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ADDITION OF PHOSPHORUS TO SUBSOIL PROMOTES ROOT DEVELOPMENT OF YELLOW BIRCH

Pot-culture studies have indicated that roots of yellow birch (*Betula alleghaniensis* Britton) develop more prolifically in humus than in sandy mineral soil (Hoyle 1965; Winget *et al.* 1963; Redmond 1954; and Tubbs 1963). This situation has also been observed during root-excavation studies (Redmond 1957; Spaulding and MacAloney 1931). Results of these studies generally indicated that soil temperature, soil moisture, and bulk density were not limiting factors in mineral horizons. Better root development in humus, and in mineral soil with high organic matter content, suggested that nutrient conditions were critical in sands. However, Tubbs (1963) did not obtain a rooting response after fertilizing mineral soil.

The problem remained: to clarify whether or not subsoil nutrient deficiency inhibits root development of yellow birch. The purpose of the work reported here was to study how root development of yellow birch in a sandy subsoil is affected by nitrogen (N), phosphorus (P), and potassium (K) in the presence or absence of limestone.

Methods

Plastic pots were filled with B_{23} horizon material collected from a Hermon soil under second-growth northern hardwoods on the Bartlett Experimental Forest in the White Mountains of New Hampshire. The Hermon soil is a well-drained sandy loam developed from granitic till. The subsoil is very acid, high in exchangeable aluminum, and low in clay and exchangeable bases. For a more detailed description of this soil see Hoyle (1965).

Combinations of nutrient salts were prepared for two series of pots. Dolomitic limestone was mixed with soil in half the pots at the rate of 2,000 pounds/acre. This gave a limed and unlimed series of pots variously treated with nitrogen, phosphorus, and potassium (table 1). Nitrogen was supplied as NH_4Cl (320 pounds N/acre), phosphorus as NaH_2PO_4 (187 pounds P/acre), and potassium as KCl (363 pounds K/acre). Salts for each treatment were weighed and dissolved in 250 ml. of distilled water.

Three yellow birch seedlings with four true leaves present were lifted from germination trays and planted in each pot. The pots were set under artificial lighting (cool-white fluorescent plus incandescent) using a 21-hour photoperiod.

Soil moisture was maintained at field capacity with distilled water.

Table 1.—*Schedule of nutrient salt treatments*

Limed series	Unlimed series	Treatment designation
NPK	NPK	Complete
NP	NP	Minus K
NK	NK	Minus P
PK	PK	Minus N
None	None	Check

Table 2.—*Height and weight of yellow birch seedlings grown in Hermon subsoil variously treated with nitrogen (N), phosphorus (P), and potassium (K)*

Nutrient treatment	Average height[1] of stems	Total weight[1] of stems/pot	Total weight[1] of roots/pot
	mm.	*mg.*	*mg.*
Unlimed series			
NPK	73.3	108.0	213.2
NP	61.3	54.0	112.3
NK	58.3	70.5	75.7
PK	88.3	217.5	683.1
Check	54.7	53.2	82.1
Limed series			
NPK	140.0	362.0	784.5
NP	82.7	167.4	216.4
NK	48.3	40.0	63.2
PK	102.7	425.2	894.4
Check	62.7	94.0	124.7

[1] Basis: 3 seedlings.

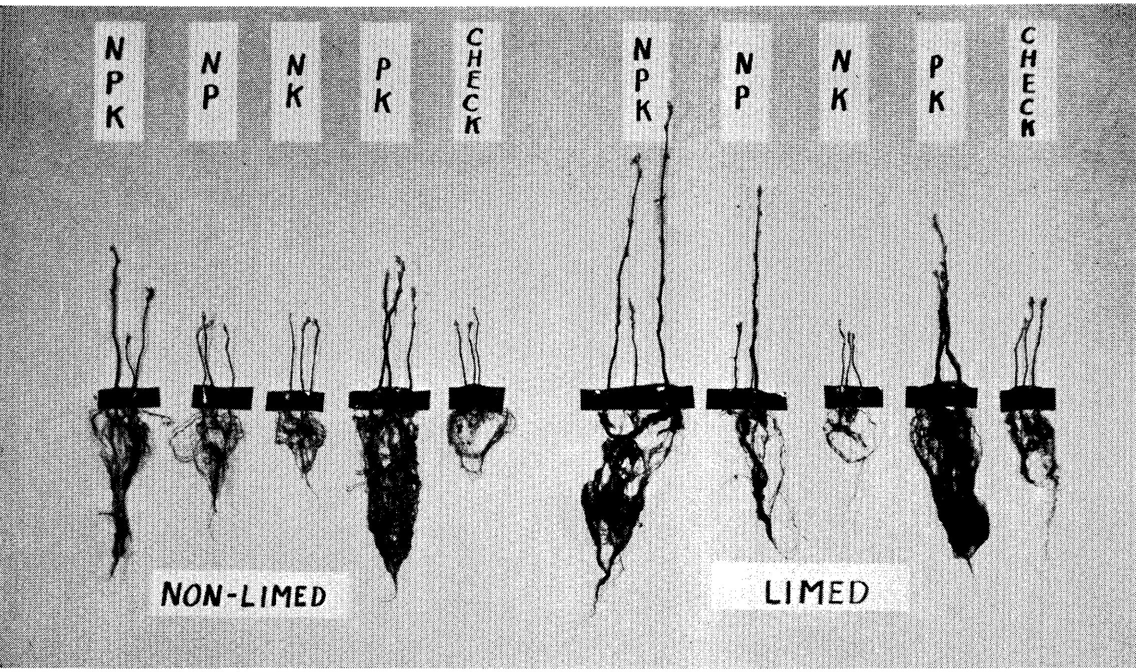

Figure 1.—Root development of yellow birch seedlings in limed and unlimed subsoil variously treated with nitrogen (N), phosphorus (P), and potassium (K).

Five-ml. aliquots of the various nutrient salt solutions were diluted to 10 ml. and first applied to the pots 8 days after planting. This procedure was continued for 3 additional weeks. Thereafter, larger undiluted aliquots were applied with greater frequency to complete the nutrient treatments. After 70 days, all plants were washed from the soil, oven-dried, and measured.

Results

Seedling development. — Results of nutrient additions are illustrated in figure 1. Absolute data are given in table 2, and relative gains in figure 2. Stem weights are for stems only and do not include leaf weights.

Poorest stem and root development occurred in the NK (minus P) treatment for both the limed and unlimed series. Greatest stem and root weights were recorded for the PK treatment in each series; seedling stem and root weights of the NPK treatment were slightly less. Possibly the high level of supplied N interacted with P to reduce gains. Some secondary response to N was suggested by the greater stem height and larger leaf development of seedlings in the NPK treatment, limed series.

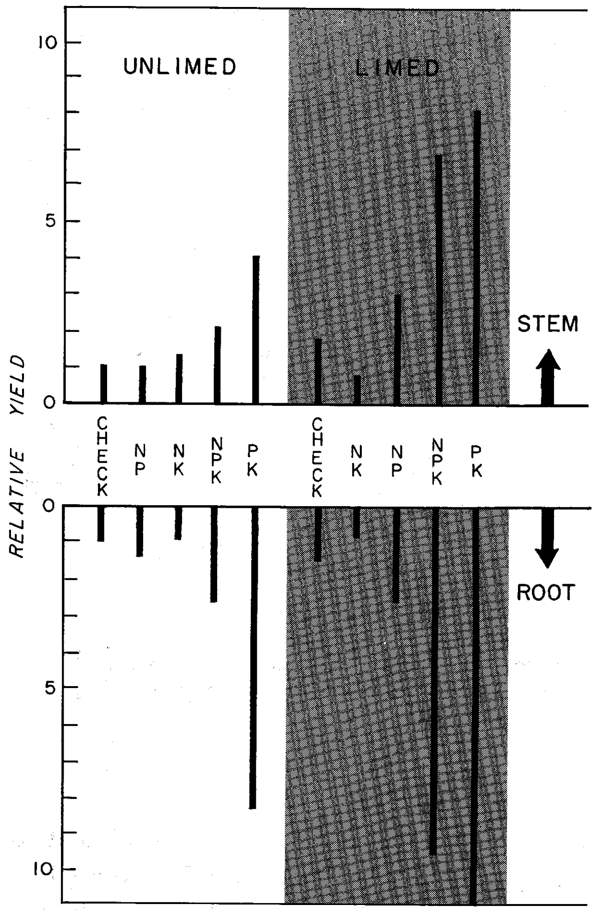

Figure 2.—Relative yield of stem and root weights. The data have been normalized, taking the unlimed check as 1.

Response to added P was greater for all treatments in the limed series than in the unlimed series (figs. 1 and 2). In the absence of tissue analyses, the reasons for this are not clear.

Though additions of P to this subsoil improved growth of yellow birch seedlings, optimum growth[1] was not achieved. Length of internodes and size of leaves on all treatments were less than normal. In addition, the leaves of the seedlings, especially those in the unlimed series, showed marginal necrosis, varying degrees of chlorosis, and curling.

Soil microflora. — A green mat of microflora developed on the soil surface of all pots receiving P, but not on those without P (NK and check) in both series. The microflora consisted of green algae (Chloro-

[1] Assuming growth of yellow birch in humus would be near optimum, a height of about 380 mm. in 70 days is possible (Hoyle 1965).

phyta). Two forms, spherical and cylindrical, were prevalent. It was interesting to note that P in this subsoil could also be limiting to the growth of microflora as well as higher plants.

Discussion and Conclusions

This study suggests that a deficiency of P in the Hermon subsoil may limit the root development of yellow birch seedlings. This interpretation offers a plausible explanation of why natural stands of yellow birch growing on this soil generally display only sparse rooting in the deeper horizons. Having obtained a rooting response to P applications under laboratory conditions, we might reasonably expect that subsoil treatment with P in the forest would stimulate root development of yellow birch when other factors are not restrictive. Research in Canada indicates that subsoil moisture and temperature under northern hardwood forest conditions generally are not limiting in well-drained soils (Fraser 1957a and 1957b; Redmond 1957). However, additional pot-culture studies in controlled environments, plus complementary field experiments, are needed to document these preliminary findings, and to achieve greater understanding about response to P and possible secondary responses to other nutrients.

Response to added P in the Hermon subsoil is probably due to: (1) small total amounts of P because of mineralogical composition; (2) presence of P in unavailable forms; and (3) toxic levels of aluminum (Al). Soil analyses by the author indicated that 2.1 to 0.3 milliequivalents/100 g. (A to C horizon) of exchangeable aluminum are present. High levels of available Al can be taken up by plants and precipitate P in the roots. In this acid subsoil (pH 5.2), Al has probably combined with native P to form insoluble aluminum phosphates. Phosphorus for plant use is thus greatly reduced or tied up completely, depending on the severity of conditions in the soil. To some extent, iron (Fe) will also fix phosphorus in this way.

Phosphorus deficiency in acid soils can be alleviated by P fertilization and liming. Addition of phosphate fertilizer reduces the level of exchangeable Al and increases the immediate supply of P. Liming induces release of bound P that occurs naturally in the soil by two processes. First is the hydrolysis of inorganic Fe and Al phosphates; second is an increase in the rate of mineralization of organic P. Liming may also increase availability of some micro-elements.

In our study, both of these practices were effective. Phosphorus supplied to the unlimed soil induced better growth than that of the controls.

However, additional P and liming together yielded further improvement. Since this subsoil contained little or no exchangeable Ca, liming may also have had some effect by supplying Ca in the role of a plant nutrient as well as soil conditioner.

These results are important for two reasons. First, previous studies by other workers have not clearly indicated why yellow birch roots develop poorly or not at all in mineral horizons of forest soils. Inadequate moisture, temperature, or nutrients were thought to be limiting, but no clear demonstration of these limitations was given. Work described in this paper indicates that the problem lies in the realm of soil fertility, and that P is the major limiting nutrient.

Second, it should be pointed out that this subsoil P deficiency and/or Al toxicity is severe and critical. Without some kind of treatment to alleviate the condition, seedling mortality is very high on mineral subsoil. Survivors maintain a marginal existence. The effect of this condition in the subsoil on large established trees in the forest is not known. For young stands in clearcut areas, superficial layers (humus and A horizon) of the forest soil probably satisfy the P requirements of yellow birch; but with increasing size and greater demands, inadequate P nutrition might possibly develop.

At present there are large gaps in our knowledge about the nutritional requirements of yellow birch and the extent to which our forest soils can satisfy these needs. Successful management of yellow birch is contingent upon closing these gaps in our knowledge about forest soil fertility and its effects on tree growth.

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