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Tree Growth Benefits and Water Quality Impacts of Using Animal Manure to Fertilize Pine Plantations: Project Summary

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***Abstract*.** The objective of this project was to observe the water quality impacts and tree growth benefits associated with annual and one-time fertilization of commercial loblolly pine plantations using irrigated swine lagoon effluent and surface applied poultry litter. Annual application rates ranged from 60 to 150 lb PAN/ac in the months of March, May, July, November, and December. One-time applications of turkey litter were made in May and December at rates of 300 lb PAN/ac. Major results at the end of this 4-year study are listed below.

- No detrimental effects were observed in soil or groundwater for any application level at the two sites.
- Spring application of 120 lb PAN/ac yielded $253 per acre more in wood value than the control trees (79% more).
- Surface application of turkey litter at all rates provided significant increases in wood value due to the poor initial soil fertility and low stand density. The increase in wood value as compared to the control trees ranged from 75 to 150%.
- Soil data indicated that 38% of the total N in the irrigated effluent appeared as available-N on soil test. The increase in the available N in the soil from surface application of litter ranged from 12% to 20% of the total N applied depending on the month of application.
- The amount of total P applied that appeared as available-P in the soil ranged from 21% for surface applied turkey litter to 54% for irrigated swine lagoon effluent.

Keywords. Manure management, Land application, Swine, Poultry

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INTRODUCTION

Using the plant nutrients in animal manure to fertilize commercial pine plantations has the potential to provide a new environmentally responsible use of the plant nutrients in animal manure. The additional wood volume could provide an increase in income to landowners and increase the supply of raw materials needed by the paper and lumber industry. Previous work , performed at Clemson University, on one-time application of municipal biosolids resulted in wood volume increases of 20 to 35% over unfertilized stands. No data is available in the literature to define environmentally sound annual application rates using livestock manure.

The objective of this project was to observe the water quality impacts and tree growth benefits associated with annual and one-time fertilization of commercial Loblolly pine plantations using irrigated swine lagoon effluent (lagoon surface water), and surface applied poultry litter.

DESCRIPTION OF THE STUDY SITES AND PROCEDURES

Two project sites were established where swine and turkey manure were used to fertilize Loblolly pine plantations. One site was located in the upper Coastal Plain and the other was located in the Sand Hills Region of South Carolina.

The 4.0-acre site that received swine lagoon effluent as the nutrient source was located on private land in Clarendon County, SC in the upper Coastal Plain. The trees were machine planted at a spacing of 6 ft by 10 ft and fertilization began at a stand age of 10 years. The site selected was previously used for row crop production and the Fuquay soil (loamy, siliceous, thermic Arenic Plinthic Paleudult) at the site is one of the most common soil types in the South Carolina Coastal Plain. The stand was not thinned prior to or during the study period. There were 611 trees per acre on the site at the onset of the study.

Turkey litter was applied to a 22-year old Loblolly stand in Chesterfield County located in the Sand Hills State Forest. Soils in the Sand Hills Region of South Carolina (Troupe and Ailey series) are typically deep sands with very poor fertility and poor moisture holding capacity. The stand received a 5^{th} row thinning prior to the study to provide 147 trees per acre across the entire site. A prescribed burn was carried out prior to the first application and two additional prescribed burns were required to reduce the understory vegetation to reduce forest fire risk, and to facilitate application of turkey litter and soil sampling.

Twelve 0.36 ac plots were established at the Clarendon County site and were randomly assigned to one of the 4 treatments defined in Table 1 to give 3 replicate plots for each treatment. Each of the fertilized plots received 120 lb of plant available nitrogen (PAN) per year. The only difference between the fertilized treatments was the timing of the application. Three of the plots received the total amount in one application in March. Soil moisture levels and nutrient requirements for pine trees are typically higher in the spring. Therefore, the timing of this application was to coincide with the period of maximum nutrient demand. Pine trees are typically actively growing in the early fall. However, pine trees are typically dormant sometime in the months of December through early February. The November application of 120 lb PAN/ac was selected to observe the water quality and tree growth effects of applying a significant amount of nutrients 30 to 60 days prior to the beginning of the dormant season. The second treatment listed in Table 1 is a split application of 60 lb PAN/ac in March and July. The purpose of this treatment was to determine if additional tree growth or any water quality protection advantages could be observed by fertilizing the trees twice during the growing season instead of once. Swine lagoon effluent was applied to each of the fertilized plots (treatments 2, 3 and 4) using a specially designed irrigation system that was described by Lucas et al. (1999).

Table 1. Defined treatments for application of swine lagoon effluent and turkey litter in commercial Loblolly pine plantations based on the amount of plant available nitrogen (PAN) applied per acre and season.

Site Description	No.	Treatment Description
Clarendon County	1.	Control - 0 lb PAN / ac
- Irrigated swine lagoon effluent	2.	60 lb PAN / ac applied each March- and July
- Stand age = 10 years	3.	120 lb PAN / ac applied each March-
- Located on private land	4.	120 lb PAN / ac applied each November
Chesterfield County	5.	Control - 0 lb PAN / ac
- Surface applied turkey litter	6.	75 lb PAN / ac applied each May
- Stand age = 22 years	7.	75 lb PAN / ac applied each December
- Located in a section of the	8.	150 lb PAN / ac applied each May
Sand Hills State Forest	9.	150 lb PAN / ac applied each December
	10.	300 lb PAN / ac applied once in May
	11.	300 lb PAN / ac applied once in December

Twenty-one 0.34 acre plots located in the Sand Hills State Forest were randomly assigned to the 7 treatments 5 through 11 defined in Table 1. The treatments differed by the amount of PAN applied per acre, the season of the year, and the application frequency. Two of the treatments consisted of one-time applications of 300 lb PAN/ac in the late fall (early December) and the spring (early May). Annual litter applications were performed in May and December at levels of 75 and 150 lb PAN/ac.

Tree Measurements and Calculations

Each tree in the measurement area of each plot was tagged. Tree growth was observed by measuring the diameter at breast height (DBH, 4.5 ft above the ground) and the total height prior to and at intervals during the course of the study. All tree measurements were made in the months of December and January while the trees were dormant. Baseline measurements were taken in the winter of 1998 at both sites. The initial applications began in July of 1998 at the Clarendon County site. Trees were measured again in Clarendon County in 2000, 2001, and January 2002. The first litter applications at the Chesterfield site occurred in May 1999. The trees were measured following the initial litter applications in January 2000, December 2000, and January 2001. The DBH and H measurements were correlated with respect to time (t = 0 in 1998) for each treatment. The regression equations for DBH (in) and H (ft) for each treatment were used to calculate the average stem volume (SV, ft^3) using the following equation developed by Baily et al. (1985) for Loblolly pine trees in the Upper Coastal Plains of Alabama, Georgia, and South Carolina:

$$SV = 0.0014793\ DBH^{1.821}\ H^{1.1629}. \tag{1}$$

The average stem volume does not include the effects of tree mortality. The total stem volume per acre (TSV) at any time during the project was calculated as:

$$\text{TSV} = \text{SV} \times n_T / 128. \tag{2}$$

Where,

TSV = total stem volume, cords/acre, and
n_T = number of trees per acre.

The number of trees per acre (n_T) varied each year during the study at each site due to tree mortalities. Tree mortalities included the smallest trees in each plot, trees damaged by weather (hurricane-related wind and ice), and insect damage. The overall mortality ranged from 2.2% in the Sand Hills State Forest to 15% at the Clarendon County site. The Clarendon County site mortality was greater due to tree losses from over crowding, insects, and high winds from a hurricane.

Groundwater Monitoring Wells

Groundwater monitoring wells were installed in each plot in the project area in Clarendon County. The average depth of the wells installed at the Clarendon Site was 20 ft because this was the shallowest depth that water was available year round. A total of 14 monitoring wells were installed at the site in Chesterfield County. Seven of the plots were directly uphill from another row of 7 plots. It was believed that these two rows of plots could not be monitored independently due to the porosity of the deep sandy soil and the greater anticipated depth of each individual well. Wells at the Chesterfield site ranged in depth from 19 to 24 ft deep.

All wells were installed under the supervision of a certified well driller employed by the Natural Resource Conservation Service (NRCS) according to specifications required by the South Carolina Department of Health and Environmental Control (SCDHEC). The well casing was 2-inch diameter schedule 40 PVC pipe. The bottom of the well casing had a 5 ft long section of 0.01 mm slotted screen to allow ground water to migrate into the well.

After the well had been bored, the casing was centered in the hole and the slotted screen was covered with #1 grade filter sand to provide for filtration of ground water into the well casing. The filter sand extended 1 ft above the top of the slotted screen to prevent the annular seal from clogging the screen openings. An annular seal was created by pouring 3/8-inch bentonite pellets around the well casing. The water in the well aided in hydrating the pellets to create the seal. The rest of the bored hole was filled with grout (Portland cement with 5% granular bentonite) to within 6 inches of the soil surface. A 20-inch diameter concrete cap was installed which filled the remainder of the bored hole. A lockable metal cover was installed at the time the cap was poured to protect the well from any type of disturbance. A crown was installed above the cap, which allowed water to drain away from the well.

Groundwater monitoring wells were sampled on a quarterly basis (January, April, July, and October). The wells were purged at least three times after completion, and before baseline samples were taken from the wells. The parastolic sampling pump and tubing were cleaned between sample using 1 to 2 L of deionized water. The water sample was collected in 1000 ml high density polyethylene bottles (HDPE) and stored on ice during transport and in a refrigerator prior to analysis. The sample was split into two subsamples. One subsample was stabilized with H_2SO_4 to a pH<2 and was analyzed for nitrate-N and organic-N. The other subsample was stabilized with HNO_3 to a pH<2 and was analyzed for copper, zinc, and arsenic. Two field blanks were collected at the time of the water sampling. The analyses of these field blanks were use to check for significant constituent contributions from the rinse water. The results indicated that the rinse water did not influence the well water data. All samples were filtered through a 45 mm glass fiber filter and a 45 μm filter before analysis. The water samples were also checked with laboratory duplicates. The data were acceptable if the coefficient of variation was within 5% (CV=s/mean *100).

Soil Sampling

Soil samples were collected from 8 to 10 locations in each of the fertilized plots prior to application and 30, 60, and 90 days post application using a stainless steel auger. The control plots were sampled in the winter (February) and the summer (July). Baseline soil samples were taken in all plots prior to application. Soil was collected by depth at 0 to 3 in, 3 to 6 in, 6 to 12 in, and 12 to 24 in. Well-mixed, composite samples at each depth for each plot were placed in sealable plastic bags, put on ice in coolers, and transported to Clemson University for further processing and analysis. The soil samples were analyzed to determine the concentration of total-N (using the Dumas procedure), nitrate-N (NO_3-N), ammonium-N (NH_4-N), available P expressed as P_2O_5 (using the Mehlich-I procedure), available K_2O, copper, and zinc. The nutrient content in each of the sampled horizons were combined to provide a measure of the total available N, P, K, Cu, and Zn in the top 2 ft of soil.

Rainfall Measurements

Rain was measured at both sites using a recording tipping bucket rain gauge. The annual cumulative rainfall was computed each month and is compared to the average annual rainfall over the last 50 years at the Clarendon County site in Figure 1. Cumulative rainfall at the Chesterfield County site is compared with the 70-year average in Figure 2. Rainfall was above normal while both sites were being established and when the baseline tree measurements were taken. The first application of lagoon effluent occurred in July 1998 (60 lb PAN/ac) at the Clarendon County site. This site was in a drought situation from February 1999 to the end of the study. The first application of turkey litter occurred in May 1999 during drought conditions. A few large rainfall events in the Sand Hills State Forest provided some drought relief in late 2000.

Manure Sampling and Land Application

Manure was sampled and analyzed for plant nutrients prior to each application to determine concentrations of the total ammoniacal nitrogen (TAN = NH_4-N + NH_3-N), TKN, total P (expressed as P_2O_5), total K (expressed as K_2O), copper (Cu), zinc (Zn), and total solids content (TS). The organic-N was calculated as TKN – TAN. For swine lagoon effluent, the plant available N was estimated as: PAN =0.75 TAN + 0.50 Org-N. For surface applied turkey litter, PAN was estimated as: PAN =0.50 TAN + 0.45 Org-N.

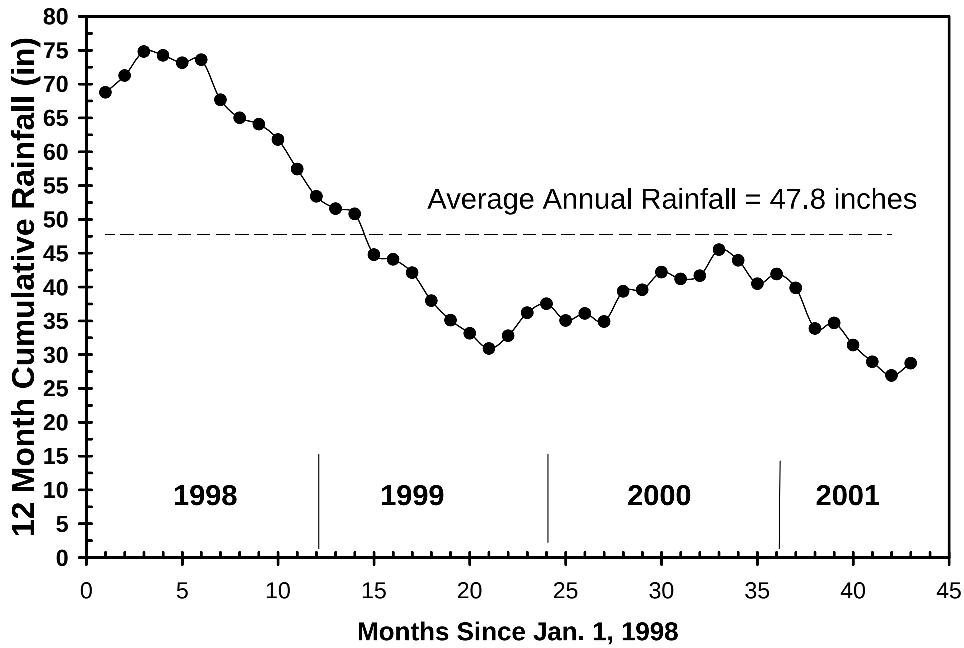

Figure 1. Rainfall at the Clarendon County site as compared to the 50-year average annual rainfall.

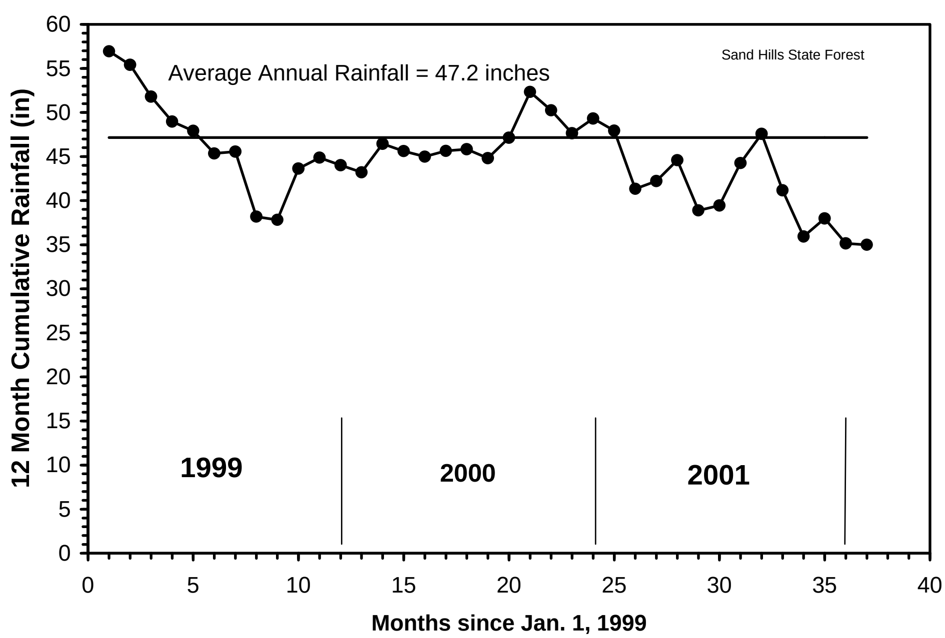

Figure 2. Rainfall in the Sand Hills State Forest site as compared to the 70-year average annual rainfall.

The swine lagoon effluent was applied using a specially designed irrigation system (Lucas et al., 1999). A representative sample of lagoon water was collected 2 to 3 weeks prior to application to determine the amount of effluent to apply. The flow rate for each nozzle was determined using flow calibration equations and pressure measurements 10 ft away from the sprinklers. Lagoon effluent was sampled periodically during application, using a valve on the irrigation pipe that was approximately 30 ft away from the pump discharge. The samples were stored on ice and transported to Clemson University for analysis. The actual amount of plant nutrients applied were computed using the irrigated volume and concentrations observed on the day of application.

Turkey litter was surface applied using a twin auger, side-discharge spreader. Litter samples were collected from several locations within the pile 2 to 3 weeks prior to application. A well-mixed representative sample was analyzed to determine the moisture content and the concentrations of the previously defined nutrients. The estimate of PAN was used to calculate the amount of litter to be applied per acre to provide the desired available nitrogen application rate for a given treatment (Table 1). The spreader was calibrated to provide the required litter application rate (tons/ac) to within 13% of the desired value prior to each application.

Sample manure nutrient analyses and other application data for swine lagoon effluent and turkey litter are given in Tables 2 and 3.

TREE GROWTH RESULTS

Baseline tree measurements were made at both sites in January and February of 1998. Diameter at breast height (DBH) and total height (H) measurements were taken again at both sites during the winters of 2000, 2001, and 2002. Since the time frame of the manure applications were different for the two sites the tree growth data will be summarized separately for each site.

Tree Growth Resulting from Irrigation of Swine Lagoon Effluent

The variation in diameter at breast height and total height during the 4-year study period for the control and fertilized trees at the Clarendon County site are shown in Figures 3 and 4. Each of the points in these figures is the mean of 136 to 192 individual measurements. The regression equations that correspond to the lines shown in the figures are listed in Table 4.

Table 2. Sample application manure nutrient analysis data for irrigated swine lagoon effluent. Data from all three applications of 120 lb PAN/ac in March.

APPLICATION # 1	**March of 1999**			
Constituent	Pre Application Concentration (lb/1,000 gal)	Target Amount (lb/ac)	Application Concentration (lb/1,000 gal)	Actual Amount (lb/ac)
TS	0.47 %		0.31 %	
TAN	8.99		9.07	155
Org-N	0.67		0.58	10
TKN	9.66		9.65	165
PAN	*7.08*	*120*	*7.09*	*121*
P_2O_5	3.41		3.16	54
K_2O	10.91		10.99	188
Cu	0.015		0.013	0.23
Zn	0.010		0.014	0.24
Volume Applied =	4,325 gal			
Application Depth =	0.63 in			

APPLICATION # 2	**March of 2000**			
Constituent	Pre Application Concentration (lb/1,000 gal)	Target Amount (lb/ac)	Application Concentration (lb/1,000 gal)	Actual Amount (lb/ac)
TS	0.56		0.52	
TAN	8.49		9.41	159
Org-N	1.50		1.75	30
TKN	9.99		11.16	189
PAN	*7.12*	*120*	*7.93*	*134*
P_2O_5	3.91		3.58	61
K_2O	11.49		10.74	183
Cu	0.015		0.019	0.31
Zn	0.015		0.018	0.31
Volume Applied =	4,288 gal			
Application Depth =	0.62 in			

APPLICATION # 3	**March of 2001**			
Constituent	Pre Application Concentration (lb/1,000 gal)	Target Amount (lb/ac)	Application Concentration (lb/1,000 gal)	Actual Amount (lb/ac)
TS	0.51		0.42	
TAN	7.74		7.66	110
Org-N	1.75		1.17	17
TKN	9.49		8.83	127
PAN	*6.68*	*120*	*6.33*	*91*
P_2O_5	3.08		2.16	31
K_2O	9.24		8.74	126
Cu	0.030		0.017	0.25
Zn	0.040		0.022	0.32
Volume Applied =	4,598 gal			
Application Depth =	0.67 in			

Table 3. Sample manure analyses and application data for turkey litter applied in the Sand Hills State Forest (Chesterfield County).

Applications in May 1999		**Target = 75 lb PAN/ac**	**Target = 150 lb PAN/ac**	**Target = 300 lb PAN/ac**
Litter Applied (ton/ac)		**2.4**	**4.8**	**9.6**
Constituent	Litter Content (lb/ton)	Amount Applied (lb/ac)	Amount Applied (lb/ac)	Amount Applied (lb/ac)
Moisture	29.74 %	N/A	N/A	N/A
TAN	16.8	40	81	161
Org-N	57.7	139	277	554
TKN	74.5	179	358	715
PAN	**34.4**	**83**	**165**	**330**
P_2O_5	91.2	219	438	876
K_2O	45.4	109	218	436
Zn	0.74	1.8	3.6	7.1
Cu	0.68	1.6	3.3	6.5
Applications in December 1999		**Target = 75 lb PAN/ac**	**Target = 150 lb PAN/ac**	**Target = 300 lb PAN/ac**
Litter Applied (ton/ac)		**2.4**	**4.9**	**9.8**
Constituent	Litter Content (lb/ton)	Amount Applied (lb/ac)	Amount Applied (lb/ac)	Amount Applied (lb/ac)
Moisture	25.03%	N/A	N/A	N/A
TAN	18.2	44	89	178
Org-N	43.2	104	212	423
TKN	61.4	148	301	601
PAN	**28.5**	**68**	**140**	**279**
P_2O_5	90.3	217	442	885
K_2O	46.8	112	229	459
Zn	0.94	2.3	4.6	9.2
Cu	0.83	2.0	4.1	8.1

Table 4. Regression equations for variation of diameter at breast height (DBH, in) and total height (H, ft) with respect to time (t, years) for all treatments at the Clarendon County site.

Treatment	Regression Equations for DBH and H (t = 0 in 1998)	r^2
Control	DBH = 0.3926 t + 5.524 $H = 31.298 + 3.7309\,t - 0.1655\,t^2$	0.9991 0.9985
60 lb PAN/ac March and July	DBH = 0.3532 t + 5.682 $H = 32.699 + 6.2816\,t - 0.8008\,t^2$	0.9989 0.9966
120 lb PAN/ac March	DBH = 0.4241 t + 6.241 $H = 32.583 + 5.7164\,t - 0.4951\,t^2$	0.9926 0.99999
120 lb PAN/ac November	DBH = 0.4387 t + 5.765 $H = 31.677 + 4.6406\,t - 0.2908\,t^2$	0.9958 0.9976

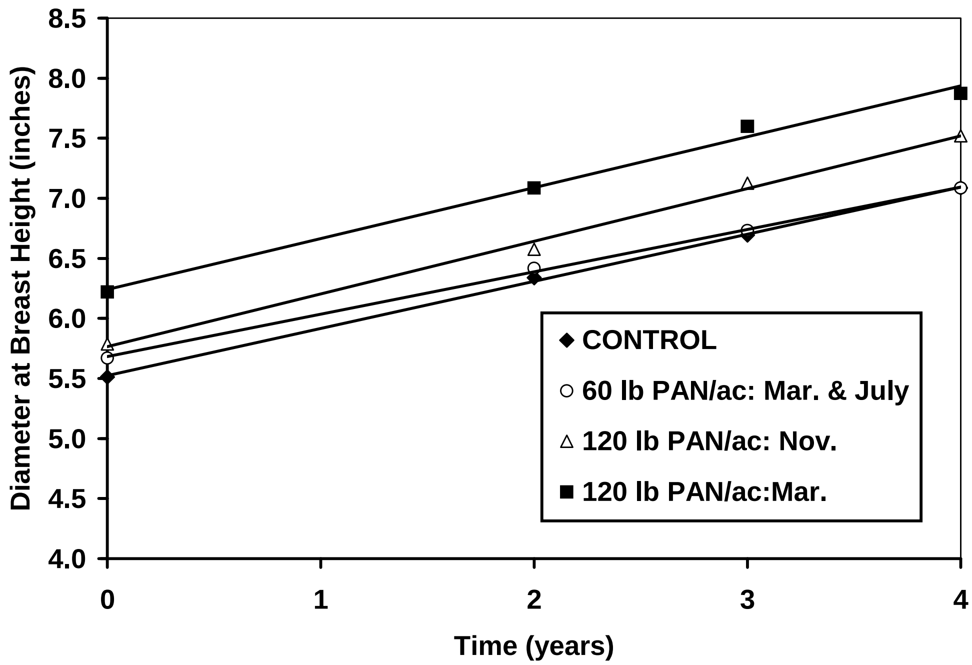

Figure 3. Variation in diameter at breast height for the control and fertilized trees at the Clarendon County site.

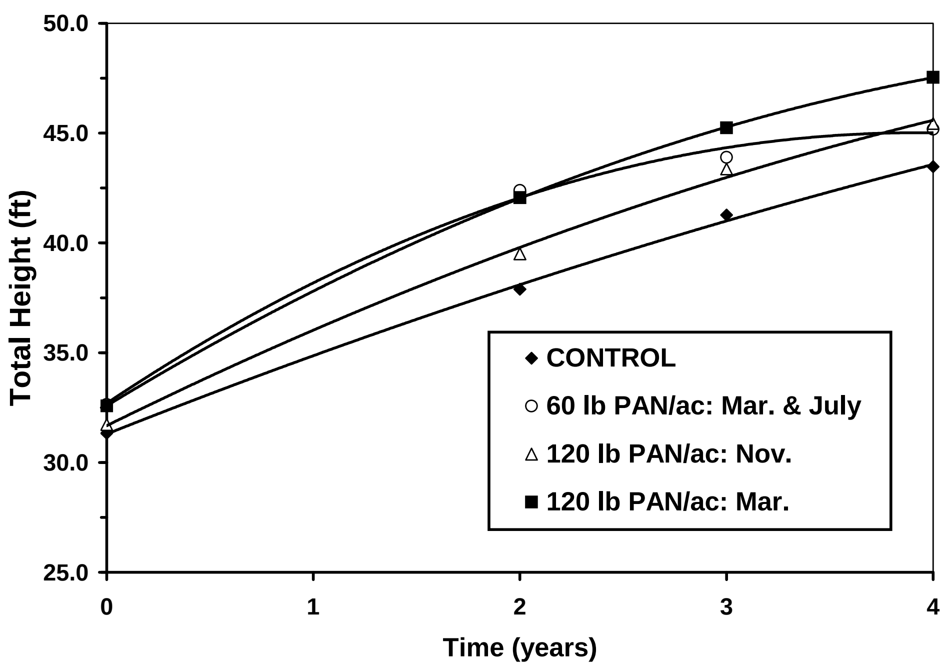

Figure 4. Variation in average total height for the control and fertilized trees at the Clarendon County site.

The DBH varied linearly with respect to time for all treatments (Figure 3). Therefore, the diameter growth rates were all constant during the study period. Since the initial DBH varied by treatment. Therefore, the change in DBH (ΔDBH) was calculated as the difference between the mean DBH measurement at time t and the initial value for each treatment. The trees that received 60 lb PAN/ac in March and November grew at the slowest rate and did not increase in diameter as compared to the control trees. The trees that received 120 lb PAN/ac per year in March and November increased in ΔDBH more than the control trees following the 3rd and 4th years of fertilization. The greatest increase in tree diameter occurred after the third year. The trees that received 120 lb PAN/ac per year in November increased in ΔDBH 13.3% more than the control trees following the 3rd year of fertilization. Application of 120 lb PAN/ac in March resulted in a ΔDBH increase of 16.7% over the control trees following the 3rd year. At the end of the study the trees that received 120 lb PAN/ac in March and November had increased in ΔDBH 5 to 10% more than the control trees respectively. It is believed that the high stand density impaired the increase in tree diameters for all treatments.

The total height measurements varied in a curvilinear (parabolic) manner with respect to time for the control and fertilized trees (Figure 4). As a result, the growth rate for total heights decreased for all trees during the study. It is believed that lack of normal rainfall (Figure 1) and the effects of stand stagnation due to a lack of thinning are the reasons for the decrease in height growth rates. The “leveling off” of total height was the greatest for the trees that received 60 lb PAN/ac in March and July. These plots contained 19% more trees to the acre at the beginning of the study than the other plots that were fertilized.

Following two years of fertilization, all of the fertilized trees increased in height as compared to the control. The greatest increase in the change in H (ΔH) was 48.5% and occurred for the trees that received 60 lb PAN/ac in the spring and summer and occurred following the 2nd year of the study. The trees that received 120 lb PAN/ac in the spring increased in ΔH 44.5% more than the control trees after 2 years. The fall-fertilized trees increased in ΔH the least as compared to the control (18.5%) following 2 years of annual application. As the project continued into the 3rd and 4th years the fertilized trees still increased in height at a greater rate than the control trees. At the end of the study, the trees that received 120 lb PAN/ac in March had increased in ΔH 23.2% more than the unfertilized trees. Fall application (November) of 120 lb PAN/ac yielded a 13.0% increase in the change in H. The trees that were given 60 lb PAN/ac in March and July did not increase in ΔH significantly over the control trees (3.2% more than control). Again, this decrease in growth rate is believed to be due to the persistent drought and the need for thinning. The majority of the enhanced tree growth in this study was in H and not DBH since the stand was dense.

The change in DBH and H does not give the full picture of the value of fertilizing Loblolly pine plantations with swine lagoon effluent. Consideration must also be given to the change in wood value classes and the value of the standing timber. The trees in each of the treatments were divided into wood value classes prior to application, using the 1998 data, and at the conclusion of the study using the data taken in January 2001. The following wood value classes were used: pulp wood (4.5 in ≤ DBH < 9 in), chip-and saw (9 in ≤ DBH ≤ 12 in), saw timber (DBH > 12 in), and wood with no value (DBH < 4.5 in). The TSV and the wood volume in each wood value class and the net stumpage values were calculated for each treatment and are compared in Table 5.

The results presented in the table indicate that the trees that received 120 lb PAN/ac in November and March increased in value by 29.3% and 79.0% more than the control trees respectively. The majority of the increase in value was due to significant increases in the amount of the standing timber that was in the chip and saw value class. The spring application, 120 lb PAN/ac in March, provided the greatest increase in wood volume and value per acre since the trees were able to take advantage of spring rains and had the majority of the growing season available. The trees that received the split application did not increase in value as compared to the control trees. Adequate rainfall rarely occurred in the months following application of 60 lb PAN/ac in July due to drought conditions.

Table 5. Change in wood value classes and net stumpage value per acre for control and fertilized plots at the Clarendon County site.

	CONTROL	120 lb PAN/ac November	120 lb PAN/ac March	60 lb PAN/ac March & July
1998				
Trees/ac	662	562	555	666
TSV = Cords/ac	9.43	8.77	10.34	10.51
Pulp	7.62	7.09	8.36	8.49
Chip & Saw	0.09	0.087	0.10	0.10
Saw Timber	0.00	0.00	0.00	0.00
<4.5 in	1.72	1.60	1.88	1.91
Net Value, $/ac	$132.21	$123.01	$145.03	$147.31
2001				
Trees/ac	562	469	483	566
TSV= Cords/ac	18.55	18.14	21.64	19.40
Pulp	14.00	13.20	15.45	15.97
Chip & Saw	2.85	4.27	6.03	2.48
Saw Timber	0.11	0.00	0.15	0.00
<4.5 in	1.59	0.67	0.00	0.95
Net Value, $/ac	$452.83	$537.68	$719.08	$449.09
Increase, $/ac	$320.62	$414.66	$574.05	$301.78
$/ac/year	$80.15	$103.67	$143.51	$75.45
INCREASE OVER CONTROL		**29.3%**	**79.0%**	**-5.9%**

Note: Net stumpage values used were: $16.43/cord for pulp, $74.14/cord for chip-n-saw, and $79.34/cord for saw timber (Dickens et al, 2002). Trees with a DBH less than 4.5 inches were assigned no value.

Tree Growth Resulting from Surface Application of Turkey Litter

The variation in the tree growth parameters (DBH and H) at the study site located in the Sand Hills State Forest are given in Figures 5 through 8. The regression equations for DBH and H are given in Table 6.

Table 6. Regression equations for variation of diameter at breast height (DBH, in) and total height (H, ft) with respect to time (t, years) for all treatments at in the Sand Hills State Forest.

Treatment	Regression Equations for DBH and H (t = 0 in 1998)	r^2
Control	$DBH = 7.032 + 0.3258\ t - 0.0321\ t^2$ $H = 47.452 + 2.697\ t - 0.3626\ t^2$	0.99997 1.0 *
300 lb PAN/ac: 1X May	$DBH = 6.9536 + 0.1714\ t + 0.0185\ t^2$ $H = 47.704 + 2.951\ t - 0.3151\ t^2$	0.9901 1.0
300 lb PAN/ac: 1X Dec.	$DBH = 7.2671 + 0.1614\ t + 0.0219\ t^2$ $H = 49.875 + 2.3928\ t - 0.2124\ t^2$	0.9997 1.0
150 lb PAN/ac/yr: May	$DBH = 6.8425 + 0.2114\ t + 0.0048\ t^2$ $H = 46.510 + 2.4454\ t - 0.1804\ t^2$	0.9881 1.0
150 lb PAN/ac/yr: Dec.	$DBH = 7.1388 + 0.1195\ t + 0.0324\ t^2$ $H = 47.964 + 1.6989\ t - 0.0403\ t^2$	0.99997 1.0
75 lb PAN/ac/yr: May	$DBH = 7.1847 + 0.1262\ t + 0.0252\ t^2$ $H = 47.980 + 1.8753\ t - 0.1277\ t^2$	0.9912 1.0
75 lb PAN/ac/yr: Dec.	$DBH = 7.3159 + 0.1735\ t + 0.0095\ t^2$ $H = 49.140 + 2.6748\ t - 0.2878\ t^2$	0.9982 1.0

* Only three years of height data were available. Therefore, r^2 was 1.0 for all treatments.

Diameters and heights were measured in 2000. However, the person taking the total height measurements in the winter of 2000 made a uniform error. As a result, these data were lost. The correlations for H given in Table 6 all had values of r^2 equal to 1.0 since only three mean values were obtained per treatment.

All of the DBH regression equations for the Clarendon County site were linear indicating a constant growth rate in diameter. In contrast, all of the DBH equations at the Chesterfield County site were parabolic indicating a variable growth rate in diameter. In addition, all of the parabolic equations that described the change in DBH with respect to time for the fertilized trees curved upward indicating an increase in the DBH growth rate. The regression equation for the control trees curved downward indicating a decrease in DBH growth rate. Fertilization of trees with turkey litter significantly increased the change in DBH (Δ DBH) as compared to the change in DBH for the control trees. One-time application of 300 lb PAN/ac in May and December provided a 71% to 107% increase in ΔDBH at the end of the study as compared to the control trees. Annual application of 150 lb PAN/ac provided an additional increase in ΔDBH of 49% for the May application and 118% for the December application by the end of the study. Annual application of 75lb PAN/ac provided an increase in ΔDBH of 64% regardless of time of application. All of the regression equations for H as a function of time were parabolic indicating a variable growth rate for total height. The rate of change in H (ΔH) for the control trees was greatly reduced by drought and poor soil fertility near the end of the project as indicated in Figure 7. Comparison of the change in H between the fertilized and control trees at the end of the study indicated that:

- One-time application of 300 lb PAN/ac provided an additional 57% in ΔH for the May application and 92% for the December application,
- Annual application of 150 lb PAN/ac increased the ΔH by 91% for the May application and 142% for the December application, and
- Annual application of 75 lb PAN/ac increased ΔH by 48% to 67% as compared to the control ΔH.

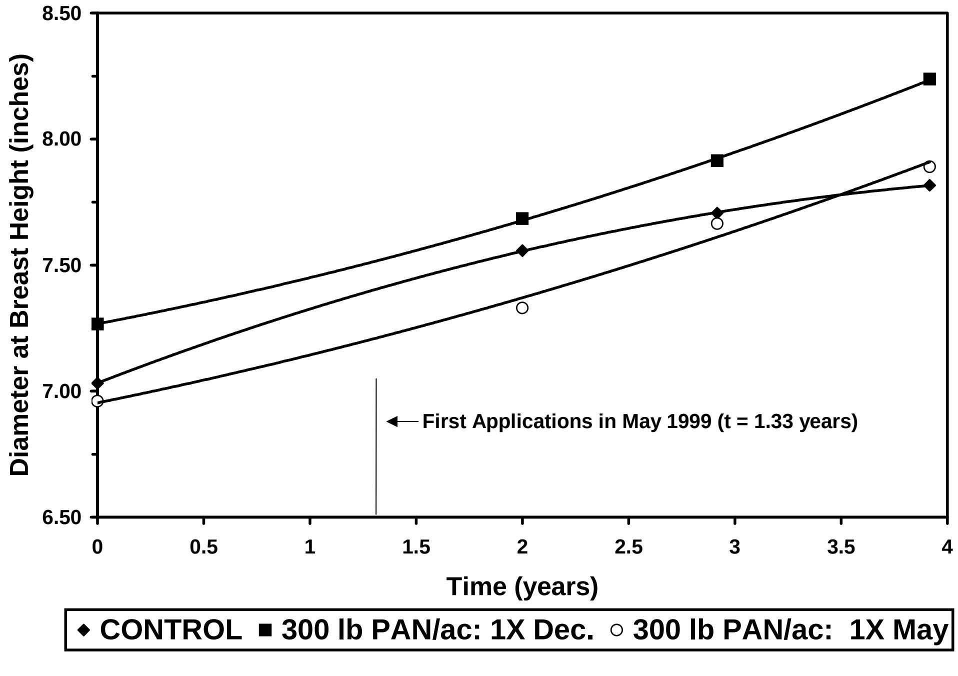

Figure 5. Variation in DBH for the control trees and the trees that received one-time applications of turkey litter.

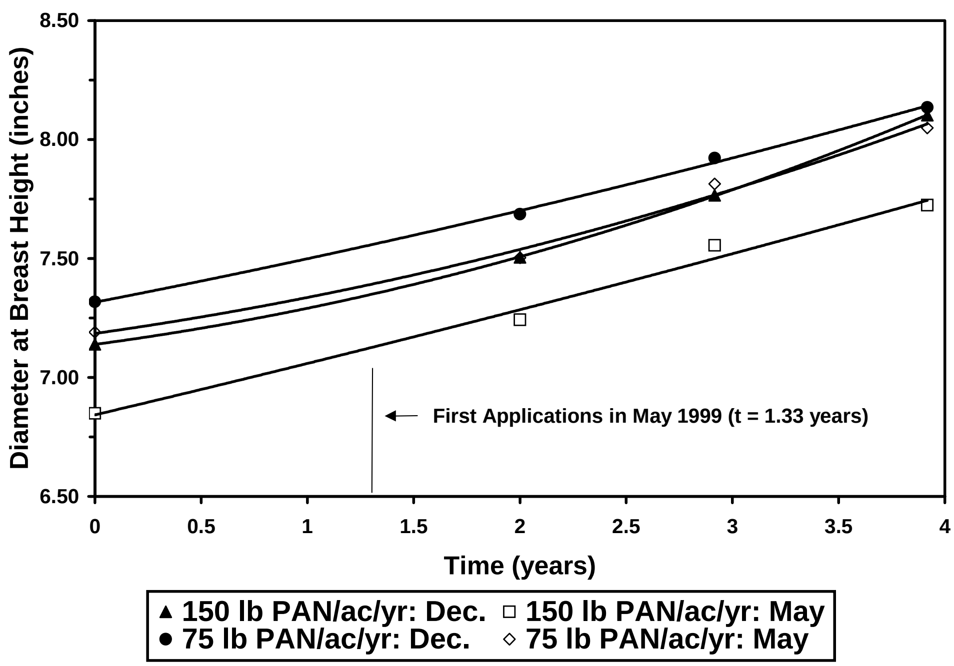

Figure 6. Variation in DBH for the trees that received annual applications of turkey litter.

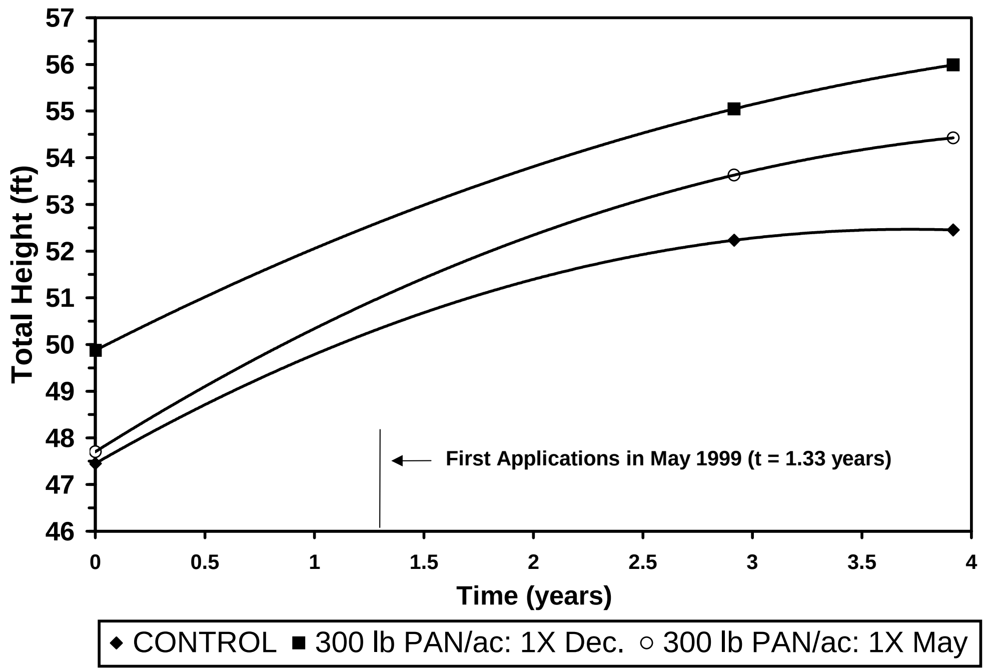

Figure 7. Variation in H for the control trees and the trees that received one-time applications of turkey litter.

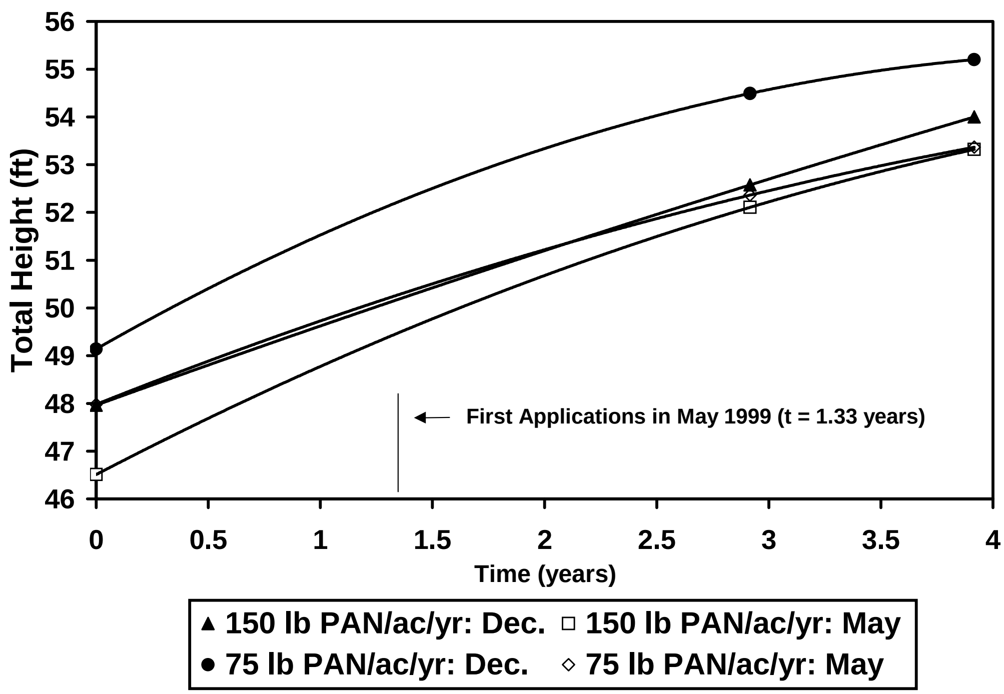

Figure 8. Variation in H for the trees that received annual applications of turkey litter.

The change in wood value classes and the net stumpage value per acre are compared for all fertilized and control trees in Table 7. The same wood value assumptions were made as described previously for the Clarendon County site. Fertilization of pine trees with turkey litter provided increases in wood value per acre of 74.6% to 150.1% as compared to the control trees over the same time period. The highest increase in wood value occurred for the trees that received one time application of 300 lb PAN/ac in December. On the average, fertilization with turkey litter increased the wood value by $16 /ac per year more than the control trees and was much lower than for the Clarendon County site. Addition of any amount of turkey litter gave a significant increase in wood volume due to the poor initial soil fertility.

SUMMARY OF SOIL DATA RESULTS

The analysis of plant nutrients in animal manure includes the soluble and insoluble fractions. After manure is applied to the soil only a fraction of the nutrients would be expected to show up on a standard soil test, which generally only provides a measure of the available nutrients. The applications of swine lagoon effluent and turkey litter were made based on an estimate of the plant available nitrogen content (Table 2 and 3). The amount of nitrogen released can vary greatly depending on a variety of factors. Some of the most important are soil pH, moisture content, temperature, and the degradability of the organic-N. Therefore, data were also taken to determine the total amount of N, P, and K applied. The soil in all of the plots was sampled prior to the initial application at both sites to a depth of 2 ft. The soil in the fertilized plots was sampled prior to each application and 30, 60, and 90 days post application. These soil data provided the means to observe the cumulative change in plant available nutrients following each application with respect to time. The control plots were sampled each winter and summer during the project. Large amounts of soil data were collected at both sites. The purpose of this section is to provide a summary of the most important impacts on soil fertility resulting from application of liquid (swine lagoon effluent) and solid manure (turkey litter) in Loblolly pine plantations.

Initial Soil Fertility at Both Sites

The soil nutrient content was measured to a depth of 2 feet prior to application in all plots at each site. These data were averaged to provide the overall baseline means for each site. The baseline soil data for the Sand Hills State Forest and the Clarendon County sites are compared in Table 8. In addition, soil data from the control plots taken at each site during the final winter of the project (January 2001) are also compared. The total mineralized nitrogen (TMN) is the sum of the nitrate and ammonium nitrogen and is a measure the plant available-N in the soil. At the beginning of the study, the soil in the Sand Hills State Forest contained only 3.1 lb of available nitrogen per acre in the top 2 ft of soil. The soil at the Clarendon County site contained 10.9 lb TMN/ac prior to the first application. Although this is not a large amount of nitrogen the Clarendon County soil had 3.5 times more available-N than the Sand Hills State Forest soil. Loblolly pine trees need a minimum of 13 lb of available P_2O_5/ac to support good growth rates. The soil in the Sand Hills State Forest contained only 4.2 lb P_2O_5/ac as compared to 62.7 lb P_2O_5/ac in Clarendon County. Potassium (K) is an important nutrient for any evergreen plant. The soil in Clarendon County had more than twice as much K as the soil in the Sand Hills State Forest.

Table 7. Change in wood value classes and net stumpage value per acre for control and fertilized plots in the Sand Hills State Forest.

	CONTROL	300 lb PAN/ac DEC 1X	300 lb PAN/ac MAY 1X	150 lb PAN/ac/yr DEC	150 lb PAN/ac/yr MAY	75 lb PAN/ac/yr DEC	75lb PAN/ac/yr MAY
1998							
Trees/ac	155	142	159	136	149	141	150
TSV = Cords/ac	5.54	5.72	5.64	5.07	4.97	5.65	5.65
Pulp	4.13	4.26	4.20	3.78	3.70	4.21	4.21
Chip-N-Saw	0.86	0.89	0.88	0.79	0.77	0.88	0.88
Saw Timber	0.01	0.01	0.01	0.01	0.01	0.01	0.01
< 4.5 in	0.54	0.56	0.55	0.49	0.48	0.55	0.55
Net Value, $/ac	$133.44	$137.69	$135.73	$122.06	$119.60	$136.04	$136.08
2001							
Trees/ac	146	136	151	129	146	136	145
TSV = Cords/ac	6.57	7.89	7.87	6.96	7.15	7.60	7.66
Pulp	4.63	4.23	5.14	4.63	4.30	4.68	4.53
Chip-N-Saw	1.54	2.91	2.06	2.07	2.17	2.31	2.19
Saw Timber	0.07	0.11	0.10	0.05	0.10	0.22	0.26
< 4.5 in	0.34	0.63	0.57	0.21	0.58	0.39	0.68
Net Value, $/ac	$197.34	$297.51	$247.27	$235.99	$241.68	$268.03	$259.45
Increase, $/ac	$63.89	$159.82	$111.54	$113.93	$122.09	$131.99	$123.37
$/ac/yr	$16.30	$40.77	$28.45	$29.06	$31.14	$33.67	$31.47
INCREASE OVER CONTROL		**150.1%**	**74.6%**	**78.3%**	**91.1%**	**106.6%**	**93.1%**

Note: Net stumpage values used were: $16.43/cord for pulp, $74.14/cord for chip-n-saw, and $79.34/cord for saw timber. Trees with a DBH less than 4.5 inches were assigned no value.

The pH of the soil at both sites was much lower than the 5.8 to 6 that are recommended for most agricultural crops. Low soil pH tends to slow down many of the microbial processes that are responsible for the mineralization of organic-N and the conversion of ammonium-N to nitrate-N in the soil. Therefore, the release of organic-N is often much slower in forest soils than in an agricultural field.

Table 8. Comparison of the nutrients and pH in the top 2 feet of soil at the two study sites before application (baseline data) and in the control plots at the end of the study.

	Baseline Site Means		**Means in Control Plots at End of Study (January 2001)**	
Soil Constituent	Sand Hills State Forest - 1999 (lb/ac)	Clarendon County - 1998 (lb/ac)	Sand Hills State Forest (lb/ac)	Clarendon County (lb/ac)
Nitrate-N	0.5	2.4	0.1	0.4
NH_4-N	2.6	8.5	1.0	0.7
TMN	3.1	10.9	1.1	1.1
TN	1362	1160	1289	1441
Organic-N	1359	1149	1288	1440
P_2O_5	4.2	62.7	2.3	38.5
K_2O	37.8	84.2	40.5	49.3
Cu	2.1	2.3	0.9	0.3
Zn	6.7	2.7	1.8	2.1
pH	4.79	5.54	4.74	5.35

The total nitrogen was also measured allowing an estimate of the organic-N in these forest soils. Both sites were very high in organic-N and accounted for 99% or more of the total-N in the soil. Organic-N is not available to the trees and generally requires soluble N for the required decomposition processes. As a result, a significant amount of soluble-N from the applied manure would be expected to be immobilized due to the high organic matter content.

At the end of the study period at each site the fertility of the soil in the control plots had decreased substantially at each site. Available N, P, Cu, and Zn decreased at both sites. Potassium was not significantly different in the Sand Hills State Forest but fell by 41% in Clarendon County.

Effect of Manure Applications on Available N, P, and K in Forest Soils

Soil in all plots was sampled by depth to 2 ft. Roots of 10 to 22 year old pine trees in Coastal Plains and Sand Hills soils typically penetrate beyond 2 feet. Therefore, all of the nutrients in the top 2 ft of soil were in the active root zone.

The change in available N, P, and K in the top 2 feet of soil was plotted with respect to sampling time for each application of each treatment. The plots were used to determine the maximum amount of a given plant nutrient that appeared on soil test and the time required for release in the soil. Sample plots for a spring application of swine lagoon effluent and a fall application of turkey litter are given in Figures 9 through 12.

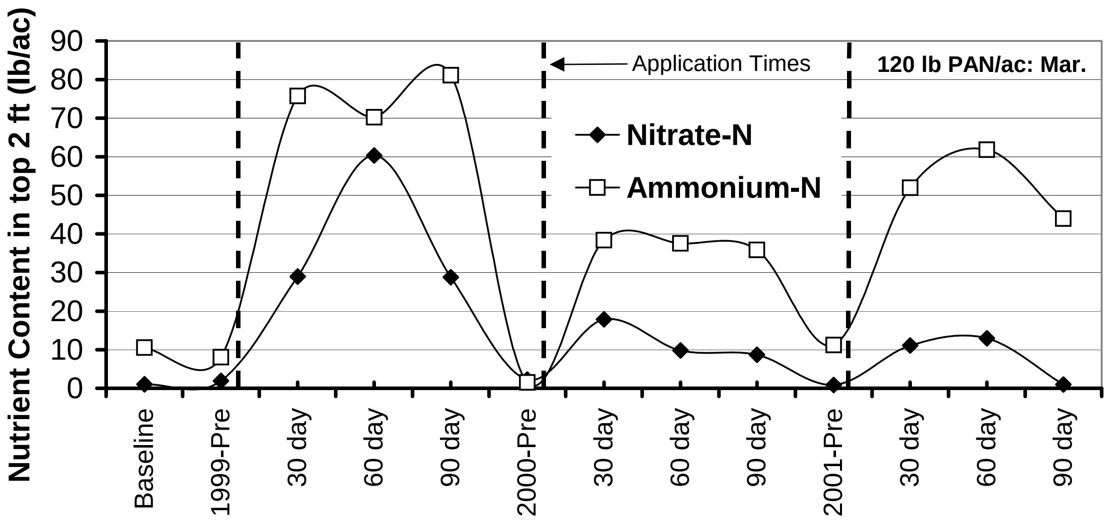

Figure 9. Mineralized nitrogen in the plots that received 120 lb PAN/ac from swine lagoon effluent in the spring (Clarendon County, top 2 ft of soil).

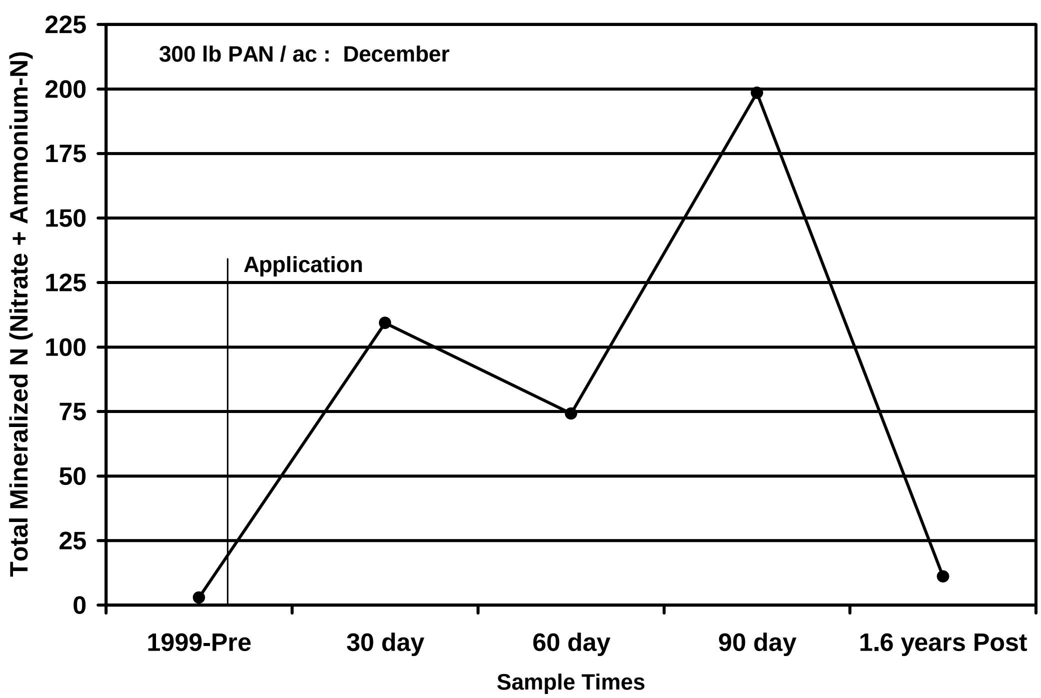

Figure 10. Mineralized nitrogen in the plots that received a one-time application of turkey litter to provide 300 lb PAN/ac in December (Sand Hills State Forest, top 2 ft of soil).

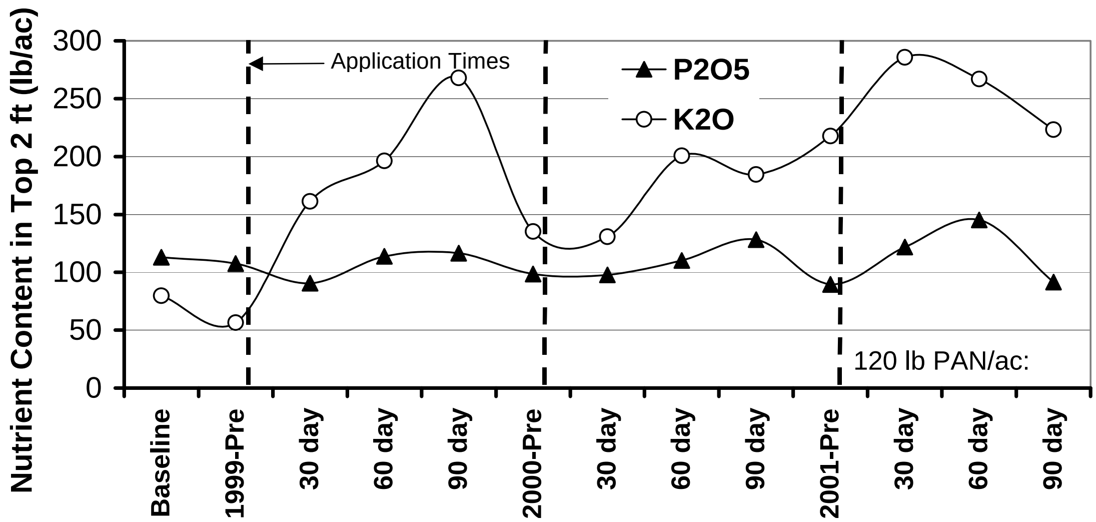

Figure 11. Soil test P_2O_5 and K_2O in the plots that received 120 lb PAN/ac in the spring using lagoon effluent (Clarendon County, top 2 ft. of soil).

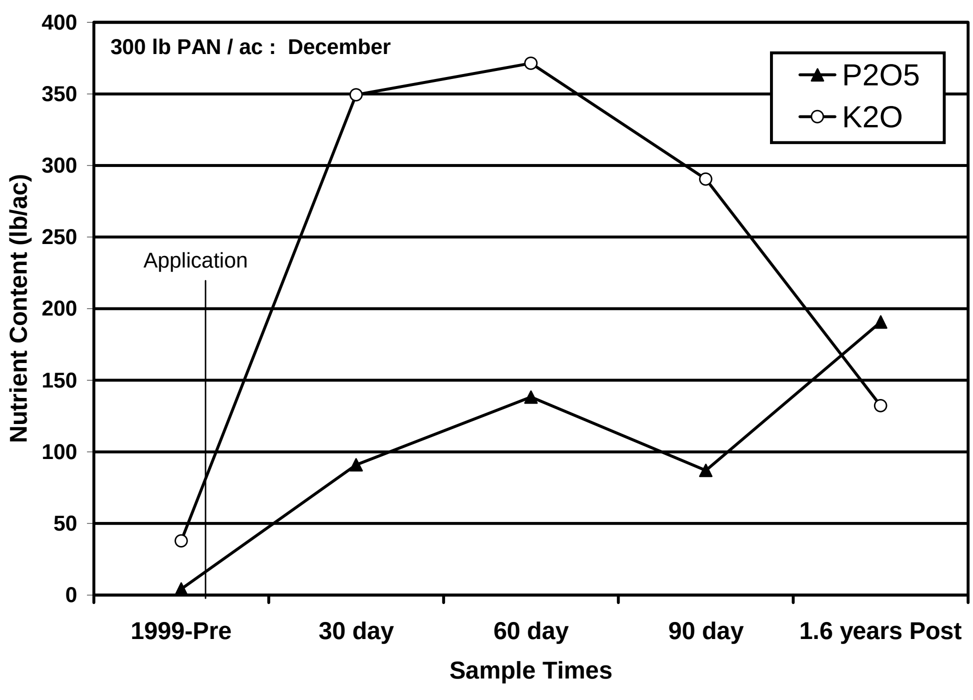

Figure 12. Soil test P_2O_5 and K_2O in the plots that received 300 lb PAN/ac one time in December using turkey litter (Sand Hills State Forest, top 2 ft. of soil).

Sample Plots of Mineralized N with Respect to Time Following Application

A well-defined peak in the soil data was observed in the mineralized nitrogen (nitrate-N and ammonium-N). The spring application of swine lagoon effluent that was intended to provide 120 lb PAN/ac resulted in a well-defined peak in ammonium-N 30 days following the application (Figure 9). The nitrate-N peak lagged the ammonium-N peak by 30 days since additional time was required for the nitrifying bacteria to convert the applied NH_4-N to NO_3^--N. This actually took longer than expected due to the low soil pH. However, during the second and third applications, 1999 and 2000, very little nitrate-N was observed. This was believed to be the result of the drought conditions that prevailed at the Clarendon County site as the study progressed. Low soil moisture greatly reduces nitrification rates. Application of turkey litter in the dry sandy soil of the Sand Hills State Forest resulted in very low nitrification rates. Only 3.7 lb of NO_3^--N per acre was formed following application of turkey litter intended to provide 300 lb PAN/ac as compared to 193 lb NH_4-N/ac. As a result, the sum of nitrate and ammonium nitrogen (TMN) was plotted with respect to sampling time for this application (Figure 10). In general, the TMN content of the soil fell to near pre-application values prior to the next annual application. Very little available-N was carried over to the next year.

Sample Plots of Soil Test P and K with Respect to Time Following Application

Sample data for variation of the phosphorous and potassium in the soil at the Clarendon County sites is shown in Figure 11. The P associated with application of 120 lb PAN/ac from swine lagoon effluent resulted in modest increases in soil test P_2O_5 following each application, but fell to near baseline levels prior to each application. Soil test P_2O_5 is a measure of the available P and does not include the stable organic fraction. A large build-up in soil test P was not observed in the plots that were fertilized with lagoon effluent. The lack of a build-up in soil test P was due to the fact that the PAN:P_2O_5 ratio of the manure was about 2 and the excess soluble P was used to satisfy soil fixation capacity. In contrast, the K_2O concentration rose sharply following application and fell back to a lower, yet elevated level prior to the next application. This increase in K would be very beneficial for any type of evergreen plant.

The PAN:P_2O_5 ratio in turkey litter was on the order of 0.35. Therefore, a large amount of total P was applied relative to the available nitrogen. Consequently, large increases were observed in the soil test P_2O_5 following litter applications. A sample data set is given in Figure 12. Large amounts of potassium were also present in the turkey litter relative to the PAN and a large increase in K_2O was observed following each application. One-time application of turkey litter to provide 300 lb PAN/ac in December resulted in peak soil tests for P and K in February. The soil content of both nutrients decreased significantly by 90 days post application. The soil was sampled again in the plots that received a one-time application of litter 1.6 years post application. Soil test K decreased further but was still significantly above pre –application levels indicating a long-term benefit. Soil test P 1.6 years post application was elevated above the 90 day soil test. These data point out that a portion of the soluble P resulting from litter application can be bound in an unstable organic form, that does not show up on soil test, and can be released at a later date. This was observed following a few, but not all applications of litter and lagoon effluent.

Maximum Change in Available N, P, and K in Response to Manure Application

The effectiveness of the applications of litter and lagoon effluent was determined by observing the maximum amount of available N, P, and K present in the top 2 feet of soil following each application. The change in available nutrient was calculated as the difference between the peak soil test value and the initial soil test value (prior to each application) divided by the total amount of nutrient applied with the animal manure. The sampling time associated with the peak soil test was also recorded (days to peak).

Analyses of variance were performed to determine if the month of application had a statistically significant effect on the change in available N, P, and K, and the time required for the maximum to occur (days to peak). The results for the turkey litter and swine lagoon effluent applications are given in Tables 9 and 10.

Table 9. Effect of month of application on the amount of applied N, P, and K that was observed in the top 2 feet of soil and days to peak soil test following applications of turkey litter.

	Mean for May Applications	Mean for December Applications	Overall Mean	Standard Deviation
ΔTMN_P / $TN_{APPLIED}$	0.12	0.20 *	0.16	0.06
Days to Peak	51	78**		15
Δ $P_2O_{5\ P}$ / $P_2O_{5\ APPLIED}$	0.22	0.19	0.21	0.10
Days to Peak	64	48	56	19
ΔK_2O_P / $K_2O_{APPLIED}$	0.93	0.65 **		0.19
Days to Peak	60	48	54	21

* Indicates significant difference at the 90% level

** Indicates significant difference at the 95% level

Table 10. Effect of month of application on the amount of applied N, P, and K that was observed in the top 2 feet of soil and days to peak soil test following applications of swine lagoon effluent.

	Mean for November Applications	Mean for March Applications	Mean for July Applications	Overall Mean	Standard Deviation
ΔTMN_P / $TN_{APPLIED}$	0.36	0.38	0.42	0.38	0.18
Days to Peak	30	50**	30	40	11
Δ $P_2O_{5\ P}$ / $P_2O_{5\ APPLIED}$	0.30	0.81	0.25	0.54	0.58
Days to Peak	50*	75	70	65	10
ΔK_2O_P / $K_2O_{APPLIED}$	0.67	0.52	0.68	0.60	0.42
Days to Peak	30**	65	60	55	24

* Indicates significant difference at the 90% level

** Indicates significant difference at the 95% level

The results for turkey litter applications summarized in Table 9 indicated the following.

- Significantly more nitrogen was released following the December applications of turkey litter as compared to the May applications. This increase in N release was attributed to the fact that more rainfall occurred in the months following the applications in December as compared to May. On the average, only 16% of the total nitrogen applied in the turkey litter was available for use by the trees.

- The initial estimate of PAN for turkey litter was 46% of the total nitrogen. Therefore, the actual available N was about two thirds lower than expected.
- Application of litter in December required 78 days for the maximum release of N to occur as compared to 51 days in May. Higher soil temperatures would be expected to increase the mineralization rate of organic-N.
- Only 21% of the total P_2O_5 applied in the litter was observed as available P_2O_5 in the top 2 feet of soil 56 days following application. There was no significant difference based on the month of application.
- Significantly more of the K_2O in the surface applied poultry litter appeared as available K_2O in the soil following the May applications. On the average 93% of the applied K_2O showed up on soil test following the May applications as compared to 65% for applications in December. The amount of time for the maximum change in soil test K_2O was highly variable with an average of 55 days.
- In most cases, it is assumed that all of the P_2O_5 and K_2O in litter are available. This was obviously not the case for surface application of turkey litter in a pine plantation.

Irrigated swine lagoon effluent was a better source of available nitrogen than surface spread turkey litter (Table 10). The month of application did not have significant effect on N availability. On the average, 38% of the total nitrogen applied in the lagoon effluent became available within 40 days post application. The initial estimate of available N for lagoon effluent was about 72%. Therefore, the PAN estimates over predicted availability by a factor of about 1.9. Phosphorous from the irrigated effluent was also more available than for the poultry litter. Fifty-four percent of the applied P_2O_5 appeared on soil test. The maximum soil test P_2O_5 was observed 73 days post application for the March and July applications and 50 days following the November applications. Sixty percent of the applied K_2O appeared on soil test 55 days post application. Substantially less of the applied P_2O_5 and K_2O impacted soil fertility than expected at the Clarendon County site.

Effect of Lagoon Effluent and Litter Applications on Soil Test Zinc and Copper

Only small amounts of copper and zinc were added to the soil with each application of swine lagoon effluent. Application of lagoon effluent to provide 120 lb PAN/ac per year added about 0.3 lb of Cu and Zn per acre per year (Table 2). After three years of application, the soil in the control and fertilized plots contained 0.6 lb Cu/ac in the top 2 ft of soil, a value that was 74% lower than the site baseline. However, irrigating lagoon effluent to provide 120 lb PAN/ac for three years did not significantly change the amount of available Zn in the soil. The baseline and ending values were both 2.7 lb Zn/ac.

Each application of turkey litter added 1.6 to 8.1 lb of copper per acre and 1.8 to 9.2 lb of zinc per acre depending on the application rate (Table 3). Larger application rates, such as 300 lb PAN/ac, provided 8.1 lb Cu/ac and 9.2 lb Zn/ac. In this case, 32% of the applied copper appeared on soil test in the top 2 ft of soil 90 days post application. The top 2 feet of soil contained 2.3 times more Cu per acre than the initial value 1.6 years following litter application. Soil test zinc fell drastically following litter application and then increased 1.6 years post application. At the end of the study, the Cu content in the top 2 ft of soil ranged from 2.1 to 3.9 lb /ac whereas the control plots averaged 0.9 lb Cu/ac. The site baseline value was 2.1 lb Cu/ac. One-time applications of litter to provide 300 lb PAN/ac and annual applications of 150 lb PAN/ac resulted in a sustained increase in available Cu. The available Zn in the top 2 ft of soil at the end of the study was lower than the site baseline values for the control and all fertilized treatments (1.8 to 4.8 lb Zn/ac versus 6.7 lb Zn/ac for baseline). Therefore, a build-up in available Zn was not observed. It is believed that much of the Zn was fixed into organic compounds that do not appear on soil test.

SUMMARY OF GROUNDWATER MONITORING WELL RESULTS

Groundwater quality was monitored at both sites throughout the study period. No detrimental impacts were observed at either site during the study period.

Samples were collected prior to the first application and every quarter there after at each site. The maximum allowable concentration for nitrate-N is 10 ppm. None of the well water samples contained more than 5 ppm nitrate-N and the highest concentration occurred for a well in a control plot at the Clarendon County site 66 days following installation. The excess nitrate was believed to be due to contamination by topsoil during well installation. Only 6 well samples were above 3 ppm, which is often the level that is considered indicative of impact by human activities. All six of these observations occurred at the Clarendon County site. The maximum nitrate concentration observed in the well water from the Sand Hills State Forest was 2.09 ppm.

Well water samples were also analyzed for organic-N, copper, zinc, and arsenic. The maximum observed concentrations and the maximum allowable concentrations are given in Table 11. None of the concentrations were close to the maximum allowable concentrations. Therefore, no detrimental effects were observed on groundwater from application of swine lagoon effluent or turkey litter during the study period.

Table 11. Maximum concentrations observed in monitoring wells at both sites.

Parameter	Permissible Concentration (ppm)	Maximum Observed at Clarendon County Site (ppm)	Maximum Observed at Sand Hills Site (ppm)
Nitrate-N	10	5.00*	2.09
Organic-N	--	0.50	0.63
Copper	1.0	0.07	0.042
Zinc	5.0	1.96	0.080
Arsenic	0.05	0.03	0.028

* Observed in well in control plot 66 days post installation.

CONCLUSIONS

- No detrimental effects were observed in groundwater for any application level (60 to 300 lb PAN/ac) at the two sites during the study period.
- Irrigation of swine lagoon effluent to provide 120 lb PAN/ac each March provided the best tree growth response since it coincided with the spring flush of growth, and more rainfall occurred in the months following fertilization.
- Spring application of 120 lb PAN/ac yielded an additional $253 per acre more than the control trees (79% more than control).
- Fall application of swine lagoon effluent to provide an estimated 120 lb PAN/ac/yr provided a 29% increase in wood value as compared to the control trees.

- Providing two applications of lagoon effluent, 60 lb PAN/ac in March and July, did not provide an increase in wood value. The dry conditions following the July application and a higher than optimal stand density is believed to be the reasons for this poor performance.
- Surface application of turkey litter at all rates provided significant increases in wood value due to the poor initial soil fertility and low stand density. The increase in wood value as compared to the control trees ranged from 75% to 150%.
- Lagoon effluent and turkey litter was applied based on an estimate of the plant available nitrogen (PAN) in the material. It was estimated that about 72% of the total N in lagoon effluent would be available. However, soil data indicated that only 38% of the total N in the irrigated effluent appeared as available-N on soil test.
- Turkey litter was spread assuming that 46% of the total N would be available. However, the increase in the available N in the soil from surface application of litter ranged from 12% to 20% of the total N applied depending on the month of application.
- The amount of total P applied that appeared as available-P in the soil ranged from 21% for surface applied turkey litter to 54% for irrigated swine lagoon effluent.
- The availability of applied K ranged from 60% to 93% depending on manure type and month of application.
- Significant build-up of Cu and Zn was not observed in the soil following three applications of swine lagoon effluent since very little was applied. The amount of Zn and Cu applied from turkey litter was substantially greater than for lagoon effluent. A build-up of available Zn was not observed. The sustained increase in Cu was related to the amount of Cu applied.

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References

Baily, R.L., G.E. Grider, J.W. Rheney, and L.V. Pienaar. 1985. Stand Structure and Yields for Site-Prepared Loblolly Pine Plantations in the Piedmont and Upper Coastal Plain of Alabama, Georgia, and South Carolina. University of Georgia Research Bulletin 328. 118p.

Dickens, E.D., C.E. Dangerfield, Jr., and D.J. Moorhead. 2002. Short Rotation Management Options for Slash and Loblolly Pine Plantations, Including Fertilization, Thinning, and Pinestraw in South Georgia. 5 pp. Daniel B. Warnell School of Forest Resources, The University of Georgia, Athens, GA 30602.

Lucas, W.D., J.P. Chastain, and E.D. Dickens. 1999. Water quality impact of using swine lagoon effluent to fertilize loblolly pine plantations. Presented at the 1999 ASAE/CSAE-SCGR Annual International Meeting, ASAE Paper no. 994072. ASAE, 2950 Niles Rd., St. Joseph, MI 49085-9659 USA.