BIOMASS YIELDS AND NUTRIENT REMOVAL IN SHORT ROTATION BLACK LOCUST PLANTATIONS[1/]

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Abstract.--Black locust (Robinia pseudoacacia L.) plantations, at initial spacings equivalent to 5,000, 10,000 and 20,000 seedlings/ha, were established on sites typical of farmland (FL), abandoned old fields (AOF) and reclaimed surface-mined land (RML) in Indiana, Ohio and Illinois. Each spacing treatment received 50 kg/ha of elemental P and K or no fertilizer and competing vegetation was mechanically controlled. Survival averaged 96% and was unaffected by site or cultural treatments. After two growing seasons, total seedling and annual coppice height (cm) were greatest on the FL site (317 and 255 cm, respectively) followed by the AOF (169 and 172) and RML (189 and 167) sites. Phosphorus and K fertilization significantly increased foliar N and K concentrations and were associated with increased total soil N. Dry matter for seedlings harvested at 2-year intervals and accumulative dry matter for annual harvests was greatest on the FL (13.47 and 6.93 mt/ha, respectively), followed by the RML (6.38 and 4.22) and the AOF (2.93 and 1.85) sites. As initial spacing increased, total dry weight of individuals tended to increase. For a given spacing and harvesting interval, fertilization tended to increase the dry matter produced, especially on the marginally productive sites. Total dry weight of annual coppice or individuals 2-years-old could be adequately predicted (R^2 = 0.63) from regression equations using total soil N, % foliar N and Bray I extractable soil P as independent variables. Nitrogen and phosphorus nutrient drain is inversely related to harvesting frequency but directly related to harvesting intensity, i.e., inclusion of stem and foliage components. Nitrogen losses are negligible but P losses are high especially on marginal sites.

Keywords: P-fertilization, plantation density, site, nitrogen-fixation, nutrient cycling, nutrient release, Robinia pseudoacacia L.

INTRODUCTION

An uninterrupted supply of wood fiber is essential to accommodate a growing forest products industry. Wood is also the largest biomass energy

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resource in the United States and its importance as an alternate or supplemental fuel is dramatized by recent fossil fuel shortages. The Office of Technology Assessment (1980) indicates woody biomass, in addition to its traditional uses, will play a major role in future energy production through gasification or conversion to liquid fuels. In the short run, most of the energy resource needs from biomass are expected to come from residues in conventional harvesting, but an increase in the intensity of forest management, including the establishment of biomass/silage plantations, may be essential to achieve the projected energy yield from wood while maintaining the supply of material to forest industries.

Closely spaced, short rotation and intensively cultured fiber plantations can contribute large quantities of biomass ranging from 7-15T/ha/yr (McAlpine et al. 1966, Wittwer et al. 1978). Factors which influence fiber yields include site (Broadfoot et al. 1971, Wittwer et al. 1978); site preparation (Carter and White 1970); planting stock (Kennedy 1972, Belanger and Saucier 1975); spacing (Belanger and Pepper 1978, Wittwer et al. 1978); cultural treatments, including weed control and fertilization (Blackmon and White 1972); harvesting interval (Belanger and Saucier 1975, Perala 1979); and season (Clark 1975, Belanger 1979). In addition, efforts have been made to determine the productive potential of root stocks (Belanger 1979, Perala 1979) and to assess the impacts of short rotations and intensive harvesting on long-term site productivity (Blackmon 1979, DeBell and Radwan 1979).

In many areas of the country, only the less productive sites are relegated to forestry. In the midwestern United States, most of the lands which are potentially available for the establishment of woody biomass plantations fall into this marginally productive category. If biomass plantations are established in this area, information concerning the productivity of these marginal lands is essential. Black locust (Robinia pseudoacacia L.) was selected for investigation because it is a pioneer species capable of rapid growth over a range of soil and site conditions and responds to cultural treatments. The objectives of this study were to determine the influence of site, cultural practices, including fertilization and spacing density, and harvesting frequency and intensity on dry matter yields and nitrogen dynamics in black locust biomass plantations.

METHODS AND MATERIALS

Site Selection

Three planting sites were identified: (1) farmland, (2) abandoned old field and (3) reclaimed mineland (Table 1). The farmland site occurred in Tippecanoe county, Indiana on a somewhat poorly drained Fincastle silt loam with 1-3% slope and site index (base age 50) of 80 to 95 for yellow poplar (Liriodendron tulipifera L.). The site had been in corn production for approximately ten years, left fallow for two years, then plowed and disced prior to tree planting. The abandoned old field site was on an eroded phase of Zanesville silt loam, 3-5% southwest slope in Dubois county, Indiana; the site index (base age 50) for yellow poplar was 55 to 60. For both sites, all herbaceous and woody plants were mowed to a 5 cm stubble in November in preparation for seedling planting in the spring. The reclaimed mineland site located in Sullivan county, Indiana was on a 10 to 20% slope with a south to southwest aspect. No information is available on site index. The rooting

Table 1.--Site characteristics of the three locations assessed for woody biomass production.

	Farm Land	Abandoned Old Field	Reclaimed Mineland
Soil Type	Fincastle	Zanesville	15-30 cm graded
	(Aeric, Ochraqualfs [Typic] fine-silty, mixed mesic)	(Typic Fragiudalfs, fine silty, mixed mesic)	Cast overburden over unconsolidated material
Distinguishing Characteristic	Somewhat poorly drained	Eroded-Fragipan at 20-30 cm	Excessively drained
Slope (%)	1-3	5-7	10-20
Aspect	-	SW	S-SW
Estimated Site Index[1/]	85-90	55-60	

[1/] Site index at a base age of 50 years for yellow poplar (Liriodendron tulipifera L.)

media consisted of 15 to 20 cm of graded cast overburden, a mixture of soil, loess and Illinoian glacial till, over unconsolidated material. The site was reclaimed in October 1978 and seeded with fescue and various legumes. No additional site preparation was conducted prior to seedling planting in the spring of 1979.

Spacing and Fertilization

One-year-old bareroot black locust seedlings were planted by 15 May 1979 in pure stands at densities equivalent to 5,000, 10,000 and 20,000 plants per ha, representing spacing of 2 x 1, 1 x 1, and 0.5 x 1 m, respectively.

Following site preparation soil samples 0-30 and 30-60 cm in depth on the farmland and old field sites and 0-20 and 20-40 cm on the reclaimed mineland site were collected at 25 random locations and analyzed for chemical properties (Table 2). Similarly, soil samples were collected in September each year from one random location in each of the 36 subplots on each site and analyzed. Available soil P was determined colorimetrically using ammonium molybdate reagent following extraction with Bray I solution, available K, Ca and Mg were determined by atomic absorption following extraction with 1 N ammonium acetate and available NH_4-N and NO_3-N and total N were determined by 2 N KCL extraction and wet digestion, respectively, and distillation. These data were used in regression equations to predict dry matter accumulations for specific spacing and fertilizer treatments for each site.

Table 2.--Chemical analysis of the soils for the farmland (FL), abandoned old field (AOF) and reclaimed mineland (RML) sites prior to fertilization. (All values reported as ppm unless otherwise stated).

	FL		AOF		RML	
	Depth (cm)					
	0-30	30-60	0-30	30-60	0-20	20-40
pH	6.4	5.8	5.6	5.3	7.0	7.7
O.M. (%)	1.2	.4	1.5	0.4	0.1	0.3
NH_4-N	1.8	1.4	2.6	1.5	1.3	1.20
NO_3-N	2.0	3.0	0.8	1.6	0.9	1.21
Total N(%)	0.15	0.08	0.08	0.07	0.07	0.05
P	20	3	2.5	2.5	3.5	2.2
K	125	100	40	46	63	75
Ca	1460	1933	500	546	1680	3400
Mg	340	590	100	257	473	463
S	-	-	-	-	55	125

Hydrated lime at 7.5 x 10^3 kg/ha was applied in January 1979 to the old field plots. Fertilizer treatments, applied in May 1979, consisted of no fertilizer or a broadcast application of P and K at rates equivalent to 50 kg/ha of elemental material. Phosphorus was applied as super phosphate and potassium as potash. Competing herbaceous and woody vegetation was controlled by cultivation between the rows in mid-June of both growing seasons followed by mowing in early July and August.

Experimental Design

At each location, two fertilizer treatments were randomized over three blocks forming six main plots. Three spacings were randomly assigned to subplots within each main plot. Each subplot was 12 x 12 meters. All trees in the center of 32 m^2 of each subplot (net plots) were measured. This arrangement provides for a minimum of 27 measurement trees for the 2 x 1 m spacing, 45 trees for the 1 x 1 m spacing and 81 trees for the 0.5 x 1 m spacing. The study was arranged in a randomized complete block design and analyses based on unequal sample size.

Data Acquisition and Analysis

Stem height, diameter at 10 cm height and survival were determined annually in September for all net plot trees. To determine the influence of harvesting frequency on biomass production and nutrient drain, six interior border row stems, selected at random, were harvested in September after each growing season and six on a two growing season interval. Physical measurements included height and diameter at a 10 cm height of the tallest sprout or main stem and green and oven dry weight of the foliage, stem and

branches. Chemical measurements included N, P and K concentrations of the foliage, and stem and branch components. Nitrogen was determined by semi-micro-kjeldahl technique, phosphorus by ammonium-molybdate-vanadate indicator and potassium by atomic absorption. Biomass and N, P and K concentration of the weed component was determined by sampling a 0.5 x 0.5 m square located at random within each of the harvested six tree rows.

Data were tested by analysis of variance (ANOVA) and those variables found significant were subjected to Duncan's new multiple range test. Weights of total and component biomass of the net plot trees were estimated from data collected from the harvested trees using the linear regression model

$$\log \gamma = a + b \log x$$

where: a, b = constants
$x = d^2h$
d = stem diameter at 10 cm height
h = stem height

RESULTS AND DISCUSSION

Survival, Height and Diameter Growth

Seedling survival two growing seasons after planting was not significantly influenced by site but did range from 93% on the abandoned old field site (AOF) to 99% on the farmland (FL) (Table 3). Site did significantly affect first and second growing season height and diameter growth. In each case maximum growth was attained on the FL site followed by the RML and the AOF sites. First year coppice growth followed a slightly different pattern but again the FL site produced the greatest height growth with no difference in height growth attained on the AOF or the RML sites. No measurements are given for first year coppice diameter because, for the multi-stem characteristic of coppice growth average values have little meaning.

Plant Nutrient Concentration

The percentage of elemental nitrogen, phosphorus and potassium in the foliage and stem of black locust seedlings was significantly influenced by fertilization and site (Figure 1). No significant differences in nutrient element concentrations were evident between comparable tissue of the coppice and the two-year-old trees for the treatment combinations tested, therefore, data were combined for statistical analysis. The nutrient concentrations were greater in the foliage than the stem regardless of the fertilizer treatment, element investigated or site condition. Fertilization with P and K increased the foliar N concentration by 13, 12 and 25% and the stem N concentration by 26, -22 and -9% for the FL, AOF and RML sites, respectively. Except for foliar P concentrations on the RML site, plant P concentrations were not influenced by P fertilization. This lack of response may reflect the P-fixing capacity of the soils investigated or the relatively high amount of available P on the FL site prior to P fertilization. In response to P and K fertilization the foliar K concentration increased by 37, 27 and 57% while the K concentration in the stem increased by 36, 29 and 33% on the FL, AOF and RML sites, respectively.

Table 3.--Influence of site on survival, height and diameter growth of annual coppice and seedlings harvested after two growing seasons. Values are means averaged over all spacing and fertilizer treatments.

Variable	Farmland	Abandoned Old Field	Reclaimed Mineland
Survival (%)	99	93	97
Height (cm)			
1st year	139a[1/]	57c	97b
1st year coppice	255a	172b	167b
2nd year	317a	169b	189b
Diameter (mm)			
1st year	17.3a	7.1c	12.2b
1st year coppice[2/]	-	-	-
2nd year	25.0a	12.7b	26.8a

[1/] Row values not followed by the same letter are significantly different (Duncan's new multiple range test, $\alpha = 0.05$).

[2/] No measurement taken because of multi-stem characteristic of coppice growth.

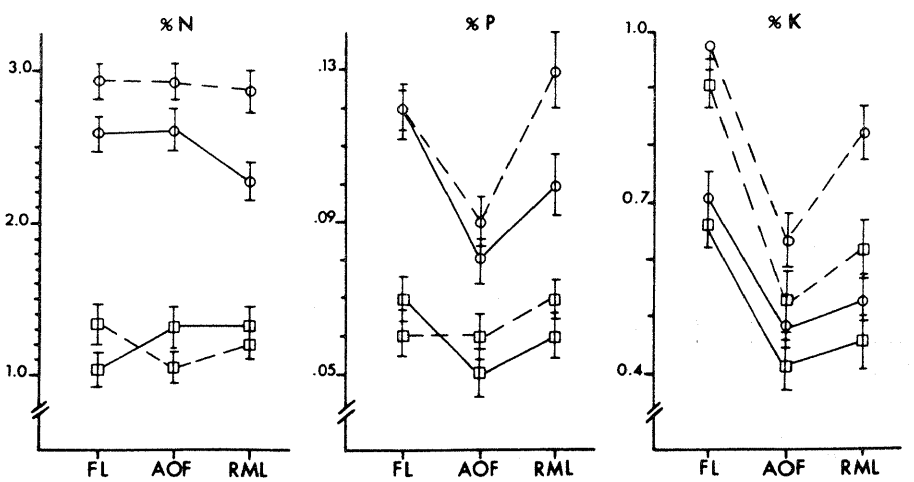


Figure 1.--Effect of fertilization and site on the concentration (percent) of elemental N, P and K in the foliage (O) and stem (□) of black locust (farmland, FL; abandoned old field, AOF; and reclaimed mineland, RML). Fertilized with 50 Kg/ha of elemental P and K (---) or Control (—). Confidence intervals represent 2 standard deviations from the mean ($\alpha = 0.05$).

After fertilization the Bray I extractable soil P in the surface horizon of the RML and AOF sites was low (<10.0 ppm). For the RML site, this may be attributed to the formation of insoluble Ca- phosphates, given the large amounts of extractable Ca and a soil reaction (pH 7.0-7.7) which is favorable to the formation of these insoluble compounds. The soil on the AOF site is an eroded phase of a Zanesville soil. The B horizon, predominated by 2:1 clays, is within 5-9 cm of the surface. It is likely these alumino-silicate clays as well as some of the Ca from the winter liming reacted with the readily soluble forms of fertilizer P rendering them insoluble.

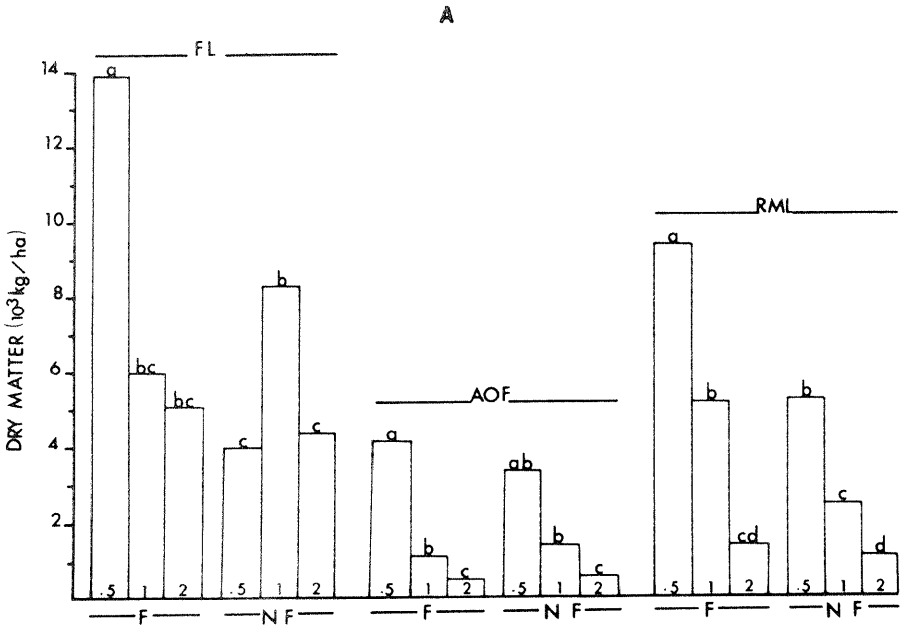
Phosphorus fertilization of some nitrogen fixing plants enhances the nitrogen fixation process resulting in elevated concentrations of foliar nitrogen (Demeterio et al. 1972). While applications of P fertilizer may not have altered the P concentration of black locust, it appears to have significantly increased the foliar N concentrations, presumably, by stimulating the nitrogen-fixing bacteria. In field observations of the present study, excavated roots of P-K fertilized black locust, on the average, had 3X the number of nodules of unfertilized trees. The nodules of fertilized trees were, on an average, larger (0.65 vs 0.31 cm) and distributed more uniformly along the lateral roots growing in the upper soil profile.

Dry Matter Production

Site significantly influenced the dry matter produced by black locust seedlings harvested annually and after two growing seasons. Averaged over all fertilization and spacing treatments, dry matter production was greatest for FL, followed by the RML and AOF sites. For each site, the dry matter attained in the two growing season rotation interval was significantly greater than the dry matter accumulated by annual harvests. Averaged for all fertilizer and spacing treatments, total dry matter produced (mt/ha) after two growing seasons and annual harvests, respectively, was 13.47 and 6.93 for FL, 2.93 and 1.85 for AOF and 6.38 and 4.22 for RML.

The interaction of site, spacing and fertilization had a profound effect on dry matter production (Figure 2a & b). Except for the no fertilizer treatment on the FL site, the two-year accumulation of dry matter for seedlings harvested annually increased as initial spacing decreased from 2 x 1 to 0.5 x 1 m (Figure 2a). Except for the fertilized RML, spacing had a similar effect on the dry matter attained by the seedlings harvested at a two-year interval (Figure 2b). Fertilization of annually harvested stems often resulted in significant increases in dry matter yields for a particular site and spacing treatment. The annual growth for this cutting regime may be highly dependent on the availability of soil nutrients, principally phosphorus. Similar results were reported for one-year growth of hybrid poplar following harvest cutting (Zavitkovski et al. 1979). Response in dry matter production to fertilization was not as dramatic for the locust harvested on a two-year rotation. The lack of response on the FL may be attributed to the inherently high levels of available nutrients in the soil prior to fertilization and/or higher levels of available soil moisture throughout the growing season.

Dry matter production per ha is a function of individual seedling size (dry weight) and number of seedlings per unit area. For a particular fertilizer treatment, the dry weight of individual seedlings or coppice per



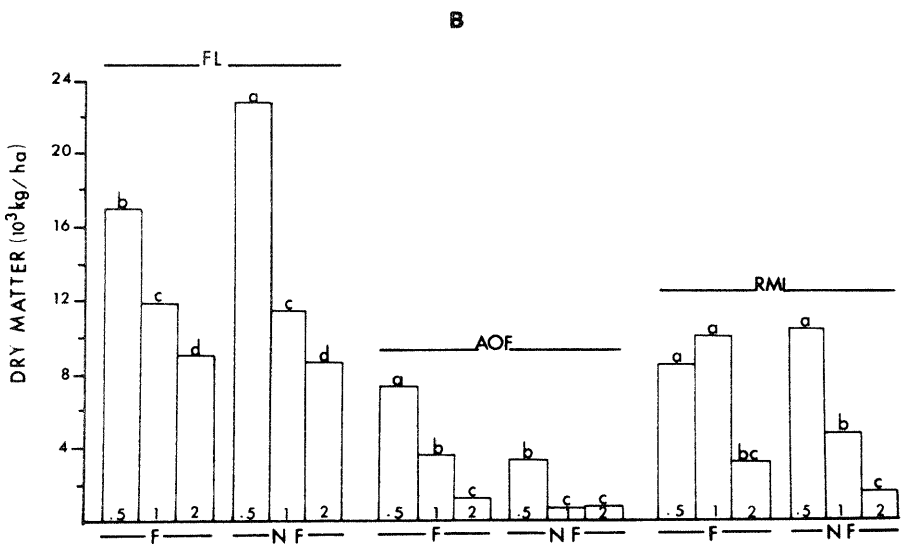


Figure 2a & b.--Influence of site, spacing, fertilization and harvest interval on the dry matter production of black locust (Robinia pseudoacacia L.). For a specific site, values not followed by the same letter are significantly different (Duncan's new multiple range test, $\alpha = 0.05$). Figure 2a and b represent dry matter production for annual coppice and 2-year harvest intervals, respectively. Sites are farmland (FL), abandoned old field (AOF), and reclaimed mineland (RML). Spacings include .5(0.5 x 1 m), 1(1 x 1 m) and 2(2 x 1 m). Fertilization is represented as F(50 kg/ha of P and K) or NF (control).

stump tended to increase with increasing spacing on the FL site (range, 850 to 1850 g/seedling and 400 to 1,000 g/stump, respectively), but decreased with increasing spacing on the AOF (range, 450 to 125 g/seedling and 250 to 100 g/stump) and RML (range, 1,500 to 375 g/seedling and 550 to 265 g/stump) sites. The decline in dry weights with wider spacings may have resulted from an increase in herbaceous weed competition within the planted row. For all spacings and sites, fertilization tended to increase seedling and coppice dry matter production.

Distribution of Dry Matter and Nutrients

Spacing, site and fertilization had no significant effect on the distribution of dry matter or elemental N and P to the stem and foliage of black locust. Seedlings harvested after two growing seasons tended to have a lower percentage of the total biomass as foliage 26% vs 33% for annually harvested coppice. The distribution of plant N and P was significantly ($\alpha = 0.05$) influenced by harvesting interval. Foliage accounted for 51 and 46% of the total N and P in the aboveground biomass of black locust harvested annually and 44 and 35% for locust harvested after two growing seasons. These differences in elemental distribution may be explained by the higher N and P concentrations in the foliage of annually harvested locust combined with the relatively larger foliage component.

Nutrient Removal

Harvesting frequency and intensity may influence long-term site productivity. The shorter the rotation and the more completely the biomass is harvested, the more severe the drain of certain nutrients from the site (Blackmon 1979). Nitrogen and phosphorus were the chemical elements identified in multiple regression equations which were significant in predicting the dry weight of seedlings and coppice [Total dry weight (g) = $b_0 + b_1$ (Tot. Soil N) + b_2 (% Foliar N) + b_3 (Bray I extr. Soil P); $R^2 = 0.63$] and may be the elements essential to maintaining site productivity. The influence of spacing and fertilization on the percentage of nitrogen and phosphorus removed from the soil-plant system of the three sites studied for two harvesting intensities is shown in Table 4a and 4b. The soil-plant system is defined as the soil to a depth of 45 cm and the aboveground biomass of the crop trees and any other vegetation. Nutrient drain is the difference in the amount and availability of a particular nutrient element in the soil-plant system, and the amount removed from the site in harvesting. Including the foliage component in the dry matter removed in harvest nearly doubles the elemental N and P removed. The percentage of N removed is low even for the closest spacing (0.5 x 1 m) and the most productive site (FL). As site quality, measured in terms of biomass production, declined or initial spacing increased the percentage of N removed in harvested biomass declined for material harvested either annually or after two years. For a given site, spacing and fertilizer treatment, the percentage of N removed from the soil-plant-system was greater for seedlings harvested at two-year rotations primarily because more biomass was removed in this frequency of harvesting.

The low percentage of N removed from the various sites is a function of the nitrogen-fixing capabilities of black locust. Monson (1978) suggested that if N could be partitioned by plant component the entire N content of the aboveground portion of nitrogen-fixing plants could be supplied by the

Table 4a & b.--Influence of harvesting intensity and rotation length in black locust stands on the percentage of nitrogen (A) and phosphorus (B) from the soil plant system for selected spacing (0.5 x 1 and 2 x 1 m) and fertilizer treatments (F = fertilized, NF not fertilized). Sites represent farmland (FL), abandoned old field (AOF) and reclaimed mineland (RML) sites. Nitrogen is total plant and soil nitrogen and phosphorus is for the total plant and Bray I extractable soil P.

A. Percent Nitrogen Removed from the Soil-Plant System

	FL				AOF				RML			
	0.5 x 1		2 x 1		0.5 x 1		2 x 1		0.5 x 1		2 x 1	
	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
Annual Harvest												
a. stem	3	1	1	1	1	1	0.2	0.2	3	4	1	1
b. stem plus foliage	7	2	3	2	2	2	0.3	0.4	5	6	2	2
2-Year Harvest												
a. stem	4	5	2	2	2	1	0.4	0.3	3	2	1	.3
b. stem plus foliage	8	9	4	3	4	2	1	1	6	3	2	1

B. Percent Phosphorus Removed from the Soil Plant System

	FL				AOF				RML			
	0.5 x 1		2 x 1		0.5 x 1		2 x 1		0.5 x 1		2 x 1	
	F	NF	F	NF	F	NF	F	NF	F	NF	F	NF
Annual Harvest												
a. stem	6	2	2	2	9	13	2	3	21	18	4	4
b. stem plus foliage	12	5	4	5	15	22	3	5	36	30	7	6
2-Year Harvest												
a. stem	9	13	4	5	17	14	3	3	19	47	8	6
b. stem plus foliage	15	22	6	7	26	23	4	5	31	67	12	10

symbiotic relationship. Auten (1945) indicated that well stocked black locust stands added 70 kg - N per ha to the soil annually. Average total soil N content (kg/ha) of the pre-planted and pre-fertilized sites was 3560 for the FL, 2848 for the AOF and 2492 for the RML. Two years after planting, the total N content for stands fertilized or not fertilized was 3740 and 3650 for the FL, 2985 and 2915 for the AOF, and 2575 and 2545 for the RML. These increases in total N in the soil component are attributed in part to the beneficial effects of the N-fixing locust and the apparent stimulation of N fixation resulting from the P-K fertilizer treatment.

The percentage of P removed from the site through stem harvest is relatively large compared to what is available in the soil-plant-system. This percentage becomes more important if the foliage is included in the biomass removed. Except for the 2 x 1 m spacing on the AOF site not receiving fertilizer, the percentage of P removed for a specific site, spacing and fertilizer treatment in the two-year harvest interval is greater than the accumulated P removed in annual harvests. The P nutrient drain is especially evident for the 0.5 x 1 m spacing. For total aboveground biomass, the percentage of P removed in annual harvests account for 12, 15 and 36% of the total Bray I extractable P present in the soil-plant-system for fertilized plots on the FL, AOF and RML sites, respectively. Similarly, plots receiving no fertilizer experienced P losses of 5, 22 and 30%. Data for P nutrient drain from plots planted with locust at 0.5 x 1 m spacing and harvested at two-year intervals were similar to the data presented for stems harvested annually.

For most soils and presumably for the ones studied here the available P fraction makes up a small component of the total soil P. While significant quantities of P become available each year, the concern is raised regarding the balance between the amount removed in harvest and the amount made available by natural processes.

SUMMARY

Biomass yields of black locust can be significantly influenced by site selection, cultural practices, including initial spacing and fertilization, rotation length (frequency of harvesting), and harvesting intensity. For any of the practices and/or sites, the total dry weight attained is, in part, a function of total soil nitrogen and extractable soil phosphorus. To maintain site productivity for N-fixing plants, adequate levels of available soil P may be essential. Biomass plantations of N-fixing species established on marginal sites may require frequent P fertilizer applications if harvest intervals are short and the soil has a high P-fixing potential. Careful investigation of the economics of short rotation biomass plantations is essential before practices can be recommended for large scale plantings.

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