ORGANIC MATTER AND NITROGEN CONTENT OF A CENTRAL HARDWOOD FOREST IN CONNECTICUT

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Abstract.--Four adjacent, 6-ha watersheds in a central hardwood forest in Connecticut are being studied to assess the impact of whole-tree and selective harvesting operations on the forest ecosystem. Since April 1980 baseline data have been collected on species distribution, basal area, mass and nutrient content of aboveground living and dead trees, and on the organic matter and nitrogen content of the soil.

Prior to cutting, dominant oak-birch vegetation in the forest was 80-110 years old. Basal areas of trees and shrubs ≥ 2 cm dbh on the watersheds ranged from 23.3 m^2/ha to 25.2 m^2/ha and densities ranged from 678-1163 trees/ha. Estimates of the organic matter mass indicate 168 Mg/ha (oven-dry-weight) of aboveground living trees, 6 Mg/ha of dead standing wood, 7 Mg/ha of dead fallen wood, 40 Mg/ha of forest floor, and 200 Mg/ha of mineral soil. Nitrogen contents were 316 kg/ha for aboveground living vegetation, 4 kg/ha for fallen dead wood, 760 kg/ha for forest floor and 3100 kg/ha for mineral soil. Approximately 40% of the organic matter and 8% of the nitrogen stored on-site are removed in the biomass from a whole-tree harvest.

Keywords: Living biomass, dead wood, forest floor, mineral soil, nutrient cycling.

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INTRODUCTION

Whole-tree harvesting or removal of the boles and branches of all trees from a site, is currently being introduced into Connecticut. The technique, which has been practiced for several years in northern New England, uses hydraulic shears, skidders, and chippers to increase commercial utilization of a forest stand. Stumps cut off close to the ground, trees < 5 cm dbh, and branches broken off during felling or skidding are the only woody material left on-site.

Whole-tree harvesting represents a substantial increase in the removal of organic matter and nutrients over a commercial, stem-only harvest, and questions have arisen about the impacts on nutrient reserves and stand regeneration. We have initiated a study of these problems in a central hardwood forest in Connecticut.

The objectives of the study are three-fold:

1) to measure the removal of biomass and loss of nutrients resulting from whole-tree harvesting relative to the organic mass and nutrient capital of the site,

2) to compare the relative environmental impacts of whole-tree harvesting with stem-only selection cutting,

3) to compare the impacts of whole-tree harvesting on our central hardwood site in Connecticut with those on other sites throughout the eastern United States.

The subjects of this paper are baseline data collected since May 1980 including the organic matter and nitrogen content of living and dead vegetation, forest floor, and mineral soil. Future work will include monitoring and analyses of the impacts of the whole-tree harvest and selection cut.

SITE DESCRIPTION

Four adjacent, forested watersheds in the Cockaponset State Forest, Chester, Connecticut, were selected for study. These four watersheds, each approximately 6 ha in area, are drained by first-order streams. They range in elevation from 121 m to 152 m above mean sea level with an average slope of 6% and a SSE aspect.

The terrain in the upper reaches of the watersheds is gently rolling, while the lower sections tend to be steep with exposed bedrock cliffs. The bedrock geology is of the upper Middletown formation, an ensemble of gneisses and schists with inclusions of sillimanite quartz and pegmatite.

The soils were formed on a mantle of glacial till. The soils on the ridge tops are generally of the Hollis-Chatfield-Rock association, which consists of shallow, somewhat excessively drained soils and exposed bedrock. The soils on the slopes of the watersheds are deep, well-drained soils of the Chatfield-Canton association. The soils in the valley floor near the stream channels are generally of the poorly-drained, acidic, Leicester series (USDA Soil Conservation Service 1981). The soils show no evidence of being plowed. The forests were probably partially cleared and possibly burned in places for grazing during the 19th century but abandoned more than 80 years ago.

Our baseline data indicate that the geology, soils, forest cover and land-use history of our site are representative of Connecticut and of the central hardwood region of New England.

Treatment of the watersheds was carried out in the winter of 1981-1982 and included a commercial, whole-tree harvest on Watershed A and a selection cut in which 33% of the basal area was removed from Watershed B. Watershed C is the uncut reference and the fourth watershed serves as an additional reference for water quality studies only.

METHODS

Stand Data

Watershed A has been studied more intensively than the others because our main objective is to evaluate the effects of whole-tree harvesting on a forest-stream ecosystem. In 1980, before harvesting, a 100% inventory of all stems, both living and dead, $\geq$ 10 cm dbh was made on Watershed A. Stems between 2 cm and 10 cm dbh were measured on seventy-one 25 m^2 plots. In the early spring of 1981, estimates of the standing vegetation, both living and dead, were made on Watershed B (before harvesting) and on reference Watershed C. The dbh and species of all stems $\geq$ 2 cm dbh were tallied on 10-BAF-prism plots located at 20 sampling points in each watershed.

Biomass Estimation

Regression equations for predicting oven-dry weight from dbh of 14 central hardwood tree species in West Virginia have been published by Brenneman et al. (1978). We designed a study of one species - *Quercus rubra* H. - to test the feasibility of applying these equations to the trees on our study area in Connecticut. Eighteen red oak trees, representative of the same diameter range used by Brenneman et al., were selected at random. Dbh and total tree height were recorded and each sample tree was felled and weighed. Actual tree height was measured and 3 to 7 discs were removed for dry weight determination after 5 to 7 days at 90° C.

Logarithmic transformations of the dbh and green weight data for trees in Connecticut and in West Virginia were compared and least-squares regression lines ($\log_{10}$ weight = a + b $\log_{10}$ dbh) were calculated. In this test the data for Connecticut and West Virginia were essentially the same (Figure 1). We decided that

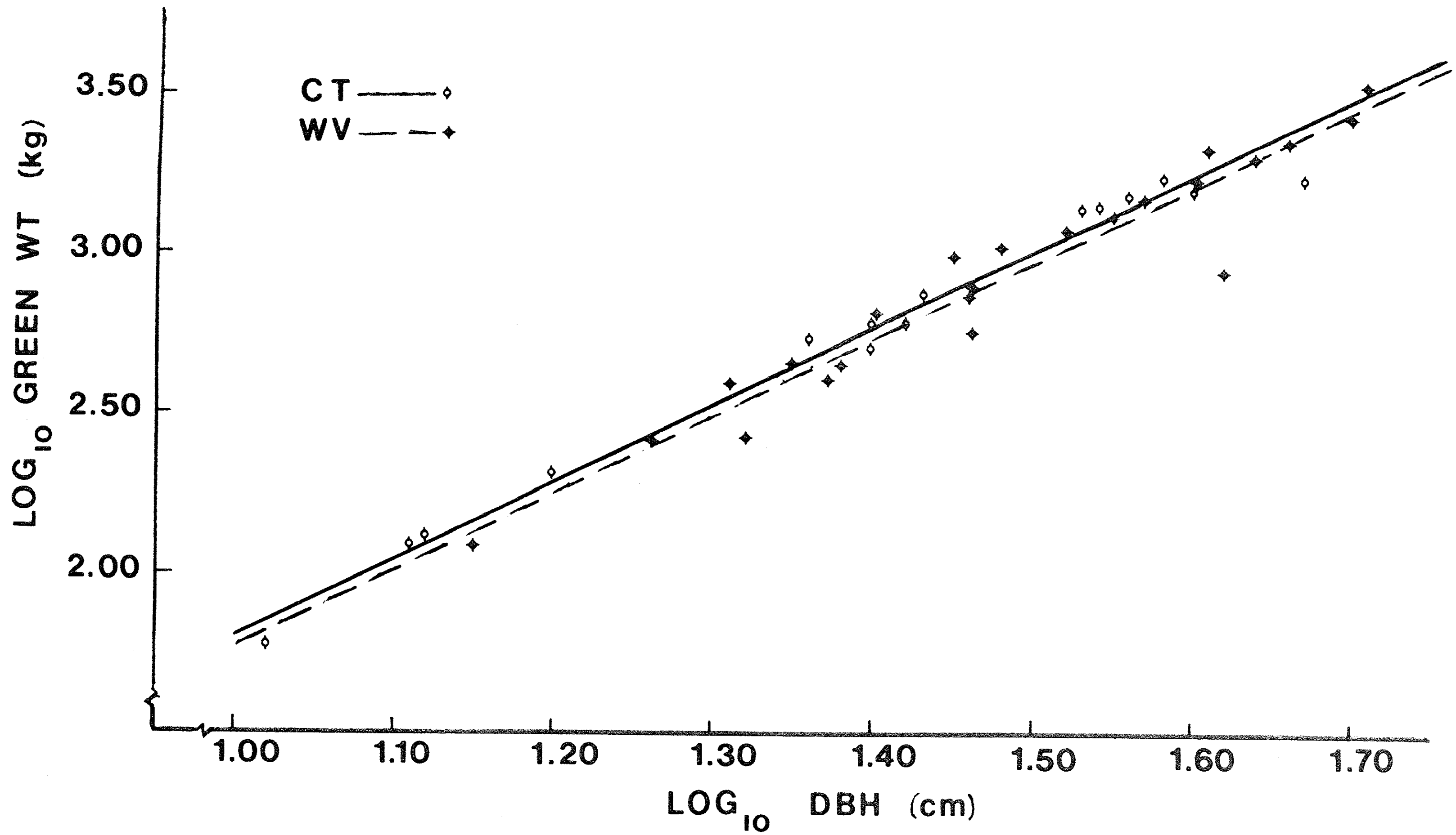

Figure 1: Comparison of dbh and whole-tree green weight data and regression lines for *Quercus rubra* growing in Connecticut (this study) and in West Virginia (Brenneman *et al.* 1978)

inclusion of height would not improve biomass predictions because actual tree heights tended to be 1 to 5 meters less than estimated tree heights.

As a result of this study, we used the published equations (Brenneman et al. 1978) for all species present on our site to calculate total aboveground living biomass. In instances where no published equations were available for a given species we used the equation for a species with similar wood density. Biomass of herbaceous plants and trees < 2 cm dbh is not included in our estimate.

Nitrogen

Seven tree species - *Quercus rubra* H., *Q. alba* L., *Q. prinus* L., *Carya* spp., *Acer rubrum* L., *Betula lenta* L., and *Cornus florida* L. - were analyzed for nitrogen content. Five to seven trees per species were felled and bucked so that an average of six discs, (approximately 5 cm thick) could be removed. Bulk samples of twigs < 1 cm also were collected. An average of four holes were drilled in each disc including bark, heartwood, sapwood, and discolored or decayed wood. The sawdust from the holes for each disc was combined, collected and dried for 48 hours at 70° C. Twigs and sawdust were separately passed through a Wiley Mill (2 mm screen). The oven-dried samples were acid digested and analyzed for nitrogen using an automated colorimetric technique.

The mean percent nitrogen content for each species was calculated and multiplied by the total biomass (kg/ha) for that species. Nitrogen values for discs taken from boles and branches $\geq$ 10 cm were kept separate from those taken from small limbs and twigs, because absolute nitrogen tends to increase with distance up the tree from the stump. Thus, the final nitrogen values for each species were weighted according to the proportion of boles and tops (Brenneman et al. 1978). Finally, kg/ha nitrogen for all species were added together to give an estimate of total stand nitrogen.

Dead Wood

Fallen dead logs and branches $\geq$ 3 cm in diameter lying on the forest floor were tallied using a line transect technique developed for estimating logging residues by Van Wagner (1968) and modified by Tritton (1980). Sample discs of each log were oven-dried at 90°C. A hole was drilled in each disc, the dimensions of the hole were measured for volume determination, and all of the sawdust was collected and oven-dried at 80°C for 24 hours. Specific gravity of the sawdust was determined and the material was acid digested and analyzed for nitrogen using an automated colorimetric technique.

Standing dead trees were tallied for dbh, species and height during the living vegetation survey. Regression equations for estimating biomass of the living trees from species and dbh were modified for use on dead trees. The predicted biomass value for each dead tree was discounted by a ratio of actual height divided by predicted height for a living tree of the same diameter, and by a factor of 50% for weight loss and decay while standing (Tritton 1980).

Soil Organic Matter and Nitrogen

The forest floor was sampled in two well-drained plots on Watershed A. In each plot 50 points were located 5 m apart in a 5 x 10 grid. At each point we collected a 10 x 10 cm area down to the top of the mineral soil. Mineral soil was defined as having less than 20% organic matter, and the separation was made visually based on color. Material from 10 points along a line were composited for analysis, giving 5 samples per plot. Organic content of each sample was obtained by weight loss on ashing for 4 hours at 550^{o} C in a muffle furnace. Total nitrogen was obtained by standard block digest and automated colorimetric analysis.

Sampling of the mineral soil has been limited so far. Two pits were dug in well-drained locations. Three cores of 68 cm^3 each were extracted and composited into one sample for each of 9 horizons in one pit and 4 horizons in the other. Organic content and total nitrogen were determined for each sample. A stone content of 15% was assumed in calculating mass per unit area.

RESULTS AND DISCUSSION

Living Vegetation

Basal area on Watersheds A, B and C were 23.3, 25.2 and 24.9 m^2/ha respectively, including trees and shrubs $\geq$ 2 cm dbh (Table 1). Stem densities ranged from 678 to 1163 per hectare. On all watersheds approximately 40 - 50% of the basal area was in oaks (Quercus rubra H., Q. prinus L., Q. alba L., Q. velutina Lam.), 20 - 30% in birches (Betula lenta L., B. alleghaniensis Britt.*), 10 - 20% in maples (Acer rubrum L., A. Saccharum Marsh.), with the rest in the species listed as "other" on Table 1. (Species names according to Fernald 1950, except for *, according to Britton and Brown 1970). Data for stems $\geq$ 10 cm, which eliminates all saplings and most shrubs, indicate basal areas of 21.8 m^2/ha, 22.8 m^2/ha, and 23.3 m^2/ha, and densities of 443, 429, and 344 stems/ha for Watersheds A, B and C, respectively.

The vegetation distribution over the 3 watersheds is uniform especially for stems $\geq$ 10 cm dbh. Watershed A had the most oaks at 47% of the basal area and the highest percentage of shrubs with 62% of the stems ranging from 2 to 9 cm dbh. Watershed C had the fewest oaks (31% of the basal area) and the greatest number of different species with 13% of the basal area in "other" species (Table 1). Watershed C also had the fewest number of stems (49%) between 2 and 9 cm dbh.

The data from these watersheds were compared with data from the nearby Turkey Hill tract which has been monitored for more than 50 years by the Connecticut Agricultural Experiment Station (Stephens and Waggoner 1980). The species distribution of the Turkey Hill stand is similar to our Watershed C, while the basal area and density are very similar to our Watershed A (Table 1).

Biomass

Estimates of oven dry weight of biomass by species groups, both living and dead, for Watershed A are given in Table 2. Of stems $\geq$ 10 cm dbh, 60% of the living biomass is in oaks and 25% is in birch. Living biomass accounts for 95% of the total aboveground organic matter.

Dead Wood Biomass

Estimated weights of standing and fallen dead wood were 6 and 7 Mg/ha respectively, a combined total of 3% of the organic matter content of the forest (Table 2). For each species standing dead wood represented about 2-3% of the living biomass. Species composition of the standing dead wood was the same as that for living biomass suggesting that the species composition of the living forest has remained constant for at least 10-20 years, or the average time a tree stands dead.

The species composition of fallen dead wood reflects the history of the site. The largest component of fallen dead wood is oak (Table 2), probably a result of drought coupled with defoliation by the gypsy moth (*Lymantria dispar* L.) in the 1960's. Defoliation of 25-75% in 1964 was documented for the nearby Turkey Hill forest (Stephens and Waggoner 1980) and indicated on the study site by small annual increments of oak tree rings during the mid 1960's. The other major component of fallen dead wood is chestnut which has persisted since the 1920's when it was killed by chestnut blight (*Endothia parasitica* (Murr.) And.) Other species, including birch, maple and hickory generally decay faster than oak and chestnut and are minor components of the total amount of fallen dead wood.

Soil Organic Matter and Nitrogen

Organic content of the forest floor averaged 0.34 g_{OM}/g_{soil} in one plot and 0.49 g_{OM}/g_{soil} in the other. However, compensating differences in floor thickness caused the total organic contents of the floor to be 38.0 Mg/ha in the first plot and 42.6 Mg/ha in the second. Nitrogen as a fraction of organic matter averaged 19.5 mg_N/g_{OM} in the first plot and 18.2 mg_N/g_{OM} in the second.

In the mineral soil organic fraction decreased monotonically with depth to about 0.02 g_{OM}/g_{soil} in the lower B horizons. Nitrogen as a fraction of organic matter declined from around 20 mg_N/g_{OM} in the upper horizons to about 12 mg_N/g_{OM} in the lower horizons. Applying bulk density, thickness, and stone content

Table 1: Basal area (m^2/ha) and density (stems/ha) of living trees ≥ 2 cm dbh of four central hardwood stands in southeastern Connecticut. Stands (watersheds) A, B and C are described in the present study; the Turkey Hill stand is described by Stephens and Waggoner, 1980. * includes *Sassifras albidum* (Nutt.) Nees, *Fraxinus americana* L., *Fagus grandifolia* Ehrh., *Castanea dentata* (Marsh) Borkh., *Liriodendron tulipifera* L., *Tilia americana* L., *Ostraya virginiana* (Mill) K. Koch., *Carpinus caroliniana* Walt., *Kalmia latifolia* L., and *Hamamelis virginiana* L.

	Basal Area (m^2/ha)				Density (stems/ha)			
Species	Stand A	Stand B	Stand C	Turkey Hill	Stand A	Stand B	Stand C	Turkey Hill
Quercus spp.	10.9	10.0	9.8	6.9	202	125	150	125
Betula spp.	6.3	7.3	5.9	6.8	174	171	164	260
Acer spp.	3.0	2.4	4.9	4.6	305	136	100	491
Carya spp.	1.6	2.4	0.5	0.4	58	44	11	25
Cornus florida L.	1.1	1.7	0.5	0.4	339	54	52	129
Other*	0.4	1.4	3.3	3.2	85	451	201	135
TOTAL	23.3	25.2	24.9	22.3	1163	981	678	1165

Table 2: Aboveground mass on Watershed A of living and standing dead trees ≥ 10 cm dbh, fallen dead wood ≥ 3 cm, shrubs < 10 cm and ≥ 2 cm, and dead wood fragments < 3 cm and ≥ 2 cm. * includes *Sassafras albidum* (Nutt.) Nees, *Liriodendron tulipifera* L., *Tilia americana* L., *Fraxinus americana* L., *Fagus grandifolia* Erhr., and *Castanea dentata* (Marsh) Borkh.

Species	(Mg/ha) Living Biomass	% of Total Living	(Mg/ha) Standing Dead Wood	% of Standing Dead Wood	(Mg/ha) Fallen Dead Wood	% of Fallen Dead Wood	(Mg/ha) Total
Quercus spp.	93.2	60	2.4	62	3.6	75	99.2
Betula spp.	39.6	25	1.0	26	.2	4	40.8
Acer spp.	14.4	9	.4	10	.1	2	14.9
Carya spp.	4.9	3	.1	2	.2	4	5.2
Cornus florida L.	.9	1	.0	0	.1	2	1.0
Other*	2.5	2	.0	0	.6	13	3.1
Subtotal	155.5	100	3.9	100	4.8	100	154.2
Shrubs	12.9	-	1.7	-	-	-	14.6
Dead wood Fragments	-	-	-	-	2.3	-	2.3
TOTAL	168.4		5.6		7.1		181.1

and summing over horizons gave an organic matter content of 204 and 193 Mg/ha and a nitrogen content of 3.0 and 3.2 Mg/ha for the two pits.

The best estimates of total organic matter and nitrogen in the soil are 240 Mg/ha and 3.9 Mg/ha respectively, with only about 20% of each in the forest floor (Table 3).

Nitrogen

Aboveground living biomass accounted for 316 kg/ha or 8% of the total nitrogen content of the forest (Table 3). Living biomass represents the most vulnerable reservoir of nitrogen in the forest since the living material is removed in a whole-tree harvest.

Nitrogen content of fallen dead wood was estimated to be 4 kg/ha or 0.10% of the total nitrogen content of the forest. While this amount seems small in comparison to the large reserves in the soil it may be important biologically. Dead wood has been shown to be a site for nitrogen fixation in hardwoods (Roskoski 1977), thus it may be an important pathway for accumulation of nitrogen following losses to the ecosystem due to cutting. Also, the small standing crop of nitrogen in dead wood may not reflect the possibility that fixation is followed by rapid breakdown or dispersion of relatively nitrogen-rich wood by fungi or insects.

Regional Comparisons

We compared the Connecticut site with other locations in the eastern United States in order to examine regional trends. We were able to find six other central hardwood sites with two or more comparable organic matter or nitrogen values and one northern hardwood forest for which extensive data exist (Table 3).

In general, the similarities seem more striking than the differences between sites. Aboveground living organic matter ranged from 146 Mg/ha for a site in Georgia to about 190 Mg/ha for sites in Pennsylvania and Illinois, and 200 Mg/ha for the northern hardwood stand in New Hampshire. The value of 168 Mg/ha for our site in Connecticut falls in the middle of this range. Dead standing organic matter, which is potentially harvestable, and fallen dead material are 6 and 7 Mg/ha for our Connecticut site, or half the amounts reported for Pennsylvania and New Hampshire.

Organic matter content of the forest floor and mineral soil are available only for the New Hampshire and Connecticut sites. The values are similar, with 40 Mg/ha in the forest floor in Connecticut and 47 Mg/ha in New Hampshire. The mineral soil contains 200 Mg/ha in Connecticut compared with 173 Mg/ha in New Hampshire and the total organic matter pool is 421 Mg/ha in Connecticut and 446 Mg/ha in New Hampshire. Aboveground living biomass is 40% of the total organic mass in Connecticut and 45%

Table 3: Organic matter and nitrogen contents of several central hardwood and one northern hardwood forests. (L = "litter" only. - indicates data not available.)

	Organic Matter (oven dry Mg/ha)							
	CT	NC	TN	PA	IL	MO	GA	NH
Aboveground Living	168	185	173	191	192	171	146	200
Standing Dead	6	-	-	11	-	-	-	12
Fallen Dead	7	-	-	-	-	-	-	14
Forest Floor (L,F,H)	40	17[L]	13[L]	51	6[L]	6[L]	12[L]	47
Mineral Soil (A_2, B)	200	-	-	24	-	-	-	173
TOTAL	421							446

	Total Nitrogen (kg/ha)						
	CT	NC	TN	PA	IL	MO	NH
Aboveground Living	316	387	510	442	478	218	351
Fallen Dead	4	-	-	-	-	-	-
Forest Floor (L,F,H)	760	120[L]	150[L]	1029	69[L]	137[L]	1100
Mineral Soil (A_2, B)	3100	6800	3380	-	6800	-	3600
TOTAL	4180						

Stand Location	Dominant Species	(yrs) Stand Age	Reference
CT: Cockaponset State Forest	Oak-birch-maple	80+	This Study
NC: Coweeta Hydrologic Station	mixed upland hardwoods	60	West et al. 1981
TN: Oak Ridge National Environmental Research Park	mixed upland hardwoods	70	West et al. 1981
PA: State College	Oaks	55	Hutnik, R.J., pers. comm.
IL: Shawnee Hills	Oaks	150	Rolfe et al. 1978
MO: Ashland Wildlife Area	Oaks	92	Rochow 1975
GA: Piedmont	Oak-hickory	mature	Monk et al. 1970
NH: Hubbard Brook Experimental Forest	Beech-birch-maple	55-60	Bormann et al. 1977 Dominski, 1971 Gosz et al. 1976 Tritton, 1980

in New Hampshire.

Nitrogen content of the aboveground living biomass ranges from 218 kg/ha in Missouri to 510 kg/ha in Tennessee. Our site in Connecticut again falls in the middle of the range with 316 kg/ha. The forest floor in Connecticut contains 760 kg/ha nitrogen compared with just over 1000 kg/ha in New Hampshire and Pennsylvania. Total nitrogen in the A and B horizons shows a wider range, from 3100 kg/ha in Connecticut to 6800 kg/ha in North Carolina and Illinois. Of the total nitrogen on the site aboveground living nitrogen amounts to 5% for North Carolina, 7% for Illinois, Missouri, and New Hampshire, 8% for Connecticut, and 13% for Tennessee.

There do not seem to be strong trends among the seven central hardwood sites. The stands in Georgia, Missouri and Connecticut are on the periphery of the central hardwood range and seem to have lower amounts of aboveground living biomass than sites located more centrally in the range. However, such comparisons are difficult to interpret because of differences in stand ages and site conditions, and in methods and objectives for measuring biomass and nutrients. In particular, we found that: 1) minimum dbh of trees included in biomass estimates were not stated, 2) definitions of the forest floor ranged from "litter" only to L, F and H layers, and 3) sampling depths of the mineral soil were not always specified.

Implications of Whole-tree Harvesting

Based on the above data, whole-tree harvesting of our site in Connecticut has the potential for removing up to 40% of the total organic matter and 8% of the total nitrogen. This is a significant increase over an estimated removal of 29% of the organic matter and 4% of the nitrogen in a stem-only harvest. The increased nitrogen removal in a whole-tree harvest is of particular concern with regard to replacement. At present precipitation provides the only measured input of nitrogen to our study site. At an estimated rate of 7 kg/ha/yr, precipitation input would take approximately 50 years to replace the nitrogen removed in a whole-tree harvest while only half of this time would be required to replace the nitrogen removed in a stem-only harvest. Replacement time would be even greater if leaching and denitrification increased the nitrogen losses following harvest.

The absence of slash after whole-tree harvesting may influence several other aspects of the nitrogen cycle. First, dead branch wood may be a site for nitrogen fixation (Roskoski 1977), and a potential reservoir for nitrogen translocated from the soil by fungal hyphae (Covington 1981). Both potentials would be greatly reduced by whole-tree harvesting. Second, branches, leaves and twigs left behind during a stem-only harvest gradually decompose and release nutrients which are available to the regenerating forest. Removal of tree tops in a whole-tree harvest would eliminate this source of nutrients. Finally, the absence of slash following a whole-tree harvest may speed the decomposition rate of the forest floor by reducing shading and increasing temperatures at the soil surface (Bormann and Likens 1979). This may be desirable if the decomposition products, such as nitrogen, can be utilized on-site by the regrowth vegetation, but may not be desirable if nitrogen is directly lost from the site in stream runoff.

In order to evaluate these aspects of whole-tree harvesting baseline levels of organic matter and nitrogen must be established. In this paper, we have presented data for a central hardwood forest prior to cutting. Changes resulting from the whole-tree harvest will be assessed as our study continues over the next few years.

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