THE EFFECT OF LARGE APPLICATIONS OF NUTRIENTS FROM ORGANIC WASTE ON BIOMASS ALLOCATION AND ALLOMETRIC RELATIONS IN LOBLOLLY PINE

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Abstract—We applied broiler litter to an 8-year-old precommercially thinned loblolly pine (*Pinus taeda* L.) stand at 0, 5.6, and 23 Mg ha^{-1}, supplying 0, 200, and 800 kg N ha^{-1}. A destructive harvest was implemented two growing seasons following litter application to evaluate treatment impacts on patterns of aboveground biomass allocation and to develop allometric functions enabling prediction of aboveground biomass components. We examined relative allocation to foliage, crown wood, and stemwood; and the proportion of current-year and second-year foliage in the upper vs. the lower crown. No treatment effects were observed in general allocation patterns between foliage, crown wood, and stemwood mass, although treatments did significantly increase the ratio of current-year to second-year foliage in the upper crown. Biomass allocation patterns within trees did vary with tree size. The ratio of foliage to woody biomass remained similar across the range of tree sizes examined; but within the woody component, the amount of crown wood relative to stemwood increased with tree size. The ratio of current-year to second-year foliage remained similar in the lower crown, but the proportion of second-year foliage in the upper crown increased with d.b.h. Statistically significant treatment differences were found in the allometric relationships for estimating stemwood, crown wood, and foliar biomass. In all cases, litter application treatments increased the slope of the relationship between the aboveground biomass component and tree size. Our results suggest that failure to account for treatment-related effects on tree allometry could result in estimation errors of 5-15 percent for individual aboveground biomass components.

INTRODUCTION

As human populations increase, the disposal of human generated waste – municipal, industrial, and agricultural – is becoming more of a problem. One option increasingly being considered is the spreading of waste on agricultural or forested lands (Dickens 2002, Endale and others 2002, Shepard 2000, Vance 1996). One major source of agriculturally-generated waste is confined animal feeding operations. For example, poultry production in the Southeastern United States, one of the regions major agricultural activities, raises over 6.2 billion broilers chickens annually with a production value of over $12.3 billion (U.S. Department of Agriculture 2002). Production is concentrated in densely populated chicken houses, resulting in tremendous amounts of litter. In 1998, for example, an estimated 12 million metric tons of poultry litter was produced nationally (Endale and others 2002). The litter generated in poultry production is rich in nitrogen (N) and phosphorus (P). The primary disposal mechanism, historically, has been application to pastureland as an organic fertilizer (Endale and others 2002, Sauer and others 1999). However, years of repeated applications have resulted in elevated soil P levels and concerns over the potential effects of nutrient-rich runoff on water quality (Sauer and others 1999, Sims and Wolf 1994).

As an alternative to pasture application, some are looking at the abundant pine forests of the South as an option for litter disposal (Beem and others 1998, Samuelson and others 1999). Fertilization research has shown that nutrient limitations occur on many southern pine stands and growth often responds positively to added nutrients (Allen and others 1990). However, little research has investigated the ability of pine stands to contain the nutrients in poultry litter on site and the effects that added nutrients in the litter would have on tree growth and development. An increase in net primary production is expected to result from the added nutrients in poultry litter; however, questions remain as to how that increased growth will be distributed within the trees. The ability to predict the amount and distribution of growth is important for a variety of reasons, including the estimation and modeling of total biomass increases. Examination of the influence of treatments on biomass distribution is commonly accomplished by testing for significant treatment effects on allometric equations (Barclay and others 1986, Gower and others 1993, Grier and others 1984, Naidu and others 1998).

In the fall of 1999, we initiated a study to examine responses in a loblolly pine (*Pinus taeda* L.) stand to a one-time large application of poultry litter. The overall objectives of this study were to investigate the ability of loblolly pine forests to contain a large, one-time application of poultry litter and to investigate the extent to which the litter will enhance tree growth. In this paper, we report on a portion of the study in which destructive sampling was used 2 years after treatment to evaluate whether litter application affected tree allometric relationships and thus the distribution of aboveground biomass.

METHODS

The study was located in Newton County, MS on the Mississippi State University Coastal Plain Branch Station (32°20'N, 89°04'W). Average annual daily high and low temperatures at the site are *ca*. 24° and 11 °C, respectively. Average annual precipitation is *ca*. 1,400 mm. Soils on the study site are a fine sandy loam in the Shubuta Series,

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Citation for proceedings: Connor, Kristina F., ed. 2004. Proceedings of the 12th biennial southern silvicultural research conference. Gen. Tech. Rep. SRS–71. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 594 p.

taxonomically classified as a fine, mixed, thermic Typic Paleudults (Ultisols). The study was established in an 8-year-old loblolly pine stand that was initiated as a plantation following a clearcut harvest but, due to heavy natural regeneration, contained over 4,000 trees per acre.

Nine 20 m x 20 m treatment plots were established and thinned to a basal area of 11 m^2 ha^{-1}. Within each treatment plot, a 10 m x 10 m measurement plot was established containing between 27 and 56 trees. In March 2000, poultry litter in the form of stock-piled cake collected from a local broiler operation near Newton, MS, was applied to the plots. At the time of application, litter moisture content was 21 percent. The elemental composition of the litter on a dry weight basis was 38 percent C, 4.3 percent N, 2.0 percent P, 3.2 percent K, 2.8 percent Ca, 0.7 percent Mg, 0.6 percent S, 590 ppm Zn, 60 ppm B, 680 ppm Mn, Fe 987 ppm Fe, and Cu 969 ppm Cu. Litter was applied at three treatment rates to three plots each in a completely randomized design. The three treatment rates were 0 Mg ha^{-1} (N_0 = Control), 5.6 Mg ha^{-1} (N_{200}), and 23 Mg ha^{-1} (N_{800}). Application rates were based on the N assay of the litter to supply *ca*. 0, 200, and 800 kg N ha^{-1}, respectively. The N_{200} treatment was designed to add N at approximately the same rate as would typically be applied in an operational commercial fertilization. This resulted in adding approximately 2-3 times more P than would typically be applied operationally. The three treatments resulted in P applications of ca. 0, 92, and 370 kg P ha^{-1}.

Trees on each measurement plot were measured pretreatment and bi-monthly thereafter for stem diameter at breast height (d.b.h.) (1.37 m) and total height (HT). Height to the base of the live crown (HT_{blc}) was measured annually. Beginning in May 2000, understory vegetation was controlled annually with herbicides. Destructive sampling took place between Aug. 25 and Sept. 8, 2001. Twenty-seven trees were sampled, nine from each of the three treatments. Trees were harvested from the treated buffer surrounding each measurement plot and were selected to represent the range of sizes found across the plots. Prior to felling, each tree was measured for dbh, HT, and HT_{blc}. Each tree was felled at ground level and the stem divided into 1-m sections. Within the crown, branches were removed separately from each section and separated into current year foliage and twigs, previous year foliage and twigs, and non-foliated branch portions. Total fresh weight of each component was recorded, and a random subsample was weighed fresh and retained for laboratory analysis. With all the branches removed, the main stem was cut into 1-m sections. Outside bark diameter and bark thickness were measured at the bottom of each section, and total fresh weight of each stem section was recorded. A 3-4 cm thick disk was removed from the base of each section, its fresh weight was recorded, and the disk retained for laboratory analysis. In the laboratory, all subsamples were dried at 80 °C to a constant weight and weighed to determine fresh mass:dry mass ratios for each component of each section. Foliage was separated from twigs to determine foliage mass:wood mass ratios. Fresh mass:dry mass ratios and foliage mass:wood mass ratios were used to determine the total dry mass of each aboveground biomass component of the tree.

Results from the destructive sampling were analyzed for size and treatment related differences in aboveground biomass allocation. Analysis of covariance was performed using the MIXED model procedure in the Statistical Analysis System (SAS Institute Inc., Cary, NC, Release 8.1). The model included a random plot effect, with d.b.h. as the covariate, to examine size related differences in biomass distribution. We looked for differences in relative allocation to stemwood (including bark), crown wood, and foliage biomass. We also tested for differences in the relative proportions of first-year foliage and second-year foliage, and whether they differed between the upper crown and the lower crown.

Because allocation patterns in trees naturally differ with tree size, differences in allocation patterns were assessed by comparing allometric functions relating biomass components to measures of tree size. Nonlinear equations were developed for estimating aboveground biomass components using the NLMIXED procedure in SAS. Indicator variables were included in the model to test for treatment effects on the allometric relationships. The general model form was:

$$Y = (\varepsilon_1 + b_0 + b_1 I_{200} + b_2 I_{800}) \cdot X^{(b3 + b4 \cdot I200 + b5 \cdot I800)} + \varepsilon_2 \qquad (1)$$

where Y is the biomass component, X = [d.b.h.^{2} x HT (D^2H)] when Y = stemwood or crown wood mass and X = d.b.h. when Y = foliage components, I_{200} and I_{800} are indicator variables for treatments N_{200} and N_{800}, respectively, b_0-b_5 are fitted regression coefficients, ε_1 is a random error term for plot-to-plot variation, and ε_2 is a random error term for tree-to-tree variation. A critical value of α = 0.10 was used in all analyses for determining significance.

In addition to testing for treatment differences in allometric relationships within individual trees, we wanted to know how much difference treatment specific allometric relationships would have on stand-level estimates of aboveground biomass. We generated biomass estimation equations both with and without treatment effects in the model. Equations without treatment effects were derived from the NLMIXED model where I_{200} and I_{800} were 0 (i.e., control trees only). The equations were applied to tree data from each plot to develop total per hectare biomass estimates of all aboveground tree components. The two sets of estimates were compared to examine treatment differences in estimates of aboveground biomass components.

RESULTS

There were size-related differences in proportional aboveground biomass allocation (fig. 1). The MIXED model results showed that relative allocation to stemwood decreased with dbh (P < 0.0001, fig. 1a), while allocation to crown wood increased with dbh (P < 0.0001, fig. 1b). Proportional allocation to foliage also increased with dbh (fig. 1c), but these values were much more variable and the relationship was not as strong (P = 0.006) as with the woody components.

Proportional allocation between stem, branches, and foliage did not differ significantly among treatments. On average, 70.1 percent of aboveground biomass was

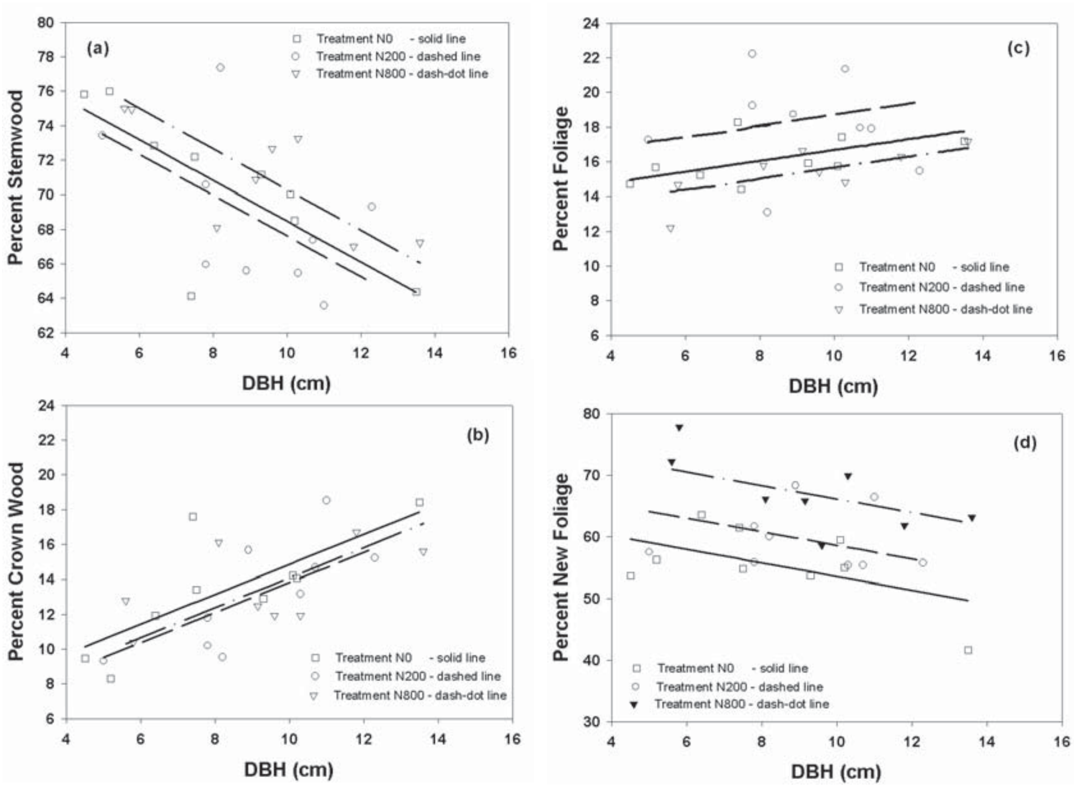

Figure 1—Tree size adjusted differences in percent aboveground biomass allocation to (a) stemwood, (b) crown wood, (c) total foliage, and (d) new foliage for three treatment levels of poultry litter application to an 8-year-old loblolly pine stand. Relationships developed from 26 trees destructively sampled near Newton, MS two growing seasons following litter application.

allocated to stemwood, 13.3 percent to crown wood, and 16.6 to foliage, although again, these values varied with tree size. One factor that did differ by treatment was the proportion of current year foliage (new foliage:total foliage) (P = 0.0078; fig. 1d). Approximately 55 percent of foliage in the control treatment (N_0) was new, compared to nearly 60 percent in treatment N_{200} and over 67 percent in treatment N_{800}. All of these values differed significantly from each other.

Treatment differences in the percent current-year foliage occurred primarily in the upper crowns, where treatments N_{200} and N_{400}, with 70.2 percent and 73.8 percent new foliage, respectively, had a significantly higher proportion of new foliage than treatment N_0, which only had 60.1 percent new foliage. In the lower crowns, the percent current-year foliage did not differ significantly between treatments, although the average percentage for N_{800} was 7-8 percent higher than in the other two treatments.

Results from the NLMIXED model suggest significant treatment effects on allometric relationships for all of the aboveground biomass components examined (fig. 2). Treatments significantly affected the relationship between stemwood biomass and D^2H (P = 0.0443). The differences were between the treated plots and the controls – there were no significant differences between treatments N_{200} and N_{800} (fig. 2a). Figure 2a shows a steeper relationship between stemwood biomass and D^2H in the two fertilization treatments than in the control.

The relationship between crown wood biomass and D^2H was also significantly affected by the treatments (P = 0.0242; fig. 2b). Again, the significant differences were between the treatments and the control, with no differences between treatments N_{200} and N_{800}. Figure 2b again shows a steeper relationship between crown wood and D^2H in the two active treatments than in the control.

The relationship between total foliage and d.b.h. again showed significant treatment effects (P = 0.0224; fig. 2c), with no difference between the active treatments. Once again, the relationship between total foliage and d.b.h. was steeper for trees from the active treatments. This same pattern holds for the relationship between the total amount of new foliage and d.b.h. The treatment effect is not as strong (P = 0.0864; fig. 2d) but is still significant; and there is no significant difference between the active treatments. The relationship between new foliage and d.b.h. was again steeper for trees from the treated plots. The only relationship examined where there was not a significant treatment effect was between the total amount of old foliage and d.b.h. (P = 0.3767, fig. 2e).

DISCUSSION

Treatment-related differences in the amount and distribution of aboveground biomass can result from two sources. One is accelerated tree growth and stand development that may occur due to treatments. Larger trees allocate biomass differently than smaller trees. The other is through treatment effects on how trees allocate aboveground

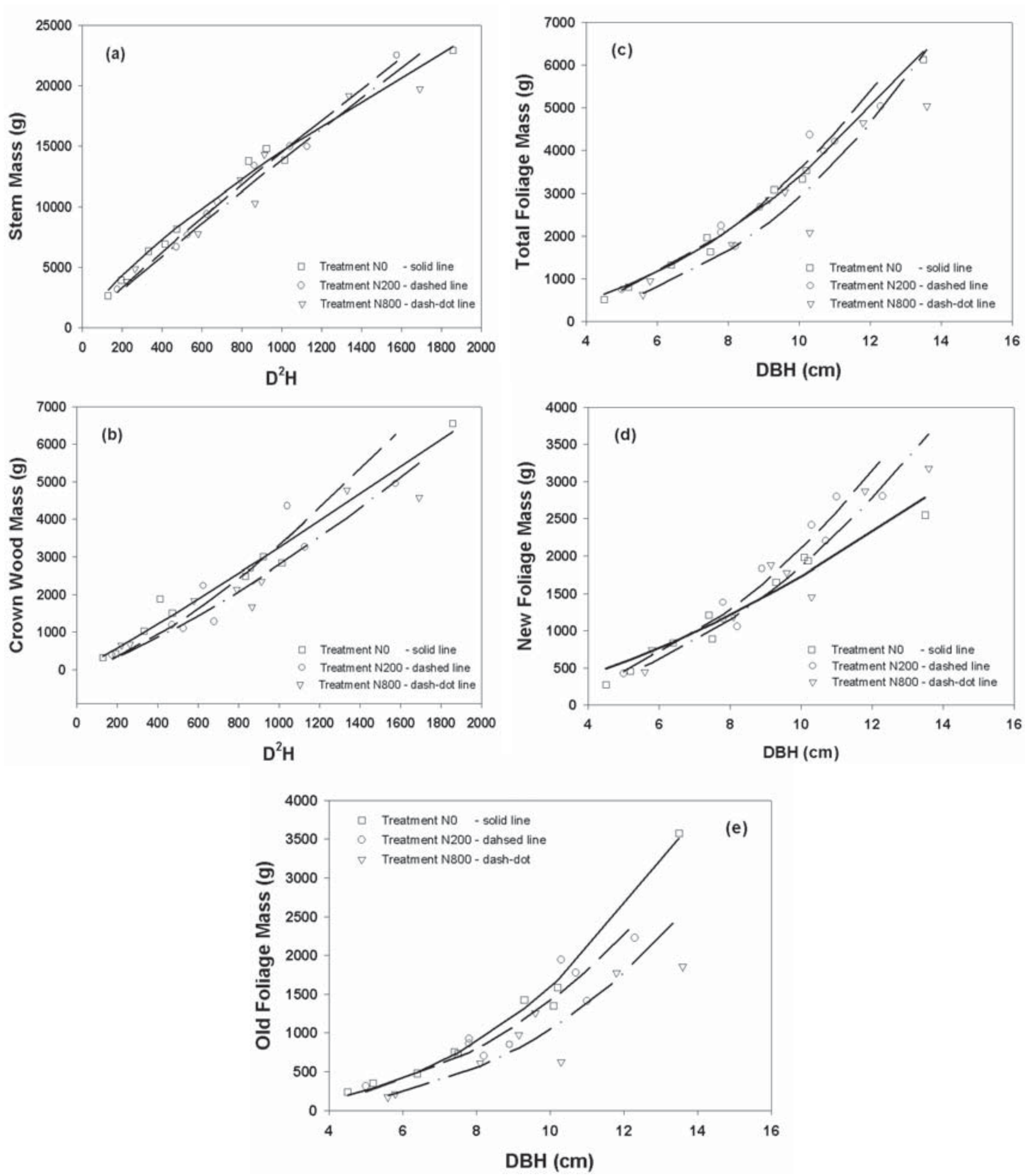

Figure 2—Allometric relationships between tree size and (a) stemwood mass, (b) crown wood mass, (c) total foliage mass, (d) new foliage mass, and (e) old foliage mass for three treatment levels of poultry litter application to an 8-year-old loblolly pine stand. Relationships developed from 26 trees destructively sampled near Newton, MS two growing seasons following litter application.

growth, that is, through changes in allometry. We observed both effects in this study. In every case where we found significant treatment effects in allometric relationships, the differences were between the treated plots and the control plots. On plots where poultry litter was applied at either 5.6 or 23 Mg ha^{-1}, no differences in tree allometries were observed. In all cases where significant differences were observed, the slope of relationship between the estimated biomass component and the measure of tree size was steeper on the treated plots than on the control plots. This implied that for a given incremental increase in tree size, treated trees added more biomass than untreated trees.

To better illustrate the potential importance of the treatment related effects, we compared the predicted mass of aboveground biomass components calculated from allometric equations that included treatment effects to the predicted mass calculated from equations that did not include treatment effects (table 1). Separate models generated in the NLMIXED model for the N_{200} and N_{800} treatments were used, although these treatments did not differ significantly. When treatment effects were not included in the model, estimates of stemwood and total foliage mass were generally higher than when treatments were considered, and estimates of crown wood and new foliage mass were generally less than when treatments were considered.

Table 1—Comparison of predicted mass of aboveground components derived from allometric equations with and without effects of poultry litter application on allometric relationships[a]

Component treatment	Predicted mass without treatment effects included	Predicted mass with treatment effects included	Difference (without treatment— with treatment)
	- - - - - - - - - - - $Mg\ ha^{-1}$ - - - - - - - - - -		- - *percent* - -
Stemwood			
N_0	33.10		N/A
N_{200}	37.09	35.19	+5
N_{800}	37.19	34.69	+7
Crown Wood			
N_0	6.11		N/A
N_{200}	7.61	7.41	+3
N_{800}	6.90	8.07	-15
Total Foliage			
N_0	7.71		N/A
N_{200}	8.93	9.19	-3
N_{800}	9.12	7.83	+16
New Foliage			
N_0	4.47		N/A
N_{200}	4.85	5.48	-11
N_{800}	4.76	5.02	-9

[a] Separate equations were used to predict component biomass for treatments $N2_{00}$ and N_{800}, even though statistical analysis showed no significant differences in the allometric relationships between these treatments.

Our analysis showed that failure to account for treatment effects could result in overestimating stemwood and total foliage mass and underestimating crown wood and new foliage mass. These estimation errors, generally in the 5-15 percent range, could significantly alter estimates of total aboveground biomass, as well as factors such as leaf area index and the distribution of aboveground nutrient pools.

ACKNOWLEDGMENTS

Approved for publication as Journal Article No. FO-230 of the Forest and Wildlife Research Center, Mississippi State University.

LITERATURE CITED

Allen, H.L.; Dougherty, P.M.; Campbell, R.G. 1990. Manipulation of water and nutrients – practice and opportunity in Southern U.S. pine forests. Forest Ecology and Management. 30: 437-453.

Barclay, H.J.; Pang, P.C.; Pollard, D.F.W. 1986. Aboveground biomass distribution within trees and stands in thinned and fertilized Douglas-fir. Canadian Journal of Forest Research. 16: 438-442.

Beem, M.; Turton, D.J.; Barden, C.J.; Anderson, S. 1998. Application of poultry litter to pine forests. OSU Extension Facts F-5037. Stillwater, OK: Oklahoma Cooperative Extension Service. 4 p.

Dickens, E.D. 2002. Effect of a one-time biosolid application in an old-field loblolly pine plantation on diameter distributions, volume per acre, and value per acre. In: Outcalt, K.W., ed. 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: 15-19.

Endale, D.M.; Cabrere, M.L.; Steiner, J.L. [and others]. 2002. Impact of conservation tillage and nutrient management on soil water and yield of cotton fertilized with poultry litter or ammonium nitrate in the Georgia Piedmont. Soil and Tillage Research. 66: 55-68.

Gower, S.T.; Haynes, B.E.; Fassnacht, K.S. [and others]. 1993. Influence of fertilization on the allometric relations for two pines in contrasting environments. Canadian Journal of Forest Research. 23: 1704-1711.

Grier, C.C.; Lee, K.M.; Archibald, R.M. 1984. Effects of urea fertilization on allometric relations in young Douglas-fir trees. Canadian Journal of Forest Research. 14: 900-904.

Naidu, S.L.; DeLucia, E.H.; Thomas, R.B. 1998. Contrasting patterns of biomass allocation in dominant and suppressed loblolly pine. Canadian Journal of Forest Research. 28: 1116-1124.

Samuelson, L.; Wilhoit, J.; Stokes, T.; Johnson, J. 1999. Influence of poultry litter fertilization on an 18-year-old loblolly pine stand. Communications in Soil Science and Plant Analysis. 30: 509-518.

Sauer, T.J.; Daniel, T.C.; Moor, Jr., P.A. [and others]. 1999. Poultry litter and grazing animal waste effects on runoff water quality. Journal of Environmental Quality. 28: 860-865.

Shepard, R. 2000. Nitrogen and phosphorus management on Wisconsin farms: lessons learned for agricultural water quality programs. Journal of Soil and Water Conservation. 55: 63-68.

Sims, J.T.; Wolf, D.C. 1994. Poultry waste management: agricultural and environmental issues. Advances in Agronomy. 52: 1-83.

U.S. Department of Agriculture. 2002. Poultry - production and value: 2001 summary. Pou 3-1(02)b. Washington, D.C.: National Agricultural Statistics Service. 9p.

Vance, E. 1996. Land application of wood-fired and combination boiler ashes: an overview. Journal of Environmental Quality. 25: 937-944.