To the Graduate Council:

I am submitting herewith a thesis written by EveLynn J. Brinker entitled " The Effects of Different Rates and Duration of Manure Applications on No-till Corn Silage Yields and Soil Properties." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Plant and Soil Science.

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The Effects of Various Rates and Durations of Manure Applications on Corn Silage Yields and Soil Properties

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Abstract

Manure applications to soil can result in increased plant growth but also in accumulations of excess nutrients, of which N and P are of special concern. This experiment was initiated to evaluate the residual effects of dairy manure applications on corn silage yields and accumulations of N and P. Rates of 112, 224, and 336 kg manure-N ha^{-1}, were applied for one, two, or three years to no-till corn silage. Inorganic N fertilizer was applied as 84, 168, or 252 kg NH_4NO_3 each year as well as 90 kg P_2O_5 and 168 kg K_2O in accord with soil test recommendations. Manure application rates were derived assuming 75% N availability. Less than 75% of the N in the manure was available when uptake efficiency is defined as (the amount of N recovered - the amount recovered from the control plots) / the amount of N applied.

Soil parameters evaluated were total C, total N, and Mehlich I extractable P and K. Total N and pH were largely unaffected by manure applications during the first two years of the study. After two years of application, in 1995, there were differences in total C only in the top 7.5 cm of soil with the highest levels of carbon from the 3M2 (336 kg manure-N applied for two years) treatment. Although the soils have been in no-till for several years, the additional C from the manure has impacted these soils at the surface.

Yields with the highest rate of inorganic fertilizer were significantly higher than all the manure treatments for all three years. The 336 kg manure-N treatment

applied for three years (3M3) did produce yields comparable to those with the recommended rate of inorganic fertilizer for silage,168 kg NH_4NO_3 (2AN). Silage yields did increase within a given manure rate as years of application increased. In almost every instance, yields in the no-till systems were similar to if not the same as, those in conventional till systems.

The pre-sidedress nitrate test although developed for manured situations did not provide a good correlation between silage yield and nitrate test level in this research. The manure and inorganic fertilizer treated soils had nearly equivalent yields after three years but the PSNT values were quite low with the manure and very high in the inorganic treatments. In the treatments that did not receive manure in a given year, the low PSNT values did indicate a nitrogen deficiency which was seen in the low yields. As the years of application increased, the manured yields increased to levels comparable to those from the inorganic treatments, but the PSNT values were still lower than the critical ranges.

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Part I

Introduction

Manure has been used as a soil amendment to improve plant growth worldwide for centuries. With the post-World War II advent of cheap commercial inorganic fertilizer, the use of manure as a sole fertilizer decreased, and it has often been regarded simply as waste without benefit. Often farmers will land apply their manure as a means of disposal and also apply additional N, P, and K fertilizers for crop use. This creates a situation of excess nutrients leaving the system by means such as leaching. Farmers can end up potentially polluting their wells and other groundwater sources with nitrates and surface waters with phosphates. In losing nutrients they are also losing money spent on inputs.

According to the Tennessee Agricultural Statistical Service (TASS, 1995), the number of small farms ($1000- $9999) in the state is decreasing. It could only help small farmers to reduce their off farm inputs and recycle a commodity that would otherwise need of disposal. An alternative approach to using a complete rate of commercial fertilizer would be to take into consideration the nutrients supplied by the manure and to then reduce the inorganic fertilizer by the same amount. Reducing excessive nutrient application reduces the money spent on inputs, the chance of overfertilizing, and the potential risk of water pollution.

Rather than being without benefit, manure has been described as a low grade fertilizer with a nutrient content 10% that of inorganic fertilizers (Pratt, 1976). Due

to the relatively low nutrient concentration present in the waste, large amounts of manure can be land applied. About 40,000 kg of fresh dairy cattle manure can supply 100 kg nitrogen that is plant available and equivalent to 217 kg of urea (Patni and Culley, 1989). According to TASS, in 1995 Tennessee ranked 14th in number of total cattle (2.55 million) and 17th in number of dairy cows (160,000). These numbers lead to significant amounts of animal waste that must be dealt with, preferably with benefit to the producers. Land application of manure allows for economical disposal that recycles nutrients while improving soil quality (Cooper, 1984). Using manure conserves energy and reduces the off farm inputs while minimizing potential adverse effects. Use of manure may also have a residual effect where nutrient benefits are felt in succeeding years as well.

Manure usage on land susceptible to erosion (e.g., west Tennessee) poses a management challenge. West Tennessee has a rolling topography with highly erodible silt loam soils. Because of these erodible soils, conservation tillage, especially no-till, is recommended to retain the topsoil. Tennessee has gone from having one of the worst erosion problems to cutting rates by 50% in the past decade. This is due to the numbers of farmers using conservation (tillage practice where at least 30% residue is left on the surface) and no-till (crop is planted directly into the seedbed with no tilling) practices (TASS, 1995).

These conservation practices may not be conducive to the use of manure as fertilizer due to a possible increase in nutrient loss. No-till fields can have increased

preferential flow, with larger continuous channels through the soil which can increase chances of negatively affecting subsurface water quality by nitrate leaching and nutrient runoff.

Nitrogen mineralization rates in no-till soils are initially slower than in conventional till soils. This difference is caused by accumulation of organic matter in no-till soils which decomposes more slowly on the surface than if incorporated (Magdoff, 1991). Rice and Smith (1983) found higher nitrification rates in soils under no-till which they attributed to better moisture retention in the no-till soils. Water evaporated more quickly in the tilled plots. The same study reports higher immobilization and denitrification rates in no-till situations. The availability of the N in no-till soil will approach that of conventional till as the no-till organic matter accumulates and the conventional till organic matter decreases.

Many producers in the state use no-till to conserve erodible soil, increase water use efficiency, and to comply with federal regulations. Using plots at the Martin Agricultural Experiment Station in west Tennessee allows simulation of actual conditions facing dairy producers in Tennessee. The experiment was initiated to determine the effect of rate and duration of dairy manure applications on soil fertility and residual nitrogen availability in a no-till corn silage situation. Treatments were a 0 fertilizer check and three rates of NH_4NO_3 for all three years, with three rates of manure N applied for either 1) three consecutive years 2) the first two consecutive years with no application in year three or 3) the first year with no

further application in years two and three. The intermediate inorganic treatment and a 0 nitrogen control were also applied every year with conventional tillage. The corresponding manure treatment was also applied for one, two, or three years with conventional tillage. There was no autumn crop grown. The purpose of variable years of application was to evaluate the residual availability in the manured soils.

Objectives

The objectives of this study were to evaluate different rates and timing of dairy manure applications in no-till corn silage production as they affected crop yield and soil properties in comparison with inorganic fertilizer usage. The use of manure applications under no-till farming conditions were compared with conventional tillage to evaluate a potentially negative effect.

A further objective of this study was to determine an optimum manure application rate for maximum yield with minimal nutrient loss while crediting residual nutrients from previous years. Often manure application recommendations are based on work done in other geographic regions with different climates and different soil types. In addition, another long term goal is the development of manure application guidelines for the state of Tennessee using sites that reflect conditions faced by farmers in the dairy cattle producing regions of the state.

The pre-sidedress nitrate test (PSNT) has been used in other regions of the country to predict nitrogen availability for a crop, usually corn. This available nitrate prediction leads to better nitrogen management by allowing farmers to adjust

the amount of fertilizer they would sidedress later in the season. The test has a critical range of around 20-25 ppm nitrate which correlates to the sufficiency range for corn. Soils testing below the range will benefit from further fertilization while those above will not. Another objective is to evaluate the validity of the PSNT in manured corn crops.

Part II

Literature Review

Effect of manure on yield

Manure amendments have been applied to land primarily as a nitrogen source to increase plant growth. Mineralized nitrogen from the organic matter will satisfy crop nitrogen requirements. Bagayoko et al. (1992) researched the effects of fertility treatments on soil nitrogen and grain sorghum yield. Plots that received 16 Mg ha^{-1} manure applied gave higher sorghum grain yield than plots with 90 kg fertilizer N ha^{-1} or no N. The manured grain yield increased 1.0 Mg ha^{-1} in 1988 and 0.7 Mg ha^{-1} in 1989 over the control. Plots with a history of manure treatments also produced greater stover yield than the plots with fertilizer N or the control.

Sharma and Mittra (1991) found that 10 Mg farmyard manure (FYM) ha^{-1} resulted in rice yields equivalent to those from 30 kg N_i ha^{-1} . Increasing the rate to 15 Mg ha^{-1} increased the yields further. Increasing the amount of organic fertilizer also increased the nitrogen uptake of the crop.

In obtaining improvements in sugarbeet yields, manure applications were seen to be more important than irrigation. This was attributed to the nitrogen content in the manure even though the average precipitation and evaporation around Logan, Utah were such that irrigation or special means of dry farming were essential for crop production. The eleven treatments consisted of barnyard manure applications

ranging from 0 to 40 t yr^{-1}. The results after five years showed that yields were strongly correlated to manure application rates (r = 0.77, Pittman and Fonder, 1926).

Phosphate fertilizers are known to enhance the rate of plant maturity for crops. The ability to harvest earlier reduces the loss by frosts in the fall. Working in Fargo, North Dakota, Olson and Walster (1933) looked at different soil amendments as they affected corn maturity. The fertilizer treatments were a 0 control,9-12 t $acre^{-1}$ manure alone, manure in combination with triple superphosphate, and manure, phosphate, and limestone. The highest percentage of matured plants came from the manure and phosphate combination followed by the manure, phosphate, and limestone treatment. They concluded that although applications of manure can advance plant maturity, this effect is generally controlled by seasonal environmental conditions. They proclaimed the effect to be of "doubtful significance" and not strongly correlated with increased yield.

In India on a sandy loam soil, Benbi and coworkers (1993) using 15 t ha^{-1} FYM in combination with fertilizer nitrogen, were able to increase yields of dryland wheat by 230 to 520 kg ha^{-1} which was significant in four out of five years. The addition of the manure increased the maize yield significantly in only one out of the four years. This lack of beneficial effect was attributed to N, P, and K applications across all treatments. In dryland wheat, the amount of water stored in the profile in addition to rainfall during the growing season determines potential yield. Maximum wheat yields were only attained if enough rain fell during the vegetative growth

phase. They were also looking at specific conditions under which FYM as a supplemental nitrogen source is most effective in a dryland wheat-maize rotation. They found that application of FYM increased dryland wheat yields once fertilizer N was added. The manure adds nitrogen to the soil during decomposition which may help the efficiency of the fertilizer uptake. Use of manure can also increase water use efficiency which may increase water storage. Water storage is considered more important for the crop response to fertilizer than effective precipitation.

Manure is also a source of other essential nutrients such as P and K. Motavalli and coworkers (1993) reported a greater response in corn silage yields to semi-solid dairy cow manure applications than to equivalent amounts of N fertilizer which they attributed to the other nutrients in the manure, specifically P and K. The rates of manure averaged across three years were 0, 19, 33, 60, and 121 t acre $^{-1}$. Plant uptake of P and K increased with manure applications. Applications of starter fertilizer resulted in no additional yield increase suggesting that nutrients supplied by the manure were sufficient for crop use.

Sufficient nutrients can also be supplied by previous legume crops whose ability to fix atmospheric nitrogen creates a nutrient reservoir for succeeding crops. No corn silage yield increase was seen after applications of either dairy manure at 90 t ha^{-1} or mineral fertilizer treatments providing equivalent amounts of NH_4-N when the preceding crop was alfalfa. The yields were similar whether from manured treatments or those with mineral fertilizer. Stored nutrients from the legume crop

were at sufficient levels so that the added nutrients had little beneficial effect. Phosphorus uptake was also not affected by the treatments. Potassium uptake varied over the three year course of the study but did not differ by treatment (Patni and Culley,1989).

In Italy, Giardini and coworkers (1992) found that fertilizer treatments including 2 or 4 t ha^{-1} poultry manure, or the poultry manure alone outperformed equivalent treatments of mineral fertilizers in terms of crop yields. Combining the poultry manure with the mineral fertilizer allowed a reduction in the total nutrients applied for optimal marketable yield to some crops such as sugarbeets. In this study, the use of the poultry manure resulted in greater marketable yields in the tomato crop as opposed to greater vegetative yield resulting from the mineral fertilizer. The authors speculated that P held in the organic matter is better protected from soil fixation than in the mineral fertilizer and thus more plant available. They also cited other benefits of manure such as other micronutrients and an increase in biological activity as possible reasons for the yield improvements.

Martin and Wang (1943) attributed increases in barley yields not to the nitrogen but rather to the role of biological activity in improving soil properties and other micronutrients present in cow manure compost. They also noted that tomato and barley plants growing in the manure-treated soils were more vigorous than those in all the other treatments, inorganic and other organic composts. The plants growing in the inorganic fertilizer treatments appeared to be intermediate between

the manure and the control. Although more nitrogen was removed from the inorganic fertilizer treatments, higher yields were obtained with the organic treatments. This suggests that factors other than available nitrogen, micronutrients and biotic elements, are responsible for growth improvements.

In eroded South Carolina Piedmont soils, applications of 4 t stable manure $acre^{-1}$ increased cotton yields in not only the A, and B, but also the C horizons which had been transported from the site, separated, and planted in cotton. This increase in plant yield was due to the addition of organic matter and plant nutrients. The application of the manure resulted in increases beyond those achieved with 400 lbs $acre^{-1}$ with inorganic fertilizer (4-12-4). The beneficial effect of the manure application was even more pronounced in the C horizon which may have been relatively infertile even before farming (Lantham, 1940).

In Canada, Chang and coworkers (1994) investigated the effect of long-term manuring on nutrient uptake in barley and the subsequent effect on yield. Feedlot cattle manure was applied at rates of 0, 30, 60, and 90 Mg ha^{-1} on non-irrigated land and doubled rates on the irrigated land. The maximum recommended rates were 30 Mg ha^{-1} and 60 Mg ha^{-1} for dry and irrigated land respectively. For all elements except Ca, the concentrations in the plant tissue from the dryland plants increased with the rate of manure. The same trend occurred in the irrigated plots. In a previous study on the effect of long term manuring on barley, Chang et al. (1993) found that in non-irrigated conditions when moisture was inadequate, any manure

application regardless of rate had a negative effect on yield in the non-irrigated plots. In this instance, water was the growth limiting factor. Generally, the grain yield decreased with increasing rates of manure. Usually, the yields at 30 Mg ha^{-1} exceeded the two higher rates. Under irrigation, grain and straw yields were improved with the manure application. Application of the higher rates did not result in further yield increases.

The value of animal manure as a nutrient source is not necessarily the amount of nutrient present but rather the availability of the nutrient for plant uptake. In Australia, Brechin and McDonald (1994) compared the effect of two rates of liquid swine manure (16 kL ha^{-1} and 32 kL ha^{-1}) on barley yield with that of a superphosphate-urea combination and solid swine manure (0.5 t ha^{-1}). Both the liquid manure and the mineral fertilizer increased yield significantly. This increase was attributed to additional nitrogen in the mineral fertilizer and the slurry. More phosphorus was applied in the mineral fertilizer yet yields were higher with the slurry. They found that nitrogen in liquid swine manure was more available than N in solid waste. At 125 days, the barley crop had recovered 42% of the N in the low manure rate (40 kg ha^{-1}) and 56% of the N in the high manure rate (80 kg ha^{-1}). From the solid swine manure, 0% and 5% N were recovered from the low and high manure treatments, respectively. From the inorganic treatment, a superphosphate-urea mix (25 kg ha^{-1}) 37% of the N was recovered in the crop. Liquid swine manure improved

barley growth throughout the season, and higher rates were visibly more effective earlier.

Appropriate application rates are crucial in controlling loss of nitrogen. Corn crops grown for silage will generally not remove more than 200 kg N ha^{-1} yr^{-1}, and the percentage utilized by the crop will decrease with increased rates of manure. High application rates can lead to nitrogen losses when the applied rate exceeds the amount the crop can utilize. Kanneganti and Klausner (1994) looked at the nitrogen recovered by orchardgrass from dairy manure alone and in combination with fertilizer nitrogen. The dairy manure was applied so that 150 kg N ha^{-1} yr^{-1} was supplied with 0, 150, 300, and 600 kg N ha^{-1} from ammonium nitrate fertilizer imposed in a factorial treatment. Across the fertilizer treatments, the liquid manure increased the yield over control treatments by 43% in 1990 and 23% in 1991. The equivalent values for the solid manure were 21% in 1990 and 24% in 1991. From the liquid manure treatments alone, only 40% of the applied N was recovered in the forage averaged across the years. From solid manure 13 and 39 % of the applied nitrogen was recovered in the forage in 1990 and 1991, respectively.

Yields increased with moderate rates of manure application (79 ton ha^{-1} dry manure and 21 ton ha^{-1} liquid manure) in sudangrass and barley and declined at higher rates. The yield decreases at the highest application rates were attributed to salt toxicities in the soil (Pratt, 1976). Motavalli and coworkers (1993) evaluated the effect of dairy manure on corn silage yields. They found that at the highest applied

rate of manure (about 121 tons $acre^{-1}$ $year^{-1}$), plant populations decreased perhaps due to salt toxicity. They also postulated that the high rates of manure caused problems in disking high amounts of crop residue into the soil that prevented incorporation of the manure, and the decomposing nutrients may not have been as plant available.

Patni and Culley (1989) found that with exception of exchangeable K, the moderate rates of liquid manure did not affect soil chemical properties. After three years of manure application (90 t ha^{-1}) at twice the rate of fertilizer N, the amount of extractable inorganic N did not increase. At harvest, soil N concentrations were similar from the fertilized and manured plots. Compared with the control, the fertilized plots were significantly higher in the surface layer.

In India, in flooded rice cropping conditions, Sharma and Mittra (1991) found yield decreases with increased organic matter applications. This yield decrease can also be attributed to the negative effect on nitrogen uptake with application of high rates of high carbon materials like 15 t ha^{-1} paddy straw with a C:N ratio of 71:1. Increasing mineral N up to 90 kg N ha^{-1} increased yields significantly until the mineral fertilizer was applied to increased rates of the organic fertilizer. With the increased rates of fertilization, the percentage of nitrogen recovered by the crop declined.

Applying nitrogen in excess of crop uptake will result in loss from the soil. In an N balance done by Cooper and coworkers (1984), 36% of the inorganic fertilizer N added was removed by the crop while less than 10% of the manure N

added was removed by the crop. They applied 32, 61, and 121 Mg ha^{-1} cattle manure and 94 and 184 Mg ha^{-1} poultry manure. The inorganic treatment was 168-49-93 kg ha^{-1} yr^{-1} and a control with 49 kg P ha^{-1} yr^{-1}. At low manure application rates, more N was removed in quantity and percentage by the crop than in the higher rates when compared to the control plots. Compared to both poultry litter rates (94 and 184 Mg ha^{-1}), the crop in the 0 N control plots removed more total N. The decreased yields resulted in decreased removal of N. The corn grain yield decrease from the manured plots, 34% lower than yield from the fertilizer treatments, was attributed to salt toxicity. At the two highest rates of poultry litter and cattle manure, 45 to 60% of the total N added could not be recovered.

Kingery and coworkers (1994) reported that long-term poultry litter applications for 15 to 28 years have led to a substantial increase in mineralizable N necessitating some application guidelines. These litter applications, ranging from 6 to 22 Mg ha^{-1}, have also resulted in increased levels of soil K, Ca, and Mg. Soil P accumulations were more than six times greater in the manured soils versus the unmanured soils. At excessive levels these increases in all the elements can cause a variety of problems from nitrate leaching to grass tetany to plant nutrient imbalance to nutrient runoff.

Effect of manure on soil properties

Apart from nutrient storage, the benefits of manure also include higher cation exchange capacity due to increased organic carbon, and improvements in physical

soil structure. Martens and Frankenberger (1992) stated that organic residues increase soil aggregation, microbial respiration, and water infiltration as well as decreasing bulk density. Adding barnyard manure is also a means of adding organic matter to the soil in no-till situations as more organic matter is created than decomposed. Organic matter improves structure, aeration, drainage, water holding capacity, reduces erosion, and enhances soil warming in the spring. Organic matter increases soil colloids, microorganisms, and buffer capacity. When mineralized, organic matter releases N and micronutrients. (Powers and Lewis, 1930, Campbell et al., 1986, Bhagat and Verma, 1991)

White (1926) describes the organic matter and nitrogen content of the soil as reaching an ultimate level depending on the type of cropping system. Efforts to increase or maintain higher levels of organic matter by adding excessive amounts of manure failed and rather resulted in loss of organic carbon and nitrogen. Nitrogen applied to crop residues seemed to stimulate the decomposition rate rather than increase amount of the organic matter. Addition of nitrogen did increase dry matter yield but reduced the amount of residual organic matter.

In agreement with those findings, Metzger (1933) in 25 years did not find an increase in soil nitrogen after adding 40 or 60 tons of manure. Increases in soil carbon and nitrogen levels were attributed to surface residues rather than to the manure.

Contrary to the findings of both White and Metzger, Powers and Lewis (1930) report that long-term (16 years) additions of 10 tons manure $acre^{-1}$ applied every three years accumulated levels of total N and carbon that led to marked increased in bean, barley, and clover yields. The gain in soil nitrogen added 320 lbs nitrogen dry farmed and 408 lbs when irrigated. The yields on average from the manured plots were increased by 7.0 bushels $acre^{-1}$.

More recent literature is also in disagreement with the concept of not being able to increase levels of soil organic matter. In a two year study on increasing the infiltration rate in a California soil, Martens and Frankenberger (1992) were able to increase the organic matter content of the soil by 57% with applications of poultry manure at 25 Mg ha^{-1} .

Cooper and coworkers (1984) in studying the nitrogen distribution after heavy manure applications, found that levels of organic N in the top 60 cm increased with increased application rates of cattle and poultry manure. The amount of N that remained in the organic phase also increased with the increased applications.

Rasmussen and Parton (1994) in a study initiated in 1931 looked at the long-term effect of residue management on soil organic matter. Manure treatments that supplied 111 kg N ha^{-1} resulted higher soil C and N levels than all other treatments. Over time the other treatments have had declining soil C and N levels compared to the manured treatments. The highest N uptake also occurred in the manure treatment.

In Denmark, on a sandy loam soil where for 61 years plots have been given equivalent amounts of nitrogen from either mineral fertilizer or animal manure (121 kg N ha^{-1}), Christensen (1988) studied the effect of the treatments on the C and N levels of the soil fractions. He found that both applications of manure and the fertilizer increased C and N levels in the clay and silt fractions as well as the whole soil when compared to untreated soils. Manure additions caused changes in the organic matter with an increase of 36% in the clay and silt fractions compared to increases of 14% and 21% respectively for mineral fertilizer.

Kingery et al. (1994) studied long-term (15-28 years) effects of poultry litter on soil properties in Alabama. With the long term application of broiler litter, organic C and total N were increased to depths of 15 and 30 cm, respectively. The manured soils compared to the untreated soils had a lower C: N ratio in the top 15 cm due to mineralization of the accumulated organic N. A pool of mineralizable N has been created.

Campbell et al. (1986) studied Canadian clay soils in Saskatchewan to determine the effects of various rates of manure (13.4, 20.2, and 26.9 Mg ha^{-1} and fertilizer P (monoammonium phosphate at 112 kg ha^{-1}) on soil characteristics particularly as they influence yield. Experiments were initiated at this site in the 1940s. Over time, the manured plots showed appreciably better soil tilth but this study was unable to demonstrate any differences in physical measurement. They found that neither manure nor phosphate had any effect on bulk density. Use of the

manure did increase the biochemical constituents like humic acid and humin. These materials are highly colloidal and can stabilize soil aggregates. Applications of manure did increase total C, humic acid, net rate of N mineralization, and available inorganic P. Organic N was not affected by treatment. The manure did not affect amounts of potentially mineralizable N but rather made the N more available. Manure is beneficial in improving yields by increasing the available N and P in the soil and by affecting humic colloids in improving the physical properties of the soil.

Schlegel and coworkers (1992) looked at the effect of composted manure on soil properties. Soil P, K, and organic matter increased linearly with increased rates of compost. Increased rates of inorganic fertilizer decreased P and K but had no effect on organic matter. The compost additions increased soil K levels by up to 150 ppm. The organic matter was increased by 0.26% by three compost applications of 7.2 ton $acre^{-1}$. In this study, the nitrogen from the compost was less available than the nitrogen in the fertilizer. The efficiency from the compost was 13% compared to 36% efficiency from the fertilizer.

Smaling and coworkers (1992) looked at maize yields with additions of inorganic fertilizer and 5 Mg ha^{-1} manure in Kenya on three sites with different soils and climates. They found that manure is especially effective in improving yields in phosphorus-fixing soils due to mineralization causing a slow release of phosphorus.

Avnimelech and Cohen (1988) working with a Vertisol in Israel found that in lab studies, soil samples mixed with manure had improved (reduced) bulk density

and aggregate stability when combined aerobically. When mixed anaerobically, there was no effect from the addition of the manure which was attributed to a decrease in microbiological activity. With the addition of 10 Mg ha^{-1} poultry manure, Obi and Ebo (1994) were able to lower the bulk density of a degraded Nigerian Ultisol. The erosion rate and soil degradation are such that productivity can not be restored with inorganic fertilizers. Amendments to restore soil organic matter levels, soil fertility, and physical structure are considered necessary. The manure amendments increased organic matter which increased the available water holding capacity and water retention rate, improved the infiltration rate, and increased the total porosity of the soil. The soil organic matter also had a high correlation to yield ($r = 0.86$).

Additions of 5 Mg FYM ha^{-1} with 5 Mg ha^{-1} rice straw as well as additions of the manure alone improved physical properties in the soil which markedly increased yields. Parameters studied were bulk density, water stable aggregates, porosity, available water holding capacity, and hydraulic conductivity. All parameters were higher with the manured treatments with the exception of the bulk density which decreased (Bhagat and Verma,1991).

In Ethiopia, on poorly aerated soils with low water infiltration, Girma and Endale (1995) found that 5 Mg ha^{-1} incorporated FYM increased both maize yield and dry matter production. The manure application also resulted in higher but not statistically significant bulk density and lower soil porosity. The authors hypothesize

that more time was needed for the manure to decompose and cause a significant measurable difference in porosity. The low amount of pore space was attributed to monocropping which is a standard practice.

Effect of manure on water quality

Microbial decomposition of organic matter like plant residues, manure or other nitrogenous wastes, results finally in nitrate formation. This form of N is an anion (NO_3^-) which is not held on the CEC sites in the soil. The anion is soluble and so able to move through the soil profile to groundwater supplies. This is of concern because too much nitrate can cause methemoglobinemia, nitrate toxicity, in infants and young animals. This condition causes blood to not absorb oxygen and can be fatal. High nitrate levels can cause intestinal problems for adults (Meints and Vitosh, 1988). Nitrates also pose problems for the adult population as they transform to nitrites and react with amines in the body to form nitrosamines, which are extremely strong carcinogens (Bouwer, 1990).

Nitrate pollution of groundwater sources has been attributed to excessive N fertilization, especially in systems like corn production that depend on manuring for an N source. Inorganic N is immediately plant available and taken up during the growing season. Long-term manuring will lead to more mineralizable N due to continued decomposition of the organic residues after plant uptake ceases. Nitrate left in the profile after harvest is subject to loss by leaching. In Pennsylvania, Roth and Fox (1990) studied nitrate accumulations in the soil after corn grown with

various rates of fertilizer. They found that site history impacts nitrate accumulation as sites with prior manure applications generally have greater concentrations of nitrate. The greatest differences in fall and spring nitrate concentrations were at the highest fertilization rates. All treatments resulted in nitrate levels in patterns similar to the control plots suggesting an equilibrium nitrate level below which leaching is minimal.

Jemison and Fox (1994) looked at nitrate leaching losses in zero-tension pan lysimeters under corn fertilized with inorganic fertilizer and manure. Nitrate levels averaged across all three years of the study for all treatments receiving the economic optimum nitrogen (EON) fertilizer rates (100 and 200 kg N ha^{-1}) exceeded 10 mg NO_3 -N L^{-1}. The same trends were found in the manured plots indicating that the leaching characteristic was similar in both systems. They also found that if nitrate levels in the soil profile were less than 112 kg NO_3 -N ha^{-1} , the leachate concentrations would be less than 20 mg NO_3 -N L^{-1}. Only at rates of N application where the plants were visibly stunted and nitrogen deficient were the levels of nitrate below the drinking water standard of 10 mg NO_3 -N L^{-1}.

Angle and coworkers (1993) conducted a three year study looking at nitrate concentrations under corn as affected by manure and fertilizer application. Rates of 90, 180, and 260 kg N ha^{-1} were used to simulate suboptimal, optimal, and excessive rates for corn. Nitrate leaching increased with increased rates of fertilizer N especially as the applied N exceeded crop uptake under both no-till and conventional

till. The differences in tillage were the greatest at the higher fertilization rates. No-till soil nitrate concentrations were lower than conventional tillage concentrations. Yields and grain concentrations were higher in the no-till plots.

Jokela (1992) looked at the effects that nitrogen fertilizer applied at 56 and 112 kg ha^{-1} and dairy manure applied at 9 Mg ha^{-1} have on corn yields and soil nitrate concentrations. Nitrate leaching potential from manure sources is similar to or less than equivalent amounts of mineral fertilizer. Nitrate levels increased with the higher fertilizer N rate.

Edwards and Daniel (1994) conducted a study looking at the effect of swine manure application rate and rain intensity on nutrient runoff. Manure was applied at 0, 193, and 387 lb N $acre^{-1}$. They determined that application rate rather than rain intensity was the factor in the runoff nutrient amount in a "near worst-case scenario". This worst case scenario was the application of manure to moist soils a day before heavy simulated rainfall. Runoff was higher from the plots treated with manure than those with none. There was no difference in runoff between the plots receiving 193 and 387 lb N $acre^{-1}$.

Bielby and coworkers (1973) evaluated the nitrate content from lysimeters under plots receiving liquid poultry manure over a three year period. Low concentrations of nitrate appeared in the lysimeters during the growing season indicating crop uptake was high. From manured plots, 10% of the total nitrate concentration was discharged prior to planting with 60 to 84% discharged after the

corn harvest. Averaged over two years, 28 and 37% of added manure N was recovered in either corn uptake or lysimeter percolates during the growing season. Average nitrate concentration increased with the increased rates of applied nitrogen. The average concentration of the nitrates from all treatments and years were all over 10 ppm.

In the Netherlands, Schroder et al. (1993) looked at the effect of nitrification inhibitors on fertilizer N and nitrate losses over eight years. They found that the mineral N rate related to the highest economic return resulted in groundwater nitrate levels well above the EC drinking water standard of 10 mg NO_3 -N L^{-1}. The use of nitrification inhibitors slowed the nitrification rate and reduced loss of nitrate.

Angle et al. (1993) found that no-till plots in corn yielded a significant reduction in subsurface water nitrate levels. For the plots that received the highest fertilization treatment, the nitrate concentrations under the no-till plots were half those under the conventional till. Denitrification rates are generally higher in a no-till situation.

Patni and Culley (1989) looked at the effect of 90 t ha^{-1} yr^{-1} dairy manure applied to corn silage to groundwater quality. Treatments included a 0 control and inorganic fertilizer providing the same amount of nitrogen as the manure applications. Nitrate concentrations in groundwater were always higher than the 10 mg L^{-1} drinking water limit in all treatments, even the control. They concluded that

manure and fertilizer applied at recommended rates for corn production is unlikely to meet the limit.

Harris and coworkers (1994) looked at phosphorus mineral retention from manure applied phosphorus in sandy soils. Dairy manure can lead to excess P in runoff causing eutrophication of surface waters. In studying the sediment composition they found a lack of Ca-P minerals despite years of heavy manuring. Manure constituents such as organic acids, Mg, and Si may inhibit Ca-P mineral crystallization leaving the P in a soluble phase not retained by the soil.

Residual nitrogen

Residual nitrogen is that inorganic N remaining at the end of a growing season. While available for the next crop, this nitrogen is also subject to loss by leaching or denitrification. Fertilizer or inorganic N is readily available at application leaving little after crop uptake. Conversely, manure decomposes and mineralizes through the year creating a pool of nitrates during a time of no crop uptake. If there should be significant precipitation, this source of nitrates is potential leaching loss. Management practices that reduce the amount of inorganic N such as using an organic source with a slow mineralization rate will reduce the potential loss.

Bell, in 1935, looked at the effect of organic matter decomposition on a Norfolk sand. Comparing soils treated with organic matter with untreated control plots, all the treated soils had an increase in residual nitrogen. Addition of inorganic

salts also resulted in a slight increase in nitrogen compared to the untreated check soils. At the end of the experiment, he found a residual organic matter effect in plots with organic amendments.

As early as 1943, Martin and Wang reported a greater residual effect from cow manure than artificial manures on plant growth. Barley and tomato plants growing in the cow manure compost were also visibly more vigorous. They hypothesize that the manure contained a better nutrient balance and that the plants were able to use that nitrogen more efficiently. More nitrogen was removed in plots treated with complete fertilizer but yields were higher in from the other treatments.

Weidemann (1943) found that the residual effect from 5 tons top dressed horse manure was greater than that of 10 tons incorporated commercial fertilizer in clover yields. The crop rotation was corn-wheat-barley-clover with fertilizer applied to the first two crops, the last two to recover the unused fertilizer. The clover yields from the manured plots were greater than from the commercially fertilized plots. In the barley, applications of 10 tons manure plowed in were more effective than 5 tons top dressed. Again, the barley growth was dependent on residual fertility which was greater from manured treatments than inorganic fertilizer. The soils in the untreated check plots grew less productive each year.

Jokela (1992) studied the effects of nitrogen fertilizer and dairy manure on soil nitrate levels. Due partially to mineralization of past manure applications, the second and third years of a three year study showed a greater effect on yields from

the manure applications. Angle and coworkers (1993) found in a three year study that in the last two years N was being mineralized from not only the present manure application but also the past applications showing a need to account for long term manure applications as an N credit. The manure supplied N to be mineralized beyond that utilized effectively by the crop in a growing season.

Bagayoko et al. (1992) found that the amount of soil nitrate in the top 30 cm was highest for plots that had previously been in manure indicating residual effects from the manure applications. The previous manure applications were approximately 170 kg ha^{-1} total N per year over a period of seven years. Nitrogen mineralized in the first year followed the expected trend of rapid N release 13-67 % of the total in the first season.

Chang et al. (1994) found that five years after cessation of 30 or 60 Mg ha^{-1} yr^{-1} manure applications that had been instituted for thirteen years, grain yields still responded to the residual manure, perhaps due to increases in soil N and P as well as reduced salinity. Plant nutrient concentrations were less than those still receiving manure application.

In a study using orchardgrass, Kanneganti and Klausner (199 4) reported no residual effects on dry matter production or N uptake from manure applications of 150 kg N ha^{-1}. The crop studied was orchardgrass, a perennial forage which may have utilized the continuously mineralized N from the manure throughout the year.

Orchardgrass has been shown to use excess N in the soil which annual crops such as corn can not.

Brassica crops given the recommended rate of N (50 kg N ha^{-1}) showed a yield reduction and plant lodging due to residual soil nitrogen. In sampling, actual N levels in soil and crop residues were higher than expected. Being able to measure the soil nitrogen before planting would have allowed for adjustment of the N applied costing the farmer less economically and reducing the chance of pollution by N loss (Rahn et al., 1993).

In Virginia, soil mineral nitrogen is not counted when determining application rates because the residual nitrogen is thought to be lost over winter due to the humid climate. However, significant amounts do persist and will affect the spring crop. At sites with the highest residual N, spring yields were reduced with new applied N. Yield responses to fertilizer N were correlated to residual mineral N measured in January. More variability was seen in residual N under corn than under soybeans. This variation was attributed to corn crops receiving more fertilizer N but having variable yields and N uptake. The variation in yield was thought due to the low water holding capacity of the Coastal Plains soils and variation in summer rainfall (Scharf and Alley, 1994).

Pre-sidedress nitrate test (PSNT)

The pre-sidedress soil nitrate test was developed to give growers a better estimate of soil nitrate early enough in the growing season so that problems could be

addressed without automatically overfertilizing to ensure yields (Magdoff, 1991). The Magdoff PSNT was developed for humid regions such as the Midwest and the Northeast. Any environmental conditions that would affect plant growth will first affect the N mineralization rate. In response to concern over N pollution, the PSNT was predicted to improve N efficiency and reduce nitrate losses by giving a test level to correlate with available N. The test is termed pre-sidedress because soil nitrate levels in the top 1 ft of soil are tested a couple weeks before standard sidedressing when the corn is between 15 and 30 cm tall. The majority of fertilizer needed by corn can be applied as sidedress application. PSNT measures residual nitrate and also spring mineralized nitrate before major crop uptake, (Scharf and Alley, 1994).

Meisinger et al. (1992) did not find any residual effect of their previous N applications with the PSNT. They attributed the absence of nitrate to movement of the residual N to below 30 cm due to the amount of precipitation between the fall and the next spring. Their data indicates that the PSNT will determine sites where N is sufficient (>22 mg NO_3 -N kg soil) but is not accurate at predicting yields at where levels < 20 mg NO_3 -N kg soil. They do report that the PSNT can show differences due to organic N mineralization rates.

Jokela (1992) determined critical values for relative silage yields in northern Vermont to be 16-18 mg kg^{-1} which is in accord with the initial work by Magdoff in 1984 but lower than later works.

Blackmer and coworkers (1989) correlated soil nitrate concentrations with corn yields in Iowa. Nitrate movement down through the profile is significant just after application. This downward movement is due to water moving through preferential flow through the soil macropores. Nitrate is then present throughout the profile concentrated in the surface inches and decreasing with increasing depth. This test provides a reasonable estimate of nitrate in the rooting zone. Using the top foot of soil when the plant are 6-12 inches tall, they suggest an optimal range of 20 to 25 ppm.

Part III

Materials and Methods

Experimental plots were established at the Martin Agricultural Experiment Station in 1993. The site is located on a Collins silt loam (coarse-silty, mixed, acid, thermic Aquic Udifluvent). This site is typical of many broad floodplains in the west Tennessee loessal uplands. This site at Martin had not previously been manured.

The experimental design consisted of eighteen treatments arranged in a randomized complete block with four replications. Plots were 0.0024 ha in size. The treatments were a 0 fertilizer check, three rates of N as $NH_4 NO_3$, (84, 168, and 252 kg N ha^{-1}) and three rates of dairy manure N (112, 224, and 336 kg manure-N ha^{-1}) applied for either 1) three consecutive years, 2) two consecutive years and no application in year three, or 3) the first year with no application for years two and three (Table 1). The code for the manure treatments is the rate 1,2, or 3 first followed by the year 1,2, or 3. For example, the treatment coded 2M3 is the second rate of manure applied for three years. The inorganic treatments are coded 1,2, or 3 for the rate followed by AN for ammonium nitrate. To provide a tillage comparison, 0 N ha^{-1} (0N CT), 168 kg inorganic N ha^{-1} (2AN CT) and the 224 kg manure-N ha^{-1} treatments applied for one, two, or three years (2M1, 2M2, 2M3 CT) were established with conventional tillage (chisel, disk, and harrow) and also with no-tillage.

Table 1. Treatment numbers, identification, and description. Amounts applied are in units of kg ha^{-1}.

Treatment Number	Treatment Identification	Treatment Description	kg P Applied	kg K Applied
1	0N NT	0 N, NT	0	0
2	1M1	112 kg manure-N, 1 year	27	78
3	2M1	224 kg manure-N, 1 year	54	157
4	3M1	336 kg manure-N, 1 year	81	235
5	1M2	112 kg manure-N, 2 years	30	67
6	2M2	224 kg manure-N, 2 years	60	134
7	3M2	336 kg manure-N, 2 years	91	202
8	1M3	112 kg manure-N, 3 years	31	48
9	2M3	224 kg manure-N, 3 years	63	96
10	3M3	336 kg manure-N, 3 years	94	144
11	1 AN	84 kg NH_4NO_3	40	140
12	2 AN	168 kg NH_4NO_3	40	140
13	3 AN	252 kg NH_4NO_3	40	140
14	0N CT	0 N, CT	0	0
15	2M1 CT	224 kg manure-N, 1 year	54	157
16	2M2 CT	224 kg manure-N, 2 years	60	134
17	2M3 CT	224 kg manure-N, 3 years	63	96
18	2 AN CT	168 kg NH_4NO_3	40	140

Manure rates were derived from Pratt's (1976) decay series assuming that 75% of the N applied as liquid cattle manure would be plant available in the first year. These estimated availabilities at 84, 168, and 252 kg N ha^{-1} then match the inorganic rates. The middle rate, 168 kg fertilizer ha^{-1}, corresponds to the high end of the recommended rate of fertilizer N for corn silage in Tennessee.

Manure was obtained from a concrete holding tank. Total N was determined the day prior to application. Nitrogen concentrations in the manure ranged from 0.24% in 1993, 0.31% in 1994 and 0.20% in 1995. The manure slurry was transported to the field and pumped onto the plots using a submersible sewage pump. The slurry was constantly agitated in the tank during application and applied by volume by monitoring a calibrated dipstick in the tank.

Inorganic P and K were applied to the plots receiving inorganic fertilizer N according to soil test recommendations (90 kg P_2O_5 and 168 kg K_2O). Both manure and fertilizer were applied prior to tillage for appropriate plots. Pesticide treatments were the same for all treatments except that no burn-down herbicides were used in the conventional till plots. Silage corn was grown on all plots.

At each site, ear leaf N, silage yield and total silage N were measured. Ear leaves were collected at the silking stage for total nitrogen analysis. Ten leaves were chosen from different plants in the middle of each plot and dried overnight in an oven at 60 C. The leaves were ground and stored in plastic bags prior to analysis. Total N was determined by a combustion method on a Carlo Erba NA 1500 Nitrogen

Analyzer. Plant samples used to determine silage nitrogen content as well as total silage yield were taken in the summer at harvest. Corn silage was harvested from each plot. Two 10-ft. rows were hand harvested from the center of each plot and all vegetation was weighed for yield measurement. All harvested plants were then passed through a silage chopper and a subsample was collected from each plot. These samples were weighed and then oven-dried for moisture content. Subsamples of the vegetation were further ground to pass a 60-mesh screen. Total N was then determined. Plant tissue analysis and yield were compared across treatments for nutrient uptake efficiency. Efficiency is defined as the amount of nitrogen taken up minus the amount recovered in the 0 N control plots divided by the amount of nitrogen supplied.

Plant samples from all plots receiving manure in 1993 (1M1, 2M1, 3M1, 1M2, 2M2, 3M2, 1M3, 2M3, and 3M3) had one year of manure treatment. Those receiving manure in 1994 (1M2, 2M2, 3M2, 1M3, 2M3, and 3M3) had two years applied. Those receiving manure in 1995 (1M3, 2M3, and 3M3) had three years of manure application.

Soil samples were taken prior to manure application. Samples from 1993 had no manure added, those from 1994 had one year of treatment, and those from 1995 had two years of application. Soil samples were taken to a depth of 90 cm in both spring and fall prior to manure application to assess concentrations of N, P, and K and to evaluate changes in organic matter accumulation in the profile. Two cores

were taken per plot with a three-inch bucket auger and separated initially into 0-7.5, 7.5-15, 15-30, 30-45, 45-60, 60-75, and 75-90 cm segments. After the first sampling date in April of 1993, the segments were taken as 0-7.5, 7.5-15, 15-30, 30-60, and 60-90 cm. Data from soil analyses is presented for the first three depths. The cores are composited for each plot and the holes backfilled with similar soil from outside the plot area as well as the excess from that plot. Samples were air dried, crushed to pass through a 2-mm screen, then ground to pass a 100-mesh screen. Samples were stored in 0.5 L plastic containers until analysis.

Soil pH was determined using a 2:1 (10 ml deionized water to 5 g soil) ratio measured by combination electrode (McLean, 1982). Total organic carbon was determined with a Leco CR12 Carbon Analyzer (Nelson and Sommers, 1982) and total nitrogen by a Carlo Erba model NA 1500 total N analyzer. P and K were extracted using a double acid extraction method (Mehlich I; Olsen and Sommers, 1982) and then determined by Inductively Coupled Argon Plasma Spectrometry (ICAP). Two g of soil were extracted with 40 ml Mehlich I in 60 ml Nalgene bottles. The solution was shaken for 20 min on a shaker. After shaking, the soil was allowed to settle and the supernatant was filtered through 42 Whatman filter paper and stored in a cold room until analysis.

Pre-sidedress nitrogen test (PSNT) samples were taken from each treatment when the corn reached 15 to 30 cm in height in 1994 and 1995. Soil samples taken at this time were analyzed for nitrate-N.

Statistical analysis (analysis of variance, regression analysis, and correlation) was performed using SigmaStat (Jandel Scientific, Inc., 1995). Means were separated using the Student-Newman-Keuls procedure at $p = 0.05$.

Part IV

Results and Discussion

Soil Data

In 1993 (Table 2) and 1994 (Table 3), the soil analysis showed no significant treatment differences. In 1995, the total carbon in the top depth (0-7.5 cm) showed significant treatment effects (Table 4). The 3M2 treatment resulted in carbon concentrations that were the same as those from the 2M2 treatment but significantly higher than all other treatments. With the addition of the tillage comparison, the total nitrogen also showed some treatment effects. The 2M2 treatment was higher and different than all other treatments (1M1, 2M2 CT, 2M1 CT, 0 N CT, 2AN CT, and 2M1). The 2AN treatment was the same as the 2M2 and all the other treatments (data not shown).

Our findings of few differences in soil properties after only two years of manuring are similar to the findings of Wood et al. (1993). After two years of application of ammonium-nitrate (112, 224, and 336 kg ha^{-1}) and poultry litter (5.6, 11.2, and 22.4 Mg ha^{-1}) to bermudagrass they observed no significant differences in soil organic C and N concentrations from plots treated with the highest inorganic and litter rates. This lack of treatment difference was tentatively attributed to the short duration of the study. Soil C and N levels in the top 5 cm from plots treated with the litter were numerically higher than either plots treated with the ammonium nitrate or the control plots.

Table 2. 1993 Background soil data prior to manuring for depths 1,2, and 3.

Treatment	pH	Total C %	Total N %	Mehlich I P	Mehlich I K
Depth 1				mg kg^{-1}	mg kg^{-1}
0 N	6.14	0.93	0.11	105	196
1M1	6.38	0.92	0.13	94.	234
2M1	6.56	0.95	0.10	100	213
3M1	6.45	0.95	0.08	101	214
1AN	6.33	0.92	0.12	65	158
2AN	6.27	0.86	0.10	121	239
3AN	6.22	0.96	0.10	96	268
Depth 2					
0 N	6.74	0.57	0.07	63	120
1M1	6.54	0.55	0.09	50	156
2M1	6.95	0.52	0.07	31	127
3M1	6.75	0.56	0.07	52	166
1AN	6.55	0.52	0.09	49	123
2AN	6.74	0.57	0.07	45	119
3AN	6.68	0.51	0.06	32	123
Depth 3					
0 N	6.93	0.47	0.06	31	88
1M1	6.13	0.33	0.07	21	89
2M1	6.48	0.37	0.06	18	85
3M1	6.76	0.39	0.05	18	90
1AN	6.08	0.36	0.08	20	92
2AN	6.79	0.44	0.06	31	101
3AN	6.57	0.34	0.05	22	102

Table 3. 1994 Soil data for depths 1,2, and 3 prior to second year manuring.

Treatment	pH	Total C %	Total N %	Mehlich I P	Mehlich I K
Depth 1				mg kg^{-1}	mg kg^{-1}
0 N	6.07	1.04	0.14	72	79
1M1	6.17	1.04	0.09	55	100
2M1	6.47	1.13	0.11	105	112
3M1	6.05	0.93	0.06	74	106
1AN	5.86	0.93	0.09	81	124
2AN	6.13	1.09	0.10	94	116
3AN	5.62	1.03	0.11	60	91
Depth 2					
0 N	5.72	0.65	0.10	46	46
1M1	5.58	0.56	0.06	27	58
2M1	6.41	0.66	0.07	63	72
3M1	6.18	0.64	0.03	38	57
1AN	5.97	0.57	0.07	38	65
2AN	6.22	0.59	0.08	49	65
3AN	5.60	0.61	0.07	36	59
Depth 3					
0 N	5.89	0.47	0.07	21	38
1M1	5.92	0.38	0.04	14	45
2M1	6.38	0.39	0.05	27	44
3M1	6.13	0.44	0.02	20	43
1AN	5.43	0.34	0.05	19	45
2AN	6.28	0.53	0.07	23	44
3AN	5.28	0.42	0.06	17	50

Table 4. 1995 Soil data for depths 1,2, and 3 prior to third year manuring.

Treatment	pH	Total C %	Total N %	Mehlich I P	Mehlich I K
Depth 1				mg kg^{-1}	mg kg^{-1}
0 N	6.93	0.93 b*	0.11	32	93
1M1	6.28	0.94 b	0.10	24	64
2M1	6.74	1.07 b	0.09	38	50
3M1	6.42	0.98 b	0.10	31	65
1M2	6.43	1.09 b	0.11	30	72
2M2	6.88	1.46 ab	0.15	44	69
3M2	7.21	1.67 a	0.11	42	184
1AN	6.30	1.01 b	0.09	44	69
2AN	6.25	0.81 b	0.11	36	68
3AN	6.50	0.90 b	0.10	25	59
Depth 2					
0 N	6.80	0.42	0.08	18	73
1M1	6.33	0.51	0.06	14	41
2M1	6.86	0.61	0.08	25	38
3M1	6.42	0.59	0.07	20	57
1M2	6.43	0.64	0.07	19	48
2M2	6.68	0.62	0.07	19	49
3M2	7.13	0.62	0.06	17	201
1AN	6.46	0.57	0.06	25	53
2AN	6.64	0.60	0.07	26	150
3AN	6.34	0.52	0.06	14	40
Depth 3					
0 N	6.40	0.44	0.06	10	39
1M1	5.78	0.31	0.04	10	37
2M1	6.87	0.39	0.05	18	38
3M1	6.32	0.38	0.05	10	46
1M2	5.90	0.40	0.05	13	42
2M2	6.37	0.43	0.05	9	214
3M2	6.80	0.37	0.05	8	123
1AN	6.02	0.35	0.05	12	46
2AN	6.35	0.43	0.05	14	65
3AN	6.58	0.38	0.05	10	50

*means followed by the same letter are not different as determined by the Student-Newman-Keuls test at $p = 0.05$.

There is disagreement in the literature about whether a soil's level of carbon and nitrogen can be increased. White (1926) states that there is an ultimate level of organic matter and soil nitrogen which can not be increased or maintained with excessive amounts of farmyard manure. In 1935, Metzger reported that additions of 40 tons of manure in two rotations, a sixteen-year rotation (four years alfalfa followed by three years in corn, wheat, and wheat) and a three-year rotation (corn, soybeans, and wheat) and 60 tons of manure in continuous wheat failed to increase the nitrogen content of the soil. There was also no significant increase in soil carbon. Later works report increases in both (Cooper, 1984; Christensen, 1988; and Rasmussen and Parton, 1994)

In northern Alabama near the Sand Mountain region, Kingery et al. (1994) looked at broiler litter applications in long term sites with regard to environmental soil conditions. Litter applications at these sites increased levels of organic C to 15 cm in depth and total N increased 0.25 g kg^{-1} to 30 cm in depth when compared with the control plots. In the littered fields, pH was 0.5 units higher to 60 cm in depth. The nonlittered soils had a higher C:N ratio. The lower C:N ratio in the littered soils resulted in a pool of inorganic N through mineralization of organic matter. These long term sites have been maintained for 15-28 years. Due to the temperate climate of the region, mineralization and release of nutrients held in the organic phase in the litter were thought likely to occur through the year.

We found no differences in soil P and K levels in the two years of manuring or inorganic fertilizing. Schlegel (1992) did find that increased rates of N fertilizer (55, 110, and 165 lb acre^{-1}) decreased soil P and K levels especially at the higher rates while having no effect on soil organic matter. Subsequently, the low levels of soil P may have restricted grain yields. Increased rates of composted manure (ranging from 0, 0.9, 1.8, 3.6, and 7.2 ton dry matter acre^{-1}) increased soil P and K as well as soil organic matter.

Ear Leaf N Data

In 1993, ear leaf N concentrations were significantly higher in the 2AN treatment than all manure treatments and the 0 N control. However, 1AN and 3AN ear leaf N concentrations were not significantly different from the manured treatments (Figure 1).

After two years of manuring, there were few significance differences between treatments, although the 2AN and 3AN treatments did result in greater ear leaf N than the control. There was a tendency for higher ear leaf N in the 2M2 and 2M3 treatments, but these differences were not significant (Figure 2). The lack of differences between manure and inorganic N treatments are likely due to either an increased N supply due to continued mineralization of N from the first year or the availability of other nutrients from the manure treatments.

After three years of manuring, the 3AN treatment resulted in significantly greater ear leaf N than all other treatments with the exception of the 2AN and 3M3.

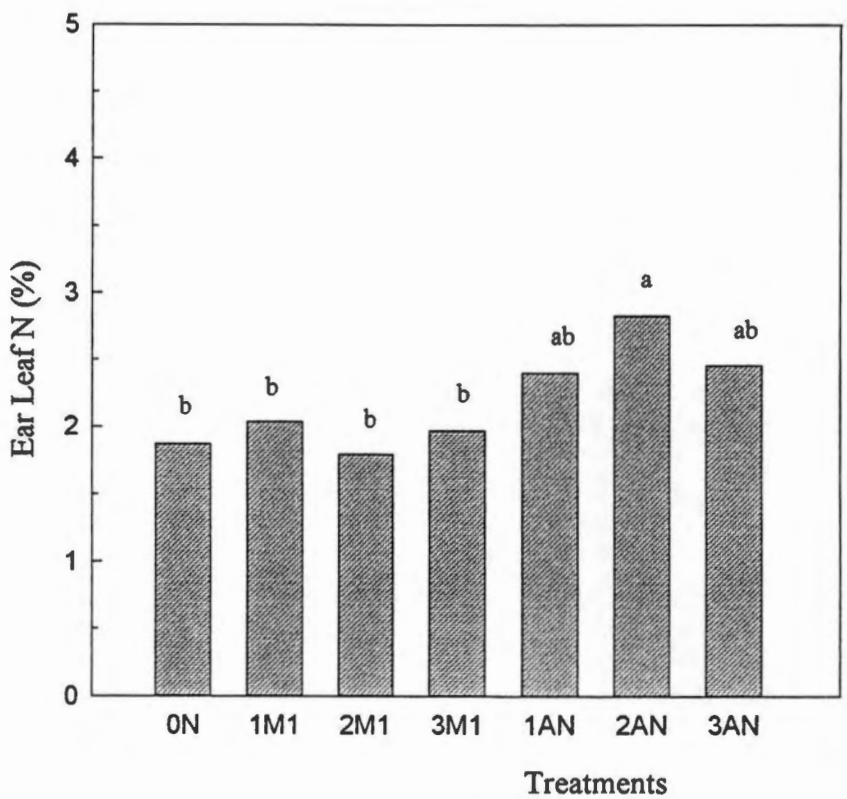


Figure 1. 1993 ear leaf nitrogen concentrations from plots receiving one year of manure application. Treatments labeled with the same letter are not different at the 5% level as determined by SNK.

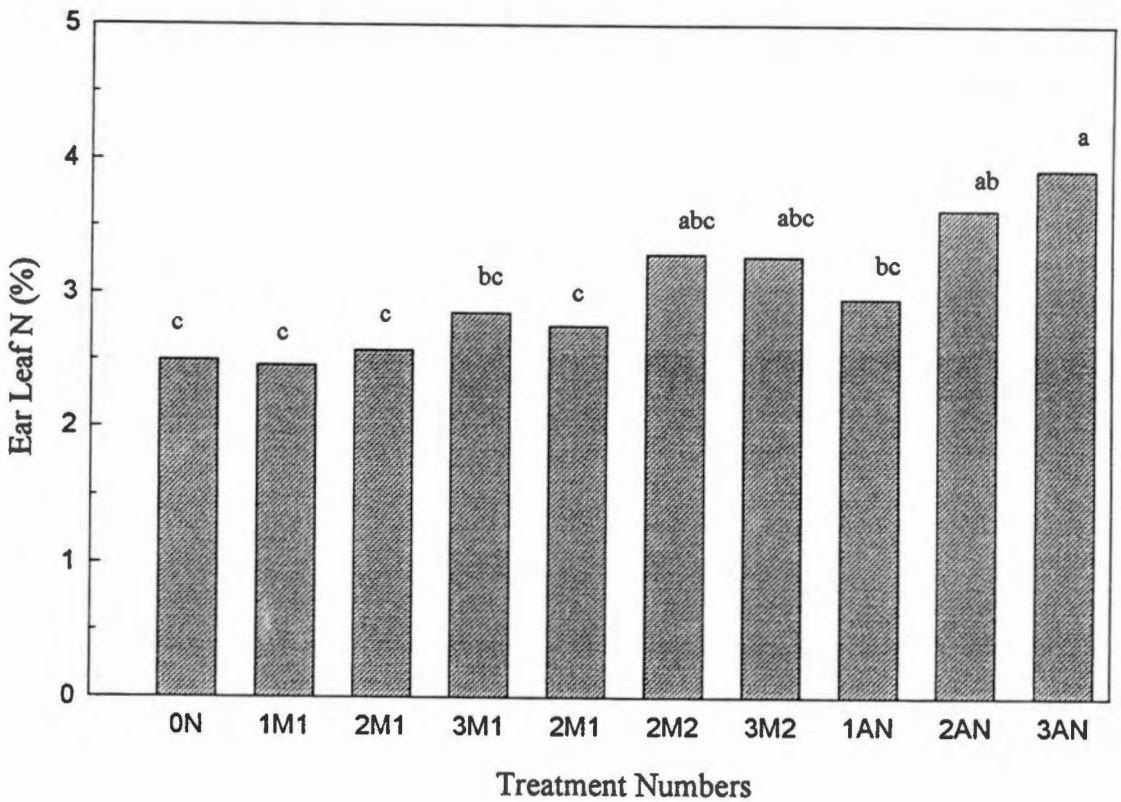


Figure 2. 1994 ear leaf nitrogen concentrations from plots receiving one or two years of manure application. Treatments labeled with the same letter are not different at the 5% level as determined by SNK.

In the second and third year treatments, there was a trend for increasing ear leaf N with increased rates of manure. The sufficiency range for ear leaf N in corn is 2.7-4.0 % (Jones et al., 1991). Until the 2M3 treatment, all the previous treatments fell in the deficient range (<2.7 %). In the first year treatments, there was a N decrease with increased rates. There is a tendency for increased ear leaf N from the manured treatments across the years. Ear leaf N in 3M3 was greater than for 3M2, while the ear leaf N in 3M2 was greater than that from the 3M1 treatment (Figure 3). These data indicate that there was more residual N available in 3M2 than 3M1. Looking at the tillage comparisons in the third year, the intermediate pairs of no-till and conventional till treatments are the same. The 0 control treatments were different than each other. The 0 CT treatment was the same as the 2M3 CT. The no-till treatments, 2M3 and 2AN were numerically higher than the conventional till counterparts. The 2AN no-till was significantly different than the 2M3 treatments but the same as the 2AN CT (Figure 4). In the previous two years there were no differences between the no-till and conventional till pairs.

Total Silage Yield

In 1993, dry matter yields in the 2AN and 3AN treatments were significantly higher than all other treatments (Table 5). The manure treatments (1M1, 2M1, and 3M1) and the 1AN were not different than the 0 N treatment. Evidently, N availability from the manure was not adequate in the first year to result in comparable yields from the higher inorganic treatments.

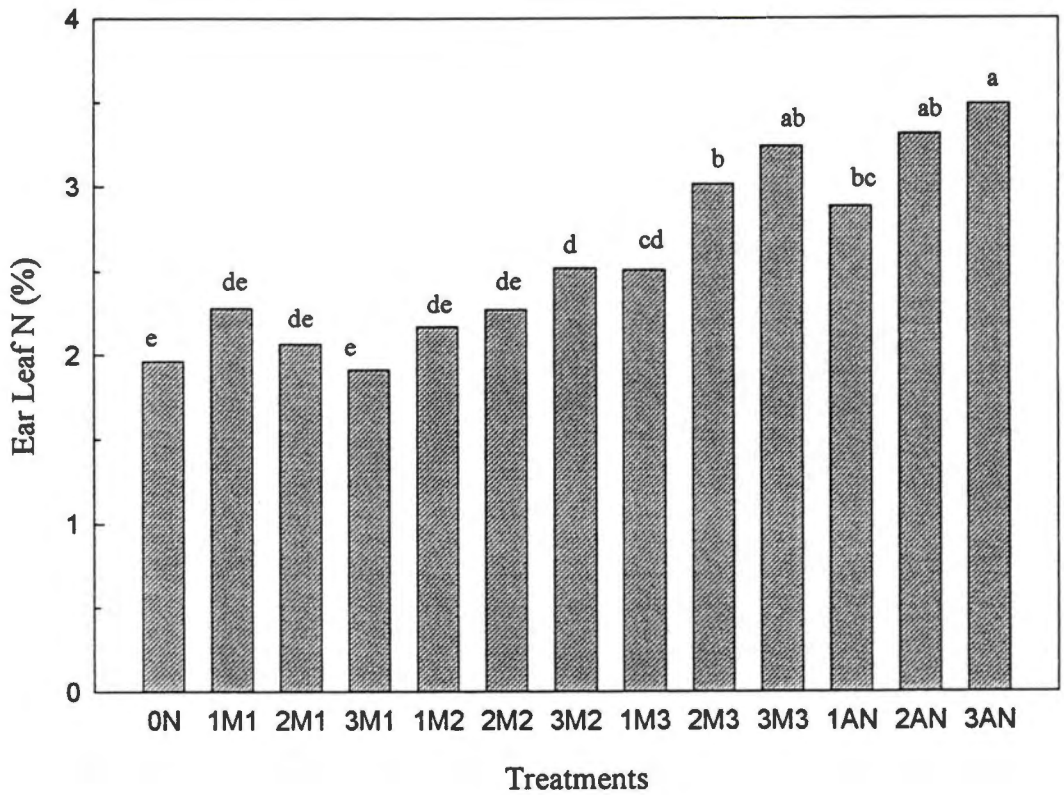


Figure 3. 1995 ear leaf nitrogen concentrations from plots receiving one, two, or three years of manure application. Treatments labeled with the same letter are not different at the 5% level as determined by SNK.

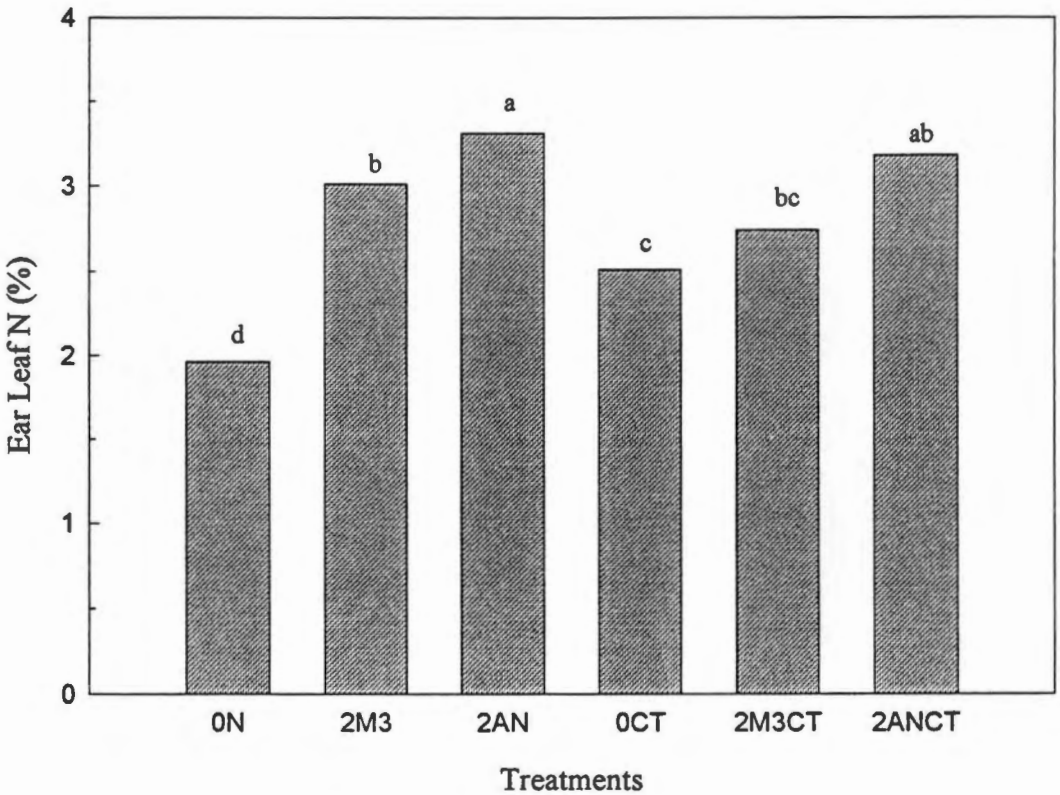


Figure 4. 1995 ear leaf nitrogen concentrations from plots receiving three years of manure application with tillage variable. Treatments labeled with the same letter are not different at the 5% level as determined by SNK.

Table 5. Silage yields, total N, and N uptake for 1993.

Treatment	Yield (Mg ha^{-1})	Silage N %	N Uptake (kg ha^{-1})
0 N	7.2 b	0.90 a	66 c
1M1	8.2 b	0.88 a	72 c
2M1	8.7 b	1.17 a	103 bc
3M1	9.3 b	0.95 a	91 bc
1AN	11.4 b	0.90 a	101 b
2AN	17.8 a	0.99 a	168 ab
3AN	18.0 a	1.09 a	195 a

*means followed by the same letter are not different as determined by the Student-Newman-Keuls test at $p = 0.05$.

In 1994, yields from the 2AN and 3AN treatments were significantly greater than those in the 0 N, 1M1, 2M1, 3M1, 2M2, and 1AN but the same as those from 1M2 and 3M2 (Table 6). In 1995, the 3AN treatment was higher and different than all other treatments. There was a trend, even if not significant, for increased yield with increased rates of application. After three years, yields from the manured treatments were essentially equivalent to those from the inorganic treatments (Table 7).

Many authors have reported yield increases from manure application in different crops such as sugarbeets (Pittman and Fonder, 1926), beans (Powers and Lewis, 1930), cotton (Latham, 1940), wheat (Bhagat and Verma, 1991) and maize (Smaling et al., 1992). Martin and Wang (1943) indicate that factors other than available nitrogen enhanced growth. Greater amounts of nitrogen were removed by the crop from their inorganic fertilizer treatment than a cow manure compost. Bhagat and Verma (1991) attribute their yield increase to better physical structure and moisture content resulting from 5 Mg FYM ha^{-1}. Giardini and coworkers (1992) observed significantly greater marketable yields in tomato with poultry litter than mineral fertilizers which they attributed to P held in the organic phase of the litter that is more plant available. Motavalli et al. (1993) observed a greater response in corn to dairy manure than inorganic fertilizer which they attributed to P, K, and micronutrients in the manure.

Table 6. Silage yields, total N, and N uptake for 1994.

Treatment	Yield (Mg ha^{-1})	Silage N %	N Uptake (kg ha^{-1})
0 N	7.2 b	0.65 a	47 b
1M1	8.2 b	0.73 a	60 b
2M1	8.6 b	0.72 a	63 b
3M1	9.3 b	0.72 a	68 b
1M2	11.1 ab	0.81 a	87 b
2M2	10.2 b	0.73 a	67 b
3M2	12.7 ab	0.70 a	92 b
1AN	11.4 ab	0.70 a	79 b
2AN	17.8 a	0.87 a	162 a
3AN	18.0 a	1.00 a	180 a

*means followed by the same letter are not different as determined by the Student-Newman-Keuls test at p = 0.05.

Table 7. Silage yields, total N, and N uptake for 1995.

Treatment	Yield (Mg ha^{-1})	Silage N %	N Uptake (kg ha^{-1})
0 N	8.7 ef	0.79 a	68cd
1M1	7.6 f	0.70 a	53 d
2M1	7.6 f	0.71 a	52 d
3M1	9.2 ef	0.66 a	61 cd
1M2	10.3 ef	0.77 a	78 cd
2M2	11.7 def	0.72 a	83 cd
3M2	10.8 ef	0.68 a	76 cd
1M3	12.7 cde	0.77 a	96 bcd
2M3	15.7 bc	0.72 a	114 bcd
3M3	17.2 b	0.85 a	146 b
1AN	15.1 bcd	0.69 a	104 bcd
2AN	16.4 bc	0.76 a	123 bc
3AN	21.1 a	0.97 a	206 a

*means followed by the same letter are not different as determined by the Student-Newman-Keuls test at p = 0.05.

In all three years there were no tillage differences. Yields from the no-till treatments were equivalent to the conventional tilled treatments. Instead of experiencing nitrogen loss from the surface applied manure, there were no differences in yields. By the third year, the manured treatments, 2M3 and 2M3 CT, were the same as the 2AN treatments (Figure 5). Enough nitrogen was plant available after three years of application to give equivalent yields as (2AN) 168 kg ammonium nitrate. Evidently, residual nitrogen from the previous two years was available during the third.

The overall trend was an increase in yield with an increase in application for both inorganic and manure treatments. All nutrient amendments increased yields over the 0 control plots. Manure applications have been shown to increase yields by improving soil structure and serving as a nutrient reservoir.

Silage Nitrogen

In 1993, all treatments were the same regarding silage nitrogen content (Table 5). The highest nitrogen value was from the 2M1 treatment at 1.2 % followed by the 3AN treatment at 1.1 %. In 1994, there were some differences between treatments. The 3AN treatment was the same as the 2AN treatment but significantly higher than all others. The 2AN treatment was statistically the same as all the treatments including the control (Table 6). In 1995, all treatments were again the same with no difference in nitrogen content. In this instance, the highest nitrogen

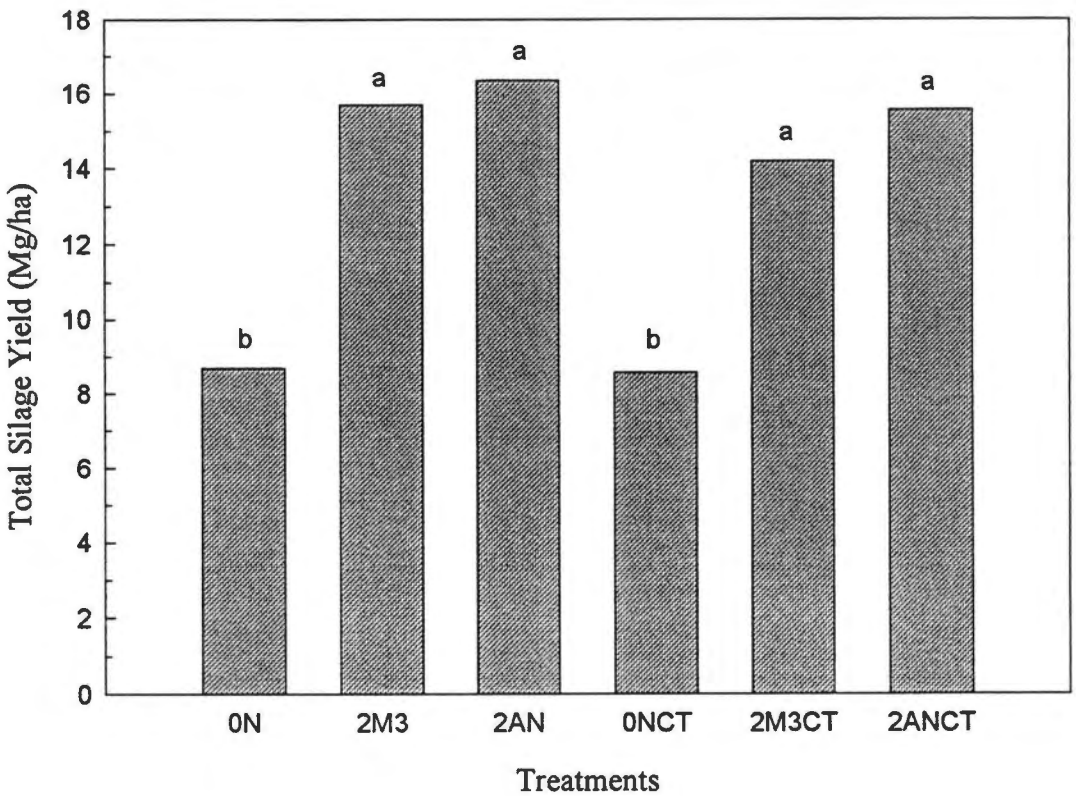


Figure 5. 1995 total silage yield from plots receiving three years of manure application with tillage variable. Treatments labeled with the same letter are not different at the 5% level as determined by SNK.

content was in the 3AN treatment at 1.0 % (Table 7). There were no differences among the tillage comparisons for all three years.

Nitrogen Uptake

In 1993, the nitrogen uptake (silage nitrogen x total silage yield) was the same for the 3AN and 2AN (Table 5). The 2AN was also the same as the 1AN and 3M1 treatments. The 0 N, 1M1, and 2M1 were the same while significantly lower than the other treatments.

In 1994, N uptake from the 2AN and 3AN treatments was higher and significantly different than all the manured treatments, the 0 control, and the 1AN treatments (Table 6). In 1995, the 3AN was different and higher than all other treatments. The next value was from the 3M3 which was the same as the other inorganic treatments and the other manure treatments from the third year (Table 7). The 3M3 treatment was higher than the 3M2 which was higher than the 3M1 showing a residual effect that increases over the years. Patni and Culley (1989) applied liquid dairy manure and inorganic fertilizer to corn and found no significant differences in uptake in their treatments. However, the site had previously been in alfalfa, and a nitrogen build up in the soil had occurred.

From the first year, there were no tillage differences in the manured treatments. All pairs of no-till and conventionally tilled treatments were the same. By the third year, the middle rate of manure (2M3) gave the same yields as the middle rate of inorganic fertilizer (2AN). Nitrogen availability evidently was not

different between tillage treatments. Loss of nitrogen by volatilization in the manured plots did not seem to be a problem.

Nitrogen Efficiency

In 1994 and 1995, the uptake efficiencies were higher at the lower rates of manure (1M2 and 1M3) than the higher rates. In 1993, the most efficient rate was the middle rate, 2M1 (Table 8). The same trend followed in the inorganic treatments in 1993 and 1994 (Table 8; Table 9). In 1995, the highest efficiency was from the 3AN treatment (Table 10). The manure N recovered in all three years did not approach the estimated 75% availability. The nitrogen efficiency was always higher from the inorganic fertilizer. Perhaps a relatively large amount of nitrogen in the manure remained in the organic phase and was unavailable even after three years.

Residual Nitrogen

The third inorganic rate (3AN) resulted in the highest yields each year. After three years, the residual effects from the manure are evident. Data for the ear leaf samples show that the nitrogen content from the third manure treatment (3M3) was the same statistically as those from the 2AN and 3AN treatments. For the silage yields, the total from the 3M3 was between the 2AN and the 3AN treatments by the third year. After three years, the nitrogen uptake in the 3M3 treatment was again greater than in the 2AN. Nitrogen uptake is a function of silage nitrogen content and dry matter yield. In all of the three years, there were no significant differences in

Table 8. Nitrogen use efficiency by silage corn for 1993.

Treatment	N uptake	N applied	N efficiency*
	kg ha^{-1}	kg ha^{-1}	%
0N	66	0	undefined
1M1	72	112	5.4
2M1	103	224	16.5
3M1	91	336	7.4
1AN	101	84	41.7
2AN	168	168	60.7
3AN	195	252	51.2

*N efficiency = (N uptake ((trt)) - N uptake ((0 N)) / N applied) * 100

Table 9. Nitrogen use efficiency by silage corn for 1994.

Treatment	N uptake	N applied	N efficiency*
	kg ha^{-1}	kg ha^{-1}	%
0N	47	0	undefined
1M2	87	112	35.7
2M2	67	224	8.9
3M2	92	336	13.4
1AN	79	84	38.1
2AN	162	168	68.5
3AN	180	252	52.8

*N efficiency = (N uptake ((trt)) - N uptake ((0 N)) / N applied) * 100

Table 10. Nitrogen use efficiency by silage corn in 1995.

Treatment	N uptake	N applied	N efficiency*
	kg ha^{-1}	kg ha^{-1}	%
0N	68	0	undefined
1M3	96	112	25.0
2M3	114	224	20.5
3M3	146	336	23.2
1AN	104	84	42.9
2AN	123	168	32.7
3AN	206	252	54.8

*N efficiency = (N uptake ((trt)) - N uptake ((0 N)) / N applied) * 100

silage N content in any treatments. Yields appeared to be in the expected range for the area; nitrogen availability does appear to be limiting. All treatments resulted in a similar level of silage nitrogen but yields were higher in the inorganic treatments. This indicates that in the manured treatments the plants grew to maintain a nitrogen level but did not increase growth beyond that point.

Motavalli et al. (1993) observed a residual effect from repeated manure treatments (0, 19, 33, 60, and 121 lb N $acre^{-1}$) over a period of five years which they attributed to accumulation of P and K and continued organic N mineralization. They observed no residual effect from applications of N fertilizer. In this study, yields for all three years from the 2AN and 3AN treatments fell between 18 and 19 Mg ha^{-1}. There was no increase over time that accumulated in the third year from the inorganic fertilizer.

In Alabama, Wood and coworkers (1993) observed residual effects in the second year of their study on the effect of poultry litter on bermudagrass yield and quality. Yields and protein content increased over the first year in the poultry litter treatments. Yields in 1991, the second year of the study, from the 11.2 and 22.4 Mg ha $^{-1}$ at the first cutting and 22.4 Mg ha $^{-1}$ at the second cutting were similar to the highest rate of inorganic fertilizer (336 kg ha $^{-1}$). By the third cutting, the 22.4 Mg ha $^{-1}$ resulted in yields higher than those from the inorganic fertilizer.

PSNT

According to the literature, the PSNT range of 20-25 ppm indicates a sufficiency range for corn yields. Above this range additional nitrogen will not significantly increase yields while below the range additional N is necessary to ensure desired yields. Meisinger et al. (1992) researched the PSNT as it relates to corn grain yield and found the critical range to be between 22 and 27 mg NO_3^--N kg^{-1} soil. Blackmer and co-workers (1989) also looked at the PSNT with regard to corn grain yield. In the surface 30 cm of soil, their optimum range was between 20 and 25 mg NO_3^--N kg^{-1} soil. Jokela (1992) found an optimum range between 16 and 18 mg NO_3^--N kg^{-1} soil for silage.

In this experiment, the 1994 yields were not different between the inorganic treatments (1AN, 2AN, 3AN) and the manured treatments for the second year (1M2, 2M2, 3M2). The PSNT values were much higher from the inorganic treatments ranging from 29.3-92.0 mg NO^-_3-N kg^{-1} soil versus 7.8-9.5 mg NO^-_3-N kg^{-1} soil from the manured plots. In 1995, the results were similar. The yields were not different from inorganic to organic treatments while the PSNT values were much higher in the inorganic treatments (Table 11). The correlations between the yield, nitrogen rate, and PSNT are presented in Tables 12,13, and 14. For all treatments in 1994, there is a good correlation between PSNT values and yield ($r = 0.811$; $p < 0.001$, Table 12). However, when manure treatments are removed, the correlation of PSNT with yield in fertilized plots is very good ($r = 0.94$; $p < 0.001$, Table 13).

Table 11. 1994 and 1995 means for silage yield and PSNT values.

Year	1994		1995	
Treatment	Silage yield (Mg ha^{-1})	PSNT values	Silage yield (Mg ha^{-1})	PSNT values
0N	7.2 b	4.6	8.7 de	5.9
1M1	8.2 b	3.0	7.6 e	4.8
2M1	8.6 b	3.5	7.6 de	5.1
3M1	9.3 b	2.3	9.2 de	6.3
1M2	11.1 ab	8.6	10.2 de	7.8
2M2	13.9 b	7.8	11.7 d	7.0
3M2	12.7 ab	9.5	8.1 de	9.3
1M3	na	na	12.6 cd	12.6
2M3	na	na	15.7 bc	12.2
3M3	na	na	17.2 b	18.4
1AN	11.4 b	29.3	15.1 bc	23.8
2AN	17.8 ab	68.8	16.4 b	57.2
3AN	18.0 a	92.0	21.1 a	83.7

Table 12. Correlation between yield, PSNT, and nitrogen rate for all treatments.

1994	N rate	PSNT
Yield (Mg ha^{-1})	0.28	0.81
N rate		0.06
1995	N rate	PSNT
Yield (Mg ha^{-1})	0.15	0.7
N rate		0.10

Table 13. Correlation between yield, PSNT, and nitrogen rate for all inorganic treatments.

1994	N rate	PSNT
Yield Mg ha^{-1}	0.82	0.94
N rate		0.89
1995	N rate	PSNT
Yield Mg ha^{-1}	0.89	0.87
N rate		0.93

Table 14. Correlation between yield, PSNT, and nitrogen rate for all organic treatments.

1994	N rate	PSNT
Yield Mg ha^{-1}	0.41	0.70
N rate		0.08
1995	N rate	PSNT
Yield Mg ha^{-1}	0.22	0.63
N rate		0.30

There is still a positive correlation for PSNT and yield in the manured plots, but the correlation is weaker ($r = 0.70$; $p < 0.001$, Table 14).

The correlation between PSNT and N rate for the organic treatments ($r = 0.08$; $p > 0.66$ in 1994, Table 14) was considerably lower than between PSNT and N rate for the fertilized treatments in the same year ($r = 0.89$; $p < 0.001$, Table 13). Although the correlation between PSNT and N rate for the organic treatments was stronger in 1995 ($r = 0.30$; $p > 0.06$, Table 14), it was still weaker than the correlation for the inorganic treatments ($r = 0.93$; $p < 0.001$, Table 13). The PSNT measures nitrogen available at the time of the test. Inorganic fertilizer is immediately available while the majority of manure N is in the organic phase and will mineralize over time. Clearly, all the nitrogen that will be made plant available during the season from the manure is not measured by the PSNT.

The low PSNT values from the treatments that did not receive manure does indicate that those treatments are nitrogen deficient and would benefit from additional N. From the inorganic treatments, the only one that fell in or close to the expected range for both years was the 1AN (29.3 in 1994 and 23.8 in 1995). However, there are yield limitations from this treatment. The 3M3 treatment fell in the lower range but again yields were not as high as the 3AN yields. The high PSNT values from the inorganic treatments may indicate little leaching loss of N.

For both years, there was a trend for increasing PSNT values with increased application of manure. This mirrored the trend for increased yields with increased

application of manure. For both years, the PSNT values from the manured treatments were lower than the critical range of 20-25 mg NO_3^--N kg^{-1} soil. However, in 1995, the 3M3 PSNT value of 18.4 mg NO_3^--N kg^{-1} soil was just over the critical range of 16-18 mg NO_3^--N kg^{-1} soil as determined by Jokela (1992). In both years, the yields from the manured treatments were not different from those from the inorganic treatments except the 3AN in 1995. The PSNT is not a good predictor of yield in these manured soils.

In both years, the PSNT values from the inorganic treatments were higher than the optimal range 20-25 mg NO_3^--N kg^{-1} soil, with the exception of 1AN in 1995 with a value of 23.8 mg NO_3^--N kg^{-1} soil. The yield from 1AN, in 1995, was 15.1 Mg ha^{-1} which was different only from the yield in the 3AN treatment (21.1 Mg ha^{-1}). The other PSNT values from the inorganic treatments were high ranging from 29.3 to 92.0 mg NO_3^--N kg^{-1} soil. This may indicate that too much nitrogen has been applied, and there is an excessive amount in the soil. This excess nitrogen may be lost via leaching from the soil.

The 1994 PSNT data for both inorganic and organic treatments did not show a very good fit to the regression line ($r^2 = 0.65$; $p < 0.001$; Figure 6). There was a cluster of data at PSNT values <12 mg NO_3^--N kg^{-1} soil which represent the manured treatments. Once the organic treatments were removed, the fit was much better ($r^2 = 0.87$; $p < 0.001$; Figure 7). There was only a weak relationship between

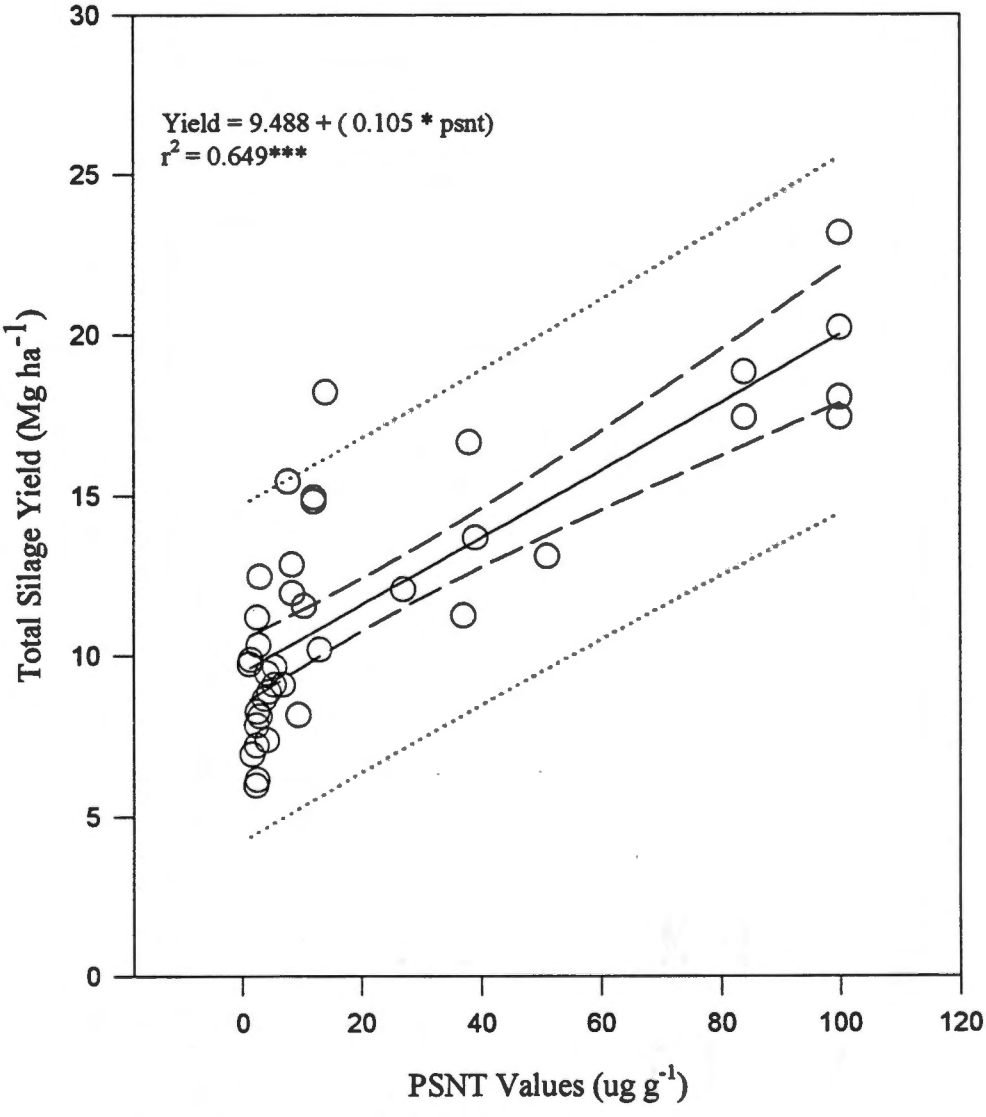


Figure 6. Linear regression for all 1994 no-till treatments.

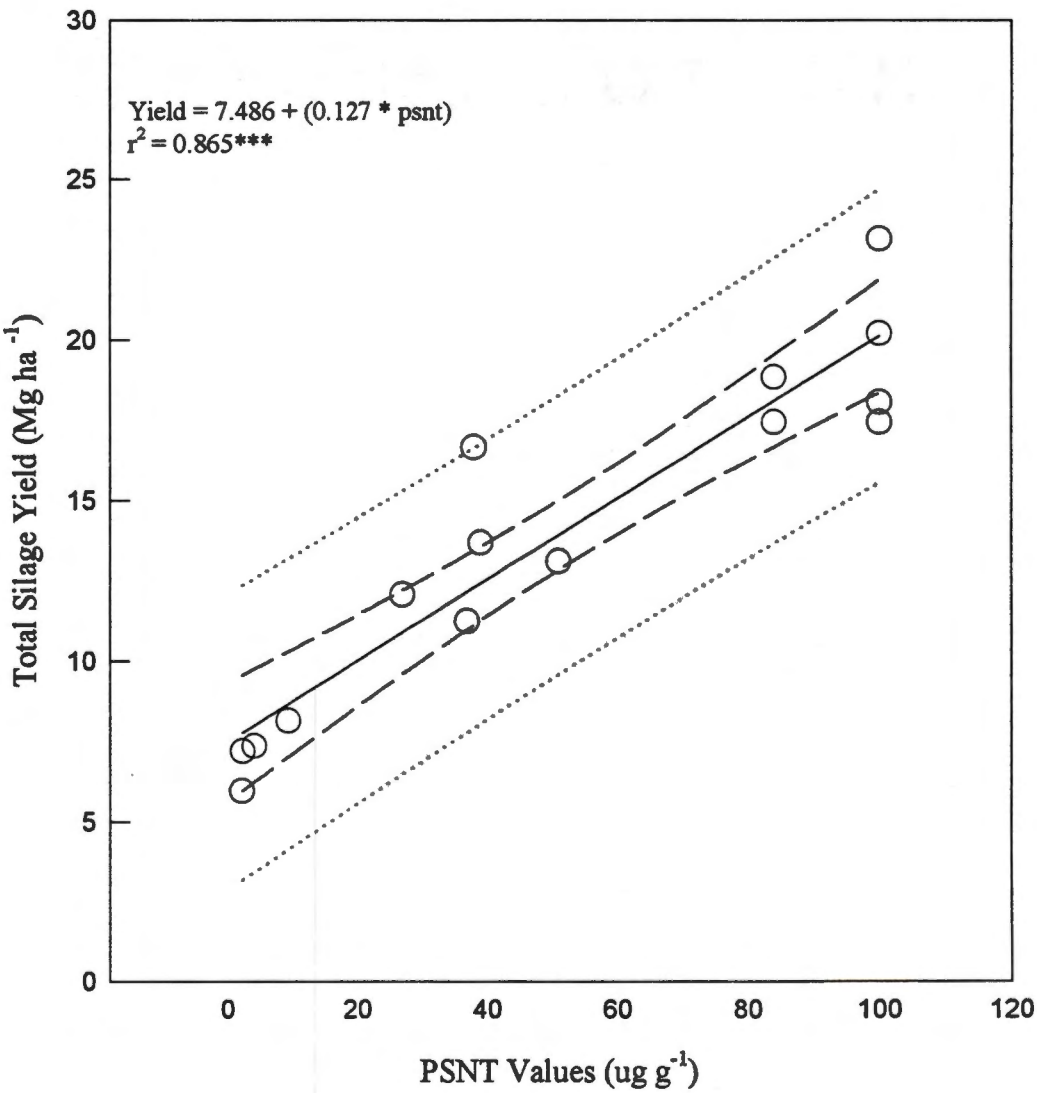


Figure 7. Linear regression for 1994 inorganic treatments.

PSNT value and yield for the manured soils ($r^2 = 0.20$; $p < 0.05$; Figure 8). Visibly, the organic treatments were scattered about the regression line.

In 1995, the combined data looked the same ($r^2 = 0.50$; $p < 0.001$; Figure 9). When the organic treatments were removed, again the fit was better ($r^2 = 0.75$; $p < 0.001$; Figure 10) but not as good as the first year. When the organic treatments were studied separately, the fit was better than the first year ($r^2 = 0.38$; $p < 0.001$; Figure 11) perhaps suggestive of mineralization from the previous year now available.

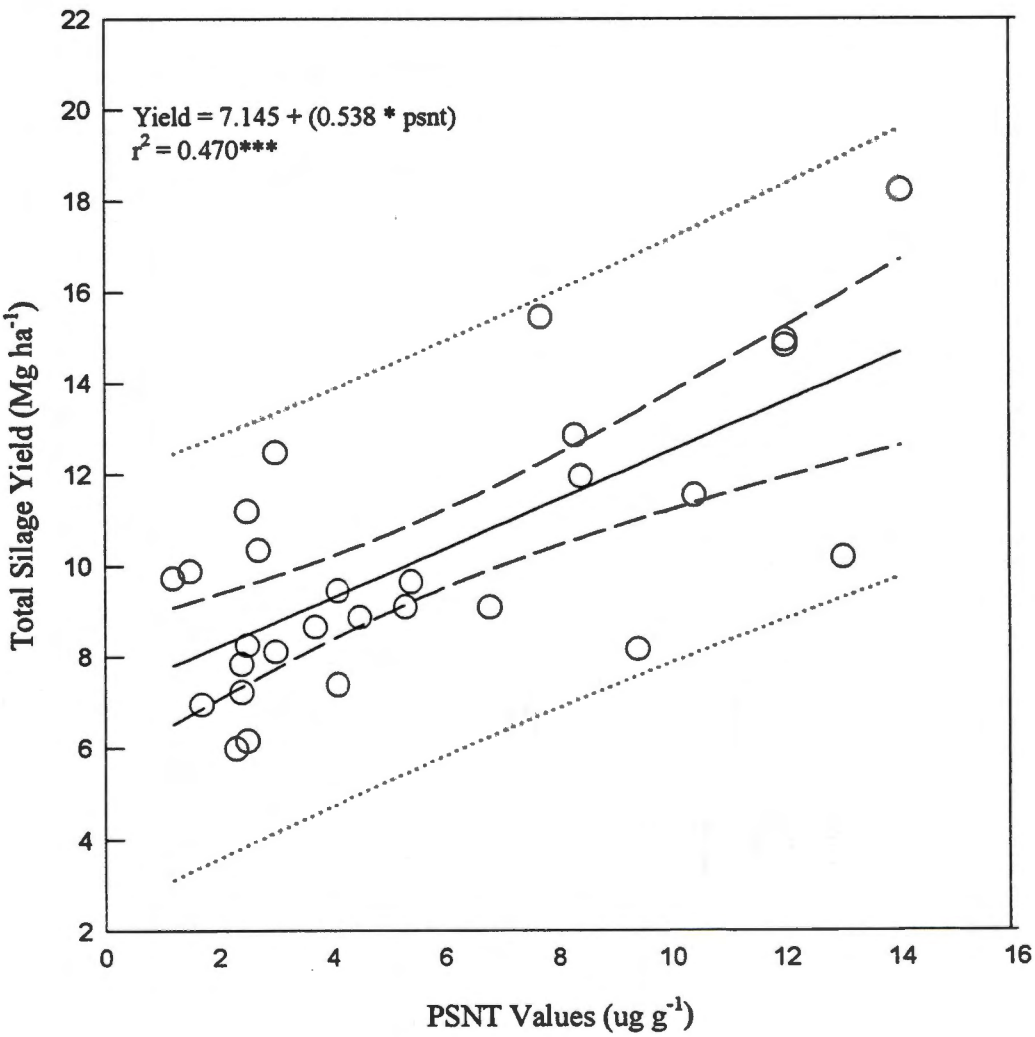


Figure 8. Linear regression for 1994 organic treatments.

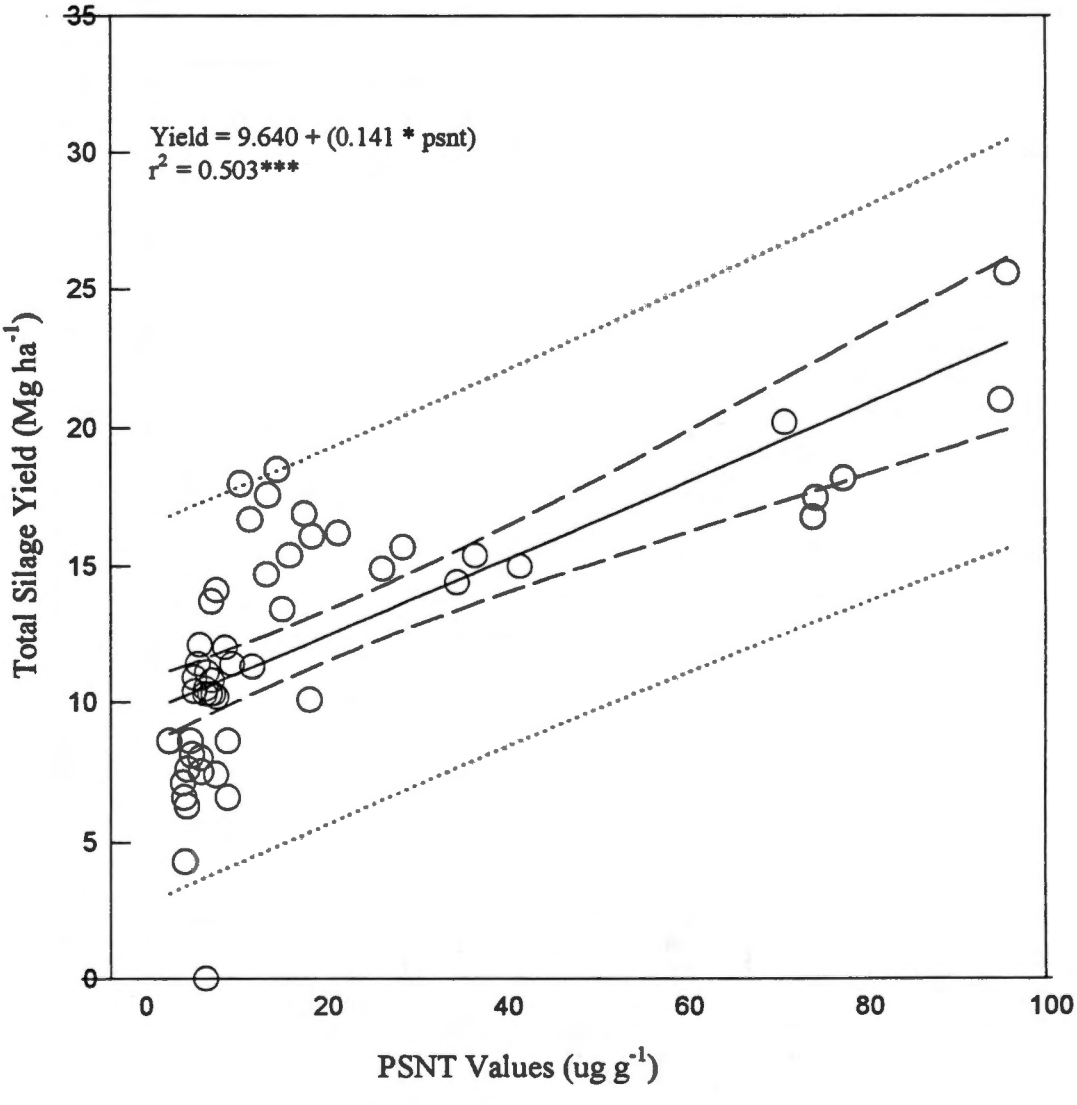


Figure 9. Linear regression for all 1995 no-till treatments.

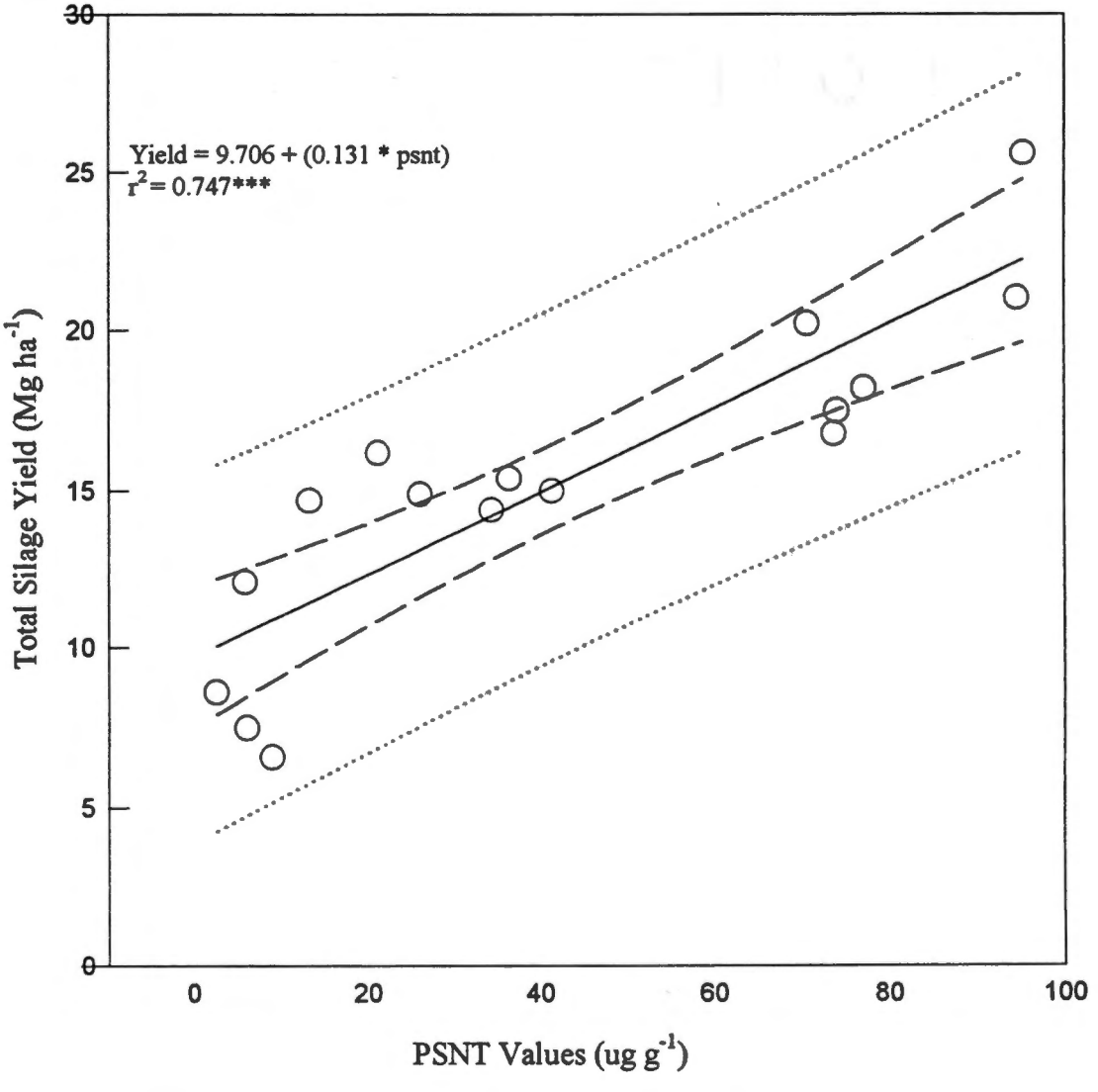


Figure 10. Linear regression for 1995 inorganic treatments.

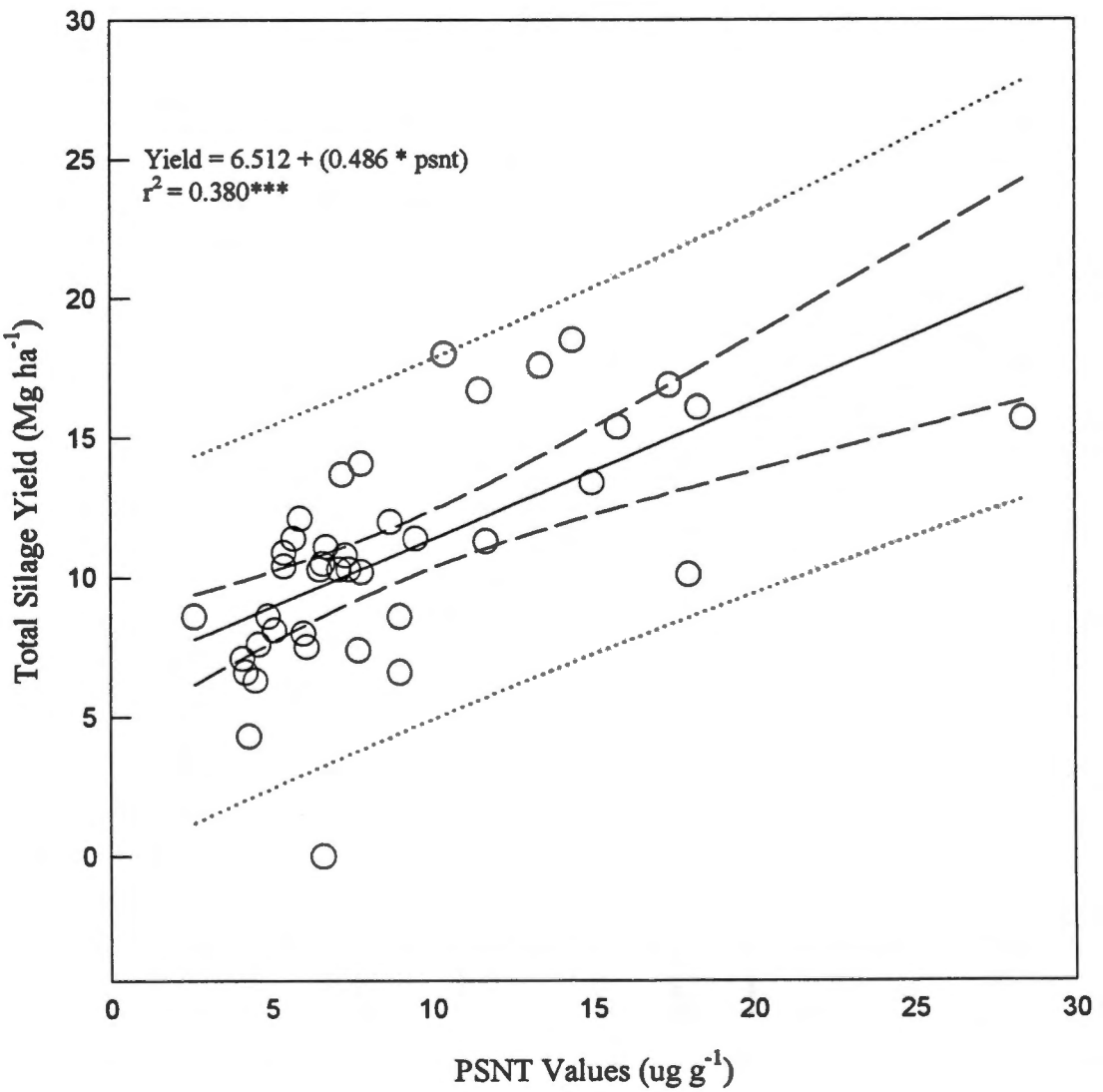


Figure 11. Linear regression for 1995 organic treatments.

Part V.

Summary and Conclusions

In three years of manure application, there were no combinations of manure rate and years of application that were as effective as 3AN, (252 kg NH_4NO_3), in producing silage. The 3AN inorganic treatment yielded 21.1 Mg ha^{-1} in 1995. The 3M3 treatment (336 kg manure-N), had a statistically lower yield in 1995 of 17.2 Mg ha^{-1}. The high manure treatment was followed by 2AN and 2M3, the respective intermediate treatments, which were statistically the same as the high manure treatment. Silage yields increased within a manure rate as years of application increased.

With respect to ear leaf nitrogen, in the third year, the high inorganic treatment (3AN) resulted in the highest N content followed by the intermediate inorganic treatment (2AN) and the high manure treatment (3M3) both of which were statistically the same as 3AN. Silage N in 1994, after two years of manure application, shows the same trend as the silage dry matter yield. The 3AN treatment resulted in higher silage N than the manure treatments, but was not higher than the 2AN treatment. The 2M1 and 2M2 treatments were the same as the 2AN but different than the 3AN.

Nitrogen uptake in 1995 from the 3AN treatment was higher and different than all other treatments. Also, in 1995, the 3M3 treatment was lower only than the 3AN treatment. In 1994, the 3M2 treatment was between the 1AN and 2AN

treatments. In 1993, the 3M1 treatment resulted in lower uptake than all the inorganic treatments. Less than 75% of the N in the manure was available in all three years when uptake efficiency is defined as (the amount of N recovered - the amount recovered from the control plots) / the amount of N applied. The highest manure N efficiency in 1993 came from the 2M1, in 1994 from the 1M2, and in 1995 from the 1M3 treatment. From the inorganic treatments, the highest efficiencies in 1993 and 1994 were from the 2AN treatment with 61 and 69 % respectively. In 1995, the 3AN treatment had the highest efficiency with 55 %.

In almost every instance, yields in no-till systems were similar to, if not the same as, those in conventional till systems. Evidently, there was no excess N loss in the no-till plots.

At the rates used in this research, (112, 224, and 336 kg N ha^{-1}), manure application did not cause a statistical yield reduction. The high rates have not been applied long enough to create a salinity problem or a residual effect beyond which further nitrogen applications cause no further increase in yields.

Soil samples were taken prior to manure application. Samples taken in 1995 followed two previous years of application. There were no significant differences in soil chemical parameters across treatments in most cases. Total N, pH, and total C were largely unaffected by manure applications during the first three years of this study. In 1995, the total C concentrations in the top 0-7.5 cm were significantly different. The highest levels of carbon were from the 3M2 treatment. Although the

soils have been in no-till for several years, the additional C from the manure treatments has impacted these soils at the soil surface.

There were no significant differences with regard to extractable K and P. In the second year after application, all the treatments for all three years at all rates resulted in levels of Mehlich I extractable P from the top 0-7.5 cm that correspond to a high soil test level in Tennessee. In the second depth, 7.5-15 cm, all the treatments with the exception of the 1M1 and 3AN were above 15 mg kg^{-1}, the high soil test concentration, and they were both slightly above 14 mg kg^{-1}. The data indicate that labile P may be accumulating and that continued application may result in runoff losses of P. Soil P increases must be monitored because surface runoff can adversely affect surface water, a complex system that is difficult to protect. Increased levels of P can cause eutrophication in lakes and streams.

The PSNT did not provide a good correlation between silage yield and nitrate test level in this research. The manure and inorganic fertilizer treated soils had nearly equivalent yields after three years, but the PSNT values were quite low with the manure and very high in the inorganic treatments. If the optimal range from the literature is used, the values in the manured soils were too low and fell out of the sufficiency range yet the yields were normal for the region with respect to soil type and climate. The inorganic treatments resulted in PSNT values that are too high and also out of the range yet again the yields were acceptable. In the inorganic treatments, the data may indicate that there is too much nitrogen in the system, and

less could be applied with no yield reduction. In the manured systems, the organic N will mineralize as a slow release fertilizer over a growing season. The PSNT takes the available nitrogen from one point in time which may not fit the dynamics of a manure system. In the treatments that did not receive manure, the low PSNT values did indicate a nitrogen deficiency which was seen in the lower yields. As the years of application increased, although the manured yields increased to levels comparable to those from the inorganic treatments, the PSNT values were still lower than the critical ranges.

Producers hoping to restore productivity or build up fertility should consider an amendment with an organic carbon source to increase soil organic matter. After three years, the 3M treatments results in yields better than the 2AN treatment which is the high end of the recommended rate for silage in the area. Manure applications at the third rate resulted over three years, in yields the same or better than the inorganic treatments while increasing soil carbon.

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