United States Department of Argriculture

Forest Service

Southern Forest Experiment Station

Research Note

SO-305
February, 1984

Yield and Nutrient Removal by Whole-Tree Harvest of a Young Bottomland Hardwood Stand

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SUMMARY

The yield and nutrient withdrawal by whole-tree harvest of young bottomland hardwoods has heretofore been unknown. In this study of intensive harvest, samples of chipped whole trees and soil from 16 test plots were analyzed for nutrient content. Eighty-two percent of the stems and 59 percent of the dry weight were green ash. The balance was divided among a number of other species. Dry weight yields averaged 37,114 lbs/a in summer and 31,964 lbs/a in winter. The annual productivity was 1.45 dry t / a / yr, which is comparable to other stands of similar age. Summer chipping removed 176 lbs N, 22 lbs P, 115 lbs K, 240 lbs Ca, and 23 lbs Mg/a. Soil reserves of these nutrients were found to be high enough to sustain intensive harvests for many 11-year rotations.

Additional keywords: Biomass, *Fraxinus pennsylvanica*, nutrient depletion.

INTRODUCTION

Forest stands can now be harvested at any age with today's chipping equipment. The choice of rotation is still primarily economic, but environmental changes must now be considered: Will intensive harvest on short rotations deplete forest sites of essential nutrients? This study was undertaken to obtain composition and yield data for a typical young stand of bottomland hardwoods and to document the export of nutrients by whole-tree chipping under short rotations. Then, knowing the nutrient reserve in the soil, a minimum pεriod that the supply will last under intensive harvest cycles can be predicted.

Yields and nutrient withdrawal by bottomland hardwoods in plantations have been reported by several authors. Krinard and Johnson (1981) measured 17.8 t/a of dry biomass in a stand of 11-year-old direct-seeded oaks (*Quercus nuttallii* Palmer) with many volunteer associates. Saucier, Clark, and McAlpine (1972) and Kennedy (1975) obtained high yields from closely spaced sycamore (*Platanus occidentalis* L.) harvested on short rotations. For short-rotation sycamore, Steinbeck and Brown (1976) reported nutrients removed by harvest, and Blackmon (1979) reported that nutrients removed equal or exceed nutrients added by natural processes. Francis and Baker (1982) calculated that hundreds of 11-year rotations of planted sweetgum (*Liquidambar styraciflua* L.) would be necessary to deplete an alluvial clay soil of nutrients. But the relationship of short-rotation yields and nutrient withdrawal by harvest of natural stands of bottomland hardwoods had not been addressed until the study reported here was undertaken.

METHODS

The sampling was conducted in an 11-year-old stand in the Delta Experimental Forest near Stoneville, Miss. This stand originated after a mature stand, dominated by bottomland oaks, was logged in the fall of 1970 and the residue was sheared and left in place. Sixteen .01-acre circular plots were laid out in a line transect across the 40-acre tract. The plots were situated in pairs spaced on 100-foot centers from the next pair. Half the plots, one randomly chosen from each pair, were harvested in summer (late August), and the remaining plots were harvested in winter (January).

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The following information was obtained from all trees taller than 4.5 feet on each plot: species, diameter breast height (dbh), total height, and green weight.

The trees were severed at 2 inches above ground. Approximately one-tenth of every tenth tree was removed, weighed green, and dried to obtain factors for converting green weight to dry weight. The remaining portions of all trees were separated into groups of important species and chipped with a limb chipper. The resulting piles of chips were mixed and "grab" samples totaling about 10 lbs each were placed in plastic bags and refrigerated. The chip samples were passed through a sample splitter several times until a few hundred grams remained. The samples were then separated into wood and other tissue (bark, leaves, and small twigs) by hand and with a sharp knife as necessary. The separated material was dried and ground for nutrient analysis. The result was 96 samples representing 16 plots, 2 tissues, and a variable number of species groups.

Nitrogen was determined by the Kjeldahl method. Phosphorus was determined colorimetrically by the molybdenum-blue method. Potassium, Ca, and Mg were determined by atomic absorption spectroscopy.

Soil samples were collected from plots of another experiment 100 feet away and paralleling plots of this study. The soil type, Alligator clay, was level and uniform across the sample area. Sixteen cores were extracted with a soil probe, and the 0 – 12-inch and 12 – 24-inch portions were taken as paired samples. The samples were dried, ground, fused in NaOH, and analyzed for total P according to the method described by Smith and Bain (1982). Potassium, Ca, and Mg were analyzed by atomic absorption spectroscopy from an acid-diluted solution of the fused sample prepared for P determination. Total N was determined by the Kjeldahl method. Nutrient levels in the first foot and second foot were compared by the paired t test with $\alpha = .05$.

RESULTS AND CONCLUSIONS

The stand had a preponderance of green ash (*Fraxinus pennsylvanica* Marsh.) stems. On the 16 plots, 82.4 percent of the stems were green ash (table 1). Other important tree species represented were American elm (*Ulmus americana* L.), black willow (*Salix nigra* Marsh.), cottonwood (*Populus deltoides* Bartr. ex Marsh.), and red maple (*Acer rubrum* L.). The miscellaneous species category was composed principally of swamp-privet (*Forestiera acuminata* (Michx.) Poir.) and hawthorn (*Crataegus* spp.). Only a few oaks (*Quercus* spp.), sweetgum, and sugarberry (*Celtis laevigata* Willd.) had grown in the sample area. Except for ash, no single species contributed a large percentage of the total stocking.

Green ash, relatively small individuals, provided a smaller portion of the basal area than of total stems. Ash accounted for 63.5 percent of the basal area, elm 9.2 percent, willow 8.8 percent, cottonwood 8.6 percent, maple 1.7 percent, and miscellaneous species 8.2 percent. Green ash provided even a smaller proportion of dry weight. Ash made up just 58.9 percent of the plots' dry weight. Elm contributed 12.6 percent, willow 8.2 percent, cottonwood 8.6 percent, maple 1.6 percent, miscellaneous species 9.5 percent, and dead stems of all species 1.9 percent of the total dry weight.

The stand was quite heterogeneous at the .01-a scale. The number of stems per acre averaged 5,888, ranging from 2,400 to 24,100 (table 2). Basal area averaged 55 ft^2/a with a range of 20 to 86 ft^2/a. Standing dry weight per acre was calculated at 37,114 lbs for the summer and 31,964 lbs for the following winter. The average annual productivity, based on winter weight divided by 11 years, was 1.45 t / a. The figure is close to the 1.62 t / a / yr obtained from an 11-year-old direct-seeded oak site (Krinard and Johnson 1981) and the 1.40 t / a / yr from a 6-year-old upland hardwood stand in Tennessee (Hitch-

Table 1.—*Total stems and proportion of stems, basal area, and dry weight of green ash and other species in sixteen .01-a plots in an 11-year-old bottomland hardwood stand*

Species	Stems		Basal area		Dry weight	
	no.	*percent*	*ft²*	*percent*	*lbs*	*percent*
Green ash	776	82.4	5.58	63.5	1,477	58.9
American elm	39	4.1	.81	9.2	315	12.6
Black willow	10	1.0	.77	8.8	174	6.9
Cottonwood	9	1.0	.76	8.6	216	8.6
Red maple	28	3.0	.15	1.7	40	1.6
Miscellaneous species	80	8.5	.72	8.2	239	9.5
Standing dead (all spp.)	------	------	------	------	45	1.9
Total	942	100	8.79	100	2,506	100

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Table 2.—*Stems, basal area, and dry weight per acre in an 11-year-old bottomland hardwood stand*

Season and plot		Stems/a	Basal area/a	Dry weight/a*
		thousands	*square feet*	*tons*
Summer	1	5.4	45	16.4
	2	6.4	86	31.8
	3	4.4	63	21.4
	4	2.9	31	14.1
	5	7.8	20	5.6
	6	24.1	80	20.8
	7	4.9	85	25.9
	8	2.4	29	12.4
Winter	9	4.7	46	14.3
	10	2.7	30	10.0
	11	4.1	40	9.7
	12	2.3	63	19.2
	13	6.1	59	16.0
	14	6.7	85	25.6
	15	3.3	48	14.6
	16	6.0	69	18.4
Mean		5.9 ± 10.9	55 ± 47	-------

*Includes dead stems

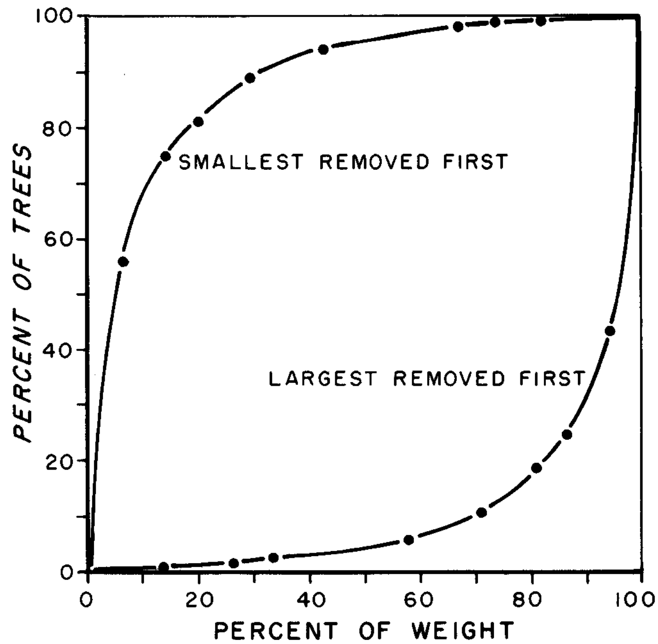

Figure 1.—*Distribution of dry weight on trees within an 11-year-old bottomland hardwood stand removed sequentially by magnitude of dbh.*

cock 1979). Although closely spaced sycamore and poplar on managed, short rotations are more productive than natural stands, the establishment cost is also much higher.

The stand average dbh, 1.0 inches, reflects the relatively small average diameter of the green ash component. The number of trees ranging from 2.0 to 6.6 inches dbh is more important than it would seem. Because dry weight increases with height and the square of the diameter, dry weight is heavily concentrated within a few of the larger trees. The relationship between percentage of total stems and dry weight is illustrated in figure 1. For example, 5 percent of the largest stems contain 50 percent of the dry weight. On the other hand, removing 50 percent of the stems, smallest first, still would leave 95 percent of the dry weight.

Concentrations of N, P, K, and Mg in chip samples from summer-harvested plots were generally higher than in samples from winter-harvested plots (table 3). Calcium averaged higher in winter-harvested plots. The other tissue fractions of the chipped material were higher for all nutrients than the woody fractions. The loss of leaves was probably the greatest cause of nutrient differences between seasons. However, Ca can accumulate in tissues, especially bark, during the dormant season (Francis and Baker 1982).

Nutrient concentration figures and dry weight yields were used to calculate weights of nutrient exported from the site during harvest. Summer chipping removed the equivalent of 176 lbs N, 22 lbs P, 115 lbs K, 240 lbs Ca, and 23 lbs Mg per acre. Winter harvesting removal equaled 146 lbs N, 17 lbs P, 95 lbs K, 305 lbs Ca, and 20 lbs Mg per acre. Removal of nutrients by winter harvest was about 20 percent smaller than by summer harvest except for Ca, of which 27 percent more was removed in winter than summer. Obviously, to preserve nutrients, winter is the preferable time to harvest whole trees. Ku, Baker, Blinn, and Williams (1980) studied understory hardwoods in pine on the Silty Uplands of Arkansas. Their summer harvest yielded a little more than half the biomass and a little less than half the nutrients per acre than the harvest in this study. However, the ratio of the five nutrients to one another in chipped material from both studies was essentially the same.

Concentration of total nutrients in the soil (available plus fixed) was surprisingly high and quite uniform with depth (table 4). Nitrogen in the first foot averaged .26 percent; P averaged .085 percent; K averaged 2.66 percent; Ca averaged .70 percent; and Mg averaged .95 percent. Concentrations in the second foot did not differ significantly. Two feet of soil weighs about 8,000,000 lbs/a. The calculated total nutrient reserves in the upper 2 feet would be:

$$N \cong 20{,}000 \text{ lbs/a}$$
$$P \cong 7{,}000 \text{ lbs/a}$$
$$K \cong 212{,}000 \text{ lbs/a}$$
$$Ca \cong 55{,}000 \text{ lbs/a}$$
$$Mg \cong 76{,}000 \text{ lbs/a}$$

These reserves are so large that, assuming no growth reduction due to diminished nutrient supply, it would take more than 100 rotations of 11 years harvested by summer whole-tree chipping to consume all the N in the upper 2 feet. The other nutrients would last even longer.

Under normal circumstances, natural gains exceed natural losses and the site accumulates nutrients as a young stand develops. A principal source of additions is rainfall. The following 11-year accumulations were calcu-

Table 3.—*Nutrient content in tissues of summer- and winter-harvested biomass and nutrient withdrawn from the site*

	N	P	K	Ca	Mg
			percent		
Stand average (summer)					
Wood	.237	.041	.212	.224	.032
Other tissue	1.019	.098	.540	1.616	.130
Total	.475	.058	.312	.647	.062
Stand average (winter)					
Wood	.253	.043	.189	.243	.030
Other tissue	.662	.054	.380	1.907	.094
Total	.396	.047	.256	.824	.052
			lbs/acre		
Nutrient withdrawn					
Summer	176 ± 168	22 ± 20	115 ± 107	240 ± 255	23 ± 24
Winter	147 ± 98	17 ± 12	95 ± 60	305 ± 208	20 ± 13

lated from nutrient contents in rainfall collected over a 2-year period about 1 mile from the study site (Lockaby 1981): 102 lbs N/a, 11 lbs P/a, 38 lbs K/a, 61 lbs Ca/a, and 16 lbs Mg/a. In every case in this study, nutrients withdrawn by harvest exceeded nutrients potentially added in rainfall during an 11-year period. The net loss, however, would be small.

From the foregoing evidence, it is clear there is little danger of depleting an Alligator soil of its vital nutrients by intensive harvests on 11-year rotations. However, this conclusion should not be extended to soils with low cation exchange capacity and low base saturation.

Table 4.—*Mean total nutrient concentration found in the first and second foot of Alligator soil*

Depth	N	P	K	Ca	Mg
inches			*percent*		
0 – 1	.260 ± .14	.085 ± .018	2.66 ± .20	.70 ± .24	.95 ± .26
12 – 24	.231 ± .16	.081 ± .018	2.63 ± .19	.67 ± .24	.95 ± .27

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