ABSTRACT

ENGOKE, CANON NORRIS SAVALA. Verification of Poultry Manure Nitrogen Availability and Fertilizer Nitrogen Equivalence Coefficients for Crop Production in North Carolina Soils. (Under the direction of Dr. Carl Crozier).

Poultry manure is a nitrogen (N) source applied at different rates and times in a multitude of crop and tillage scenarios in North Carolina. Although standard assumptions are that 50% of the total N is available to the first crop when surface applied and 60% when incorporated, soil type, application times, environments and tillage practices may all affect fertilizer N equivalence (FNE coefficients calculated from yield) or plant available N (PAN coefficients determined from plant N uptake). Therefore, information on the effect of manure type and management is required to strengthen the knowledge for profitable use of this resource and understand residual effects in the soil. The objectives of this study were to; (i) evaluate the effect of poultry manure source and management on yield and plant N uptake and to verify FNE and PAN coefficients for winter wheat (*Triticum aestivum* L.) and summer cotton (*Gossypium hirsutum*) – corn (*Zea Mays* L.) rotation, (ii) evaluate the effect of poultry manure source and management on tiller density, yield, and yield components of wheat, and (iii) determine the availability of N remaining in soils following the intended crops. Two types of field experiments (wheat and cotton-corn) were established and a follow-up laboratory study was conducted. Wheat field experiments were established at two research stations, the Lower Coastal Plain Tobacco (LCPRS) on a Goldsboro loamy sand (Aquic Paleudults) and the Tidewater (TRS) on a Portsmouth fine sandy loam (Typic Umbraquults) using broiler litter (BL) and composted layer manure (CLM) applied at three times in

2008/2009 and 2009/2010 seasons. A cotton-corn rotation study was conducted in adjacent conventional and conservation tillage fields at two research stations, the Upper Coastal Plain (UCPRS) on a Norfolk loamy sand (Typic Kandiudults), and TRS on a Portsmouth fine sandy loam in 2008, 2009, 2010 and 2011 seasons using layer manure (LM), CLM and BL. Post-harvest soils from both studies were incubated at 10, 20 or 30 ^{0}C for 112 days with N mineralization monitored by periodic sampling. Results showed that wheat FNE and PAN values were much less than the standard assumption, with FNE values of 0.31 for CLM and 0.18 for BL, and PAN values of 0.25 and 0.14, respectively, when applied at a rate of 134 kg total N ha^{-1}. At a lower application rate, coefficient values were higher, but still well below 0.5 (i.e. 50% availability). For corn, a much higher proportion of the manure N became available than for winter wheat. First year FNE coefficients ranged from 0.59 to 0.68, while PAN coefficients ranged from 0.68 to 0.81. Due to the erratic nature of the responses of cotton to inorganic N, very little manure N efficiency data could be determined. Incubation of post-harvest soil samples found relatively large amounts of mineralizable N in all samples, typically 40 to 100 kg N ha^{-1}, but net mineralization of less than 15 kg N ha^{-1} resulting from most manure N applications. Mineralization of soil and manure N was enhanced at higher temperatures, but much of the manure N was still unaccounted for in the crop N budgets. Nevertheless, 2nd and 3rd year summer crop growth trials detected residual manure effects, with 2nd year residual FNE coefficients ranging from 0.11 to 0.26 for corn and cotton, and 3rd year residual FNE coefficients ranging from 0.05 to 0.34 for corn. Poultry manure N is probably less available to winter crops than to summer crops due to temperature effects on mineralization; and although residual manure may supply N for at least an additional two crops, soil mineralization assays may not effectively quantify this due to the large background soil mineralizable N.

Verification of Poultry Manure Nitrogen Availability and Fertilizer Nitrogen Equivalence Coefficients for Crop Production in North Carolina Soils

by
Canon Norris Savala Engoke

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APPROVED BY:

Dr. Carl Crozier Chair	Dr. Jot Smyth
Dr. Ron Heiniger	Dr. David Hardy

DEDICATION

This dissertation is dedicated to Nape Victoria Mothapo, Daisy Kalondu Savala, Esnas Khavere Engoke, Sammy Chagali Engoke and Wallace Musiega Engoke for their total support and boundless love.

BIOGRAPHY

Canon Norris Savala Engoke was born and raised in Nairobi, Kenya. He received Bachelor of Science (Agriculture) and Master of Science (Soil Science) degrees from the University of Nairobi. In his M.Sc. work, he discovered an indigenous earthworm that performs as well as the industry standard (*Ensenia foeteda* ssp. *andreii*) and developed some low cost options for small-scale vermiculture. Canon and another graduate formed an NGO, the Forum for Organic Resource management and Agricultural Technology (FORMAT) which was funded by the Rockefeller Foundation, UNESCO, the Kenya Agricultural Research Foundation, the African Agricultural Technology Foundation and others to work on a variety of grassroots projects. Mr. Savala's accomplishments include development and distribution of training and extension booklets on striga management and editing the book "Organic Resource Management in Kenya" (2003) and contributing to and layout designing for "Integrated Soil Fertility Management in Africa: Principles, Practices and Developmental Process (TSBF-CIAT, 2009) book. After 9 years with FORMAT, Canon joined the department of Soil Science at North Carolina State University (NCSU) for a PhD. program under Dr. Carl Crozier. Following completion of his PhD program, he would like to continue conducting research in soil fertility and plant nutrition management.

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CHAPTER 1: EFFECT OF POULTRY MANURE ON YIELD AND YIELD COMPONENTS OF WINTER WHEAT IN THE NORTH CAROLINA COASTAL PLAINS

Abstract

Poultry manure is an important nitrogen (N) source for winter wheat (*Triticum aestivum* L.) production in the North Carolina Coastal Plain region. Poultry farms produce different types of manures; however, their accessibility and availability as a source of N for winter wheat production is not well understood. The objective of this study was to evaluate the effect of poultry manure N source, rate strategy, and application time on tiller density, yield, and yield components (seed weight, seeds per head and head density). Field experiments were established in two sites, the Lower Coastal Plain Tobacco Research Station (LCPRS) on a Goldsboro loamy sand soil (Aquic Paleudults) and the Tidewater Research Station (TRS) on a Portsmouth fine sandy loam (Typic Umbraquults); where N sources (broiler litter-BL and composted layer manure-CLM) were applied to winter wheat fields in October (pre-plant, incorporated), December/January (tillering), and February/March (pre-jointing) for 2 seasons (2008/2009 and 2009/2010) in a randomized complete block design. Supplying poultry manure increased tiller density especially when applied at a high rate. Since tiller density at most sites was above the target threshold, increasing tiller density was not necessarily correlated to high yields. No single yield component explained yield obtained based on source, application time, rate strategy or their interactions effect. Yield is

a combination of yield components acting in a compensatory manner through positive or negative correlations.

1.1 Introduction

Inclusion of poultry manure, such as broiler litter or composted layer manure, into field crop fertilization plans in the Southeastern United States requires efforts to improve usage through best management programs (Sistani et al., 2003; Sistani et al., 2008). Broiler litter is a mixture of chicken (*Gallus domesticus*) manure, feed droppings and bedding material accumulated from birds raised for meat production. Composted layer manure on the other hand, is a by-product from an egg producing facility that is processed prior to land application. Composting of layer manure is done to manage accumulation of the material, reduce pathogens to meet permit requirements and to lower cost of hauling fresh manures to distant fields for application (Brinson et al., 1994). In North Carolina (NC), poultry manure can be applied to winter wheat between the months of October at pre-plant through late February or early March at the pre-jointing stage. Poultry manure applied at pre-plant allows for soil incorporation, whereas only surface application is possible once the crop is established. A major challenge is to harmonize crop nutrient demand with availability from poultry manures for profitable production and reduced environmental pollution. Plant available nutrients in poultry manures vary based on the chicken production system (type of bird, breed, feed type and rations) and manure handling at collection, processing or storage (Zublena et al., 1997; Eghball and Power, 1999; Francesch and Brufau, 2004). In efforts to compensate for variability in both nutrient composition and release, poultry manures can be applied together with inorganic fertilizers in a dual source strategy (Efthimiadou et al., 2010; Gioacchini et al., 2006).

Manure effectiveness in crop production can be improved through modification of application rate, time and method based on nutrient content (Chastain et al., 2001; Randall and Vetsch, 2005; Diaz and Sawyer, 2008; Girma et al., 2010; Weisz et al., 2001; Abedi et al., 2011; Hayashi et al., 2011) and climate conditions (Hammond et al., 1994). If the manure application rate decision is made based on one critical element, it is unlikely to supply other elements at an appropriate rate. For instance, N based rates could lead to excess loading of phosphorus (P), zinc (Zn) or copper (Cu) into the environment (Endale et al., 2009). On the other hand, P based rates supply insufficient N. Therefore, a dual source strategy, manure at P rate and supplemental inorganic N are used to provide more balanced nutrients for crop production (Kaur et al., 2005; Kaur et al., 2008; Akande et al., 2010). When poultry manures are applied to winter wheat or other crops early in the season during slow growth, losses can lead to reduced yields as a result of low N uptake (Hansen et al., 2004). A dual source strategy of poultry manure at pre-plant and supplemental inorganic N at a later date can be used to maintain nutrient supply to the crop at different growth stages.

Nitrogen demand varies among the winter wheat growth stages. Wheat growth is subdivided into different stages on the Feekes scale (Large, 1954). The first stage is emergence, referred to as Feekes 1. After emergence, wheat enters tillering stage from Feekes 2 to when the leaf sheath is strongly erected at Feekes 5. During tillering stage, N demand is low due to slow growth as a result of low temperatures in the winter season. Tillers which are important in determining wheat yield develop during the tillering stage. The head density yield component is dependent on the early development of vigorous tillers (Ayoola and Adeniyan, 2006). When the first node of the stem is visible (Feekes 6) after vernalization, the stem elongation or extension stage starts that coincides with peak N demand (Salomonsson et al., 1995; Weisz et al., 2001). The stem elongation stage continues until the booting stage (Feekes 10) with daily N uptake rates progressively declining (Knowles et al., 1994). An estimated 80% of the total N in wheat is accumulated before booting stage (Waldren and Flowerday, 1979); half of the grain N is translocated from the leaves and stem, while the rest is assimilated from the soil (Harper et al., 1987). The final phase before harvesting is termed as the heading and ripening stage (Feekes 11). Seed weight yield component is determined at this stage. Variation in N requirement along the growth continuum affects development of different wheat yield components.

Nitrogen source and rate strategy determine yield and yield components such as kernel size, head density and seed weight (Ayoola and Adeniyan, 2006; Ouda, and Mahadeen, 2008). Since conventional or conservation tillage systems do not affect most yield components, there is a need to understand the effect of other management practices such as nutrient management that increase winter wheat yield (Weisz and Bowman, 1999). For instance, in the NC Coastal Plains, timing of supplementary N fertilization for improved winter wheat yield can be determined after examining plant characteristics such as early season tiller density at Feekes 3 (Weisz et al., 2001). Supplying N at pre-plant and tillering stage leads to high tiller densities which contribute to improved yields (Weisz et al., 2001). Other winter wheat yield components such as head density, seeds per head and seed weight and head density are determined later in the season. Seed weight and seeds per head can be enhanced through delayed N supply in wheat unlike head density that would depend on tiller development early in the season (Balkcom and Burmester, 2011). With the existence of a wide time window in which to apply poultry manure to field crops, timing may affect yield and yield components (Diaz et al., 2011; Jn-Baptiste et al., 2012). In this study, we evaluated the effect of poultry manure source, rate strategy, and application time on tiller density, yield, and yield components, namely seed weight, seeds per head and head density. Factors evaluated represent typical options for producers to utilize poultry manure for winter wheat production.

1.2 Materials and Methods

1.1.1 Site description

Four studies were conducted in two locations in North Carolina during the 2008/09 and 2009/10 growing seasons. Field experimental locations were at the Lower Coastal Plain Tobacco Research Station (LCPRS) in Lenoir County on Goldsboro loamy sand (Aquic Paleudults) and the Tidewater Research Station (TRS) in Washington County on Portsmouth fine sandy loam (Typic Umbraquults). In each year a new experimental field was used which was previously in corn. Pre-season soil samples were analyzed at North Carolina Department of Agriculture and Consumer Services (NCDA&CS) soil testing laboratory (Table 1.1) (Mehlich, 1984).

1.1.2 Experimental design

Two chicken (*Gallus domesticus*) manure sources (S), broiler litter (BL) collected from a chicken house in Bertie County and composted layer manure (CLM) from a commercial composting facility in Hyde County, were used to supply nutrients for winter wheat production (Table 1.2). These manures were applied to winter wheat at three different times (T), October pre-plant and soil incorporated, topdressed in December/January during the tillering stage (Feekes 3), or topdressed in February/March at pre-jointing (Feekes 5). Three different rate strategies (R) were used at each application time: (i) organic 134 kg N ha^{-1} either as BL or CLM (organic high rate), (ii) dual source application of 67 kg N ha^{-1} organic (BL or CLM) + 67 kg N ha^{-1} inorganic (30% N as urea ammonium nitrate – UAN), and (iii) organic 67 kg N ha^{-1} either as BL or CLM (organic low rate). The high rate and dual source application strategy had the same amount of total N applied, 134 kg N ha^{-1}. A check plot (no N applied) was also included. Each treatment was replicated four times on 9 m by 3 m plots in a randomized complete block design (Appendix 1.1).

1.1.3 Plot management

Winter wheat cultural management practices such as liming, weeds and pests control were similar in both sites although scheduling and recommendations typical for each research station were used. Lime was applied to adjust soil pH to 6.0 for mineral and 5.5 for mineral-organic soil based on NC recommendations (Hardy et al., 2012). The seed varieties planted were Vigoro Dominion in LCPRS for both years while at TRS, Coker 9184-802R in 2008/2009 and AgriPro Panola (PAN-904) in the 2009/2010 season.

1.1.4 Data collection

Tillers with at least three fully emerged leaves (including main stem) were counted from a 0.9 m section of a middle row at Feekes 3 on control plots, and those that received manure at pre-plant and tillering stages. Tillers from plots designated for fertilization at pre-jointing stage were not counted since they had been managed the same as the control plots up to this date. Immediately before whole plot grain harvesting, a 0.9 m section was sampled from a middle row of each plot. Wheat plants were clipped aboveground and heads were counted before being separated from the stalk. Stalk samples were dried, weighed and ground, while the heads were dried, threshed and weighed to calculate harvest index values for each plot. A 250 kernel sample was counted and weighed. Seeds per head were calculated from head density and seed weight values. A middle section of 9 m by 2 m was harvested with a plot combine equipped with a grain weight recorder and moisture sensor. Calculated harvest index values were used to determine whole plot yield and stalk biomass.

1.1.5 Data analysis

Tiller densities were compared using SAS PROC MIXED for analysis of variance (ANOVA) (Littell et al., 2006) (Table 1.3). Environment, which combined year and location, was analyzed as a random effect. Two ANOVAs were conducted on yield, tiller and head density, seeds per head and seed weight. Least squares means (LSMeans) were determined for all treatments using PROC MIXED, and comparisons were made at $p < 0.05$ significance level using the Tukey's multiple comparison method (SAS, 2008; Littell et. al., 2006). This analysis was performed to establish how the check plot data differed from other treatments. Secondly, a factorial ANOVA was performed excluding check plot data. Therein, winter wheat mean yield, head and seed density, seeds per head and seed weight from treatments were analyzed with replicates and environment treated as random effects.

1.3 Results and Discussions

1.3.1 Yield and yield components

Nitrogen source, application time, rate strategy, environment and their interactions at different levels had varying effects on winter wheat tiller density, yield, head density, seeds per head and seed weight (Table 1.3). Tiller density was significantly ($p < 0.05$) affected by poultry manure rate strategy, environment and the environment by N source interaction. Main effects of N source and application time, which did not affect tiller density, had a mean of 705 tillers m^{-2}, which is above the NC threshold of 540 tillers m^{-2} (Weisz et al., 2001). In addition, main effects of N source, application time, rate strategy and environment did not influence parameters measured resulting in mean yield (3.0 ton ha^{-1}), head density (481 heads m^{-2}), seeds per head (20 seeds) and seed weight (30 mg $seed^{-1}$). Poultry manure can be applied to winter wheat fields at any time between planting and pre-jointing stage without significant yield effect, as also reported in Arkansas (Mozaffari et al., 2005) and Virginia (Clark and Mullins, 2004).

1.3.1.1 Effect of application rate on tiller density

The higher application rate of manure N, averaged across environments, manure source and pre-plant and tillering application times, significantly increased tiller density above the low rate (Figure 1.1). Both manure N rates had higher tiller densities than both the check plot mean (543 tillers m^{-2}) and the North Carolina threshold of 540 tillers m^{-2} (Weisz et al., 2001). Applying N fertilizer to winter wheat when tiller densities are below the threshold level has been shown to increase yields (Girma et al., 2006; Weisz et al., 2001;

Thomason et al., 2011; Malhi et al., 2010). Increases in wheat tiller densities above the check plot upon application of N have been reported for NC Coastal Plain soil. For instance, inorganic N gave 756 tillers m^{-2} on a Goldsboro loamy sand soil (Flowers et al., 2003), 554 – 922 tillers m^{-2} on a Roanoke silt loam (Flowers et al., 2001) and 498 – 962 tillers m^{-2} (Phillips et al., 2004) which corresponded to varying grain yields. When tiller density is above the threshold level, additional N fertilizers should be withheld until just prior to jointing stage when demand is high (Weisz et al., 2001).

1.3.1.2 Effect of environment by source interaction on tiller density

Winter wheat tiller density can be different among environments under similar management, such as same N source, due to differences in weather conditions (Phillips et al., 2004; Weisz et al., 2001). Distinct mean tiller densities were observed with poultry manure in different environments (Figure 1.2). One site year, LCPRS in 2008/2009, had higher tiller density than the other three environments. The different tiller densities within environment and N source interaction did not result in different yields (Table 1.3). Mean tiller densities in all environments and N sources were above the NC threshold. Studies have shown that when tiller density is below the regional threshold, then it is correlated to low yields (Maas et al., 1996). Using BL or CLM resulted in similar tiller density numbers within each environment. Therefore, both BL and CLM can be used to supply N to winter wheat crops with improved yields in most Coastal Plain regions. In this study, different tiller densities, all above the North Carolina threshold of 540 tillers m^{-2} (Weisz et al., 2001), resulted in similar head densities of 481 heads m^{-2} which means that many tillers did not develop into heads. In contrast, environment has been shown to affect both tiller and head density in a different southeastern USA study (Weisz and Bowman, 1999).

1.3.1.3 Effect of N source and rate strategy on yield

The interaction between N source and rate strategy influenced winter wheat yield (Figure 1.3). Dual source application (organic + inorganic at 67 kg N ha^{-1} each) had significantly higher yields than BL at 134 kg N ha^{-1} which was greater than BL at 67 kg N ha^{-1}. Similar yields were obtained from CLM at 134 kg N ha^{-1} and dual source rate strategies for both manures which were significantly higher than the lower rates. Winter wheat producers in southeastern US Coastal Plain region are likely to obtain more yields by mixing or dual source application of some organic and inorganic fertilizers (Abedi et al., 2010), as shown with BL. It has been reported that combining of organic and inorganic fertilizers could have synergistic effects on soil pH, organic C available N, P and K which contribute to higher yields (Sarwar et al., 2008, Rehman et al., 2008). Increase in yield with BL dual source application strategy could be attributed to supply of available and easily accessible N from inorganic fertilizer and other nutrients to microbes from poultry manure which in-turn lead to elevated mineralization rates of the material (Sowers et al., 1994; Matsi et al., 2003). In contrast, the CLM material has been preprocessed leading to carbon loss that reduces the C:N ratio. Therefore, N contained in CLM is easily mineralized and does not require supplementary inorganic N to hasten the process of mineralization.

1.3.1.4 Effect of application time and rate strategy on yield

Dual source application strategy with poultry manure at tillering gave significantly higher yields than the lower rate of only manure due to the additional inorganic N (Figure 1.4). Applying N to winter wheat at high rate either as poultry manure or dual source resulted in similar yields although the later had numerically higher values across all application times. Similar N rate responses have been reported (Mullen et al., 2003; Stone et al., 1996; Slaton et al., 2005). Using a dual source strategy of organic and inorganic fertilizers at planting or in split application times may result in a complimentary effect where both readily available and slow release N is supplied for plant utilization (Sowers et al., 1994; Matsi et al., 2003). Studies have shown that higher yields are obtained when fertilization strategies ensure availability and prolonged steady release of N in the soil for microbes and plants uptake (Shah and Ahmad, 2006: Shah et al., 2010).

1.3.1.5 Effect of N source by application time interaction on seed weight

The interaction between N source and application time influenced seed weight, which was the only significant effect on an individual yield component noted in this study. Late application of BL led to significantly heavier seeds, while kernels from treatments that received CLM at tillering were heavier than when CLM was applied at pre-jointing (Figure 1.5). Seed were heavier when BL was applied at pre-jointing than when CLM was applied at the same time, but applying CLM at tillering resulted in significantly heavier seeds than BL applied at the same time. Heavier kernel weight did not result in higher winter wheat yield due to with the combined effects of other yield components.

1.3.1.6 Relating yield components to yield

Yield components were not directly related to yield within main or interactions of the tested effects. Although yield components contribute to winter wheat yield, no single one had a profound effect and the relationship to each other is complex. There is a compensatory effect where some of the yield components are either positively or negatively correlated to one another with respect to a specific effect e.g. application rate (Appendix 1.3). With such relationship between the different components, no individual yield component can fully explain yield realized.

1.4 Conclusion

Poultry manure supplied N for winter wheat production which increased tiller density especially when applied at a high rate. The higher N rate resulted in better yields than the lower N rate, especially when the dual source strategy was used. Broiler litter or CLM can be applied at any time to the winter wheat within the application period window (pre-plant through prejointing stage) without a significant yield effect. Winter wheat yields were highest when poultry manures were applied using the dual source strategy or with CLM at 134 kg N ha^{-1}. Overall, no direct relationship between individual yield components and yield was noted; instead yield components contributed to yield in a complex way.

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Table 1.1. Chemical characteristics of 2008/2009 and 2009/2010 preseason soil samples for each experimental location.

Year	Location[a]	pH	CEC	Ca	Mg	K	Ac[b]	BS[c]	P	Zn	Cu
			---------- $cmol_c\ kg^{-1}$ ----------					%	------ ppm ------		
2008/2009	LCPRS	6.0	5.0	1.6	0.9	0.2	1.4	71	84	0.9	0.1
2008/2009	TRS	5.5	11.3	6.8	1.3	0.4	3.0	78	133	1.9	0.7
2009/2010	LCPRS	5.6	3.8	1.1	0.4	0.2	1.3	67	64	0.9	0.1
2009/2010	TRS	5.3	8.3	4.7	1.2	0.4	1.4	77	140	1.9	0.7

[a] LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station
[b] Ac – Mehlich buffer acidity
[c] BS-Base saturation = (Ca + Mg + K + Na/CEC) x 100%

Table 1.2. Nutrient composition of poultry manures used in each season at both experimental locations.

Year	Source[a]	C:N	N	P	K	Ca	Mg	Zn	Cu
			(%)						
2008/09	BL	14.0	1.4	0.6	1.9	1.0	0.4	0.04	0.03
2008/09	CLM	4.8	7.1	1.2	1.9	6.8	0.6	0.04	0.01
2009/10	BL	9.2	4.0	1.0	1.9	3.3	0.7	0.05	0.05
2009/10	CLM	5.0	6.3	1.6	3.1	9.1	0.7	0.06	0.01

[a] BL- Broiler litter; CLM-Composted layer manure

Table 1.3. Analysis of variance summary for tiller density, yield and yield components. Yield and yield components analyses were performed on factorial treatments excluding the check plot. Environment was treated as a random effect.

Effect[a]	Degree of Freedom	Tiller density[b]	Degree of Freedom	Yield	Head density	Seeds per head	Seed weight
Source (S)	1	ns[c]	1	ns	ns	ns	ns
Application Time (T)	1	ns	2	ns	ns	ns	ns
Rate strategy (R)	1	*	2	ns	ns	ns	ns
S x T	1	ns	2	ns	ns	ns	*
S x R	1	ns	2	**	ns	ns	ns
T x R	1	ns	4	*	ns	ns	ns
S x T x R	1	ns	4	ns	ns	ns	ns
Environment (Env)	3	***	3	ns	ns	ns	ns
Env x S	3	**	3	ns	ns	ns	ns
Env x T	3	ns	6	ns	ns	ns	ns
Env x R	3	ns	6	ns	ns	ns	ns
Env x S x T	3	ns	6	ns	ns	ns	ns
Env x S x R	3	ns	6	ns	ns	ns	ns
Env x T x R	3	ns	12	ns	ns	ns	ns
Env x S x T x R	3	ns	12	ns	ns	ns	ns

[a] Source (Broiler litter and Composted layer manure); Time (pre-plant, tillering and pre-jointing); Rate strategy (Organic low = 67 kg N ha^{-1}, Organic high 134 kg N ha^{-1}, Dual source = 67 kg N ha^{-1} Organic + 67 kg N ha^{-1} Inorganic); Environments (LCPRS-2008/2009; LCPRS-2009/2010; TRS-2008/2009; TRS-2009/2010) where LCPRS- Lower Coastal Plain Tobacco Research Station, TRS- Tidewater Research Station.

b Tiller density includes the poultry manure application times of pre-plant and tillering, because the pre-jointing stage topdressing had not been made at the time of data collection. Therefore, the dual source rate strategy treatment is not included in tiller density comparisons.

[c] Symbols indicate probability: *** <0.001, ** <0.01, * <0.05, ns>0.05.

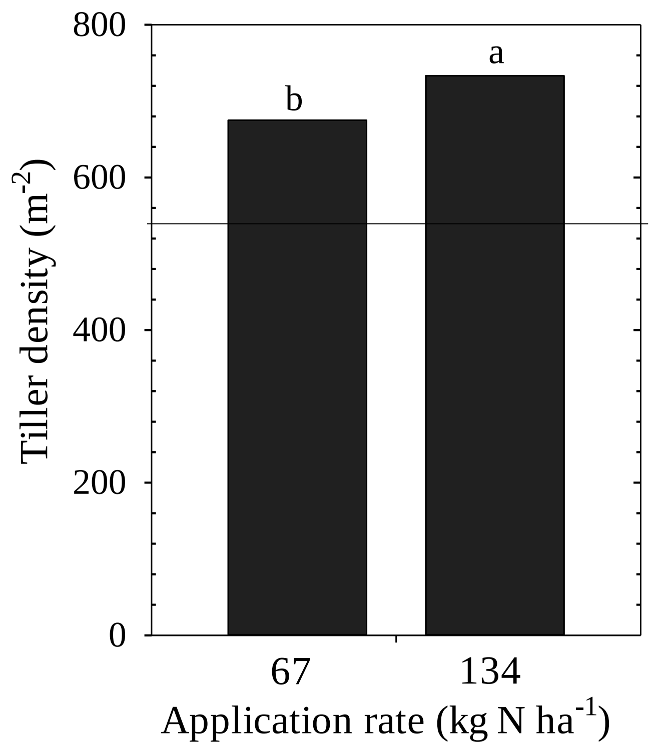


Figure 1.1. Mean tiller density with two poultry manure application rates. Mean separation indicated by lowercase letter using Tukey-Kramer value of 39 tillers m^{-2}. The line indicates the North Carolina tiller density threshold. Means were pooled across environment, source and only consider the two application times of pre-plant and tillering, which occurred prior to tiller density counts. Check plot means tiller density was 543 tillers m^{-2}.

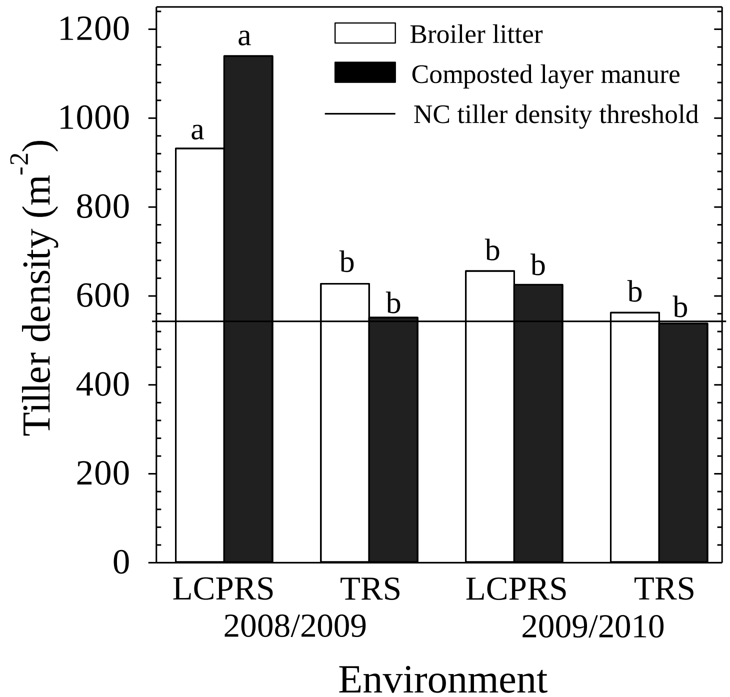


Figure 1.2. Poultry manure effect on mean tiller density in four environments averaged across application time (pre-plant and tillering), and organic rate strategy (high and low). Lowercase letter separate means based on Tukey-Kramer value 260 tillers m^{-2}, Check plot means were 2008/2009 LCPRS 760, TRS 484 and 2009/2010 LCPRS 502, TRS 430 tillers m^{-2} where LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station.

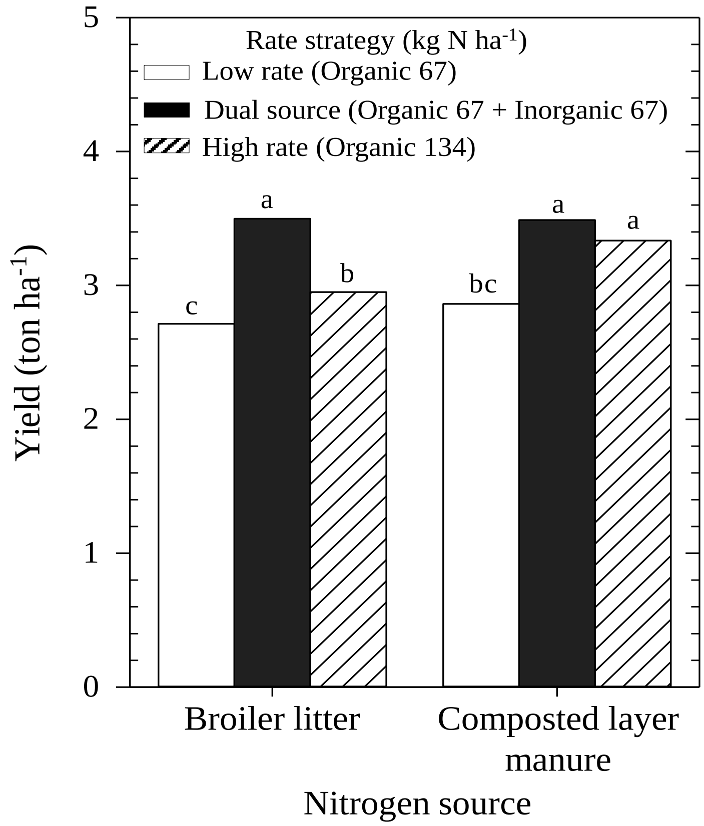


Figure 1.3. Effect of N source and rate strategy on mean winter wheat yield averaged across environment and application time and separated by lowercase letters based on Tukey-Kramer value 0.2 ton ha^{-1}. Check plot mean yield was 2.2 tons ha^{-1}

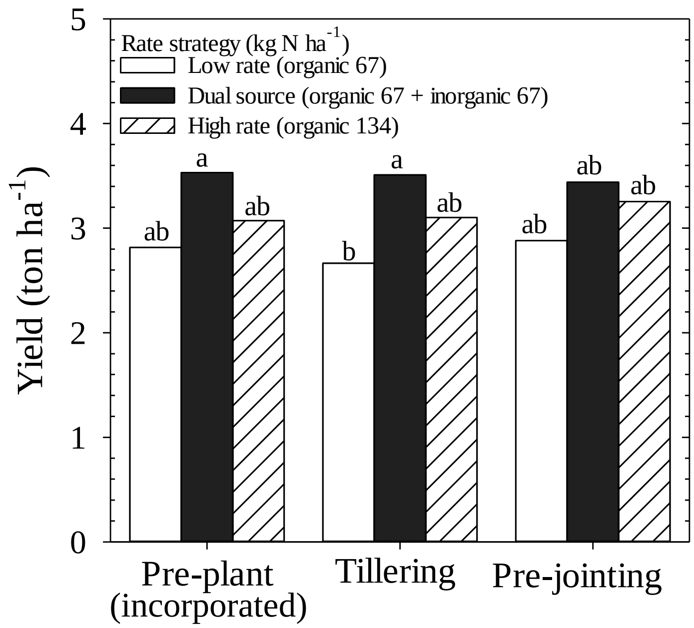


Figure 1.4. Effect of N application time and rate strategy on mean winter wheat yield averaged across environment and source and separated by lowercase letters based on Tukey-Kramer values 0.8 ton ha^{-1}. Check plot mean yield was 2.2 tons ha^{-1}.

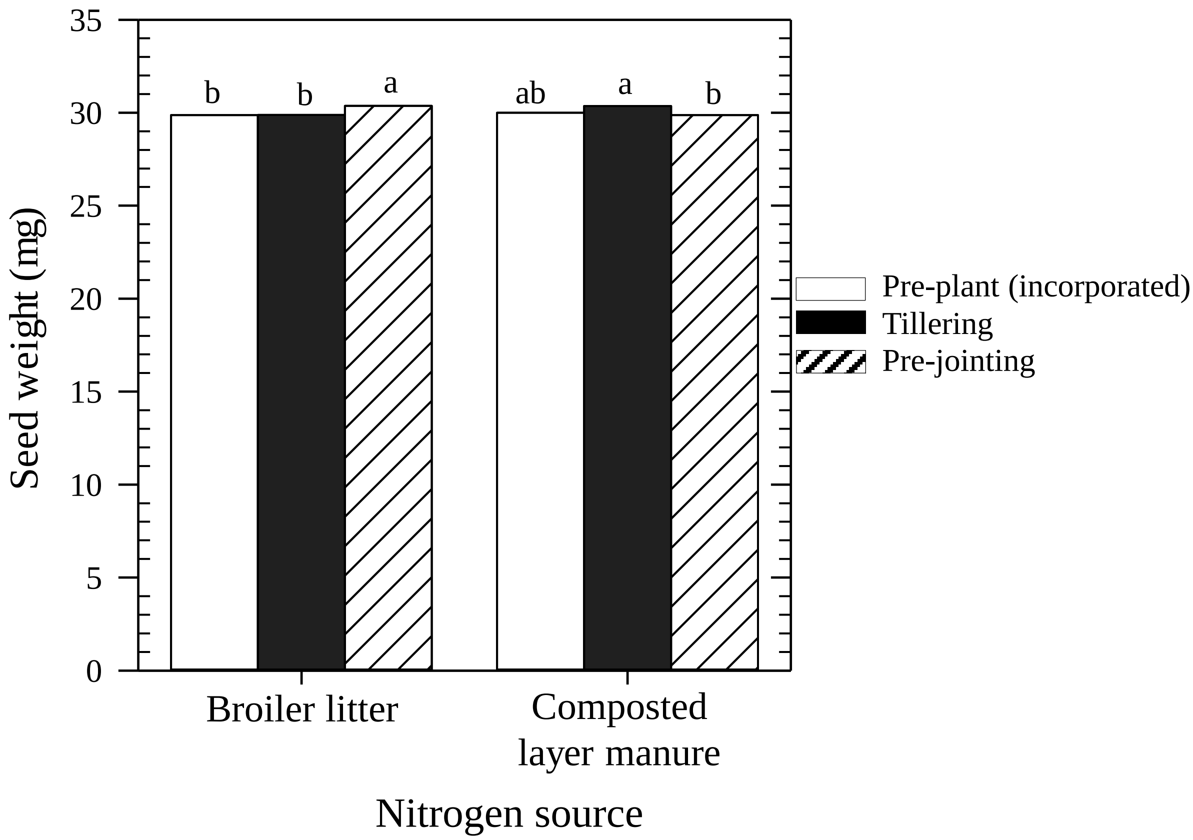


Figure 1.5. Nitrogen source and application time effect on mean seed weight averaged across environment and application rate strategy. Mean separation based on Tukey-Kramer value 0.43 mg seed weight shown by lowercase letters.

1.6 Appendices

Appendix 1.1 Winter wheat experiment treatments established in both Lower Coastal Plain Tobacco and Tidewater research stations. Data collected for analysis included tiller density, yield, plant yield components and soil characterization.

Treatment	Description
1	Check plot (0 kg N ha^{-1})
2	October broiler litter, organic 67 kg N ha^{-1}
3	October broiler litter, organic + inorganic N @ 67 kg N ha^{-1}
4	October broiler litter, organic 134 kg N ha^{-1}
5	October composted layer manure, organic 67 kg N ha^{-1}
6	October composted layer manure, organic + inorganic N @ 67 kg N ha^{-1}
7	October composted layer manure, organic 134 kg N ha^{-1}
8	December broiler litter, organic 67kg N ha^{-1}
9	December broiler litter, organic + inorganic N @ 67kg N ha^{-1}
10	December Broiler litter, organic 134 kg N ha^{-1}
11	December composted layer manure, organic 67 kg N ha^{-1}
12	December composted layer manure, organic + inorganic N @ 67 kg N ha^{-1}
13	December composted layer manure, organic 134 kg N ha^{-1}
14	February broiler litter, organic 67kg N ha^{-1}
15	February broiler litter, organic + inorganic N @ 67kg N ha^{-1}
16	February broiler litter, organic 134 kg N ha^{-1}
17	February composted layer manure, organic 67 kg N ha^{-1}
18	February composted layer manure, organic + inorganic N @ 67 kg N ha^{-1}
19	February composted layer manure, organic 134 kg N ha^{-1}

13	18	3	9	15	10	19	21	8	16	2	12	14	6	17	4	1	22	11	5	7	20
↕ 3' alley ↕																					
16	4	5	20	3	2	19	21	23	1	17	13	9	18	14	7	11	8	15	10	6	12
↕ 3' alley ↕																					
5	1	3	12	14	15	6	18	17	23	22	7	9	13	2	23	16	19	11	4	8	10
↕ 3' alley ↕																					
1	3	10	7	15	18	9	4	8	6	2	11	14	22	20	17	5	13	12	21	16	19

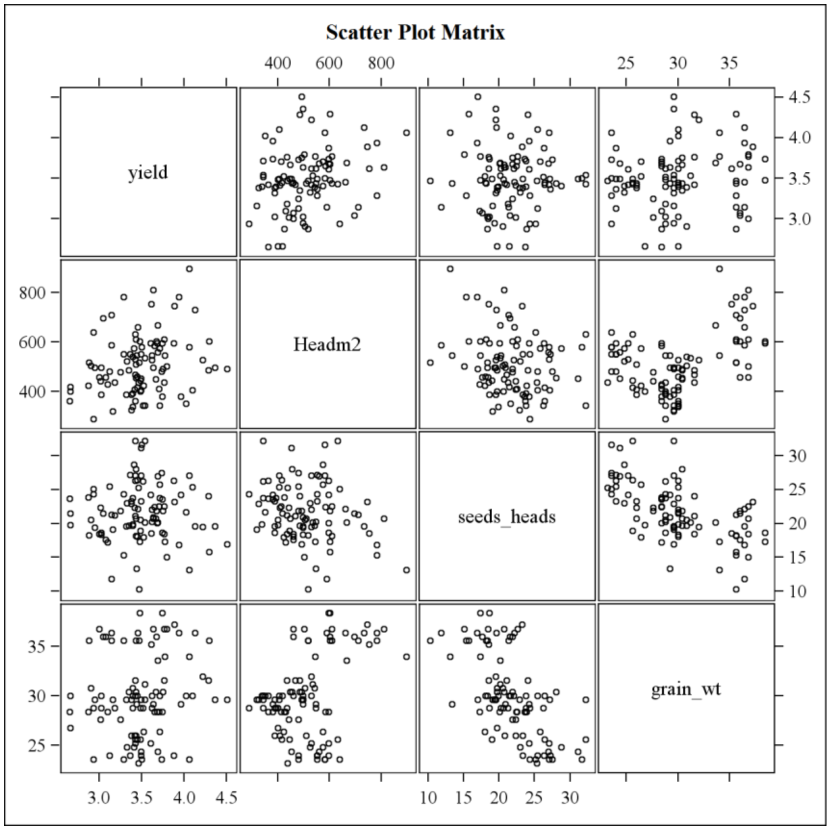
Winter wheat experiment plot layout and treatment allocation for TRS in 2008/2009 season. Shaded plots and treatments received inorganic fertilizer rates.

Appendix 1.2 Changes in soil pH, P Zn and Cu after one season of poultry manure application.

		Pre-season				Post-season			
Year	Location	pH	P	Zn	Cu	pH	P	Zn	Cu
			------ ppm ------				------ ppm ------		
2008/2009	LCPRS	6.0	84	0.9	0.1	6.0	135	1.2	0.8
2008/2009	TRS	5.5	133	1.9	0.7	5.0	141	1.8	0.9
2009/2010	LCPRS	5.6	64	0.9	0.1	5.9	94	3.1	0.8
2009/2010	TRS	5.3	140	1.9	0.7	5.0	128	1.6	0.7

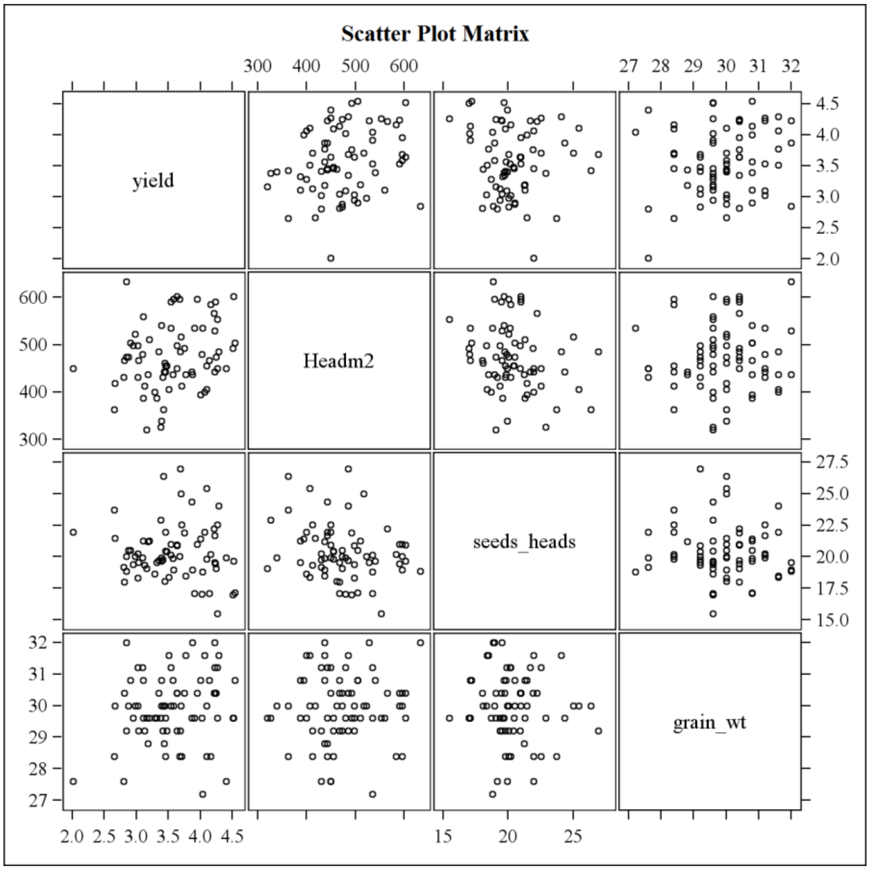
LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station

Appendix 1.3 Poultry manure Application Rate (134 kg N ha^{-1})
Pearson correlation coefficients, probability > |r| under h0: rho=0 and number of observations.



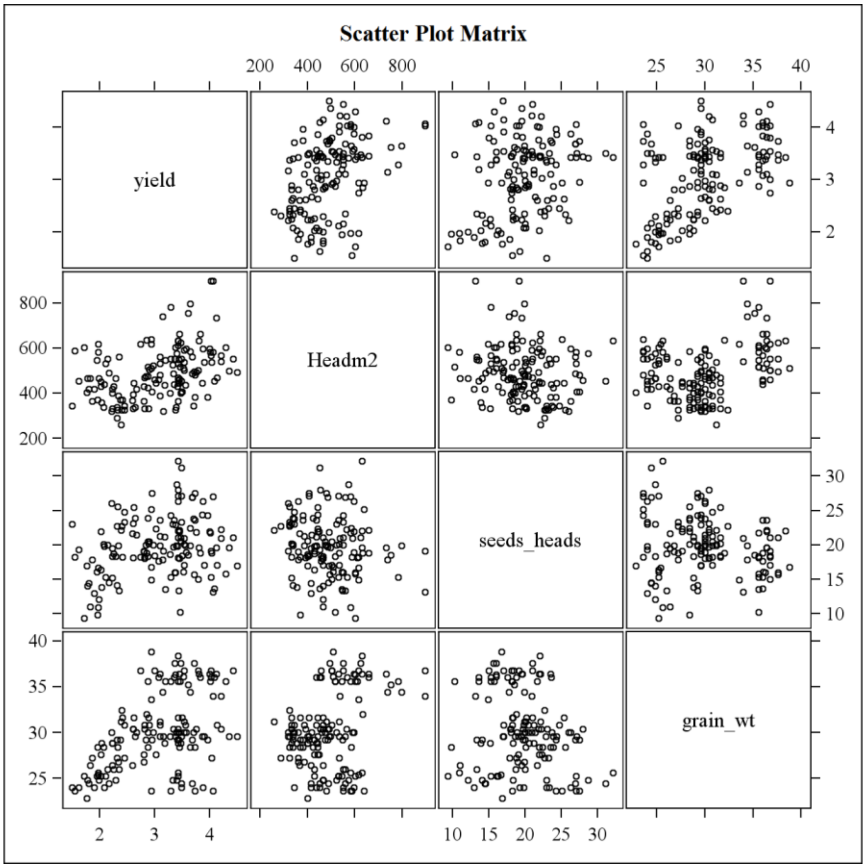
Application Rate (134 kg N ha^{-1})	yield	Head m^{-2}	Seeds per heads	Grain wt.
yield	1			
	96			
Head m^{-2}	0.25463	1		
	0.0123			
	96	96		
Seeds per heads	-0.01396	-0.22789	1	
	0.8926	0.0255		
	96	96	96	
Grain wt.	0.13037	0.40291	-0.60702	1
	0.2055	<.0001	<.0001	
	96	96	96	96

Appendix 1.4 2008/2009 TRS Pearson correlation coefficients, probability > |r| under h0: rho=0 and number of observations



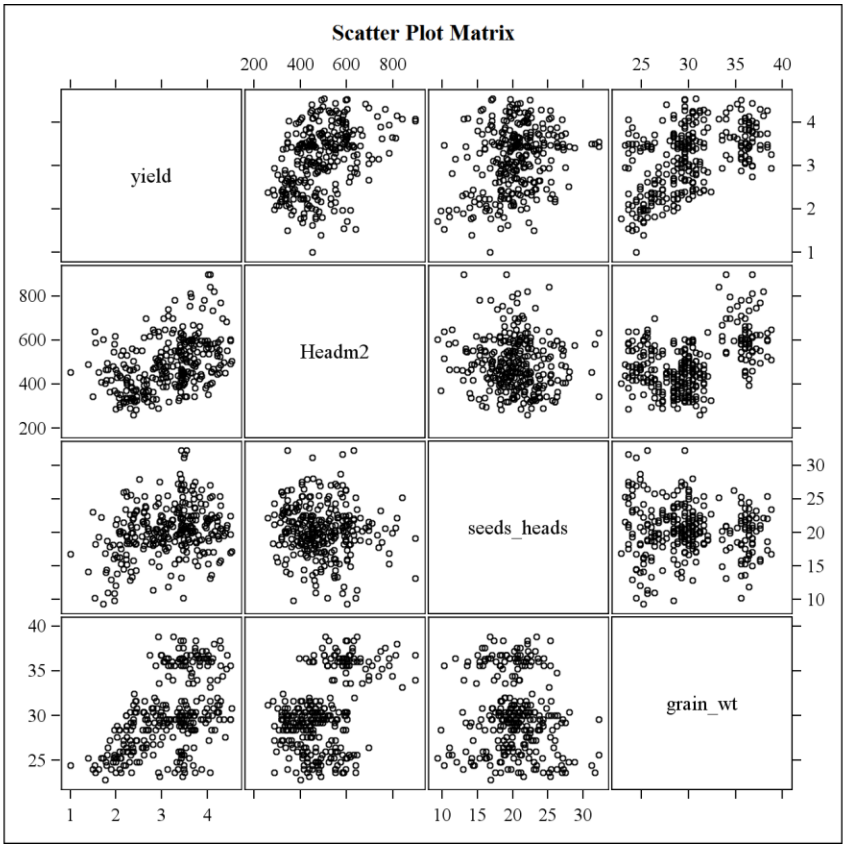
2008/2009 TRS	yield	Head m^{-2}	Seeds per heads	Grain wt.
yield	1			
	72			
Head m^{-2}	0.24425	1		
	0.0387			
	72	72		
Seeds per heads	-0.07109	-0.24031	1	
	0.5587	0.0451		
	70	70	70	
Grain wt.	0.18241	0.07169	-0.06528	1
	0.1251	0.5496	0.5913	
	72	72	70	72

Appendix 1.5 Broiler litter Pearson correlation coefficients, probability > |r| under h0: rho=0 and number of observations



Broiler litter	yield	Head m^{-2}	Seeds per heads	Grain wt.
yield	1			
	144			
Head m^{-2}	0.4074	1		
	<.0001			
	144	144		
Seeds per heads	0.27412	-0.14726	1	
	0.001	0.0814		
	141	141	141	
Grain wt.	0.49467	0.32836	-0.17695	1
	<.0001	<.0001	0.0358	
	144	144	141	144

Appendix 1.6 Overall data Pearson correlation coefficients, probability > |r| under h0: rho=0 and number of observations.



Overall Correlation	yield	Head m^{-2}	Seeds per heads	Grain wt.
yield	1			
	288			
Head m^{-2}	0.41587	1		
	<.0001			
	288	288		
Seeds per heads	0.27515	-0.09932	1	
	<.0001	0.0942		
	285	285	285	
Grain wt.	0.51212	0.41764	-0.09951	1
	<.0001	<.0001	0.0936	
	288	288	285	288

CHAPTER 2: POULTRY MANURE FERTILIZER NITROGEN EQUIVALENCE AND PLANT AVAILABLE NITROGEN COEFFICIENTS FOR WINTER WHEAT PRODUCTION IN NORTH CAROLINA

Abstract

Nitrogen (N) source, timing, placement and rate of application affect winter wheat (*Triticum aestivum* L.) growth and yield. Poultry manure is a potential source of N for winter wheat production, where timing and placement affect N availability and effectiveness. Nitrogen availability from poultry manure is affected by soil, climate and management factors. Coefficients for N availability can be calculated based on yield, i.e. fertilizer nitrogen equivalence (FNE) or based on plant N uptake, i.e. plant available nitrogen (PAN). The study objectives were (i) to assess the effect of soil, climate, N source and rate and time of application on yield and plant N uptake; and (ii) to determine FNE and PAN coefficients among different poultry manure N sources for winter wheat production. Experiments were established at Lower Coastal Plains Tobacco (LCPRS) and Tidewater (TRS) Research Stations using broiler litter (BL), composted layer manure (CLM) and inorganic fertilizer (urea ammonium nitrate) for two winter wheat growing seasons in 2008/2009 and 2009/2010. Two rates of organic inputs (67 and 134 kg N ha^{-1}) were applied to wheat fields at three different times (T): incorporated in October pre-plant, topdressed in December/January during tillering stage, or topdressed in February/March at pre-jointing. Urea ammonium nitrate was topdressed at pre-jointing stage. A check plot without applied N was also included. Each treatment was replicated four times in a randomized complete

block design. Yields were higher when poultry manures were applied at pre-jointing than when either pre-plant incorporated or topdressed during the tillering stage, with FNE values of 0.34 and 0.25, respectively. Type of poultry manure and application rate affected yield, where CLM at 134 kg N ha^{-1} gave 3.3 tons ha^{-1} and BL at 134 kg N ha^{-1} gave 3.0 tons ha^{-1}. Nitrogen source and application rate interaction was significant and resulted in FNE values of 0.31 for CLM at 134 kg N ha^{-1}, 0.34 for CLM at 67 kg N ha^{-1}, 0.18 for BL at 134 kg N ha^{-1}, and 0.29 for BL at 67 kg N ha^{-1}. Increasing application rate from 67 to 134 kg N ha^{-1} reduced FNE from 0.32 to 0.25 and PAN from 0.28 to 0.20. Nitrogen efficiency coefficients were higher in the 2008/2009 season, at 0.45 for FNE and 0.37 for PAN, than in the 2009/2010 season with 0.24 for FNE and 0.17 for PAN.   There was a small, but statistically significant advantage to surface application immediately prior to jointing. The CLM is a better N source than BL when applied at the rate of 134 kg N ha^{-1}.

2.1 Introduction

Management of low inherent nitrogen (N) content in North Carolina Coastal Plain soils is challenging because prevailing climatic conditions favor expedited transformations and losses. Nitrogen, regardless of source, is needed to improve field crop yields (Havlin et al., 2005). Poultry manure is one potential source of N and other plant nutrients necessary for crop production (Bolan et al., 2010). Applying poultry manure rather than inorganic fertilizers as a source of N is a fast growing practice on row crops in the southeastern region of the USA (Sistani et al., 2008; Sistani et al., 2003). Poultry manure improves yields in production systems such as wheat (*Triticum aestivum* L.), corn (*Zea Mays* L.) (Perkins, 1964) and cotton (*Gossypium hirsutum*) (Adeli et al., 2007; Tewolde et al., 2007).

In North Carolina (NC), most poultry farming operations are in the Coastal Plain region which also doubles as a wheat production hub. This qualifies poultry manure as an organic resource for wheat production as indicated by poultry industry enumeration figures. For instance, according to the 2010 agricultural statistics, NC was ranked 4th in broiler production worth \$2.61 billion annually from over 766 million birds, nearly an 11% share of the USA's total. In the same year, NC's egg production industry was 9th in the country with earnings over \$327 million from 13 million layers producing an average of 244 eggs each, making 5% of the nation's eggs (NASS, 2012). Production of both poultry broilers and layers account for 38% of agricultural commodity revenue earned in NC, followed by hogs at 22% (NCDA&CS, 2012). Substantial amounts of manure are produced from these bird populations, and they contain significant contents of plant nutrients. Based on Unites States Department of Agriculture Natural Resources Conservation Service (USDA NRCS) data on selected livestock and poultry annual animal units (453.6 kg live animal weight per animal unit), the poultry industry in NC has 2.5 M animal units, equivalent to 53% of the total animal production in the state (NCDA&CS, 2012). The 1.8 M animal units of broilers produce close to 27 M tons of litter which is 42% of the total annual manure production in NC, while the layers account for about 0.6 M tons (NCDA&CS, 2012).

The nutrient content in poultry manure generated in NC in 2010, based on USDA NRCS figures, could be estimated at 451 Mg of N and 138 Mg of phosphorus (P) (Williams et al., 1999). Poultry manure contains varying proportions of 13 nutrients essential for plant growth and development (Chastain et al., 2001). The amounts of available N for plant production is estimated as fertilizer nitrogen equivalence (FNE) or plant available nitrogen (PAN) depend on bird type, animal housing and feeding program (Francesch and Brufau, 2004).

Soil type, climate and field management practices affect organic and inorganic N transformations and utilization by both microbial and plant communities. Poultry manure N transformations in the field include mineralization, immobilization and losses through ammonia (NH_3^+) volatilization, nitrate (NO_3^-) leaching, and denitrification. Rates of these processes vary with weather and soil conditions (Beckwith et al., 1998; Shepherd and Bhogal, 1998). Nitrogen mineralization rate is lower in clayey than in coarse textured sandy soils, because clay particles physically protect organic matter in micropores making it less accessible to microorganisms (Griffin, 2008; Montalva Grijalva et al., 2010; Kpomblekou-A and Genus, 2012). Soil temperature and moisture content influence microbial activity, affecting N mineralization, volatilization, leaching and denitrification processes; which in turn impact N availability.   For instance, N mineralization is an aerobic process that occurs optimally between temperatures of 14 – 35 ^{0}C (Nahm, 2003). Low soil moisture levels slow down microbial activity essential for nutrient recycling, and excess soil water creates anaerobic conditions which decrease N mineralization while promoting denitrification (Crenshaw et al., 2008; Johnson, 1995; Maag and Vinther, 1996). Soil type and climate effects on the efficiency of surface or subsurface applied manures can be evaluated and compared using factors such as FNE and PAN coefficients (Hammond et al., 1994). Therefore, the ability of a wheat crop to utilize N from poultry manure is influenced by the interaction between soil and climate factors which can be quantified as FNE and PAN values.

Fertilizer N equivalence and PAN coefficients also depend on crop factors such as varietal differences, root development and N accumulation pattern. Efficiency of poultry manure N for winter wheat production relies on application timing and release that matches plant uptake. Exact N amounts and timing trends remain elusive to farmers and scientists. Coefficients such as FNE and PAN have been determined through both incubation experiments (Gale et al., 2006; Gordillo and Cabrera, 1997a; Gordillo and Cabrera, 1997b; Montalva Grijalva et al., 2010; Diaz and Sawyer, 2008) and on-farm evaluation (Crouse et al., 1993; Diaz et al., 2011). Altering manure application times could be used to improve nutrient use efficiency in winter wheat and other crops by synchronizing release and availability of N to crop uptake (Clark and Mullins, 2004; Ekbladh, 2000; Jn-Baptiste et al., 2012). Application time could also vary due to availability of poultry manure to the grower at different periods of wheat production.

Nutrient availability in an organic material estimated by FNE or PAN coefficients can provide information to plan for future crop-specific rates. Fertilizer N equivalence factors are calculated based on crop yield while PAN coefficients are determined from plant N uptake by comparing manure treatment results to that of a series of inorganic N fertilizer rates (Pehrson et al., 2011; Pierzynski and Gehl, 2005; Watts et al., 2010). Linking poultry manure PAN coefficients with defined soil release characteristics, plant nutrient demand, and climatic condition will lead to proper planning and application with reduced or no negative impact to the environment in the Coastal Plain region (Marshall et al., 2001). The study objectives were; (i) to assess the effect of soil, climate, N source, application rate and time on yield and plant N uptake, and (ii) to determine FNE and PAN coefficients among different poultry manure N sources for winter wheat production. These factors can form the basis of improving organic fertilizer use efficiency while protecting the environment from unnecessary nutrient loading.

2.2 Materials and Methods

2.2.1 Site description

Two field studies were conducted during 2008/09 and 2009/10 winter wheat growing seasons. Field experiments were established in two locations (L) with distinct soils. The Lower Coastal Plain Tobacco Research Station (LCPRS) in Lenoir County had Goldsboro loamy sand (Aquic Paleudults) while the Tidewater Research Station (TRS) in Washington County soils were Portsmouth fine sandy loam (Typic Umbraquults).

2.2.2 Experimental design

At both sites, two chicken (*Gallus domesticus*) manures were compared as N sources (S) for winter wheat: broiler litter (BL) and composted layer manure (CLM). Broiler litter was collected from a chicken house in Bertie County and CLM from the Rose Acre Farms composting facility in Hyde County. Subsamples of poultry manures were analyzed by the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) laboratory (Table 2.1). These materials were applied to wheat fields at three different times (T): incorporated in October pre-plant, topdressed in December/January during tillering stage, or topdressed in February/March at pre-jointing. Poultry manures were applied at two rates (R), designated as 1X (BL or CLM at 134 kg N ha^{-1}) and ½ X (BL or CLM at 67 kg N ha^{-1}). A check plot without applied N was also included. Each treatment was replicated four times on 9 m by 3 m plots in a randomized complete block design. An additional set of inorganic N plots were also established using a urea ammonium nitrate solution (UAN as 30% N) topdressed at pre-jointing growth stage. Four fertilizer rates (39, 78, 117, and 156 kg N ha^{-1}) were each replicated three times to model fertilizer response curves.

2.2.3 Plot management

In each wheat season, a new experimental field was used which was previously in corn and to which no poultry manure had been applied. Pre-season soil samples were collected from each field and analyzed by the soil testing division of the NCDA&CS laboratory (Mehlich, 1984) (Table 2.2). Typical winter wheat cultural management practices such as cultivar selection, seeding rate and date, liming, and weed and pest control were followed, although scheduling and recommendations differed among sites. For instance, lime was applied to attain a soil pH of 6.0 in LCPRS and 5.5 for TRS based on NC recommendations and soil analysis results (Table 2.1) (Hardy, 2012). The seed varieties planted were Vigoro Dominion in LCPRS for both years while at TRS, Coker 9184-802R was planted in 2008/2009 and AgriPro Panola (PAN-904) was planted in 2009/2010.

2.2.4 Data collection

Before whole plot grain harvesting, a 0.9 m segment was sampled from a middle row of each plot. Wheat plants were clipped aboveground and heads were counted before separation from the stalk. Stalk samples were dried, weighed and ground; while the heads were dried, threshed and grain was weighed. A grain and stalk sample from each treatment was sent to the Agronomic Division of NCDA&CS for analysis of plant N content (McGinnis et al, 2012). Sample biomass determined on a dry weight basis was used to calculate harvest index which, together with stalk and grain N analysis, were used to determine plant N uptake. From each whole plot, a middle section of 9 m by 2 m was harvested with a plot combine equipped with a grain weight recorder and a moisture sensor. Total plant N uptake was calculated from this larger grain harvest area, combined with biomass, harvest index, and stalk and grain N data from the smaller harvest segment.

2.2.5 Data analysis

Yield and plant N uptake data from check and inorganic N plots were used to model linear-plateau fertilizer response functions (Anderson and Nelson, 1987) with PROC GLM in the Statistical Analysis System (SAS) (SAS, 2008). Analysis of variance (ANOVA) of wheat yields and plant N uptake for balanced-factorial poultry manure treatments, excluding check and inorganic N treatments, were performed using SAS PROC MIXED (Littell et. al., 2006). In this ANOVA, replicates and the combination of year and location (environment) were treated as random variables. Mean comparisons were based on least squares means (LSMeans) at $p < 0.05$ significance level using the Tukey's multiple comparison method (SAS, 2008; Littell et. al., 2006). This ANOVA was used to compare among manure treatments and derive treatment means for calculation of FNE and PAN (Figure 2.1). Comparison of crop mean yields between a manure treatment and the inorganic N yield response data were the basis for calculating FNE coefficients. The PAN values were determined by comparing mean plant N uptake of a manure treatment to a linear plateau function modeled from N accumulated with inorganic fertilizer N treatments. Fertilizer N equivalence and PAN values were determined by modifying an approach developed earlier Gale and co-workers (2006) (Equations 1, 2 and 3) (Figure 2.1). Only effects found to be significant in the initial ANOVAs of plant N uptake and yield data for the manure balanced factorial treatments were used to calculate FNE and PAN respectively. Statistically similar treatment means were pooled together when calculating the availability coefficients.

Equation 1: FNE or PAN = X_f/X_m

where X_f = fertilizer N rate required to achieve same yield as that of poultry manure applied either at 1X or ½X N rate (X_m). In cases where mean yield or mean plant N uptake from poultry manure were above the inorganic linear plateau or below the check plot, FNE and PAN values could not be determined. When the y-axis was crop yield then the solution was FNE, and when the y-axis was plant N uptake the solution was PAN. The value of X_f was determined by solving the linear equation 2.

Equation 2: $X_f = (y - a)/b$

where y is the mean yield or plant N uptake of the manure treatment, a is the y-intercept, and b is the slope. Combining equations 1 and 2 resulted in equation 3:

Equation 3: $FNE \text{ or } PAN = [(y-a)/b]/X_m$

2.3 Results and discussions

2.3.1 Yield, plant N uptake FNE and PAN

Environment and N source by rate interaction significantly affected yield and plant N uptake (Table 2.3). In addition, yield was influenced by manure application time and plant N uptake was influenced by poultry manure N rate. None of the fixed effect interactions with environment were significant. Varying poultry manure application times of pre-plant, tillering and pre-jointing did not affect plant N uptake leading to a mean of 68 kg N ha^{-1} accumulated with a PAN coefficient of 0.24, in two locations for two seasons 2008/2009 and 2009/2010.

2.3.1.1 Environment effect on yield and plant N uptake

Winter wheat yield and plant N uptake differed between seasons in the two locations with 2008/2009 higher than 2009/2010 as shown by linear plateau models of the inorganic N treatments (Figure 2.2 and 2.3). Plant wilting was observed in the 2009/2010 season during stem elongation stage in March and April due to prolonged dryness. Perhaps low soil moisture caused by low rainfall amount and irregular distribution during stem elongation stage in both locations affected growth vigour and reduced N mineralization rate (Figure 2.4). When compared to the 2008/2009 season, more reduction in yield and plant N uptake occurred in LCPRS than TRS in 2009/2010 season. The irregular rainfall distribution affected plant N utilization especially at the higher rates hence reducing winter wheat yields. Probably, low soil moisture reduced crop growth, N uptake or N availability in the 2009/2010 similar to drier seasons spring barley in Sweden (Delin, 2011). When soils become dry, restricted N movement by mass flow and slow root growth may result in low plant N uptake and reduced microbial population and activity (Watts et al., 2007). On the other hand, increased soil water content and infiltration especially in sandy soils such as the LCPRS site could lead to more nitrate being leached (Hubbard et al., 2008; Sleutel et al., 2008). Freezing winter temperatures in 2009/2010 season might have led to halting of microbial activity leading to less mineralization of organic N from poultry manures (Appendix 2.2).

Yields and N uptake among organic treatments in the 2009/2010 season in both locations were reduced in relation to low rainfall. In 2008/2009 mean grain yield was 3.6 ton ha^{-1} with a plant N uptake of 84 kg N ha^{-1} higher than 2009/2010 at 2.3 ton ha^{-1} and 52 kg N ha^{-1} respectively. Winter wheat accumulated more N from poultry manure in the 2008/2009 than in the 2009/2010 season that had lower winter temperatures and low rainfall during stem elongation stage. These results are in line with earlier studies of winter wheat yields on Coastal Plain soils of NC when poultry manures and inorganic fertilizers are applied (Crouse, 1993; Cahill et al., 2007).

Winter wheat yields and plant N uptake were higher in 2008/2009 than 2009/2010 site years (Figure 2.5). Similar winter wheat yields and plant N uptake were realized from both locations in 2008/2009 while in 2009/2010, TRS was higher than LCPRS. Nitrogen availability coefficients were higher in 2008/2009 than 2009/2010 (Table 2.4). Perhaps different amounts of N were taken up by wheat due to reduced crop growth or N availability as a result of low soil moisture. In the 2008/2009 season, the mean FNE of 0.45 and PAN of 0.37 were higher than 2009/2010 season N availability for both locations. Evidence of difference in N availability between seasons in Coastal Plain regions exist. Marshall et al., (2001) reported N availability for tall fescue pastures (*Festuca arundinacea* Schreb.) of 0.34 for first year and 0.51 for following season in Coastal Plain soils of Alabama, while Crouse and co-workers (1993) reported an average N efficiency of 0.11 from a range of -0.04 to 0.20 for poultry manure applied to winter wheat in North Carolina. Therefore, using poultry manure to supply N for winter wheat production will vary with changing environments due to differences in the soil and weather conditions.

2.3.1.2 Effect of application time on yield

Yield was higher when poultry manures were applied at pre-jointing than at pre-plant or tillering (Figure 2.6). There was a small, but statistically significant advantage to delaying poultry manure applications until immediately prior to jointing. Although significant, the magnitude of this advantage is of little agronomic significance, representing a yield difference of approximately 5% unlike no significant effect of manure timing on yield when the entire set of management treatments was included in the data analysis (Chapter 1).

Applying poultry manure at the pre-jointing stage resulted in higher yields than both earlier times because N supply is closely tied to changes in weather and soil conditions and application was immediately prior to the period of peak N demand. Pre-plant and tillering yields were lower perhaps due to limited N supply or loss of a portion of the mineralized N from the system during slow plant growth stages (Keener et. al,. 2011). Soil temperatures dropped at tillering stage which could have led to reduced microbial activity and organic N mineralization in both manure sources. It is therefore advantageous to apply poultry manure to winter wheat fields at pre-jointing stage when temperatures are rising and fast plant growth leads to increased demand for N. The higher yields with the pre-jointing application resulted in FNE values of 0.34 for later application and 0.25 for the two early application times. Earlier studies have reported mean PAN values 0.21 (Slaton et. al., 2009) similar to pre-plant and tillering mean of 0.25 and FNE coefficients of 0.28 for autumn application and 0.58 for spring application of poultry manure applied to winter wheat (Birkmose, 2011).

2.3.1.3 Application rate and N source effect on yield and plant N uptake

When averaged across environments, the interaction of poultry manure source and application rate significantly affected yield and plant N uptake (Figure 2.7). Winter wheat yields and plant N uptake were highest with CLM at 134 kg N ha^{-1}. Higher yield was realized from BL at 134 kg N ha^{-1} than BL at 67 kg N ha^{-1}. The significant source by rate effect resulted in FNE values that declined with doubling of the application rate (Table 2.5). Increasing manure application rate from 67 kg N ha^{-1} to 134 kg N ha^{-1} lead to a reduction of mean FNE from 0.32 to 0.25 and PAN from 0.28 to 0.20 for both sources. Although, doubling poultry manure application rate increased yield (Figure 2.7), the proportion of increase does not match the amount of N added hence N efficiency is reduced (Kanampiu et al., 1997). Delivering high doses of manures that would not be utilized by a crop is detrimental to the environment as it leads to unnecessary loading of nutrients in ground and surface water (Read et al., 2008). Therefore varying application rates for different poultry manure types in several environments to match soil conditions such as moisture and temperature could lead to improved manure N efficiency.

2.4 Conclusion

Poultry manure improved winter wheat yields and plant N uptake in all four environments (locations and seasons) tested. Yields were higher when poultry manures were applied pre-jointing rather than pre-plant incorporated or topdressed during the tillering stage. Although significant, the magnitude of this advantage is of little agronomic significance, representing a yield difference of approximately 5% unlike no significant effect of manure timing on yield when the entire set of management treatments was included in the data analysis. Also, winter wheat yields were higher with CLM at 134 kg N ha^{-1} than with BL applied at the same rate. The highest FNE value of 0.34 was from CLM applied at 67 kg N ha^{-1} while the lowest value of 0.18 was from BL applied at 134 kg N ha^{-1}. Winter wheat accumulated more N from CLM at 134 kg N ha^{-1} which corresponded to a PAN coefficient of 0.25. Management practices such as varying application time affected yield while type of poultry manure and rate influenced both yield and plant N uptake. These coefficient values suggest that N availability from these manures was less than the standard plant available N assumption in North Carolina of 50% when surface applied and 60% when incorporated. As a result, winter wheat crops fertilized with poultry manures could be receiving less plant available N than intended. Since efficiency declines with increasing application rate, attempts to supply more N above the rate of 134 kg N ha^{-1} would probably have further lowered the coefficients. Therefore, a follow-up study is required to ascertain the range of these coefficients on many soil types under different weather conditions and to verify the fate of N not accumulated by the plant as lost or as residual N in the soil. Many factors interact to affect yield and plant N uptake which in-turn impact on FNE and PAN factors. Although manure N management is challenging, previous season FNE and PAN coefficients can be used to calculate future poultry manure application rates aimed at improving yield and plant growth while protecting the environment against unnecessary nutrient loading.

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Table 2.1. Nutrient composition of poultry manures used in each season at both experimental locations.

Year	Source[a]	C:N	N	P	K	Ca	Mg	Zn	Cu
			(%)						
2008/09	BL	14.0	2.4	0.6	1.9	2.0	0.4	0.04	0.03
2008/09	CLM	4.8	7.1	1.2	2.9	6.8	0.6	0.04	0.01
2009/10	BL	9.2	4.0	1.0	2.9	3.3	0.7	0.05	0.05
2009/10	CLM	5.0	6.3	1.6	3.1	9.1	0.7	0.06	0.01

[a] BL- Broiler litter; CLM-Composted layer manure

Table 2.2. Chemical characteristics of 2008/2009 and 2009/2010 preseason soil samples for each experimental location.

Year	Location[a]	pH	CEC	Ca	Mg	K	Ac[b]	BS[c]	P	Zn	Cu
			------------ $cmol_c$ kg^{-1} ------------					%	------ ppm ------		
2008/2009	LCPRS	6.0	5.0	2.6	0.9	0.2	1.4	71	84	0.9	0.1
2008/2009	TRS	5.5	12.3	6.8	2.3	0.4	3.0	78	133	2.9	0.7
2009/2010	LCPRS	5.6	3.8	1.1	0.4	0.2	1.3	67	64	0.9	0.1
2009/2010	TRS	5.3	8.3	4.7	1.2	0.4	2.4	77	140	2.9	0.7

[a] LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station

[b] Ac – Mehlich buffer acidity

[c] BS-Base saturation = (Ca + Mg + K + Na/CEC) x 100%

Table 2.3. A summary analysis of variance (ANOVA) of poultry manure factorial treatments on winter wheat yield and plant uptake N across both locations and both cropping seasons.

Effect[a]	Degree of freedom	Yield	Plant N Uptake
N Source	1	ns	ns
Rate	1	ns	*
Application time	2	*	ns
N Source x Rate	1	*	*
N Source x Application time	2	ns	ns
Rate x Application time	2	ns	ns
N Source x Rate x Application time	2	ns	ns
Environment	3	**	**
Environment x N Source	3	ns	ns
Environment x Rate	3	ns	ns
Environment x Application time	6	ns	ns
Environment x N Source x Rate	3	ns	ns
Environment x N Source x Application time	6	ns	ns
Environment x Rate x Application time	6	ns	ns
Environment x N Source x Rate x Application time	6	ns	ns

[a] N Source (Broiler litter and Composted layer manure); Time (pre-plant, tillering and pre-jointing); Rate (Organic high 134 kg N ha^{-1}, Organic low = 67 kg N ha^{-1}); Environments (LCPRS-2008/2009; LCPRS-2009/2010; TRS-2008/2009; TRS-2009/2010) where LCPRS-Lower Coastal Plain Tobacco Research Station, TRS- Tidewater Research Station.

[b] Symbols indicate probability: *** <0.001, ** <0.01, * <0.05, ns>0.05

Table 2.4. Environment on fertilizer N equivalence (FNE) and plant available N (PAN) coefficients for poultry manure applied for winter wheat production averaged across N sources, application time and rate.

Year	Location	FNE	PAN
2008/2009	LCPRS TRS	0.45	0.37
2009/2010	LCPRS	0.22	0.17
	TRS	0.25	0.16

Table 2.5. Fertilizer N equivalence (FNE) and plant available N (PAN) coefficients for poultry manure sources and rates of applied total N for winter wheat production averaged across environments (locations, growing seasons/years), application time and rate.

Source	Application rate (kg N ha^{-1})	FNE	PAN
Broiler litter	67	0.29	0.28
	134	0.18	0.14
Composted layer manure	67	0.34	0.27
	134	0.31	0.25

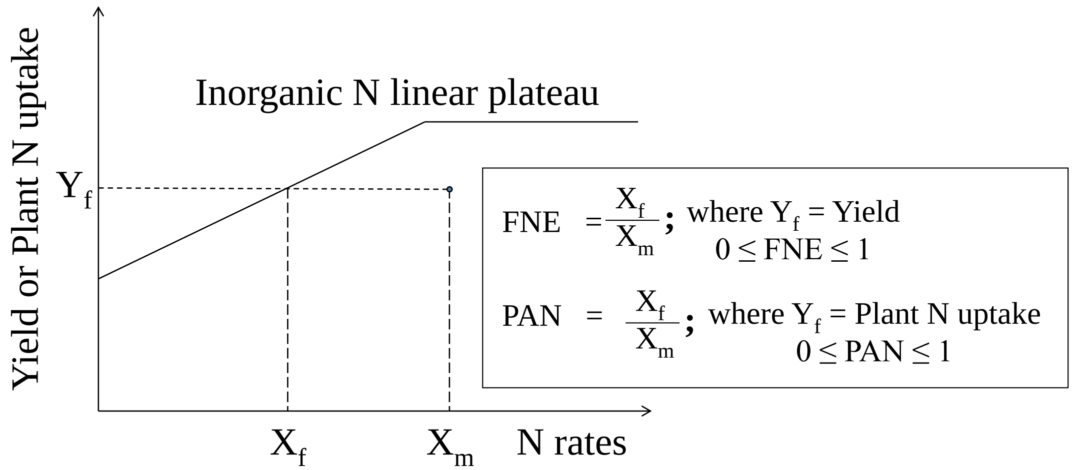


Figure 2.1. Illustration of calculation of Fertilizer N equivalence (FNE) and plant available N (PAN) coefficients by comparison of poultry manure data to modeled fertilizer N linear plateau functions.

Where X_f = fertilizer N rate required to achieve same yield as that of poultry manure applied either at 1X or ½X N rate (X_m). In cases where yield or plant N uptake from poultry manure were above the inorganic linear plateau or below check plot then FNE and PAN could not be determined.

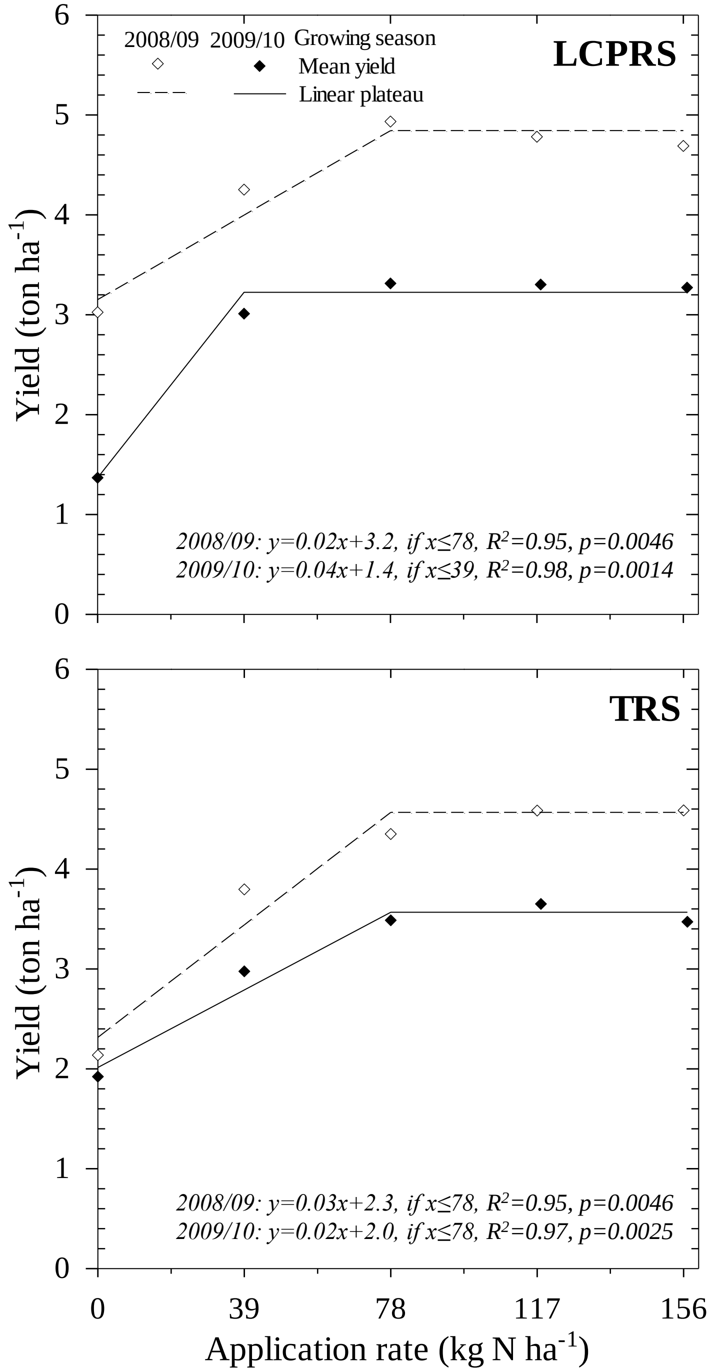


Figure 2.2 Winter wheat yield response to urea ammonium nitrate N fertilizer rates at two locations, the Lower Coastal Plain Tobacco Research Station (LCPRS) and the Tidewater Research Station (TRS) in 2008/2009 and 2009/2010 season.

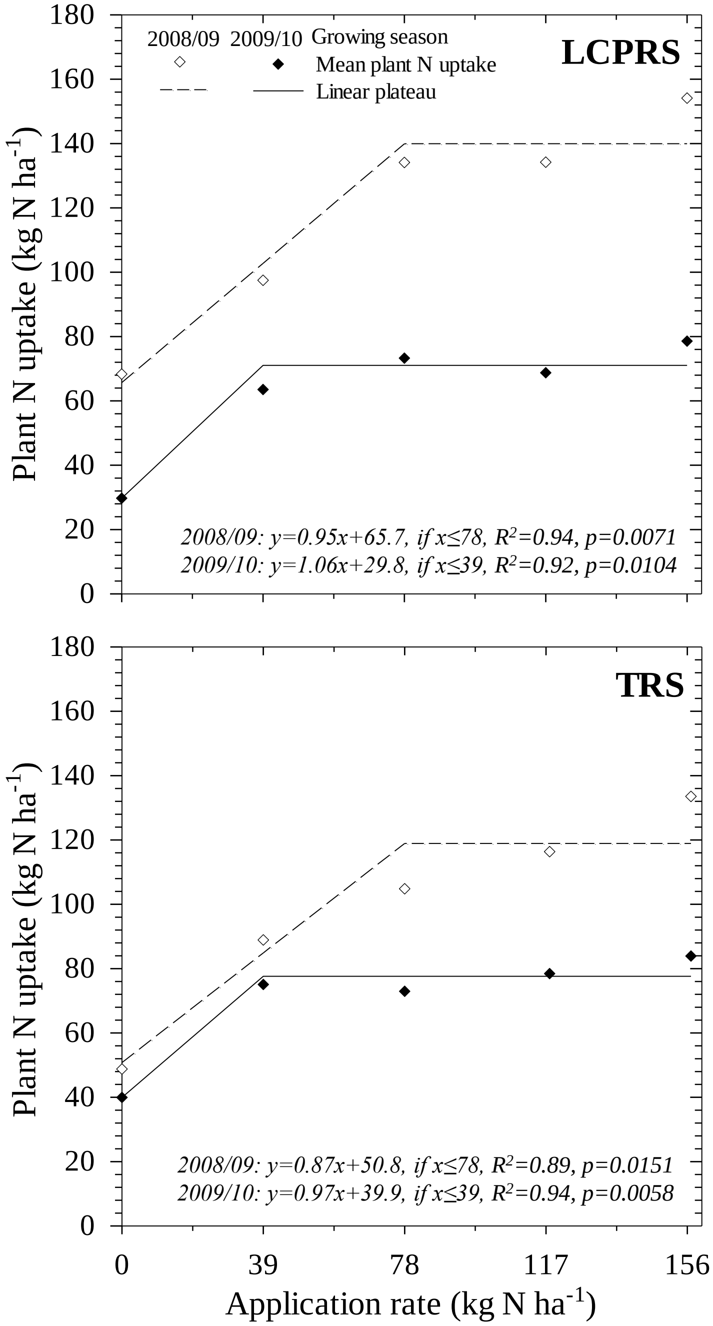


Figure 2.3 Plant N uptake response to urea ammonium nitrate N fertilizer rates for winter wheat in 2008/2009 and 2009/2010 season grown at two locations, the Lower Coastal Plain Tobacco Research Station (LCPRS) and the Tidewater Research Station (TRS).

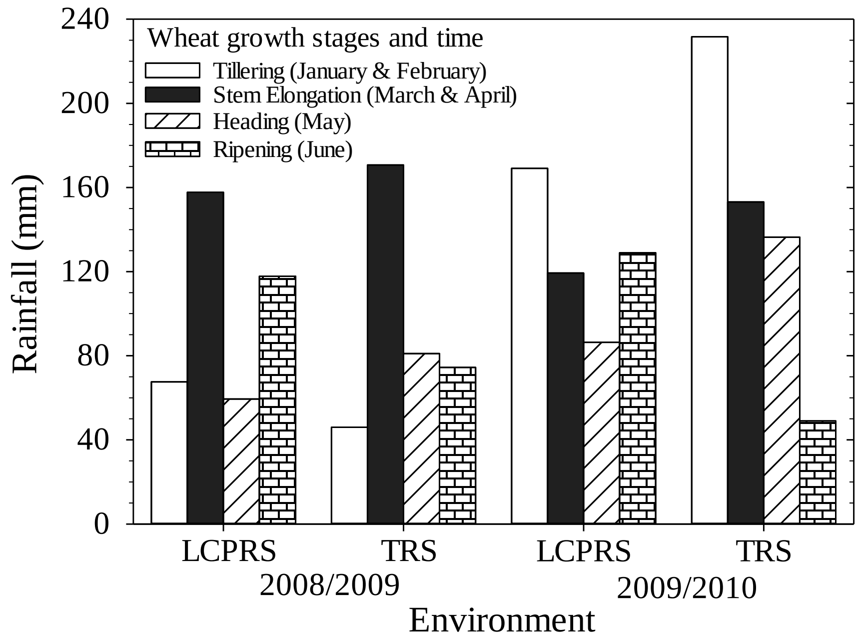


Figure 2.4 Total rainfall amount for selected winter wheat growth stages and related times for two site years of Lower Coastal Plain Tobacco Research Station (LCPRS) and the Tidewater Research Station (TRS) in 2008/2009 and 2009/2010 season. Data was collected by Climate Retrieval and Observations Network of the Southeast (CRONOS).

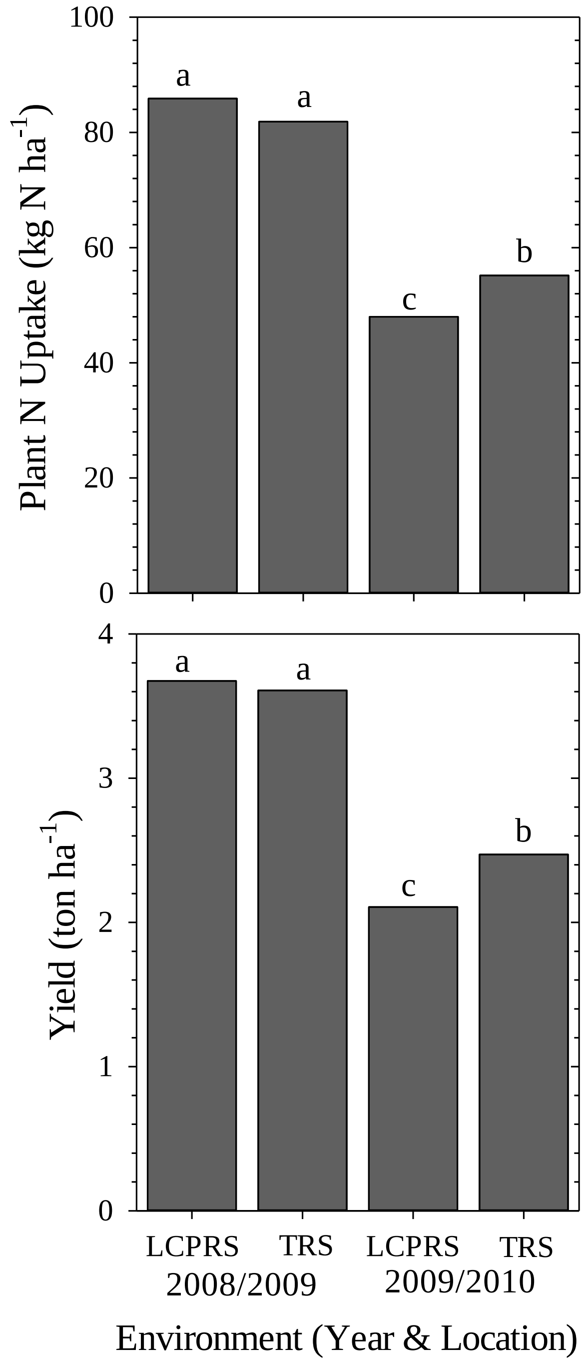


Figure 2.5. Effect of environment (year and location) on plant N uptake and yield of winter wheat averaged across N sources, application time and rate. Tukey Kramer values at $p<0.05$ were used to separate means using 5.0 kg N ha^{-1} for plant N uptake and 0.2 tons ha^{-1} for yield. Check plot means were 49 kg N ha^{-1} and 2.2 tons ha^{-1} for plant N uptake and yield respectively averaged across two site years. LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station

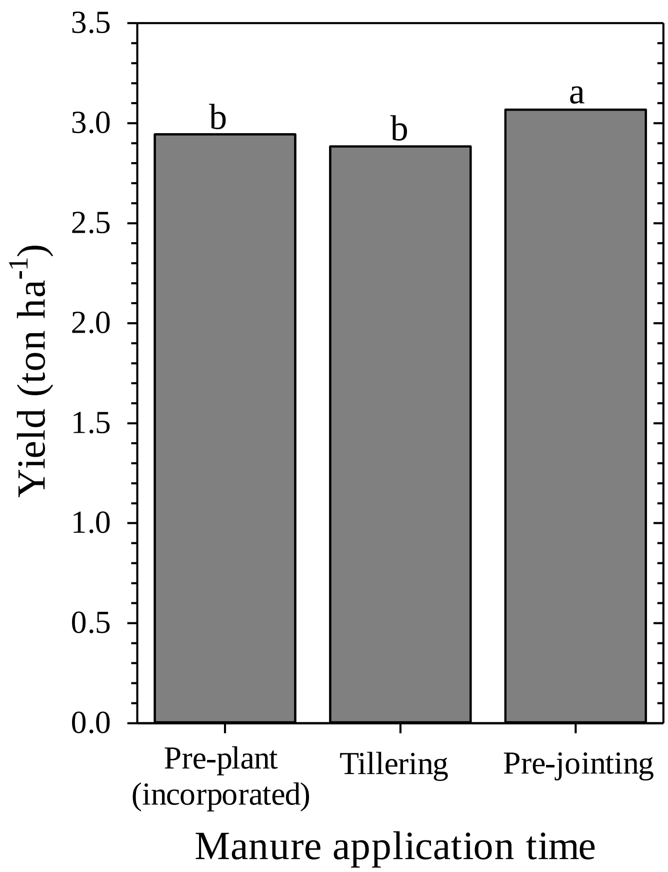


Figure 2.6 Effect of poultry manure application time on winter wheat yield averaged across four environments (locations, growing seasons/years), two N sources and two application rates. Tukey Kramer value 0.1 tons ha^{-1} was used to separate mean yields at $p<0.05$. Check plot yield was 2.2 tons ha^{-1}.

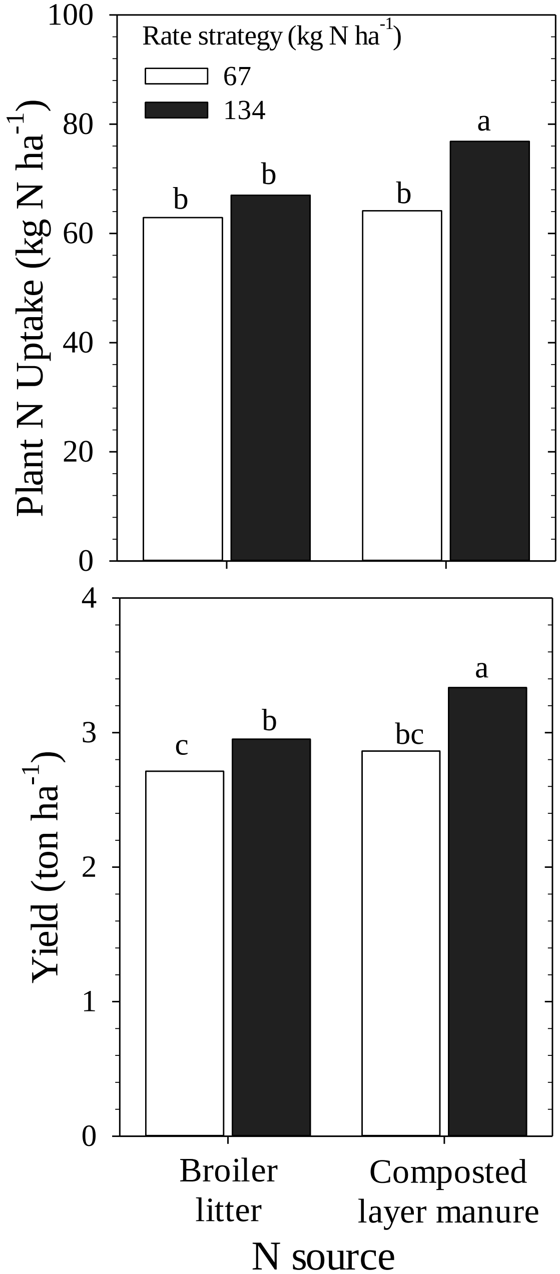


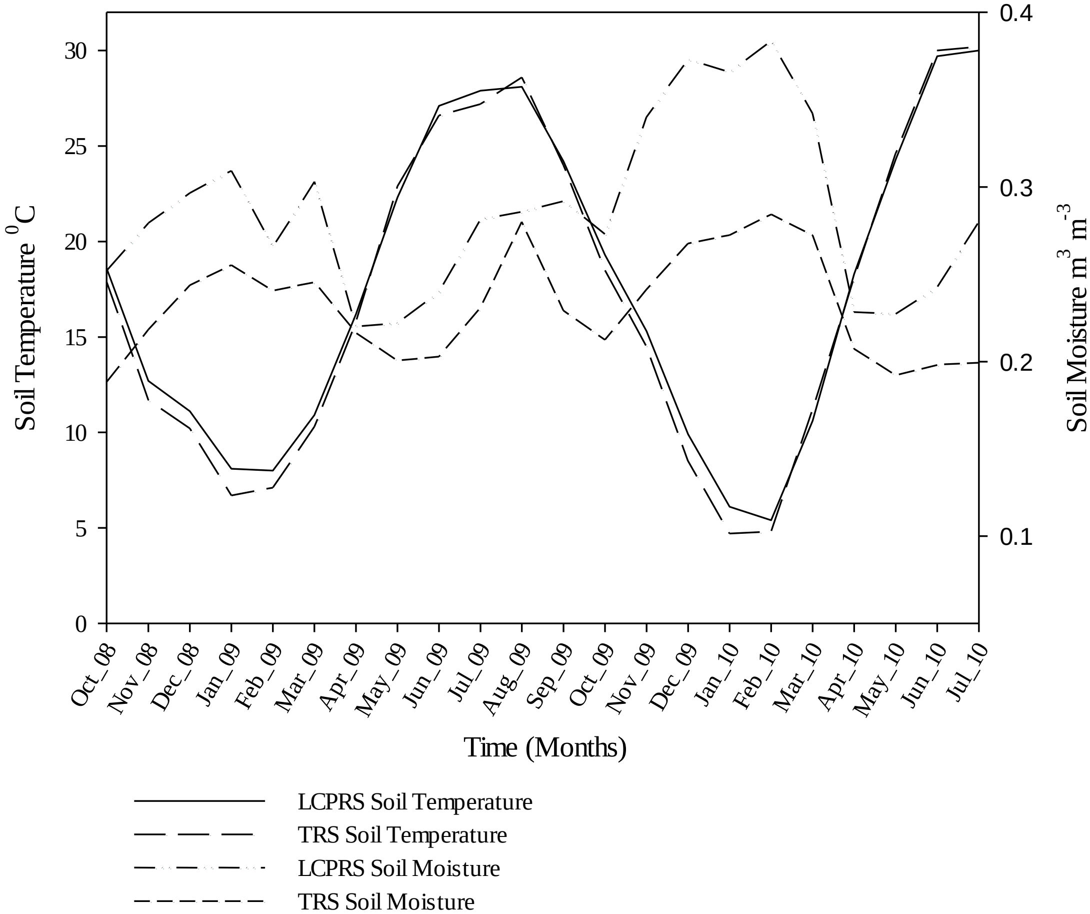
Figure 2.7 Plant N uptake and yield for poultry manure sources and rates of applied total N to winter wheat and averaged across two locations and two cropping seasons. Tukey Kramer values at $p<0.05$ were used to separate means using 5.0 kg N ha^{-1} for plant N uptake and 0.2 tons ha^{-1} for yield. Check plot means were 49 kg N ha^{-1} and 2.2 tons ha^{-1} for plant N uptake and yield respectively averaged across two site years.

2.6 Appendices

Appendix 2.1 Winter wheat experiment treatments established in both Lower Coastal Plain Tobacco Research Station and Tidewater Research Station. Inorganic N fertilizers were applied as topdress. Data collected for analysis included tiller count, yield, plant yield components and soil characterization.

Treatment	Description
1	Check plot (0 kg N ha^{-1})
2	October broiler litter @ ½ X
3	October broiler litter @ ½ X + ½ inorganic N @ 67kg N ha^{-1}
4	October broiler litter @ 1 X
5	October composted layer manure@ ½ X
6	October composted layer manure@ ½ X + ½ inorganic N @ 67kg N ha^{-1}
7	October composted layer manure@ 1 X
8	December broiler litter @ ½ X
9	December broiler litter @ ½ X + ½ inorganic N @ 67kg N ha^{-1}
10	December Broiler litter @ 1 X
11	December composted layer manure@ ½ X
12	December composted layer manure@ ½ X + ½ inorganic N @ 67kg N ha^{-1}
13	December composted layer manure@ 1 X
14	February broiler litter @ ½ X
15	February broiler litter @ ½ X + ½ inorganic N @ 67kg N ha^{-1}
16	February broiler litter @ 1 X
17	February composted layer manure@ ½ X
18	February composted layer manure@ ½ X + ½ inorganic N @ 67kg N ha^{-1}
19	February composted layer manure@ 1 X
20	39 kg N ha^{-1}(30% UAN)
21	78 kg N ha^{-1}(30% UAN)
22	118 kg N ha^{-1}(30% UAN)
23	157 kg N ha^{-1}(30% UAN)

Appendix 2.2 Lower Coastal Plain Tobacco research station and TRS soil temperature and moisture data reported by Climate Retrieval and Observations Network of the Southeast (CRONOS) during winter wheat growing season from 2008 to 2010.



CHAPTER 3: NITROGEN AVAILABILITY IN POULTRY MANURE FOR COTTON AND CORN PRODUCTION UNDER CONSERVATION AND CONVENTIONAL TILLAGE

Abstract

Several poultry manure types important for crop production are produced in southeastern United States Coastal Plain regions. These manures are applied to field crops assuming 50% of the total N is available to the first crop when surface applied, and 60% when incorporated. Manures mineralize over a long period beyond the growing season, hence contributing to a soil residual N pool that affects subsequent crops. However, this assumption might not hold constant for different crops, application times, environments, placement modes, period in the field and tillage practices, all of which affect N availability coefficients such as fertilizer N equivalence (FNE) calculated from yield or plant available N (PAN) determined from plant N uptake. Therefore, the objectives of this study were to (i) evaluate poultry manure N source, application rate and residual N effects on yield and plant N uptake in a cotton (*Gossypium hirsutum*) – corn (*Zea Mays* L.) rotation under conservation and conventional tillage; and (ii) calculate FNE and PAN for current year application and the residual availability of N in these systems. Cotton-corn rotation experiments were established in two locations, the Upper Coastal Plain Research Station (UCPRS) on a Norfolk loamy sand (Typic Kandiudults), and the Tidewater Research Station (TRS) on a Portsmouth fine sandy loam (Typic Umbraquults) over four summer growing seasons of 2008, 2009, 2010 and 2011 in adjacent conservation and conventional tillage fields. Three

chicken (*Gallus domesticus*) manure sources (So) were used; layer manure (LM), composted layer manure (CLM) and broiler litter (BL). Poultry manures were applied either as a higher total N rate of 90 kg N ha^{-1} on cotton and 134 kg N ha^{-1} on corn or a lower N rate of 45 kg N ha^{-1} on cotton and 67 kg N ha^{-1} on corn. Yields and plant N uptake from these poultry manure treatments were compared to a linear-plateau or linear functions modeled from three inorganic fertilizer (30% urea ammonium nitrate) rates and the check plot (no N applied). Manure source, application rate, crop season either as first, second or third and a combination of location and tillage plus their interactions affected yield and plant N uptake. Layer manure provided more N to the first year corn crop, with an FNE coefficient of 0.68, than second year corn crop where the FNE 0.26 indicated that residual N availability decreased with increasing seasons. First year crop N availability also varied with site when averaged across tillage. For instance, first year corn crop FNE in 2009 was 0.55 in UCPRS and 0.75 in TRS, while the second year crop FNE was almost a quarter to a third of the first at 0.16 and 0.29 for the sites respectively. When poultry manure was applied at 134 kg N ha^{-1}, corn yields increased by 52% above unfertilized plots, which was greater than the 38% increase at 67 kg N ha^{-1} although the N use efficiency declined at the high rate. Yield, plant N uptake, FNE and PAN values varied with crop year. Second and third year crop FNE values were highly variable but indicate some persistent residual N effects that are usually less than the initial year of application.

3.1 Introduction

Poultry manure has been used as a relatively cheap organic fertilizer to supply both macronutrients and micronutrients to several crops under different management and tillage practices (Adeli et al., 2007; Adeli et al., 2008; Jackson et al., 2003, Sainju et al., 2010; Sistani et al., 2010; Tewolde et al., 2008) . The importance of poultry manure in crop production has increased due to surging prices of commercial inorganic fertilizers and the availability of information on manure nutrient supply, especially nitrogen (N), that result in similar yields regardless of source (Adeli et al., 2012; Mitchell and Tu, 2005). However, excess application of poultry manure on land in the southeastern USA could result in water quality problems (Franklin et al., 2007; Franklin et al., 2006; Mitchell and Tu, 2006). Variations exist in nutrient content and availability of different poultry manure types within management systems for crop production (Gale et al., 2006). A common assumption is that 50 – 60% of the total N of poultry manure will be available to the first year crop (Nyakatawa et al., 2001; Nyakatawa et al., 2010; Schomberg et al., 2009). Nitrogen availability coefficients also depend on tillage practices (Nyakatawa et al., 2000), type of crop (Reddy et al., 2009), manure placement (Abrahamson et al., 2007; Endale et al., 2010), and application time and rate (Diaz et al., 2011). All these factors interact leading to different crop yields.

Cotton and corn rotations have been practiced under both conservation and conventional tillage in the southeastern USA Coastal Plain regions for several decades with an aim of breaking pest and diseases cycles. Therefore, there is need to consider several factors that would affect poultry manure use in these tillage practices on different soils (Sistani et al., 2009; Sistani et al., 2010; Tewolde et al., 2008). Studies have shown that poultry manure-derived nutrient distribution in the soil differs with tillage practices (Balkcom et al., 2005; Lupwayi et al., 2006). Variations in nutrient distribution in the soil with respect to tillage influence performance of either first, second or third year crops when poultry manure is used to supply N (Lupwayi et al., 2006). Other tillage-related effects that impact N use include soil erosion control, soil organic matter accumulation, water infiltration and soil moisture content (Nyakatawa and Reddy, 2000). Environmental conditions in the southeastern USA Coastal Plains region lead to expedited transformations of nutrients particularly N. As a result, frequent application of fertilizers such as poultry manure should be done at rates that do not pollute the environment (Mitchell and Tu, 2005; Mitchell and Tu, 2006). Residual N from poultry manure could be considered in determining the following season's application rate for different crops in both conservation and conventional tillage systems.

Coefficients for organic manure fertilizer nitrogen equivalence (FNE) determined from yield and plant available nitrogen (PAN) based on plant N uptake, both relative to crop performance with commercial inorganic fertilizers, are used to calculate application rates. When determined in the field, these coefficients estimate the proportion of N utilized by the crop. Field determined FNE or PAN coefficients are likely to be lower and more variable than those estimated from incubation experiments (Gale et al., 2006; Diaz et al. 2011). Many factors interact to affect field based coefficients, unlike in the laboratory where the conditions are controlled in an enclosed system. Plant available N coefficients for broiler litter, layer and turkey manure for field corn range from 0.38 to 0.55 with a mean of 0.46 (Diaz et al., 2011), and were lower than laboratory incubation values 0.55 – 0.66 for layer and turkey manure on the same soil (Diaz et al., 2008).

Most attempts to quantify N availability from organic manures are done using one crop over several seasons. However, differences in crop growth characteristics, crop rotations and tillage systems affect calculated FNE and PAN coefficients (Stone et al., 2010). For instance, in a cotton-corn rotation, nutrient use efficiency is assumed to improve because a large soil depth is explored with both the tap and fibrous root systems in cotton and corn, respectively in alternating seasons (Reddy et al., 2009). Nutrient requirements for crops used in a rotation are distinct and considered in determining application rates. This could be challenging to farm managers who combine crops with high N demand like corn and low N demand like cotton in their rotations. Individual crops also draw nutrients from different volumes of their rooting zones. If residual available N is high following a crop with elevated N requirements, there is a likelihood of over supplying N to a subsequent crop with less demand in the rotation. The residual N effect will vary with tillage practice especially where poultry manures are used in these rotations (Reddy et al., 2009). For instance, Reddy et al., (2009) reported a narrow range of residual N effect (30 – 50%) on cotton lint yield relative to a treatment without applied N that was lower than for corn grain yield (25 – 65%). Therefore, N availability coefficients vary with type of crop.

Despite numerous reports on poultry manure as a fertilizer for crop production, first year and subsequent residual N effects on yield, plant N uptake and N availability coefficients have not been widely documented in the field for a cotton-corn rotation under different tillage systems (Jn-Baptiste et al., 2012; Tewolde et al., 2007). Farmers in southeastern Coastal Plains use both conservation and conventional tillage practices (Franzluebbers, 2005) with different poultry manures in crop rotations such as cotton-corn (Nyakatawa et al., 2001; Sistani et al., 2010) and assume the same N availability. In this study, factors that affect N availability in a cotton-corn rotation production system were investigated. The objectives of this study were to (i) evaluate poultry manure N source, application rate and residual N effects on yield and plant N uptake in a cotton-corn rotation under conservation and conventional tillage; and (ii) calculate FNE and PAN for current year application and the residual availability of N in these systems.

3.2 Materials and Methods

3.2.1 Site description

Cotton-corn rotation experiments were conducted over four summer growing seasons of 2008, 2009, 2010 and 2011in adjacent conservation and conventional tillage fields on two research stations in North Carolina. The studies were conducted at the Upper Coastal Plain Research Station (UCPRS) in Edgecombe County on a Norfolk loamy sand (Typic Kandiudults), and the Tidewater Research Station (TRS) in Washington County on a Portsmouth fine sandy loam (Typic Umbraquults). The conservation tillage practice was strip-till (ST) with an in-row subsoiler at UCPRS and no-till (NT) at TRS; while conventional tillage (CT) was a combination of passes with disks, chisel plows, and shallow field cultivators at both sites. The combination of site and tillage system resulted in four experiments namely UCPRS-ST, UCPRS-CT, TRS-NT and TRS-CT.

3.2.2 Experimental design

In all experiments, three chicken manure sources (So), layer manure (LM), composted layer manure (CLM) and broiler litter (BL) were used to supply N for cotton and corn production (Table 3.1). Two rate strategies were applied on a total N basis (i) a higher N rate (1X) at 90 kg N ha^{-1} on cotton and 134 kg N ha^{-1} on corn, and (ii) a lower N rate (½X) at 45 kg N ha^{-1} on cotton, 67 kg N ha^{-1} on corn. Assessment of both current year and residual effects of poultry manures involved two sets of plots, wherein one set received manure treatments in 2008 and 2010 on cotton, and the other set received manure treatments in 2009 on corn. No poultry manures were applied to corn in 2011 to allow evaluation of residual effects on both second and third year crops. In each season, a check plot (no N applied) and 30% urea ammonium nitrate (UAN) rates of 45, 90 and 135 kg N ha^{-1} for cotton and 0, 67, 134 and 202 kg N ha^{-1} for corn were included. Inorganic fertilizers were applied as a sidedress 4 to 6 weeks after planting. Each treatment was replicated four times on 9.0 m by 5.5 m plots in a randomized complete block design.

3.2.3 Plot management

Typical cotton-corn rotation cultural management practices such as cultivar selection, seeding rate and date, liming, and weed and pest control were followed, although scheduling and recommendations differed among sites. Pre-season soils samples were collected in 2008, and characterized by the soil testing division of the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) laboratory (Mehlich 1984) (Table 3.2). Nutrient and lime inputs were made according to NC recommendations (Hardy 2012).

3.2.4 Data collection

Before whole plot harvests, five plants from middle rows were clipped above ground; harvestable seed cotton (lint + seed) or corn ears were separated from the stalk. Dry weights were determined and samples were ground for analysis. Harvest and stover sample weights were used to calculate harvest index. Subsamples of dried stover and seed cotton or grain were analyzed for N at the North Carolina State University Environmental and Agricultural Testing Service (NCSU EATS) laboratory. The middle two rows (approximately 9 m by 2 m) were harvested with a cotton picker or grain combine. Corn weights were adjusted to market standard, 15.5% moisture for yield data analysis.

3.2.5 Data analysis

Plant N uptake was calculated by combining data from stover and either seed cotton or corn grain N with respective plot yields and harvest indices. Yield and plant N uptake data from check and inorganic fertilizer N treatments were used to model fertilizer linear-plateau response functions (Anderson and Nelson, 1987) with PROC GLM in the Statistical Analysis System (SAS) (Table 3.3) (SAS, 2008). Only response functions that met the following criteria were used to derive FNE or PAN coefficients: (i) significant model sum of squares of regression at $p < 0.05$; (ii) response function data collected from more than 2 inorganic N rates, (iii) a positive linear slope to the response, and (iv) fertilizer N equivalence and PAN coefficients were defined to be between 0 and 1 i.e. ($0 \leq \text{FNE or PAN} \leq 1$). Analysis of variance (ANOVA) of poultry manure treatment crop yields and plant N uptake were performed on year and crop data subsets where residual N (either 2nd or 3rd year) and current (first) year manure applications were analyzed separately using SAS PROC MIXED (Littell et. al., 2006). These analyses enabled the assessment of manure application on first, second and third year crop performance. In these ANOVAs, sites and tillage practices were combined to form four experiments treated as random effects. All treatment mean comparisons were based on least squares means (LSMeans) at $p < 0.05$ significance level using the Tukey's multiple comparison method (SAS, 2008; Littell et. al., 2006). Effects found to be significant from factorial manure ANOVA subsets were used for subsequent calculation of FNE and PAN from selected linear plateau functions. Comparison of manure treatment crop yield means to the modeled inorganic N treatment yield response data was the basis of calculating FNE coefficients. Plant available N values were determined by comparing plant N uptake from a poultry manure treatment to that from modeled linear functions for inorganic fertilizer N treatments. The coefficients were calculated as shown by equations 1, 2 and 3 and the illustration in Figure 3.1. Only linear plateau functions which met the criteria above and had significant effects from manure factorial ANOVAs of yield and plant N uptake were used in this calculation. Means of significant effects from the poultry manure treatment yields and plant N uptake were pooled together in the calculation of the availability coefficients.

Equation 1: FNE or PAN = X_f/X_m

where X_f = fertilizer N rate required to achieve same yield as that of poultry manure applied either at 1X or ½X N rate (X_m). In cases where mean yield or mean plant N uptake from poultry manure were above the inorganic linear plateau or below the check plot, then FNE and PAN could not be determined. When the y-axis was crop yield then the solution was FNE, and when the y-axis was plant N uptake the solution was PAN. The value of X_f was determined by solving the linear equation 2.

Equation 2: $X_f = (y - a)/b$

where y is the mean yield or plant N uptake of the manure treatment, a is the y-intercept, and b is the slope. Combining equations 1 and 2 resulted in equation 3:

Equation 3: $FNE \text{ or } PAN = [(y - a)/b]/X_m$

3.3 Results and Discussion

3.3.1 Yield and plant N uptake response to inorganic fertilizer

In this cotton-corn rotation, crop yields and plant N uptake response to inorganic fertilizer (30% UAN) application was dependent on main effects for location, tillage practice and year and by most interaction effects (Table 3.3). Variables interaction and set selection criteria resulted in less modeled functions than the possible 16 for yield or plant N uptake (9 out of 16 for yield and 7 out of 8 for plant N uptake) (Figure 3.2, 3.3, 3.4 and 3.5). Cotton yield only responded to increasing N fertilizer rate in UCPRS site under strip till in 2010 (Figure 3.2). The mean cotton yield values (provided in parentheses) for tillage, location and cropping year effects without a significant relationship with UAN rates were UCPRS-ST (3.0 ton ha^{-1}), UCPRS-CT (1.6 ton ha^{-1}), TRS-NT (3.6 ton ha^{-1}) and TRS-CT (3.8 ton ha^{-1}) in 2008, and UCPRS-CT (1.5 ton ha^{-1}) TRS-CT (2.0 ton ha^{-1}) and TRS-NT (1.8 ton ha^{-1}) in 2010. Cotton yields were higher in TRS in 2008 season for both tillage practices, but no response to increase in fertilizer rates was observed. In this site, cotton followed a soybean crop which may have provided sufficient soil N leading to no response from additional fertilizer N. Increasing inorganic N application rate for cotton gave a plateau response for yields may be due to other factors like overgrown canopy leading to less boll development (Crozier, 2012; Mitchell and Phillips, 2010). In 2010, cotton N uptake increased significantly with UAN rates when averaged across the location-tillage combinations of UCPRS-ST, UCPRS-CT and TRS-CT (Figure 3.3).

Corn yields, averaged across location-tillage-year combinations, responded to UAN additions in 2009 and 2011 seasons with all models significant at the $p < 0.05$ level. The response for TRS-CT, however, was linear throughout all N rates in both years (Figure 3.4). Maximum corn yields in 2009 were greater at TRS than at UCPRS but differences in tillage systems were more pronounced at the latter. In the 2011 season, there were notable reductions in corn yields of control treatments at both sites, probably due to additional years managing the same plots without N inputs. Maximum yields only decreased at the TRS site when compared to corn in 2009 (Figure 3.4). For both seasons, UCPRS-ST resulted in higher maximum yield than UCPRS-CT. The UCPRS-CT field was on an uneven slope and some plots had incidences of flooding and/or heavy erosion. Plowing of the field in conventional tillage could perhaps have led to nutrient movement below the plant rooting zone especially in early stages of growth before a large root volume is formed. In contrast, less soil disturbance with sufficient surface cover in strip till could lead to nutrient stratification and accumulation near the surface (Bertol et al., 2011; Ginting et al., 1998). Since corn has a fibrous root system, nutrient accumulation near the surface could be advantageous and lead to increased N uptake. Plant roots could concentrate near the surface where nutrients and moisture are available (Bauer et al., 2002; Lupwayi et al., 2006). Corn N uptake across UAN rates was different among the experiments in 2009 (Figure 3.5). Plant N uptake for the 2011 season was not modeled because data was not collected from the entire range of UAN rates.

Cotton and corn yield and plant N uptake across both poultry manure and UAN treatments reflected changes in rainfall between the sites during crop growing periods (April to September) (Figure 3.6). Cumulative rainfall during the growth period in 2008 and 2010 for both sites, and 2009 and 2011 for UCPRS site was below average, while TRS 2009 and 2011 had above average rainfall. Soils in TRS are mineral-organic and can hold more water, perhaps explaining the higher check plot yields and plant N uptake realized. With low rainfall, perhaps conservation tillage retained more moisture in the rooting zone than conventional tillage, thus facilitating N movement through mass flow and affecting cotton growth. Reductions in cotton response to N fertilization occur when moisture is limiting (Bronson et al., 2001).

3.3.2 Poultry manure treatments yields, plant N uptake and FNE and PAN coefficients

Type of poultry manure affected yields for the first and second year crops of corn and the second year crop of cotton after the manure application. Nitrogen uptake for corn as the first year crop after manure was applied in 2009 was also affected by manure source (Table 3.4). Cotton plant N uptake was not influenced by the source of manure suggesting that all the manures supplied equal amounts of N, or that N was not limiting in this system. Nitrogen uptake by the cotton crop is not necessarily reflected in yield, as either excess or limited supply could lead to low yields (Tewolde et al., 2009). Application rate on the other hand, influenced the yield for first year cotton in 2008 and 2010, for corn yield in the 2009 crop and first year corn N uptake in 2009. Therefore, application rate determined amount of N accumulated and yield of the first year corn crop, but only influenced yield of cotton. Previous investigations have shown that as N application rate increases, cotton yield could increase until an optimum rate before declining (Jn-Baptiste et al., 2012).

The combination of location and tillage (i.e., experiment) was treated as a random effect and influenced first, second and third year corn crop yields and plant N uptake for all crop years except second year cotton in 2010 (Table 3.4). This experiment factor could correspond to the differences in rainfall (Figure 3.6), management practices or site characteristics such as slope. The interaction between experiment and application rate affected yield and plant N uptake for the third year corn crop. A third order interaction of experiment, N source and application rate influenced only the second year cotton crop yield in 2010.

3.3.2.1 Effect of poultry manure as an N source

Yield, plant N uptake, FNE and PAN values from the first and second year corn crop in 2009 and second year cotton crop in 2010 varied with type of poultry manure when averaged across application rates (Figure 3.7 and 3.8). Second year corn accumulated a mean of 63 kg N ha^{-1} in 2009 and cotton 66 kg N ha^{-1} in 2010 when averaged across LM, CLM or BL manures. Layer manure gave significantly higher first year corn yields and plant N uptake than CLM, and higher second year corn yields than BL (Figure 3.7). Fertilizer N equivalency coefficients for LM were also numerically higher than for the other manure sources (Table 3.5). Yields of corn in 2009 in the first year of manure application were highest with LM, intermediate with BL, and lowest with CLM resulting in FNE values of 0.76, 0.60, and 0.57, respectively. Mean FNE coefficient based on first (0.64) and second (0.22) year corn crops can be calculated from our results. The first year corn crop coefficient is higher than the value of 0.46 based on N availability from three poultry manures (broiler litter, turkey and layer manure) investigated in Iowa (Diaz et al., 2011) and the assumed first year crop availability value range of 50% when surface applied and 60% when incorporated (Zublena et al., 1997). Nitrogen available for corn from BL in central Alabama ranged from 0.25 – 0.65 (Mitchell and Tu, 2005), 0.60 for first year crop in Texas (Evers, 1998), 0.48 for a greenhouse corn experiment (Hamilton and Sims, 1995) and 0.10 – 0.49 for several cereals (Nicholson et al., 1999). First year cotton yield and plant N uptake did not vary with poultry manures or UAN rates, therefore FNE or PAN coefficients were not calculated. Second year cotton yields were significantly different among manure sources and the FNE coefficient was numerically higher for LM than for CLM (Figure 3.8 and Table 3.5). We observed lower residual manure FNE values for the second year. Residual N contribution to crop yield drops over time in the Coastal Plains soils (Mitchell and Tu, 2005). Plant N uptake for first year corn was also highest with LM, intermediate with BL, and lowest with CLM with corresponding PAN values of 0.81, 0.77, and 0.68, respectively. Montalva Grijalva et al., (2010) reported higher available N (83%) from LM applied to Lynchburg a Coastal Plain soil than from CLM (73%). In addition, second year crop yields in 2009 were highest with LM, intermediate with CLM, and lowest with BL equivalent to FNE values of 0.26, 0.22, and 0.20, respectively. Mean PAN coefficient for the first year crop from poultry manure application was 0.75 (Table 3.5) which was higher than FNE, possible because the former index combines both yield and tissue N content while that latter only considers yield. Although residual N PAN coefficient for the second year corn crop 2009 could not be determined, we expect a reduction in the value for second year crop as was shown by FNE values for the second year corn crop.

3.3.2.2 Effect of manure nitrogen application rate

Manure N application rate was directly related to yield of cotton in 2008 and 2010 (Figure 3.9). Increasing poultry manure application rate avails more N for cotton (Malik and Reddy, 2002; Reddy et al., 2008; Reddy et al., 2012) although no response was observed with inorganic fertilizer. Poultry manure could have supplied other nutrients in addition to N that were limiting in the UAN treatments. For the first year corn crop in 2009, both yield and plant N uptake increased with poultry manure application rate (Figure 3.10). Relative to the mean check plot yield of 5.0 ton ha^{-1} yield corresponding to 48 kg N ha^{-1} plant N uptake increased by 52% yield at the higher manure rate compared to a 38% increase at the lower rate. When compared to check plot yields from 18 sites across Iowa, the application of poultry manure increased corn yields by 25% when applied at the rate of 84 kg N ha^{-1} and 37% when applied at the rate of 168 kg N ha^{-1} (Diaz et al., 2011). Therefore, as poultry manure rate is increased more N is available to corn which contributes to higher yields (Jn-Baptiste et al., 2012). Fertilizer N equivalency and PAN coefficients for the first year corn crop in 2009 decreased with manure N application rate, but the PAN value for the first year cotton crop in 2010 increased with manure rate (Table 3.6). The FNE coefficients for corn are higher than those reported from Iowa, 0.38 at higher rate of 168 kg N ha^{-1} and 0.44 at 84 kg N ha^{-1} lower rate poultry manure application (Diaz et al., 2011; Diaz and Sawyer, 2008) but more similar to laboratory incubation values (61 – 83%) determined on Lynchburg soil from NC Coastal Plains (Montalva Grijalva et al., 2010). In the Southeastern US, N availability reduced from 0.62 to 0.60 when BL application rate was doubled from 353 to 706 kg N ha^{-1} on bermudagrass (Evers, 1998) and ranged from 0.98 to 0.53 for fescue pastures (*Festuca arundinacea* Schreb.) on Coastal Plain soil in Alabama (Marshall et al., 2001). Despite the lower FNE and PAN first year corn crop coefficients for the higher rate application, more N was available to the crop than at the lower rate, although the N utilization efficiency decreased. The proportion of N remaining in the environment following a higher rate of poultry manure application is also greater and presents a greater risk of loss to off-site water bodies.

3.3.2.3 Effect of experiment

Significant differences in first year cotton N uptake among location-tillage combinations in 2008 where ranked as TRS-NT > TRS-CT > UCPRS-ST = UCPRS-CT, while in 2010 ranked differences were TRS-CT > UCPRS-ST = UCPRS-CT (Figure 3.11). The amount of N accumulated by cotton was not always correlated with crop yield response. Studies have indicated that the amount of N assimilated by cotton can either have positive or negative relationship to yield (Jn-Baptiste et al., 2012). Cotton yields could be low even with more tissue N derived from an organic source (Schomberg et al., 2006) as the case observed between TRS-NT and TRS-CT (Figure 3.11). In cotton production, high amounts of available N could eventually reduce yield as fewer bolls are formed (Girma et al., 2007) or boll rot increases (Dong et al., 2012; Moore, 1998). Only PAN coefficients from could be calculated for cotton production (Table 3.7). Plant available N coefficients were less than 0.5 (50%) first year availability signifying a reduction in cotton yield. Cotton yields decline when N supply is above the optimum rate (Tewolde et al., 2009; Boquet et al., 2009; Jn-Baptiste et al., 2012) due to large vegetative growth that leads to boll rot and increased insect incidences.

Corn yield for first, second and third year crop reflected plant N uptake in these seasons from different experiments. In 2009, first year crop yield and plant N uptake, averaged across manure sources and rates, followed the order of TRS-CT > TRS- NT > UCPRS-ST = UCPRS-CT (Figure 3.12). For second year corn crop in 2009 and second and third year crop for 2011, TRS gave similar yield and plant N uptake for both tillage practices, both of which were higher than UCPRS-ST > UCPRS-CT. Conventional tillage yields were highest in the mineral organic soil at the TRS site and lowest in the mineral soil at UCPRS. Poultry manure FNE coefficients calculated for first year corn production in different environments reflect the observed yield with an average of 0.55 at UCPRS and 0.75 at TRS. Second year crop FNE coefficients for corn in 2009 and cotton in 2010were almost a third of the first year crop values for corn in 2009(Table 3.7). First year corn crop FNE values were also higher for conventional tillage (0.67) than for conservation tillage (0.63) when averaged across sites. In conventional tillage, manures are incorporated and contribute to elevated mineralization in the year of application (Reddy et al., 2009). Recommended poultry manure N availability coefficients used by the NCDA&CS are 0.6 for incorporation as in conventional tillage, and 0.5 for surface applied such as in no-till or strip till (Zublena et al., 1997). For the third year crop in 2011, FNE coefficients were highly variable but suggest no consistence decline from the second year crop values. Therefore, poultry manure application rates for first year corn crop production can be determined using either FNE or PAN coefficients which correspond to observed yield and N uptake; unlike in cotton where high coefficients could be related to either low or high yields. Nitrogen availability coefficients determined in the field during crop growth could be influenced by temporal and spatial variations in soils, tillage practice and crop nutrition regime (Tewolde et al., 2009).

3.3.2.4 Effect of experiment and application rate interaction

Third year corn crop yield and N uptake in 2011 was influenced by the interaction between experiment and application rate (Figure 3.13). Both yield and plant N uptake were significantly higher at TRS site than UCPRS. There was no rate effect within each experiment. Yield and plant N uptake varied across sites and tillage practices where TRS-NT = TRS-CT > UCPRS-ST > UCPRS-CT. Generally the yield and plant N uptake for 2011 third year corn crop were lower than the 2009 first year crop confirming the reduction in residual N availability for crop production. The FNE coefficients calculated for observed yield could not be determined for UCPRS-CT (Table 3.8). Residual effects of poultry manure N applied at 67 and 134 kg N ha^{-1} in 2009 led to similar differences in yields for the third year crop in 2011 from UCPRS-ST, UCPRS-CT, TRS-NT and TRS-CT experiments respectively. Residual N amounts from poultry manure were more variable with the lower rate coefficients higher than the higher rate values. Amount and availability of residual N in the southeastern USA Coastal Plain soils can drop to insignificant levels within a few seasons and varies among soils (Mitchell and Tu, 2005).

3.3.2.5 Effect of experiment, nitrogen source and application rate interaction

A third order interaction of experiment, nitrogen source and application rate only influenced residual N effect on the second year cotton crop yield, which was the basis for calculation of the FNE coefficient in 2010 (Figure 3.14). Second year cotton crop yield for UCPRS-ST was significantly higher than UCPRS-CT although only with 67 kg N ha^{-1} from LM. In UCPRS-ST, second year cotton yields in 2010 with the manure N rate of 67 kg N ha^{-1} applied in 2009 were similar for all three poultry manures (Figure 3.14), resulting in mean FNE value of 0.17. All other treatments performed similarly regardless of residual N application rate with UCPRS conventional tillage posting consistently low mean yields in all situations. In several cases, residual N treatment yields observed were lower than the check plot mean of 1.8 ton ha^{-1} suggesting that there was little N available for plant uptake, thus echoing the elevated transformation of organic N especially in the southeastern US Coastal Plain soils (Mitchell and Tu, 2005) or increased loss (Marshall et al., 2001). When FNE coefficients were calculated, it was evident that it is complex to relate cotton yield to N availability. Most of the FNE coefficients for the second year cotton crop could not be determined due to the absence of a significant response inorganic N fertilizer. The amount of N supplied to the second year cotton crop from 67 kg N ha^{-1} was 11 kg N ha^{-1} (FNE = 0.17) lower than the 56 – 78 kg N ha^{-1} requirement for NC (Crozier et al., 2010). Applying organic resources which result in low availability coefficients in the Coastal Plain region could raise environmental pollution concerns because farm managers would shift towards high application rates which lower the N efficiency even more.

3.4 Conclusion

When poultry manure is used to supply N in a cotton-corn crop rotation, the effects on yield, plant N uptake, FNE and PAN values are crop, N source, rate and experiment specific. Poultry manure source affected yield, plant N uptake, FNE and PAN coefficients for the first year corn crop after application more than the first year cotton crop, when averaged across all experiments and application rates. Layer manure gave higher mean yield and plant N uptake than CLM for the first corn crop and the second year cotton crop. From the first and second year corn crop FNE coefficients, it is noted that more first year availability and residual N is available from LM than from BL and CLM. The higher N available to the corn crop in the conventional tillage system can be attributed to soil incorporation which might promote mineralization in the year of application. Increasing the application rate increased both cotton and corn yields and plant N uptake, but reduced FNE and PAN coefficient for corn while resulting in high PAN values for cotton. Generally, the first year crop had higher yield and plant N uptake than the second or third year crops of cotton and corn that relied on residual N. Therefore, poultry manure residual N contribution to second year crop yield and plant N uptake is lower than the first year crop availability. Fresh applications to increase the amount of N for crop production are required especially during corn years. In the calculation of FNE and PAN coefficients, it was noted that corn had a stronger response to application rates than cotton, which complicates N management in this rotation as a result of different fertilization regimes (Boquet et al., 2009). The use of poultry manure for crop production in NC, based on the assumption that 50% of total N is available when surface applied and 60% when incorporated should be refined to reflect the differences in crop and soil conditions. For instance, from this study corn FNE coefficient for conventional till was 0.67 while conservation till was 0.63, evident that poultry manure supplies more N for crop production when applied subsurface than on the surface.

3.5 References

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Table 3.1. Dry matter, C:N ratio, $CaCO_3$ equivalence (CCE) and nutrient concentrations of poultry manures used in the cotton-corn rotation studies.

Year	Source[a]	C:N ratio	Dry matter	CCE	N	P	K	Ca	Mg	Zn	Cu
			-----	-----	-----	-----	(%)	-----	-----	-----	-----
2008	LM	9	87	10.8	3.5	1.2	2.6	9.0	0.7	0.07	0.01
	CLM	5	72	10.5	7.1	1.2	2.9	6.8	0.6	0.05	0.01
	BL	14	77	0.3	2.5	0.7	1.9	2.0	0.4	0.04	0.03
2009	LM	9	85	27.5	3.2	1.5	2.8	11.2	0.8	0.07	0.01
	CLM	5	71	17.5	6.3	1.6	3.1	9.1	0.7	0.06	0.01
	BL	11	74	1.3	4.0	1.0	2.9	3.3	0.7	0.05	0.05
2010	LM	-	77	-	3.4	2.3	2.9	8.9	0.8	0.07	0.01
	CLM	6	84	8.8	5.6	1.7	3.0	7.8	0.6	0.05	0.01
	BL	-	70	-	2.9	1.8	2.7	3.6	0.8	0.05	0.02

[a] LM - layer manure, CLM - composted layer manure and BL - broiler litter

Table 3.2. Chemical characteristics of preseason soil samples in 2008 for each experimental field.

Site[a]	Tillage[b]	pH	CEC	Ca	Mg	K	Ac[c]	BS[d]	P	Zn	Cu
			----------- $cmol_c\ kg^{-1}$ -----------					%	------- ppm -------		
UCPRS	ST	6.0	7.1	4.4	0.9	0.02	1.3	82	122	1.9	1.0
UCPRS	CT	5.5	5.1	2.8	0.8	0.01	1.2	77	81	1.3	0.7
TRS	NT	5.6	9.5	4.5	1.5	0.02	3.1	68	66	1.6	1.0
TRS	CT	5.3	9.4	4.6	1.4	0.02	2.9	69	73	1.6	1.2

[a] LCPRS- Lower Coastal Plain Tobacco Research Station; TRS- Tidewater Research Station
[b] Tillage practices were ST-strip-till CT-conventional tillage and NT- no-till
[c] Ac – Mehlich buffer acidity
[d] BS-Base saturation = (Ca + Mg + K + Na/CEC) x 100%

Table 3.3. Analysis of variance for inorganic fertilizer (30% UAN) treatments.

Source	Degrees of freedom	Yield	Degrees of freedom	Plant N
Location[a]	1	***	1	***
Tillage[b]	1	***	1	**
Year	3	***	3	***
Rate	3	***	3	***
Location x Tillage	1	***	1	***
Location x Year	3	***	3	***
Location x Rate	3	***	3	**
Tillage x Year	3	***	3	ns
Tillage x Rate	3	***	3	*
Year x Rate	9	***	5	*
Location x Tillage x Year	3	***	3	ns
Location x Tillage x Rate	3	ns	3	ns
Location x Year x Rate	9	**	5	ns
Tillage x Year x Rate	9	**	5	ns
Location x Tillage x Year x Rate	9	ns	5	ns

[a] UCPRS- Upper Coastal Plain Research Station; TRS- Tidewater Research Station
[b] Tillage practices were ST-strip-till CT-conventional tillage and NT- no-till

Table 3.4. ANOVA for poultry manure factorial treatments, where experiment was treated as a random effect.

Effect[a]	DF	2008	---------2009--------		--------2010[b]--------		-------2011[cd]-------	
		-First year crop-		Second year crop	First year crop	-Second year cro--		Third year crop
		cotton	corn	corn	cotton	cotton	corn	corn
		-------------------------------------Yield------------------------------------						
N Source	2	ns[e]	*	*	ns	*	ns	ns
Application rate	1	*	*	ns	*	ns	ns	ns
N Source x Application rate	2	ns	ns	ns	ns	ns	ns	ns
Experiment	3	ns	***	***	ns	ns	**	**
Experiment x N Source	6	ns	ns	ns	ns	ns	ns	ns
Experiment x Application rate	3	ns	ns	ns	ns	ns	ns	*
Experiment x N Source x Application rate	6	ns	ns	ns	ns	*	ns	ns
		------------------------------Plant N uptake-----------------------------						
N Source	2	ns	*	ns	ns	ns	ns	ns
Application rate	1		***	ns	ns	ns	ns	ns
N Source x Application rate	2		ns	ns	ns	ns	ns	ns
Experiment	3	*	***	***	*	ns	**	**
Experiment x N Source	6	ns	ns	ns	ns	ns	ns	ns
Experiment x Application rate	3		ns	ns	ns	ns	ns	*
Experiment x N Source x Application rate	6		ns	ns	ns	ns	ns	ns

[a] Experiment combined location (UCPRS- Upper Coastal Plain Research Station, TRS- Tidewater Research Station) and tillage practices (conservation and conventional); [b] Two year residual N in plots that received current year manure application; [c] No poultry manures were applied in 2011. Therefore, 1and 3 vs 2 year residual N was evaluated; [d] One and three year residual N; [e] Symbols indicate probability: *** <0.001, ** <0.01, * <0.05 and ns>0.05.

Table 3.5. Poultry manure fertilizer nitrogen equivalence (FNE) and plant available nitrogen (PAN) coefficients for corn and cotton production in 2009 and 2010 seasons averaged across experiments.

N Source	First year corn crop 2009		--Second year crop --	
	FNE	PAN	Corn FNE 2009	Cotton FNE 2010
Layer manure	0.68	0.81	0.26	0.18
Composted layer manure	0.59	0.68	0.22	0.11
Broiler litter	0.64	0.77	0.20	0.18

Table 3. 6. Effect of application rate on fertilizer nitrogen equivalence (FNE) and plant available nitrogen (PAN) coefficients for corn and cotton production in 2009 and 2010 seasons averaged across experiments and N sources.

Application rate[a]	First year corn 2009		First year cotton 2010[b]	
	FNE	PAN	FNE	PAN
½X	0.72	0.82	0.14	0.14
1X	0.57	0.72	nd	0.25

[a] Poultry manure application rates for ½X and 1X in the 2009 season on corn were 67 and 134 kg N ha^{-1} , while 45 and 90 kg N ha^{-1} were applied to cotton in 2010 .
[b] Only one experiment was considered in the calculation for UCPRS-ST, Upper Coastal Plain Research Station -strip-till.
nd- not determined because coefficient greater than 1 or less than 0 or linear plateau model was not significant.

Table 3.7. Fertilizer nitrogen equivalence (FNE) and plant available nitrogen (PAN) coefficients for crop production in different experiments (site & tillage combinations) averaged across N sources.

Site[a]	Tillage[b]	----First year----		Second year	First year	Third year
		-----------Corn 2009-----------			Cotton 2010	Corn 2011
		FNE	PAN	FNE	PAN	FNE
UCPRS	ST	0.55	0.73	0.16	0.22	0.34
	CT					0.47
TRS	NT	0.71	0.88	0.29	nd	0.17
	CT	0.78	nd		0.19	

[a] UCPRS- Upper Coastal Plain Research Station; TRS- Tidewater Research Station
[b] Tillage practices were ST-strip-till CT-conventional tillage and NT- no-till.
nd- not determined because coefficient greater than 1 or less than 0 or linear plateau model was not significant.

Table 3.8. Fertilizer nitrogen equivalence (FNE) coefficient determined from yield for the third year corn crop after manure applications in different combinations of sites, tillage practices and application rates in the 2011 season and averaged across N sources.

Site[a]	Tillage[b]	Third year corn crop FNE 67 kg N ha^{-1}	Third year corn crop FNE 134 kg N ha^{-1}
UCPRS	ST	0.34	0.17
	CT	nd	0.05
TRS	NT, CT	0.17	0.11

[a] UCPRS- Upper Coastal Plain Research Station; TRS- Tidewater Research Station
[b] Tillage practices were ST-strip-till CT-conventional tillage and NT- no-till.
nd- not determined because coefficient greater than 1 or less than 0 or linear plateau model was not significant.

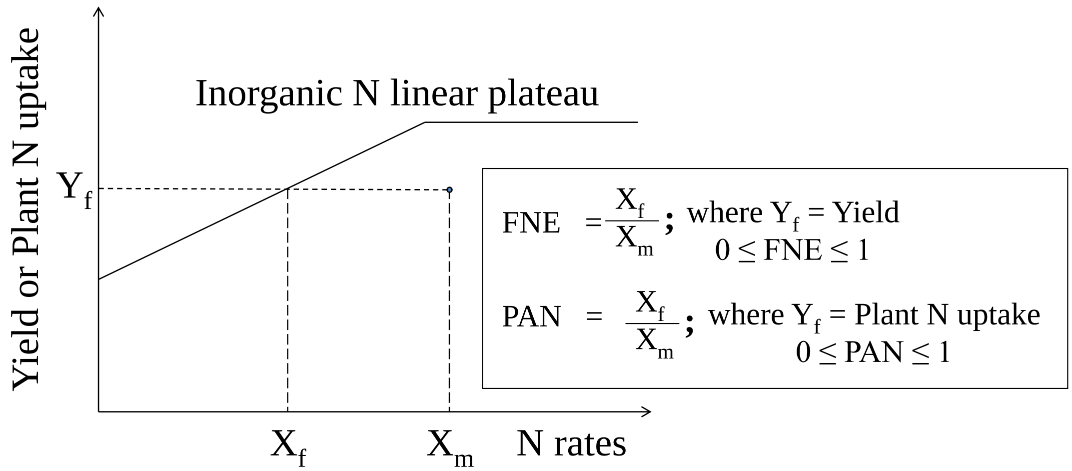

Figure 3.1. Illustration of calculation of Fertilizer N equivalence (FNE) and plant available N (PAN) coefficients by comparison of poultry manure data to modeled fertilizer N linear plateau functions.

Where X_f = fertilizer N rate required to achieve same yield as that of poultry manure applied either at 1X or ½X N rate (X_m). In cases where yield or plant N uptake from poultry manure were above the inorganic linear plateau or below check plot then FNE and PAN could not be determined.

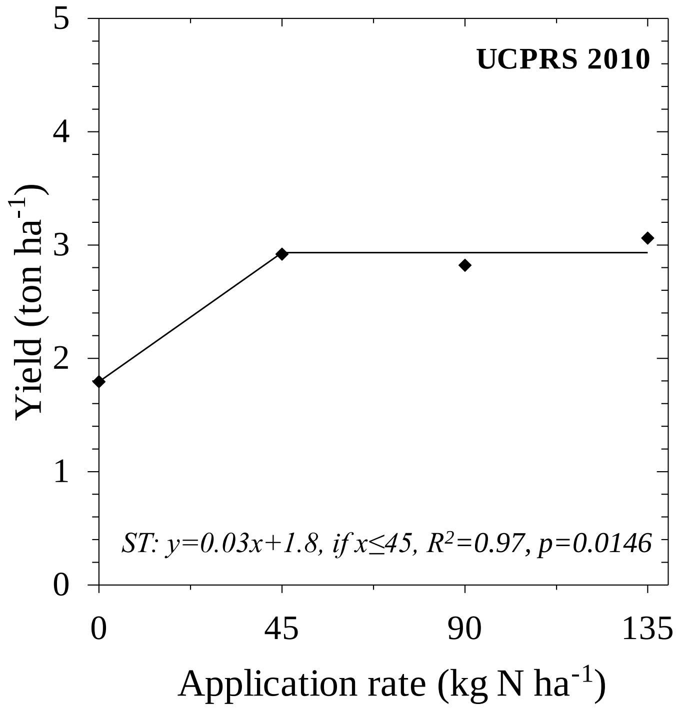

Figure 3.2. Cotton yield response to urea ammonium nitrate N fertilizer under ST- strip till at the Upper Coastal Plain Research Station (UCPRS) in 2010 growing season

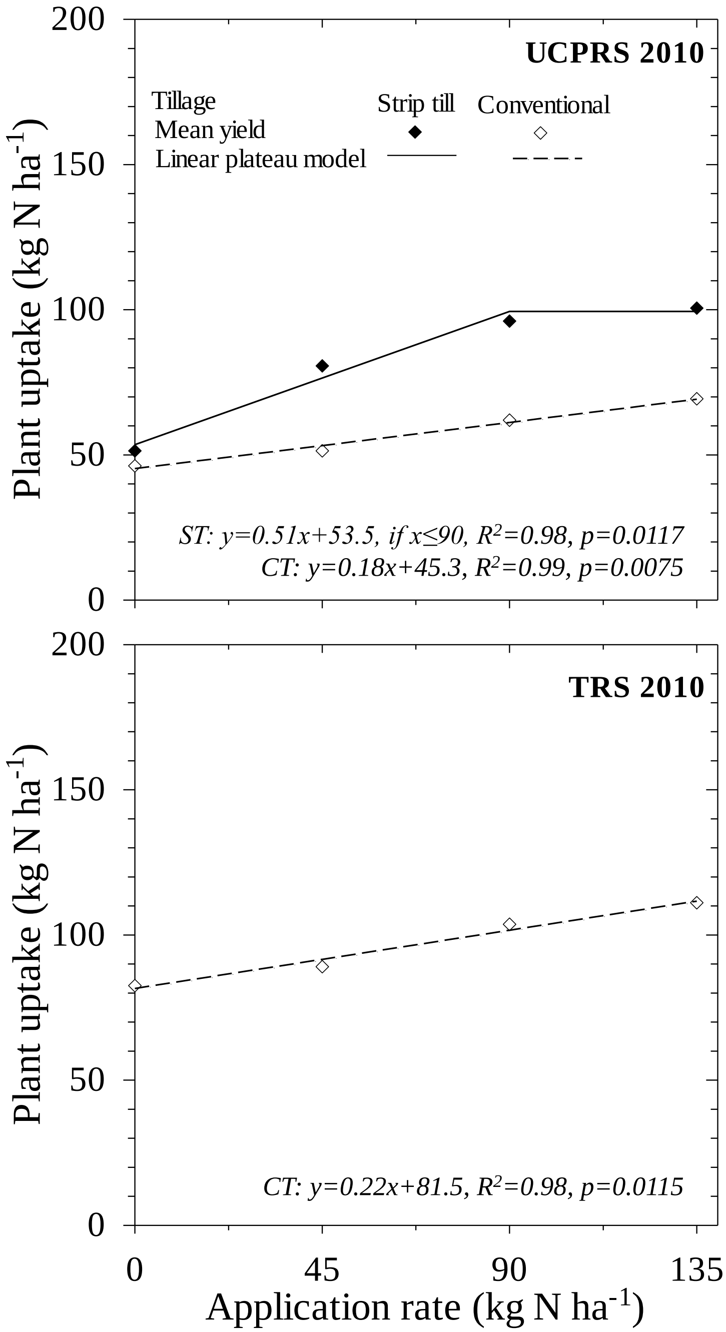

Figure 3.3. Cotton N uptake response to urea ammonium nitrate N fertilizer under ST- strip till, and CT- conventional tillage practices at the Upper Coastal Plain Research Station (UCPRS) and the Tidewater Research Station (TRS) locations in 2010.

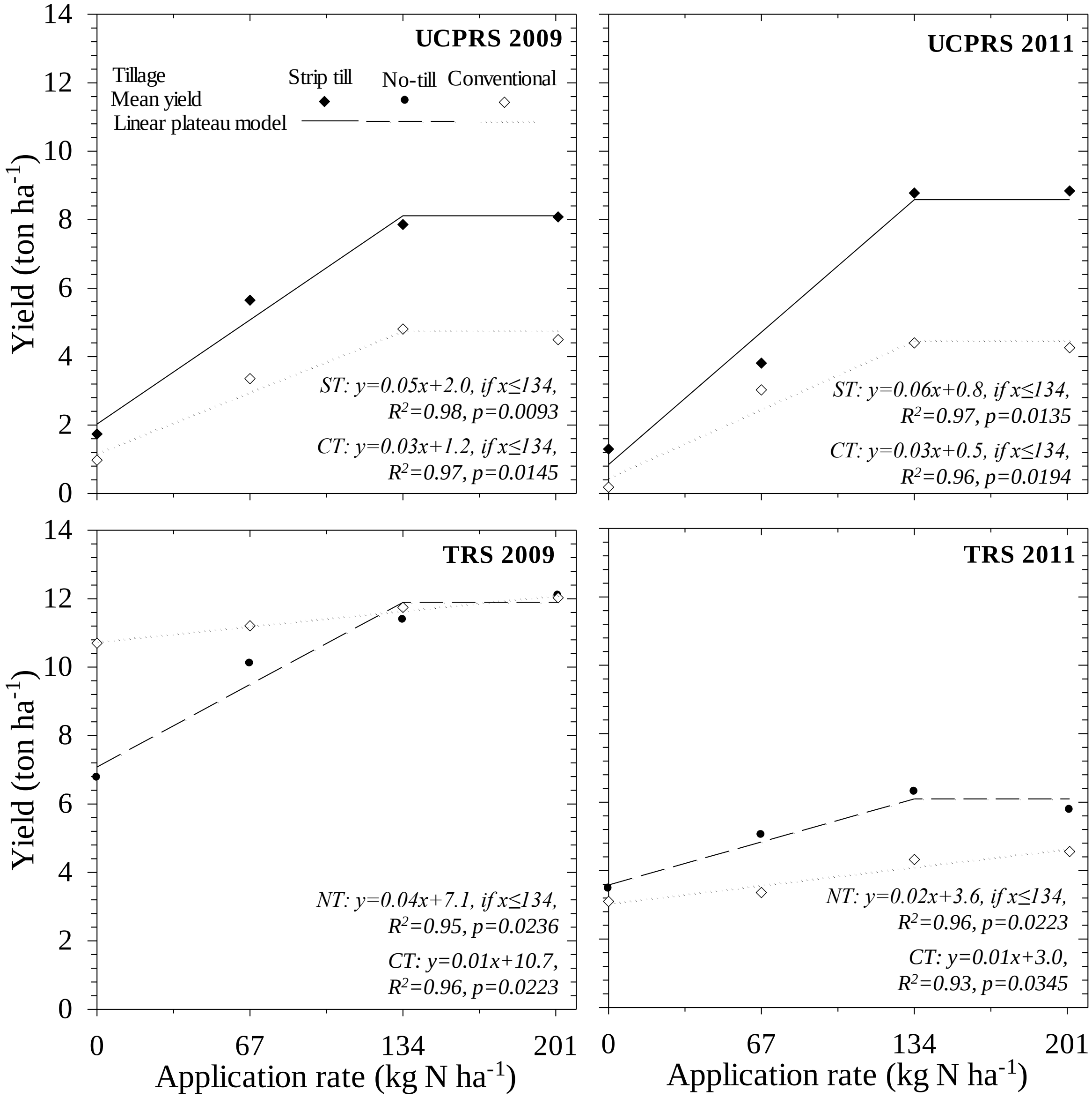

Figure 3.4. Corn yield response to urea ammonium nitrate N fertilizer under ST- strip till, NT- no-till and CT- conventional tillage practices at the Upper Coastal Plain Research Station (UCPRS) and the Tidewater Research Station (TRS) locations in 2009 and 2010 summer seasons.

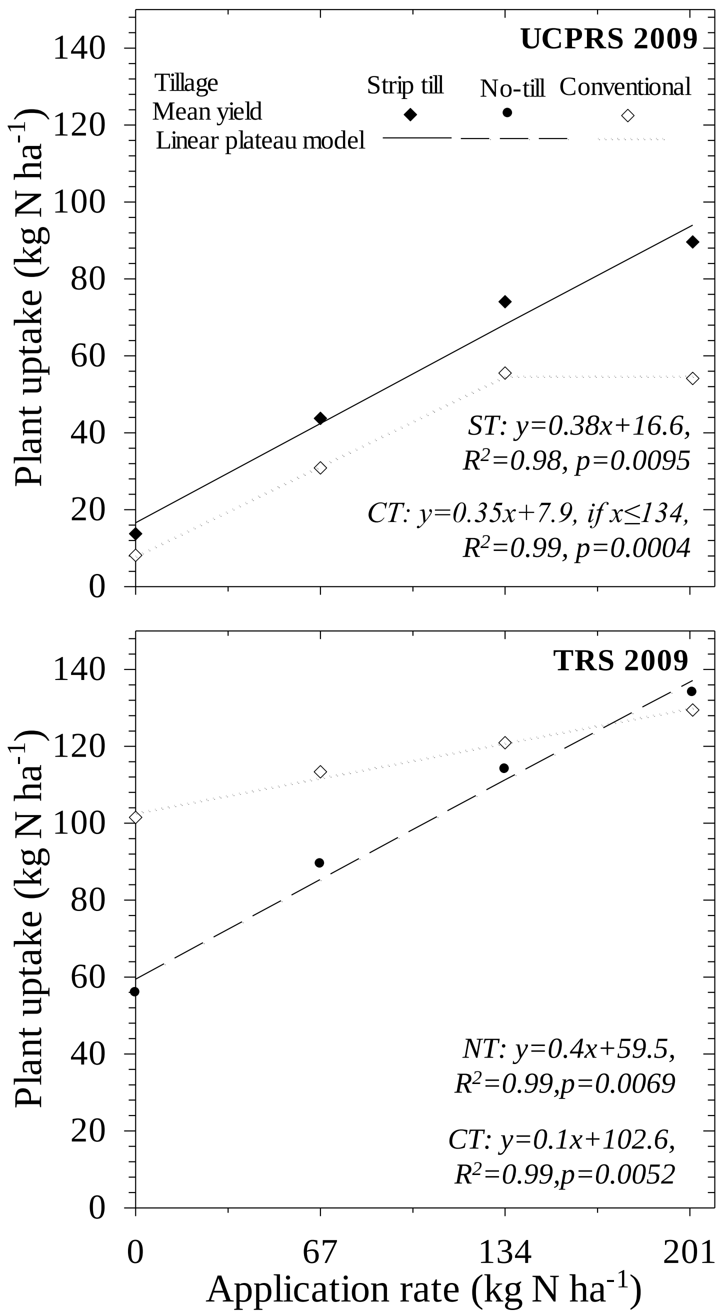

Figure 3.5. Corn N uptake response to urea ammonium nitrate N fertilizer under ST- strip till, NT- no-till and CT- conventional tillage practices at the Upper Coastal Plain Research (UCPRS) and the Tidewater Research Station (TRS) locations in 2009.

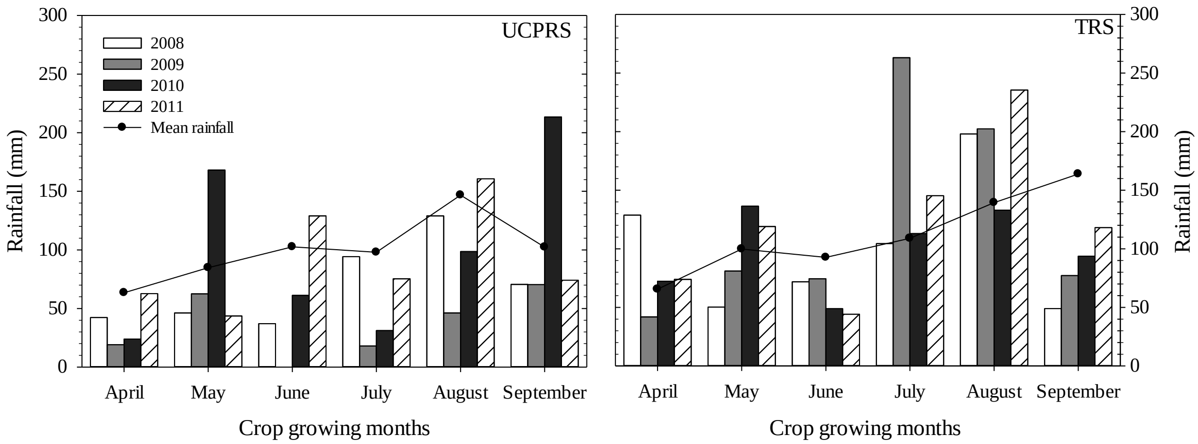

Figure 3.6 Rainfall amount during crop growing period recorded by North Carolina Environment and Climate Observing Network (NC ECONet) station located at Upper Coastal Plain Research Station and Tidewater Research Station

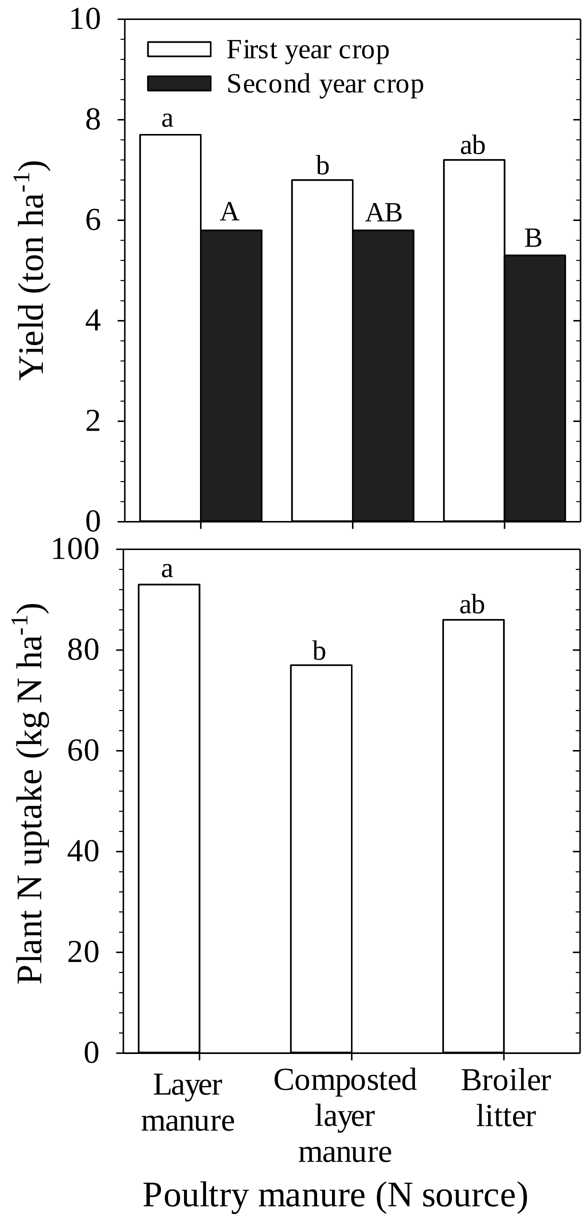

Figure 3.7. Effect of poultry manure on first and second year corn crop yield and N uptake in 2009. Means were averaged across experiments and separated using Tukey-Kramer value of 0.9 and 0.4 tons ha^{-1} for first and second year yield and 15 kg N ha^{-1} for first year N uptake.

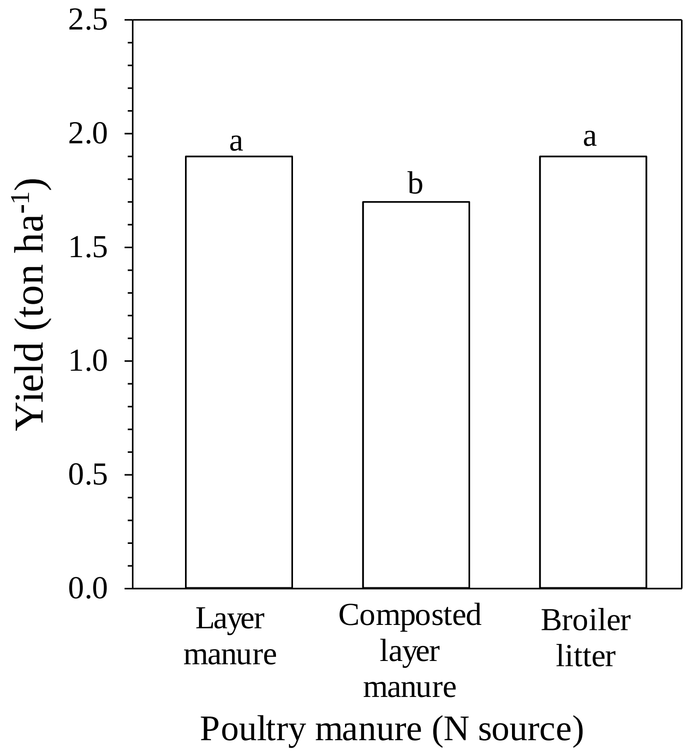

Figure 3.8. Effect of poultry manure on second year cotton crop yield in 2010 season. Means were averaged across experiments and yield separated using Tukey-Kramer value of 0.2 tons ha^{-1}.

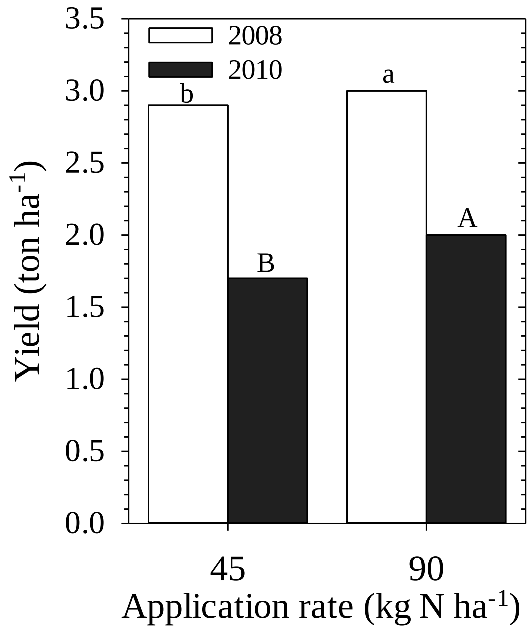

Figure 3.9. Effect of application rate on first year cotton crop in 2008 and 2010 averaged across experiments and poultry manure N sources. Means were separated by Tukey-Kramer values of 0.1 and 0.2 ton ha^{-1} for 2008 and 2010 respectively.

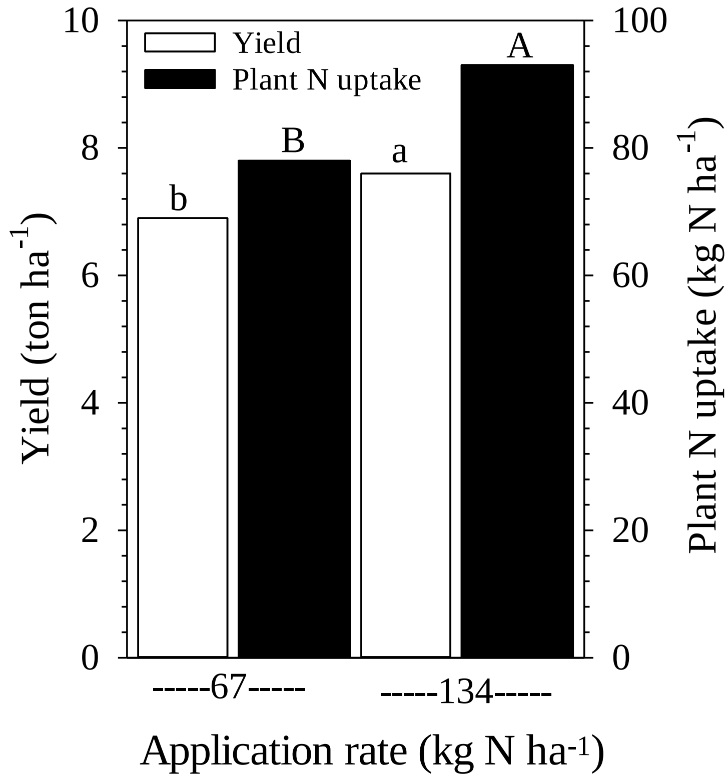

Figure 3.10. Poultry manure application rate effect on first crop corn yield and plant N uptake averaged across experiment and N source 2009 season. Significant differences between yield means were determined using Tukey's multiple comparison value of 0.3 ton ha^{-1} yield (lowercase letters) and 5 kg N ha^{-1} for plant N uptake (uppercase letters).

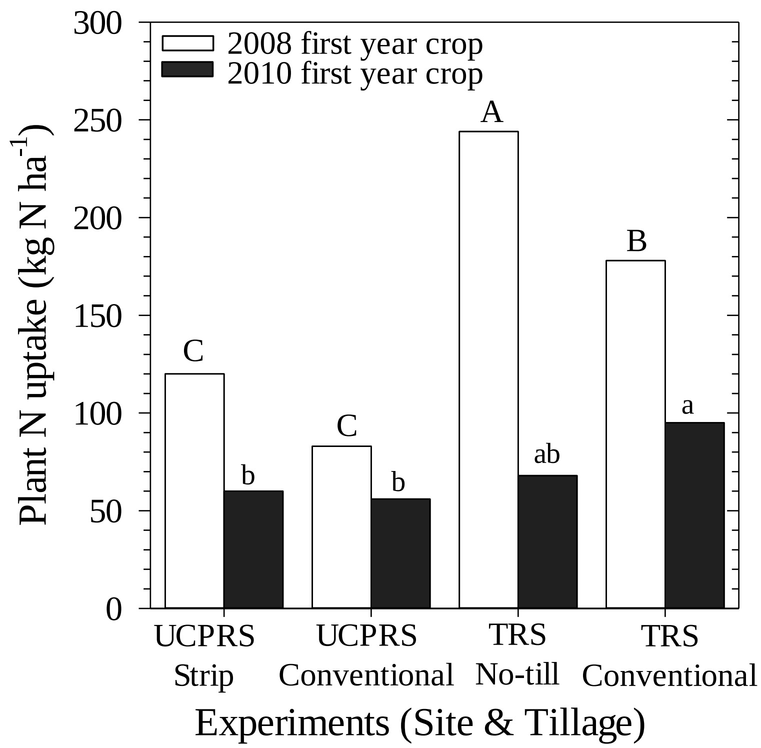

Figure 3.11. Effect of experiment on cotton N uptake in 2008 and 2010 averaged across application rates and poultry manure sources. Plant N uptake means were separated by Tukey-Kramer value of 27 and 33 kg N ha^{-1} for 2008 first year crop (uppercase letters) and 2010 second year crop (lowercase letters) respectively.

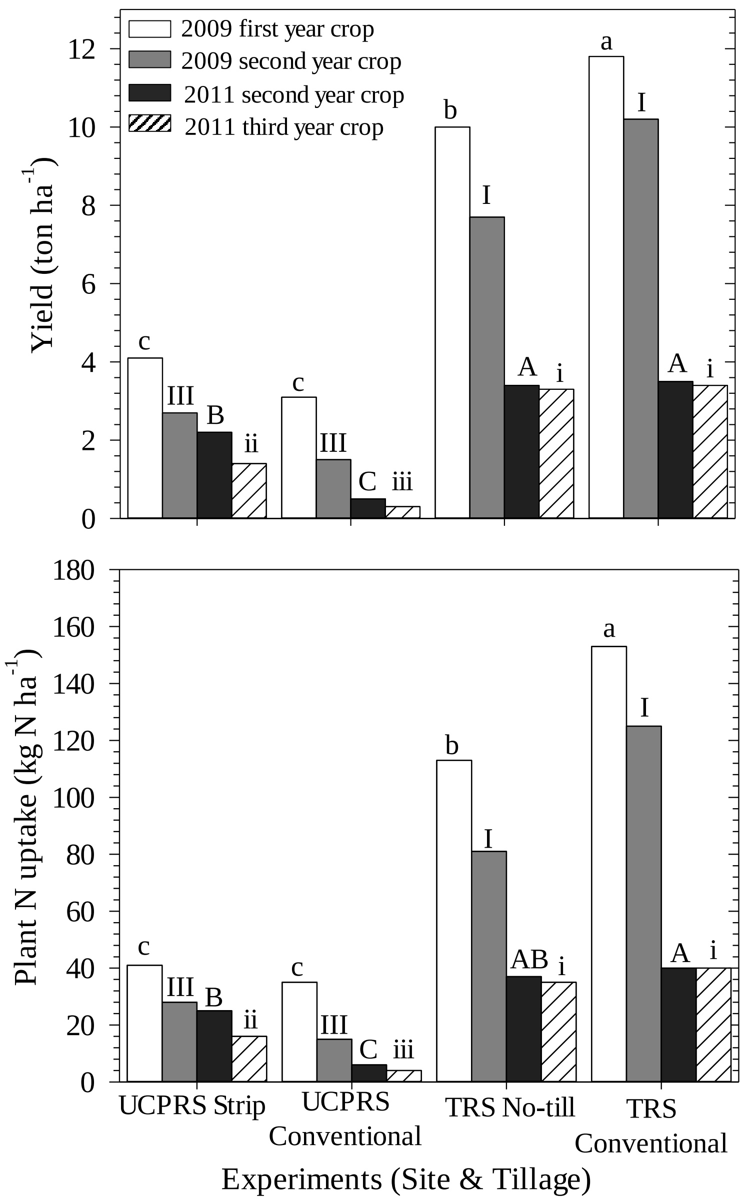

Figure 3.12. Effect of experiment on yield and N uptake of corn from poultry manure application at different times in UCPRS-Upper Coastal Plain Research Station and the TRS-Tidewater Research Station locations in 2009 and 2011 summer seasons averaged across N sources and application rates.

Means were separated using Tukey's multiple comparison method with values of 1.7 ton ha^{-1}, 37 kg N ha^{-1} in 2009 first crop (lowercase alphabetical letters), 2.8 ton ha^{-1}, 49 kg N ha^{-1} 2009 second crop (Uppercase roman numerals), 1.2 ton ha^{-1}, 12 kg N ha^{-1} 2011 second crop (uppercase alphabet) and .06 ton ha^{-1}, 7 kg N ha^{-1} 2011 third crop (lowercase roman) for yield and plant N uptake respectively.

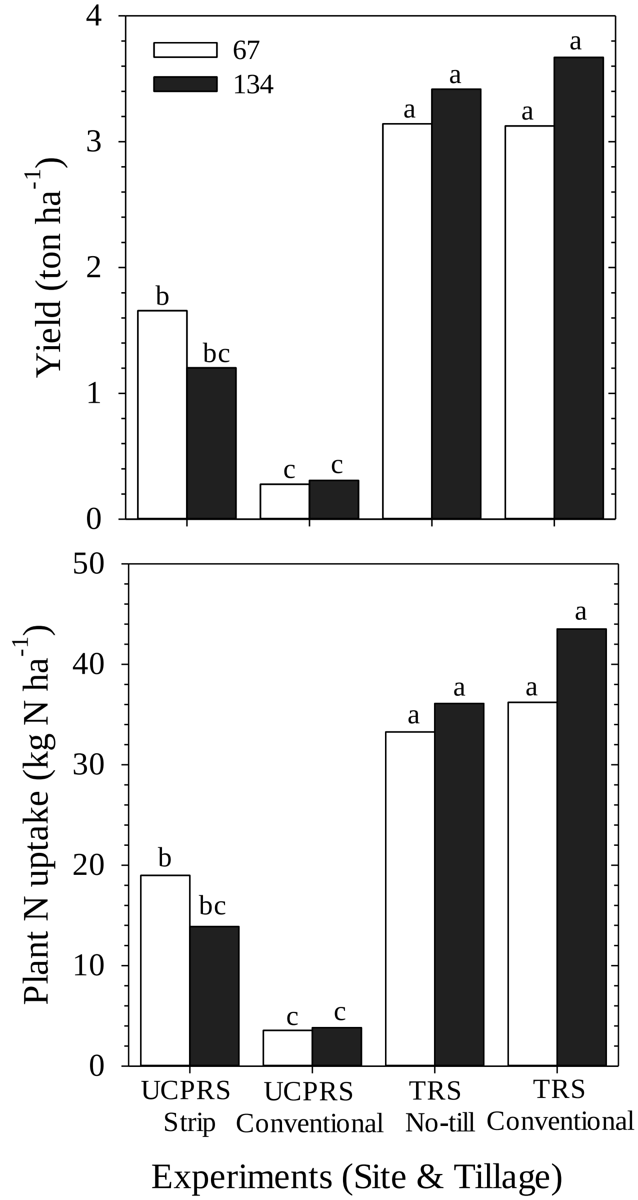

Figure 3.13 Effect of application rate of residual N on third year corn crop yield in 2011 averaged across application rate and poultry manures. Means were separated by Tukey-Kramer values of 1.0 ton ha^{-1}, 11 kg N ha^{-1} for yield and plant N respectively

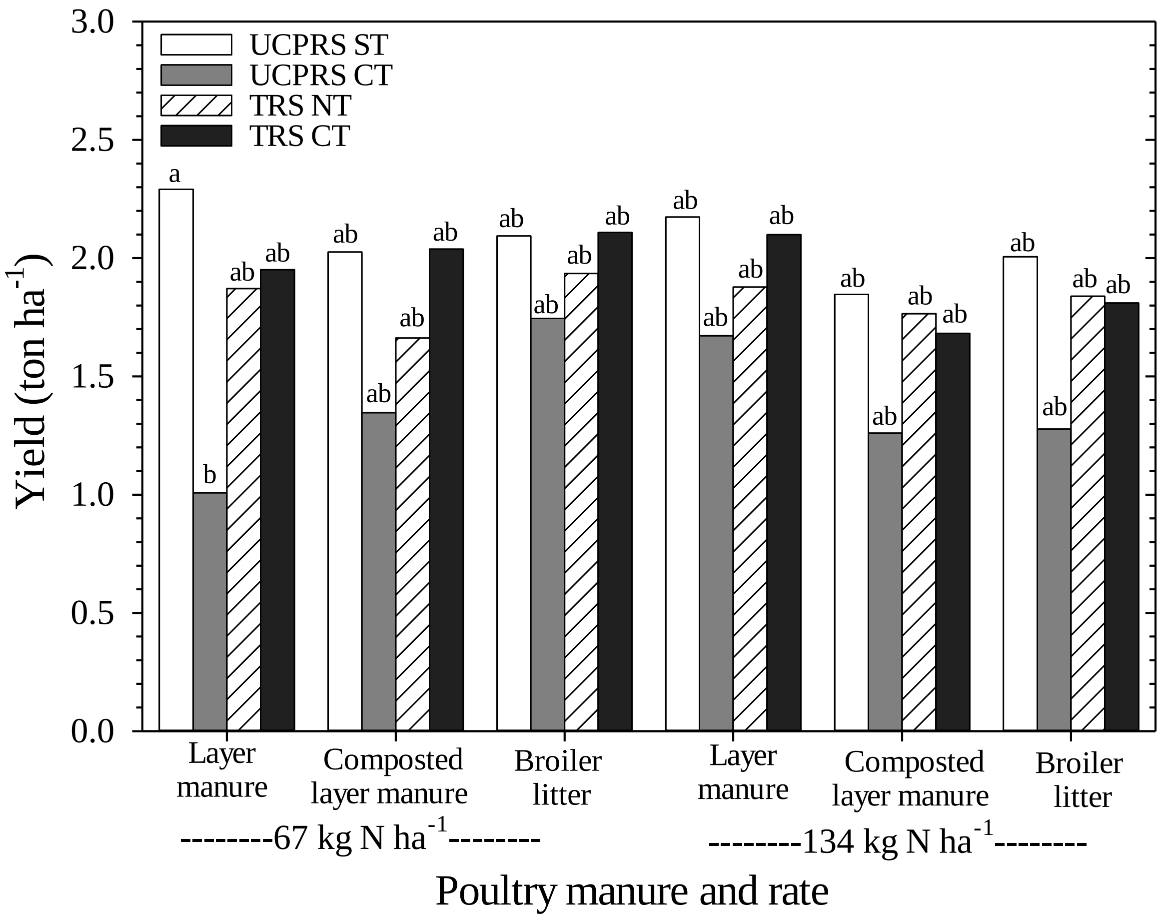

Figure 3.14. Experiment, source (residual N) and application rate interaction effect on cotton yield in 2010 season. Means were separated by Tukey-Kramer value of 1.3 ton ha^{-1}.

CHAPTER 4: RESIDUAL NITROGEN MINERALIZATION FROM SOILS OF TWO CROPPING SYSTEMS, WINTER WHEAT AND SUMMER COTTON-CORN ROTATION

Abstract

Manures supply N for several seasons of crop production. Soil organic N from manures continues to mineralize during off-season periods adding inorganic N to the residual N pool that could benefit subsequent crop production. Environmental factors such as temperature and soil moisture affect the amount and rate of residual N mineralized in the soil. Our study objectives were to (i) determine the amounts of residual N mineralized from poultry manure applied to winter wheat (*Triticum aestivum* L.)and summer cotton (*Gossypium hirsutum*) – corn (*Zea Mays* L.) cropping systems, (ii) evaluate the effects of temperature on poultry manure residual N mineralization and (iii) quantify the fate of N from poultry manure applied to winter wheat and two summer crops in developing N budgeting on a mass balance basis. Post-harvest soil samples (0 – 15 cm) from plots that received poultry manure for winter wheat or cotton-corn summer crops were incubated in the dark at 10, 20 and 30 ^{0}C in constant temperature incubators for 112 days. Inorganic N (NH_4^+ + NO_3^-) mineralized from these soil samples were determined over time. The largest amounts of residual N were mineralized from poultry manure at 30 ^{0}C. Residual soil mineralizable N accounted for 3 – 9 % of the applied N with no significant difference between poultry manure types. First year crop N removal was less than 50% (e.g. wheat 27 – 31%, cotton and corn 6 – 28%) of the applied N, but only a fraction of the remaining N can be detected in

residual soil N mineralizable forms. A large proportion of poultry manure N unaccounted for could be either lost from the system or remain in recalcitrant soil forms.

4.1 Introduction

Organic materials applied to field crops are presumed to persist for longer periods in the soil than does inorganic fertilizer, creating the need to quantify residual N availability over multiple crop years (Alva, 2006; Diaz et al., 2012). Residual N availability decreases over time (Pratt et al 1972; Cusick et al., 2006; Munoz et al., 2008), first year manure N availability assumed to be about 50% of the total N applied (Zublena et al., 1997; Diaz et al., 2011; Diaz and Sawyer, 2008). Variations in manure composition and field conditions have led to investigations of residual effects of manure N using different methodologies (Jensen et al., 1999). Residual N can be estimated from plant biomass and yield data, soil N measurements, or directly using ^{15}N labeled manure (Cusick et al., 2006). In some cases, high application rates of manures result in large amounts of residual N that will mineralize to NO_3-N between crop growing seasons (Gilmour et al., 1977).

Poultry manure mineralization can result in NO_3-N that is prone to leaching or denitrification losses (Jokela and Randall, 1989). Attempts to reduce loss of organic N mineralized between seasons include use of cover or trap crops which are recycled back into the soil to reduce fertilization costs (Randall et al., 2008). However, no precise method for quantification of residual N exists and determining soil N could be misleading as soil and weather conditions could elevate losses in the field. Vicissitudes in rate of N mineralization occur naturally due to fluctuations in seasonal soil moisture and temperature (Cookson et al., 2002; Sierra, 1997; Ellert and Bettany, 1992; Stanford and Smith, 1972). Exploring and verifying N mineralization from organic soil amendments could provide guidelines for increasing N use efficiency (Abbasi et al., 2007; Agehara and Warncke, 2005).

Nitrogen availability fluctuates in soils in response to the type of material applied, soil temperature, soil pH and soil moisture; which all affect microbial activity and N mineralization. Other factors that impact N mineralization and leaching are the application rate and mode of incorporation, soil type and the crop in the field. For instance, it has been reported that increasing application rate could elevate N mineralization rate of soil organic amendments up to 34% (Barbarika et al., 1985) or by 40 to 130% depending on the soil organic C availability (Terry et al., 1979). Soil is a complex growing medium where changes in the rate of N mineralized in response to temperature are not linear (Sierra, 2002) because substrate amount and quality varies, and microorganism functions vary over a wide range of temperatures (Nahm, 2003; Nahm, 2005).   However, it is beneficial to estimate residual nutrient amount in N budgeting to avoid unnecessary nutrient loading into the environment by reducing applications in subsequent seasons (Shepherd and Bhogal, 1998).

Studies have been conducted on poultry manure N dynamics in fields, laboratories and greenhouses where N fluxes and amounts can be estimated based on mass balance (Cabrera and Gordillo, 1995; Marshall et al., 2001; Applegate et al., 2003; Hristov et al., 2009; Luebbe et al., 2012; Rock and Mayer, 2006). Accurate estimation of N budgets or fluxes in the ecosystem is possible when the amount of N required to produce a healthy crop and plant available N for a particular manure are known (Haynes et al., 1993). In addition, the soil N balance should consider all other inputs, beneficial removal (crop uptake), undesirable losses and residual N which could be used to compare different crop management systems. Changes in N mineralization processes for both freshly applied manure and residual N are seldom captured in real time and therefore they are explained using models (Sierra, 2002). Objectives of this study were to (i) determine amounts of residual N mineralized from poultry manure applied to winter wheat and summer cotton-corn cropping systems, (ii) evaluate temperature effects on poultry manure residual N mineralization, and (iii) quantify the fate of N from poultry manure applied to winter wheat and summer crops.

4.2 Materials and Methods

4.2.1 Soil Sampling and handling

Four field replicates of higher rate poultry manure-amended and check treatments plots were sampled at the depth of 0–15 cm at the end of the 2009/2010 winter wheat and summer 2010 cotton-corn crop rotation growing seasons. From the wheat experiment, only plots that received 134 kg N ha^{-1} from manure at pre-plant or pre-jointing were sampled. Two sets of soil samples were collected from the summer crop experiments based on the crop cycle: (i) 2009-2010 corn-cotton soil where manure was applied to corn at 134 kg N ha^{-1} and soils sampled after 20 months, and (ii) 2010 cotton soil where manure was applied to cotton at 90 kg N ha^{-1} and soil samples taken after 8 months. The winter wheat field studies were conducted at the Lower Coastal Plain Tobacco Research Station (LCPRS) in Lenoir County on a Goldsboro loamy sand (Aquic Paleudults) and the Tidewater Research Station (TRS) in Washington County on a Portsmouth fine sandy loam (Typic Umbraquults). The summer season cotton-corn rotation was conducted at both the Upper Coastal Plain Research Station (UCPRS) in Edgecombe County on a Norfolk loamy sand (Typic Kandiudults) and the TRS on a Portsmouth fine sandy loam (Typic Umbraquults). Soil samples were air dried in a greenhouse for 4 – 6 days before grinding and screening to pass a 2-mm aperture sieve. Random representative subsamples were taken from each batch to determine container capacity (Howard et al., 2010). The soils were stored in polythene zip lock bags at room temperature between one to two months before laboratory incubations. From each field plot sample, four replicate subsamples were incubated, making a total of 16 bags for each field treatment tested.

4.2.2 Container capacity

Four sets of 7.6 cm diameter by 2.5 cm height cylinder rings were stacked and secured with a watertight transparent tape. The base ring had a mesh and cheese cloth. Air dry soil was then filled into the stacked rings and its volume determined and recorded. Known volumes of water was poured at the top open end of the rings and allowed to percolate by gravity. After 24 hours, the rings with wet soil were separated and weighed before being oven dried till constant mass was attained (Howard et al., 2010). Rings at the base with partly or completely dry soil were excluded. To determine soil moisture content required during mineralization, water content was gravimetrically calculated based on the geometry of the rings. This represented 100% container capacity which is water held in the soil but not saturated. To ensure enough moisture without water logging conditions, incubation soils were adjusted to 80% container capacity (Montalva Grijalva et al., 2010).

4.2.3 Residual N mineralization study

Using 200 g soil sample sets from three locations (Lo), a laboratory incubation study was established to determine residual N mineralized from four N sources (So): layer manure (LM), composted layer manure (CLM), broiler litter (BL) and reagent grade urea. Post-harvest soils from summer crop plots had two manure application times (Sam_Mo) of 8 and 20 months in the field before sampling. Manure had been applied to the preceding crop of each field study (no fresh manures were applied prior to incubation) while urea rates added prior to incubation to respective check plot soil samples were the equivalent of 134 kg N ha^{-1} for winter wheat season soils and 90, 134 and 180 kg N ha^{-1} for summer crop season soils. Check plot soils without inorganic N were also included. Both the winter and summer season soils were arranged in a completely randomized design. The soils were placed in 20 x 15 cm (8 x 6") 3 Mil slider zip plastic bags. Soils were added to the plastic bags and moisture adjusted to 80% container capacity using deionized water by considering air-dry soil moisture content. Urea was dissolved in water before being added to the soil. The soils were incubated in the dark at 10, 20 and 30 ^{0}C in constant temperature (Te) incubators. Samples bags were opened bi-weekly to aerate for 1 hour and weighed to adjust water content whenever moisture loss was greater than 5% on a weight basis (Honeycutt et al., 2005). Incubated soils were sampled on a weight basis equivalent to 10 cm^3 volume at sampling 0, 3, 7, 14, 28, 56, 84 and 112 days (Sday), and extracted with 1 mol L^{-1} KCl (Keeney and Nelson, 1982; Bremner, 1965) through washed and dried filter papers (modified procedure from Khan et. al., 1991). Ammonium (NH_4^+) and nitrate (NO_3^-) concentrations in extracts were determined by flow injection on a Lachat8000 Milwaukee, WI.

4.2.5 Data analysis

Data from urea amended treatments were used for quality control purposes and, therefore, analyzed separately to determine N recovery from the soils. Winter and summer season residual inorganic N mineralization data were analyzed separately. Analysis of variance (ANOVA) of residual N from poultry manure treatments (Table 4.1 and 4.2) was done using SAS PROC MIXED (Littell et. al., 2006). Since no single model adequately described temporal mineralization patterns, the mean value at each sampling date was used to characterize mineralization. These values were either pooled or represented by the overall mean across all sample days, or in some cases the maximum mineralization by a specific sample day was reported. Net N mineralized was calculated by subtracting check plot N value from manure and urea amended treatment value for each sample day. Summer season data were analyzed in two sets based on the field crop cycle (2009 – 2010 corn-cotton; 2010 cotton). In these ANOVAs, replications and locations were treated as random effects. All treatment mean comparisons were done based on least squares means (LSMeans) at $p < 0.05$ significance level using the Tukey's multiple mean comparison method (SAS, 2008; Littell et. al., 2006). Apparent N recovery from inorganic and manure amended treatments was calculated from plant N uptake amounts winter wheat (Chapter 2) and summer crops rotation (Chapter 3) (equation 1). Nutrient budgets included inorganic N mineralized from post growing season soils, and plant N uptake data for winter wheat (Chapter 2) and summer

$$\text{Apparent N Recovery} = \frac{\text{Treatment N accumulated} - \text{Check plot N accumulation}}{\text{Treatment N application rate}} \times 100 \quad \text{(Equation 1)}$$

crops rotation (Chapter 3).

4.3 Results and Discussion

4.3.1 Incubation study ANOVA summary

Residual net soil mineralizable N from wheat soils were significantly affected by, sampling day (Sday), location (Lo) x temperature (Te), and N source (So) x manure application time (Sam_Mo) x sampling day (Table 4.1). Different effects were significant between the two summer crop cycle soils (Table 4.2). When corn was fertilized in 2009 and soils sampled at the end of the 2010 season after cotton, temperature, N source x Sday, Te x Sday, Te x So x Sday, Lo x Te x So, and Lo x Te x Sday significantly affected residual N mineralized (Table 4.2). Residual N mineralized from plots that received manure in 2010 on cotton was significantly affected by location x Sday and Lo x Te x Sday interactions.

4.3.2 Urea recovery

Increasing the incubation temperature for wheat soils lead to more urea recovery: by the later sampling days: 30 ^{0}C > 20 ^{0}C > 10 ^{0}C (Figure 4.1). Urea recovery was 100% by day 56 at 30 ^{0}C, 74 – 95% by day 112 at 20 ^{0}C and 64 – 73% by day 112 at 10 ^{0}C. In addition, more N was recovered from Tidewater Research Station (TRS) at 30 ^{0}C and 10 ^{0}C than from Lower Coastal Plain Tobacco Research Station (LCPRS) soils. In some instances more than 100% urea N was recovered from the soil especially TRS at 30 ^{0}C. This could be attributed to a priming effect which is an increase in mineralization of indigenous soil organic N as a result of adding easily available ancillary N to soil or decomposing organic material (Handayanto et al., 1995; Rees and Castle, 2002). Urea N recovery from post summer cotton-corn rotation soils from different rates was similar between the three incubation temperatures (Figure 4.2). By the 14th sampling day, 60 to 80% of urea N could be recovered. In general, at least 90% of the added urea N was recovered from incubated soils after 112 days, an indication that little N was lost from the system. Similar results of 92% recovery have been reported from a sandy loam soil incubated at 25 ^{0}C (Van Kessel et al., 2000) and 84% from 90 day incubation at 25 ^{0}C from a mineral organic Coastal Plain soil (Montalvo Grijalva et al., 2010).

4.3.3 Residual N mineralization

4.3.3.1 Check plot

Nitrogen mineralized from the wheat location check plot soils were affected by temperature, with TRS samples at 30 ^{0}C leading to the highest cumulative amount and LCPRS at 10 ^{0}C the lowest (Figure 4.3). The summer season check plot soils also had a variation in native N mineralized with the highest in samples from TRS at 30 ^{0}C and lowest from UCPRS 10 ^{0}C (Figure 4.4). At the highest temperature, soil from the TRS winter and summer crop experiments mineralized 100+ kg N ha^{-1} , while soils from the Coastal Plain sites (UCPRS, LCPRS) had maxima <70 kg N ha^{-1}. Studies have shown that increasing incubation temperature increases the amount of N mineralized from soils especially those with high organic matter (De Neve et al., 2003).

4.3.2.2 Wheat soils

4.3.2.2.1 Effect of N source and manure application time

The interaction of N source x application time x sampling day affected net residual N mineralized from wheat soils (Figure 4.5), although the amounts were low compared to the background soil N (Figure 4.3). While mineralization on sampling day 84 was greater from soils that had received CLM applied pre-jointing rather than CLM applied pre-plant or BL applied pre-jointing, there were no significant differences among the manure and application time combinations by the end of the incubation on sampling day 112.

4.3.2.2.2 Effect of temperature and location

Net N mineralized from wheat soils, averaged across sampling time and N source, was significantly higher at TRS at 30 ^{0}C than all other temperature-location combinations, except UCPRS at 20 ^{0}C (Figure 4.6). Similar to the N source and manure application time interaction, the amount of residual N mineralized from poultry manures in these sites was low (<10 kg N ha^{-1}) when compared to the background N in the unfertilized plots at each location (Figure 4.3). Although it has been shown that soils high in organic matter retain more applied N, which is later released slowly for a longer period (Trehan and Wild, 1993), the amount of residual N mineralized from poultry manures is low relative to agronomic needs for crop production. The maximum amount of residual N mineralized was about 5% of the 134 kg N ha^{-1} manure rate used in the field study. In organic-based cropping systems, inorganic N pool sizes may be less than mineralizable N pool sizes and both are relatively small compared to the total N amount in the soil (Crozier et al., 1994).

4.3.3.3 Summer crop soils

4.3.3.3.1 Effect of location, temperature and incubation sampling day

The location x temperature x sampling day interaction affected residual N mineralization from poultry manure applied to corn-cotton and cotton crop cycles (Figure 4.7). For instance, N mineralization peaked for TRS soils incubated at 20 ^{0}C and 30 ^{0}C on sampling days 14 and 28 in both corn-cotton and cotton soils; while mineralization in the UCPRS soils increased steadily throughout the 112 days in the corn-cotton soils, and increased for up to 84 days for the cotton soil Residual N mineralization from corn-cotton soils at UCPRS indicates a consistent temperature trend with less mineralization at 10 ^{0}C throughout sampling days and with 30 > 20 ^{0}C up to 112 days in corn-cotton soils and up to 56 days in cotton soils. Overall, maximum mean residual N mineralized from these soils was low, <15 kg N ha^{-1}, or 3 – 9% of applied manure N. The amount of N mineralized from poultry manure applied to the corn-cotton 2009-2010 and cotton 2010 crop cycles was similar to low residual N values reported from Tennessee valley and northern Alabama soils (Mitchell and Tu, 2005).

4.3.3.3.2 Effect of location, N source, temperature and incubation sampling day

The interaction of location, N source, temperature and sampling day affected amount of residual N mineralized from the soils. Maximum N mineralized from the summer season soils following this interaction was on day 112 (Figure 4.8). Poultry manure residual N from UCPRS BL at 30 ^{0}C was highest while UCPRS CLM at 10 ^{0}C was the lowest. Temperature effect on N mineralization was varied among the locations and poultry manures, but were unlikely to represent agronomically significant differences in amounts of N mineralized.. It has been reported that N mineralization from organic materials can occur over a wide temperature range between 10 and 45 ^{0}C, although optimum level varies with soil and manure type (Nahm, 2005).

4.3.4 Apparent N recovery and budget

Apparent N recovery from inorganic fertilizer applied to wheat (Table 4.3) and summer crops (Table 4.4) was higher than poultry manure, probably due to N application rate differences. Almost all the inorganic N applied was recovered (85 to 100%) from these soils when calculated based on N rate at the winter wheat production plateau points of 78 kg N ha^{-1} in 2008/2009 season and 39 kg N ha^{-1} 2009/2010 season (Table 4.3 and Chapter 2). In contrast, only 28 to 55% of the manure N was recovered in wheat biomass (grain + stover). While this could be a result of lower recovery efficiency due to the organic versus inorganic source, it could also be a case of less efficient N use at higher N application rates. Apparent inorganic fertilizer N recoveries of 83% with a range of 3.2 – 136% (Crouse et al., 1993) and 76 – 84% (Montalvo Grijalva et al., 2010) from NC soils have been reported; higher than 24 – 56% from spring wheat production soils in eastern Québec-Canada (Gagnon et al., 1997).

A lower inorganic fertilizer N recovery percent (10 – 51%) was calculated for summer soils (Table 4.4 and Chapter 3), but optimum N application rates were higher. Interestingly, in cases where manure N application rates were lower than the optimum inorganic fertilizer N application rate, the apparent manure N recovery was greater than was the apparent inorganic fertilizer N recovery. This suggests that the apparent N recovery is perhaps more influenced by the N application rate than by the N source. Other studies have reported inorganic fertilizer N recovery in the range of 31 – 35% (Fernandez et al., 2010), and 50 – 70% from irrigated loamy sand and 20 – 50% from silt loam soils under corn (Oberle and Keeney, 1990; Gagnon et al., 1997).

Nitrogen is very dynamic in the soil leading to a wide range of recoveries from both inorganic and organic sources. Consequently, N budgets were calculated to include the highest amount mineralized from the soils during incubation since there was no source effect on residual N (Figure 4.9, 4.10 and 4.11). Winter wheat accumulated between 36 – 42% N from the 134 kg N ha^{-1} rate applied which ranged from 48 kg N ha^{-1} for BL in October (pre-plant, incorporated) to a high of 56 kg N ha^{-1} from CLM applied in February at pre-jointing stage. Mean N uptake by winter wheat was 39% (52 kg N ha^{-1}). This estimate falls within ranges determined for poultry manure applied to fields in the southeastern Coastal Plains region of Georgia, 31 – 67% (Cabrera and Gordillo, 1995); North Carolina, 44 – 55% (Chescheir et al., 1985); and Iowa, 43 – 53% (Diaz and Sawyer, 2008). The amount of N available to winter wheat was lower than fresh manure incubation results between 61 – 83% (Gale et al., 2006; Gordillo and Cabrera, 1997a; Gordillo and Cabrera, 1997b; Montalvo Grijalva et al., 2010) but higher than a mean of 11 % for wheat production with poultry manure in North Carolina Coastal Plain soils (Crouse et al., 1993). Residual soil mineralizable N recovered from poultry manure was 6% for wheat soils (Figure 4.9), 4 % for corn-cotton cycle summer soils (Figure 4.10) and 5% for cotton cycle in 2010 summer soils (Figure 4.11). The amount of N unaccounted for ranged from 52 – 58 % for winter wheat production which was similar to 57% recorded in fescue pastures (*Festuca arundinacea*

Schreb.) on Coastal plain soil in Alabama (Marshall et al., 2001). More N, 66 – 88% was unaccounted for in summer crop cycles. Further studies should be done to verify if the unaccounted for N is still in the soil in recalcitrant forms or lost from the system. Since first year crop FNE and PAN coefficients for corn were higher than wheat, and since N contributions to second and third season summer crops were noted (Chapter 3), it is unlikely that more N was lost from the summer crop systems.

4.4 Conclusion

Residual N mineralized from soils was between 40 and 100 kg N ha^{-1} from inherent soil N pools. Net N mineralized from poultry manures was relatively low (<15 kg N ha^{-1}), and difficult to measure against the inherent soil N background. The amount of poultry manure residual N mineralized from both winter wheat and summer crop cycles is very low compared to the agronomic rates recommended in these soils. In situations where high N rates are required, the effect of estimating a residual amount to correct for past manure application could be negligible in these Coastal Plain soils of North Carolina. Although in some cases mineralization differed among the poultry manure sources when incubated at different temperatures and for different amounts of time, the magnitude of any such differences are unlikely to be of agronomic significance. Additional study is needed to verify the fate of unaccounted for N either as recalcitrant forms or lost from the soil through leaching, volatilization, run-off and denitrification.

4.5 References

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Table 4.1 Net residual N mineralization analysis of variance from wheat soils.

Effect on residual N mineralization	------------Wheat soils-----------	
	Degree of Freedom	Inorganic N
Temperature (Te)	2	ns
Sampling day (Sday)	7	*
N source (So)	1	ns
Application time Sam_Mo	1	ns
Te x Sday	14	ns
Te x So	2	ns
Te x Sam_Mo	2	ns
So x Sday	7	ns
So x Sam_Mo	1	ns
Sam_Mo x Sday	7	ns
Te x So x Sday	14	ns
Te x Sam_Mo x Sday	14	ns
Te x So x Sam_Mo	2	ns
So x Sam_Mo x Sday	7	**
Te x So x Sam_Mo x Sday	14	ns
Location (Lo)	1	ns
Lo x Te	2	*
Lo x So	1	ns
Lo x Sam_Mo	1	ns
Lo x Sday	7	ns
Lo x Te x So	2	ns
Lo x Te x Sam_Mo	2	ns
Lo x Te x Sday	14	ns
Lo x So x Sday	7	ns
Lo x So x Sam_Mo	1	ns
Lo x Sam_Mo x Sday	7	ns
Lo x Te x So x Sday	14	ns
Lo x Te x So x Sam_Mo	2	ns
Lo x Te x Sam_Mo x Sday	14	ns
Lo x So x Sam_Mo x Sday	7	ns
Lo x Te x So x Sam_Mo x Sday	14	ns

[a] Location for winter wheat season soils were (Lower Coastal Plain Tobacco Research Station-LCPRS, Tidewater Research Station-TRS) and summer season soils were (Upper Coastal Plain Research Station -UCPRS, Tidewater Research Station-TRS)

[b] Symbols indicate probability: *** <0.001, ** <0.01, * <0.05 and ns>0.05.

Table 4.2 Analysis of variance of net residual poultry manure N mineralization from summer crop soils sampled at the end of 2010 growing season.

Source	Degrees of freedom	Corn fertilized Corn – cotton 2009-2010	Cotton fertilized Cotton 2010
Temperature (Te)	2	*	ns
Sampling day (Sday)	7	ns	ns
Poultry manure (So)	2	ns	ns
Te x Sday	14	**	ns
Te x So	4	ns	ns
So x Sday	14	**	ns
Te x So x Sday	28	***	ns
Location (Lo)	1	ns	ns
Lo x So	2	ns	ns
Lo x Te	2	ns	ns
Lo x Sday	7	ns	*
Lo x So x Sday	14	ns	ns
Lo x Te x So	4	**	ns
Lo x Te x Sday	14	***	***
Lo x Te x So x Sday	28	ns	ns

[a] Location summer season soils were (Upper Coastal Plain Research Station -UCPRS, Tidewater Research Station-TRS)

[b] Symbols indicate probability: *** <0.001, ** <0.01, * <0.05 and ns>0.05.

Table 4.3 Apparent N recovery from inorganic fertilizer at linear plateau leveling point (in parenthesis) and manure application on winter wheat.

		----------Inorganic N----------		----------Manure N----------	
Location	Season	Optimum rate	Apparent recovery	Rate	Apparent recovery
		kg N ha^{-1}	%	kg N ha^{-1}	%
UCPRS	2008/2009	78	95	134	55
	2009/2010	39	106	134	31
TRS	2008/2009	78	87	134	51
	2009/2010	39	97	134	28

Table 4.4 Apparent N recovery from inorganic fertilizer at linear plateau leveling point (optimum rate) and manure application on corn in 2009 and cotton 2010.

Location	Tillage	Corn 2009				Cotton 2010			
		Inorganic N		Manure N		Inorganic N		Manure N	
		Optimum rate	Apparent recovery	Rate	Apparent recovery	Optimum rate	Apparent recovery	Rate	Apparent recovery
		kg N ha^{-1}	%	kg N ha^{-1}	%	kg N ha^{-1}	%	kg N ha^{-1}	%
UCPRS	ST	201	38	134	57	90	51	90	51
	CT	134	35	134	35	135	18	90	27
TRS	NT	201	40	134	60	135	nd[1]	90	nd
	CT	201	10	134	15	135	22	90	33

[1]nd – Not determined.

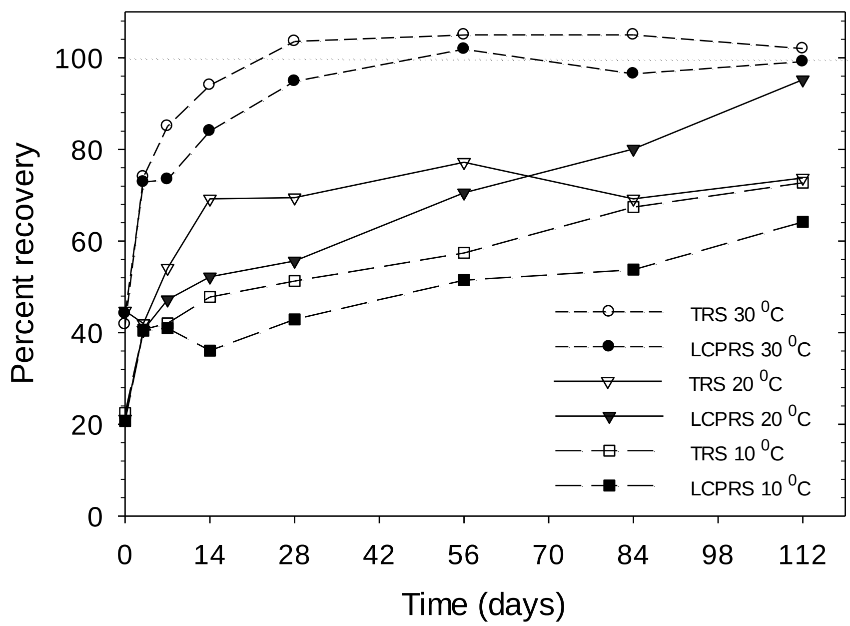

Figure 4.1 Urea recovery from winter wheat soils

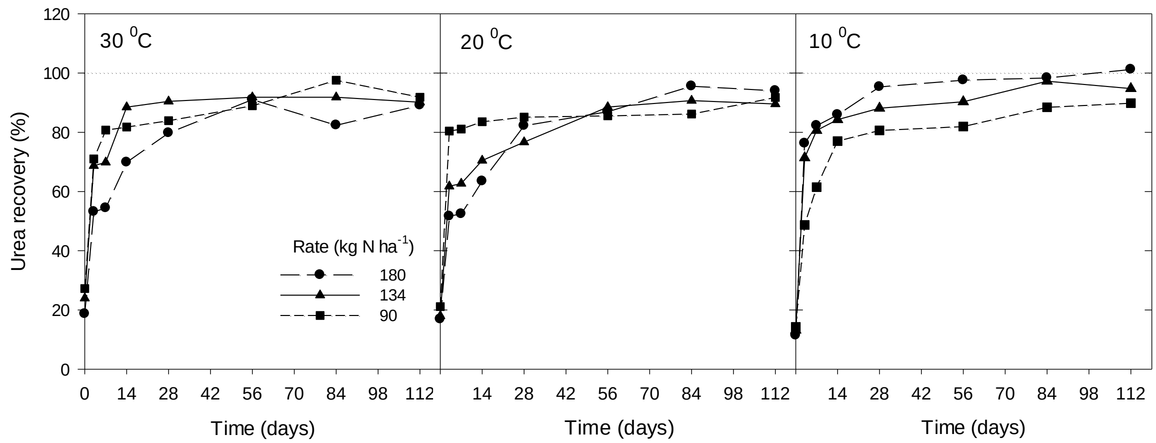

Figure 4.2 Effect of temperature, rate and sample day interaction on urea recovery from summer crop soils averaged across location

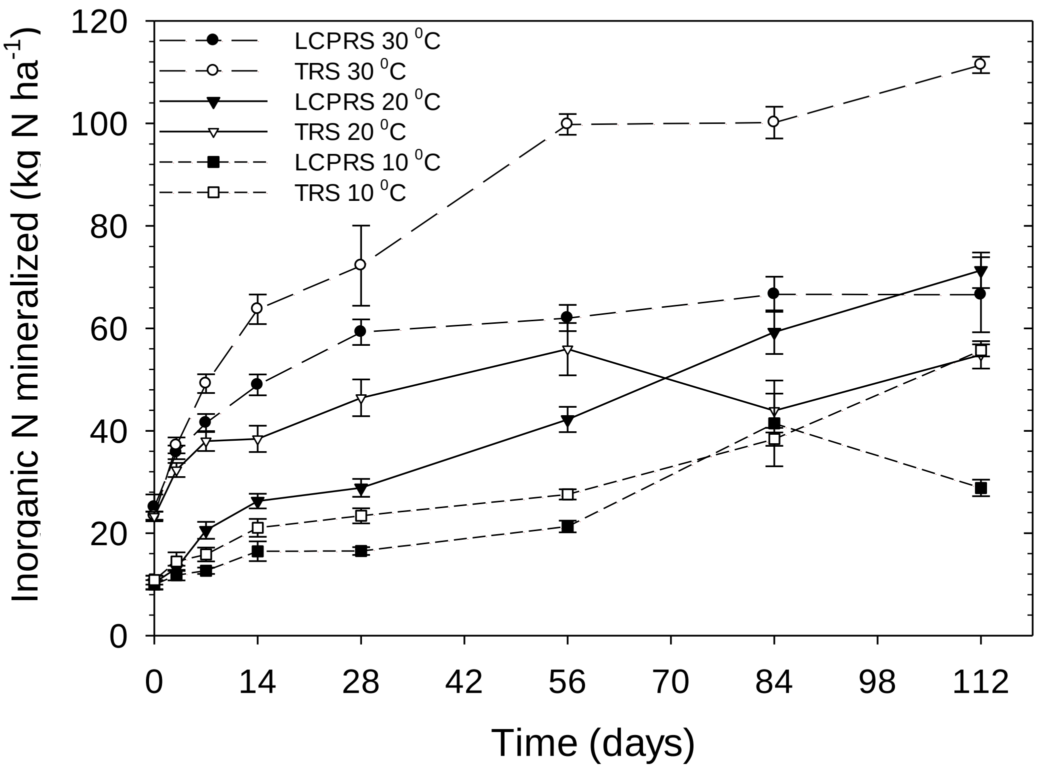

Figure 4.3 Cumulative inorganic N mineralized from wheat check plot soils from two locations incubated at three different temperatures. Means were averaged across N sources and error bars represent means standard error.

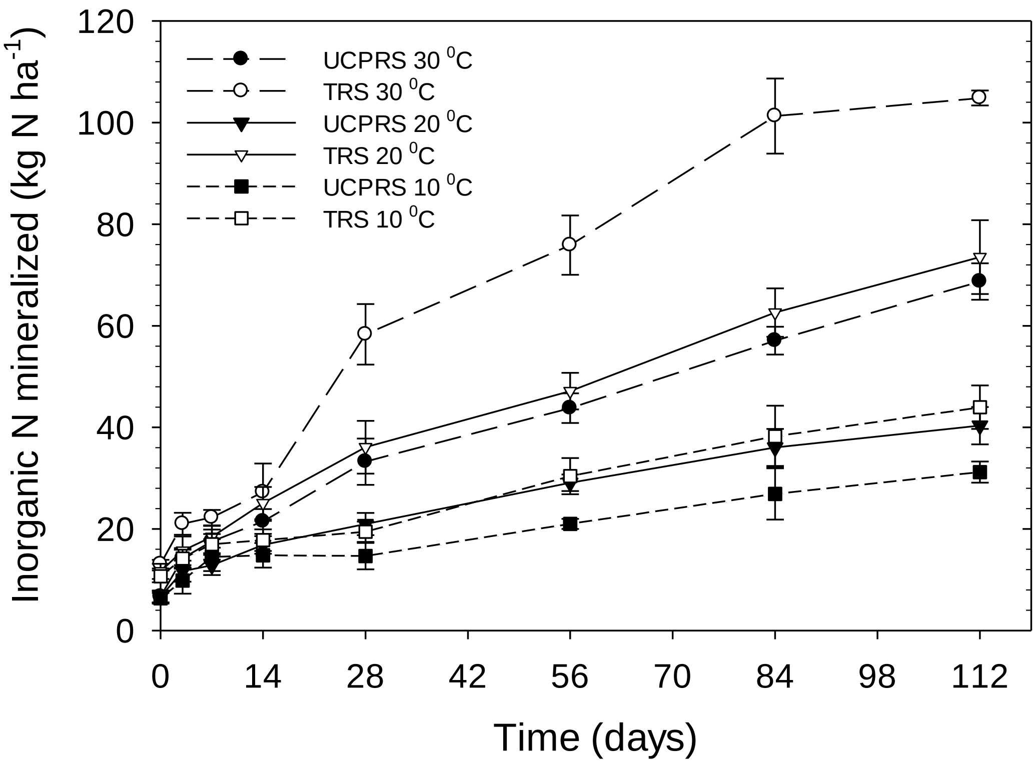

Figure 4.4 Cumulative inorganic N mineralized from summer crop check plot soils from two locations incubated at three different temperatures. Means were averaged across N sources and their variation indicated by standard error bars.

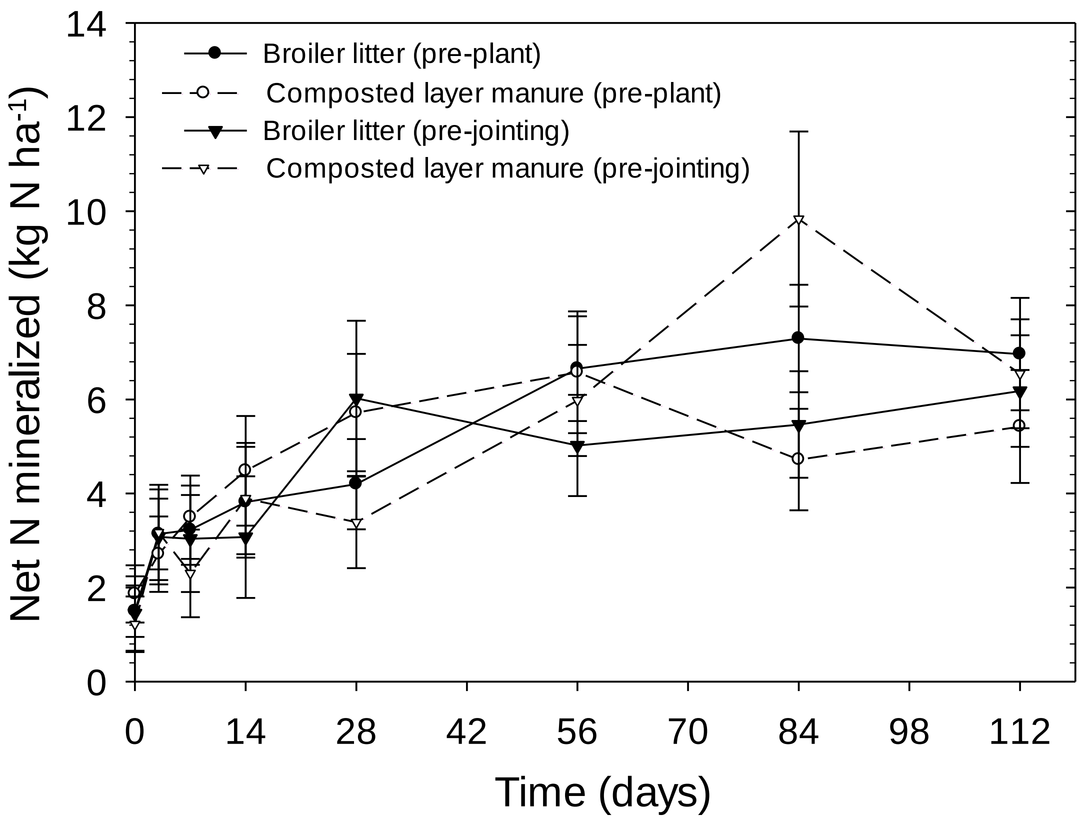

Figure 4.5 Effect of N source and application time on wheat soils over the sampling period. Means were averaged across locations and error bars show means standard errors.

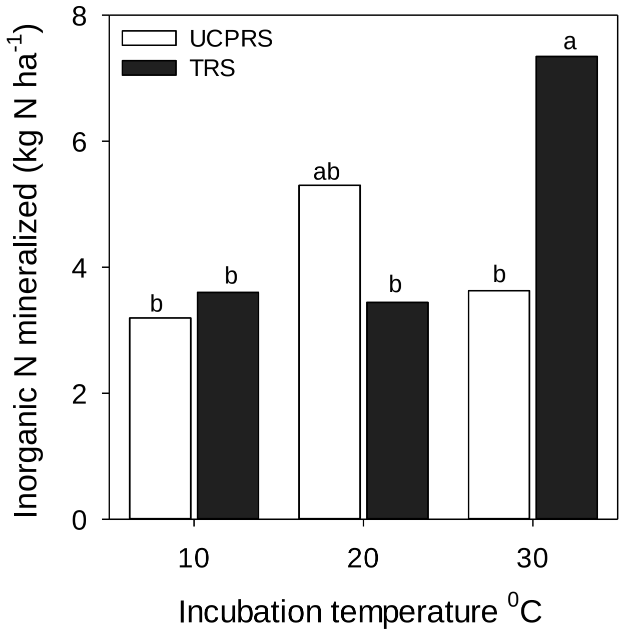

Figure 4.6 Effect of location and temperature interaction on wheat soils. Means were averaged across sampling day and N source and separated by Tukey-kramer value of 2.9 kg N ha^{-1}.

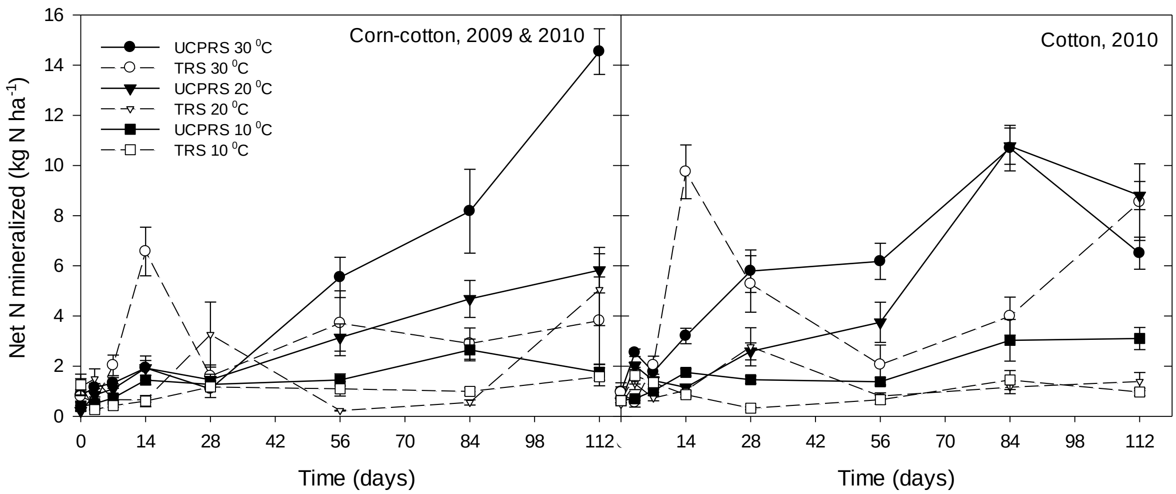

Figure 4.7 Effect of Location and temperature interaction over sampling time on net residual N mineralized from summer crop soils after 2 year cropping season 2009 &2010 (left) and one cropping season cotton crop 2010 (right). Means were averaged across N sources.

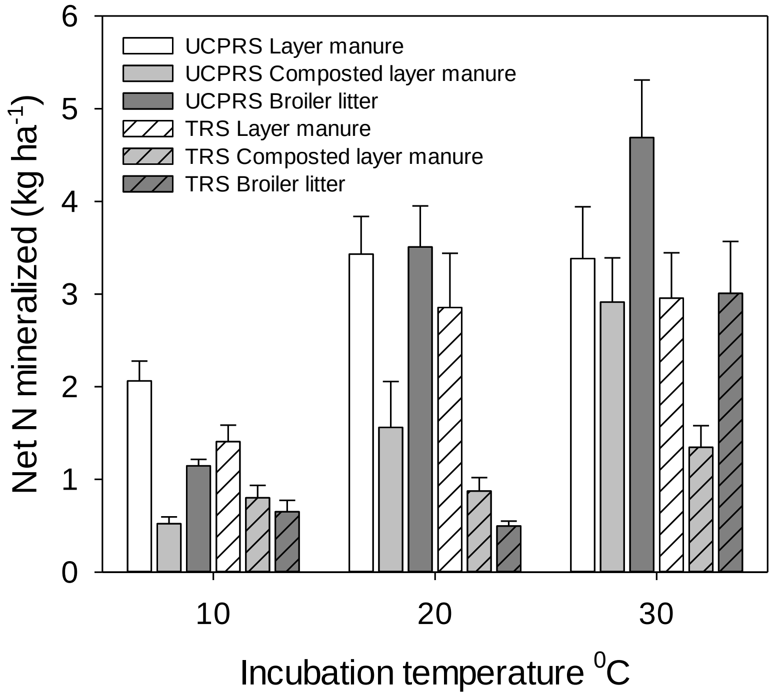

Figure 4.8 Effect of Location, source and temperature interaction on 112 day net residual N mineralized from post summer cotton-corn (2009 – 2010) 2 year crop rotation soils.

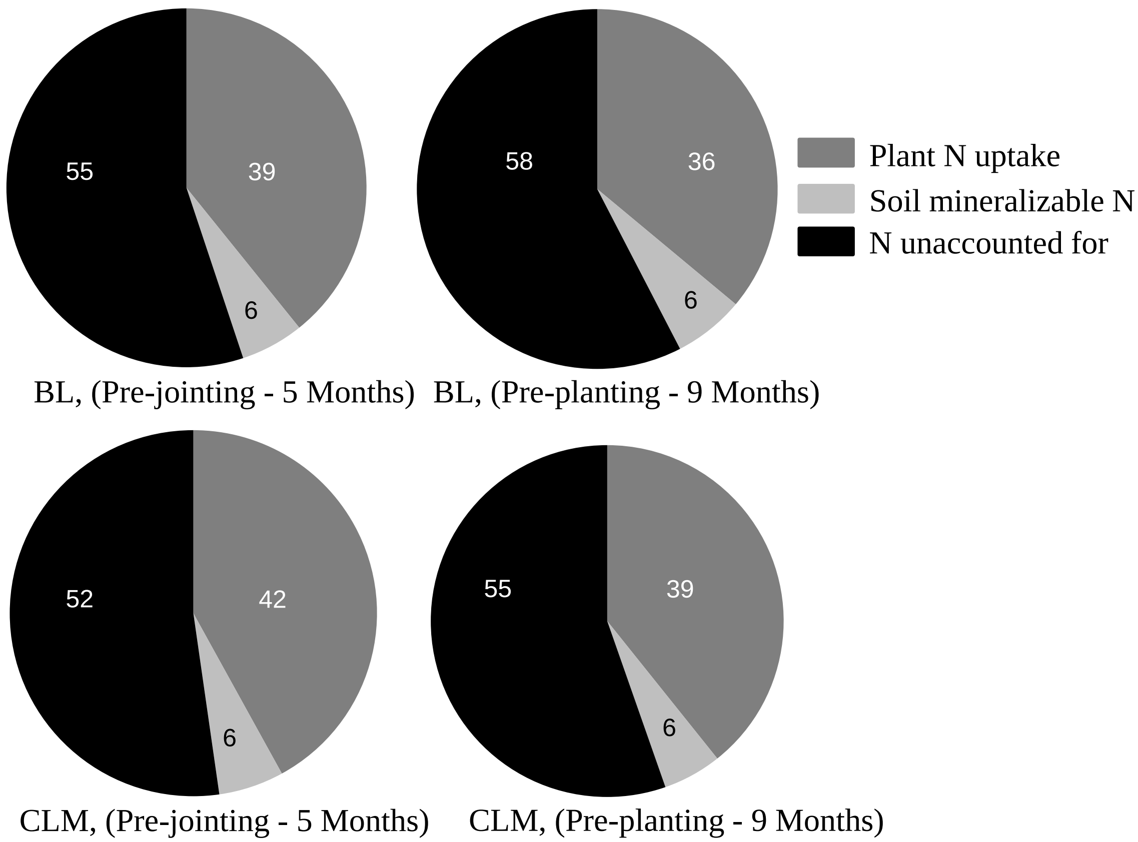

Figure 4.9 Nitrogen budgets for wheat based on poultry manure source by application time treatment interaction. Poultry manures application rate was 134 kg N ha^{-1} and residual soil mineralizable N from the highest mean net mineralization at 30 ^{0}C.

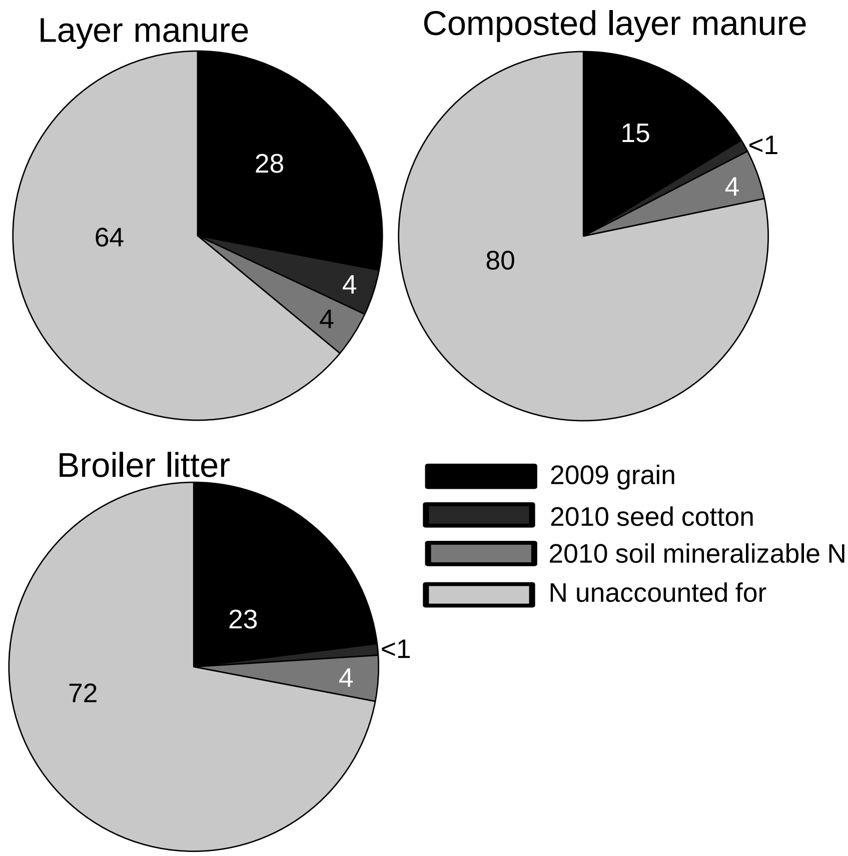

Figure 4.10. Nitrogen recovery from 134 kg N ha^{-1} as poultry manure after two seasons of crop cycle. Residual soil N based on the mean highest net mineralization at 30 ^{0}C.

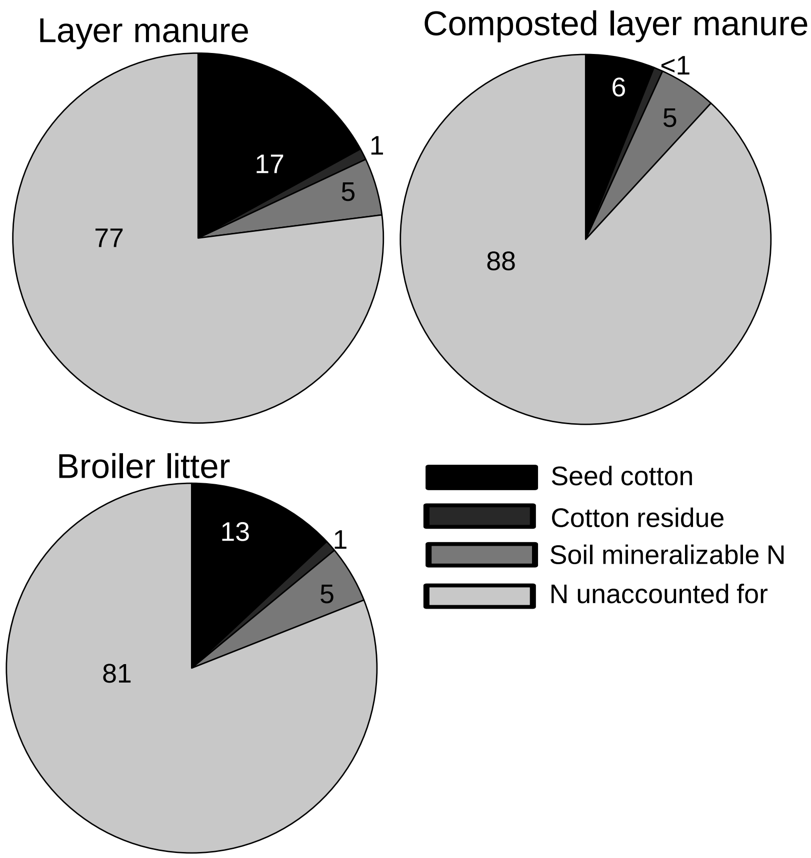

Figure 4.11. Nitrogen recovery from 90 kg N ha^{-1} as poultry manure after one year of cotton production. Residual soil N based on the mean highest net mineralization at 30 ^{0}C.

5.0 APPENDICES

Appendix 5.1 North Carolina Coastal Plains Climate, Soils and Manure Use

The Coastal Plain of North Carolina lies along the Atlantic Ocean which influences the climate keeping the temperatures mild in winter and moderate in the summer. Daytime temperatures rarely drop below 40 ^{0}F (4.4 ^{0}C) in winter while high temperatures average less than 89 ^{0}F (31.6 ^{0}C) in summer (SCO-NC, 2012). Temperatures hardly drop below freezing even at night resulting in only one inch (2.5 cm) of snow and/or ice annually, and in some years none. The Coastal Plain is almost half of the state and is subdivided into three parts Upper, Lower and Tidewater regions based on the elevation and soil types (Buol et al., 2003). The Tidewater area is generally flat and swampy, while the interior section is mostly gently rolling and well drained. Elevations of the Coastal Plain range from sea level in the east to about 600 feet (183 m) inland to the west. This region is very important in agricultural production of tobacco, cotton (*Gossypium spp*.), soybeans, peanuts, potatoes, and sweet potatoes, along with some types of grains such as winter wheat (*Triticum aestivum* L.) and corn (*Zea mays* L.) (AAC-NC, 2009). A large area is also covered by forest. Soils of the Coastal Plains were derived from marine deposits. Profile development of these soils is more distinct in the Upper Coastal Plain region than the lower plains (Buol et al., 2003).

Appendix 5.1.1 Upper Coastal Plain Soils

The soils are highly dissected, older and well drained lying between 275 feet (84 m) to 600 feet (183 m) above sea level (Daniels et al., 1999). The soils have sediments of fluvial origin and contain resistance quartz and kaolinitic clays which render them less fertile than Lower Coastal Plain soils. The profile has deep and highly weathered soils with frequency of occurrence of plinthite despite its great depth and thickness (Daniels et al., 1999). There exists an intermediate part along the landscape referred to as the Middle Coastal Plain that lies at an elevation between 95-275 feet (29-84 m).

Appendix 5.1.2 Lower Coastal Plain Soils

These soils extend from sea level to 95 feet (29 m) elevation in North Carolina. They are young soils where the interstream divide widens which leads to an increase in the proportion of poorly drained soils in this region. Also the depth of weathering and solum development decrease considerably. The clay mineral portions reflect more montmorillonite and mica but not kaolinite as depicted in the Upper Coastal (Daniels et al., 1999). The lower surface occurring after the Suffolk scarp is dominated by very poorly drained soils and high organic soils (Histisols). The Suffolk scarp marks an important mineralogical change in sand fraction from siliceous to the west to a mixed class to the east. There are more organic soils in the Lower than the Upper Coastal Plains (Daniels et al., 1999).

In general soils of the Coastal Plains have a drainage concern especially in the lower part where the interstream divide is affected by a high water table. The particle size (texture) is distinguished based on the energy of the water during deposition. The thickness of the solum is large and nature of the horizons development is better in the Upper than the Lower Coastal Plains soils of North Carolina. The mineralogy of the control section is skewed towards kaolinitic in the Upper and montmorillonite and mica in the Lower Coastal Plains.

Appendix 5.1.3 Coastal Plain of North Carolina soils fertility status

Coastal Plain soils of North Carolina are commonly regarded as remarkably important for agricultural production (AAC-NC, 2009). The soils vary vastly in texture depending on parent material deposition mode. As a result these soils have low soil fertility characteristics because of their sandy nature, slightly acidic, low organic matter, low cation exchange capacities and dominated by kaolinitic clays. Most of these sandy soils are Ultisols (Buol et al., 2003) and have been under continuous cultivation of crops for decades (Novak et al., 2009). Following this use, bases have been severely leached out, leading to low soil pH values that warrant liming. These characteristics lead to concerns of soil fertility for agricultural production. Best management practices like fertilizer application are needed to maintain crop production. As such, poultry manure has been one of the organic materials used by farmers to supply plant nutrients especially N. Nitrogen from organic and inorganic fertilizers can readily be leached out of these sandy soils (Zotarelli et al., 2007). These properties and events result in low soil fertility and hence crop production must be sustained through external nutrient supply. Crop production on poor soil fertility raises environmental concerns about the sustainability of agriculture through frequent nutrient application in this region.

Appendix 5.1.4 Reference

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Appendix 5.2 Residual soil fertility effects of summer crop poultry manure study

Methods and Materials

4 Experiments: 2 Sites x 2 Tillage methods

Sites
The studies were conducted at the Upper Coastal Plain Research Station (UCPRS) in Edgecombe County on a Norfolk loamy sand (Typic Kandiudults), and the Tidewater Research Station in Washington County (TRS) on a Portsmouth fine sandy loam (Typic Umbraquults).

Tillage
- Conventional tillage (chisel, disk)
- Conservation tillage (TRS: no-till, UCPRS: strip-till)

5 N Sources
- Non-amended check treatment
- Inorganic N: cotton, 134 kg N/ha; or corn, 202 kg N/ha as UAN30%
- Manures at 90 kg N/ha to cotton in 2008 & 2010 (no manure for corn in 2009)
    - -Layer manure (LM)
    - -Composted layer manure (CLM)
    - -Broiler litter (BL)

Statistical design: RCBD with 4 replicates

Soil samples: 0-10 cm & 10-20 cm depths post-harvest; Mehlich-3 extractant used for soil nutrients, and pH was determined in water.

Data analysis
SAS PROC Mixed, with Tukey-Kramer test for means comparisons; Experiment and replication were random effects. Stratification ratio calculated as soil test value in 0-10 cm layer divided by value in 10-20 cm layer.

Table 5.1.5.1 ANOVA results for manure & inorganic N sources. Probabilities of significance: * 0.05, ** 0.01, and *** 0.001. (from SSSA 2012 poster).

Effects	df	pH	P	K	Ca	Zn	base sat.
Fixed Effects							
Year (Y)	2	*				*	
Depth (D)	1			*		*	*
N Source (N)	4	*	*	***	*	***	**
Y x D	2		***	**	*	**	
Y x N	8		***		**	***	
D x N	4	**	***		***	***	**
Y x D x N	8		***			*	
Random Effects							
Expt (E)	3	**			**		
E x Y	6		***	*			
E x D	3	*	***	***			
E x N	12	*	***				
E x Y x D	6	***		***	**		***
E x Y x N	24		***	*			**
E x D x N	12			**			**
E x Y x D x N	24						

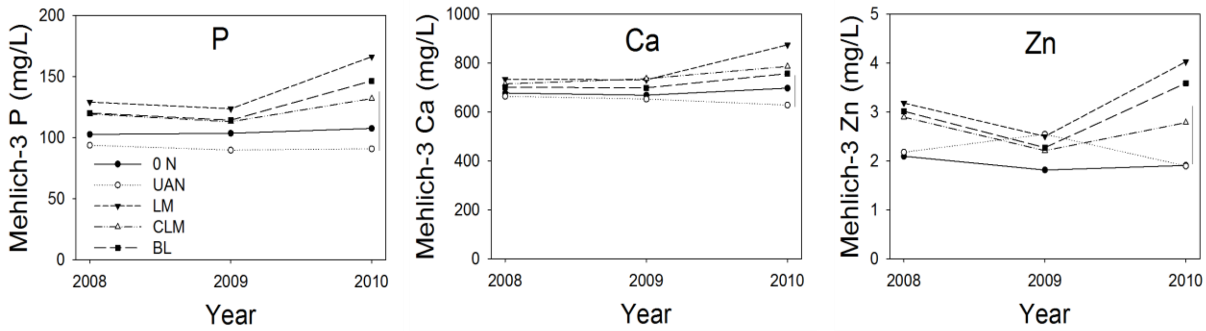

Figure 5.1.5.1 Changes in the 0-10 cm soil depth layer averaged across 4 experiments (both sites & both tillage methods) associated with different N sources. (from SSSA 2012 poster).

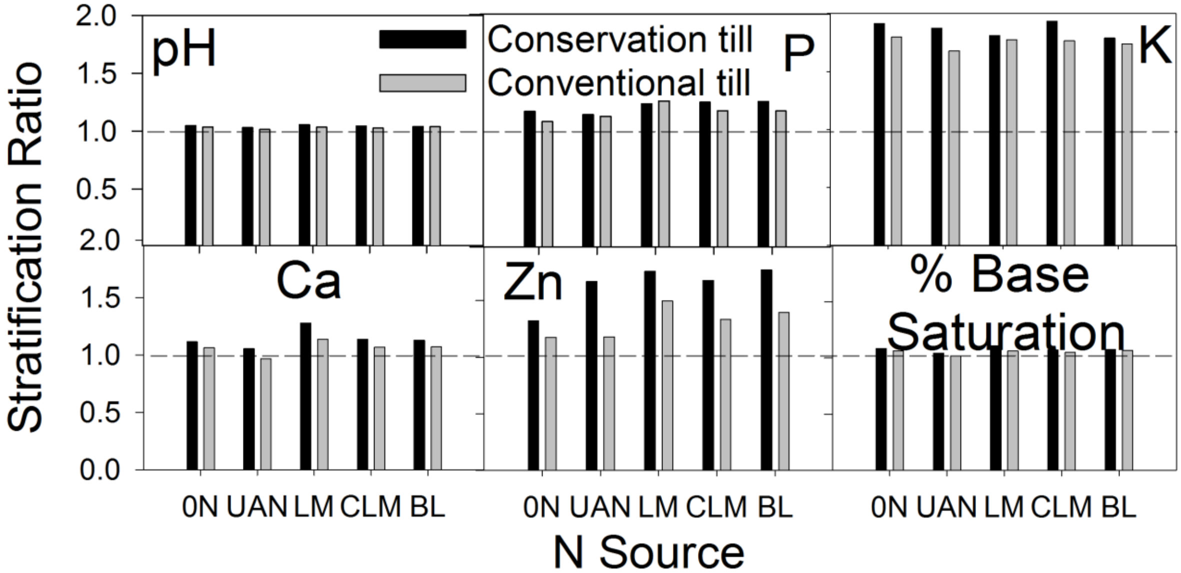

Figure 5.1.5.2 Soil stratification ratios for each N source pooled across sites and years.

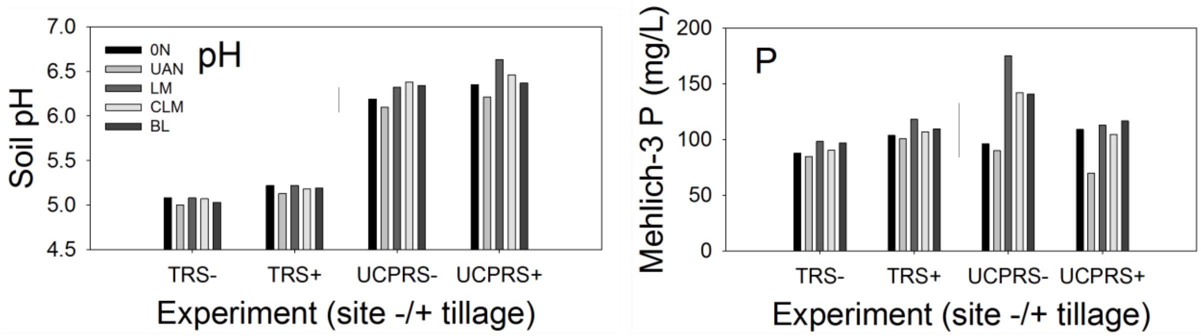

Figure 4. Means for each experiment and N source combination, pooled across depths and years. Vertical lines represent differences required for significance, p<0.05, Tukey-Kramer test.