ALTERATION OF NUTRIENT STATUS BY MANIPULATION OF COMPOSITION AND DENSITY IN A SHORTLEAF PINE-HARDWOOD STAND

Hal O. Liechty, Valerie L. Sawyer, and Michael G. Shelton[1]

Abstract—Uneven-aged management is used to promote adequate pine reproduction and control species composition of shortleaf pine (*Pinus echinata* Mill.)-hardwood stands in the Interior Highlands of the southern United States. The modification of pine-hardwood composition in these stands has the potential to alter nutrient pools and availability since nutrient uptake, retranslocation, and/or cycling significantly differs in pines and hardwoods. Nutrient status and availability were monitored in a study investigating the effects of different residual pine and hardwood densities on pine reproduction in a mature shortleaf pine-hardwood stand located in the Ouachita Mountains of Arkansas. In 1989 pine basal area was reduced to 13.8 m^2/ha. and hardwood basal area was reduced to 0.0, 3.4, or 6.9 m^2/ha using single-tree selection. A portion of the unaltered stand was used as a control. Nutrient contents of and concentrations in litterfall, forest floor, and soils were monitored 3 and 11 years after harvesting. Nutrient contents and concentrations were then compared among treatments using these data to determine short and long-term changes of nutrient status resulting from the alteration of pine-hardwood composition and density.

INTRODUCTION

Partial cuttings of shortleaf pine (*Pinus echinata* Mill.)-hardwood stands in the Ouachita Mountains are used to regenerate and maintain shortleaf pine as well as to control pine-hardwood composition to meet various wildlife, aesthetic, and diversity objectives. Changes in species composition due to silviculture or natural processes such as succession can alter nutrient regimes, cycling, and availability in forest ecosystems. For example, Alban (1982) compared nutrient levels in soils, forest floor, and litterfall in adjacent 40-year-old plantations of aspen (*Populus tremoloides* Michx.), white spruce (*Picea glauca* Moench), red pine (*Pinus resinosa* Ait.), and jack pine (*Pinus banksiana* Lamb.). Levels of Ca and Mg were generally lower in the soils but higher in the litterfall and forest floor of the aspen than the pine stands (Alban 1982). Binkley and Valentine (1991) found greater accumulations of several base cations and lower net mineralization rates in soils 50 years after an old field was planted to green ash compared to white pine. In the southern United States, Hinesley and others (1991) documented increased nutrient levels in late succession oak-hickory forests compared to early successional pine forests. Switzer and others (1979) found that as old field succession proceeds from pine to oak-hickory communities, soil surface contents of C, N, P, Ca, and Mg increase as does forest floor contents of Ca and Mg. Rates of decomposition nutrient mineralization, or nutrient immobilization are also altered with species composition. Lockaby and others (1995) found that changes in N and P concentration in litter were more dynamic in mixed pine-deciduous stands than in pine-only stands. Decomposition rates appeared to be greater for the mixed stands than pine-only stands (Lockaby and others 1995). Results from these studies suggest that manipulation of the composition of shortleaf pine-hardwoods by partial cutting may potentially alter nutrient cycling and regimes. To better quantify the effects of partial cutting and stand composition on nutrient cycling and regimes, we monitored nutrient concentrations/contents in litterfall, forest floor, and soils 3 and 11 years after application of several uneven-age reproductive cutting prescriptions in a shortleaf pine-hardwood stand. Prescriptions retained 13.8 m^2/ha of overstory pine basal area and 0.0, 3.4, or 6.9 m^2/ha of overstory hardwood basal area. Pine/hardwood composition differed among prescriptions and during the two study periods.

METHODS

Study Site

The study area is located in Perry County Arkansas (34° 52' 12" N Latitude and 92° 49' 30" W Longitude) near Lake Sylvia on the Winona Ranger District of the Ouachita National Forest. Elevations at the site range from 195 to 240 m above mean sea level. Slopes within the study site range from 8 to 21 percent and soils are classified as Typic Hapludults of the Carnasaw and Pirum series and are well drained and moderately deep (Townsend and Williams 1982). Treatment plots were established along an east-west running ridge typical of Ouachita Mountains physiography.

Vegetation in the study area is typical of the Ouachita Mountains where upland forests are dominated by shortleaf pine and mixed oak species (Guldin and others 1994). The site index for shortleaf pine in the study area averaged 17.4 m at 50 years. White oak (*Quercus alba* L.) is the most prevalent hardwood and had an average site index of 16.2 m

[1]Assistant Professor and Graduate Research Assistant, School of Forest Resources, University of Arkansas-Monticello, PO Box 3468, Monticello, AR, 71656; and Research Forester, USDA Forest Service, Southern Research Station, Monticello, AR., 71656, respectively.

Citation for proceedings: Outcalt, Kenneth W., ed. 2002. Proceedings of the eleventh biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–48. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 622 p.

at 50 years. Smaller quantities of post oak (*Q. stellata* Wangenh.), black oak (*Q. velutina* Lamarch), blackjack oak (*Q. marilandrica* Muenchh.), and southern red oak (*Q. falcata* Michx.) are present on the site along with ash (*Fraxinus* spp.), hickory (*Carya* spp.), red maple (*Acer rubrum* L.), serviceberry (*Alemanchier arborea* [Michx. f.] Fern.), blackgum (*Nyssa sylvatica* Marsh.), and dogwood (*Cornus florida* L.). Understory vegetation consists mainly of shade tolerant shrubs such as huckleberries (*Vaccinium* spp.) and hawthorns (*Crataegus* spp.) (Shelton and Murphy 1997).

Typical of a number of stands located in the Ouachita Mountains, the stand at the study site developed after intensive harvesting of virgin pine forests in the early twentieth century. Harvesting in the early twentieth century removed high quality pines and oaks with stump diameters of 36 cm or more but left smaller, poorer quality trees (Shelton and Murphy 1991). Establishment of fire suppression during the 1930's resulted in the reestablishment of hardwoods in the understory of these forests. As a result, 90 percent of pines and oaks present prior to the study establishment ranged in age from 50-80 and 40-70 years, respectively (Shelton and Murphy 1991). The youngest age classes found in the overstory for both pines and oaks

Table 1—Mean litterfall and forest floor mass (O_i and O_e) for each harvesting treatment and component in a shortleaf pine-hardwood stand located Perry County, Arkansas

Component	0.0[a]	3.4	6.9	Uncut
	Litterfall Mass (kg/ha) 1991			
Pine Foliage	1,871a[b]	1,481a	1,367a	2,210a
Hardwood Foliage	30c	889b	1,647a	1,361ab
Total Foliage	1,902c	2,370bc	3,014ab	3,571a
Woody Debris	488a	529a	712a	1,017a
Reproductive	287a	274a	444a	387a
Total Litterfall	2,676c	3,173bc	4,171ab	4,975a
	Litterfall Mass (kg/ha) 1999			
Pine Foliage	2,913a	2,580a	2,132a	3,160a
Hardwood Foliage	1,170b	1,744ab	2,480a	1,735ab
Total Foliage	4,083a	4,324a	4,613a	4,896a
Woody Debris	1,528a	1,294a	1,327a	1,576a
Reproductive	628a	669a	730a	619a
Total Litterfall	6,239a	6,287a	6,669a	7,091a
	Forest Floor Mass (kg/ha) 1991			
O_i	7,157a	6,317a	4,939a	5,892a
O_e	14,022a	13,580b	9,150b	12,542ab
Total	21,180a	19,898a	14,090b	18,435ab
	Forest Floor Mass (kg/ha) 1999			
O_i	5,018a	4,802a	4,846a	5,762a
O_e	17,012a	17,963a	18,315a	16,331a
Total	22,031a	22,765a	23,162a	22,094a

[a] Retained hardwood basal area (m^2/ha) after harvesting the pine component to 13.8 m^2/ha.
[b] Treatments with the same letter for a given component and year are not significantly different at α = 0.05.

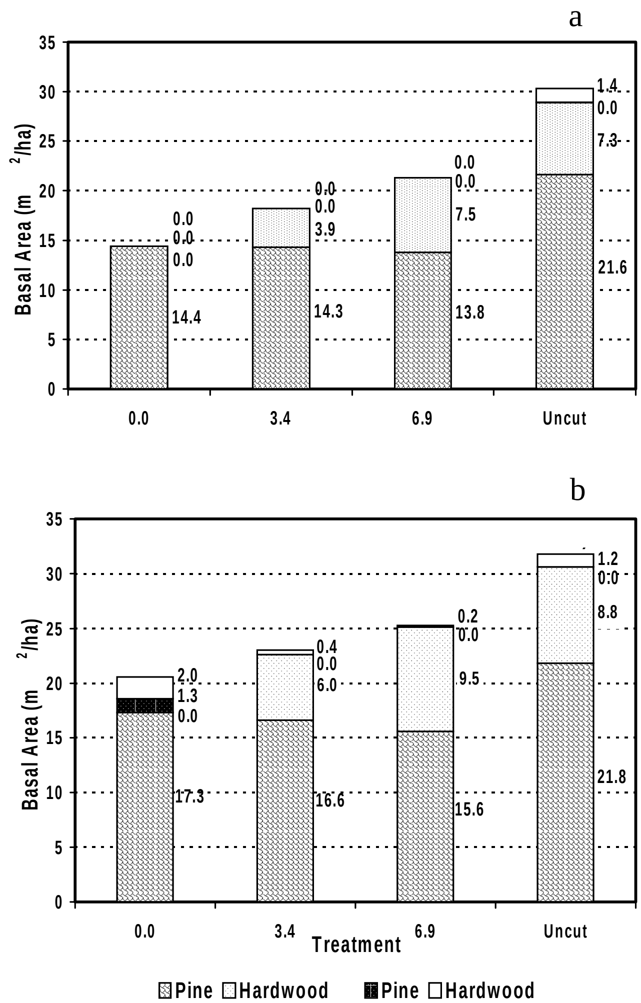
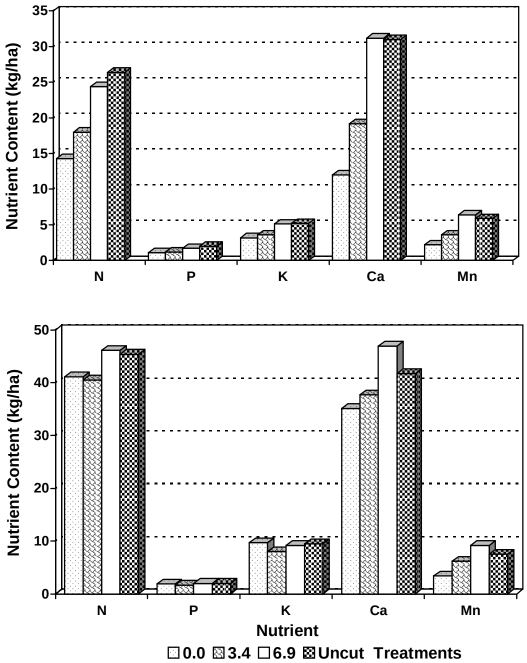


Figure 1—Basal area of pine and hardwood overstory and saplings in a) 1991 and b) 1999 by harvesting treatment (retained hardwood basal area in m^2/ha) in a shortleaf pine-hardwood stand located in Perry County, Arkansas.

suggests that regeneration of overstory species had been inhibited 30-40 years prior to the initiation of the study. Average basal areas of shortleaf pine and hardwoods were respectively 21.5 and 6.9 m^2/ha prior to harvesting in 1988.

Study Design and Treatment

In late winter of 1988 and spring of 1989, three harvesting treatments were established in four different slope/aspect blocks in a randomized block design. In the three harvested treatments, overstory pine basal area was reduced to 13.8 m^2/ha while hardwood basal area was reduced to 0.0, 3.4, or 6.9 m^2/ha. Higher quality white and red oaks were retained in a uniform distribution within treatments that maintained residual hardwoods. The basal area-maximum diameter-quotient method of single-tree selection was used to regulate the pine component on each of the harvested treatments (Farrar 1984). The selection targets were 13.8 m^2/ha of basal area, 45.7-cm maximum d.b.h., and a 1.2 quotient for 2.5-cm d.b.h. classes. Pine after felling was yarded using mules. No markets were available for the hardwoods, thus all unwanted hardwoods $\geq$2.5 cm d.b.h.



a
b

Figure 2—Selected nutrient contents of litterfall in a) 1991 and b) 1999 by harvesting treatment (retained hardwood basal area in m^2/ha) in a shortleaf pine-hardwood stand located in Perry County, Arkansas. For a given nutrient, treatments with the same letter are not significantly different $\alpha = 0.05$.

were injected with triclopyr amine during April 1989. A 0.2-ha net plot surrounded by a 17.7-m isolation strip was established in each harvesting treatment and block. Net plots were established in a portion of the uncut stands in each block in 1990. The uncut plots have no isolation strip as the surrounding undisturbed stand acts as an isolation strip.

Sample Collection and Preparation

Litterfall was collected on a 1 to 3 month interval for nutrient analysis and mass determination during 1991 and 1999. Litterfall was collected in four 0.08-m^2 circular traps in each net plot during 1991 and in two additional 0.08-m^2 circular trap plus three 0.5-m^2 square traps in each net plot during 1999. All litter was sorted into four components: hardwood foliage, pine foliage, woody debris, and reproductive material. Woody branches and stems greater than 1.25 cm in diameter were excluded from sampling in 1991 while in 1999 only debris greater than 7.50 cm were excluded.

Forest floor was collected on the border of each net plot using three 0.1-m^2 frames in 1991 and six 0.1-m^2 frames in 1999. Forest floor samples were separated into the O_i and the O_e horizons. The O_i was further separated into hardwood foliage, pine foliage, woody debris, and reproductive material in 1999. In 1991 samples were not separated by component but the proportion of O_i in each component determined in 1990 was used to estimate component mass from each treatment using total 1991 O_i mass. Maximum branch or stem size included in the samples for 1991 was 2.5 cm and in 1999 was 7.5 cm. Nutrient concentrations for each component for 1991 were determined from the separated samples collected in 1990. Since no sampling was performed in the uncut treatment in 1990, nutrient concentrations for each component in the 6.9-m^2/ha treatments were used to estimate the uncut nutrient concentrations.

Mineral soil was collected at the border of the net plot and isolation strip for each plot. In 1991 mineral soil from the 0–15.0 cm depth was collected using a shovel at two locations at the border of the harvested net plots and outside the border of the isolation strips. The samples collected from outside the isolation strips were used as the uncut treatment samples in 1991. Mineral soil was collected from six locations to a depth of 7.5 cm along the border of each net plot using an 8.5 cm impact soil sampler in 1999. Samples were collected from both harvested and uncut control plots.

Litterfall and forest floor samples were dried at 65 °C for at least 48 hours after collection. Samples for each collection period were weighed and then subsamples from each component and type were ground to pass a 1-mm sieve for chemical analysis. Mineral soil was air-dried and passed through a 2-mm sieve. Samples from a given depth, plot, and year were then composited prior to chemical analysis.

Chemical and Statistical Analysis

For litterfall and forest floor samples, P, K, Ca, Mg, S, and micronutrients were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory 1990a) after a perchloric acid digestion (Alder and Wilcox 1985). N concentration was determined using micro-Kjeldhal techniques (University of Arkansas, Soil Test Laboratory 1990b). Mineralizable N (Powers 1980), total N, P, K, Ca, Mg, and micronutrients were determined for the mineral soil samples in 1999 but only P, K, Ca, Mg, S, and micronutrients were determined in 1991. P, K, Ca, Mg, S, and micronutrients were determined using inductance coupled plasma (University of Arkansas, Soil Test Laboratory 1992) after a Mehlich 3 soil extraction (Mehlich 1984). N was analyzed using a Skalar autoanalyzer after digestion by Kjeldhal techniques (Bremner 1982).

Analysis of variance was used to evaluate differences in nutrient concentrations, nutrient contents, or mass among treatments. Where differences were significant, Tukey's Honestly Significant Difference test was used to separate treatments means. An a=0.05 was used except where noted.

RESULTS AND DISCUSSION

Litterfall

Three years after harvesting total, total foliage, and hardwood litterfall amounts were significantly lower in the 0.0-m^2/ha residual hardwood treatment than in any of the other three treatments (table 1). Generally hardwood foliage, total foliage, and total litterfall amounts reflected differences in basal area and composition among treatments (figure1a). By 1999 the total amounts of litterfall and litterfall foliage did not differ among treatments but the amount of hardwood litterfall was still significantly less in the 0.0-m^2/ha treatment than that in the 6.9-m^2/ha treatment (table 1). Total and hardwood tree basal area in 1999 still reflected the initial residual densities of the treatments but differences

Table 2—Average forest floor contents and mineral soil concentrations for selected nutrients in each harvesting treatment during 1991 and 1999 in a shortleaf pine-hardwood stand in Perry County, Arkansas

Nutrient	0.0[1]	3.4	6.9	Uncut
Forest Floor Content (kg/ha) 1991				
N	195a[2]	183a	129a	172a
P	13a	11a	9a	12a
K	22a	17a	14a	18a
Ca	194a	148a	145a	181a
Mn	23a	20a	20a	25a
Forest Floor Content (kg/ha) 1999				
N	181a	204a	212a	181a
P	10a	10a	11a	9a
K	11a	13a	16a	13a
Ca	137a	147a	165a	147a
Mn	16b	26ab	32a	28ab
Mineral Soil (mg/kg) 1991[3]				
P	13a	13a	13a	13a
K	48a	42a	30a	44a
Ca	174a	142a	174a	131a
Mn	66a	67a	63a	60a
Mineral Soil (mg/kg) 1999[4]				
Total N	1102a	944a	903a	846a
Mineralizable N	58a	41a	54a	45a
P	4a	4a	5a	4a
K	57a	47a	54a	48a
Ca	246a	98b	119ab	100b
Mn	58a	36a	54a	34a

[1] Retained hardwood basal area (m^2/ha) after harvesting the pine component to 13.8 m^2/ha.
[2] Treatments with the same letter for a given nutrient and year are not significantly different at $\alpha = 0.05$.
[3] 0-15 cm depth.
[4] 0-7.5 cm depth.

were reduced among treatments compared to those observed in 1991 (figure 1). Approximately 3.3 m^2/ha of sapling (1.5-8.9 cm d.b.h.) basal area was present in the 0.0-m^2/ha treatment. The amount of hardwood foliage litterfall collected in the 0.0-m^2/ha treatment during 1999 was 39 times more than that collected during 1991 and reflected the partial recovery of the hardwoods in this treatment. The total amount of litterfall collected in the uncut treatment was respectively 42 percent more in 1999 than 1991. A portion of this increase reflected the larger diameter of woody litterfall included in collections from 1999 ($\leq$7.5 cm) compared to 1991 ($\leq$1.25 cm). However total foliar litterfall also increased by 37 percent during this period. Thus it seams likely that the increased levels of litterfall in 1999 compared to 1991 reflected natural variation in litterfall amounts and the continuing growth of trees in the plots.

Total litterfall nutrient contents in 1991 were generally greatest in the uncut and 6.9-m^2/ha treatments than in the 0.0- or 3.4-m^2/ha treatments (figure 2a). Nutrient contents of litterfall in 1991 closely reflected the differences in the amount of litterfall and basal area among treatments (figure 1; table 1). Removal of pine and hardwoods reduced the inputs of foliage and reproductive material in the litterfall thereby reducing nutrient contents. However, differences in nutrient concentrations of litterfall were evident. Concentrations of Ca and Mn were significantly lower while concentrations of K were significantly higher in the 0.0-m^2 treatment than the uncut and/or the 6.9-m^2/ha treatments. Concentrations in the 0.0-m^2/ha treatment differed from those in the uncut and 6.9-m^2/ha treatment by as much as 30 to 70 percent. These differences were in part related to the changes in the pine/hardwood foliage proportions in the litterfall after applying the harvesting treatments. However, concentrations of K in pine foliage litterfall were also significantly higher in the 0.0-m^2/ha treatment (0.15 percent) than in either the 6.9-m^2/ha treatment (0.11 percent) or uncut (0.11 percent) treatments. These results suggest that harvesting treatments had altered the availability, competition for, or retranslocation of K, Ca, or Mn within these treatments during 1991.

In 1999, 11 years after harvesting treatment application, litterfall nutrient contents generally did not differ among treatments (figure 2b). The similar nutrient levels among treatments reflect the rapid recovery of foliar production in the treatments since harvesting (table 1). Litterfall contents of Mn were still significantly lower in the 0.0-m^2/ha treatment than the uncut or 6.9-m^2/ha treatments. The differences in Mn content are primarily related to the lower concentrations of Mn in the litterfall of the 0.0-m^2/ha treatment. Mn concentrations in the foliar litterfall of the 0.0-m^2/ha treatment (0.10 percent for hardwood and 0.06 percent for pine) were significantly lower than concentrations in the 6.9-m^2/ha treatment (0.17 percent for hardwood and 0.12 percent for pine) and uncut (0.16 percent for hardwood and 0.11 percent for pine) treatment. Mn concentrations in 1991 and 1999 were strongly correlated to the amount of hardwoods retained and basal area harvested. Apparently, reduction of hardwoods alters cycling of Mn by shortleaf pine and hardwoods for a number of years after harvesting.

Forest Floor

Forest floor mass in 1991 was generally the least in the treatments that had little or no hardwood removal, and greatest in treatments that had the greatest hardwood removal. Increased mass of the forest floor in the 0.0- and 3.4-m^2/ha treatments appeared to reflect bark and woody inputs from hardwoods that were killed with herbicide. Eleven years after harvesting in 1999, forest floor mass did not significantly differ among treatments. Recovery of the forest floor mass in the 0.0-m^2/ha treatment was evident, and mass generally varied by less than 10 percent among treatments.

Differences in forest floor nutrient contents among treatments in 1991 were not significant (table 2). However, like forest floor mass, nutrient contents were consistently greatest in the 0.0-m^2/ha treatment. In 1999 differences among treatments were significant for Mn contents but not for N, P, K, or Ca. Differences in forest floor Mn like litterfall can be attributed to lower concentrations of Mn in the 0.0-m^2/ha treatment. Forest floor Mn concentrations were significantly lower in the 0.0-m^2 treatment (0.07 percent) than in the uncut (0.13 percent) or 6.9-m^2/ha treatments

(0.14 percent). Forest floor Mn concentrations were twice as great in the 6.9-m^2 treatment than the 0.0-m^2 treatment. These differences were similar to those observed in the litterfall and generally reflect differences in litterfall Mn concentrations.

Mineral Soil

Mineral soil concentrations with the exception of Ca in 1999 did not significantly differ among treatments (table 2). Frequently, nutrient concentrations were greatest in the 0.0-m^2/ha treatment during 1999, but differences between this treatment and the others were not significant for any nutrient other than Ca. These results suggest that although nutrient cycling may have been altered by the harvesting treatments, this alteration has had minimal impacts on the nutrient levels in the soils in these treatments. It should however be noted that the statistical power of the study design and sampling scheme was lower for the mineral soil component than for either the litterfall or forest floor.

SUMMARY

Changes in stand density and composition due to harvesting treatments significantly impacted the levels of specific nutrients in this study. Impacts were generally greatest in 1991 due to the changes in litterfall and forest floor amounts. However, differences in K and Mn concentrations in litterfall or forest floor altered total amounts of these nutrients in the treatments. By 1999 differences in nutrient contents were minimal among treatments. However, litterfall and forest floor Mn levels in the 0-m^2/ha treatment were still lower than those in the uncut or 6.9-m^2/ha treatments. Any changes in litterfall or forest floor nutrient contents did not appear to alter nutrient concentrations in soils. Concentrations of nutrients did not significantly differ among treatments either 3 or 11 years after harvesting.

ACKNOWLEDGEMENTS

This work was jointly supported by the Arkansas Forest Resources Center and the Southern Research Station.

REFERENCES

Alban, D.H. 1982. Effects of nutrient accumulation by aspen, spruce, and pine on soil properties. Soil Science Society of America Journal. 46: 853-861.

Alder, P.R.; Wilcox, G.E. 1985. Rapid perchloric acid digest methods for analysis of major elements in plant tissue. Communication in Soil Science and Plant Analysis. 16: 1153-1163.

Binkley, D.; Valentine, D. 1991. Fifty-year biogeochemical effects of green ash, white pine, and Norway spruce in a replicated experiment. Forest Ecology and Management. 40: 13-25.

Bremner, J.M. 1996. Nitrogen-Total. In Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A. Johnson, C.T., and Sumner, M.E. (ed). Methods of soil analysis. Part 3. Soil Science Society of America Book Series, 5: 595-624.

Farrar, R.M. 1984. Schnur's site index curves formulated for computer applications. Southern Journal of Applied Forestry. 9: 3-5.

Guldin, J.M.; Baker, J.B.; Shelton, M.G. 1994. Midstory and overstory plants in mature pine/hardwood stands of the Oucahita/Ozark forests. In: Baker, J.B., comp. Proceedings of the symposium on ecosystem management research in the Ouachita Mountains: pretreatment conditions and preliminary finding. 1993 October 26-27. Hot Springs, AR. Gen. Tech. Rep. SO-112. New Orleans, LA: U.S. Department of Agriculture Forest Service; Southern Forest Experiment Station: 29-49.

Hinesley, L.E.; Nelson, L.E.; Switzer, G.L. 1991. Weight and nutrient content of litter during secondary succession on well-drained uplands of the East Gulf Coastal Plain in Mississippi. Canadian Journal of Forest Research. 21: 848-857.

Lockaby, B.G.; Miller, J.H.; Clawson, R.G. 1995. Influences of community composition on biogeochemistry of loblolly pine (*Pinus taeda*) systems. American Midland Naturalist. 134: 176-184.

Mehlich, A. 1984. Mehlich 3 soil extractant: A modification of Mehlich 2 extractant. Communications in Soil Science and Plant Analysis. 15: 1409-1416.

Powers, R.F. 1980. Mineralizable soil nitrogen index of nitrogen availability to forest trees. Soil Science Society American Journal. 44: 1314-1320.

Shelton, M.G.; Murphy, P.A. 1991. Age and size structure of a shortleaf pine-oak stand in the Ouachita Mountains: Implications for uneven-aged management. In: Coleman, S.S.; Neary, D.G., comps. Proceedings of the sixth biennial southern silvicultural research conference. 1990 October 30-November 1. Memphis, TN. Gen. Tech. Rep. SE-70. Asheville, NC: U.S. Department of Agriculture Forest Service, Southeastern Forest Experiment Station: 67-72.

Shelton, M.D.; Murphy, P.A. 1997. Understory vegetation 3 years after implementing uneven-aged silviculture in a shortleaf pine-oak stand. Res. Pap. SO-296. Asheville, NC: U.S. Department of Agriculture Forest Service, Southern Research Station. 13 p.

Switzer, G.L.; Shelton, M.G.; Nelson L.E. 1979. Successional development of the forest floor and soil surface on upland sites of the East Gulf Coastal Plain. Ecology. 60: 1162-1171.

Townsend, W.R.; Williams, L. 1982. Soil survey of Perry County, Arkansas. Washington, DC: U.S. Department of Agriculture Soil Conservation Service and Forest Service; Fayetteville, AR: Arkansas Agricultural Experiment Station. 113 p. + maps.

University of Arkansas, Soil Test Laboratory. 1990a. Procedure No. PL-0003: Total plant tissue digest-ICAP analysis for Ca, Mg, Na, K, Fe, Mn, Zn, Cu, P, S, and B. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.

University of Arkansas, Soil Test Laboratory. 1990b. Procedure No. PL-0004: Plant tissue total nitrogen analysis. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.

University of Arkansas, Soil Test Laboratory. 1992. Procedure No. SO-0001: Soil-ICAP analysis for Ca, Mg, Na, K, Fe, Mn, Zn, Cu, P, S, and B. Fayetteville, AR: University of Arkansas, Soil Test Laboratory. 3 p.