Reprinted from the *Soil Science Society of America Proceedings*
Volume 38, no. 6, November-December 1974
677 South Segoe Rd., Madison, Wis. 53711 USA

Biomass Production and Nitrogen Recovery after Fertilization of Young Loblolly Pines[1]

J. B. Baker, G. L. Switzer, and L. E. Nelson[2]

ABSTRACT

Ammonium nitrate applied at rates of 112 and 224 kg of N/ha in successive years to different areas of a young loblolly pine (*Pinus taeda* L.) plantation increased aboveground biomass by 25% and N accumulation by 30%. Fertilization at plantation age 3 resulted in significantly greater biomass and N accumulations in the pine; fertilization at age 4 caused greater accumulations of biomass and N in the herbaceous fraction. These differences are related to changes in the composition of the herbaceous species. Fertilization had little effect on distribution of biomass or N within the pine component of the system. Comparable but generally small proportions of applied N were recovered in the aboveground vegetation in spite of twofold differences in quantities of applied N and threefold differences in biomass development. Nitrogen recovery was influenced only by the frequency of N application.

Additional Index Words: ***Pinus taeda*** **L., forest fertilization, nutrient cycling.**

Although forest fertilization is gaining acceptance, knowledge of the fate of the applied fertilizer materials is still fragmentary or suppositional (1, 4, 5, 8, 13). Understanding of the disposition of such materials in forest ecosystems will lead to more efficient and judicious application.

This paper reports some effects of N-fertilization rates and time of application on N recovery in a young loblolly pine (*Pinus taeda* L.) plantation. Accumulation and distribution of applied N by the various components of the system were also studied. In addition, biomass response of the vegetative components was assessed.

METHODS

Study Area

A 3-year-old loblolly pine plantation on a rolling upland of the Interior Flatwoods in northcentral Mississippi was selected for the study. Soils are an association of the Prentiss (coarse-loamy, siliceous, thermic family of Glossic Fragiudults), Freestone (fine-loamy, siliceous, thermic family of Aquic Paleudalfs), and Wilcox (fine, montmorillonitic, thermic family of Vertic Hapludalfs) series. The entire area is underlain by the nearly impervious Porters Creek formation. Vegetation, other than the planted pines, was composed of typical successional species that occur on abandoned agricultural fields in the South, i.e., primarily broomsedge (*Andropogon virginicus* L.), dog fennel [*Eupatorium capillifolium* (Lam.) Small], blackberry (*Rubus* spp.), and sunflower (*Helianthus angustifolius* L.)

Treatments

Ammonium nitrate was applied to separate plots at rates of 0, 112, and 224 kg of N/ha. The material was broadcast on the soil surface of 0.04-ha plots in late April at plantation age 3 years. One year later (age 4), in an adjacent area of the same plantation, 224 kg of N/ha were broadcast in a single (224-1) and in a split (224-2) application. The single and half of the split application were made in early May; the remainder of the split treatment was completed in August. Treatments in each year were replicated four times in randomized complete block designs.

Field Measurements and Sampling

Samples of tree biomass, herbage, and soil were collected from each plot before and 2 years after fertilizer application (ages 5 and 6). The 5-year-old stand was sampled in August, the 6-year-old stand in October. Samples were weighed, and their N contents were determined by the standard Kjeldahl procedure.

The aboveground portions of one small, one medium, and one large tree from each plot comprised the tree biomass samples. These trees were measured and separated into stemwood, stembark, current branches, old branches, dead branches, current foliage, and old foliage. Dry weight and N content of each component were calculated.

Tree biomass and N content before and 2 years after treatment were estimated with 74 equations (2) derived from the sample tree data and plot populations. Various forms of equations with several expressions of tree height and diameter were screened to find the one whose predicted weights and N contents for sample trees were most closely correlated with observed values. Plot estimates of biomass and N content, 2 years after treatment, were adjusted by covariance analysis with initial biomass or initial-N content and number of trees per plot as concomitant variables.

Herbaceous samples were collected from three 1-m^2 quadrats/plot. Dry weight and N content of samples were expanded to estimate total weight and N content of aboveground herbage.

Recovery of applied N in the aerial portions of trees and herbs was determined by comparing N contents of these fractions on treated and control plots 2 years after treatment. Fertilizer N remaining in the soil in mineral form was estimated by comparing mineral-N content of the surface 0.3 m of soil of control plots with that of fertilized plots 2 years after treatment.

RESULTS AND DISCUSSION

Biomass Response

At age 3, the untreated system had an aboveground biomass of 11 tons/ha, of which only 5% was in trees. At age 6, biomass on untreated plots had increased to 24 tons/ha, of which 75% was in trees (Fig. 1). During this period of

[1] Contribution from the USDA-F.S. and the Mississippi Agr. and For. Exp. Sta. (MAFES), Miss. State, 39762. MAFES Journal Contribution no. 2668. Presented before Div. S-7, Soil Sci. Soc. of Am., at Miami Beach, Fla., 2 Nov. 1972. Received 26 Apr. 1974. Approved 14 Aug. 1974.

[2] This work was done while the senior author was Research Forester with the Southeast. For. Exp. Sta., Marianna, Fla.; he is now Soil Scientist at the South. Hardwoods Lab., South. For. Exp. Sta., USDA-F.S., Stoneville, Miss. 38776. The junior authors are Forester and Agronomist, MAFES, Miss. State, respectively. This work was partially supported by McIntire-Stennis funds.

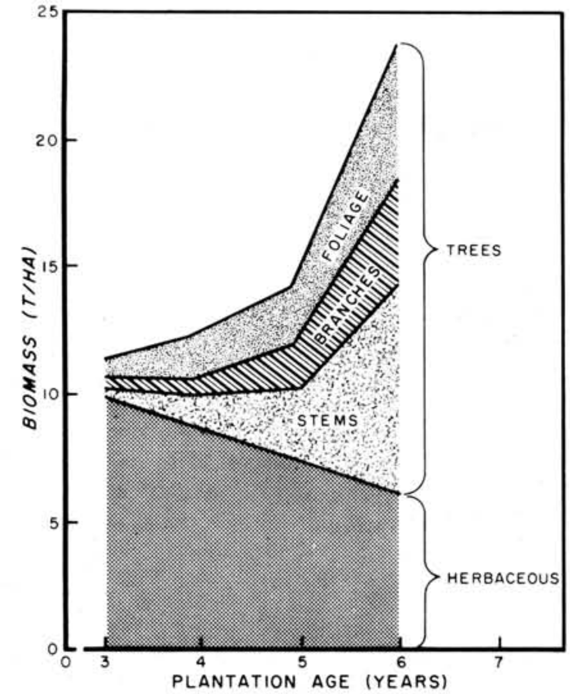

Fig. 1—Accumulation and distribution of aboveground biomass in a developing loblolly pine ecosystem (control plots).

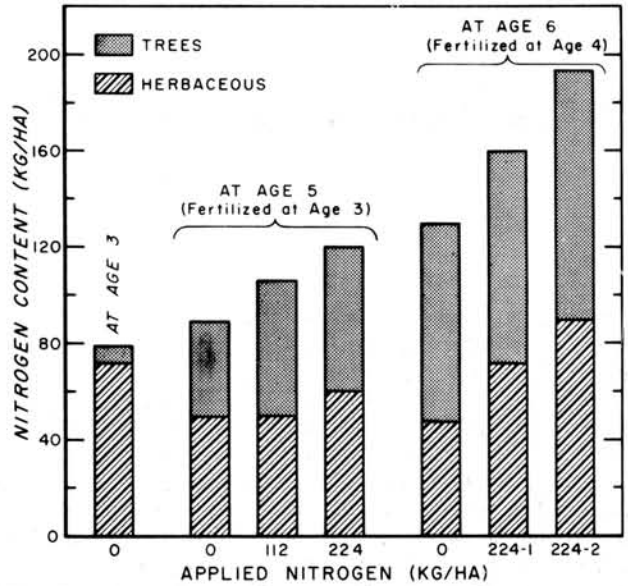

Fig. 2—Nitrogen accumulation in aboveground fractions of the 5- and 6-year-old systems as influenced by N application.

rapid development, distribution of biomass within the pine component changed. At age 3, foliage made up 50% of the tree biomass. At age 6, stems composed 50% and foliage comprised only 30%, even though it had increased from 0.3 tons/ha at age 3 to 4.5 tons/ha at age 6.

Nitrogen fertilization resulted in significant increases in aboveground biomass 2 years after treatment, although there were no differences between rates of N (Table 1). Application of 112 kg of N/ha at age 3 increased biomass production by 4.0 tons/ha over the control; 224 kg of N/ha increased production by 5.5 tons/ha. About 75% of the biomass increase was in the trees. When 224 kg of N/ha were applied at age 4, biomass production increased by 3.4 tons/ha with the single application and by 4.4 tons/ha with the split application. In this case, the herbaceous component was responsible for over 80% of the increase and total tree biomass was not significantly affected.

Table 1—Adjusted estimates of aboveground biomass and N content 2 years after fertilization°

Treatment	Biomass Pine	Biomass Herb	Biomass Total	N Content Pine	N Content Herb.	N Content Total
	t/ha			kg/ha		
At Age 5--Fertilized at age 3						
Control	7.4b	7.5a	14.9b	40.4b	49.4a	89.8b
112N	10.4a	8.2a	18.9a	54.8a	50.6a	105.4a
224N	11.5a	8.9a	20.4a	60.0a	•61.2a	121.2a
At Age 6--Fertilized at age 4						
Control	17.4a	6.6b	24.0b	80.8b	48.0b	128.8b
224N-1	17.9a	9.5a	27.4a	86.4ab	73.0a	159.4ab
224N-2	18.2a	10.2a	28.4a	92.3a	91.3a	183.6a

° For each age group, means in the same column and followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

The different biomass responses of plots fertilized at age 3 and at age 4 were caused by a change in the composition of the herbaceous species. The 3-year-old plots contained few sunflowers. One year later, large numbers of sunflower seedlings were present at time of treatment. Sunflowers on plots fertilized at age 4 grew rapidly and attained heights of about 2 m. Plants on control plots grew only about 0.5 m tall. Density of the sunflowers was fairly uniform on all plots, but their dry matter was much greater on fertilized plots.

Fertilizing at age 3 increased biomass in all tree components; branch weights were affected most (Table 2). By age 5, treatments had resulted in average stem, foliage, and branch weight increases of 41, 50, and 56%, respectively, over the control. Will (14) also found that number and length of lateral branches of *Pinus radiata* consistently increased with increasing levels of soil N. Raising the N level from 112 to 224 kg/ha increased weight of current foliage by 22% and the weight of current branches by 30% (Table 2). Both these components are associated with apical development, and both reflect second-year response. Old branch and old foliage weights, reflecting first-year responses, were about equal regardless of rate of fertilizer.

Although treatments applied at age 4 had no significant effect on total tree biomass, the split application significantly increased the weight of current foliage by 20% and of current branches by 27% (Table 2). These increases are again a reflection of a second-year response.

Regardless of fertilization schedule, the weight increases in various tree components were not great enough to change the biomass distribution of the whole tree. As a result, biomass of all trees at age 5, whether fertilized or not, was composed of about 40% stems, 20% branches, and 40% foliage. At age 6, biomass distribution of all trees changed to 50% stems, 20% branches, and 30% foliage. Differences in dry matter distribution between ages 5 and 6 probably result from the allometric nature of normal stand de-

Table 2—Adjusted mean dry weight of pine biomass 2 seasons after application*

Treatment	Stem			Foliage			Branches			Total tree
	Wood	Bark	Total	Current	Old	Total	Current	Old	Total	
	t/ha									
	At Age 5--Fertilized at age 3									
Control	2.1b	0.7b	2.8b	1.9c	1.1b	3.0b	0.6c	1.0b	1.6c	7.4b
112N	2.9a	0.9a	3.8a	2.6b	1.7a	4.3a	0.8b	1.5a	2.3b	10.4a
224N	3.1a	1.0a	4.1a	3.0a	1.7a	4.7a	1.0a	1.7a	2.7a	11.5a
	At Age 6--Fertilized at age 4									
Control	6.6a	2.1a	8.7a	3.4b	1.3a	4.7a	1.1b	2.9a	4.0a	17.4a
224N-1	7.1a	2.3a	9.4a	3.4b	1.3a	4.7a	1.2b	2.6a	3.8a	17.9a
224N-2	6.6a	2.0a	8.6a	4.1a	1.0a	5.2a	1.4a	3.0a	4.4a	18.2a

* Means are adjusted by covariance analysis, with initial biomass as the concomitant variable. For each age group, means in the same column and followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

velopment; the changes are consistent with data reported by Smith et al. (10) and Switzer et al. (11).

Fate of Applied Nitrogen

Nitrogen Accumulation and Distribution—Nitrogen usually accumulates as forest ecosystems mature. In this study, N accumulation was closely related to the increasing dominance of the tree component. This relationship is demonstrated by the general increase with time in N content of the trees on control plots (Fig. 2).

Except for the single application at age 4, all N treatments significantly increased N accumulation in the aboveground biomass (Table 1). On plots fertilized at age 3, most of the increase in N accumulation was in the trees; on those fertilized at age 4, N gains were mainly in the herbaceous fraction (Fig. 2). This difference was caused by the presence and prolific growth of sunflowers on plots fertilized at age 4.

Treatments also influenced N accumulation within tree components (Table 3). Generally, the differences in N content merely reflect the biomass response. However, for the split treatment, they also result from changes in N concentration of tissues.

Although treatments caused greater accumulations of N in some tree components, the increases were too small to change the N distribution of the whole tree. Thus, foliage, stems, and branches of both fertilized and control trees contained the same proportions (75, 15, and 10%, respectively) of N. Treatments at age 3 caused only a slight increase in N content of dead herbaceous material, a result of the first-year response of this vegetation to fertilizer. However, the split application at age 4 resulted in slightly more N in the living herbaceous fraction than did either the control or the single treatment.

Nitrogen Recovery—Recovery of N applied at age 3 ranged from 22 kg/ha for the 112 N treatment to 44 kg/ha for the 224 N treatment (Table 4). With each treatment, about 20% of the applied material was recovered.

A single application of 224 kg of N/ha at age 4 resulted in the recovery of 43 kg, or about 20% of the applied material (Table 4). With the split application, 67 kg, or 30% of the applied N, was recovered.

The chief source of recovered N varied according to plantation age at time of treatment. When the high N rate was applied at age 3, most (46%) of the recovered N was in the trees. When the same treatment was applied to an adjacent area of the plantation a year later, most (58%) of the recovered N was in the herbaceous fraction (Table 5).

Pinus ecosystems apparently exhibit relatively low recoveries of applied N (Table 6). Nitrogen recovery in such ecosystems ranges from 3 to 24% and averages 14%.

In the present study, N recoveries were relatively consistent over a broad range of circumstances, but split applications of fertilizer improved accountability somewhat. Recovery was about 10% greater with the split treatment than with the single treatment, primarily because of higher N concentrations in the aboveground vegetative tissue.

Application as	Tissue collections of		
	Oct. of 1st yr.	July of 2nd yr.	Sept. of 2nd yr.
	% N		
Single	1.29	1.21	1.19
Split	1.41	1.38	1.24

The difference in N concentration of foliage on single and on split treatment plots ranged from 0.05 to 0.17% and averaged 0.11%.

Table 3—Adjusted mean N content of pine components 2 seasons after application*

Treatment	Stem			Foliage			Branches			Total tree
	Wood	Bark	Total	Current	Old	Total	Current	Old	Total	
	kg/ha									
	At Age 5--Fertilized at age 3									
Control	4.1b	2.6c	6.7b	19.2c	9.9b	29.1b	2.3c	2.3b	4.6b	40.4b
112N	5.1a	3.3b	8.4a	25.6b	13.6a	39.2a	2.9b	4.3a	7.2a	54.8a
224N	5.1a	3.8a	8.9a	30.0a	13.6a	43.6a	3.4a	4.1a	7.5a	60.0a
	At Age 6--Fertilized at age 4									
Control	11.6b	6.3b	17.9b	38.1b	11.4a	49.5b	4.4b	9.0a	13.4a	80.8b
224N-1	14.5a	7.7a	22.2a	39.7b	12.0a	51.7b	5.6a	6.9b	12.5a	86.4ab
224N-2	13.9a	6.8a	20.7ab	46.3a	10.6a	56.9a	6.4a	8.3ab	14.7a	92.3a

* Means are adjusted by covariance analysis, with initial N content as the concomitant variable. For each age group, means in the same column and followed by the same letter are not significantly different at the 5% level of probability according to Duncan's multiple range test.

Table 4—Recovery of fertilizer N

System component	N applied at age 3		N applied at age 4	
	112	224	224-1	224-2
	kg/ha			
Trees	15	20	6	12
Herbaceous	1	12	25	43
Soil	6	12	12	12
Total	22	44	43	67

Table 5—Comparison of distribution of recovered N in 5- and 6-year-old systems

System component	224 kg of N/ha (Single application)	
	Applied at age 3	Applied at age 4
	%	
Trees	46	14
Herbaceous	27	58
Soil	27	28
Total	100	100

GENERAL DISCUSSION AND CONCLUSIONS

Allison (1) concluded that N recovery by agricultural crops is rarely greater than 70% and may often be less than 50%. For several reasons, forest ecosystems may be even less efficient than agronomic systems in taking up applied N from the soil. First, optimum application time and rate are unknown for forest systems. Suboptimal time and rate of application may cause excessive leaching and denitrification. Second, vegetative production per unit of time and area is greater for most agronomic crops during the growing season than for forest systems. Thus, applied N can be better utilized by fast-growing, high-density, short-duration agronomic crops than by *Pinus*.

Two factors appear important for maximizing recovery of applied N and thus biomass response in *Pinus* ecosystems. One is the nature of herbaceous vegetation, and the other is the timing of fertilizer application.

The present study indicates that if herbaceous vegetation on the treated area has high growth potential, the herbs will obtain a large portion of the applied N. Hence, N uptake and growth by trees will be limited. The response to the split treatment indicates that efficiency of N utilization can be improved by applying lower rates of N at intervals throughout the growing season.

Table 6—Comparative recovery of applied N by the aboveground vegetation in *Pinus* ecosystems

System character	Initial system biomass	Quantity of applied N	Observation duration	Recovered N	Source
	t/ha	kg/ha	years	%	
Scots pine @ 15 years	50	60	1.0	9 & 24	Bjorkman, et al. (3)
Scots pine @ 39 years	-	200	5.0	12	Tamm (12)
Scots pine @ 12 years	-	50	1.0	3 & 8	Nommik (7)
Scots pine @ 74 years	-	122	4.0	15	Popovic & Burgtorf (9)
Slash pine @ 13 years	60	224	1.5	21	Mead (6)
Loblolly pine @ 5 years	11	112	2.0	14	Ours
Loblolly pine @ 5 years	11	224	2.0	14	Ours
Loblolly pine @ 6 years	12	224-1	2.0	14	Ours
Loblolly pine @ 6 years	12	224-2	2.0	24	Ours

LITERATURE CITED

1. Allison, F. E. 1966. The fate of nitrogen applied to soils. Advan. Agron. 18:219–258.
2. Baker, J. B. 1971. Response of sapling loblolly pine (*Pinus taeda* L.) to nitrogen fertilization: growth, accumulation, and recovery. Ph.D. diss., Miss. State Univ. Microfilm no. 71-23,646, University Microfilms, Ann Arbor, Mich. Diss. Abstr. 32:1304B.
3. Bjorkman, E., G. Lundeberg, and H. Nommik. 1967. Distribution and balance of ^{15}N labelled fertilizer nitrogen applied to young pine trees (*Pinus sylvestris* L.) Stud. For. Suec. no. 48. 23 p.
4. Cole, D. W., and S. P. Gessel. 1965. Movement of elements through a forest soil as influenced by tree removal and fertilizer additions. p. 95–104. *In* C. T. Youngberg (ed.) Forest-soil relationships in North America. Oregon State Univ. Press., Corvallis.
5. Jansson, S. L. 1963. Balance sheet and residual effects of fertilizer nitrogen in a 6-year study with N^{15}. Soil Sci. 95: 31–37.
6. Mead, D. J. 1971. Movement of added nitrogen and phosphorus in a pine forest ecosystem. Ph.D. diss., Univ. Fla. Microfilm no. 72-21,082, University Microfilms, Ann Arbor, Mich. Diss. Abstr. 33:524B.
7. Nommik, H. 1966. The uptake and translocation of fertilizer ^{15}N in young trees of Scots pine and Norway spruce. Stud. For. Suec. no. 35. 18 p.
8. Overrein, L. N. 1969. Lysimeter studies on tracer nitrogen in forest soils. II. Comparative losses of nitrogen through leaching and volatilization after the addition of urea-, ammonium- and nitrate-N^{15}. Soil Sci. 107:149–159.
9. Popovic, B. O., and H. Burgtorf. 1964. Upptagningen av växtnäring efter gödsling ett tallbestand i Lappland. Rapp. Uppsats. Instn. Skogsekol. Skogshögsk., Stockh. no. 4. 15 p.
10. Smith, W. H., L. E. Nelson, and G. L. Switzer. 1963. The characterization of dry matter and nitrogen accumulation by loblolly pine (*Pinus taeda* L.) on poor sites. Soil Sci. Soc. Am. Proc. 27:465–468.
11. Switzer, G. L., L. E. Nelson, and W. H. Smith. 1968. The mineral cycle in forest stands. p. 1–9. *In* Forest fertilization—theory and practice. TVA Nat. Fert. Develop. Cen., Muscle Shoals, Ala.
12. Tamm, C. O. 1963. Die nahrstoffaufnahme gedungter fichten-und kiefernbestand. Archiv. für Forstwesen 12(2): 211–222.
13. Tamm, C. O. 1968. An attempt to assess the optimum nitrogen level in Norway spruce under field conditions. Stud. For. Suec. no. 61. 67 p.
14. Will, G. M. 1971. Nitrogen supply, apical dominance and branch growth in *Pinus radiata*. Plant Soil 34:515–517.