BIOMASS AND NUTRIENT ACCUMULATION IN YOUNG BLACK LOCUST STANDS ESTABLISHED BY DIRECT SEEDING ON SURFACE MINES IN EASTERN KENTUCKY

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Abstract.--Average dry weight yields of aboveground biomass ranged from 4.7 mt/ha for 2-year-old stands to 62.1 mt/ha for 13-year-old black locust stands established by direct-seeding on surface-mined land in eastern Kentucky. Foliage represented 38 percent of total weight in 2-year-old stands and 11 percent in 13-year-old stands. Average annual growth increased with stand age. Stand density decreased from more than 28,000 stems/ha in 2-year-old stands to 2,000 stems/ha in 13-year-old stands.

Biomass nutrient content followed the order of N > K > Ca > Mg = P > Mn for young stands but Ca content exceeded K in age 9 years or older. The percentage of the nutrients contained in the foliage decreased with tree age; in 2-year-old stands, 60 percent of the nutrients were contained in the foliage while 28 percent were contained in the foliage of 13-year-old trees.

Total N and exchangeable P in the soils were low compared to agricultural soils. Nitrogen content of the soils increased with stand age. Levels of exchangeable K, Ca, Mg, and Mn were intermediate as compared to agricultural soils. Soil pH ranged from extremely acid to moderately alkaline while texture ranged from clay to sandy loam.

Additional keywords: Biomass production, nutrient cycling, *Robinia pseudoacacia* L.

Studies have demonstrated that forest biomass production can be increased by nitrogen (N) fertilization. Large expenditures of fossil fuels required to manufacture and transport N fertilizers have reduced their cost effectiveness and stimulated new interest in N-fixing species such as black locust (*Robinia pseudoacacia* L.). Increases in N occurring from black locust have seldom been

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assessed quantitatively. Surface mines offer sites to study the effects of N-fixing species because new spoil materials are generally low in N. Nutrient accumulation and removal through harvesting are important factors which need to be quantified for short rotation tree crops.

Our goal is to determine the feasibility of growing black locust in short rotations on reclaimed surface mine sites for use as a supplemental fuel source. Interest in the use of wood for fuel for both heating purposes and the generation of electrical power has increased greatly in recent years. This interest has led to the concept of fuelwood plantations which involves the production of fast growing tree species at close spacings specifically for use as a fuel source in the form of wood chips (Naughton and Geyer 1978).

The specific objectives of this study were to assess the biomass and nutrient accumulation in black locust stands grown on surface mine sites and to determine the effects of harvesting this material on the nutrient status of the site. Consideration of the effects of removing short rotation biomass on fragile, N-deficient sites as surface mines and the possibility of reducing inorganic fertilizer application by using N-fixing species are also major concerns.

STUDY AREA

The study area encompassed a large portion of eastern Kentucky. Study plots were established on surface-mined land in Floyd, Martin, Johnson, Breathitt, and Bell Counties, Kentucky. Both mountaintop removal and bench-strip methods of mining have been used in this region of the Southern Appalachian Mountains. Generally the spoil materials are a heterogeneous mixture derived from Pennsylvanian-age sandstones and shales.

Soil materials encountered ranged from being extremely acid (pH 3.7) to moderatly alkaline (pH 8.3). Textures ranged from sandy loam to clay. In the soil material, both rock content and size varied greatly between sites. Slopes were well-drained while flat areas were poorly drained to moderately well-drained.

METHODS

Experimental Design and Biomass Sampling

During the summer of 1978, we sampled established stands of black locust on surface-mined sites in eastern Kentucky. The stands were established by direct-seeding black locust with a hydroseeder at a rate of 4 to 6 kg/ha and most stands received 225 to 450 kg/ha of fertilizer (16-32-8 or 18-46-0). Seventy-two stands were sampled, ranging in age from 2 to 13 years. At each sample site a plot center was randomly chosen and all stems were counted within a $100m^2$ (radius = 5.64m) circular plot. Using the same plot center, all ground line diameters were measured with calipers within a $50m^2$ (radius = 3.99m) circular plot. Similarly, a $10m^2$ (radius = 1.78m) circular plot was established and all trees within this plot were harvested. Basal diameter, height, and age were determined for each tree and each tree was separated into foliage and current year's growth (new growth), while branches and bole were combined.

The branch and bole samples were divided into 2.5cm-diameter classes. Each tree component was weighed in the field and subsamples were taken from each component for dry weight determination and laboratory analyses. Biomass yields (mt/ha) were computed from the biomass harvested from each $10m^2$ circular plot.

Two soil pits were dug at each site, one on each side of plot center at a distance of 4m. Soil samples were collected from four depths: 0-15cm, 15-30cm, 30-45cm, and 45-60cm. Bulk density of the surface horizon was obtained using a penetrometer. Bulk soil samples were taken to determine rock content and size.

Laboratory Analyses

In the laboratory, biomass subsamples were oven-dried at 60°C, weighed, and total biomass yields per hectare were calculated. A portion of the bole-wood subsamples were stripped of bark and bark percentages calculated for each diameter class. All biomass subsamples were ground in a Wiley mill and passed through a 2mm sieve. Biomass samples were digested for 24 hours using a nitric-perchloric acid solution (10:1 ratio) in covered flasks on a steam hot plate. The cover glasses were removed and the liquid contents were evaporated on a gas hot plate. The residue was dissolved in 10ml of 1N HCl. Aliquots of these solutions were analyzed for Ca, Mg, K, and Mn by atomic absorption spectroscopy and P colorimetrically with a Technicon Auto Analyzer. All samples were analyzed for total N by the macro-Kjeldahl process modified to include nitrates (Cope 1916).

Soil samples were air-dried, ground, and passed through a 2mm sieve. The pH of each sample was determined on a 1:1 soil to water paste with a Beckman pH meter. Texture was determined using the pipette method as outlined by the USDA Soil Conservation Service (1967). Total N was determined by the macro-Kjeldahl process. P was analyzed using the Bray I extraction method. K, Ca, Mg, and Mn were extracted with 1N NH_4OAc adjusted to pH 7. Aliquots of these solutions were analyzed for K, Mg, and Mn by atomic absorption spectroscopy and for Ca by a flame photometer.

RESULTS AND DISCUSSION

Biomass Yields

Biomass production ranged from an average of 4.7 mt/ha for 2-year-old stands to 62.1 mt/ha for 13-year-old stands (Table 1). Young stands were very dense averaging 28,700 stems/ha for 2-year-old stands. At age 13, density had decreased to an average of 2,000 stems/ha. Average annual growth increased with stand age, ranging from 1.7 mt/ha in 3-year-old stands to 4.8 mt/ha at age 13. Branch and bole percentage increased with age. Two-year-old stands averaged 62 percent woody biomass compared with 89 percent in 13-year-old stands.

Average dry weight yields for each stand age and tree component are presented in Table 2. Foliage in 2-year-old stands averaged 1,729 kg/ha and increased to 6,839 kg/ha for 13-year-old stands. However, the weight of new growth remained relatively constant for all stand ages. Only stands above age 9 produced diameter classes greater than 10cm (Carpenter and Eigel 1979).

Table 1.--Growth and stand density characteristics by age class for 72 black locust stands established by direct-seeding on surface mines in eastern Kentucky.

Stand age (yrs)	No. of sites sampled	Average dry wt. yields (mt/ha)	Average density (stems/ha)	Avg. annual[a/] growth (mt/ha/yr)	Branch and bole (%)
2	7	4.7 (1.7)[b/]	28700 (9625)	2.4 (0.84)	62 (5.2)
3	2	5.1 (1.5)	10050 (7000)	1.7 (0.50)	68 (0.3)
4	12	8.1 (3.7)	14783 (8532)	2.0 (0.93)	76 (7.4)
5	14	12.7 (6.0)	12800 (9142)	2.5 (1.20)	77 (7.9)
6	17	17.8 (6.2)	8800 (5459)	3.0 (1.04)	81 (4.3)
7	5	24.5 (9.4)	5320 (3576)	3.5 (1.35)	87 (2.7)
8	4	24.2 (7.4)	3250 (1330)	3.0 (0.92)	84 (1.1)
9	8	39.1 (11.3)	3913 (1016)	4.3 (1.25)	87 (2.2)
10	1	41.5	2900	4.2	84
13	2	62.1 (6.1)	2000 (707)	4.8 (0.47)	89 (0.6)
Total	72				

[a/] Average annual growth was calculated by dividing average biomass yield by stand ages.

[b/] Standard deviations are in parentheses.

Table 2.--Average dry weight yields of black locust by stand age and tree component on surface mines in eastern Kentucky.

Tree Component	Age									
	2	3	4	5	6	7	8	9	10	13
	kg/ha									
Foliage	1729	1650	1852	2644	3213	3264	3865	4827	6603	6839
New Growth	1123	1043	1072	914	1041	1021	1155	1274	3175	1333
Wood										
0- 2.5cm	1663	1743	3373	4565	5673	6077	5532	8504	5431	9685
2.5- 5.0cm	20	270	1056	2890	4325	6904	5744	8101	5676	6821
5.0- 7.5cm	-	-	30	197	1150	3481	4231	6654	3787	15816
7.5-10.0cm	-	-	-	-	131	330	309	3867	8366	10468
10.0-12.5cm	-	-	-	-	-	-	-	318	3419	2180
Bark										
0- 2.5cm	188	322	579	920	1259	1427	1335	2112	1331	2429
2.5- 5.0cm	3	43	179	514	776	1324	1265	1567	1347	1301
5.0- 7.5cm	-	-	6	33	199	619	702	1247	663	3009
7.5-10.0cm	-	-	-	-	22	55	63	624	1173	1893
10.0-12.5cm	-	-	-	-	-	-	-	50	534	364
Total (kg/ha)	4726	5071	8147	12677	17789	24502	24201	39145	41505	62138

Vail (1978) reported yields of 29 to 36 mt/ha for 10-year-old black locust trees growing on surface mine spoil in eastern Kentucky. These trees averaged 11,11, 23, and 55 percent foliage, bark, branches and bolewood, respectively.

Biomass Nutrient Content

Nutrient content for all tree components increased with stand age, primarily due to the increase in biomass. Some of the nutrient differences may be due to time of harvest since harvesting was done throughout the growing season. Total nutrient content followed the order of N > K > Ca > Mg = P > Mn in all stands less than 9 years of age. In older trees, total Ca content was found in greater amounts than K, probably because wood and bark components increased. Ca is a constituent of plant cell walls and is somewhat immobilized in older tissue (Kramer and Kozlowski 1979). Vail (1978) found the nutrient content of 10-year-old black locust grown on surface mines to be highest in N, followed in decreasing order by Ca, K, Mg, and P.

Nutrient contents are presented for stands at age 2, 6, and 13 (Table 3) to represent accumulation trends for young, intermediate, and older stands. Average aboveground biomass accumulation rates increased by a factor of 4 from age 2 to 6 and by 3 between 6 to 13 (Table 2). Nutrient accumulation increased at a lesser rate (Table 3), except for Mn and Ca. Accumulation of Mn increased 7 times from age 2 to age 6. However, accumulation rates from age 2 to 6 for N, P, K, Ca, and Mg were only about 3 times greater. From age 6 to 13, accumulation rates for N, P, K, and Mg were about 2 times greater. Mn content decreased from age 6 to 13. Ca content was 4 times greater at age 13 than age 6, which surpassed the dry weight accumulation rate.

In 2-year-old stands (Table 3), the elemental content of N, P, K, Ca, Mg, and Mn was greatest in the foliage, followed in decreasing order by new growth, 0-2.5cm wood, 0-2.5cm bark, 2.5-5.0cm wood, and 2.5-5.0cm bark. The percentage of nutrients in the total aboveground biomass contained in the foliage was 62 percent of the N, 57 percent of the P, 59 percent of the K, 60 percent of the Ca, 72 percent of the Mg, and 77 percent of the Mn. The remainder was contained in the wood, bark, and new growth.

The distribution of N, P, K, Ca, Mg, and Mn in 6-year-old stands was similar to the trend found in 2-year-old stands, except that higher nutrient levels were found in the wood and bark components of the 0-2.5cm and the 2.5 to 5.0cm diameter classes than was found in the new growth component. All elements were present in greater amounts in the foliage except for Mn, where the highest levels were contained in the 2.5-5.0cm diameter bark class. Foliage contained 45 percent of the N, 39 percent of the P, 45 percent of the K, 33 percent of the Ca, 48 percent of the Mg, and 22 percent of the Mn contained in the total aboveground tree parts. The remainder was contained in the woody components.

In stands at age 13, N, P, K, and Mg were found at higher levels in the foliage, however, Ca content was greatest in the 5.0-7.5cm diameter wood component and Mn content was greatest in the 2.5-5.0cm diameter bark component. Nutrient content of the wood and bark components from the 0-2.5cm diameter class through the 5.0-7.5cm diameter class were higher than the content of the

Table 3.--Average nutrient content of black locust biomass in kg/ha for age 2-, 6-, and 13-year-old stands on surface mines in eastern Kentucky.

	kg/ha					
Age 2 (N=7)[a]	N	P	K	Ca	Mg	Mn
Foliage	62.8	2.9	29.2	19.2	5.9	0.20
New Growth	17.9	1.7	11.9	7.0	1.4	0.03
Wood						
0- 2.5cm	16.9	0.4	6.5	3.0	0.7	0.02
2.5- 5.0cm	0.1	<0.1	<0.1	<0.1	<0.1	<0.01
Bark						
0- 2.5cm	3.6	0.1	2.1	2.7	0.2	0.01
2.5- 5.0cm	<0.1	<0.1	<0.1	<0.1	<0.1	<0.01
Total	101.3	5.1	49.7	31.9	8.2	0.26
Age 6 (N=17)	N	P	K	Ca	Mg	Mn
Foliage	118.1	6.3	57.6	35.2	9.2	0.43
New Growth	15.4	1.8	11.1	8.2	1.4	0.04
Wood						
0- 2.5cm	39.8	2.8	21.6	15.8	2.8	0.15
2.5- 5.0cm	33.5	2.9	15.1	12.6	2.0	0.87
5.0- 7.5cm	10.2	0.6	3.5	3.4	0.6	0.19
7.5-10.0cm	1.1	<0.1	1.3	0.2	0.1	<0.01
Bark						
0- 2.5cm	24.7	0.9	9.6	17.5	1.3	0.15
2.5- 5.0cm	15.6	0.7	7.2	9.7	0.8	0.06
5.0- 7.5cm	4.4	0.1	1.6	2.6	0.2	0.02
7.5-10.0cm	0.5	<0.1	0.1	0.2	<0.1	<0.01
Total	263.3	16.1	128.7	105.4	18.3	1.9
Age 13 (N=2)	N	P	K	Ca	Mg	Mn
Foliage	201.5	9.5	101.9	64.7	15.2	0.29
New Growth	18.2	2.0	12.4	13.0	1.8	0.02
Wood						
0- 2.5cm	54.5	4.1	31.2	50.3	6.2	0.08
2.5- 5.0cm	44.3	1.5	16.9	43.7	2.0	0.06
5.0- 7.5cm	93.1	5.5	30.1	66.2	6.3	0.09
7.5-10.0cm	56.6	1.3	9.1	26.5	2.4	0.05
10.0-12.5cm	9.7	0.5	0.8	4.4	0.3	<0.01
Bark						
0- 2.5cm	45.7	0.6	14.8	33.7	1.9	0.05
2.5- 5.0cm	25.1	0.6	7.4	23.2	0.8	0.41
5.0- 7.5cm	60.5	1.3	13.1	62.2	2.0	0.10
7.5-10.0cm	42.6	0.6	7.0	45.7	1.2	0.06
10.0-12.5cm	9.3	<0.1	0.7	7.5	0.2	0.02
Total	661.1	27.5	245.4	441.1	40.3	1.23

[a] Numbers of sites sampled are in parentheses. On each site, three trees were chosen randomly to be analyzed for elemental contents.

new growth component. This corresponds with the large increases in biomass of the wood and bark components at older ages as shown in Table 2. Foliage contained 30 percent of the N, 34 percent of the P, 41 percent of the K, 15 percent of the Ca, 38 percent of the Mg, and 23 percent of the Mn contained in the aboveground tree components with the remainder contained in the woody components.

For 2-, 6-, and 13-year-old stands, N accumulation in the aboveground biomass was 101, 263, and 661 kg/ha, respectively. In comparison, Switzer et al. (1976) found 330 kg/ha of N in the aboveground biomass (119.3 mt/ha) of unthinned, natural stands of 12-year-old eastern cottonwood (Populus deltoides Bartr.) on productive sites in the southeastern United States. This content is approximately one-half the N content accumulated in aboveground biomass of 13-year-old black locust (62.1 mt/ha) grown on surface-mined sites in eastern Kentucky which are generally low in soil N. Vail (1978) also found higher N content in 10-year-old black locust stands than in eastern cottonwood and Virginia pine (Pinus virginiana Mill.) at age 10 on surface mines in eastern Kentucky. Nitrogen content for total aboveground biomass averaged 600 kg/ha for black locust compared with only 345 and 265 kg/ha for cottonwood and Virginia pine, respectively. This indicates the beneficial effects of growing N-fixing species such as black locust on N-deficient sites such as mine spoil.

Based on biomass and nutrient distribution at the time of sampling (May through August) for the 6-year-old stands, harvesting only the woody material would remove 82 percent of the aboveground biomass and about 58 percent of the accumulated nutrients. Harvesting of the 13-year-old stands in the same fashion would have resulted in removal of approximately 89 percent of the aboveground biomass and 72 percent of the accumulated nutrients in the stands. It is important to note that the nutrient percentages would probably change somewhat if these sample trees had been harvested during a dormant period. These differences in nutrient content would be due to such factors as translocation of nutrients, and seasonal variations in nutrient concentrations (Baker and Blackmon 1977).

It is apparent that these young, dense stands of black locust rapidly accumulate large quantities of nutrients, especially N. A large proportion, from 15 to 77 percent, depending on the element, is in the foliage. Nutrient removal from the site can be substantially reduced by harvesting after leaf-fall, thus not removing the foliage from the site. This would be especially beneficial with respect to N, a nutrient that is often limiting for tree growth.

Soil Nutrient Content

Chemical and physical properties of the soil material replaced on an area after surface mining vary considerably between sites in the eastern Kentucky coalfields. Rock formations surrounding coal seams consist of alternating layers of shales and sandstones. The sandstones are generally acid while the shales may be calcareous with near neutral pH. Soils resulting from mining in the region may be predominantly sandstone, shale, or a mixture of both materials.

Generally, the 2-year-old stands sampled were on recently reclaimed areas. These sites were lowest in total N, ranging from 2910 kg/ha in the top 15cm to

1965 kg/ha at the 45-60cm depth (Table 4). Total N tended to increase under the older stands, especially between 30 and 60cm. The surface 0-15cm, layer showed a difference of about 300 kg/ha of total N between the 2-year-old and the 13-year-old stand. This difference may be attributed largely to recycling by foliage although atmospheric inputs may have made some contribution.

Table 4.--Average soil nutrient contents and pH range of four sampling depths for age 2-, 6-, and 13-year-old stands growing on surface mines in eastern Kentucky.

	kg/ha						
		Exchangeable					(Range)
Age 2 Depth (cm)	Total N	P	K	Ca	Mg	Mn	pH
0-15	2910	41.8	173.2	1598.3	778.7	26.0	4.3-8.2
15-30	2113	11.2	170.7	1531.1	828.6	19.3	4.5-8.2
30-45	2175	9.4	190.8	1608.0	853.8	14.4	4.4-8.3
45-60	1965	9.4	182.2	1451.2	821.8	12.3	5.1-8.2
Age 6							
0-15	3039	22.2	172.0	1192.5	671.4	38.5	3.9-7.6
15-30	2439	9.5	150.4	1025.1	772.9	28.0	3.9-7.6
30-45	2537	9.0	147.3	1088.4	798.1	23.7	3.7-7.8
45-60	2614	8.7	154.7	1114.1	875.3	28.8	3.8-8.0
Age 13							
0-15	3324	9.0	161.3	2273.6	754.3	28.1	6.2-6.5
15-30	2101	6.2	127.7	2492.0	697.8	11.6	5.8-7.0
30-45	5595	5.6	137.8	2536.8	784.6	8.2	5.8-7.4
45-60	5601	7.3	135.0	2581.6	776.2	8.5	6.0-7.5

The greatest increases in soil N were found between 30 and 60cm, where contents under the 13-year-old stands were more than double that found for the 2-year-old stands. Vail (1978) compared soil nutrients under 10-year-old plantations of three tree species and found significantly more N at the 10-30cm depth under black locust than under eastern cottonwood or Virginia pine. Another study in New York (Ike and Stone 1958) found a significant N increase under 16 to 20-year-old black locust stands, with the increase occurring between 18 and 50cm.

Levels of P tended to decrease with stand age and also sample depth. These trends may result from the addition of P fertilizers when the stands were established. Levels of K and Mg tended to decline slightly with increasing stand age. Calcium was considerably higher under the older stands and the soils tended to be less acid. The sample sites for the 2 and 6-year-old stands represented a broader range of soil conditions with pH values between 4.0 and 8.0. Thus, soil conditions were probably the major factor contributing to differences in Ca levels. The Mn levels did not appear to be related to stand age. The lower values under the older stand may also reflect the less acid spoil materials

under these stands, since solubility of this element decreases with increasing pH.

CONCLUSIONS

Since our primary goal is to produce black locust biomass on surface-mined sites for use as a fuel source, then short rotation crops would be essential in developing this plan. Biomass accumulation, nutrient uptake and soil nutrient status are important parameters in production of short rotation tree crops. Black locust seems to be very desirable as a site ameliorator.

Harvesting only the branch and bole material in a 6-year-old stand would result in removal of about 82 percent of the aboveground biomass and 58 percent of the nutrients in the stand. Harvesting a 13-year-old stand in the same fashion would result in removal of about 89 percent of the aboveground biomass and 72 percent of the nutrients in the stand.

Several authors have expressed concern that more intensive forest management practices such as whole-tree harvesting and shorter rotations may result in removal of substantial quantities of nutrients from the soil nutrient pool (Weetman and Webber 1972, White 1974 Wood et al. 1977). Since nutrient accumulation is probably highest early in the life of a stand, short rotations could conceivably deplete the soil nutrient pool when an intensive system of biomass production is used, especially on sites with low fertility such as surface mines.

We have examined nutrient removal through harvesting, but we have not determined inputs into the soil by leaf litter, precipitation, stemflow etc. which are needed in assessing the total cycle of nutrients. This type of research is planned in the near future. We suggest using N-fixing species to at least minimize problems of nutrient removal through harvesting.

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