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Using Poultry Litter to Fertilize Longleaf Pine Plantations for Enhanced Straw Production

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Abstract. *Longleaf pinestraw is high-quality landscape mulch that is in large demand in many urban and suburban areas of the Southeastern United States. In many cases, the annual income from pinestraw production is just as important to forestland owners as the value of the standing timber.*

A three-year study was conducted in an intensively managed longleaf pine plantation located in Kershaw County, SC. The purpose of the project was to compare the pinestraw production between unfertilized trees, trees fertilized with commercial fertilizer (17% N - 17% P_2O_5 - 17% K_2O), and trees fertilized with poultry litter from a turkey grow-out barn. The commercial fertilizer and the poultry litter were applied so as to provide about 90 kg of plant available N (PAN) per hectare.

The results of the study indicated that the enhancement of pinestraw production using granular fertilizer and turkey litter was similar. Providing a one-time application of 90 kg PAN/ha increased pinestraw production by 29% over the three-year study. The return on investment ranged from 968% for the granular fertilizer to 1590% for turkey litter. The advantages of using poultry litter were the greater persistence of plant available N and K in the soil, the addition of key minor plant nutrients, a small but sustained increase in soil pH, and a slight increase in cationic exchange capacity.

Keywords. Land application, manure management, forestry

Introduction

Pinestraw is high-quality landscape mulch that is in large demand in many urban and suburban areas of the Southeastern United States. The most valuable straw is produced by the longleaf pine (*Pinus palustris*). In many cases, the annual income from pinestraw is just as important to the forestland owner as is the production of lumber.

Annual harvest of longleaf pinestraw can deplete the pool of plant nutrients that is recycled in a forest stand and reduce a stands health and productivity (Blevins et al., 2005). Periodic fertilization, that is fertilization every four to six years, has been shown to not only maintain stand productivity but to increase pinestraw production. Fertilized research plots in North Carolina produced 25% to 50% more pinestraw as compared to control plots (Blevins et al., 2005).

Periodic fertilization of longleaf pine stands has also been shown to enhance tree growth. Trees in research plots located in the North Carolina Sandhills increased in tree diameter by 49% as compared to unfertilized trees after the second growing season (Blevins et al., 2005).

Over fertilization of longleaf pine trees must be avoided to prevent damage to the stand. The maximum recommended single-application fertilization rates for longleaf pine are 112 kg N/ha, 67 kg P_2O_5/ha, 67 kg K_2O/ha, 112 kgCa/ha, and 28 kg Mg/ha (Blevins et al., 2005). Additional details related to stand management are provided by Allen (1987), Morris et al. (1992), and Blevins et al. (2005).

A three-year study was conducted in an intensively managed, 22-year old longleaf pine plantation located in Kershaw County, South Carolina. The goal of the project was to compare the pinestraw production between unfertilized trees, trees fertilized with granular fertilizer (17% NH_4^+-N - 17% P_2O_5 - 17% K_2O), and trees fertilized with poultry litter from a turkey grow-out barn over a period of three years. The commercial fertilizer and the poultry litter were applied so as to provide about 90 kg of plant available N (PAN) per hectare which was 20% less than the maximum recommended application rate.

The objectives were to measure the affect of fertilization with the two nutrient sources on:

1. tree diameter and height,
2. pinestraw production, and
3. the change in soil-test nitrate-N, P, K, pH, and cationic exchange capacity.

Experimental Methods

Many of the soils in the Sand Hills Region of South Carolina are not very suitable for row-crop production. They tend to be deep, excessively drained sandy soils. As a result, many landowners have planted loblolly and longleaf pine plantations to produce wood for lumber and pinestraw for landscape use.

The slow growing longleaf pine is uniquely suited to the dry soil conditions of the Sand Hills Region and is currently the pine tree recommended by the South Carolina Forestry Commission for planting new fields.

The longleaf pine provides two sources of income for the landowner. Straw from the longleaf pine is considered to be one of the most valuable, long lasting materials for use as landscape mulch and can provide annual income. The other product is high-quality wood that is used for structural lumber, flooring, paneling, plywood, and long structural poles.

Kershaw County, located in the eastern part of the SC Sand Hills, is a very rural county that is the main base of operations for a large turkey production company. As a result, grow-out farms are common in the county and are located near loblolly and longleaf pine plantations.

The project site was located in north Kershaw County, SC in a 4.8 ha longleaf pine stand. The field was machine-planted in longleaf pine in 1981. In subsequent years, trees were hand-planted to replace mortality. The trees were planted 1.8 m apart at a row spacing of 3 m. The site had not been thinned and was intensively managed for production of straw. Intensive management and a high tree density resulted in a pine plantation that was free of weeds and under story woody plants (Figure 1).

Figure 1. Tagged longleaf pine trees in a study plot.

The baled pinestraw was marketed directly to residential customers though a landscape contractor, and typical straw production was on the order of 740 bales per hectare per year.

The soil types in the plantation were a combination of Lakeland and Ailey. Both of these soils were deep sands with very poor fertility (CUE, 2001). These soils drain excessively, and were characterized by a deep water table. The depth to the subsoil ranged from 30 cm (Ailey) to over 80 cm (Lakeland). Before planting with pine trees, the field was used to produce soybeans which provided some residual fertility.

Description of Treatment Plots

Three rectangular plots were defined near the center of the field. Great care was taken to define plots with the same area and with the same number of trees. However it was not possible to fit three identical plots in the location designated by the cooperating landowner. Two of the plots had 46 trees and one had 55 trees. The tagged tree area of the plots ranged from 0.052 to 0.055 ha. An unfertilized buffer of 6 m or more was provided around the plots.

The study included three plot treatments with no plot replication. The plot with 55 trees was assigned the unfertilized control treatment. One of the 46-tree plots was fertilized to provide 90 kg N/ha using turkey litter. The remaining plot was fertilized with a complete granular fertilizer (17% N - 17% P_2O_5 - 17% K_2O) to provide the same amount of plant available-N.

Tree Measurements and Calculation of Stand Characteristics

Each tree in each plot was tagged with a numbered, aluminum tree tag. Tree growth was observed by measuring the diameter at breast height (*D*, 1.38 m above the ground) and the total height (*TH*) prior to fertilization and at the end of the study. Baseline tree measurements were taken on March 4, 2003. Tree measurements were taken again after the final pinestraw harvest on June 6, 2006.

Pinestraw production of a longleaf pine plantation depends on soil fertility, soil moisture holding capacity, weather conditions, and stand density (Blevins et al., 2005). Stand density is described by the basal area which is defined as the total tree cross-sectional area per hectare. The basal area (*BA*, m^2 / ha) was calculated as:

$$BA = 0.25\, \pi\, D^2\, N. \qquad (1)$$

Where,

D = average tree diameter in the plot (m), and
N = number of trees per hectare.

As trees grew during the study period the diameters increased. As a result, the basal area (*BA*) varied throughout the study. Variation in *BA* during the study period was estimated by linear interpolation between the beginning and ending values.

Measurement of Pinestraw Production

Pinestraw was harvested three times during the study. Turkey litter and commercial fertilizer were applied to two of the plots in May 2003. Pinestraw was harvested from all three plots 456, 806, and 1120 days following fertilization.

Pinestraw was harvested by raking each plot under the direction of the landowner, and baling the straw with a pinestraw baler. Each bale was weighed using a hanging scale soon after it was removed from the baling machine. The number of bales harvested and the wet weight of each bale were recorded for each plot.

Pinestraw production was expressed as the number of bales harvested per hectare (*BPH*) and as the bales harvested per unit basal area (BPH/BA). The bale harvest per unit basal area provided a means to normalize the data with respect to the number and size of trees per plot. In other words, the bale production per unit basal area provided a measure of the amount of straw produced per unit cross-sectional area of live tree in each plot.

Whole bale samples were collected and stored in large, sealed plastic bags to limit the evaporation of moisture. These sample bales were transported to Clemson University where the dry matter contents of the samples were determined.

Pinestraw samples were placed in brown paper bags and dried using standard oven drying techniques for plant biomass. The oven was maintained at a temperature of 27ºC. The bags were weighed several times during the drying process. They remained in the oven for one to two weeks until the sample weight stabilized.

Bale samples were collected for all three harvests. However, damage to the plastic bags, and other problems corrupted the samples for the first and the third harvest. There were 12 bale samples from the second harvest. The dry matter fraction of these 12 bale samples was found to correlate well with respect to the wet field weights. The regression equation was used to estimate the dry matter fractions for the two years with missing data.

Application of Turkey Litter and Granular Fertilizer

Pinestraw was raked and baled in all three plots a few days before turkey litter and granular fertilizer were applied. The unmarketable straw was also removed leaving nearly bare soil prior to fertilization.

It was important to rake the straw from all three plots prior to beginning the study for two reasons. The first was to provide a uniform initial site condition to ensure that all measured straw only fell during the study period. The second reason to rake straw prior to fertilization was to minimize degradation of the pinestraw product. The forest floor has a very high C:N (≈100) and addition of N on top of the pinestraw could potentially result in reduction of straw quality.

Granular 17-17-17 fertilizer was purchased from a local merchant in bags. The mass of fertilizer was weighed and applied to the plot as uniformly as possible using a rotary drop spreader. Fertilizer was applied at a rate of 504 kg/ha. As a result, nitrogen was applied at the rate of 86 kg N/ha— only 4.4% lower than the target rate of 90 kg/ha.

A half-ton truck load of turkey litter was obtained from a nearby farm. Prior to receiving the litter, a sample of litter was collected from the farm and analyzed to determine the major and minor plant nutrient content. It was determined that the plant available nitrogen content of the litter from this sample was 21.9 kg PAN per 1000 kg of litter. The results of this analysis were used to calibrate the manure spreader on the day of application. A second litter sample was collected on the day that litter was applied and the average nutrient contents of the two samples were used to calculate the application rates for each constituent.

Turkey litter was applied to one of the plots using a small box spreader (Figure 2). The width of the spreader box was only 51 cm. The chain driven conveyor in the bottom of the box and the flail at the back was driven by the wheels and not a power-take-off unit (PTO). Therefore, the application rate was solely a function of ground speed. The higher the ground speed the greater the litter application rate. The spreader was pulled through the forest with a small all-terrain vehicle (ATV) that was equipped with a pin hitch.

Figure 2. Small box spreader used to apply the turkey litter in the plot.

The spreader was calibrated with turkey litter on the day of application in an open area away from the study plots. By trial and error it was determined that the spreader would apply about a 46 cm wide strip at a relatively slow ground speed. The speed of the ATV was set by fastening a block of wood below the throttle pedal so that the correct ground speed would be maintained if the accelerator pedal was pressed all the way down. The study site was nearly level. Therefore, the selected ground speed was relatively constant.

The amount of litter applied at the selected ground speed was measured by recessing a plastic rectangular container of known surface area into the ground. The container was narrow enough to fit between the wheels of the spreader, but wide enough to catch almost all of the litter that was applied. After several runs it was determined that the spreader was set up to apply 0.73 kg of litter per m^2.

The plot that was to receive turkey litter had six lanes to be fertilized. It was determined that the litter would be applied in bands between each row of trees. The plot was 32.6 m in length. Based on calibration results, it was determined that one pass of the spreader down the entire length of the plot would apply 10.9 kg of litter. In order to apply 90 kg PAN/ha it was determined that four passes with minimal overlap would be needed for each of the six lanes. This group of four passes was considered one litter band.

After all six of the bands were applied the width of each band was measured five times to yield a total of 30 observations. The average band width was 1.75 m with a standard deviation of 0.143 m (CV = ± 8.17%). The total area that received litter was equivalent to 54% of the plot area.

Since the turkey litter was applied in six bands there were two application rates that were of interest. The first was the overall application rate for the plot. The other was the application rates within the litter bands.

The plant nutrient concentrations of the turkey litter (mean of two samples) and the resultant application rates for the plot and in the bands are shown in Table 1. The litter, or material, application rate in the bands was almost twice the value for the whole plot. The target nitrogen application rate was 90 kg PAN/ha. It was estimated that 92 kg PAN/ha was applied— only 2% more than the target. The table also provides the comparable application rates for the granular fertilizer.

Soil Sampling

Soil within each plot was sampled prior to beginning the study to access the initial fertility of the site. About 18 evenly distributed cores were collected from the lanes between the trees using a 60 cm soil probe. The cores were divided into 15 cm sections to provide soil test results for three layers: 0 to 15 cm, 15 to 30 cm, and 30 to 46 cm.

Table 1. Constituent concentrations and resulting application rates for the longleaf pine plots fertilized with turkey litter and fertilizer.

	------------- Turkey Litter -------------			----- 17-17-17 Fertilizer -----	
		Application Rate			Application Rate
	Concentration	In Plot	In Bands	Concentration	In Plot
	kg / 1000kg	kg / ha	kg / ha	kg / 1000kg	kg / ha
Material	NA	4170	7622	NA	504
TAN	10.0	42	76	---	---
Org-N	28.3	118	215	---	---
NO_3-N	0.3	1.4	2.5	---	---
TN	38.6	161	294	170	86
PAN	**22.1[a]**	**92**	**169**	**170**	**86**
P_2O_5	44.5	186	339	170	86
P	19.6	82	149	75	38
K_2O	20.6	86	157	170	86
K	17.1	72	131	141	71
Ca	29.2	122	222	---	---
Mg	3.2	13	24	---	---
S	3.9	16	30	---	---
Zn	0.45	1.9	3.4	---	---
Cu	0.33	1.4	2.5	---	---
Mn	0.39	1.6	2.9	---	---
Na	3.1	13	24	---	---
Moisture	34.47%	NA	NA	---	---

[a] Plant available nitrogen (PAN) in the turkey litter was estimated assuming that 50% of the TAN, 60% of the organic-N, and all of the nitrate-N will be available to the trees (Chastain et al., 2001).
NA - not applicable
--- = not measured

The initial, or baseline, soil samples were analyzed to determine the soil pH, buffer pH, cation exchange capacity (CEC), nitrate-N, plant-available phosphorus, potassium, calcium, magnesium, zinc, manganese, copper, boron, and sodium.

Additional soil samples were collected to define the change in soil pH, cation exchange capacity (CEC), nitrate nitrogen, phosphorus, and potassium with respect to time in the three defined soil layers following application of 17-17-17 fertilizer and turkey litter. Soil samples were collected according the schedule given in Table 2.

Table 2. Post-application soil sampling schedule for the two fertilized plots

Nutrient Source	Days Following Application						
17-17-17 Fertilizer	15	35	56	78	106	127	189
Turkey Litter	17	37	58	80	108	129	191

All of the soil cores from a particular plot for a defined soil depth were mixed in a large plastic container. A well-mixed sample was placed in a sealed plastic bag, stored on ice, and was transported to Clemson University for analysis.

All of the soil analyses were performed by the Agricultural Services Laboratory at Clemson University (ASL, 2000). The measurements of plant available phosphorus, potassium, calcium, magnesium, zinc, manganese, copper and boron were determined using a Mehlich-1 extraction.

Results

Affects of Fertilization on Stand Characteristics

As was noted previously, the amount of pinestraw produced correlates with the basal area as defined in equation 1. Therefore, changes in tree diameters during the study must be considered when evaluating pinestraw production.

The number of trees per hectare, diameter at breast-height, and total heights were measured at the beginning and the end of the study for each plot. These characteristics along with the calculated basal areas are shown in Table 3.

Table 3. Affect of fertilization on stand characteristics (before and 3.27 years following fertilization).

Characteristic		Control	17-17-17 Fertilizer	Turkey Litter
Number of trees per hectare (per plot)				
	March 4, 2003	1006 (55)	847 (46)	884 (46)
	June 6, 2006	1006 (55)	828 (45)	884 (46)
Diameter (cm, s_P^2 = 9.059 [a])				
	March 4, 2003	19.3 ± 3.020[b]	21.1* ± 3.048	19.0 ± 2.464
	June 6, 2006	20.3 ± 3.332	22.9* ± 3.150	20.8 ± 2.921
	Change in *D*	5.2%	8.5%	9.5%
Total Height (m, s_P^2 = 1.308)				
	March 4, 2003	13.5 ± 1.12[c]	14.3* ± 1.09	12.9* ± 1.04
	June 6, 2006	15.2 ± 1.32	16.2* ± 0.98	14.6* ± 1.25
	Change in *TH*	12.6%	13.3%	13.1%
Basal Area (m^2 / ha) [c]				
	March 4, 2003	29.4	29.6	25.1
	June 6, 2006	32.6	31.5	30.3
	Change in *BA*	10.9%	6.4%	20.7%

* Significantly different from control at the 95% level.
[a] S_P^2 is the pooled variance from the analysis of variance (Steel and Torrie, 1980).
[b] standard deviation for the plot
[c] Calculated using equation 1.

Significant growth in *D* and *TH* was observed for each plot. However, the slightly higher *increase* in *D* and *TH* for the two fertilized plots was not statistically different from the control trees. Therefore, tree growth was not statistically significant in this study. It was thought that the dry soil conditions combined with high stand density impaired tree growth.

The basal area increased in each of the three plots during the course of the study. At the beginning of the study (March 4, 2003), the plot that was assigned the turkey litter treatment had the lowest basal area—15% smaller than the other two plots. By the end of the study the *BA* of this plot had increased by 20.7% and was only 4% less than the *BA* of the control plot and 7% less than the *BA* of the plot that received fertilizer.

Affects of Fertilization on Straw Production

Pinestraw was harvested three times after the granular fertilizer and litter was applied to two of the plots. The pinestraw harvests occurred 1.25, 2.21, and 3.07 years following application. The data from each harvest is provided in Table 4.

Table 4. Affect of fertilization on longleaf pinestraw production and bale weights.

Characteristic	Control	17-17-17 Fertilizer	Turkey Litter
Bales per Hectare (*BPH*)			
1st harvest 1.25 years post application	1205	1640 (36.1%) [a]	1374 (14.0%) [a]
2nd harvest 2.21 years post application	659	786 (19.3%)	808 (22.6%)
3rd harvest 3.07 years post application	982	1207 (22.9%)	1133 (15.4%)
Basal Area (m^2 / ha) [b]			
1st harvest 1.25 years post application	30.7	30.4	27.2
2nd harvest 2.21 years post application	31.6	30.9	28.7
3rd harvest 3.07 years post application	32.6	31.5	30.3
Bale Production per Unit Basal Area (*BPH / BA*)			
1st harvest 1.25 years post application	39.3	53.9 (37.2%)	50.5 (28.5%)
2nd harvest 2.21 years post application	20.9	25.4 (21.5%)	28.2 (34.9%)
3rd harvest 3.07 years post application	30.1	38.3 (27.2%)	37.4 (24.3%)
Wet Bale Weights (kg)			
1st harvest 1.25 years post application	6.84 ± 1.12[c]	6.13 ± 0.44	6.33 ± 0.49
2nd harvest 2.21 years post application	6.94 ± 0.33	7.57 ± 0.32	6.33 ± 0.30
3rd harvest 3.07 years post application	6.68 ± 0.30	6.59 ± 0.63	6.52 ± 0.36
Bale Dry Matter Fraction			
1st harvest 1.25 years post application	0.85 [d]	0.88 [d]	0.87 [d]
2nd harvest 2.21 years post application	0.843 ± 0.004	0.809 ± 0.017	0.864 ± 0.005
3rd harvest 3.07 years post application	0.86 [d]	0.86 [d]	0.86 [d]

[a] Percent change as compared to the control plot.

[b] Basal area changes as trees grow. Values shown for the 1st and 2nd harvests were estimated based on linear interpolation between the values given in Table 3. The *BA* for the third harvest was based on the final *D* measurements (Table 3).

[c] Standard deviation of wet bale weights taken in the field.

[d] Estimated based on a correlation of 12 bale samples taken from the 2nd harvest and given in equation 2.

The bales harvested from each plot were counted and the number of bales per plot was divided by the area that was raked. The data are given in the table as bales per hectare (*BPH*). Fertilization with granular fertilizer (17-17-17) provided increases in *BPH* of 19.3% to 36.1% as compared to the control plot. The greatest increase in bale production for this plot occurred 1.25 years following fertilization. Bale production per hectare was increased by 14.0% to 22.6% for the plot that received turkey litter with the maximum increase occurring 2.21 years post application. While these data indicate a substantial increase in pinestraw harvest for both fertilized plots they do not take into account the initial differences in basal area between plots or the increase in *BA* that occurred due to tree growth.

The dates of the initial and final tree measurements and the dates for each bale harvest were recorded. The basal area of each plot was calculated for the first and second bale harvests by linear interpolation using the initial and final *BA* values given in Table 3 to account for the change in basal area with respect to time. The *BA* for the third bale harvest was the *BA*-value calculated from the final diameter measurements.

In order to take into account the differences in *BA* between plots and the change in *BA* with respect to time the straw production for each harvest was expressed as the bale production per unit basal area. This normalization parameter was calculated as *BPH* divided by *BA* (*BPH / BA*) and provided a measure of the bales of pinestraw produced per unit cross-sectional area of living tree. The bale production per unit *BA* removed bias associated with differences in stand densities between plots.

The amount of needle fall during the first year following fertilization was unusually heavy, but the benefits of fertilization were observed for all three harvests. Nevertheless, the normalized bale production of the first harvest was 28.5% to 37.2% higher for the two fertilized plots as compared to the control plot. Enhanced bale production due to fertilization was observed to persist to the third year and provided 24.3% to 27.2% more bales per *BA* than the control plot.

The normalized bale production for the first harvest was the greatest for the plot that received granular fertilizer. However, the plot that received turkey litter lagged by only 6.3%.

By the second harvest the turkey litter plot produced the most pinestraw per unit *BA*, and exceeded the production of the plot that received granular fertilizer by 11%. It is believed that this 2.21 year lag in peak straw production was related to the fact that most of the plant nutrients provided in litter were in organic or slow-release forms.

By the third harvest the normalized bale production of the two fertilized plots were essentially the same—differing by only 2.3%.

The results given in Table 4 indicate that the difference between the two sources of plant nutrients was the timing of the peak bale harvest.

The three-year increase in bale production for the two fertilized plots was calculated using the site mean *BA* for each harvest to remove the influence of variable stand quality (Table 5). At the end of three years, the enhanced bale production for the two fertilized plots differed by only 5%. Therefore, it was concluded that a one-time application of fertilizer or litter to provide about 90 kg N/ha provided a 29% increase (803 *BPH*) in bale production over a three-year period.

The material and application cost for the turkey litter was about $US 185/ha and the total cost for application of granular fertilizer was estimated to be $US 309/ha. The return on investment (ROI) for using fertilizer was 968% whereas the ROI for using turkey litter was 1590%. The difference in ROI was primarily a function of the cost to purchase the nutrient source.

Table 5. Calculation of the three-year bale production and return on investment for fertilization using the mean basal area of the site for each harvest.

Site Mean *BA* (m2 / ha) [a]	Harvest No.	Control (Bales / ha)	17-17-17 Fertilizer (Bales / ha)	Turkey Litter (Bales / ha)
29.4	1	1155	1585	1485
30.4	2	635	772	857
31.5	3	948	1206	1178
	Bales / ha in 3 years =	2738	3563	3520
	Difference from control (Bales / ha / 3 yr) =		825	782
	Value of 3-year increase in production ($US 4/bale) =		$US 3300/ha	$US 3128/ha
	Fertilization cost =		$US 309/ha	$US 185/ha
	Return on Investment [b] =		968%	1590%

[a] Site mean *BA* is the average *BA* for all three plots.

[b] Return of investment = ROI = 100 [(Gain - Cost) / Cost].

Each bale was weighted in the field as it was counted. It was determined that the wet weight of the pinestraw bales was not affected by fertilizer type. Instead the bale weights varied with moisture content. All of the bale harvests occurred during hot summer conditions and the bale weights decreased throughout the day as the straw dried.

As was stated previously in the description of the experimental methods, bale samples were collected in the field, stored in large plastic bags, and were transported to Clemson University to determine the dry matter content. Only the bale samples for the second harvest provided valid data. The samples for the first and third harvests were corrupted by either damage to the plastic bags that allowed samples to dry or by irreconcilable errors that occurred during the drying process.

However, the in-field observations of a decrease in bale weight as the straw dried during the day was supported by the bale samples collected during the second harvest. It was found that the dry matter fractions (*DMF*) from these 12 samples correlated well (R^2 = 0.856, standard error of y-estimate = 0.010) with respect to the wet bale weight (*BW*). The resulting equation was:

$$DMF = 1.15 - 0.044\ BW. \quad (2)$$

The above equation was used to estimate the average dry matter fractions for the first and third harvest as indicated in Table 4.

Using the *DMF* values shown in Table 4 it was determined that the average bale in the study contained 5.7 kg of dry matter. The mean wet weight was 6.6 kg and the mean *DMF* was 0.86.

Affect of Fertilization on Soil

Soil Characteristics Prior to Fertilization

Soil samples were collected from each of the three plots prior to fertilization to provide a measure of initial soil fertility by depth for the site. The means and standard deviations of each of the soil characteristics that was measured are given by depth in Table 6.

The soil pH ranged from 5.0 in the top layer (0 to 15 cm) to 5.3 in the lower layers. The target pH range for pine trees is 5.0 to 6.5. Therefore, pH of the soil of the site was at the lower limit of the desirable pH range for pine trees at the beginning of the study (CUE, 2001).

The buffer pH was relatively high and indicated that the soil was not very resistant to a change in pH. For a given value of soil pH the amount of agricultural lime required to raise the pH increases as the buffer pH decreases. In this case, it would only require 1230 kg of agricultural lime per hectare to increase the soil pH from 5.0 to 5.5 using the Adam-Evans Method (CUE, 2001). Therefore, the calcium contained in the poultry litter (Table 1) may be sufficient to raise the soil pH in the top 15 cm.

The cationic exchange capacity is a measure of the quantity of positively charged ions (cations) that can be retained by the soil. The number of exchange sites depends on the amount of clay and organic matter contained in the soil. The Lakeland and Ailey soil in the study plots had very little clay and minimal organic matter as indicated by low values of CEC shown in Table 6. The CEC in the second and third soil layers were below 2.0 indicating that potassium and ammonium would be expected to move downward rapidly in the soil profile. The organic matter in the turkey litter may be sufficient to increase the CEC in the top soil layer (0 to 15 cm).

Table 6. Initial soil fertility status and characteristics of the study site by depth.

		0 to 15 cm		15 to 30 cm		30 to 46 cm	
	Units	Mean [a]	S [b]	Mean [a]	S [b]	Mean [a]	S [b]
Soil pH		5.0	0.10	5.3	0.20	5.3	0.06
Buffer pH		7.73	0.06	7.82	0.06	7.85	1.19E-07
CEC	meq/100g	2.5	0.55	1.9	0.53	1.6	0.12
Nitrate-N	kg/ha	ND [c]		ND		ND	
P	kg/ha	28 L	6.17	17 L	3.42	10 L	2.24
K	kg/ha	19 VL	1.71	12 VL	0.65	11 VL	1.71
Ca	kg/ha	131 VL	39.63	157 VL	52.43	138 VL	45.34
Mg	kg/ha	15 L	1.94	15 L	2.59	21 L	6.37
Zn	kg/ha	0.90	0.30	0.52	0.28	0.56	0.30
Mn	kg/ha	6.7	2.24	6.4	4.24	6.4	3.94
Cu	kg/ha	0.26	0.065	0.30	0.065	0.30	0.129
B	kg/ha	0.04	0.065	ND		0.07	0.065
Na	kg/ha	6.4	1.29	6.0	0.65	6.4	0.65

[a] Mean from composite samples from all three plots.

[b] Standard deviation from composite samples from all three plots.

[c] ND = not detected.

VL Very low level based on soil classification.

L Low level based on soil classification.

The plant nutrients of greatest concern were N, P, K, Ca, and Mg. No nitrate-N was detected in the soil prior to fertilization. All of other key nutrients tested low (L) to very low (VL) in all three soil layers. Therefore, application of N, P, K, Ca, and Mg was recommended. Only turkey litter provided any amount of Ca and Mg (Table 1).

The recommended application rates for P_2O_5 and K_2O were each 67 kg/ha (Blevins et al., 2005). Application of poultry litter to provide 92 kg PAN/ha in the plot resulted in an over application of P_2O_5 by a factor of 2.78 and of K_2O by a factor of 1.28 (Table 1). The plot that was fertilized using granular fertilizer received 28% more P_2O_5 and K_2O than recommended.

Variation in Soil Nitrate-N

Soil samples were collected from all three plots following application of fertilizer and turkey litter on the days listed previously in Table 2. It was impossible to completely account for the fate of all of the N, P, and K applied since measurements were not made to quantify losses of N to the air, uptake by the trees, or soluble nutrients in the soil below a depth of 46 cm. The low value of CEC indicated that leaching of K and nitrate-N below the sampling depth was to be expected.

Nitrate-N moved downward in the soil profile so rapidly that it was evenly distributed between the three soil layers in both of the fertilized plots for all but two sampling days. Therefore, the trends were best observed by plotting the total nitrate-N contained in the top 46 cm of soil with respect to time following application.

The variation in the total soil nitrate-N is given for both fertilized plots in Figure 3. No nitrate-N was observed on the 15th to 17th day post application for either nutrient source, and equal amounts (7 kg NO_3-N/ha) appeared on by the 35th and 37th days. Soil was sampled in the plot that was fertilized with granular fertilizer on the 56th day, but the soil nitrate was below detection limits. It is possible that all of the nitrate leached out of the sampled layers since it reappeared on the 78th day as more ammonium-N was nitrified.

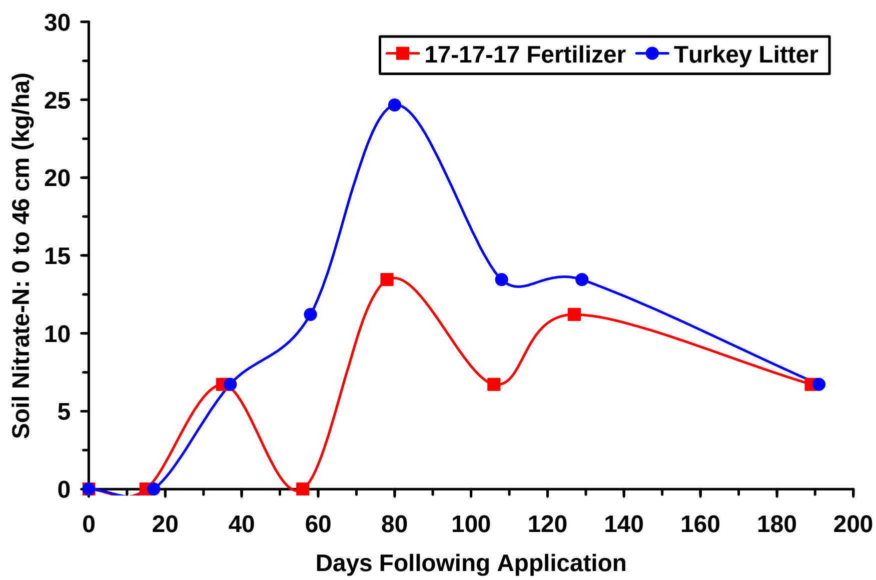

Figure 3. Variation of nitrate-N in the top 46 cm of soil following application of granular fertilizer and turkey litter.

The peak amount of nitrate observed in the top 46 cm of soil occurred at about the same time for both nutrient sources, but in differing amounts. The maximum amount of nitrate-N that was observed for the plot that received 86 kg NH_4^+-N/ha in fertilizer was only 14 kg/ha. That is, only 16% of the available-N that was applied in the plot that received granular fertilizer appeared on soil test. The peak of 24 kg NO_3-N/ha for the turkey litter plot was on the 80th day following application for the litter. This was only 14% of the plant available-N that was applied in the bands between the rows of trees (169 kg PAN/ha, Table 1).

In warm sandy soil, such as was present at the study site, the conversion from organic-N to ammonium-N, and from ammonium-N to nitrate-N would be expected to occur rapidly. In addition, the deep sandy soil was very prone to leaching as indicated by very low values of CEC (given previously in Table 6). Ammonium-N can easily move downward with the soil water in sandy, low CEC soil. Therefore it was possible that a portion of the ammonium-N moved with soil water below the 46 cm depth prior to nitrification. It is also probable that a portion of the soluble N was immobilized by organic matter near the soil surface.

It is the opinion of the authors that much of the soluble N moved below the 46 cm depth at a rate sufficient to prevent it from showing up in our soil sampling regimen. Much of the soluble N that leached past our soil sampling zone would still be available to pine trees. Pine trees develop extensive root systems in sandy soils that can easily penetrate to depths greater than 1.8 m. In addition, the depth to the water table in this region of South Carolina is typically in the range of 6 to 12 m.

It should not be concluded that ammonium fertilizer nor turkey litter are poor N sources for longleaf pine trees. In fact, both nitrogen sources provided similar enhancements in pinestraw production.

Variation in Soil-Test K

Potassium is a cation that will easily leach from a sandy soil with a low CEC, but is typically easier to observe than nitrogen since it does not undergo similar reactions in the soil. In many cases, the observed movement of K mirrors the movement of ammonium and nitrate nitrogen.

Unlike nitrate-N there were measurable amounts of potassium in the soil at the beginning of the study. Therefore, the K added by fertilization was calculated at each point in time as: $\Delta K = K(t) - K_{INITIAL}$. The variation in the change in soil-test K by depth for both of the fertilized plots is compared in Figure 4.

The potassium in the granular fertilizer (K_2O) released rapidly as indicated by a sharp peak in ΔK on the 15th day following application (Figure 4a). Soil-test K was unchanged in the second and third soil layers (15 to 30 cm and 30 to 46 cm) until the 56th day post application. After the 78th day, the K levels of the soil layers decreased steadily till the 189th day as K was leached below 46 cm. On the 189th day, only 7 kg K/ha of the applied K, or 10%, remained in the top 46 cm of soil.

The peak in soil-test K was 69 kg/ha in the top 15 cm of soil on the 15th day after fertilizer was applied. Therefore, 97% of the K that was applied (71 kg K/ha) appeared as plant available K.

Turkey litter was applied in 1.75 m wide bands between rows of trees. As a result the application rate for K within these bands was 131 kg K/ha even though the application rate for the plot was 72 kg K/ha. The soil in this plot was sampled within the band so the application rate for comparison with soil-test results was 131 kg K/ha.

The data for the turkey litter plot is given in Figure 4b. The rate of release of plant available K from the litter was much slower than for the granular fertilizer. Furthermore, the K readily leached from the top 15 cm of soil and was built up in the 15 to 30 cm layer, and to a lesser extent in the 30 to 46 cm layer.

The peak values of soil-test K occurred on the 80th day after spreading the litter and the top layer of soil contained less K than on the day of application (- 3 kg K/ha). The second and third layers had increased by 82 kg K/ha and 24 kg K/ha respectively. Since the soluble K from the turkey litter moved down in the soil quickly it is very unlikely that all of the K that was released was observable using our soil-testing schedule. However 81% of the K applied in the litter bands (106 kg K/ha) was accounted for by soil testing. On the 191st day post application 82 kg/ha of plant available K, or 62% of the amount applied, was still in the top 46 cm of soil.

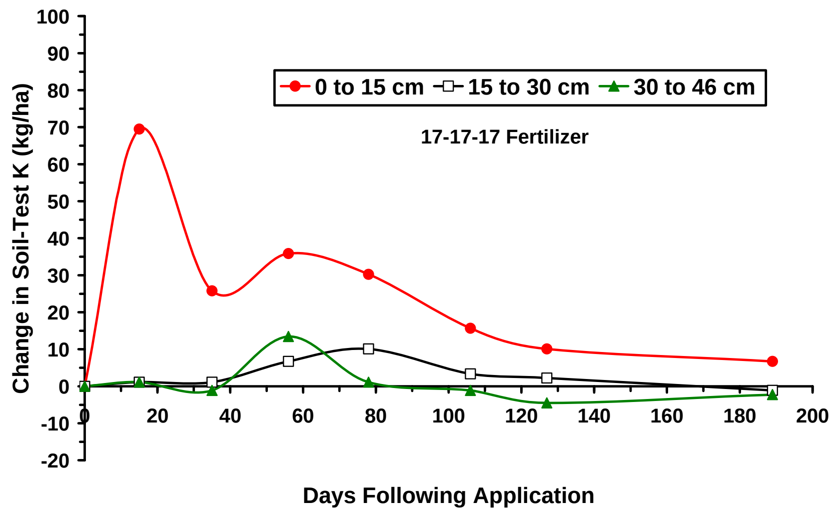

Figure 4a — 71kg K/ha applied in the plot.

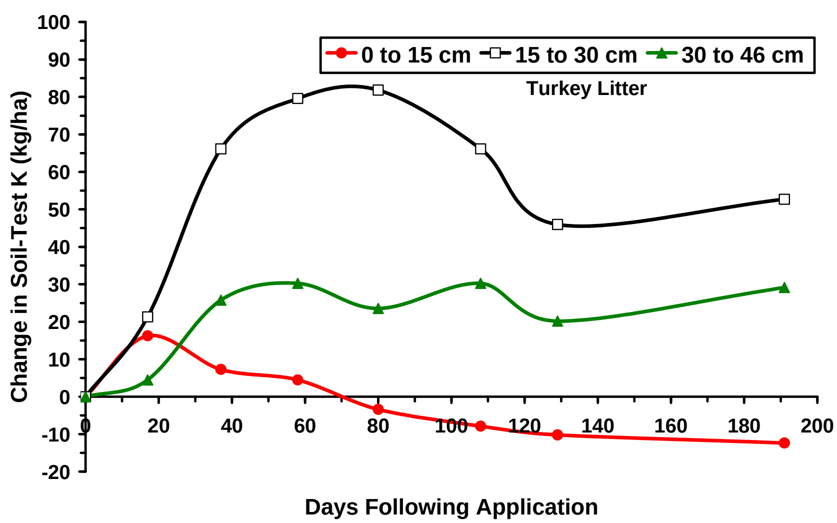

Figure 4b — 131 kg K/ha applied in the litter bands.

Figure 4. Variation in soil-test K by soil depth following application of fertilizer and turkey litter.

It appears that turkey litter provided a longer lasting, organic form of potassium that was less prone to leaching. However, the extreme rooting depths of pine trees render these differences of little consequence for pinestraw production.

Variation in Soil-Test P

Prior to fertilization the average amount of plant available phosphorus in the 46 cm sampling zone was 55 kg / ha with 51% (28 kg P/ha) located in the top 15 cm of soil (Table 6). As a result, the affect of fertilization on soil-test P was calculated at each point in time as: $\Delta P = P(t) - P_{INITIAL}$.

A rapid increase in soil-test P was observed on the 15th and 17th days following application of granular fertilizer and turkey litter. A change in soil-test P was obvious in the top two layers sampled, 0 to 15 cm and 15 to 30 cm, but was not apparent in the 30 to 46 cm soil layer.

Two statistical analyses were performed on the ΔP data to determine the affects of fertilization on soil-test P (Steel and Torrie, 1980). The first analysis was a t-test on the mean value of ΔP for each of the defined soil layers in each plot. Each mean was tested to determine if it was significantly different from zero. The second was a linear regression of ΔP with respect to the number of days following application (t). An analysis of variance was calculated for each regression and the F-statistic for the regression was computed. The 95% level of probability was selected to determine if a regression was significant. The results of these two statistical analyses are given in Table 7.

Table 7. Results of t-tests and regression analysis on the change in soil-test P (Mehlich-1) following fertilization by soil layer.

Nutrient Source	Mean ΔP [a] (kg/ha)	S [b] (kg/ha)	R^2 [c]	F_{REG} [d]
17-17-17 Fertilizer				
0 to 15 cm	26*	4.73	0.235	1.537
15 to 30 cm	6*	6.74	0.097	0.536
30 to 46 cm	-1	1.71	0.049	0.258
Turkey Litter				
0 to 15 cm	90*	28.48	0.847	27.642*
15 to 30 cm	10*	5.57	0.265	1.803
30 to 46 cm	-1	1.69	0.072	0.390

* Significant at the 95% level of probability.

[a] Change in soil-test P with respect to the initial site value [$\Delta P(t) = P(t) - P_{INITIAL}$].

[b] Standard deviation of ΔP. The number of observations was seven.

[c] Coefficient of determination assuming the equation $\Delta P = b\, t + a$.

[d] F-statistic to test for significance of the regression.

It was determined that application of neither nutrient source influenced the amount of phosphorus observed in the third soil layer (30 to 46 cm). Therefore, these data did not indicate that P moved past the 46 cm depth. This was surprising since downward movement of soluble-P with soil water in very sandy soil had been observed in a previous study (Chastain et al., 2003).

The soil-test P contained in the second soil layer (15 to 30 cm) was increased by 6 kg/ha following application of granular fertilizer and 10 kg/ha following application of turkey litter. The change in P in the second layer was not significantly correlated with respect to time following application. Therefore, application of both materials resulted in a step increase in P fertility. The turkey litter resulted in a higher value of ΔP since more P_2O_5 was applied (Table 1).

The majority of the applied P_2O_5 showed up in the top 15 cm of soil in both cases (81% for the fertilizer and 93% for litter). Following application of fertilizer, the amount of P in the top 15 cm increased in a single increment of 26 kg P/ha. That is, there was not a significant variation of soil-test P with respect to time (Table 7 and Figure 5). The P_2O_5 in the poultry litter behaved differently. The organic phosphorus contained in the litter released over time in a linear manner as shown in Figure 5.

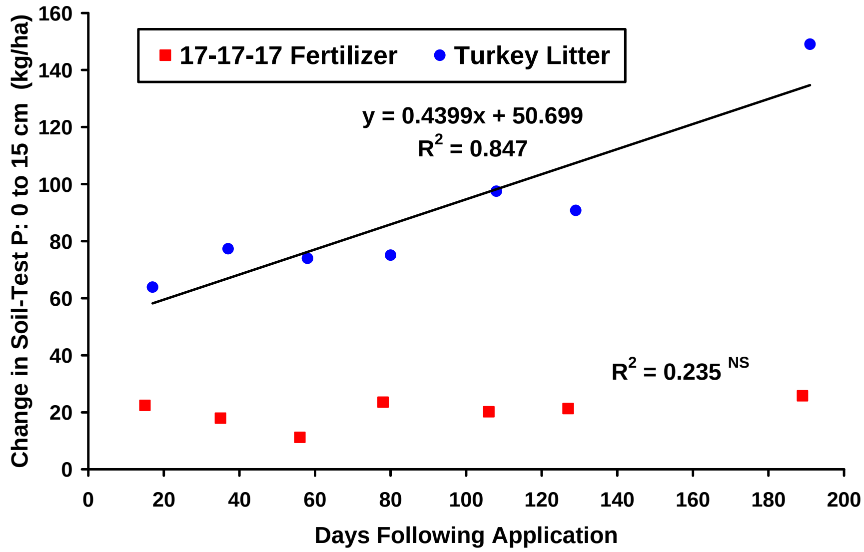

Figure 5. Variation in plant available P in the top 15 cm of soil for the two fertilized plots (NS indicates an insignificant relationship between y and x).

The plot that received granular fertilizer received a uniform application of 38 kg P/ha (Table 1). The soil-test results indicated that 32 kg P/ha appeared in the top 30 cm of soil which was 84% of the P applied.

The other plot received 82 kg P/ha, but it was applied in bands with a width of 1.75 m. Therefore, the application rate in the bands was estimated to be 149 kg P/ha. Using the regression equation given in Figure 5 it was determined that 190 days following application of the litter, 134 kg P/ha appeared in the top 15 cm of soil. Combining this with the 10 kg P/ha that was observed in the second sampled layer gives a total of 144 kg P/ha that was released from the litter. Consequently, 97% of the P in the litter showed up as an increase in soil test. This was higher than expected. In a previous study concerning the benefits of applying litter to loblolly pine (Chastain et al., 2003) only 21% of the P in the litter appeared on soil test.

The soil at this study site was very sandy and had a very low cationic exchange capacity (Table 6). It is common for such soils to have a low P-fixation capacity. Prior to planting pine trees on this site it was used for soybean production. It is believed that the fertilizer that had been applied to the soil prior to conversion to pine plantation had satisfied the P-fixation capacity. As a result the majority of the phosphorous that was applied either in fertilizer or litter remained in a plant available form since the fixation capacity of the soil had already been satisfied.

Soil pH and CEC

Two advantages of using turkey litter over granular fertilizer are the presence of minor plant nutrients such as Ca and Mg, and the addition of organic matter to the soil. Prior to fertilization, the pH of the top soil layer was 5.0. The desirable pH range for longleaf pine is 5.0 to 6.0. Application of granular fertilizer yielded a small, short-lived increase in soil pH as shown in Figure 6. Sufficient amounts of Ca were applied with the turkey litter to yield a peak pH of 6.6 that decreased to a sustained value of 5.6. The organic matter contained in the poultry litter provided a small, but significant, increase in CEC in the top 15 cm of soil as shown in Table 8.

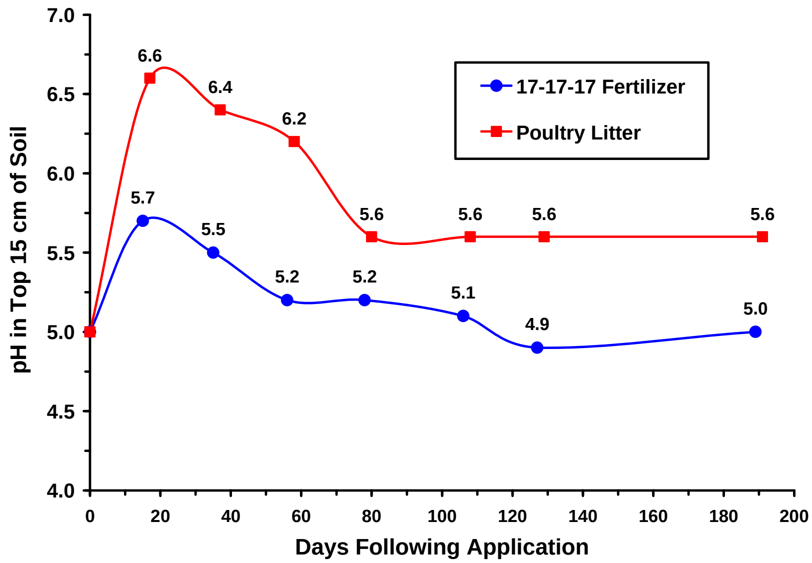

Figure 6. Affect of fertilization on soil pH.

Table 8. Affect of fertilization on cationic exchange capacity (CEC) by soil layer.

	CEC [a] (meq/100g)	S [b] (meq/100g)	ΔCEC [c] (meq/100g)
17-17-17 Fertilizer			
0 to 15 cm	2.7	0.868	0.2
15 to 30 cm	1.4	0.341	-0.5*
30 to 46 cm	1.3	0.264	-0.3*
Turkey Litter			
0 to 15 cm	3.0	0.478	0.5*
15 to 30 cm	2.2	0.416	0.3
30 to 46 cm	1.8	0.608	0.2

* Significant at the 95% level of probability.

[a] Average of all CEC values following fertilization.

[b] Standard deviation of CEC values following fertilization.

[c] $\Delta CEC = CEC_{AVE} - CEC_{INITIAL.}$ Values of $CEC_{INITIAL}$ were given in Table 1.

Conclusion

A three-year study was conducted in an intensively managed, 22-year old longleaf pine plantation (*Pinus palustris*) located in Kershaw County, South Carolina. The goal of the project was to compare the pinestraw production between unfertilized trees, trees fertilized with granular fertilizer (17% NH_4^+-N - 17% P_2O_5 - 17% K_2O), and trees fertilized with poultry litter from a turkey grow-out barn for a period of three years. The commercial fertilizer and the poultry litter were applied so as to provide about 90 kg of plant available N per hectare.

Previous studies concerning fertilization of longleaf pine reported statistically significant increases in tree diameters (at 1.38 m above the ground). In the current study, fertilized trees increased in diameter and height slightly more than the unfertilized control trees, but the increase was not statistically significant.

The results of the study indicated that over the three-year study period, pinestraw production was increased by 29% for both fertilized plots. That is, granular fertilizer and poultry litter performed similarly.

The value of the three-year increase in pinestraw production was about $US 3200/ha. Turkey litter provided a return on investment of 1590% in three years as compared to 968% for granular fertilizer. The return on investment was higher for turkey litter than for fertilizer due to lower cost for the nutrient source.

Only 14% to 16% of the available N that was applied to either fertilized plot showed up on soil test. It is believed that much of the soluble-N moved downward past the 46 cm sampling depth at a rate sufficient to prevent it from showing up in our soil sampling regimen.

Pine trees develop extensive root systems in deep sandy soils that can penetrate to depths greater than 1.8 m. Therefore, much of the soluble-N that leached past our sampling zone was still available to the trees.

Potassium is another plant nutrient that can readily leach through soil. Although leaching of K was observed, the soil-testing regimen was able to account for 97% of the K from granular fertilizer and 81% of the K that was applied with the turkey litter.

The majority of the P that was applied with the litter and the granular fertilizer showed up as plant available P in the soil. This was not surprising since the soil types at the project site have a low P-fixation capacity, and the site had received prior fertilization. Eighty-four percent of the P in the granular fertilizer was observed in the soil post application with 81% residing in the top 15 cm of soil. Ninety-seven percent of the P applied with the turkey litter appeared on soil-test with 93% remaining in the top 15 cm of soil.

The advantages of using poultry litter over granular fertilizer were the greater persistence of plant available N and K in the soil, the addition of key minor plant nutrients, a small but sustained increase in soil pH, and a slight increase in cationic exchange capacity.

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