EFFECT OF NATURAL SUBIRRIGATION ON THE UPTAKE OF NUTRIENTS BY FOREST PLANTATIONS

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EFFECT OF NATURAL SUBIRRIGATION ON THE UPTAKE OF NUTRIENTS BY FOREST PLANTATIONS[1]

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Introduction

During the past three years Wisconsin conducted the all-state survey of soils supporting forest plantations (WILDE, 1962). Some of obtained results have indicated a close correlation between the levels of fertility of non-phreatic, coarse textured soils and the growth of red pine, *Pinus resinosa*, stands aged from 15 to 32 years.

Plantations of the lowest rate of growth, approaching site index 45, are confined to soils depleted by fires or a prolonged farming use and to pure lysiliceous sands of aeolian deposits, river terraces, and the bottom of the former glacial Lake Wisconsin. The stands of the medium productive capacity, of approximate site index 57, are largely found on non-podzolic soils of glacial outwash enriched in feldspathic, micaceous and ferromagnesian minerals. The most rapidly growing plantations of site index 68 occur on moderately podzolized, sandy loam soils of partly assorted glacial deposits. In terms of the north-European classifications these three groups are close to *Cladonia-Empetrum-Calluna*, *Vaccinium vitis-idaea* and *V. myrtillus* sites, or oligotrophic bor, eutrophic bor and soobor types (CAJANDER, 1949; POGREBNIAK et al., 1944).

Table 1 presents, in a way of illustration, arithmetic averages of fertility factors in non-phreatic soils supporting stands of different rates of height growth and volume increment. The averages of both soil and growing stock characteristics were established on the basis of 132 one-tenth acre plots distributed throughout Wisconsin. No erratic values were rejected in averaging the results of either soil or mensuration analyses.

This picture of a regimented soil-forest relationship, however, failed to appear when soil and mensuration analyses were extended to plantations established

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Table 1. Average state of fertility factors in soils supporting red pine plantations of different rates of growth.

Site quality and height growth In./yr.	Ave. growth m³/yr.	pH	Silt plus clay %	Organic matter %	Exch. capacity me/100 g.	Tot. N %	Avail. P_2O_5	Avail. K_2O	Exch. Ca	Exch. Mg
							kg/ha		me/100 g.	
Low: 45 7—13	1.5	5.0 [1]	7.3	1.20	2.75	0.048	45.0	73.2	0.76	0.18
Medium: 57 14—17	3.1	5.2	8.8	1.31	3.19	0.059	66.0	83.5	0.84	0.24
High: 70 18—24....	5.0	5.0	12.0	1.81	4.48	0.078	95.5	131.0	1.41	0.33
Satisfactory minimum level [2]			8.7	1.50	3.50	0.060	56.0	78.5	0.80	0.20

[1] Medians instead of arithmetic averages are given for all pH values because of the logarithmic nature of this factor.

[2] Average of 7 least values for soils supporting stands of the best site quality.

on deep-gley soils (WILDE, 1940), underlain at a depth of 3 to 9 feet by ground water. These naturally subirrigated soils with well aerated surface layers yielded results which are in discord with our ideas of soil fertility and which cannot be readily explained on the basis of our present knowledge. The details are reported in this paper.

Growth of Red Pine Plantations on Subirrigated Soils

By random procedure, the survey encountered 20 red pine plantations on soils underlain by a deep ground water table accessible to tree roots through their contact with gley horizon or with extended capillary fringe. This constitutes about 15 per cent of all surveyed stands of this tree species.

The growth data were obtained by measuring diameters of trees at breast height and then by determining the age, current diameter increment, height, and 5-year intercept of seven dominant and codominant trees of the average diameter. The specific gravity was determined on increment cores taken from the same trees at breast height. The yields were obtained from circular nomographs constructed on the basis of a conservative formula: $Y = 0.32\ B \times H$, where Y is the volume of merchantable timber in cubic feet per acre, B is the basal area in square feet per acre, and H is the average height of the stand. The results of mensuration analyses are given in Table 2.

With the exception of four stands (5, 49, 108 and 154), the plantations on these soils have attained height growth between 18 and 24 inches (45—60 cm) per year. On the basis of average values, the annual height growth of these plantations is 19 inches, the current diameter growth is 0.22 inches (0.56 cm) per year, and the annual volume increment is 80 cubic feet per acre (5.6 m³/ha) at the age of 22 years. At this rate of growth, the expected yield at the age of 40

Table 2. Growth of red pine plantations on naturally subirrigated soils.

Plot No.	Soil Type	Age Yrs.	Ave. Ht. m	5-year intercept m	H/Age cm	Ave. BHD cm	Stems per ha	B.A. m²/ha	Ave. Ring Width mm	Volume m³/ha	Spec. Grav.
5	Ella sand	21	8.5	3.4	40	14.0	2 660	41.3	3.6	135	0.360
21	Sparta sand	21	10.8	2.8	51	14.7	2 370	40.0	2.5	140	0.360
25	Coloma sand	28	13.9	3.2	50	17.0	1 730	57.2	2.4	254	0.344
27	Coloma sand	20	10.6	2.9	53	19.3	990	28.4	3.2	97	0.350
29	Coloma sand	18	10.8	2.8	60	13.5	1 330	19.0	3.4	67	0.320
32	Plainfield sand	32	15.2	3.3	48	20.3	3 080	45.2	1.8	221	0.350
49	Hiawatha sandy loam..	27	10.1	2.8	37	11.4	2 660	27.0	1.7	71	0.378
55	Hiawatha sandy loam..	22	10.5	2.0	48	14.2	2 590	40.6	2.8	136	0.365
81	Hiawatha sandy loam..	18	8.8	1.9	49	14.0	960	14.1	3.7	40	0.330
108	Shawano fine sand	19	6.7	1.8	35	9.6	3 410	23.0	3.4	49	0.363
138	Vilas sandy loam	17	7.8	3.0	46	14.2	1 800	28.0	5.1	70	0.345
154	Hiawatha sandy loam..	27	11.6	2.1	43	14.2	2 270	35.6	2.3	130	0.368
170	Tustin sand over clay..	25	12.8	2.6	51	15.7	2 690	55.1	2.8	226	0.347
180	Grundy sand	27	13.7	3.0	51	19.5	1 780	55.1	3.0	242	0.409
183	Merrillan f. sandy loam	22	11.3	2.9	51	16.0	2 320	47.4	2.8	174	0.411
192	Morocco sandy loam ..	19	9.6	2.6	51	13.5	1 830	28.0	3.2	68	0.440
193	Wyeville sand over clay	20	9.8	3.3	49	13.0	2 220	28.0	3.0	87	0.413
196	Plainfield sand	17	9.5	3.5	56	11.9	2 300	25.9	3.2	78	0.400
203	Boone sand	18	9.0	2.9	50	10.9	2 810	27.1	3.2	71	0.381
205	Boone sand	20	9.8	2.0	49	13.7	2 150	32.5	3.2	101	0.391
	Average	22	10.5	2.7	48	14.5	2 200	34.9	2.9	320	0.371

years would exceed 40 cords per acre or about 250 solid cubic meters per hectare (Figure 1).

All surveyed stands exhibit a high ratio of the average annual height growth to the 5-year intercept, a characteristic brought about by contact of root systems with the capillary fringe. The average specific gravity of stems is nearly identical with that of red pine supported by better non-phreatic soils of sandy texture. A rapid growth of trees and a reduced volume of knots denote a high percentage of useable cellulose.

Thus, mensuration analyses have suggested that soils underlain at a suitable depth by ground water are the choice grounds for forestry enterprise. This is true even when ground water is not enriched in nutrients and hence does not exert fertilizing effect upon trees. The soils under discussion are derived from coarse glacial deposits of crystalline rocks and are subirrigated by acid ground water of a very low specific conductance (WILDE and RANDALL, 1951; PIERCE, 1953).

Figure 1. An example of red pine plantation on naturally subirrigated sandy loam soil of Hiawatha series with ground water table at a depth of 2.5 m. This stand with material removed in two light thinnings produced at the age of 48 years a yield of about 400 m^3 per ha (Star Lake plantation in Vilas County. Photo by Wisconsin Conservation Department, Madison, Wisconsin).

Fertility of Subirrigated Soils Supporting Red Pine Plantations

The sampling of soils was accomplished in two stages. First, two composite samples of the 6-inch surface soil layer were collected from the entire area of the sample plot by means of a calibrated sampling tube 1.2 inches in diameter; each of the two samples was comprised by seven to nine 6-inch cores. This sampling helped to determine the most representative place for location of a trench, which then was excavated to an approximate depth of 5 feet. In the absence of gleization, deeper soil layers were probed by a 3 foot long sampling tube. If the soil profile exhibited ecologically important variations, additional samples were collected from layers enriched in mineral colloids, organic matter or carbonates. In all cases the results of analyses express the maximum supply of colloids and available nutrients or the critical state of auxiliary fertility

factors encountered within the root zone. The analyses were performed by methods described by Wilde, Voigt and Iyer (1963).

The results, given in Table 3, show that in many instances soils supporting rapidly growing plantations are extremely low in mineral colloids, organic matter and nutrients. In fact, some plantations of this group produced a very high increment on soil which on the basis of chemical analyses should be regarded as critically deficient in nitrogen (29, 196), phosphorus (81, 108, 180, 192), and potassium and other bases (49, 193, 203, 205).

This cardinal discrepancy, inexplicable on the basis of our present knowledge, poses a question: from which sources and in what manner trees acquired sufficient amount of nutrients for their rapid growth and for the supply incorporated in their foliage? The following hypothetical assumptions are offered as plausible explanations of the problem at hand.

(*a*) The moisture content of coarse-textured non-phreatic soils remains near the wilting point during a large part of the growing season with subsequent reduction of transpiration and uptake of nutrients (Haberland and Wilde, 1961; DeVries and Wilde, 1962; Smith and Wilsie, 1961). Contrary to this,

Table 3. State of soil fertility in subirrigated soils supporting red pine plantations of different rates of growth (critical deficiencies of nutrients are marked by asterisks).

Soil sample No.	Reaction pH	Silt plus clay %	Organic matter %	Total N %	Avail. P_2O_5 ppm	Avail. K_2O ppm	Exch. Ca me/100 g.	Exch. Mg me/100 g.
5	4.1	12.8	4.0	.166	23	60	0.75	0.43
21	5.8	7.0	1.4	.056	48	37	1.84	0.45
25	5.1	7.0	0.8	.030	27	32	0.87	0.25
27	5.0	5.5	1.1	.035	44	32	0.76	0.35
29	5.5	9.0	0.5	.018*	21	28	0.83	0.36
32	4.9	5.7	2.0	.090	29	30	1.40	0.17
49	4.8	9.7	1.4	.045	32	37	0.60	0.10*
55	5.0	10.2	1.2	.038	38	47	1.18	0.18
81	4.6	4.5	1.2	.048	4*	27	0.68	0.19
108	5.3	5.0	1.7	.060	9*	39	1.23	0.25
138	5.5	20.0	2.8	.095	40	76	3.42	0.39
154	4.5	11.0	2.1	.077	16	47	1.56	0.52
170	5.7	6.0	1.8	.063	41	33	2.51	0.54
180	4.5	17.0	2.2	.079	3*	28	0.42	0.16
183	5.0	33.0	2.3	.081	110	69	1.69	0.34
192	4.5	17.0	4.3	.151	6*	44	0.97	0.24
193	4.9	7.0	1.0	.032	39	23*	0.18*	0.07*
196	5.2	5.0	0.4	.018*	107	33	0.24	0.13
203	4.8	13.0	0.8	.027	31	17*	0.15	0.02*
205	4.7	10.0	0.8	.032	21	13*	0.15*	0.02*
Ave.		10.8	1.7	.062	34.4	37.6	1.07	0.26

the capillary fringe provides an inexhaustible supply of water which permits uninterrupted activity of root systems during the entire growing season. Under such conditions, trees may derive an adequate supply of salts and exchangeable ions from comparatively infertile substrata.

(*b*) The process of tree nutrition on soils with a suitably located ground water is benefited by two conditions: adequate aeration of the surface soil layers which is not impeded by water of capillary fringe; increased activity of fungus mycelia and, in turn, intensified solid phase feeding, i.e., a mycotrophic uptake of nutrients from unweathered minerals (Wilde and Iyer, 1962).

(*c*) The above effects of natural subirrigation should radically change the concept of soil fertility based on mere chemical analyses. The time during which the feeding roots are engaged in active absorption appears to be of equal or even of greater importance as the concentration of nutrient elements in available form.

By and large, the gulf between soil nutrient content and performance of trees is confined to younger coniferous plantations. Such stands incorporate during their first 20 to 30 years of growth most of extracted nutrients in their rapidly growing wood and abundant foliage. In advanced age, however, leaf fall and leachates from the crowns are bound to reestablish the normal level of soil fertility. Unter Wisconsin conditions, the spectacular effect of natural subirrigation was brought to light largely by the previous extensive deforestation and subsequent depletion of soils by clear cut logging, severe forest fires and often prolonged farming use.

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SELOSTUS:

POHJAVEDEN LÄHEISYYDEN VAIKUTUS VILJELYMETSIKÖIDEN RAVINTEIDEN OTTOON.

Wisconsinin osavaltiossa U.S.A:ssa olevien viljelymetsiköiden inventoinnissa tavattiin 20 punamänty- (*Pinus resinosa*) istutusta maalla, jossa 1—2 metrin syvyydellä oli niukkaravinteinen pohjavesi. Useimmissa näistä istutuksista oli kuitenkin sangen hyvä kasvu lähennellen 6 m^3/ha vuodessa. Tämä puuston hyvä menestyminen oli jyrkässä ristiriidassa analyysitulosten kanssa, joiden mukaan maissa oli yleisesti suurta typen, fosforin ja kalin tai muiden emästen puutetta. Havaitun ristiriidan selitykseksi esitetään seuraava olettamus.

Karkearakeisissa maissa, joissa pohjavesi on syvällä, kosteus on suuren osan kasvukautta lähellä lakastumispistettä, mikä vähentää puiden veden ja ravinteiden ottoa. Jos sen sijaan pohjavesi on niin lähellä maanpintaa, että juuret ovat sen kapillaarisessa vaikutuspiirissä, juuret pystyvät toimimaan häiriöttä koko kasvukauden. Kapillaariveden jatkuva saanti edistää sienirihmastojen kasvua ja siten lisää ravinteiden mykotrofista ottoa rapautumattomista mineraaleista. Siten puut voivat saada riittävästi vaihtuvia ioneja suhteellisen niukkaravinteisestakin kasvualustasta.

Luonnollinen alhaalta päin tapahtuva kastelu saattaa muuttaa sitä käsitystä, joka maan viljavuudesta saadaan pelkästään kemiallisen analyysin perusteella. Aika, jonka ravinteita ottavat sieni-juurisysteemit pystyvät toimimaan, näyttää olevan ainakin yhtä tärkeä kuin tiettyjen liukoisessa muodossa olevien ravinteiden väkevyys maassa.