come in since the original forests were heavily cut over."

In late years this pine has spread to some extent over much of southern Indiana, so much so, indeed, that it has attracted attention by its rapid and wide-spread invasion and ecesis in new localities. Usually the whole consocies can be traced to one or a few parent trees which had been planted in a farmyard.

Characteristics of the Tree. If one would understand the behavior of a plant it is necessary to study its strong points and its weaknesses, these are the laws through which Nature controls, and Nature's laws are finely balanced. One is first of all impressed with the virility of the pine consocies at these places, and with its present dominance, but at the same time one cannot but be just as forcefully impressed with its physical weakness which will in time eliminate the Jersey pine from the region if human interference does not divert the course of Nature. *Pinus virginiana* is a mesophanerophyte with evergreen leaves reaching

a trunk-height of approximately 50 to 65 feet; it is extremely intolerant to shade, seemingly even as seedling, differing in this respect from *Pinus strobus* and *P. resinosa*. The extensive shade-killing is at once evident and striking. Of the trees in dense stands all branches below the top-most crown are dead, so are all smaller trees. Numerous young trees of approximately 25 feet in height were dead. To be exact, in Grove "A" in 1,260 sq. m. there were 35, in Grove "B" 67 in 1,350 sq. m. One will see old trees, evidently pioneers among the invaders, covered with dead branches to within a few feet of the crown. The characteristic of intolerance to shade will be considered more fully in the discussion of the quadrat study. In open places the pine is branched almost to the ground with hardly a dead branch to be noticed. The tree grows rapidly, reaching a diameter of 18 to 20 inches at d. b. h. in 30 to 40 years. Mr. C. J. Pennington has some eight-year old trees near his home which now measure approximately 15 feet in height.

Sargent (4) says, "It is a tree usually 30 to 40 feet high, with a short trunk rarely more than 18 inches in diameter, long horizontal or pendulous branches in remote whorls forming a broad open often flat-topped pyramid . . . its wood is often used for fuel and occasionally manufactured into lumber. It is usually small in the Atlantic states and only on light sandy soil, spreading rapidly over exhausted fields; attaining its largest size west of the Allegheny mountains on the low hills of southern Indiana." Sargent's description of size is not quite in conformity with the size of the older trees in the present study, for there are some trees which reach a height of nearly 65 feet. It does not seem to be choicy as to soil conditions. Some of the trees grow in places where bedrock is close to the surface, on barren soil, showing a decided preference for eroded wornout clay hills, or in fertile soil. Once cut, the stumps decay very readily.

The leaf is very variable in size, ranging from two to three and one-half inches in length, and from straight to a curled form. While the common leaf grouping is two to a fascicle some trees frequently show a three-to-a-fascicle grouping. The cones develop most prolifically on exposed branches, they begin to open early in November. The cone scales are extremely hygroscopic which causes the opened scales to clamp shut rapidly after wetting and to open just as rapidly when dried in wind and sunshine. Seed production is prolific, at least three-fourths of the cone bears well-developed seeds, and as many as 75 seeds to a cone were counted.

General Discussion of the Methods of Study. The problem was attacked from several angles. First of all the old time-tried observational method was employed; information was obtained from the owners of the land who had seen the grove develop.

Soil moisture was recorded from three stations in the Freeman-Christie groves. Station "S" was located in a dense grove of young trees about fifteen years of age as well as in a comparative area just outside of the grove in an open place. The station was on top of the ridge in grove "A". Station "T" was to the eastward of station "S" in the same grove, near the eastern limits of the area. One set of soil samples was taken from an area where the sassafras had been cut

and left an open place just beyond the shade of an old pine. Seedlings and four- to five-year old trees were abundant, the comparative part of the same station was about twenty feet eastward under the shade of the parent tree where few seedlings were found. Station "R" was located in grove "B". It was divided into two divisions. One set of samples was taken from the upper limits of the grove and the second set from the lower limits of the same grove, both, however, under the dense shade of pine. Soil samples were taken at one, three and twelve-inch depths. The work was carried on from May to October.

Evaporation observations were made at stations "S" and "T" with the Livingston clay atmometers. The period of observation was also from May to October.

TABLE II

Strip transect through *Grove "A"*. 10 x 128 meters
Tabulation of trees one inch or more in diameter D. B. H.

Species	D.B.H. in inches																	Density	Basal area sq. ft.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	21		
Acer saccharum	4	1	5	2		2					1							15	1.517
Amelanchier canadensis	1																	1	.006
Asimina triloba	2																	2	.012
Carya cordiformis		1																1	.022
Cornus florida		1	2			1												4	.316
Crataegus sp.		9	1															10	.247
Fraxinus americana	3	7	1	1	1	2												15	.836
Juniperus virginiana	8	1	3	1														13	.304
Liriodendron tulipifera								1								1		2	1.745
Malus malus				1														1	.087
Pinus virginiana	30	37	34	20	7	12	19	3	5	6	4	4	5	4	3	1	1	195	11.868
Prunus serotina	1	1															1	3	2.549
Pinus strobus											1							1	.660
Quercus palustris							1											1	.267
Quercus rubra	1	1																2	.028
Sassafras variifolium	74	7		1						1								83	1.230
Tecoma radicans	12	3																15	.138
Ulmus fulva	4	2	2	4														12	.514
Vitis sp.	24	3	1															28	.259
Cercis canadensis												1						1	.785

Soil acidity tests were made on soil from representative areas of the groves, comparing, especially, soil where seedlings were dense with soil where seedlings were lacking. The samples of soil were collected in small glass vials. Computation of the acidity was made with the Youdon Hydrogen Ion Concentration Apparatus. Correlation was made between similar areas where the pine had established itself. The groves were studied by the strip transect method. Two areas of prolific seedling reproduction were mapped (one of these in the Pennington grove). The ground cover was listed in 50 quadrats scattered throughout grove "B". Tree study was conducted as follows: In grove "A" the woody plants were studied by the strip transect method. One strip 10 x 128 meters was taken through the center of the grove from the north to the south, and a second strip 10 x 70 meters from the west to the east, about to the center of the grove. (Tables II and III.) A special list of trees according to d. b. h. from one inch up was made in all the areas studied, and a second count was taken of all woody plants one meter

TABLE III

Strip transect through *Grove "A"*. 10 x 128 meters. Area identical with the one on which tabulation of Table II is based. Density of woody plants one meter or higher, less than one inch D. B. H.

Species	Density: Total number of stems present	
Acer saccharum	26	
Amelanchier canadensis	4	
Asimina triloba	33	
Celastrus scandens	31	
Cercis canadensis	7	
Carya laciniata	1	
Carya cordiformis	1	
Cornus florida	16	
Crataegus sp.	2	
Fraxinus americana	33	
Juniperus virginiana	17	
Liriodendron tulipifera	4	
Malus malus	1	
Morus rubra	7	
Nyssa sylvatica	1	
Pinus virginiana	51	
Pinus virginiana. dead in area		35
Prunus serotina	13	
Quercus alba	3	
Quercus rubra	1	
Rosa sp.	4	
Sassafras variifolium	203	
Tecoma radicans	61	
Ulmus fulva	23	
Vitis sp.	12	

or over in height but less than one inch in diameter. Besides that a tabulation was made of all dead pine in the areas studied. (Table III.)

The areas were laid off with a heavy cord, measurement being made with a tape line, adjustments were made every ten to fifteen meters for the running of the second line, parallel to the first, so that the measurement was quite accurate. A representative small area 8 x 8 meters was mapped accurately to show position of large trees with reference to

TABLE IV

Strip transect through *Grove "B"*. 10 x 128 meters
Tabulation of trees one inch or more in diameter

Species	D.B.H. in inches															Density	Basal area sq. ft.
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	
Acer saccharum	6			2		1											9	.406
Cornus florida	2	6	9	1													18	.672
Crataegus sp.	2																2	.012
Cercis canadensis	9	5		2	1	1											18	.670
Fraxinus americana	43	7	7	2	1	3	3	1	1								68	3.245
Juniperus virginiana	18	8	8	4													38	1.024
Liriodendron tulipifera												1				1	2	2.181
Pinus virginiana	6	18	26	21	21	24	24	16	17	6	1	4	2	1	3	1	191	45.659
Prunus serotina	5	1	1					1									8	.450
Quercus rubra		1															1	022
Sassafras variifolium	6	8	4	5	1												24	.979
Rhus toxicodendron	1																1	.006
Ulmus fulva		3	1														4	.115
Vitis sp.	8	3															11	.114

TABLE V

Strip transect through *Grove "B"*. 10 x 186 meters. Area identical with the one where tabulation for Table IV was made. Woody plants one meter or more in height but less than one inch D. B. H.

Species	Density: Total number of stems present	
Acer saccharum	5	
Asimina triloba	4	
Cercis canadensis	6	
Cornus florida	9	
Celastrus scandens	2	
Fraxinus americana	102	
Juniperus virginiana	19	
Nyssa sylvatica	4	
Pinus virginiana	1	
Pinus virginiana dead in area		67
Prunus serotina	3	
Rosa sp.	1	
Sassafras variifolium	5	
Ulmus fulva	7	
Vitis sp.	8	

the seedlings of *Pinus virginiana*. (Figure 4.) This area has been retained as a permanent quadrat.

In grove "B" a transect was made through the entire length of the grove from east to west, 10 x 135 meters, and a similar strop 10 x 51 meters was run along the eastern border from the north to the south. Tabulation was identical with that described under grove "A" (Tables IV-V). In this area a list of species representing the ground cover was made in 50 quadrats of one meter square, scattered throughout the grove. (Table I.) Along the southern edge of the grove a special study was made of *Pinus virginiana* and *Juniperus virginiana* seedlings. Fifty quadrats of one meter square, alternating with one meter skip were taken. These transects represent about 10 per cent of the total area of grove "A" and 20 per cent of grove "B". The climatological data were taken from the weather report of the Bloomington station. As the areas studied are all within a radius of ten miles from Bloomington, and more or less in the same altitude, these data should be very reliable.

FACTORS HAVING BEARING UPON REPRODUCTION AND GROWTH OF PINUS VIRGINIANA

Let us first consider three factors which might have a decided influence on seedling establishment, i. e., light, soil moisture and soil acidity. Former discussions brought out the fact that light is seemingly a vital factor in the life of this pine. Since few seedlings are found under the old trees (see Table 1) and on the other hand appear in great abundance where older trees have been removed or where older trees are exposed to part of the sunlight during the day, as well as in open fields, along roadsides, and in pastures, one may well conclude that the seedlings must have light to establish themselves, and perhaps even that the seeds need light for germination as do those of *Tsuga canadensis*. The quadrat study of the ground cover (Table I) revealed

an almost total absence of seedlings of the dominant species. Only one seedling was found in the 50 quadrats in grove "B", and seeding must be abundant in the old grove. The same absence of young trees is accentuated in the tabulation of trees below one inch in diameter in the four strips studied. Only 51 such young pine were found in 1,980 square meters in Grove "A" and one in 1,860 square meters in grove "B". (Tables III and V.) Comparing with these results the quadrat study along the border of the grove we have 99 pine seedlings in 50 square meters. The most graphic story is told by the mapped area of 8 x 8 meters in grove "A". The area is a rather open place in the northwest corner of the grove in the otherwise dense woods, just adjacent to the strip tabulated which showed no young trees of one meter or over in height. Apparently an old tree had been removed from the place, the growth of sassafras had been cut. While four large pines shaded the spot to some extent, the center is unshaded from the vertical light, and there is an open path for both southwest and northeast light. The

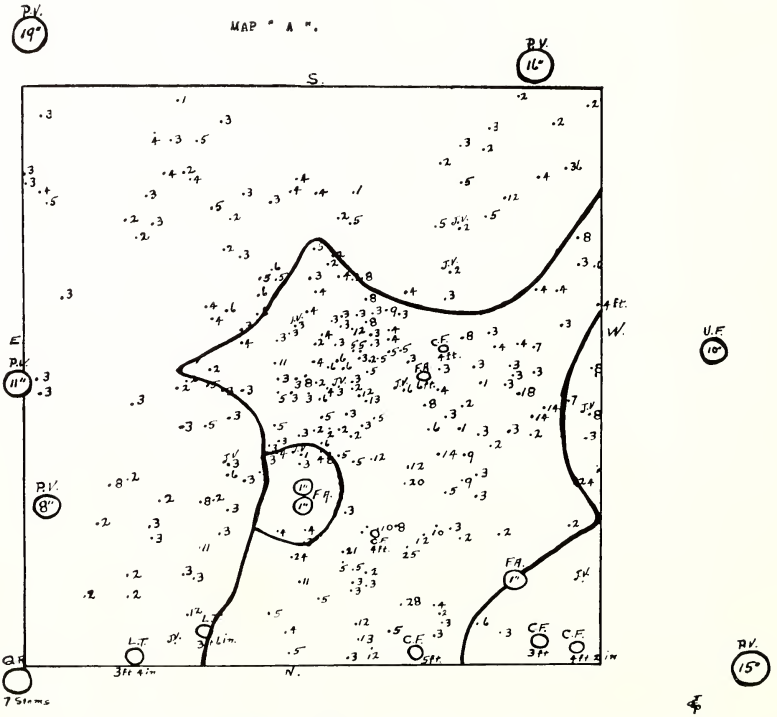


Fig. 4—Distribution of *Pinus virginiana* seedlings in an area 8 x 8 meters. Grove "A".

LEGEND

(C.F.) Cornus florida
(F.A.) Fraxinus americana
(J.V.) Juniperus virginiana
(L.T.) Liriodendron tulipifera
(P.V.) Pinus virginiana
(Q.R.) Quercus rubra
(U.F.) Ulmus fulva

Dots= Pine seedlings
Figures=Heights in inches
Curved Lines=Shading, vertical
Figures in Circles=d.b.h. in inches

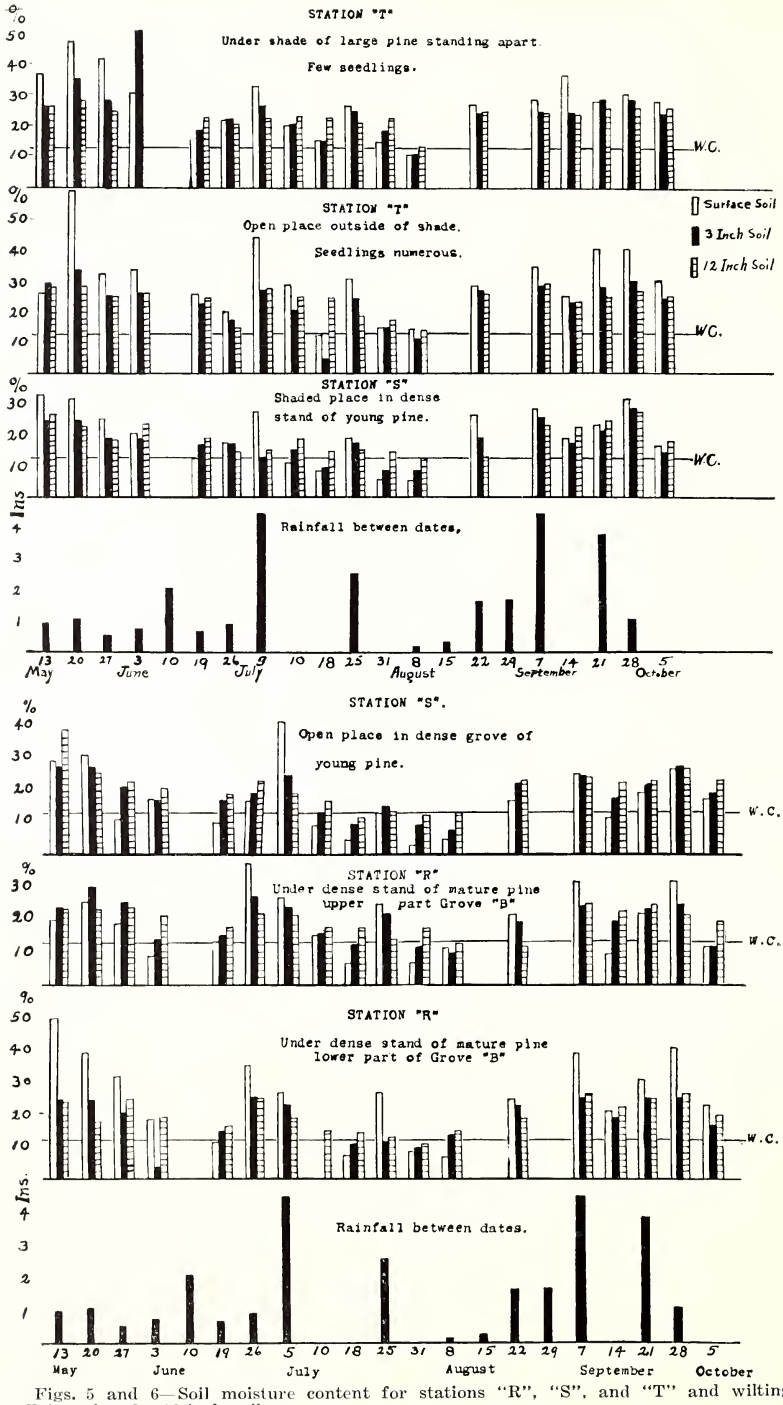
distribution of seedlings is extremely dense in the little plot (251 seedlings), but the most striking thing is that these seedlings are clustered in the central part where the light is unobstructed and in the path of the northeast and southwest exposure to sunlight. The response to the light factor is so immediate that one can almost trace the rim of the shade by the reduction of numbers of pine seedlings. (Figure 4.) The seedlings have invaded the roadside, ditches, fence corners and even quite extensively the pasture, in spite of the grazing interference. On the upper border of grove "A" they have taken possession of an abandoned strip of land grown over with herbaceous plants and some *Rubus allegheniensis*. Mr. Freeman said that hundreds of the seedlings would invade the area east of grove "B" whenever it was left in grass for a few years.

Let us turn our attention to the question of soil acidity. Since seedling establishment would be most influenced by the condition of the surface soil, investigation on acidity was limited to this layer. Soil was taken from areas which were close to the parent trees so that the question of seeding is comparable. It is rather striking that the surface soil under the old pine shows so little acidity since the leaves of conifers are acid in their reaction. The samples of group "A" were taken from beneath the older pine trees, the pH was as follows: 6.89, 6.81, 6.43, 6.57, 7.15, 7.73. There is, thus, a range of acidity in pH between 6.43 and 7.73.

The samples of group "B" were taken from beneath deciduous trees. The distribution of the acidity in pH is as follows: 6.40, 6.81, 7.35, 7.40, 7.42, 7.44, 7.5, 7.56, 7.58, 7.73, 7.9. While the difference in acidity between the various soil samples shows a considerable range, the difference between the two groups is not great. If seedling growth were promoted by slight variation in acidity or alkalinity of soil, one should expect to find seedlings in one of these two areas which are comparable as to seeding but diverge slightly as to range of acidity. In neither of these areas was there a noteworthy seedling growth. There is not even a definite indication of preference for acid or alkaline soil in places where the seedlings are numerous as shown by the samples of group "C," which showed the following range: 6.44, 6.49, 6.72, 7.0, 7.06, 7.12, 7.23, 7.23, 7.73, 7.85, 7.92. There is approximately the same range in pH as in the previous groups. One might argue that soil acidity is subject to local fluctuations due to the influence of grass or herbaceous plants and that seedlings might thus show a selective preference for certain soils. We admit such a possibility, but the soil under pine and deciduous trees shows just such a fluctuation and yet seedlings are absent from these areas. From the evidence on hand we must conclude that acidity or alkalinity of soil is not a critical factor in retarding or promoting establishment of seedlings of *Pinus virginiana*.

The results of the soil moisture measurements are rather striking in a number of ways. One is impressed with the many weeks during which soil moisture dropped below the wilting coefficient. It was most frequent in the surface soil and least in the soil at 12-inch depth. (See Figures 5 and 6 and Table VI.)

This lack of soil moisture becomes doubly significant when correlated



Figs. 5 and 6—Soil moisture content for stations "R", "S", and "T" and wilting coefficient for the 12-inch soil.

Lower graph shows rainfall in inches between dates of collection.

TABLE VI

Number of weeks when soil moisture dropped below wilting coefficient during a period of 18 weeks of observation. Abridged from Figures 5 and 6

Station	Location	Surface soil	3-inch	12-inch
R	Upper edge Grove "B"	6	4	2
	Lower	4	4	1
S	Open place	7	3	3
	Dense grove	5	3	1
T	Open place	1	2	0
	Under old tree	1	1	0

with the rainfall for the summer. The summer of 1931 had an abundance of rain in every month of the summer, but with May rising above normal, with July double that of normal, and September more than three times that of the normal. As figures of monthly rainfall do not show the significance of this moisture to the soil, since they cannot indicate the distribution of the rainfall over the period, a special graph has been added to each figure showing the soil moisture for the 21 weeks while the investigation was conducted in order to indicate the distribution of the rainfall week by week. As a whole the rainfall was well distributed; during ten weeks there was at least an inch or more of precipitation. (Figures 5 and 6.)

Under such conditions of precipitation one would expect sufficient soil moisture to keep the amount of water in the soil above the wilting coefficient. The low water content of the soil may be partly attributed to the Karst region, which permits a rapid underground flow-off.

There was a remarkable lack of soil moisture under the shade of dense stands of pine, even the open place at station "S" which was exposed to sunlight almost the entire day was not so very much lower in soil moisture than the areas under dense groves of pine. In fact, the 3-inch level in the exposed area was one week less below the wilting coefficient than those of station "R" lower down the slope under a dense pine grove. Station "T" on a plateau of the lower part of the ridge showed least lack of soil moisture of all stations. One might expect that, since it was less subjected to rapid run-off on account of its topographic position.

It must also be taken into consideration that station "S" was near a sink, so that the greatest lack of water in the soil could be expected there, but station "R" near the foot of the upland registers almost as many weeks below the wilting coefficient and in the 3-inch soil even more.

Here it must be a case of root absorption as has been shown by trenching experiments carried out by Toumey and Kienholz (6). On the other hand one must not look for the entire explanation of this lack

of soil moisture in root competition. After years of observations on trenched areas, the last-named authors make the following statement: "We are coming to believe that the nature and conditions of the reproduction and other surface vegetation beneath living canopies are not due to any single factor such as light or soil moisture, but to a complex of factors."

The soil moisture condition is also greatly influenced by the interception of rainfall by the crowns of the trees. Zon (7) says: "As a result of a great number of investigations it may be assumed that coniferous forests intercept more precipitation than broad leaf forest." Ney found that pine forest intercept fully 20 per cent of the precipitation, while beech forest but 9 to 15 per cent. (See Zon, loc. cit., page 26.)

Considering the factors which seem to prevent seedling establishment, one must conclude that root competition, interception of rainfall

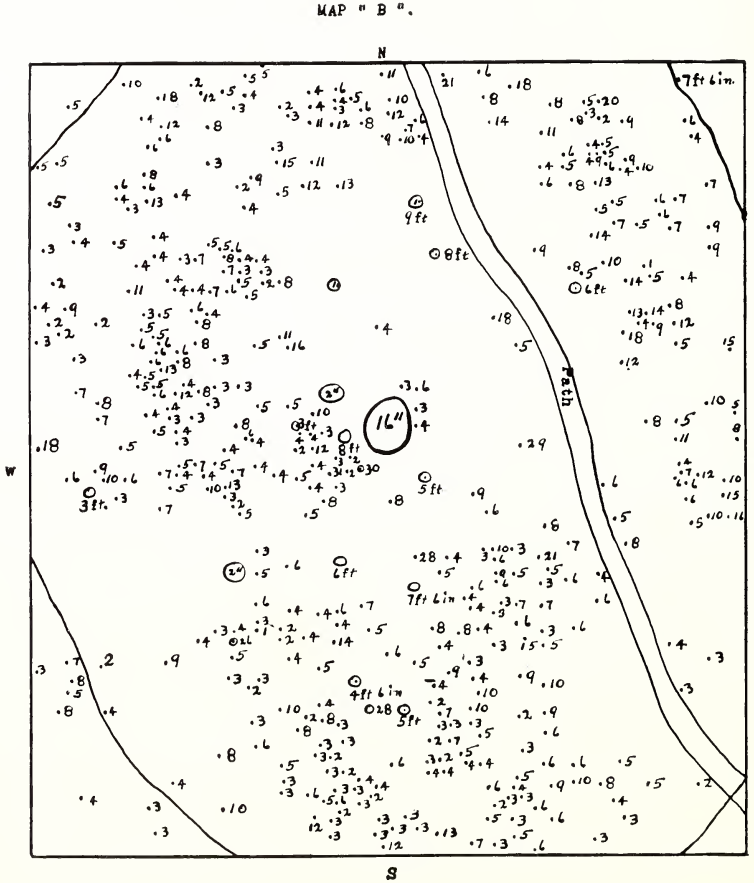


Fig. 8—An area 9 x 10 meters under a mature pine in the Pennington grove. Lines in the corners mark extent of branch-spread. Each dot represents a seedling, figures indicate size in inches.

by the tree crowns, and shading are the most prominent in the case of *Pinus virginiana*. From the general appearance of things, the writer is inclined to consider intolerance to shade the most vital of all. Not only is the absence of seedlings under the dense stand of older trees a striking feature in all the groves investigated, but likewise the killing of young trees up to two inches in diameter where the crowns do not reach above the canopy and the killing of all shaded branches of the older trees. When a tree grows in the open it retains its branches alive to the very lowermost branch. In the Pennington grove are several large areas within the dense stand of old trees which are not occupied by big pine and to all appearance should have a reduced root competition, but the crowns cause shading for the greater part of the day. No seedlings have come in. Nearby is a similar area partially encircled by *Cornus*

Fig. 7—The sharp demarkation of pine between upland and lowland in the Pennington grove.

florida and Liriodendron tulipifera, leaving, however, an open path to the morning sun and a thrifty growth of young pine occupies the area. Likewise seedlings were found in profusion under older trees which occupied an isolated open position. The most outstanding case of this nature was mapped and is shown in Figure 8. The old tree occupies an isolated position towards the top of the slope, the east, southeast, north, and northwest sides are flanked by open fields, while a grove of 22 young trees about 18 years of age is to the west; few seedlings are found in the grove; about eight meters to the south is the dense main forest with almost a total absence of seedlings and young trees.

Root competition must certainly be intense under the parent tree, yet the parent tree is not only void of dead branches but there is also an amazing number of young trees ranging from two inches to nine feet within the boundary of its branch-spread; 455 seedlings and small trees in a limited area of 9 x 10 meters. Many of these seedlings grow in dense mats of Poa, and also among *Rubus allegheniensis*, even near a path which crosses the area. These are all conditions which certainly point to a severe root competition or its equivalent with which the young growth must compete and does compete successfully. Pearson (3a) found that in some instances light was a more important factor in inhibiting seedling establishment than soil moisture in forests of the Southwest, and cites cases identical with those given by the writer.

In order to study more definitely the role which root competition plays in the elimination of seedlings under dense stands of older trees, the writer has planned a trenching-experiment. Mr. C. J. Pennington has most kindly granted permission for such an experiment in his woods.

The fact that the Jersey pine readily takes possession of dry wornout hillsides and does not invade the more moist lowlands also argues against the soil moisture factor as an extreme controlling influence on the establishment of seedlings under parent trees. In the Pennington grove one finds a sharp line between dense growth of pine on the dry uplands and the total absence along an intermittent little creek in the valley, unoccupied areas are numerous. (See Figure 7.)

Another unusual feature in the present soil moisture studies is the close range of the wilting coefficients in all three layers of soil, and at all three stations. In collecting the soil a hole about 14 inches deep was dug with a spade and the soil samples taken from the wall of the opening at the depths from which measurements were to be made. The soil was collected in two and one-half by three-quarter inch cans with a tight-fitting lid on which the weight of the can, the station, and the depth of soil were written with ink. These cans were usually weighed on the day of soil collection, then with lids removed placed into an electric drier during at least four days at 103 C. At the end of the drying the cans were closed one by one as they were removed from the oven and weighed immediately for the computation of water loss.

In the figure showing the soil moisture data, the wilting coefficient is that for the 12-inch soil. The distribution of the w. c. for the various stations and soil depths were as follows:

TABLE VII

The wilting coefficient for the various stations

Stations and Designated Area	Surface	3-inch	12-inch
Station "R"—			
Upper part of grove	11.7	12.4	12.7
Lower part of grove	12.8	11.8	12.3
Station "S"—			
Dense grove of pine	11.1	11.8	12.6
Open place near pine	11.7	11.1	12.5
Station "T"—			
Outside of shade of old tree	13.5	12.1	12.9
Under shade of tree	12.9	12.8	13.0

Evidently there must be a more or less complete oxidation of the decaying plant remains on the surface soil. Pine leaves also yield a much more scant amount of leaf-remains than broad leaf trees, and these factors combined will make the layers of soil at different depths more uniform than is the case in forest of deciduous trees.

As already stated, the areas studied are at present dominated by *Pinus virginiana*. This will also be borne out by the figures of the strip transect studies which have been tabulated in Tables II and IV.

Compacting these figures still more, we have a grand total as shown in Table VIII.

TABLE VIII

The number of individuals of *Pinus virginiana* in area

Grove	Area tabulated	Trees having diameter of 1 to 21 inches D. B. H.	Below 1 inch D. B. H.
A	1,980 sq. meters	205	51
B	1,860 sq. meters	193	1

The whole area shows a marked absence of competitors in large-leaved trees, there are really only two species which show any amount of representation, i. e., *Acer saccharum* and *Fraxinus americana*, neither of them comparable in numbers with *Pinus virginiana*. A further study of the size of the trees as shown in Tables II and IV reveals the fact that nearly all the large trees are pine. A compact tabulation of size distribution of *Pinus virginiana* in the tabulated areas is shown in Table IX.

TABLE IX

The distribution as to size of *Pinus virginiana* in mapped areas

Grove	Measurement D. B. H. in inches																	
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	21
A	30	37	34	20	16	12	19	3	5	6	4	4	5	5	3	1	...	1
B	6	18	26	20	21	24	24	16	17	6	1	4	2	1	3	3	1	...

The situation becomes different when examining Tables III and V, showing the distribution of trees below one inch in diameter, the aspect of the area pointing into the future. Of this more will be said under the topic of predictions.

Ever and again one is impressed with the importance of shading in the elimination of reproduction of *P. virginiana*. Even the climatological data show this importance. Monroe County is well within the deciduous forest area of North America, which means that its climatic conditions are such as to make dense forests and wide range of deciduous trees possible. Also the individual species are represented in large numbers within a forest, this makes for increased competition. The average rainfall for the Bloomington area is approximately 44 inches a year, and while there might be a fluctuation from the normal monthly and yearly amount, over a period of years these differences tend to smoothen out along the normal curve. Figure 9 shows the normal rainfall in inches and its monthly distribution for the Bloomington area.

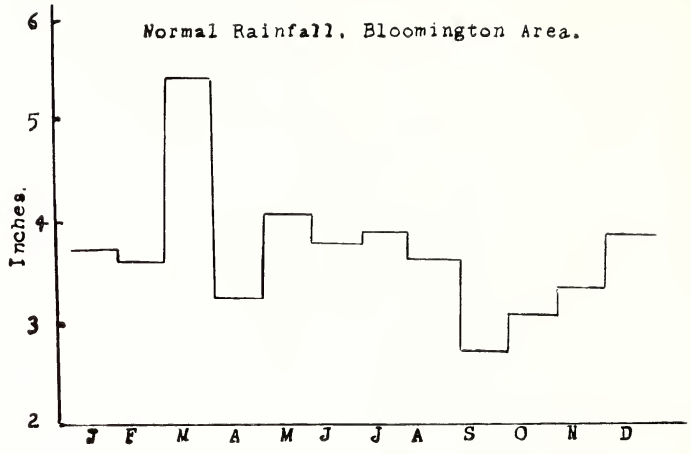


Fig. 9

In its regional distribution the Jersey pine follows quite closely the areas between the 40 and 50 inch isohyet lines, so the Bloomington area precipitation seems to be just the ideal for its moisture requirement. From the description of Sargent (4) one can well deduct that it can readily adapt itself to less favorable moisture conditions brought about by physiographic features of the locality than many of the deciduous trees, for it takes possession of the sandy soil in the East and spreads readily over slopes of uplands where moisture conditions are more severe than in the lowlands due to greater run-off and increased evaporation brought about by exposure to increased air currents. This habit of invading less favorable areas, again, points to the same weakness of intolerance to shading. While it can adapt itself to the drier uplands many of the broad-leaved competitors cannot and are so eliminated, which means a partial protection from shading by larger trees. The readiness with which it invades drier uplands would make it a desirable tree for reforesting idle and eroding uplands of central and southern Indiana. Even the seedlings tend to prove that this pine can endure unfavorable soil moisture conditions, for although the year 1930 was one of great drought which affected full-grown trees on the uplands and killed 84 per cent of a series of hemlock seedlings in Brown County, Indiana, which were under the observation of Professor Ray C. Friesner and the writer, the mapped areas in grove "A" and the Pennington grove as well as the quadrat study along the southern border of grove "B" indicated no great losses during that year for many of the seedlings were of that year's germination.

Evaporation is somewhat linked up with the relative humidity of the air so that evaporation increases with the increase of the air temperature. However, the influence of isolation upon evaporation is only a part of the story, especially when local limited areas are concerned, for moisture may also be transferred by air currents. This movement of water vapor by air currents is indicated by the present evaporation studies.

TABLE X

Standard evaporation for nineteen readings. Averaged weekly

Station	Set	Location	Weeks and amount of evaporation in cc.																		
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
S	1	Dense grove....	137.6	92.4	60	....	.....	36.0	37.0	....	.....	46.4	144.7	105.7	88.0	88.0	32.9	92.8	71.2	52.8	100.8
S	2	Open place.....	126.4	108.2	88.5	83.7	98.3	55.3	47.3	93.9	152.1	92.4	164.0	123.7	105.0	105.0	74.6	97.9	77.4	....	109.0
T	3	Outside of shade of old tree....	135.4	116.2	101.4	82.1	96.9	42.9	54.1	72.5	115.9	44.4	109.0	81.6	66.6	66.6	....	111.0	76.2	51.1	97.7
T	4	Under the shade of old tree....	142.1	124.3	109.5	99.9	136.9	51.8	43.6	96.6	134.1	48.1	130.7	102.3	100.6	100.6	47.0	119.1	86.6	68.1	102.9

The atmometers for results of sets one and four of Table X were in a shaded area yet the amount of evaporation is in some instances higher than of those in the open sunlight. It is especially pronounced in set four when compared with set three. Only during one week was there more evaporation in the open than in the shade of the large pine where the atmometer for set three results was located. This can only be explained on the basis that the atmometer was in a less protected position as far as air currents were concerned.

As a whole, the evaporation was low for the whole season and this makes the lack of soil moisture so much more difficult to explain. Excessive flow-off on the steep slopes, porous bed-rock account for a part of it, the balance must have been evaporated through the tree crown. After all, evaporation figures from studies of these processes near the surface convey only a partial idea to what extent plants of the ground cover are affected by evaporation, for the taller trees are subjected to an evaporation at least 75 per cent higher than are the plants protected by the forest. This was shown by King (2) on observations of the influence of wind-breaks on field crops.

The results also show that evaporation data alone do not convey a great deal of information as to the effect water loss has upon plant growth, for evaporation is only one part in a complex of factors involved in the understanding of the relationship between precipitation and soil moisture.

Predictions. To judge by the situation in the observed areas as well as from reports on numerous other places where this pine has given expression to rapid spread, one may expect that within the next 50 years wide areas in southern Indiana will be invaded, for the tree is seen in many places near homes. Waste lands and abandoned fields will be possessed by the rapidly growing conifer. The future may also show some important economic value for the timber. Mr. E. F. McCarthy, formerly of the United States Department of Agriculture, Central States Forest Experiment Station wrote me the following of its economic possibilities: "*Pinus virginiana* will have a certain amount of value as saw timber, especially in farming communities where other more desirable softwood species cannot be secured. It has already been used for pulpwood and in small sizes with an excess of sapwood it may be possible to develop satisfactory sulphite pulp." Since the tree grows very readily on poorer upland soil as well as on rocky hillsides and waste lands in general, it may serve as a forest-crop on lands lying idle at present, and thus put a stop to much wasteful erosion of deforested uplands.

No doubt every life-form has its proverbial Achilles heel, and so has the Jersey pine. Since it is very intolerant to shade, any invasion of the consocies by taller trees will readily eliminate it from an area where it was dominant for a time. Such invasion is also very probable in the Freeman-Christie groves, since seedlings do not develop under the parent trees. In these groves the invader seems to be *Fraxinus americana*. In the tabulated area of grove "A" this species is represented by 15 individuals one inch or more in diameter and 33 of smaller diameter, one meter or more in height. In grove "B" there are 68 above one inch

in diameter and 102 of the smaller sizes. Comparing the representation of the small growth of *Pinus virginiana* with these figures we have only 51, so one can readily picture the eventual fate of the conifer in that area. At present all other species, even the common middle layer trees of our deciduous forests, i. e., *Cercis canadensis* and *Cornus florida*, are poorly represented. In the dense stand of grove "B" even sassafras is very scarce. So for the present *Pinus virginiana* dominates in the described areas, as soon as taller shade-resisting trees come in the smaller pine will be eliminated from the area.

Summary

1. *Pinus virginiana* is spreading rapidly in some areas of Monroe County, Indiana, as an escape from isolated trees in cultivation.

2. The preferred places are waste lands, abandoned fields, cut-over woods, especially of the more dry upland types.

3. Its foremost assets in aiding establishment are ready self-seeding in open places, rapid growth in dense consocies, and adaptability to semi-xerophytic conditions.

4. Its greatest weaknesses are small size and extreme intolerance to shade.

5. There is practically no reproduction under the parent trees where the crown is so dense as to greatly reduce sunlight.

6. The lack of seedling establishment under dense growth of parent trees is seemingly the result of lack of light and soil moisture; of the two, lack of light seems to be the greater inhibiting factor.

7. The prolific reproduction in open areas and on worn-out land, as well as its rapid growth would adapt it admirably to projects of reforestation of waste lands and barren hills.

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