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Estimating Nitrogen Credits from Poultry Litter on Silt Loam Soils in Arkansas Using the Nitrogen-Soil Test for Rice: N-STaR

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ABSTRACT

Rice (*Oryza sativa* L.) is one of the most important global cereal crops and is grown on a substantial number of hectares in Arkansas each year. Consequently, Arkansas is the leading rice producing state in the United States accounting for almost half of domestic production. The development and release of N-STaR (Nitrogen-Soil Test for Rice) allows producers to predict site-specific N fertilizer needs for rice production in Arkansas, with N-STaR being a predictor of potentially mineralizable-N. Furthermore, poultry production is a thriving commodity in Arkansas, producing a substantial amount of poultry litter (PL) annually. Rice producers are applying PL to their land either as a fertilizer source or to restore productivity to precision leveled fields and using the N-STaR to determine N fertilizer recommendations. However, N-STaR has not been sufficiently researched on soils that have recently received an application of PL, potentially leading to an over or under recommendation in N fertilizer as a result of N contained in the PL. Therefore, the first research objective was to evaluate the ability of N-STaR to quantify N release from a pelletized PL application and identify how a PL application influences N-STaR recommendations over time in a field study. Results of this study indicated that the N-STaR method used in this study was very sensitive to slight changes in potentially mineralizable-N following PL applications resulting in small changes in alkaline hydrolyzable-N (AH-N) being statistically significant. Following typical PL application rates of 2240 and 4480 kg litter ha^{-1}, the N-STaR N rate recommendation only decreased by 3 and 8 kg N ha^{-1}, respectively. Alkaline hydrolyzable-N and N-STaR are reasonable predictors of potentially mineralizable-N from pelletized PL, indicated by the ability of N-STaR to quantify differences in potentially mineralizable-N from the addition of PL over a 45 cm deep soil sample. The second objective of this study was to quantify how different sources of PL, varying in moisture and

composition, influence N-STaR soil test values and inorganic-N concentrations in a 60-d aerobic soil incubation study to determine guidelines for soil sampling protocols to determine N fertilizer recommendations. Significant fluctuations in AH-N, NH_4-N, and NO_3-N were observed within the first 15 d of the experiment. After the 15 d extraction time, changes in N were minimal and equilibrated for the further duration of the study. Information relating to the influence of PL on N-STaR soil test values allow us to ensure that the proper N recommendation is determined using N-STaR following a PL application. Our results show that the direct steam distillation method quantifies AH-N in the soil and PL indicating the importance of soil sampling time for N recommendations for rice using N-STaR following a PL application. This study demonstrates the ability to design soil sampling protocols, recommending that rice producers applying PL need to delay at least 15 d following a PL application before collecting soil samples for N recommendations using N-STaR.

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DEDICATION

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CHAPTER I

Introduction and Literature Review

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important cereal crops in the world (The Columbia Electronic Encyclopedia, 2007) and grown in a wide variety of climates. Rice is an important commodity in Arkansas being grown on approximately five hundred thousand hectares each year making it the leading rice producing state in the United States. Nitrogen (N) is considered one of the most limiting nutrients for cereal crops and accounts for a substantial portion of the capital cost associated with obtaining maximum yields, with N expected to represent roughly 20% of the total operating expenses in rice production (University of Arkansas, 2012). Nitrogen fertilizer cost has dramatically increased in the last few years (USDA, 2012a) and indicators suggest that this trend will continue. Optimum N rates improve the overall health of rice including plant height, tillering, leaf number/weight, root development, and increased yield (Chaturvedi, 2006). Generalized N recommendations do not take into consideration N mineralized in the soil which can lead to erroneous applications of N resulting in extensive economic and environmental implications. Consequently, due to the dynamic nature of soil-N, estimating plant available N (PAN) is challenging with N-cycle processes being controlled by microbial activity, temperature, and moisture.

Within the past decade substantial advancements have been made towards the development of a chemical soil test method that can accurately predict N mineralization. Biological methods such as aerobic and anaerobic incubations have been the most favorable approach in estimating N availability. Aerobic and anaerobic incubations measure the amount of inorganic-N that is mineralized over a specific time period. However, time requirements needed to incubate the soil make biological methods strenuous for routine analysis, stimulating the search for a chemical method. Chemical methods that are used to predict N availability are much

faster, but have previously been unsuccessful at consistently being correlated to crop N uptake or crop yield.

In the search to identify the soil organic-N fraction that affects crop responsiveness to N fertilization, Mulvaney et al. (2001) evaluated specific fractions of hydrolyzable soil-N to predict N mineralization. Their results revealed the soil amino sugar-N fraction as a vital factor influencing the responsiveness of corn (*Zea mays* L.) to N fertilizer, indicating highly significant correlations between amino sugar-N and corn fertilizer-N response. This research led to the development of the Illinois Soil Nitrogen Test (ISNT) (Khan et al., 2001) that was developed to predict when corn responds to N fertilization using a simple diffusion method to quantify alkaline-hydrolyzable-N (AH-N), which estimates NH_4-N and amino sugar-N.

Research conducted by Bushong et al. (2008) highlighted the development of a direct steam distillation (DSD) technique which is highly correlated with the ISNT and anaerobic incubation, without the lengthy time requirements of diffusion methods. The DSD technique uses a 10 mol L^{-1} NaOH distillation to quantify amino sugar-N and hydrolyzable NH_4-N with values almost identical to the ISNT. Further work indicated the DSD technique as an alternative to the ISNT as means to correlate and calibrate a soil test for N-fertilizer recommendations (Roberts et al. 2009a) based on its ability to accurately estimate potentially mineralizable-N in a relatively short time (~ 7 min). Roberts et al. (2009b) conducted a study to identify the relationship between AH-N, Total N (TN), and soil depth. Results from this study identified the ability of AH-N levels to significantly change with sampling depth, indicating the importance of collecting soil samples within the crop's effective rooting depth prior to the correlation and calibration of a N soil test.

The most recent advancement in predicting N fertilizer needs for rice production in Arkansas is the correlation and calibration of the Nitrogen-Soil Test for Rice (N-STaR) by Roberts et al. (2011). The N-STaR method is a soil-based N test that predicts the potentially mineralizable soil-N (e.g., amino sugars, amino acids, and NH_4) for silt loam soils using the DSD technique. The basis of N-STaR is the correlation of AH-N values from the DSD method to rice response parameters such as TN uptake and check plot grain yield and the calibration of AH-N to predict the fertilizer rate needed to achieve 90, 95, and 100% relative grain yield (RGY) for a specific location. Roberts et al., 2013 indicated that the N-STaR 95 and 100% RGY calibration curves can predict accurate N rates for rice produced on silt loam soils in Arkansas to achieve maximum yield.

Concurrently, the poultry industry has become a thriving business in many southern states, including Arkansas. Arkansas is ranked second in the nation for poultry production (USDA, 2011). Large amounts of poultry litter (PL) are produced each year in Arkansas, containing an average analysis for N-P_2O_5-K_2O per metric ton of litter of approximately 24.5-22.5-18.5 kg (Ritz, 2006). Based on its nutrient content and availability, Arkansas rice producers are using PL as a fertilizer source and to restore productivity to precision-leveled fields.

Poultry litter applications normally range from 2241 to 4483 kg ha^- and are applied in the fall or spring, recommended to be applied as close to planting as possible. Regardless of timing, litter is recommended to be incorporated immediately following application. High rates of PL can cause salinity problems for rice due to increasing concentrations of soluble salts (Norman et al., 2003). Even though rice is considered to be moderately susceptible to salinity, there can be detrimental effects to rice during emergence. The effects of salinity on rice occur from the

increased osmotic pressure of the soil solution impairing the plants ability to absorb water at the seedling growth stage.

Typical uses for PL in rice production include: restoration of fields which were leveled to create a slight slope gradient that is uniform to obtain an even distribution of water during irrigation, and to satisfy P and K recommendations. However, ~ 25% of the N in PL is recovered by rice (Golden et al., 2006). Land leveling has the potential to decrease soil fertility by exposing the subsoil causing a decline in productivity (Brye et al., 2005). An application of PL can result in a rapid restoration of productivity to precision graded rice fields from increasing organic matter and nutrient concentrations. Nearly a 2241 kg ha^{-} PL application is recommended for silt loam soils in Arkansas to restore productivity lost by leveling (Slaton, 2001).

The release of N-STaR to predict field-specific N rates is expected to become a standard procedure for rice produced on silt loam soils; however rice producers in the delta region receive about 91 Gg litter yr^{-1} from Arkansas (Kellogg et al., 2000) and there has been little research concerning the ability of N-STaR to estimate N credits from PL applications. Mulvaney et al. (2001) conveyed that the concentration of amino sugar-N tended to be higher for soils that have received manure than for non-manured soils. Knowing that PL releases N, knowledge of how N-STaR quantifies the release of N from PL amended soils is important. These experiments were designed to evaluate N-STaR's ability to quantify the potentially PAN in soil that has received a PL application.

LITERATURE REVIEW

Arkansas is ranked first among the six main rice-producing states and accounts for approximately 44% of the U.S rice production (USDA, 2012b). Substantial amounts of land are

dedicated to rice production each year in Arkansas, making it the state's second highest value commodity and top agricultural export. Rice production in Arkansas is concentrated on the eastern half of the state and typically grown on silt loam soils, with an increasing number of hectares producing rice on clay and clay loam soils. Arkansas's seven largest rice-producing counties, representing ~ 47% of the state's total rice hectares, are Arkansas, Poinsett, Cross, Jackson, Greene, Lawrence and Lonoke counties (USDA, 2012c). The state-average yield of rice is the second highest first crop average in the U.S. trailing only California; conversely, Arkansas has the highest total production and harvested rice producing hectares. In the past 20 years, the state average yields increased ~ 2573 kg ha^{-1} or 117 kg ha $year^{-1}$, with improvements being attributed to improved varieties and management (Wilson and Runsick, 2007).

In Arkansas, rice is typically grown using the direct-seeded, delayed-flood production system. The University of Arkansas currently has two recommendation options for N fertilization of direct-seeded, delayed flood rice: a two-way split N application and a single optimum preflood N application (Wilson et al., 2001). The two-way split N application strategy includes N being applied at preflood (4-5 leaf growth stage) and midseason (beginning internode elongation (BIE)). The single optimum preflood N application integrates a large amount of N applied at the 4-5 leaf stage, followed by monitoring for additional N needs. Regardless of the strategy used, NH_4-based fertilizer is recommended to be applied preflood at the 4-5 leaf stage to a dry soil immediately prior to flooding. The current N fertilizer recommendation rates are based on cultivar, previous crop, and soil texture (Wilson et al., 2001).

Approximately 95 to 99% of the potentially PAN in the soil is in the organic form, either in organic matter or organic materials added to the soil (plant/animal residues), requiring mineralization before being plant available (Stevenson and Cole, 1999). Nitrogen mineralization

is the process by which organic-N is converted to plant-available inorganic forms, completed by microbes as a by-product of organic matter decomposition.

Fertilizer recommendations should be based on available nutrients in the soil, crop requirement, cropping sequence, and crop management practices. However, current N fertilizer recommendations do not account for the amount of N supplied by the soil for that particular season or location due to the lack of a routine N soil test. Generalized N recommendations can result in an over or under application of N, possibly causing negative economic and environmental impacts, including increased lodging, decreased yields, speed or delay maturity, eutrophication, and increased disease susceptibility from rapid growth. Various methods to predict N mineralization have been suggested, with none of them being widely accepted as a routine N soil test.

Illinois Soil Nitrogen Test and Direct Steam Distillation

Khan et al. (2001) developed the ISNT in the search for a chemical method that could predict a crop response to N fertilizers through a one-time soil test prior to the growing season. The purpose of this study was to develop a simple technique to quantify amino sugar-N to detect sites that do not require N fertilizers. The ISNT is a diffusion method that is able to predict when corn will respond to N fertilizer by estimating (NH_4-N + amino sugar)-N. The ISNT uses an alkali diffusion technique that involves direct soil diffusion by heating with NaOH and recovers exchangeable NH_4-N as well as amino sugar-N. Heating is used to promote the alkaline decomposition of amino sugars, therefore proper temperature control is crucial for reliable estimations of potentially available soil N. Soil samples collected at a depth of 30 cm with test values of 250 mg kg^{-1} or higher indicates that corn will be nonresponsive to N fertilizers and 300

mg kg^{-1} or higher if soil sample is taken at a depth of 15.2 or 16.8 cm (15N Analysis Service, 2004). Issues concerning the ISNT include sample variability, analysis time (5 hr), and space requirement, which led to the development of the DSD technique.

The DSD technique developed by Bushong et al. (2008) can be used as an alternative to the ISNT, based on its strong correlation to the ISNT and relatively short analysis time per sample (Roberts et al., 2009a). Bushong et al. (2008) evaluated a DSD technique to determine if developmental methods that quantify hydrolyzable amino sugar-N accurately predict N mineralization when compared to anaerobic incubations. The DSD technique was compared to the ISNT using three concentrations of NaOH (2, 5 and 10 mol L^{-1}). Results indicated a strong correlation for all the concentrations of NaOH, with the 10 mol L^{-1} NaOH method producing values almost identical to the ISNT. The DSD technique quantifies amino sugar-N and hydrolyzable NH_4-N. Both the ISNT and DSD indicate the ability to estimate potentially mineralizable-N by displaying a significant recovery of glucosamine-N, however the DSD is equally reliable with quick analysis time. The search to improve N fertilization for rice production in Arkansas lead to the development of the N-STaR using the DSD method.

Nitrogen-Soil Test for Rice (N-STaR)

The N-STaR procedure is a site specific soil-based N test for rice fertilizer recommendations in Arkansas on silt loam soils developed by Roberts et al. (2011). The N-STaR method is used to predict potentially mineralizable soil-N, in the form of amino sugars, amino acids, and NH_4, to determine N fertilizer needs for direct-seeded, delayed-flood rice to achieve 95% RGY. Nitrogen response trials were conducted on silt loam soils at experiment stations and producer fields throughout Arkansas to evaluate AH-N quantified by DSD and ISNT (Roberts et

al., 2011). Total N uptake and grain yield data collected from field studies receiving six N fertilizer rates ranging from 0 to 202 kg N ha^{-1} were used for correlation and calibration of N-STaR. Response trials were used to correlate AH-N, measured by DSD and ISNT, to rice response parameters consisting of TN uptake, check plot grain yield, and percentage of RGY of the check plot and calibrated AH-N to predict the fertilizer N rate required to achieve 90, 95, and 100 % RGY.

Alkaline hydrolyzable N as measured by the ISNT and DSD method is significantly influenced by the interaction of site and soil depth (Roberts et al., 2009b), indicating the importance of proper sampling depth. In the correlation and calibration of N-STaR, soil samples were collected at the same soil depth as the crop's rooting depth, respectively, to account for subsoil N mineralization resulting in N-STaR requiring a 45 cm soil sample for rice produced on silt loam soils. Following the successful development of a calibration curve ($r^2 = 0.89$) to predict site-specific N fertilizer rates, field validation studies were established throughout Arkansas on silt loam soils (Roberts et al., 2010).

Field validation studies were used to evaluate the ability of N-STaR to accurately predict N rates that maximize rice yield; results indicate that N-STaR was successful at predicting site-specific N rates, with the N rates recommended by the 95% and 100% RGY curves not being significantly different in yield than the standard Arkansas N rate recommendation though N-STaR typically recommended less N. Soil samples for N-STaR can be collected any time after the harvest of the previous crop. A high N-STaR value corresponds to the soil having large amounts of potentially PAN, resulting in a low N fertilizer recommendation (i.e. a AH-N value of 136 mg N kg $soil^{-1}$ recommends 50 kg N ha^{-1}); Correspondingly, a low N-STaR value relates to the soil having small amounts of potentially PAN for that specific growing season, resulting in

a high N fertilizer recommendation (i.e. a AH-N value of 70 mg N kg soil^{-1} recommends 190 kg N ha^{-1}).

Poultry Litter as a N Fertilizer

Poultry litter is one of the most nutrient rich manures and is applied to a large amount of row crop hectares each year in Arkansas. Poultry litter is typically applied near the poultry houses due to transportation costs of bulky litter, but high fertilizer prices allow for an increase in the geographical range in which it is applied; financial assistance is also available to compensate for the transportation cost of PL outside the nutrient surplus watersheds in northwest Arkansas through the U.S. Environmental Protection Agency PLT Project. Poultry litter is a combination of poultry manure and bedding materials, which can include rice/peanut hulls, wheat straw, wood shavings, sawdust, recycled paper, and other dry, absorbent, low-cost organic materials.

Poultry litter has been recognized to improve physical and chemical properties of the soil, while increasing organic matter and soil moisture retention capacity (Adeleye et al., 2010). The average N:P_2O_5:K_2O ratio found in Arkansas PL is approximately 3.0:3.0:2.5. The nutrient content of PL will fluctuate depending upon the type of birds, number of flocks raised on the litter before removal, type of bedding material, moisture content and storage time before field application (Malone et al., 1992). The nutrient supply of litter initially increases as the number of flock increases, but starts to level off after the fourth or fifth flock. With the extensive variability of nutrient and moisture contents of PL, it is recommended to sample and analyze the litter before applying it.

A study conducted by Golden et al. (2006) to determine the preflood urea-N equivalence of PL, indicated that about 25% of the TN applied as PL was recovered by the rice crop and there was no significant difference in the amount of N mineralization between pelleted and fresh litter. Results of this research should allow urea-N rates to be reduced by the total-N content of the litter multiplied by 0.25. Other research has also shown that rice yield is significantly increased by PL with a N recovery efficiency of 19% (Wild et al., 2011). Additionally, Wild et al. (2011) indicated maximal N uptake in rice plants between tillering and panicle initiation indicating the need for N mineralization proximal to this occurrence.

Depending on time of application and management practice, a wide range of N in PL (15 to 75%) is plant available within the first year for summer crops (Beegle, 1997). A common 3-yr decay series assumption of 0.60, 0.20, and 0.10 is used for PL mineralization. Other research also indicated rice recovered between 0 and 10% of PL-N by 0.5-in internode elongation (IE) and 5 to 25% of PL-N by heading (Slaton et al., 2003). Poultry litter contains both inorganic and organic forms of N. The inorganic-N is readily available for plant uptake after the application, however the organic-N must be mineralized before it can be utilized by the plant. Most of the N in PL is in the organic form (Bitzer and Sims, 1988) approximately 70%, with the remaining 30% of the total-N found in PL as inorganic-N, mainly in the form of NH_4-N. Nitrogen availability from animal manures to plants is dependent on the rate of mineralization.

Previous research has displayed the mineralization of organic-N in PL separated into distinct phases including initially shows a rapid rate of mineralization, followed by a slow release of mineral-N (Hadas et al., 1983; Wild et al., 2011). Hadas et al. (1983) reported 30 to 35% of the TN in poultry manure was mineralized in the soil within the first 7 d, with pelleted litter releasing more N than ground manures. Furthermore, after two months 34 to 50% of the TN

in poultry manure was mineralized with PL pellets releasing equal or less mineral-N than ground manures. Cabrera et al. (1994) showed that 36% of the organic-N in PL was mineralized within 3 d in an aerobic incubation. Whereas, an anaerobic incubation conducted by Wild et al. (2011) to simulate the environment of irrigated rice indicated 14% of the N in PL was mineralized after 60 d.

Summary

Rice producers apply N rates based on soil texture and previous crop with little to no accountancy for residual soil N as a result of not having a routine soil test that can accurately predict N requirements over the growing season for their specific field. The N-STaR was developed to eliminate this problem by quantifying AH-N in the soil, in the form of amino sugars, amino acids, and NH_4-N (Roberts, T.L. 2010) to provide N fertilizer recommendations. However, N-STaR has not been adequately researched on soils that have recently received an application of PL. Accurately estimating a N credit from PL is important to account for potentially PAN in fields that received PL in the fall, weeks, or months in advance of rice growth and collection of N-STaR soil samples. With a portion of the N in PL residing in the form of amino acids and approximately 25% in the form of NH_4-N, N-STaR should be able to accurately quantify the amount of potentially PAN in soil that has received a PL application. Knowing that rice producers are using PL and N-STaR, it is imperative to understand how PL influences N-STaR soil test values, to ensure the proper N recommendation is determined. Therefore, the objective of this study was to evaluate the ability of N-STaR to quantify N release from PL in lab and field studies.

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CHAPTER TWO

Poultry Litter Rate Influences Rice Response and N-STaR Soil Test Values on Silt Loam Soils in Arkansas

ABSTRACT

The N Soil Test for Rice (N-STaR) is a soil-based N test developed to predict N fertilizer needs for rice (*Oryza sativa* L.) production in Arkansas, quantifying alkaline hydrolyzable-N (AH-N). The objective was to identify how poultry litter (PL) influenced AH-N values and ultimately N-STaR based N-fertilizer rate recommendations for rice produced on silt loam soils. Four field experiments were established to evaluate rice response parameters including TN uptake and grain yield, as well as changes in AH-N values following application of pelletized PL rates ranging from 0 to 6720 kg litter ha^{-1}. Rice grain yield and TN uptake increased as PL application rate increased up to 4480 kg litter ha^{-1}. Results indicated that the AH-N method used in this study was very sensitive to slight changes in potentially mineralizable-N following PL applications resulting in changes as small as 8 mg N kg $soil^{-1}$ being statistically significant. Following typical PL application rates of 2240 and 4480 kg litter ha^{-1}, the N-STaR N rate recommendation only decreased by 3 and 8 kg N ha^{-1}, respectively. The ability of N-STaR to quantify differences in potentially mineralizable-N from the addition of PL over a 45 cm deep soil sample indicates that AH-N and N-STaR are reasonable predictors of potentially mineralizable-N from pelletized PL.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the world's most important cereal crops, with roughly half of the world's population depending on it for adequate nutrition (Kasetsart University, 2013). In Arkansas, rice is grown on roughly 500,000 ha (USDA, 2012) and Arkansas is ranked first among the six main rice-producing states in the U.S., producing about 45% of the total U.S. production. Nitrogen (N) is an essential macronutrient for rice and N application rate has a significant effect on biomass production, tillering, yield (Chaturvedi, 2006), and disease susceptibility. Nitrogen fertilizer costs make up a substantial portion of a rice producer's yearly expense representing roughly 20% of the total operating costs associated with rice production (University of Arkansas, 2012). Poultry production is also a significant industry in the northwest corner of Arkansas and PL is transported to eastern Arkansas and has been previously applied to row crop fields at about 91 Gg litter yr^{-1} (Kellogg et al., 2000) to reclaim productivity in precision leveled fields. Currently, transport and land-application to rice fields are expected to be higher based on the cost and availability of the PL, increasing cost of synthetic fertilizers, as well as application rate limitations in nutrient-sensitive watersheds in the northwest corner of the state.

Poultry litter is most often used for restoring productivity to precision-leveled soils, and nutritionally applied to satisfy P and K needs. However PL contains 3% N on average and can provide some N to growing rice plants. Golden et al. (2006) indicated that about 16% of the TN applied as PL was recovered by the rice crop. Slaton et al. (2005) concluded that the N-fertilizer value of pelleted PL applied 10 d prior to seeding was 16% lower than pelleted PL applied the same day as seeding on a Calhoun (fine-silty, mixed, active, thermic Typic Glossaqualfs) silt loam soil in Arkansas. A majority of the N in PL is found in the organic form (Bitzer and Sims,

1988) (approximately 70%), with the remaining (30%) TN found in PL as inorganic-N, mainly in the form of NH_4-N. Most of the organic-N in PL is in the form of uric acid and urea, which can represent up to 80% of the TN in PL (Kelleher et al., 2002; Nahm, 2003). With mineralization catalyzed by microbial activity, the rate in which the organic-N fraction of PL is mineralized can be rapid and is influenced by litter characteristics (Nahm, 2005) and soil temperature, soil moisture (Sims, 1986), and soil texture. Wild et al. (2011) identified that roughly 19% of the N applied as PL was recovered by the rice plant. Brye et al. (2006) indicated that the decomposition of PL that was incorporated in the soil and N release and uptake by rice under field conditions were unaffected by PL form (i.e. source and bedding material) but were generally affected by the rate of application and environmental factors. Depending on time of application and management practices used, 15 to 75% of the TN content of PL is plant available within the first year for summer crops (Beegle, 1997). The transportation and usage of PL in the delta region of Arkansas is directly related to price and availability of the PL, with the potential to have substantial changes in PL-amended hectares each year.

Traditionally N-fertilizer recommendations for rice production in Arkansas are based on variety by N-rate trials throughout the state, which do not account for field specific potentially mineralizable-N. Roberts et al. (2011) developed the first site-specific, soil-based N test for direct-seeded, delayed-flood rice production and is referred to as N Soil Test for Rice or N-STaR, which predicts potentially mineralizable soil-N (e.g., amino sugars, amino acids, and NH_4-N) as AH-N. The N-STaR soil test uses a 45 cm deep soil sample, which is equivalent to the effective rooting depth of the rice plant and accounts for subsoil N mineralization (Roberts et al., 2009a; Roberts et al., 2013). Field validation studies were used to evaluate the ability of N-STaR to accurately predict site-specific N-fertilizer rates for rice and results indicated that N-

STaR is successful at predicting N recommendations that maximize rice yield for rice produced on silt loam soils in Arkansas (Roberts et al., 2013).

The N-STaR has been released for use in Arkansas to predict field-specific N requirements for rice (Norman et al., 2013). However, there has been little research concerning the effect of PL applications on N-STaR soil test values and -rate recommendations for rice. Poultry litter is sometimes applied to fields that will be cropped to rice as a source of P and K and the PL may be applied before soil samples are collected for determination of N-STaR. Thus, there is the need to understand how PL rate and application time influence N-STaR soil test values and rice response to N rate. The objective of this research was to quantify the effects of PL application rate and time on N-STaR soil test values and rice response parameters to evaluate the ability of N-STaR to estimate N credits from PL applications.

METHODS AND MATERIALS

Site Description

Four field experiments, two in 2011 and two in 2012, were established to evaluate rice TN uptake and grain yield as well as changes in N-STaR soil test values following surface application and incorporation of pelletized PL. Field trials were located at the Pine Tree Research Station (PTRS, Colt, AR) on Calhoun (fine-silty, mixed, active, thermic Typic Glossaqualfs) and the Rohwer Research Station (RRS, Rohwer, AR) on an Hebert (fine-silty, mixed, active, thermic Aeric Epiaqualfs) silt loam. Selected physical and chemical properties of the soils used in this study were quantified and presented in Table 2.1. These locations were selected to represent soils commonly cropped to rice, but requiring higher than average N rate recommendations (>165 kg N ha^{-1}) based on N-STaR soil test values.

Pelletized PL was obtained from Perdue Agricycle (Seaford, DE) and contained 37 g N, 10 g P, and 27 g K kg^{-1} when analyzed on an 'as-is' or moist basis. Four PL treatments were applied by hand to a dry tilled soil surface at rates of 0, 2240, 4480, and 6720 kg litter ha^{-1} (N rate equivalent to 0, 85, 170, and 255 kg total-N ha^{-1}) to generate a N-response curve and allow quantifiable changes in the soil N status. Immediately following the PL application, a rototiller was used to incorporate PL to a 10 cm depth. The two PL application times were 4 wk (at-planting) and 8 wk (1-month prior to planting) prior to flooding. Phosphorous, K, and Zn fertilizer was broadcasted on all plots at each location at rates of 40 kg P_2O_5 ha^{-1}, 90 kg K_2O ha^{-1}, and 11 kg Zn ha^{-1} to ensure that these nutrients were not limiting rice growth.

The rice variety CL 261 was drill seeded at a rate of 90 kg seed ha^{-1} in plots that were 1.98-m wide by 4.88-m long. Within each field experiment there were an equal number of plots with and without rice. The plots with rice were used to determine TN uptake and rice grain yield, whereas the plots without rice were soil sampled to identify changes in N-STaR soil test values. Plots were flooded when the rice reached the 4-to 5-leaf stage and remained flooded until the rice was mature. Daily precipitation as well as PL application and flooding dates for 2011 and 2012 are displayed in Fig. 2.1 and 2.2, respectively.

Soil Sampling and Analysis

Soil samples were collected three times from the plots devoid of rice in 2-wk intervals; sampling was initiated immediately following planting and continued until flooding. Soil samples were taken from four depths (e.g., 0-15, 15-30, 30-45, and 45- 60 cm). A minimum of three soil cores (2.22 cm dia.) were taken to form a composite sample at depth increments of 0-15, 15-30, 30-45, and 45-60 cm depths, respectfully, in each plot using a slide hammer and core

tip. Samples were dried at 40^{o}C and crushed to pass through a 2-mm sieve (James and Wells, 1990) and stored for chemical analysis. Each soil sample was subjected to N-STaR analysis based on the procedure outlined by Roberts et al. (2011) which provides AH-N in mg N kg soil^{-1} and N rate recommendations in kg N ha^{-1}.

Rice Response Parameters

Rice tissue samples were collected to determine TN uptake (kg N ha^{-1}) by removing the aboveground biomass of a 0.91 m linear section of an inner row from each plot containing rice. Tissue samples were collected at 50% heading, representing maximum N uptake in direct-seeded, delayed-flood rice (Norman et al., 1992). Samples were dried at 55^{o}C, weighed, ground to pass through a 1-mm sieve, subsampled (0.1 g), and analyzed for TN by combustion utilizing an Elementar vario Macro (Elementar Analysensysteme GmbH, Hanau, Germany). The product of TN concentration and weight of dry biomass was used to calculate TN uptake. At maturity, the center five rows of each plot were harvested, the moisture content (collected using a moisture meter (GAC 2100, Dickey-John)) and weight of the grain was collected to determine rice grain yield expressed as kg rough rice ha^{-1} at 120 g H_2O kg^{-1}.

Statistical Analysis

All statistical analyses were carried out using JMP PRO 9.0 (SAS Institute, Inc., Cary, NC). Data analysis for the rice TN uptake and grain yield utilized a randomized complete block design with treatments arranged in a split-plot structure with four replications; with PL application time and location representing the main-plot factors, PL rate of application representing the split-plot factor and, year as a random effect. Statistical analysis for AH-N concentrations and recommendations were treated as a randomized complete block design with

treatments arranged in a split-split plot structure with four replications. Poultry litter application time and location represented the main-plot factors, PL rate of application represented the split-plot factor, and soil sample time represented the split-split plot factor with year as a random effect. Analysis for N-STaR was performed on the 0-15 and 0-45 cm depths as these two depths represent the depth of PL incorporation and the recommended soil sampling depth for silt loam soils, respectively (Roberts et al., 2011). To obtain values for the 0-15 and 0-45 cm depths for each plot, values for individual depths were summed and divided by the number of depths used in the summation. For example, the value for 0-45 cm depth represents the mean value of the 0-15, 15-30, and 30-45 cm depths for that plot. Soil depth means were calculated by averaging replicates for each depth increment. Appropriate means were separated using Fisher's protected LSD method, assessing significant differences when $P< 0.05$.

RESULTS AND DISCUSSION

Rice Response Parameters

Rice TN uptake was significantly influenced by the two-way interaction of location x PL rate (Table 2.2). Total-N uptake was significantly greater at the RRS than at the PTRS location at all PL litter rates except the 6720 kg litter ha^{-1} rate (Fig. 2.3). Trends in TN uptake varied by location with a linear increase at PTRS from the lowest to highest PL rate, but this was not observed at the RRS location. Results from the RRS location for TN uptake increased as PL rate increased for the 0, 2240, and 4480 kg litter ha^{-1} treatments, but then decreased for the 6720 kg litter ha^{-1} application, with the 6720 kg litter ha^{-1} rate being nearly equivalent to the 2240 kg litter ha^{-1} rate for TN uptake. Maximum TN uptake for the RRS location was 100 kg N ha^{-1} at the 4480 kg litter ha^{-1} and was significantly higher than maximum TN uptake at the PTRS location which was 80 kg N ha^{-1} at the 6720 kg litter ha^{-1} rate. Previous research has shown that TN

uptake generally increases with increasing PL application rate due to the associated increase in applied N (Golden et al., 2006). However, the decrease in TN uptake at the RRS at the highest PL rate could be attributed to increased salts associated with this high litter rate negatively affecting the amount of biomass produced. The 6720 kg litter ha^{-1} rate had a similar tissue N concentration to the 4480 kg litter ha^{-1} rate, but resulted in significantly lower biomass production (data not shown).

Rice grain yield was significantly influenced by PL rate and the two-way interaction of PL application time x location, both with a *P*-value of <0.0001 (Table 2.4). As PL rate increased there was an increase in rice grain yield for the 0, 2240, and 4480 kg litter ha^{-1} PL application rates, with the 6720 kg litter ha^{-1} rate not being significantly different than the 4480 kg litter ha^{-1} rate (Fig. 2.4). Maximal yield was achieved when PL was applied at a 4480 kg litter ha^{-1} rate with a rice grain yield of 6316 kg ha^{-1} (Fig. 2.4). When evaluating the two-way interaction of PL application timing x location, the PTRS location attained the overall highest rice grain yield when PL was applied at-planting with a rice grain yield of 6687 kg ha^{-1} (Fig. 2.5). However, the at-planting PL application time at the RRS location produced the overall lowest yield.

The decrease in yield at the RRS location for the at-planting PL application when compared to the PTRS location could have been caused by a high accumulation of salt associated with PL rates greater than 2240 kg litter ha^{-1} being present during the growing season when applied closer to crop establishment. This image (Pic. 2.1) displays the effect of high PL rates for the 1-month prior to planting PL application on weed germination and growth prior to rice planting at the RRS location which could have also influenced overall rice growth and yield. High rates of PL can cause salinity problems for rice due to increasing concentrations of soluble salts (Norman et al., 2003). The effects of salinity on rice occur from the increased osmotic

pressure of the soil solution impairing the plant's ability to absorb water at the seedling growth stage. Two weeks following the application and incorporation of PL at the RRS location, the $EC_{1:2}$ of the 0-15 cm soil depth was 0.165, 0.213, 0.221, and 0.324 dS m^{-1} for the 0, 2240, 4480, and 6720 kg litter ha^{-1} treatments, respectively. Previous research has found that salinity levels equivalent to the 6720 kg litter ha^{-1} treatment (0.324 dS m^{-1}) can be harmful to rice growth at the seedling growth stage (Wilson et al., 2000). The 1-month prior to planting PL application resulted in similar yields for both the RRS and PTRS locations with yields of 5635 and 5779 kg ha^{-1}, respectively (Fig. 2.5). Our results indicate that the applied PL is effecting rice grain yield similarly at both locations when applied 1-month prior to planting, allowing for N transformations and losses to occur prior to plant utilization.

N-STaR Soil Test Values (0-15 cm Depth)

Poultry litter had a significant influence on AH-N involving the main effect of PL rate, and the two, two-way interactions of PL application time x soil sample time, and soil sample time x location for both the 0-15 and 0-45 cm soil sample depths (Table 2.3). The 0-15 cm depth soil sample increment can be used to show how a PL application influences N-STaR soil test values within the depth of incorporation and for crops that use a shallow (0-15 cm deep) soil sample (e.g. wheat (*Triticum aestivum* spp.)). Although not statistically compared, the 0-15 cm soil depth had higher numerical values of AH-N when compared to the 0-45 cm soil depth following a PL application. This is potentially a result of the 0-15 cm soil sample depth only encompassing the volume of soil that the PL was incorporated into, while the 0-45 cm soil depth includes the surface soil and subsoil with a lower N concentration which results in lower AH-N values when compared to the 0-15 cm soil depth. Previous research has also identified that AH-N values measured by the Illinois Soil N Test and N-STaR decrease as soil sampling depth

increases (Mulvaney et al., 2006; Roberts et al., 2009a), describing why the untreated control of the 0-15 cm sapling depth resulted in higher AH-N values than the untreated control of the 0-45 cm sampling depth.

Alkaline hydrolyzable-N increased as PL rate increased (*P*-value of 0.0042; Table 2.3), with AH-N values ranging from 84 to 92 mg AH-N kg soil^{-1} for the 0 and 6720 kg litter ha^{-1} rates, respectively (Fig. 2.6). Increases in PL rate resulted in a linear increase in AH-N values with significant differences when comparing the 0 to the 4480 kg and 6720 litter ha^{-1} rates and comparing the 6720 to the 0 and 2240 litter ha^{-1} rates. The resulting difference in AH-N of 8 mg N kg soil^{-1} between the untreated control and highest PL application was significant and indicates the sensitivity of the N-STaR method for identifying small changes in AH-N values. The source of interaction of soil sample time x location effect on AH-N is the differences in trends for AH-N over time at both locations. When evaluating the 0-15 cm soil sample, the PTRS location slightly increased numerically in AH-N over time (Fig. 2.7). Conversely, the RRS location initially numerically increased in AH-N by 4 mg N kg soil^{-1} in the initial 2 wk following planting, followed by a numerical decrease in AH-N by 6 mg N kg soil^{-1} between the 2 wk and 4 wk sampling time (Fig. 2.7). However, when comparing AH-N values within a location there were no significant differences identified across soil sampling times. The PTRS location had significantly higher AH-N values at all three soil sampling times compared to the RRS location, with differences between locations within a single soil sampling time as great as 25 mg N kg soil^{-1}.

Alkaline hydrolyzable-N in the 0-15 cm depth was significantly influenced by soil sample time x PL application time (*P*<0.0001, Table 2.3). When comparing AH-N within a PL application time across soil sampling times, there were no significant differences observed (Fig.

2.8). However, when comparing PL application times within a single soil sampling time, there was only a significant difference found at the 0 wk soil sample time with a difference of 14 mg N kg soil^{-1} between treatments. The 1-month prior to planting PL application resulted in numerically higher AH-N values at all three soil sampling times potentially caused by the earlier application allowing more time for the organic-N in the PL to mineralize into plant available N. The soil sample time x PL application time interaction is a result of different responses in AH-N across soil sampling time for the PL application treatments.

N-STaR Soil Test Values (0-45 cm Depth)

Alkaline hydrolyzable-N was significantly influenced by the main effect PL rate, and PL application time x soil sample time and soil sample time x location interactions similar to the trends seen with the 0-15 cm sample depth (Table 2.3). Poultry litter rate as a main effect significantly increased in AH-N as PL application rate increased (*P*-value of 0.0096; Table 2.3), where treatment values ranged from 54 to 61 mg AH-N kg soil^{-1} (Fig. 2.9). The 7 mg N kg soil^{-1} difference in AH-N values when comparing the 0 and the 6720 kg litter ha^{-1} rate application was statistically significant and helps support the ability of N-STaR to identify small changes in potentially mineralizable soil-N.

Alkaline hydrolyzable-N was also significantly influenced by the two-way interaction of soil sample time x location ($P<0.0001$;Table 2.3), with the PTRS location having statistically higher AH-N values at all three sample times when compared to the RRS location (Fig. 2.10). This is potentially a result of more subsoil N (depths > 15 cm) being mineralized at the PTRS resulting in higher overall AH-N values. The RRS location had a slight numerical decreased in AH-N from 49 to 43 mg N kg soil^{-1} within four weeks after planting; whereas, the AH-N values

at the PTRS location had a slight numerical decreased between the 0 wk and 2 wk soil sampling times and then increased between the 2 wk and 4 wk soil sampling times. The difference between the locations in regard to AH-N values may be related to soil properties such as slight textural differences. Although both of these soils are classified as silt loams and can be cropped to rice, the Hebert silt loam at the RRS has a noticeable higher sand content, with greater internal drainage and potential for leaching of N. On average, there was an AH-N difference of 21 mg N kg soil^{-1} between the two locations at all three soil sampling times (Fig. 2.10). Furthermore, the significant interaction (P= 0.0152) of PL application time x soil sample time (Table 2.3) resulted in a significant difference between the PL application times only at the first soil sampling time, with the remaining sample times not being significantly different across PL application times (Fig. 2.11). However there were no significant differences in AH-N within a PL application time for all three soil sampling times suggesting that the addition of PL provide fairly stable AH-N values over the course 4 wk course of soil sample collection.

N-STaR N Rate Recommendation (45 cm Depth)

Currently N-STaR N rate recommendations are determined from AH-N values obtained from a 0-45 cm depth and the linear N rate prediction equation provided by Roberts et al. (2011). Therefore, nearly identical statistical results were identified between the AH-N values and N-STaR N rate recommendations for the 45 cm depth soil samples (Table 2.3). The N-STaR N rate recommendation was significantly influenced by PL rate as a main effect, location x soil sample time, and PL application time x soil sample time interactions (Table 2.3). Although the statistical analysis for N-STaR N rates was identical to AH-N, the trends in the data are opposite since the two values are inversely proportional. Increases in AH-N values result in lower N-STaR N rate recommendations and vice versa. As the rate of PL applied increased, there was a significant

decrease in the N-STaR N rate recommendation identified (*P*-value of 0.0096) with only an 11 kg N ha^{-1} difference in the N rate recommendation between the 0 and 6720 kg litter ha^{-1} PL rate applications using N-STaR analysis (Fig. 2.12). Similar to the results for AH-N there were significant differences in the N-STaR N rate recommendations when comparing the 0 to the 4480 kg and 6720 litter ha^{-1} rates and comparing the 6720 to the 0 and 2240 litter ha^{-1} rates. However, following typical PL application rates of 2240 and 4480 kg litter ha^{-1}, the N-STaR N rate recommendation only decreased by 3 and 8 kg N ha^{-1}, respectively.

The N-STaR N rate recommendation was significantly influenced by the interaction of soil sampling time x location (*P*= 0.0002; Table 2.3). The RRS had significantly higher N-STaR recommendations at all soil sample times when compared to the PTRS location (Fig. 2.13). The average N-STaR N recommendation rate for the RRS location was 40 kg N ha^{-1} higher than the PTRS location across all soil sampling times as a result of the PTRS location having a higher residual available N content and AH-N values. At the RRS location, the N-STaR N rate recommendation linearly increased from 232 to 244 kg N ha^{-1} across the 4 wk soil sampling period, representing the maximum difference in the N-STaR N rate recommendation within a location of 12 kg N ha^{-1}. Similar to the trends for AH-N these results highlight the sensitivity of the N-STaR procedure to identifying changes in potentially mineralizable-N across locations, but also indicates that there is fairly little fluctuation in these values within a location over the 4 wk window during which soil samples were taken. Evaluation of N-STaR N rate recommendations for the interaction of PL application time and soil sampling time (*P*=<0.0001) indicated the largest difference in AH-N between PL application time treatments was a 7 mg N kg $soil^{-1}$ change in AH-N, representing a 15 kg N ha^{-1} difference in the N recommendation using N-STaR (Fig. 2.14). Across sampling times and PL applications times there was on average only a 2 mg

AH-N kg soil^{-1} difference in the AH-N value between the two PL application treatments which represents a 4 kg N ha^{-1} difference in the N rate recommendation.

Previous research estimating N availability from PL applied prior to planting in direct-seeded, delayed-flood rice production systems on silt loam soils in Arkansas ("rule of thumb") has shown that roughly 16% of the total N applied as PL is utilized by the rice plant at heading (Golden et al., 2006). For example, using the 6720 kg litter ha^{-1} (255 kg N ha^{-1}) PL rate application, 41 kg of N ha^{-1} should be mineralized and taken up by the rice plant. At the highest PL application rate in this study (6720 kg litter ha^{-1}) there was a decrease of 20 kg of N ha^{-1} in the N recommendation using N-STaR when compared to the untreated control. However, the differences in TN uptake by the rice plant when comparing the untreated control to the highest PL rate was 23 kg ha^{-1} for the PTRS location, suggesting that for these particular locations and pelletized PL source that N-STaR is good estimate of potentially mineralizable-N and rice response to PL additions. Based on the results of this study it appears that AH-N and N-STaR are reasonable predictors of potentially mineralizable-N from pelletized PL and are better able to adjust N fertilizer rates than the standard "rule of thumb" approach. A potential limitation of AH-N methods and N-STaR in particular when quantifying potentially mineralizable-N from PL is the low recovery of urea and uric acid type compounds. Roberts et al., (2009b) indicated that less than 10% of urea was quantified using AH-N methods such as N-STaR, but can be a substantial component of the organic-N found in PL.

CONCLUSION

The focus of this study was to identify how PL applications influenced AH-N values and ultimately N-STaR N rate recommendations for rice produced on silt loam soils. Results of this

2-yr field study, at two locations, indicated that AH-N and N-STaR N rate recommendations are significantly influenced by: litter rate, soil sample time by location, and soil sample time by PL application time. The AH-N method used in this study was very sensitive to slight changes in potentially mineralizable-N following PL applications resulting in changes as small as 8 mg N kg soil^{-1} being statistically significant. Alkaline hydrolyzable-N is significantly influenced by a PL application, however from a practical standpoint the influence is insignificant when fertilizer application technology is considered. Although there were significant differences in AH-N values the results indicate that even large additions of PL have very little influence on the resulting N-STaR N rate recommendations.

These minimal changes in N-STaR recommendations are related to soil sample depth and the dilution associated with incorporation of PL in the top 15 cm of the soil profile. Soil sampling for N-STaR requires a 45 cm depth soil sample on silt loam soils and the magnitude of change in AH-N values when comparing the 0-15 cm depth to the 0-45 cm depth was quite different. The ability of N-STaR to quantify differences in potentially mineralizable-N from the addition of PL over a 45 cm deep soil sample indicates that it is truly able to quantify the forms of N that are mineralizing and feeding the rice plant throughout the growing season. Additionally, comparison of the TN uptake data suggests that N-STaR was a better predictor of the N credits from this pelletized PL source across locations and years than the previous "rule of thumb" approach that indicated 16% would be utilized by the rice crop. Further work is needed to identify how urea and uric acid type organic-N compounds fit into this relationship as they are not readily quantified by current AH-N methods such as N-STaR, but are contributing to plant total N uptake and yield. Previous research conducted by Diaz et al., 2008 indicated rapid hydrolysis of uric acid and urea-N, with total mineralization occurring within 14 d in an aerobic

incubation study. There is the potential that these types of compounds are quickly mineralized to ammonium, which are quantified using N-STaR and the N credit is actually captured during this phase prior to nitrification.

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Table 2.1. Selected soil characteristics at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

Year	Location	Soil Series	pH	Total N (mg N kg^{-1})	Total C (mg C kg^{-1})
2011	PTRS	Calhoun	7.8	900	8,100
2011	RRS	Hebert	5.9	1,000	9,300
2012	PTRS	Calhoun	7.7	600	6,600
2012	RRS	Hebert	6.2	700	7,800

Table 2.2. Analysis of variance for rice grain yield and total-N uptake as influenced by location, poultry litter (PL) application time, PL rate, and soil sample time.

Source of Variance	Total-N Uptake		Rice Grain Yield	
	DF	P-value	DF	P-value
Location	1	<0.0001	1	<0.0001
PL Application Time	1	0.3545	1	0.2486
PL Rate	3	<0.0001	3	<0.0001
Location x PL Application Time	1	0.7923	1	<0.0001
Location x PL Rate	3	0.0350	3	0.1142
PL Application Time x PL Rate	3	0.3035	3	0.4618
Location x PL Application Time x PL Rate	3	0.2732	3	0.0522

Table 2.3. Analysis of variance for the 0-15 and 0-45 cm depth soil samples for alkaline hydrolyzable-N (AH-N), and N-STaR (Nitrogen-Soil Test for Rice) nitrogen (N) rate recommendation for the 0-45 cm soil sample depth as influenced by location, poultry litter (PL) application time, PL rate, and soil sample time.

Source of Variance	DF	AH-N 0-15	AH-N 0-45	N-STaR N Rate Recommendation
		P-value	P-value	P-value
Location	1	0.0902	0.1083	0.1083
PL Application Time	1	0.4146	0.7500	0.7500
PL Rate	3	0.0042	0.0096	0.0096
Soil Sample Time	2	0.0865	0.0430	0.0454
Location x PL Application Time	1	0.5602	0.6244	0.6244
Location x PL Rate	3	0.8541	0.6569	0.8541
Location x Soil Sample Time	2	0.0127	<0.0001	0.0127
PL Application Time x PL Rate	3	0.1446	0.7496	0.1446
PL Application Time x Soil Sample Time	2	<0.0001	0.0152	<0.0001
PL Rate x Soil Sample Time	6	0.7742	0.9873	0.9879

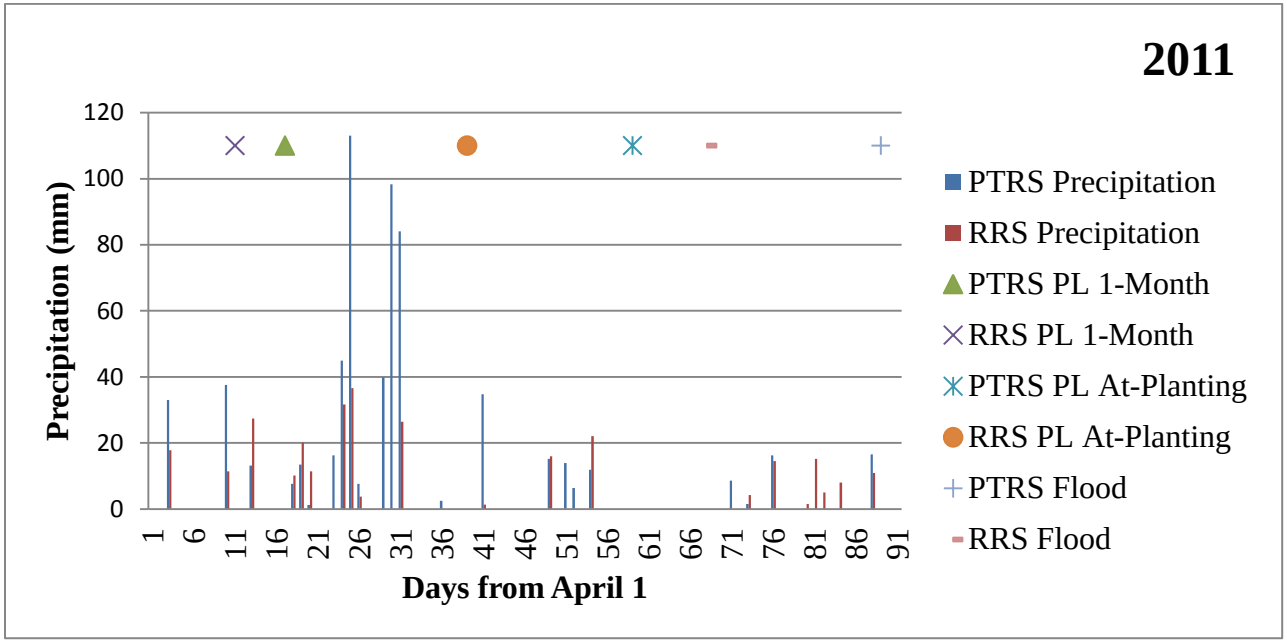


Figure 2.1. Daily precipitation in mm, poultry litter (PL) application, and flooding days, reported from April 1, 2011 as measured by the National Oceanic and Atmospheric Administration weather station for the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

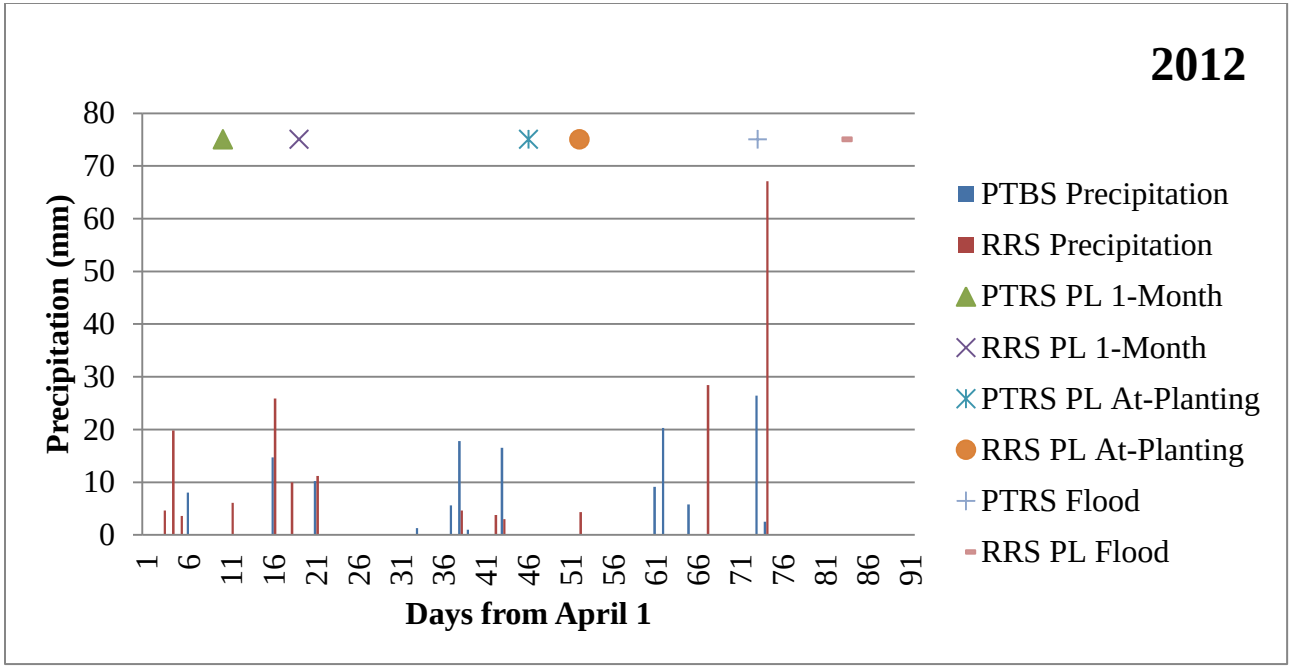


Figure 2.2. Daily precipitation in mm, poultry litter (PL) application, and flooding days, reported from April 1, 2012 as measured by the National Oceanic and Atmospheric Administration weather station for the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS).

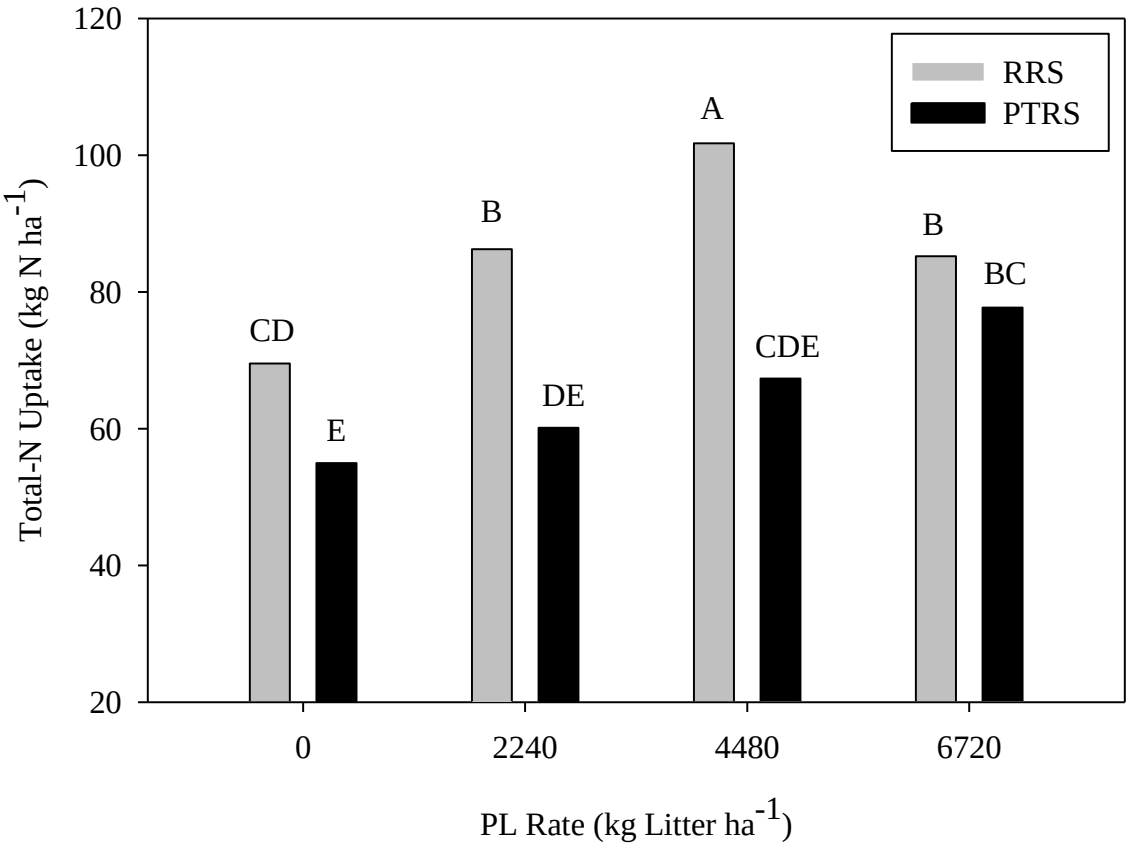


Figure 2.3. Influence of poultry litter (PL) rate and location on total-N uptake for the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). Means with the same letter are not significantly different at the $P<0.05$ level.

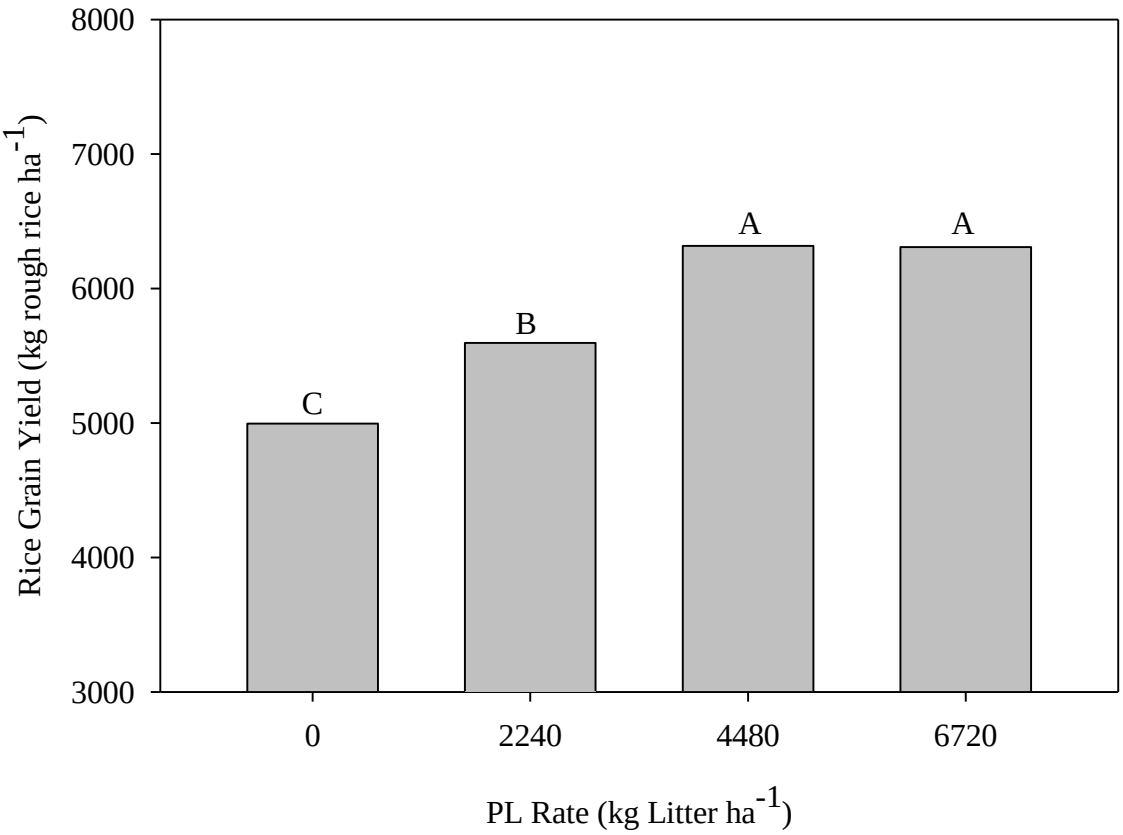


Figure 2.4. Influence of the main effect of poultry litter (PL) rate on rice grain yield. Means with the same letter are not significantly different at the $P<0.05$ level.

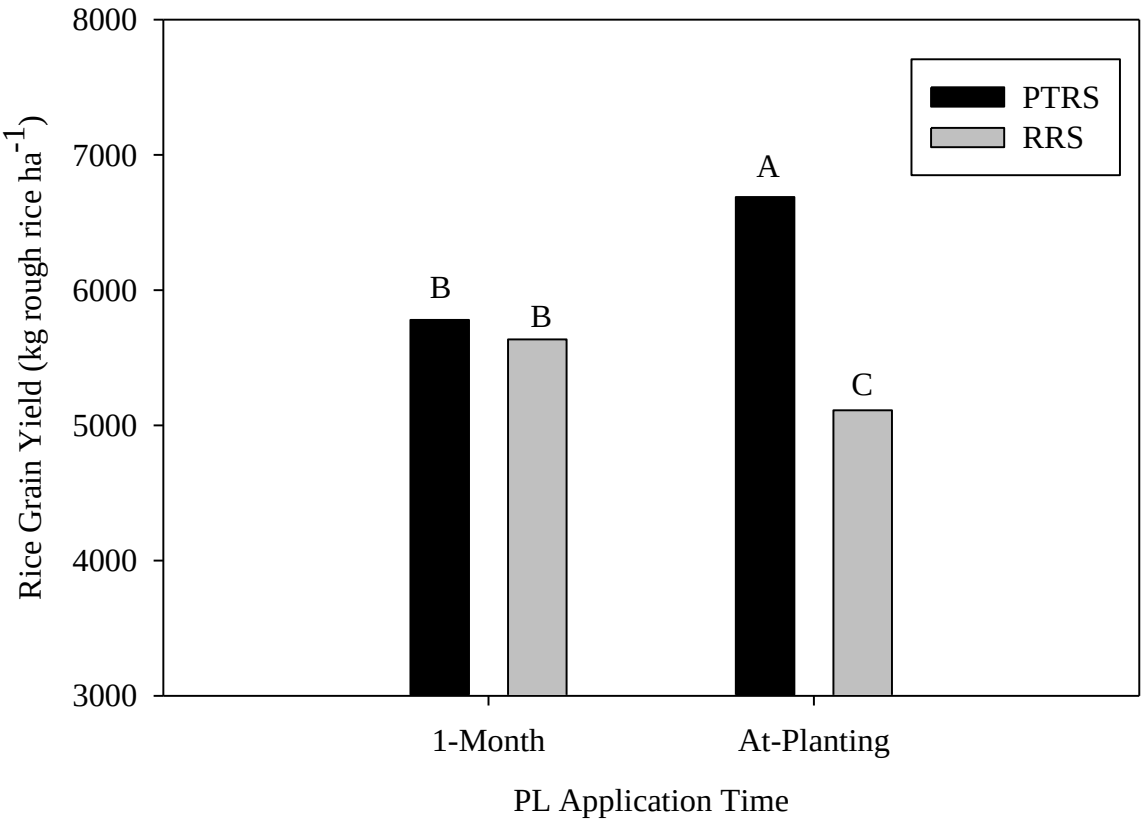


Figure 2.5. Influence of poultry litter (PL) application time and location on rice grain yield at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). Means with the same letter are not significantly different at the $P<0.05$ level.

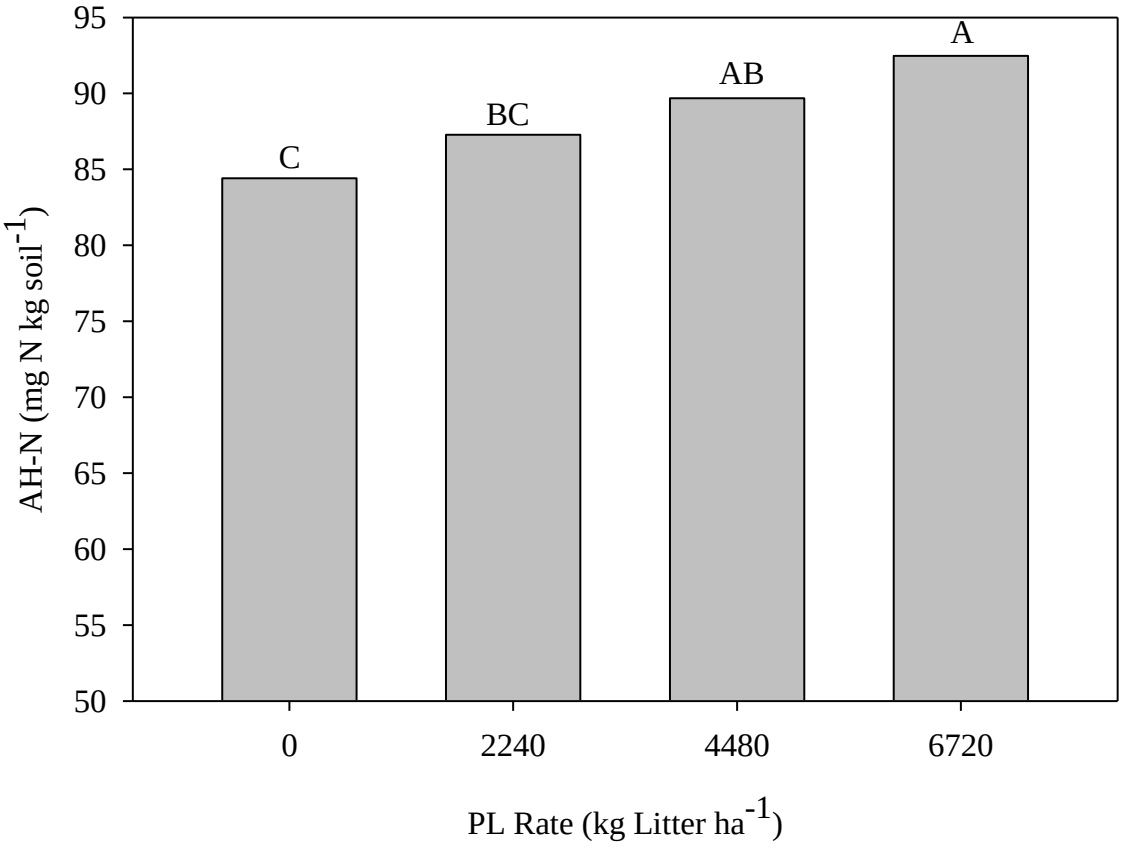


Figure 2.6. Influence of poultry litter (PL) rate on alkaline hydrolyzable-N (AH-N) for the 0-15 cm depth. Means with the same letter are not significantly different at the $P<0.05$ level.

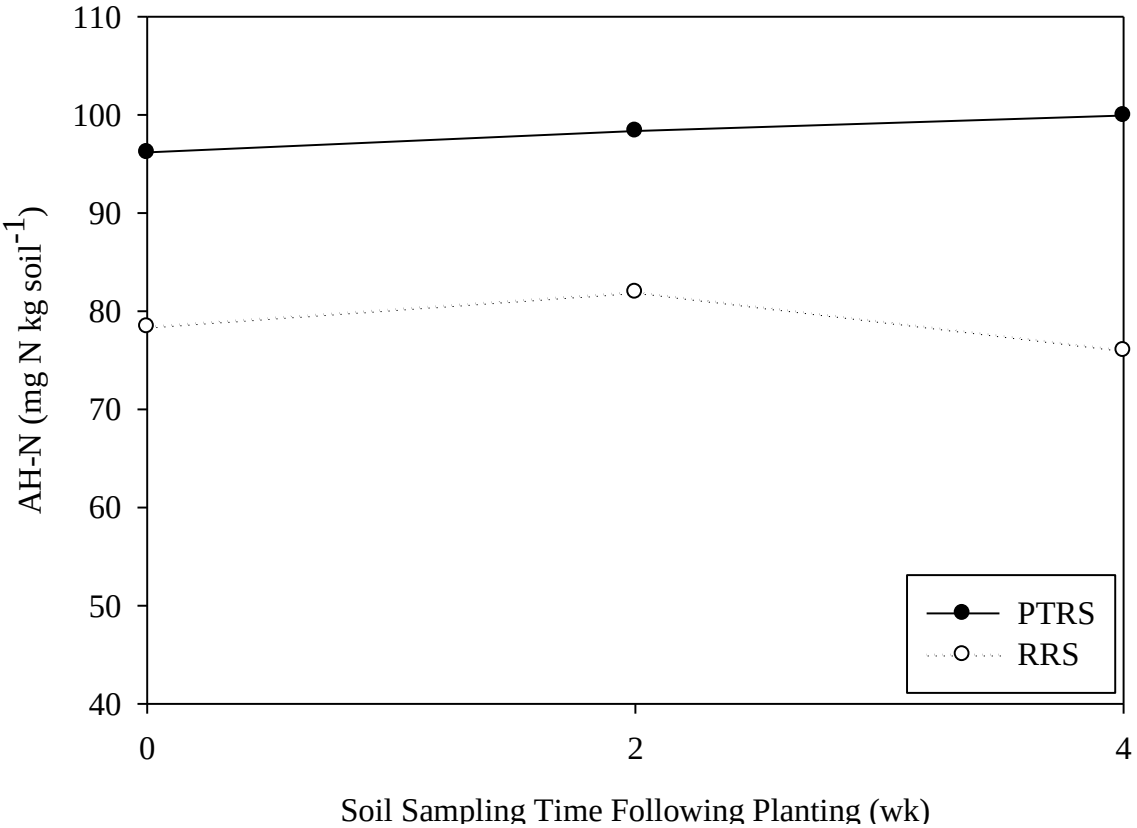


Figure 2.7. Influence of soil sample time and location on alkaline hydrolyzable-N (AH-N) for the 0-15 cm depth soil sample at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). LSD 0.05 to compare within a location across soil sampling times was 11.13 mg N kg soil^{-1} and the LSD 0.05 to compare across locations within a soil sample time is 12.44 mg N kg soil^{-1}.

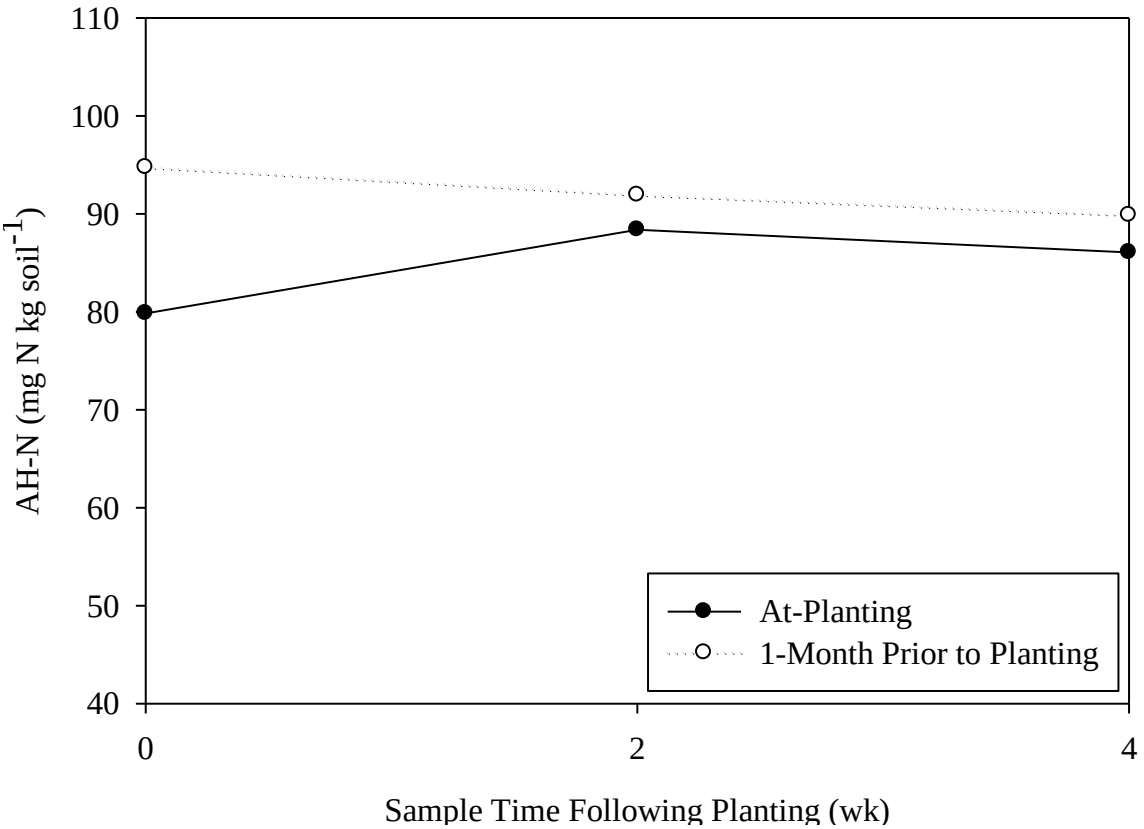


Figure 2.8. Influence of soil sample time and poultry litter application time on alkaline hydrolyzable-N (AH-N) for the 0-15 cm depth. LSD 0.05 to compare within a poultry litter application time across soil sampling times was 11.13 mg N kg soil^{-1} and the LSD 0.05 to compare across poultry litter application times within a soil sample time is 12.44 mg N kg soil^{-1}.

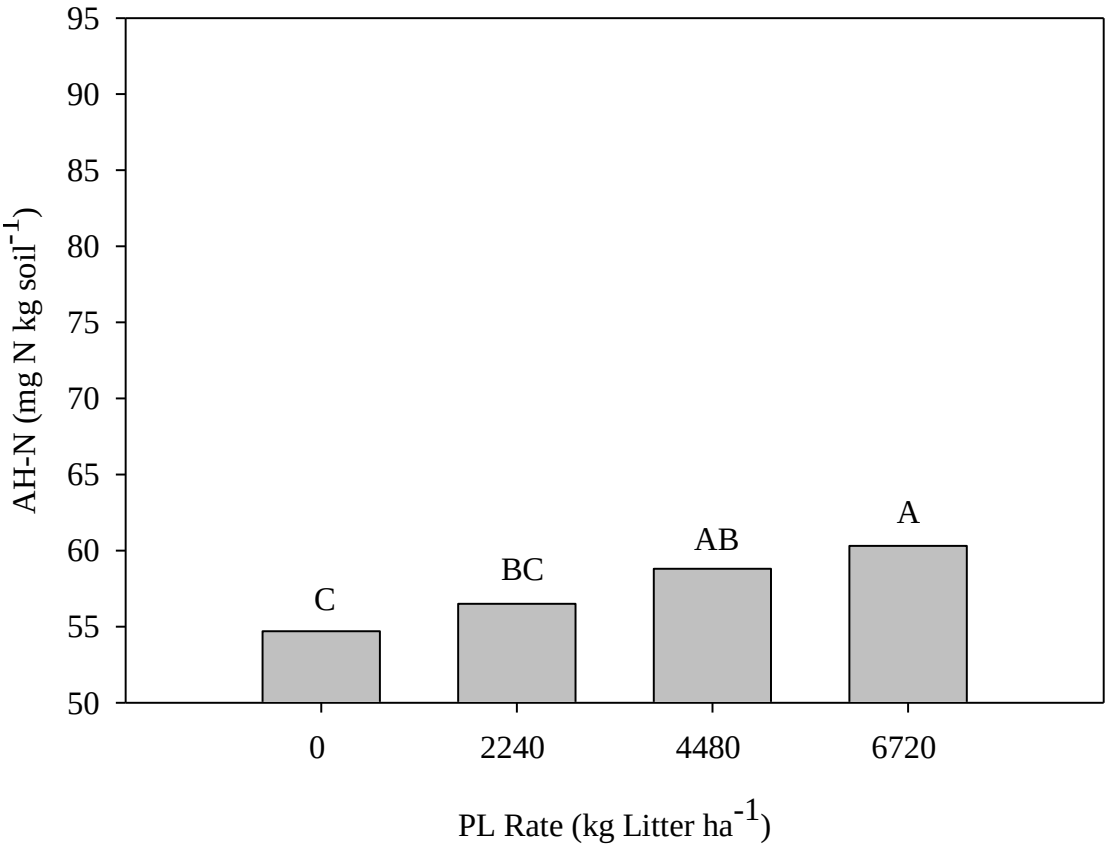


Figure 2.9. Influence of poultry litter (PL) rate on alkaline hydrolyzable-N (AH-N) for the 0-45 cm depth. Means with the same letter are not significantly different at the $P<0.05$ level.

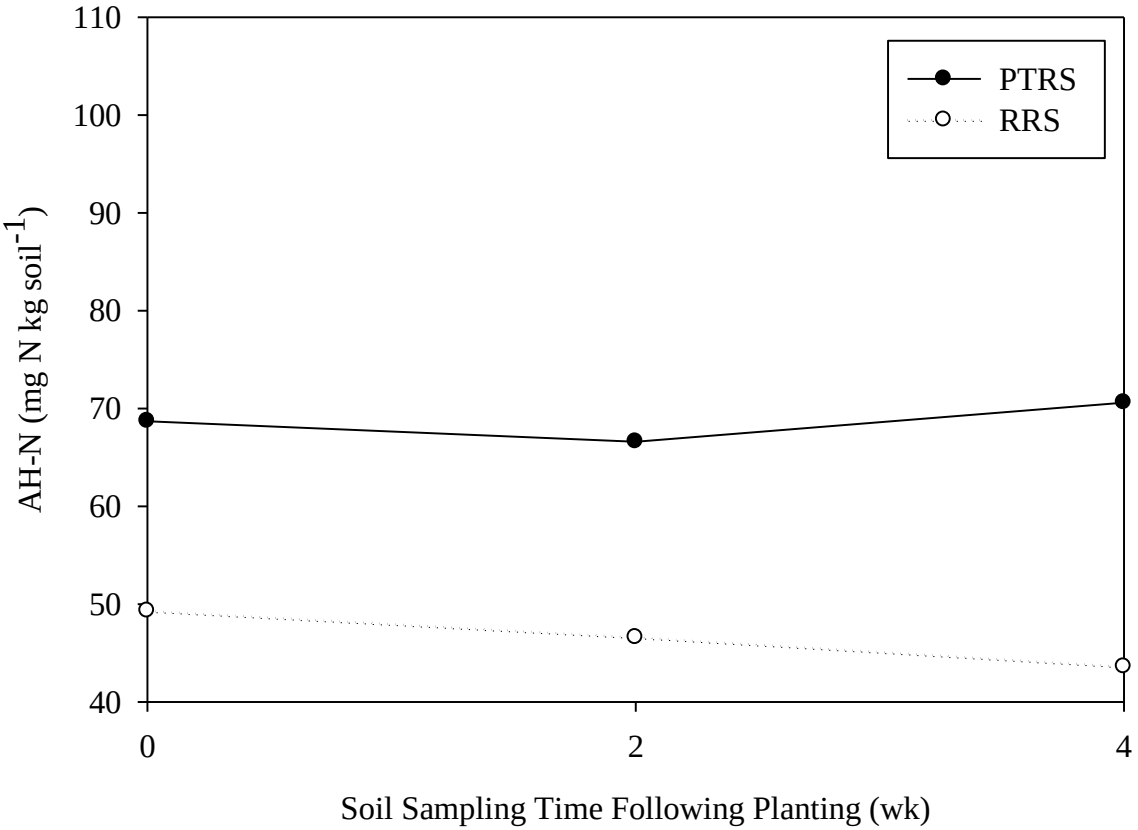


Figure 2.10. Influence of soil sample time and location on alkaline hydrolyzable-N (AH-N) for the 0-45 cm depth soil sample at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). LSD 0.05 to compare within a location across soil sampling times was 7.35 mg N kg soil^{-1} and the LSD 0.05 to compare across locations within a soil sample time is 5.99 mg N kg soil^{-1}.

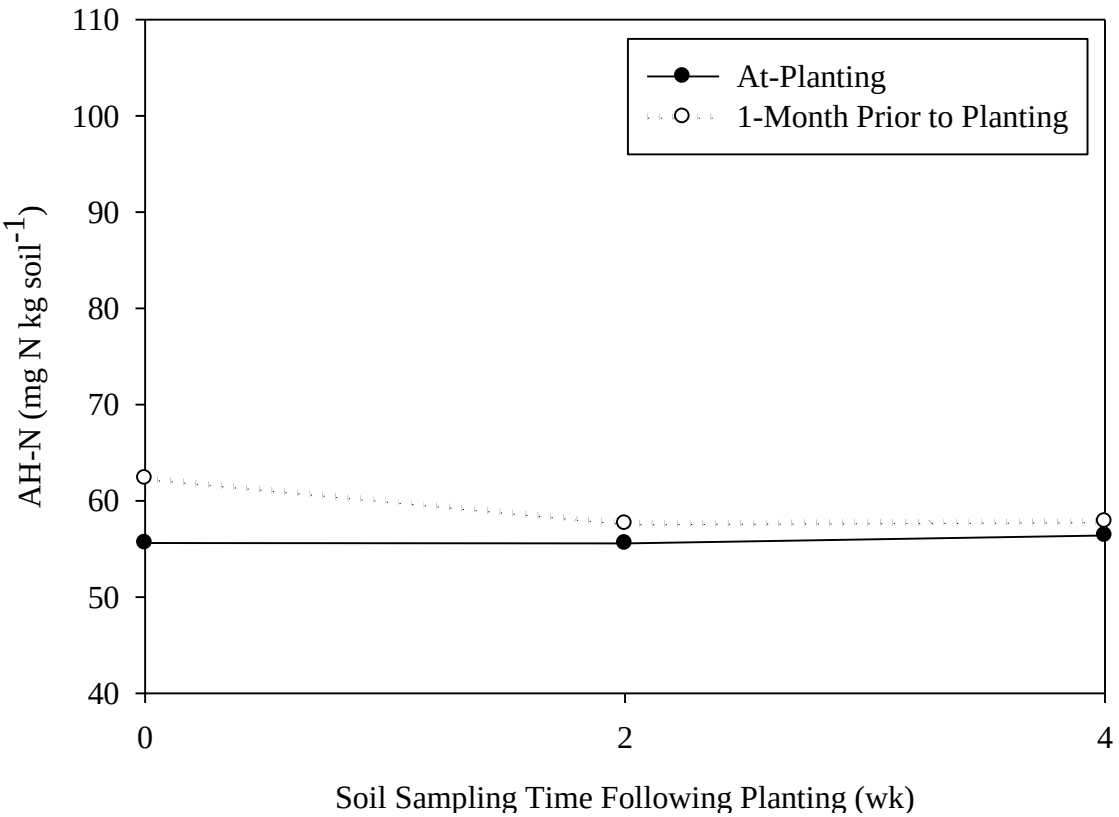


Figure 2.11. Influence of soil sample time and poultry litter application time on alkaline hydrolyzable-N (AH-N) for the 0-45 cm depth soil sample. LSD 0.05 to compare within a poultry litter application time across soil sampling times was 7.35 mg N kg soil^{-1} and the LSD 0.05 to compare across poultry litter application times within a soil sample time is 5.99 mg N kg soil^{-1}.

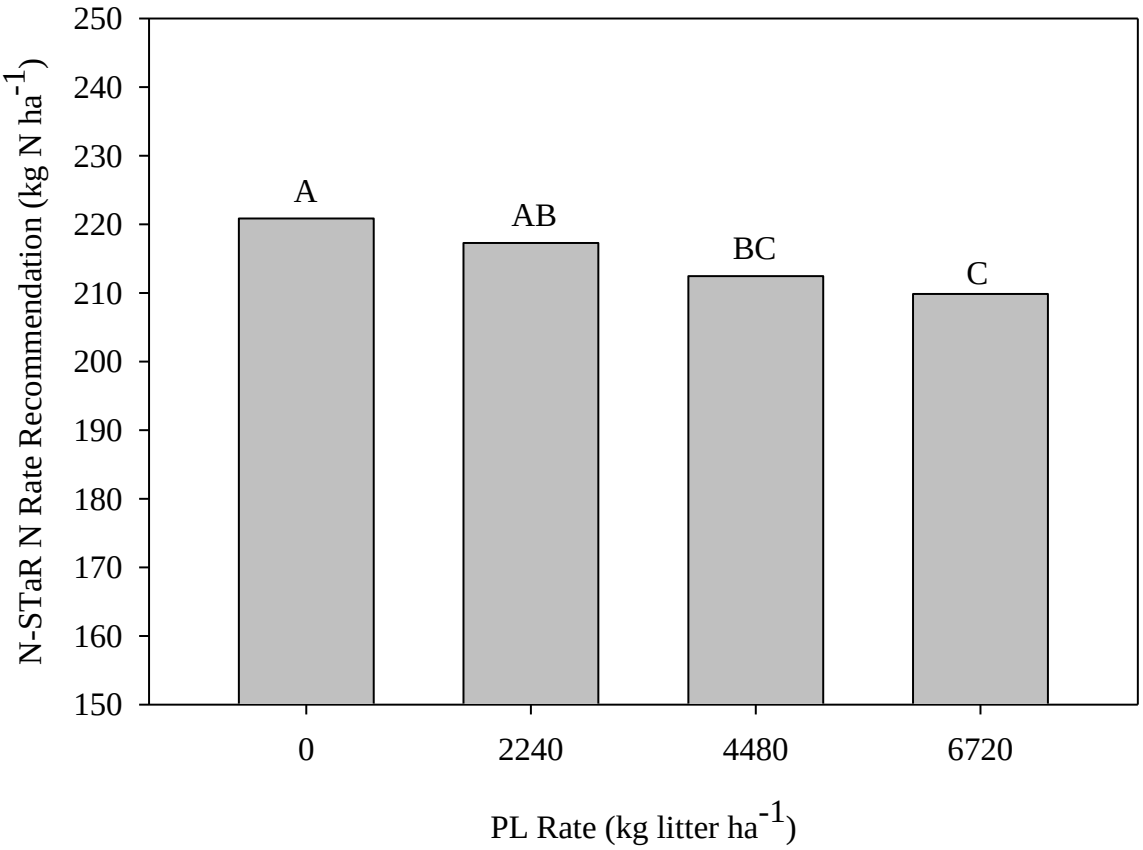


Figure 2.12. Influence of poultry litter (PL) rate on N-STaR (Nitrogen-Soil Test for Rice) nitrogen (N) rate recommendation. Means with the same letter are not significantly different at the $P<0.05$ level.

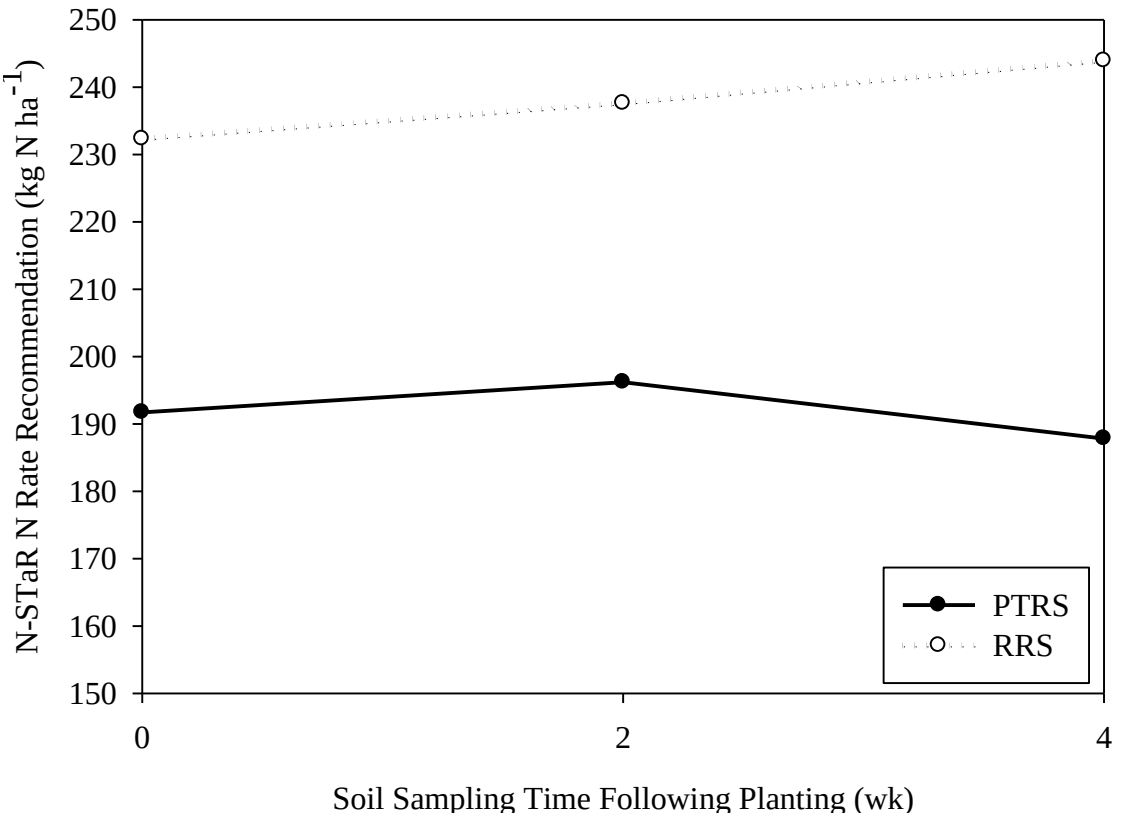


Figure 2.13. Influence of soil sample time and location on N-STaR (Nitrogen-Soil Test for Rice) nitrogen (N) rate recommendation for the 0-45 cm depth soil sample at the Pine Tree Research Station (PTRS) and Rohwer Research Station (RRS). LSD 0.05 to compare within a location across soil sampling times was 13.67 kg N ha^{-1} and the LSD 0.05 to compare across locations within a soil sample time is 11.14 kg N ha^{-1}.

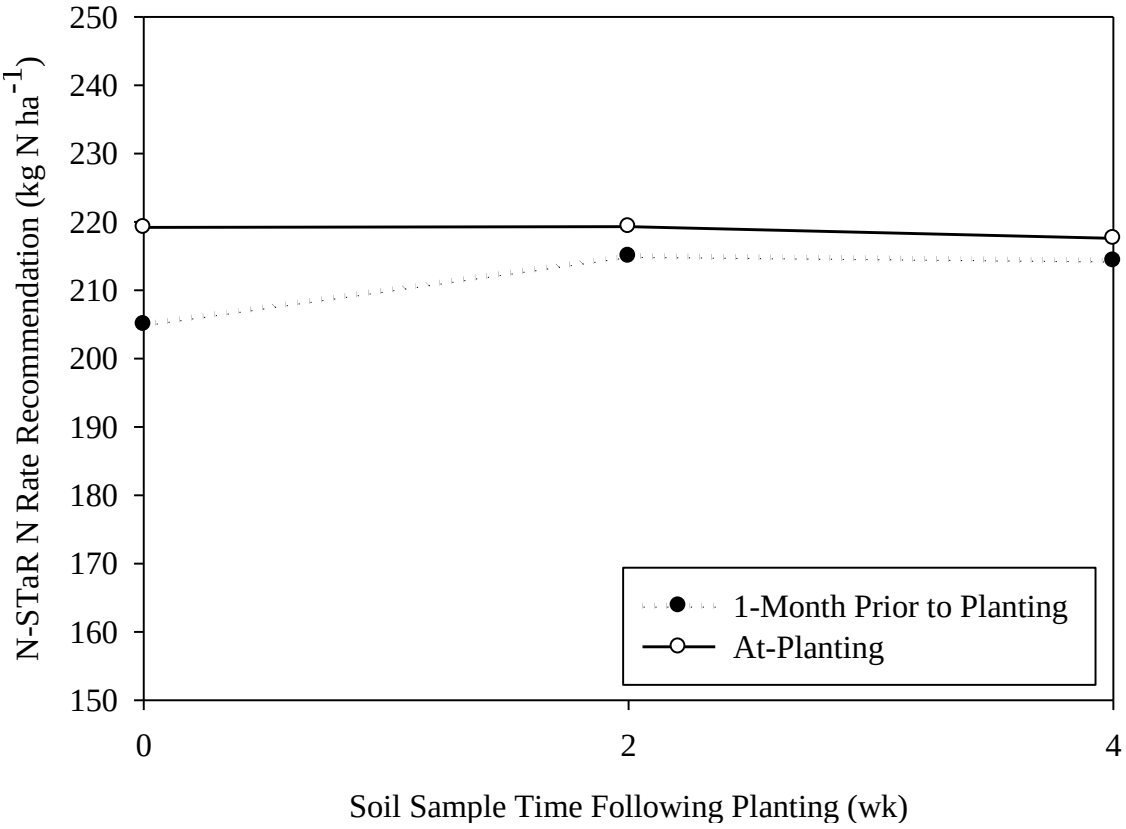
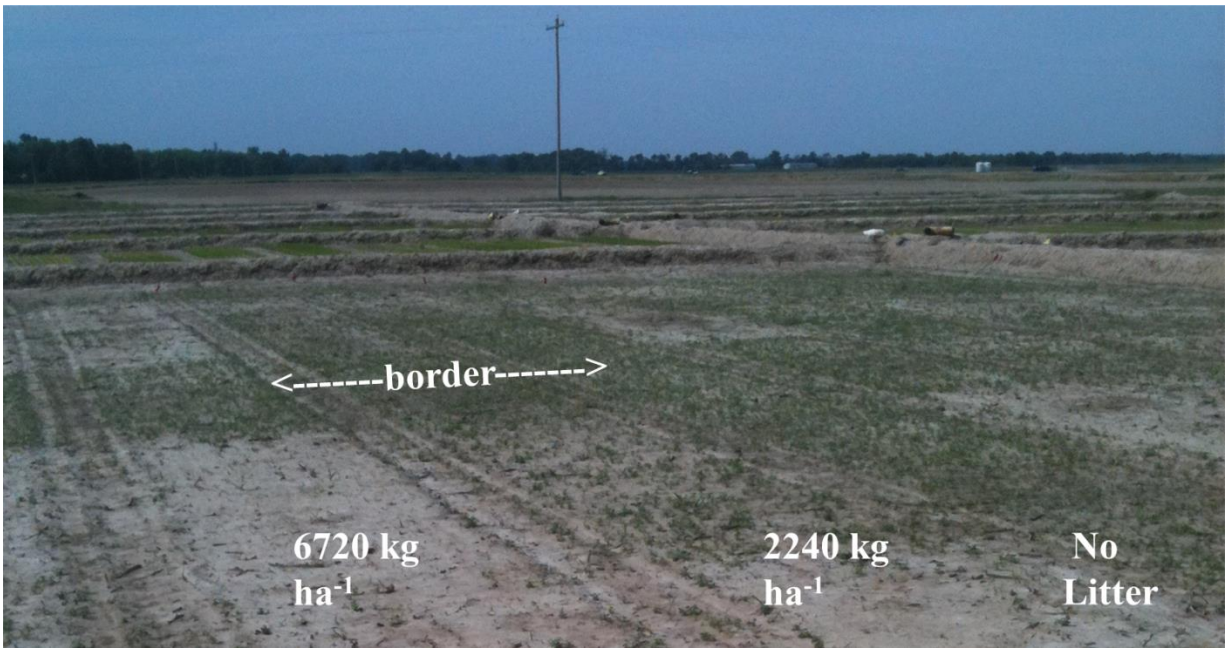


Figure 2.14. Influence of soil sample time and poultry litter application time on N-STaR (Nitrogen-Soil Test for Rice) nitrogen (N) rate recommendation for the 0-45 cm depth soil sample. LSD 0.05 to compare within a poultry litter application time across soil sampling times was 13.67 kg N ha^{-1} and the LSD 0.05 to compare across poultry litter application times within a soil sample time is 11.14 kg N ha^{-1}.



Picture 2.1. Effect of various poultry litter (PL) rates on weed growth prior to planting at the Rohwer Research Station (RRS) indicating the presence of salts associated with high PL application rates (photographed by author).

CHAPTER THREE

Laboratory Evaluation of Poultry Litter Sources Impact on N-STaR Soil Test Values and Inorganic Nitrogen Concentrations

ABSTRACT

The recently developed Nitrogen Soil Test for Rice (N-STaR) has become the standard soil test for N recommendations for rice (*Oryza sativa* L.) in Arkansas. The addition of poultry litter (PL) as a fertilizer source has increased in popularity in the delta region of Arkansas where the majority of row crop production occurs. The research objective was to quantify how different PL sources, varying in moisture and composition, influence N-STaR soil test values and inorganic-N concentrations over time to determine guidelines for soil sampling protocols to determine N-fertilizer recommendations. A 60-d aerobic soil incubation study was established using five PL sources and a temperature of 23^{o}C. Significant fluctuations in alkaline hydrolyzable-N (AH-N), NH_4-N, and NO_3-N were observed within the first 15 d of the experiment. After the 15 d extraction time, changes in N were minimal and equilibrated for the duration of the study. Information relating to the influence of PL on N-STaR soil test values ensures that the proper N recommendation is determined using N-STaR following a PL application. When using AH-N for N recommendations in rice it is essential to wait until AH-N reaches an equilibrium and conversion to NO_3-N has occurred prior to soil sampling. The results of this study demonstrate the ability to design soil sampling protocols, recommending that rice producers need to wait at least 15 d following a PL application before collecting soil samples for N recommendations using N-STaR.

INTRODUCTION

Arkansas is the leading rice (*Oryza sativa* L.) producing state in the U.S., with rice occupying approximately 500,000 ha in Arkansas annually. Rice production in Arkansas is concentrated on the eastern half of the state and is typically produced on silt loam soils, with an increasing number of hectares being devoted to rice production on clayey soils. Poultry litter (PL) is considered one of the most nutrient-rich animal manures and is applied to a large number of row-crop hectares each year in Arkansas. Poultry production in Arkansas is concentrated in the northwest corner of the state and can produce a substantial quantity of PL requiring transportation before being applied to production fields. Poultry litter consists of poultry manure and bedding material, which can consist of rice/peanut (*Arachis hypogaea* L.) hulls, wheat (*Triticum aestivum* spp.) straw, wood shavings, sawdust, recycled paper, and other dry, absorbent, low-cost organic materials.

Poultry litter is usually applied near poultry houses but due to the nutrient sensitive watershed areas in the northwest Arkansas, PL is transported to the delta region at ~91 Gg litter yr^{-1} (Kellogg et al., 2000). A representative analysis of PL in Arkansas is 3% N, 3% P, and 2.5% K and is applied at various times in the year ranging from the fall through the spring. Rice producers are applying PL as a fertilizer source when it is available and cost effective to apply. Poultry litter is typically applied to satisfy P and K recommendations, however previous research has shown as much as 16 to 19% of the total nitrogen (TN) applied as PL was recovered by the rice crop (Golden et. al., 2006; Wild et. al., 2011). Nyakatawa et al. (2010) found that surface applications of PL can rapidly increase soil organic matter, subsequently improving crop growth, soil water conservation, and yield. Diaz et al., 2008 showed that NH_4-N and uric acid-N in PL can provide a readily available source of inorganic-N for plant use. Estimating potentially

available N (PAN) from poultry manure can be difficult due to the variability associated with urea hydrolysis.

A concern when using PL as a N source is the variability in the N content of different litters as a result of different types of poultry, bedding materials, moisture contents, animal feed, and age (Chadwick et al., 2000). Approximately 89% of the N in PL is in the organic form, with the remaining TN found in PL as inorganic-N, with about 9% of the inorganic-N residing in the form of NH_4-N (Gaskin et al., 2013). With mineralization catalyzed by microbial activity, the rate in which the organic-N fraction of PL is mineralized can be rapid and is influenced by litter characteristics and soil temperature, moisture, and texture. Sharifi et al. (2011) found that the labile mineralizable-N pool of a soil is most sensitive to long-term additions of manure when compared to the intermediate pool of mineralizable-N, when the manure rate is within the plant N demand. Mulvaney et al. (2001) conveyed that the concentration of amino sugar-N tended to be higher for soils that have received manure than for non-manured soils.

For rice, PAN includes labile forms of organic-N as AH-N and NH_4-N. Due to the establishment of a permanent flood involved in the direct-seeded, delayed-flood production of rice, the majority of soil NO_3-N will be denitrified following the establishment of a permanent flood rendering it unavailable for crop uptake. However, for upland crops such as corn (*Zea mays* L.), AH-N, NH_4-N, and NO_3-N can be potentially plant available throughout the growing season. Studies have indicated that similar amounts of N from PL can be mineralized when comparing pelletized litter to fresh litter sources (Hadas et. al., 1983). Furthermore, regardless of the form of litter, similar plant N uptake and yield have been identified between pelletized and fresh litter sources (Golden et. al., 2006). Research has shown that mineralization and nitrification of PL-N is rapid following a PL application. Gordillo and Cabrera (1997) identified 33% of N from PL

was mineralized within 24 h and 59% mineralized within 1 wk in an aerobic incubation study. Laboratory incubation research conducted by Diaz et al. (2008) and Gordon et al. (2011) indicated NH_4-N concentrations following a PL application peaked within 1 wk.

A recent improvement in predicting N fertilizer requirements for rice production in Arkansas was the development of the Nitrogen-Soil Test for Rice (N-STaR) (Roberts et al., 2010; Roberts et al, 2011). This is a site-specific, soil-based N test that predicts potentially mineralizable soil-N (e.g., amino sugars, amino acids, and NH_4-N) as AH-N. Alkaline hydrolyzable-N is used to determine N fertilizer needs for rice on silt loam soils (Roberts et al., 2013) and uses the modified direct steam distillation (DSD) method (Bushong et al., 2008). This test uses a 45-cm deep soil sample (Roberts et al., 2009a) that can be collected any time following the harvest of the previous crop. The majority of labile organic-N recovered using the DSD procedure is amino sugar-N (e.g., galactosamine, glucosamine, mannosamine, and *N*-acetylglucosamine), and only recovers roughly 10% of the N in the form of urea (Roberts et al., 2009b). Furthermore, research conducted by Roberts et al. (2009b) has shown that N-STaR can be used as an alternative to the Illinois Soil N Test (ISNT), with both methods resulting in relatively the same amount of AH-N for a particular soil. Sharifi et al. (2011) identified no significant differences in the ISNT values as the rate of long-term additions of manure increased for dike-land soils, however there were numerical differences observed illuminating the ability of this test to be sensitive enough to detect minor changes in amino sugar-N following long term additions of manure.

The N-STaR method was developed to adjust N-fertilizer recommendations to maximize rice yield by accounting for N being supplied from the soil. Currently N-STaR is used to predict field-specific N requirements in Arkansas (Norman et al., 2013), however there is a lack of

research concerning the effect of PL applications on N-STaR soil test values. With rice producers using N-STaR and applying PL, it is imperative to understand how a PL application can influence N-STaR soil test values and inorganic-N concentrations. Therefore, the objective of this research was to quantify the influence of PL source on N-STaR soil test values and inorganic-N concentrations in a controlled laboratory incubation. Our goal was to determine the minimum time following a PL application needed to collect soil samples for accurate N fertilizer recommendations using N-STaR.

METHODS AND MATERIALS

Aerobic Soil Incubation

To evaluate the effects of PL source on N mineralization and N-STaR soil test values using KCl extraction (Mulvaney, 1996) and DSD (Bushong et al., 2008), a 60-d aerobic laboratory incubation was conducted. Treatments for this experiment included an no-PL control (no-PL) and five sources of PL (Table 3.1), arranged in a randomized complete block design with three replications. Four of the PL sources used in this incubation were collected from fresh litter samples submitted to the University of Arkansas Agricultural Diagnostic Laboratory (Fayetteville, AR) for nutrient analysis from Northwest Arkansas. The fifth PL sample was pelletized poultry litter (PPL) acquired from Perdue Agricycle (Seaford, DE). The four fresh PL sources were blended and stored in sealable bags. Poultry litter sources with widely ranging g kg^{-1} TN, g kg^{-1} TC, and g kg^{-1} moisture (Table 3.1) were used to cover a wide variation of potential PL sources that could be applied to rice production fields.

Soil used in incubation was collected at the University of Arkansas Pine Tree Research Station (PTRS, Colt, AR) mapped as a Calhoun silt loam (fine-silty, mixed, active, thermic

Typic Glossaqualfs) that was collected from the upper 15 cm (pH 7.9, 0.654 g kg^{-1} Total N, 6.565 g kg^{-1} Total C, and 18.2 g kg^{-1} soil organic matter).The soil was dried in a greenhouse, mixed, and crushed to pass a 2-mm sieve. The particle-size fraction of sand (8%), silt (74%), and clay (17%) of the soil was determined using the 24-h hydrometer method (Gee and Bauder, 2006); the Soil-Plant-Atmosphere-Water (SPAW) program (v6.02.75, USDA- ARS, Washington D.C.; Saxton and Rawls, 2006) was used to determine the relationship between soil gravimetric water content and matric potential. Based on the soil organic matter plus percent sand, silt, and clay, the SPAW program estimated a gravimetric water content of 0.20 kg H_2O kg^{-1} corresponding to a matric potential of -85 kPa and a bulk density of 1.3 g cm^{-3}, using data collected from previous research on soil from the same field (Gordon et al., 2011).

Following soil collection, the incubation was performed in 100-mL specimen cups filled with 100 g of soil. Filled cups were moistened and placed in an incubation chamber at 23^{o}C for a 10 d preincubation period. Immediately after the preincubation, PL was weighed (0.1612 to 0.3701 g PL100 g^{-1} soil; to the nearest 0.0001 g) to supply 166 kg N ha^{-1} (equivalent to 4.5 t ha^{-1} of the PPL) and added to the appropriate cup and mixed into the entire volume of the soil. Specimen cups with the amended PL were lightly covered with plastic wrap and placed in an incubation chamber at a constant temperature of 23^{o}C (average temperature of Mariana, AR in April and May of 2011). A -85 kPa matric potential (20% gravimetric moisture) was maintained throughout the duration of the incubation using deionized water. The specimen cups were checked every 4 d by weighing each cup and adding the appropriate amount of deionized water to maintain the adequate matric potential. Extractions to quantify soil inorganic-N content and AH-N analyses were performed at 0, 3, 7, 11, 15, 24, 33, 42, 51, 60 d after initiation of the incubation, using a 1 mol L^{-1} KCl solution and DSD apparatus. Since the KCl extraction and

DSD procedures are destructive in nature, duplicate samples were prepared for each PL sample time combination.

KCl Extraction and Direct Steam Distillation (DSD)

At each extraction time, corresponding specimen cups were removed from the incubator and soil was transferred into a 1 L bottle, 1 L of 1 mol L^{-1} KCl solution was added, and bottles were shaken for 1 h. After shaking, the mixture was filtered (Whatman 4, qualitative filter papers) into scintillation vials and sent to the University of Arkansas Agricultural Diagnostic Laboratory for analysis of NH_4-N and NO_3-N using a Segmented Flow Auto Analyzer (San System, Brenda, Netherlands). Concurrently, duplicate specimen cups were also removed from the incubator and the soil was transferred into soil boxes, dried at 55^{o}C, crushed to pass through a 2-mm sieve, and sent to the University of Arkansas N-STaR Soil Testing Laboratory to determine AH-N concentration using a modified alkali distillation procedure outlined by Roberts et al. (2011). The change in AH-N, NH_4-N, and NO_3-N concentrations were calculated by subtracting the measured concentrations from soil receiving PL by the concentration of the untreated control soil at each extraction time.

Statistical Analysis

Statistical analyses were carried out using JMP PRO 9.0 (SAS Institute, Inc., Cary, NC). Data were analyzed as a split-plot design with the whole plot being a randomized complete block design with 6 treatments (PL source) and 3 replications. The whole-plot factor was PL source and the split-plot factor was soil extraction time. Replicates were treated as a random effect while PL source and extraction time were fixed effects. Untreated control means were achieved by averaging the replicates at each extraction time. Means for AH-N, NH_4-N, and NO_3-N were

achieved by averaging the replicates at each extraction time and then subtracted by the averaged untreated control for each extraction time. Means were separated using the least significant difference (LSD) test, assessing significance at $P< 0.05$.

RESULTS AND DISCUSSION

With N-STaR being used on an increasing number of rice hectares annually, it is essential to understand how N recovery using this test is altered when PL is applied before soil samples are collected. This knowledge will allow us to ensure determination of the proper N recommendation that will produce the maximum yield, avoiding an over/under application of N when N-STaR samples are collected following an application of PL.

Soil AH-N Concentrations

There was a significant influence on net change in AH-N values as a result of a PL application, which was further influenced by the two-way interaction of PL source x extraction time ($P<0.0001$, Table 3.2). This interaction is a result of significant differences in AH-N values among litter sources for the 0 and 3 d extraction time (Fig. 3.1), demonstrating that N-STaR is quantifying N from the soil and PL concurrently. Substantial fluctuations in AH-N were observed within the first 7 d and peaked within the first 3 d. Significant differences among PL sources were observed only within the first 3 d of the incubation (Fig. 3.1). Changes in AH-N following PL addition ranged from 0 to 29 mg N kg soil^{-1}. Alkaline hydrolyzable-N stabilized around 2 to 6 mg N kg soil^{-1} after 15 d into the incubation for the fresh-1, -3, and PPL sources, with no significant changes in AH-N following the 15 d extraction (Fig. 3.2A, C, and E). Furthermore, following the 15 d extraction, AH-N for the fresh-1, -2, and PPL sources were not significantly different than the untreated control AH-N values. The fresh-2 and -4 PL sources did not become non-significantly different than the untreated control until the 24 d extraction, except

for the 60 d extraction for the fresh-4 PL source (Fig. 3.2B and D). This increase in AH-N at the 60 d extraction for the fresh-4 PL could be caused by immobilization of N by microbes, however this increase was not a sizable amount (less than 1.5 mg N kg soil^{-1}from being not significantly different than the untreated control) when determining N fertilizer recommendations using N-STaR. This indicates the importance of delaying soil sampling until AH-N values stabilize following the addition of PL.

Previous research has shown PL mineralization separated into distinct phases including a rapid initial flux of N mineralization followed by a slower rate (Hadas et al., 1983; Wild et al., 2011). Correspondingly, this experiment displays two phases of N mineralization with initial rapid fluctuations within 1 wk trailed by slow rate of mineralization which is relatively constant (Fig. 3.1). The AH-N concentrations followed similar trends to NH_4-N soil concentrations following a PL application identified by Hadas et al. (1983), reaching a maximal concentration within the first week followed by a substantial decrease. A large fraction of the organic-N in PL is in the form of urea or uric acid, the rapid mineralization of N in PL is associated with the rapid hydrolysis of urea into NH_3-N and then NH_4-N (Schefferle, 1965).

The fresh-2, -3, and -4 litters contained greater numerical initial inorganic-N concentrations than the fresh-1 and PPL, resulting in an immediate decrease in AH-N values from the establishment of the incubation (Fig. 3.2B, C, and D) potentially caused by nitrification and immobilization. However, the fresh-1 and PPL sources had greater N in the organic form, resulting in an initial increase in AH-N from the 0 to 3 d extraction followed by a significant decrease. All litter sources leveled-off at the 15 or 24 d extraction time, with a steady mineralization rate (Fig. 3.2). Also, PL sources that displayed delays in their peak AH-N concentrations (PPL and fresh-1) contained significantly lower initial moisture contents with at

least a 10% less moisture when compared to the other litter sources (Table 3.1). The higher moisture content of fresh-2, -3, and -4 litter sources potentially could have influenced microbial activity and caused this rapid initial mineralization. For the PPL and fresh-1 litter, there was an initial increase in AH-N from the 0 to 3 d extraction. This increase indicates that the organic-N in the PL was in a form that N-STaR could not quantify (i.e. urea) and was then hydrolyzed into a form of N that N-STaR could quantify (i.e. NH_4-N). Following this initial increase, there was a rapid decrease in AH-N between the 3 and 7 d extractions, resulting in another transformation of organic-N that N-STaR could not quantify (i.e. NO_3-N, or microbial biomass).

NH_4-N Concentrations

The net change in NH_4-N concentrations exhibited a significant PL source x extraction time interaction (P<0.0001, Table 3.2) similar to those seen with AH-N. The typical trend for changes in NH_4-N concentration following a PL application identified in this study illustrates an initial high concentration immediately following a PL application, as high as 15.5 mg N kg soil^{-1}, directly followed by a rapid decrease within the first 7 d (Fig. 3.3). Similar results were observed for an incubation experiment using PL and a Calhoun silt loam soil in Arkansas conducted by Gordon et al. (2011), reporting peaks in NH_4-N concentrations within the first 7 d after PL was applied. Wild et al. (2011) also found that PL-N mineralization occurred rapidly within the first 9 d in an anaerobic incubation followed by a slower rate of mineralization, with only 14% of PL-N mineralized after 60 d. Diaz et al. (2008) indicated that NH_4-N accumulation occurred immediately following an addition of PL until the end of 1 d, followed by a quick decrease by 3 d. This indicates that unidentified NH_4-N accumulation could have occurred in this study between our 0 and 3 d extractions.

After 7 d, NH_4-N values stabilized around 1.5 mg N kg soil^{-1} with negligible fluctuations occurring throughout the rest of the study for all the PL sources (Fig. 3.4). In this study, NH_4-N is a fluid N pool that is very transient leading to the majority of NH_4-N that is mineralized being nitrified. When comparing the NH_4-N concentrations for the five PL sources within a single extraction time, there was a significant difference identified at 0 and 3 d following the addition of PL (Fig. 3.3) potentially caused by differences in the initial N fractions (NH_4-N and urea) and moisture contents among litter sources (Table 3.1). After 3 d following the addition of PL, there were no significant differences between the five PL sources in NH_4-N values (Fig. 3.3).

When observing the various litter sources across time, similar trends were identified between AH-N and NH_4-N (Fig. 3.2 and 3.4), which was anticipated with NH_4-N being quantified as part of the AH-N values using N-STaR. Substantial NH_4-N concentration differences were identified between the 0 and 7 d extractions, indicating rapid mineralization and nitrification. Following the 7 d extraction, there were no significant differences in NH_4-N for the PPL and fresh-1, -3, and -4 litter sources. Fresh-2 litter had a numerical increase in NH_4-N at the 35 d extraction though it was only 4 mg N kg soil^{-1} higher than the previous and subsequent extraction times and was not statistically significant. When assessing changes in AH-N and NH_4-N, fluctuations in AH-N are not equivalent to changes in NH_4-N. This demonstrates the possibility of unidentified ammonification that ended up as NO_3-N due to a lack of adequate time resolution early in the incubation, with only two extraction times in the first 10 d after the initial 0 d extraction.

NO_3-N Concentrations

Analysis of variance *p* values indicate a significant two-way interaction involving PL source x extraction time ($P<0.0001$, Table 3.2). Soil NO_3-N concentrations followed similar

trends across time for all PL sources and displayed typical NO_3-N accumulation curves that would be expected following a PL application (Fig. 3.5). Nitrate-N trends displayed an initial increase in NO_3-N as the NH_4-N was being nitrified. Once the NH_4-N is consumed the NO_3-N concentration stays relatively constant. Less than 5 mg N kg^{-1} soil of NO_3-N was quantified for all PL sources in the 0 d extraction, indicating low initial NO_3-N concentrations were present in the PL. Nitrate-N accumulation after 3 d was rapid, suggesting rapid nitrification of NH_4-N (Fig. 3.5).

The NO_3-N concentrations equilibrated around 25 mg N kg $soil^{-1}$ after 15 d, with no significant differences identified among PL sources until the 42 d extraction (Fig. 3.5). At 42 d fresh-1 litter indicated an anomaly, reaching the level-off period but then found a peak in NO_3-N of 10 mg N kg $soil^{-1}$ when the N in the litter is nitrified followed by a decrease as immobilization occurs (Fig. 3.6), a potential reason for this could be due to the makeup of litter having the highest TN and TC (Table 3.1). For all PL sources, conversions of N were rapid, with nearly entire mineralization and nitrification occurring in the first 15 d of the incubation (Fig. 3.3 and 3.5).

When evaluating NO_3-N concentration changes over time within a single PL source, fresh litter-2 and -3 peaked within the first 3 d of the incubation (Fig. 3.6). The NO_3-N concentration of the PPL and fresh-1 litter did not plateau until the 15 d extraction, possibly a result of both litters having the highest TN and TC with the lowest initial moisture content (Table 3.1). Similar results were observed by Diaz et al. (2008) indicating maximum accumulation of NO_3-N from PL by 14 d in an incubation study at 25^{o}C. Fresh-4 litter equilibrated around 20 mg N kg $soil^{-1}$ at the 7 d extraction, but exhibited an anomaly at 11 d reaching a NO_3-N concentration of 35 mg N kg $soil^{-1}$, which contained the lowest TN when compared to the other litter sources.

Comparison of Concurrent Changes in AH-N, NO_3-N, and NH_4-N

Maximal changes in AH-N are relatively similar to the maximal changes in NO_3-N, even though the changes in NH_4-N concentrations are not equivalent to the change in NO_3-N concentrations from the PL. For example, fresh-2 litter has a maximum change in AH-N from the PL of 24 mg N kg soil^{-1} at the 0 d extraction, which also has a maximal NO_3-N change of 24 mg N kg soil^{-1} at the 15 d extraction. Conversely, the maximum change in NH_4-N for the fresh-2 litter is 8 mg N kg soil^{-1} at the 0 d extraction. An explanation for this is that there were inadequate extraction times early in the incubations resulting in unmeasured mineralization of N from the PL, indicating that NH_4-N is an intermediate N form between mineralization and nitrification. Studies have shown that N mineralization from PL can occur rapidly within 24 hr (Gordillo and Cabrera, 1997). Diaz et al. (2008) concluded that PAN in PL is primarily from uric acid-N, NH_4-N, and labile amino acids. Changes in AH-N values followed similar trends to NH_4-N concentrations, which were both inversely related NO_3-N concentration (Fig. 3.1, 3.3, and 3.5).

CONCLUSIONS

Information relating to the influence of PL on N-STaR soil test values ensure that the proper N recommendation is determined using N-STaR following a PL application. Results from this incubation study indicate rapid mineralization and nitrification of PL-N. Using the N-STaR N recommendation curve for silt loam soil, if N recommendations for rice were based on AH-N values within the first two weeks following the PL application, the resulting N recommendation from N-STaR could have been changed by 60.5 kg N ha^{-1} (29 mg N kg soil^{-1}). However, the largest change in the N rate recommendation from N-STaR between 15 to 60 d after the PL application was 20.5 kg N ha^{-1} (10 mg N kg soil^{-1}). Our results show that the DSD method

quantifies AH-N in the soil and PL indicating the importance of soil sampling time for N recommendations for rice using N-STaR following a PL application.

When using AH-N for N recommendations in rice it is essential to wait until AH-N reaches an equilibrium and conversion to NO_3-N has occurred prior to soil sampling, knowing that a large portion of NO_3-N will be lost via denitrification following the establishment of a permanent flood. For upland crops, soil sampling time is not as sensitive with these crops having the ability to access and utilize NO_3-N. By combining estimates of both AH-N and NO_3-N, we can potentially determine PAN for upland crops where NO_3-N is less likely to be lost via denitrification. Further research is needed to evaluate changes in the labile organic-N fraction of PL-amended soils when long-term additions of litter have been applied and its influence on N-STaR soil test values. Even though PL can increase the labile organic-N fraction of a soil immediately following application, it might not significantly increase the more stable-N pools and ultimately the amount of PAN for rice. The results of this study demonstrate the ability to design soil sampling protocols, recommending that rice producers wait at least 15 d following a PL application before collecting soil samples for N recommendations using N-STaR.

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Table 3.1. Characteristics of the poultry litter (PL) utilized in the 60-d incubation study.

					on "as-is" basis g kg^{-1}		
Treatment	Litter Type	Bedding Material	Animal Type	C:N Ratio	Total N	Total C	Moisture
PPL†	pelletized	none given	none given	8:1	37.0	302.4	114.0
fresh-1‡	fresh	rice hull	cornish hen	7:1	45.6	322.7	167.0
fresh-2‡	fresh	shavings/sawdust	pullet	8:1	25.4	206.2	290.9
fresh-3‡	fresh	none given	broiler	7:1	33.3	220.3	430.8
fresh-4‡	fresh	rice hull/shavings	broiler	14:1	19.9	292.1	274.0

† PPL, pelleted poultry litter obtained from Perdue AgriRecycle (Seaford, DE)

‡ Fresh PL sources obtained from the University of Arkansas Diagnostic Laboratory (Fayetteville, AR)

Table 3.2. Analysis of variance for net alkaline hydrolyzable-N (AH-N), NH_4-N, and NO_3-N as influenced by poultry litter (PL) source and extraction time.

Source of Variation	AH-N		NH_4-N		NO_3-N	
	DF	P-value	DF	P-value	DF	P-value
PL Source	4	0.0850	4	<0.0001	4	0.3354
Extraction Time	9	<0.0001	9	<0.0001	9	<0.0001
PL Source x Extraction Time	36	<0.0001	36	<0.0001	36	<0.0001

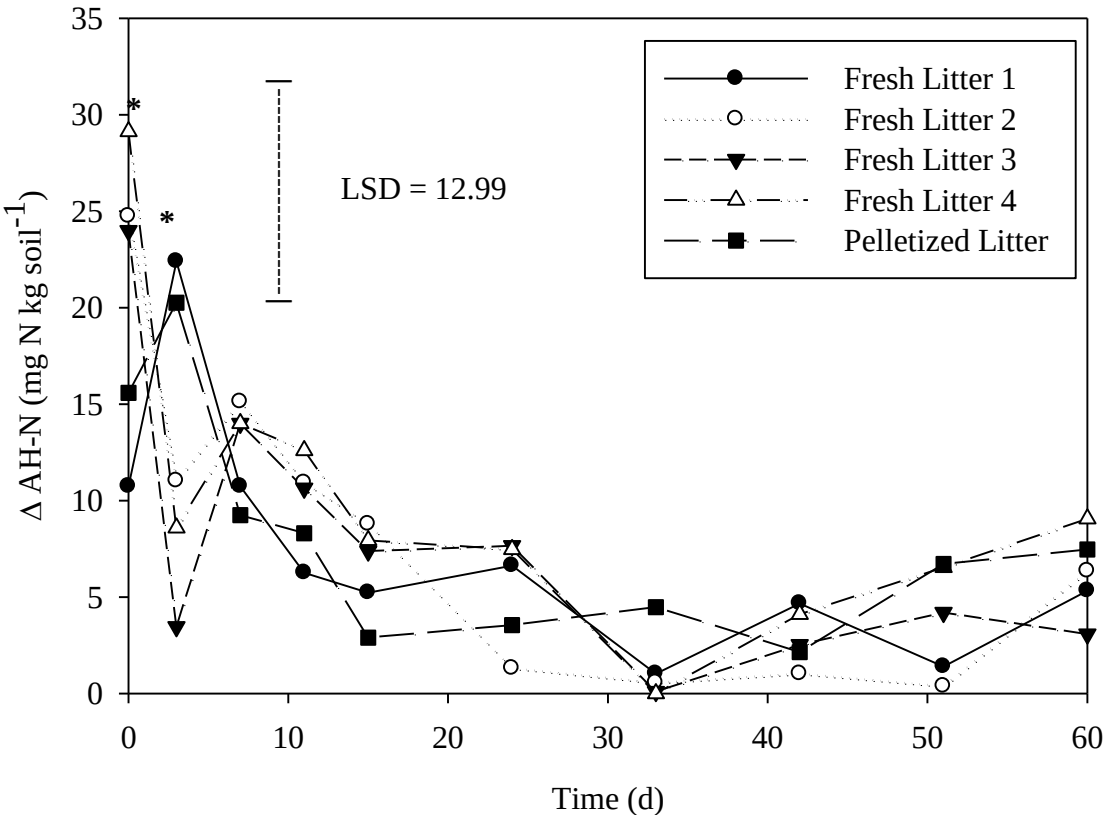

Figure 3.1. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) to compare litter sources within the same extraction time. The * indicates a significant difference among litter sources within an extraction time at the $P<0.05$ level.

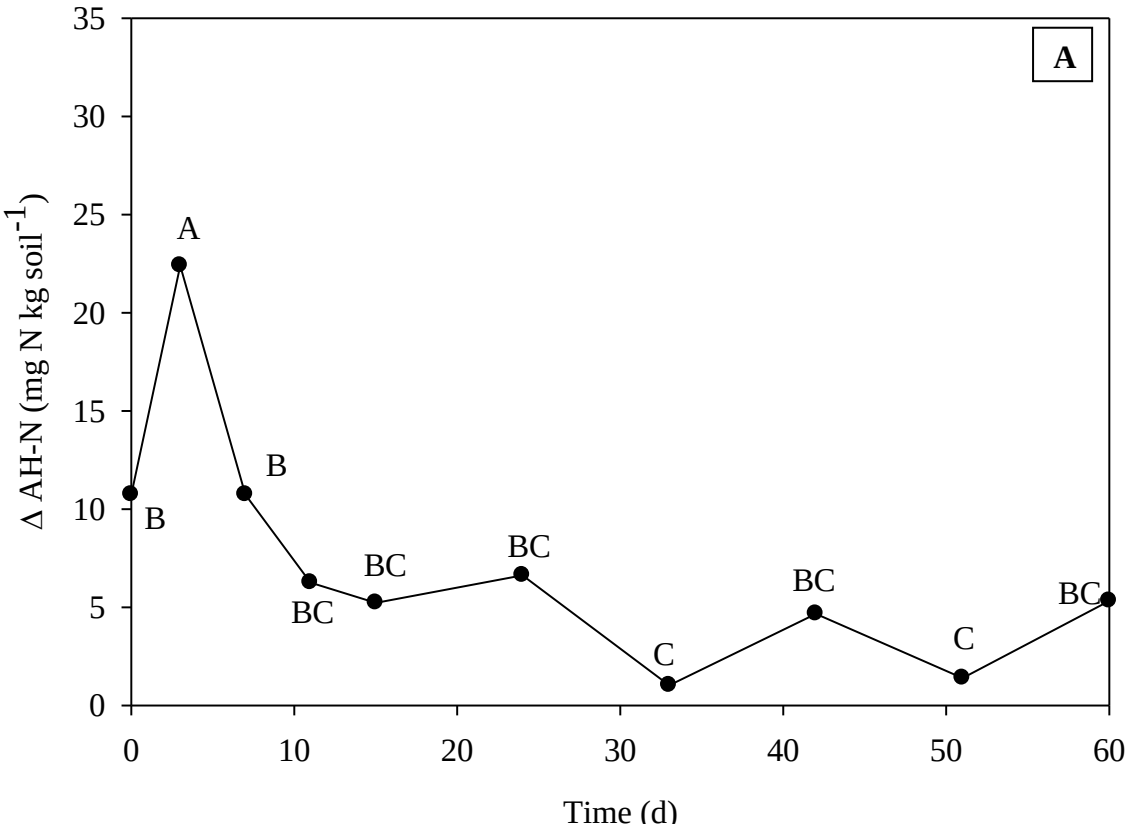

Figure 3.2. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) for A) fresh litter-1. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.7 mg N kg soil^{-1}.

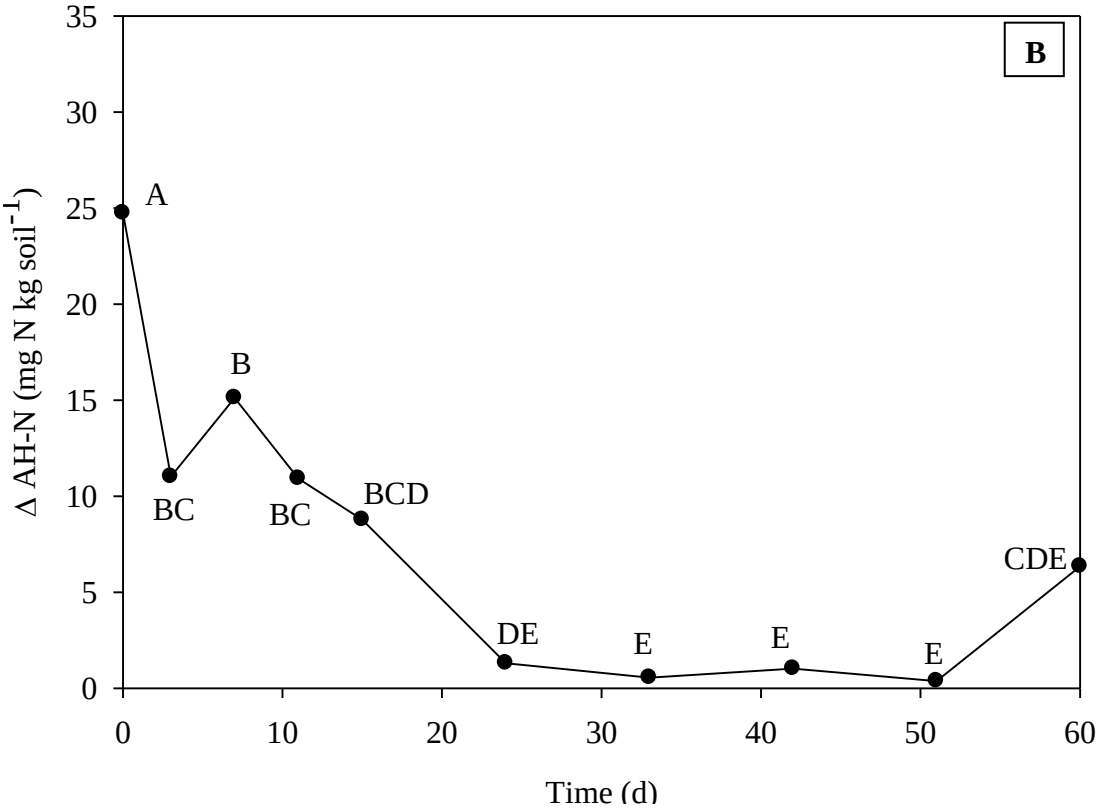

Figure 3.2. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) for B) fresh litter-2. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.7 mg N kg soil^{-1}.

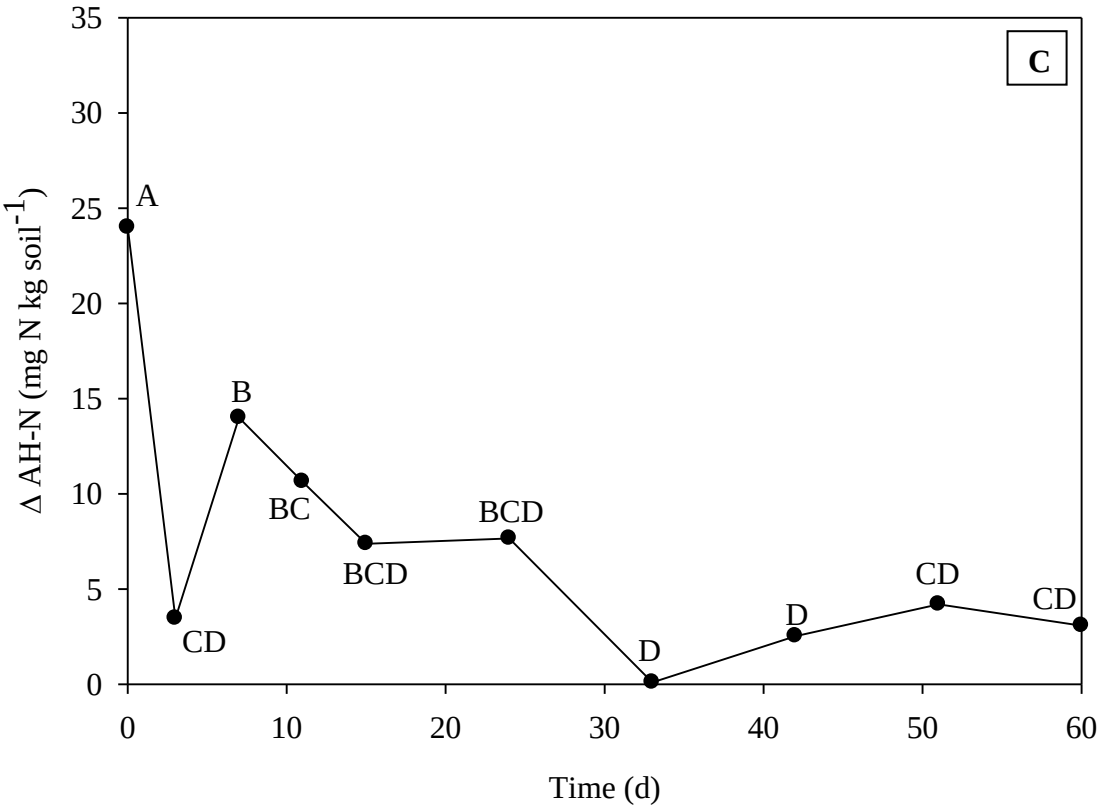

Figure 3.2. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) for C) fresh litter-3. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.7 mg N kg soil^{-1}.

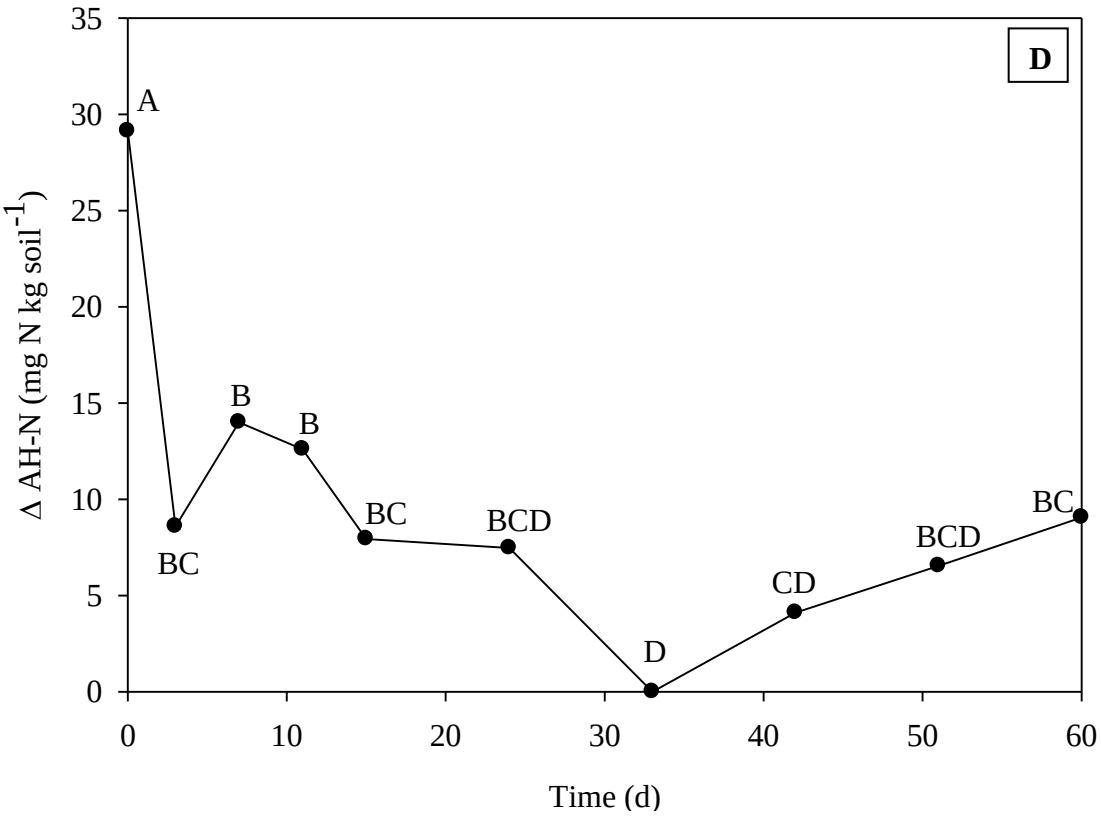

Figure 3.2. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) for D) fresh litter-4. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.7 mg N kg soil^{-1}.

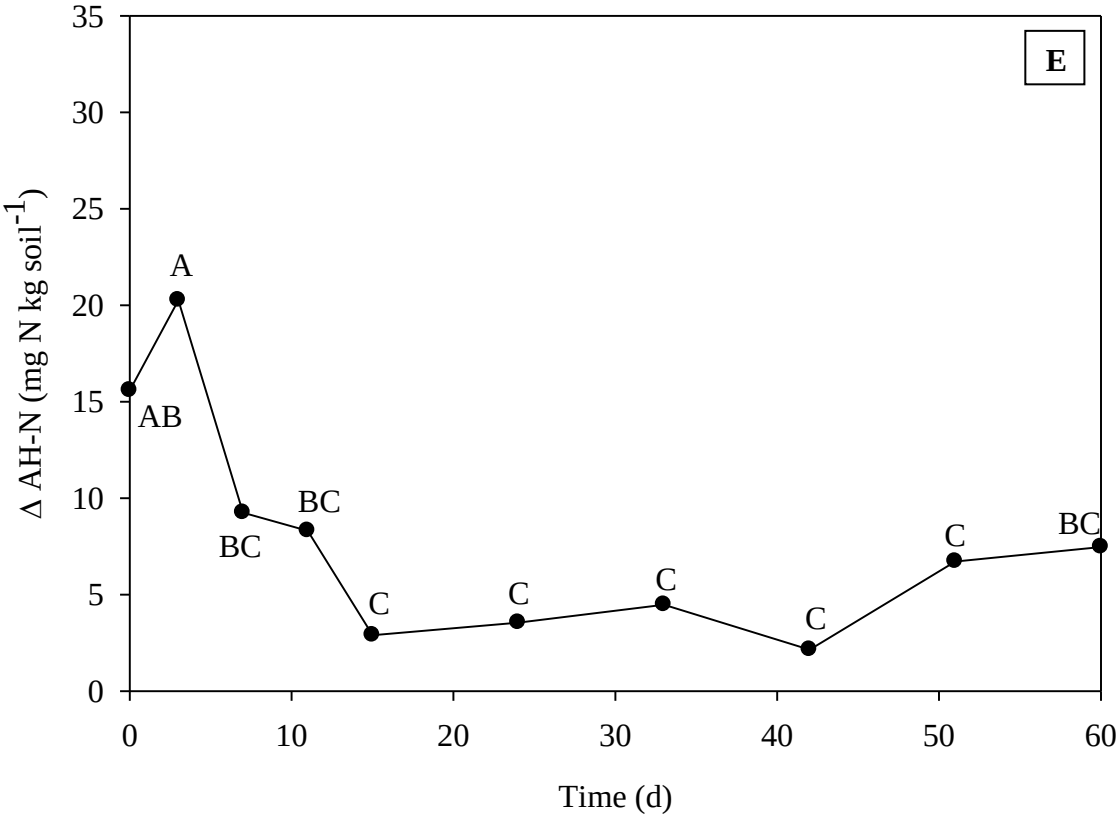

Figure 3.2. Influence of poultry litter (PL) source and extraction time on the net change in alkaline hydrolyzable-N (AH-N) for E) pelletized PL. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.7 mg N kg soil^{-1}.

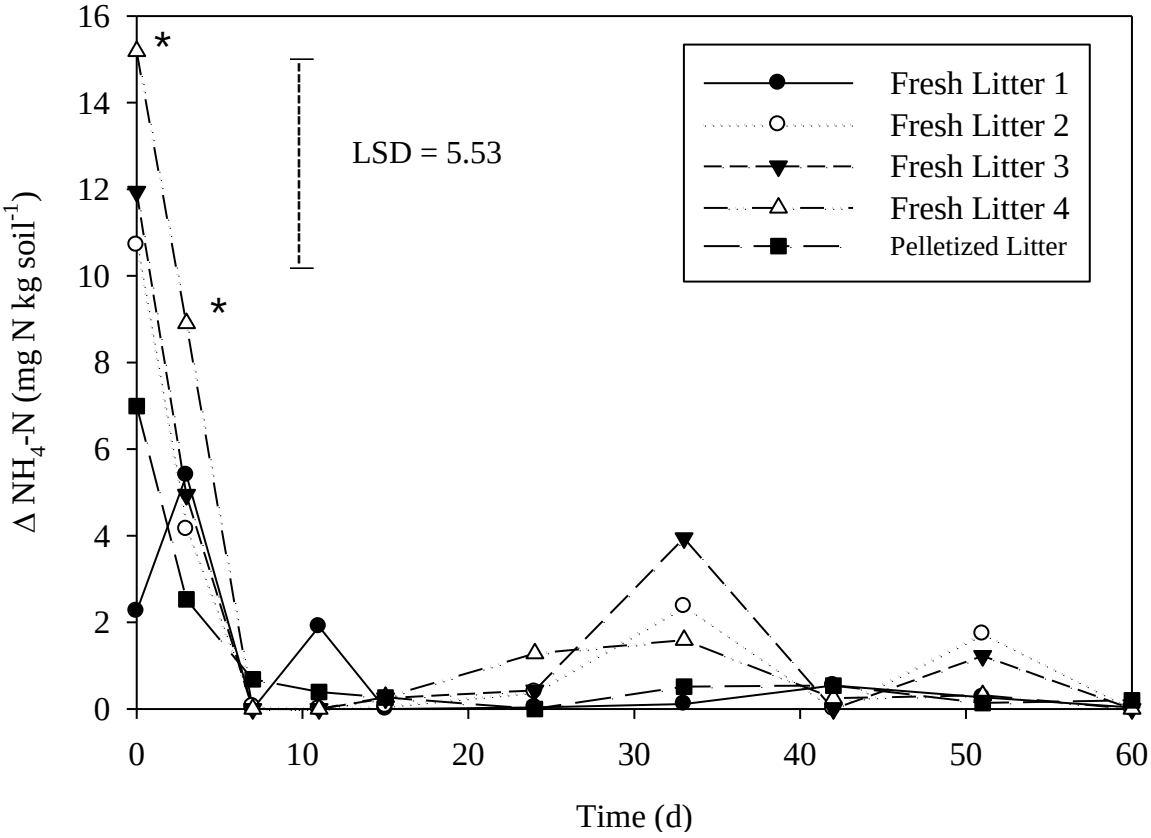

Figure 3.3. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentration to compare litter sources within the same extraction time. The * indicates a significant difference among litter sources within an extraction time at the $P<0.05$ level.

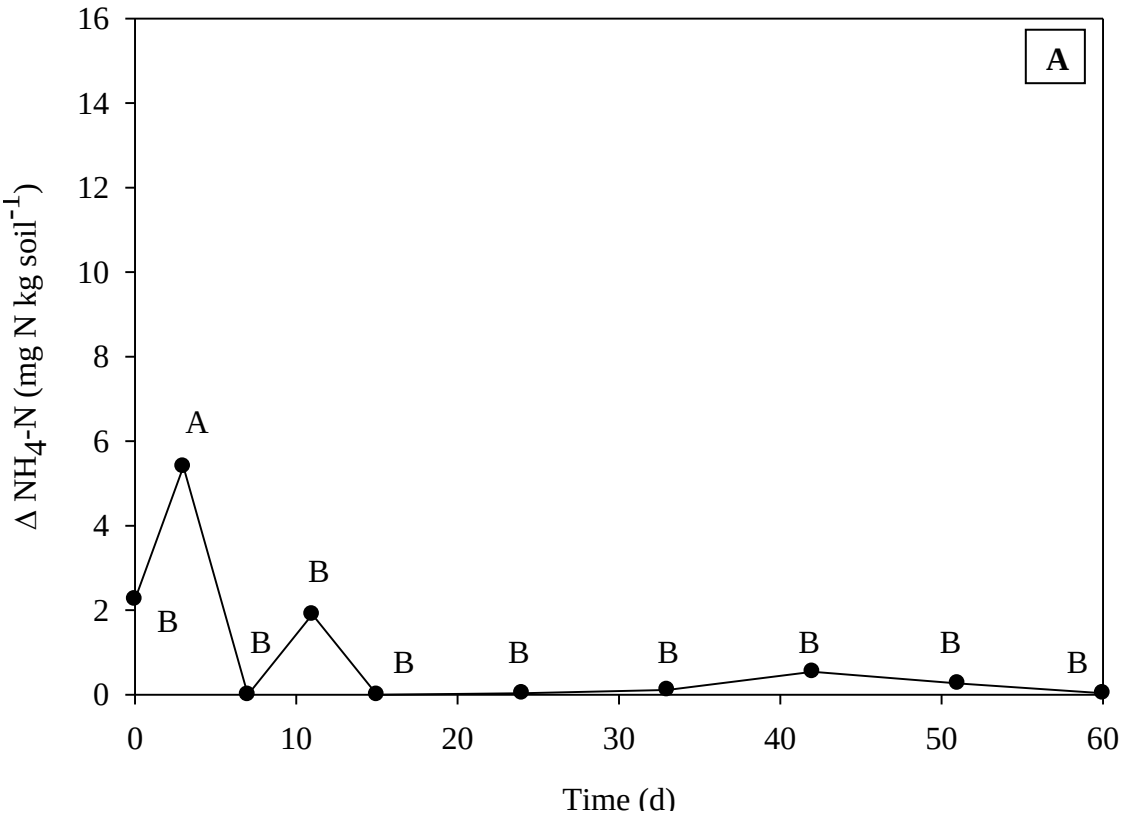

Figure 3.4. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentrations for A) fresh litter-1. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 3.1 mg N kg soil^{-1}.

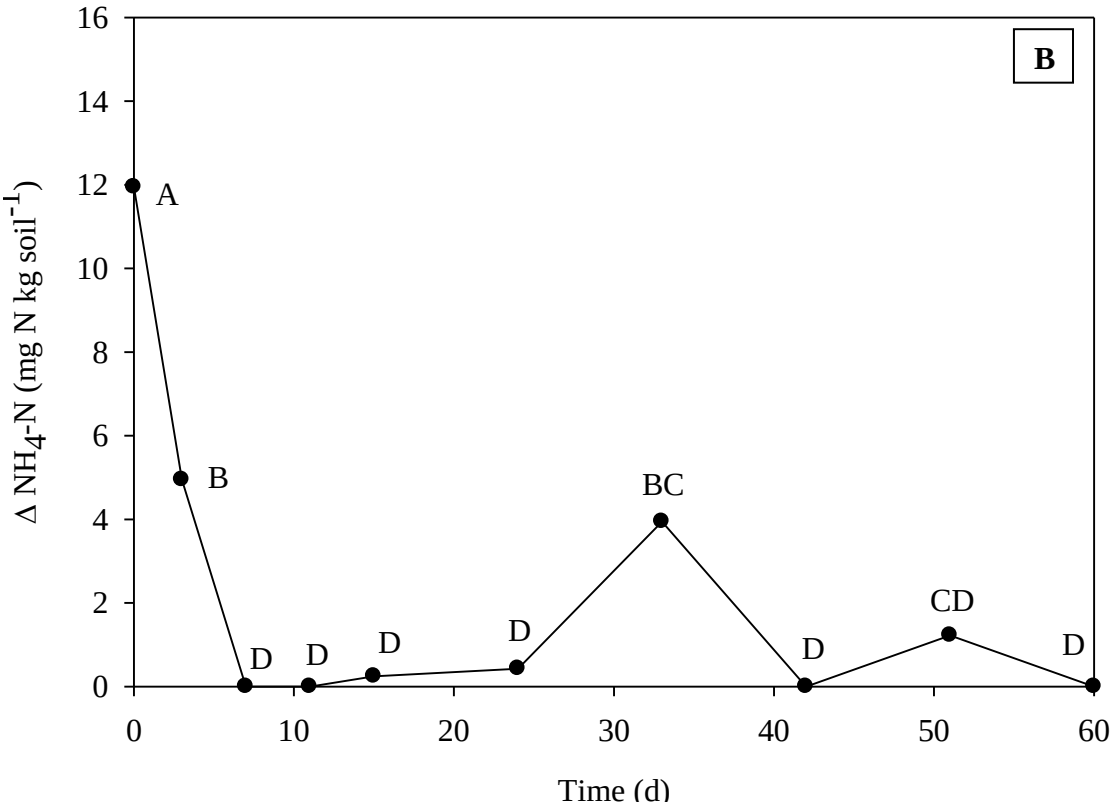

Figure 3.4. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentrations for B) fresh litter-2. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 3.1 mg N kg soil^{-1}.

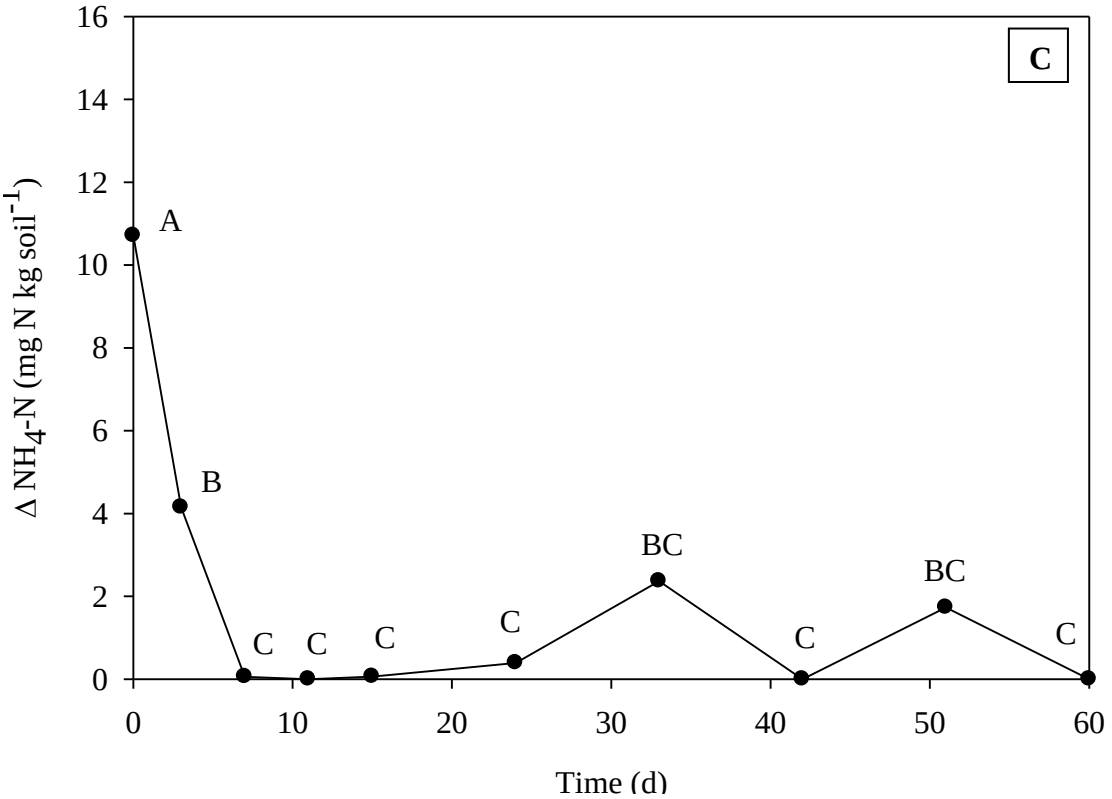

Figure 3.4. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentrations for C) fresh litter-3. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 3.1 mg N kg soil^{-1}.

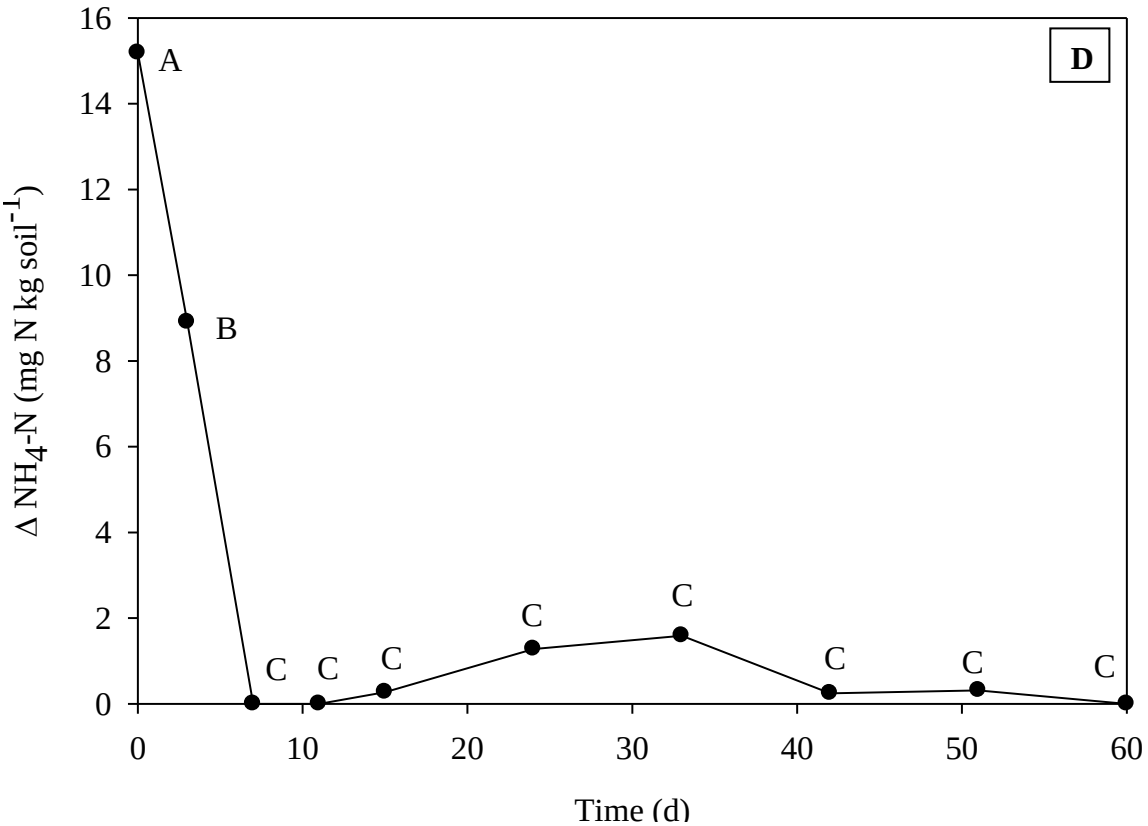

Figure 3.4. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentrations for D) fresh litter-4. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 3.1 mg N kg soil^{-1}.

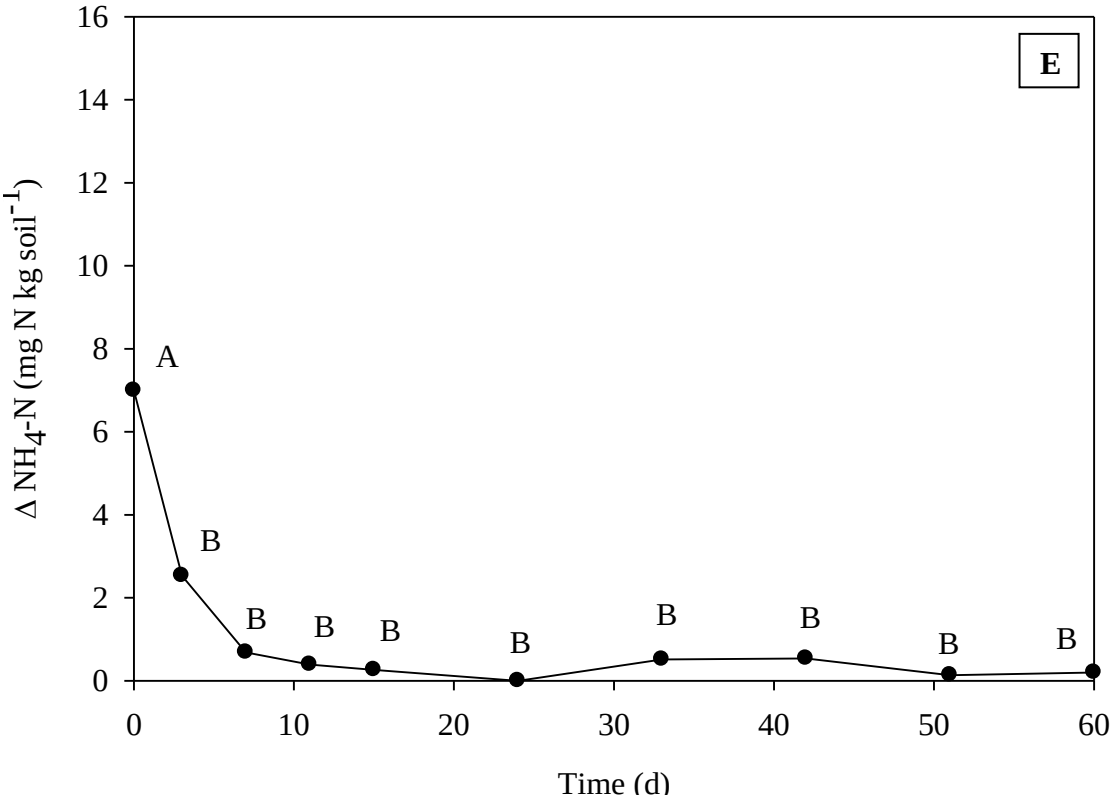

Figure 3.4. Influence of poultry litter (PL) source and extraction time on the net change in NH_4-N concentrations for E) pelletized PL. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 3.1 mg N kg $soil^{-1}$.

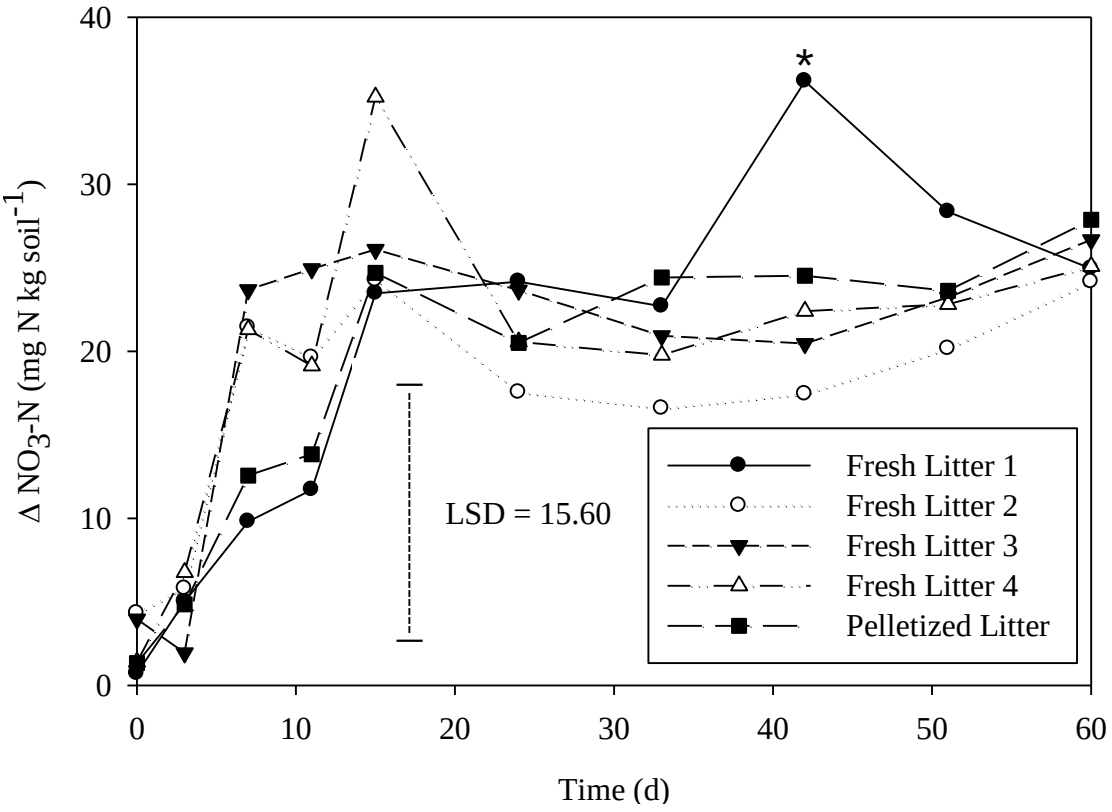

Figure 3.5. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration to compare litter sources within the same extraction time. The * indicates a significant difference among litter sources within an extraction time at the $P<0.05$ level.

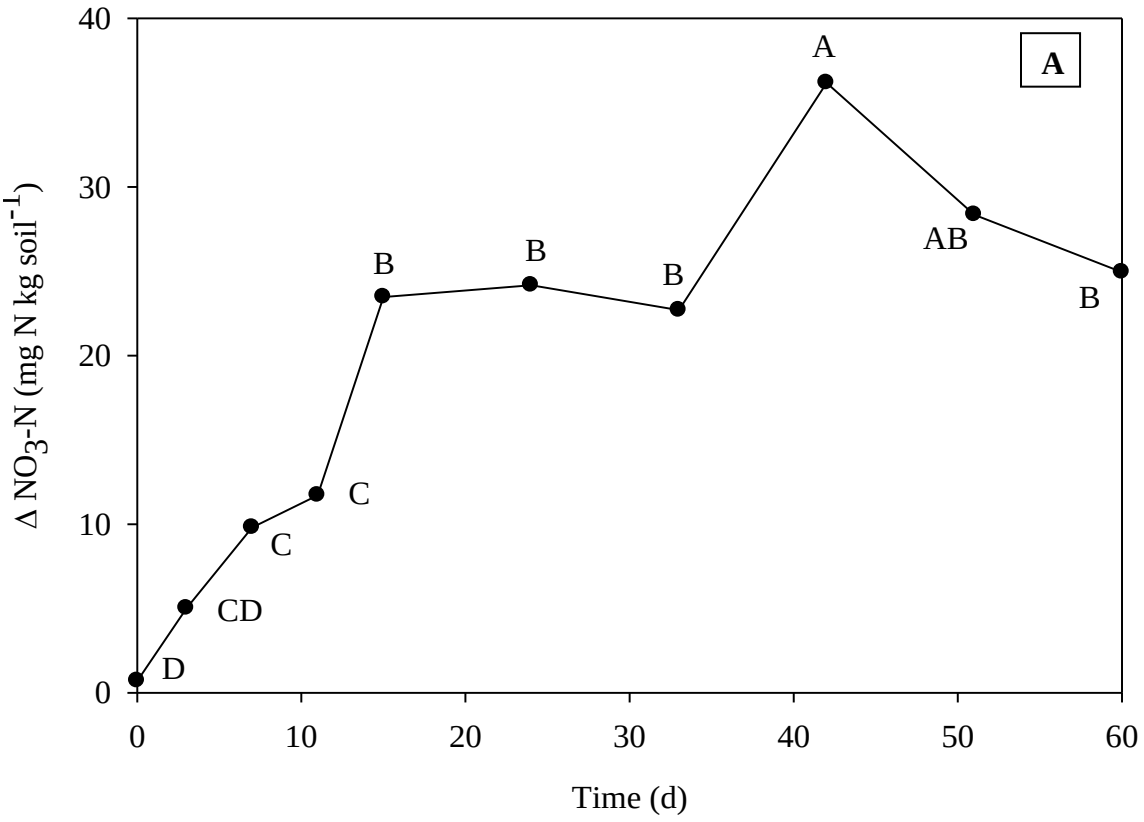

Figure 3.6. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration for A) fresh litter-1. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.9 mg N kg soil^{-1}.

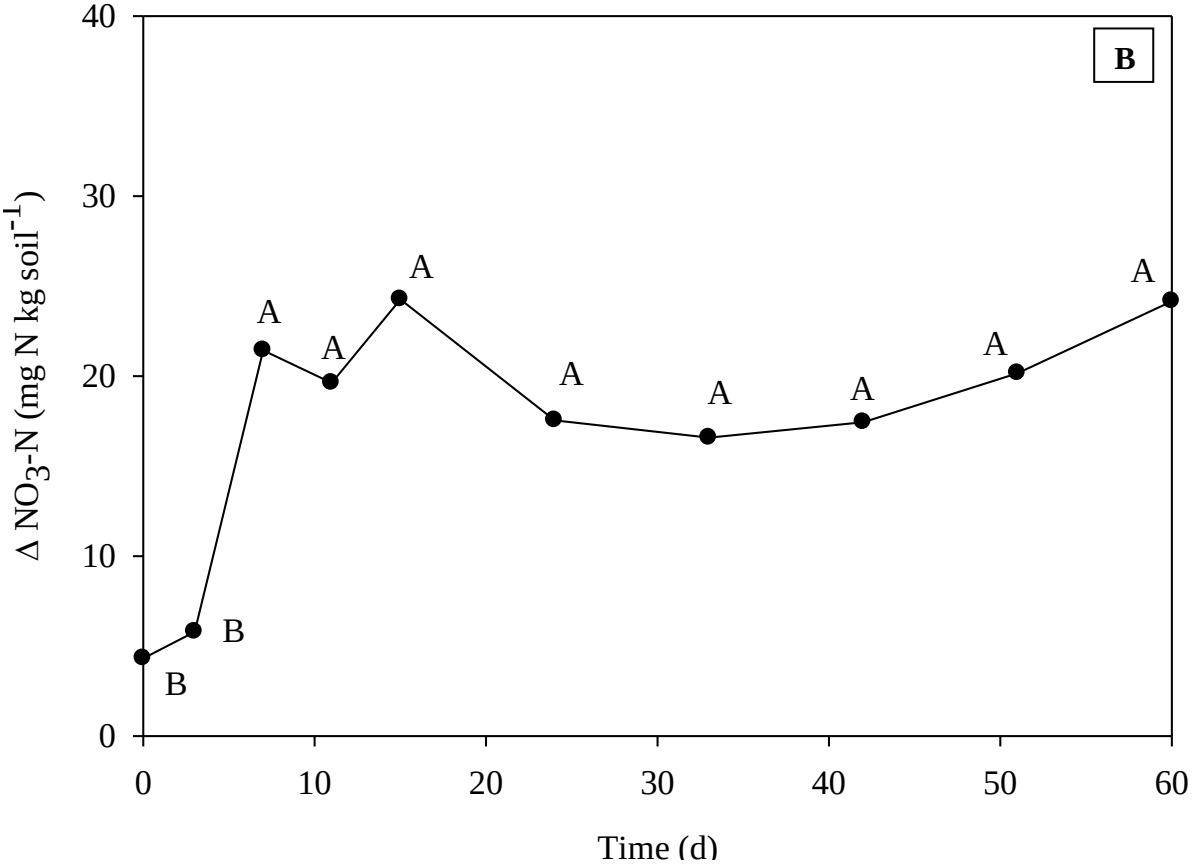

Figure 3.6. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration for B) fresh litter-2. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.9 mg N kg soil^{-1}.

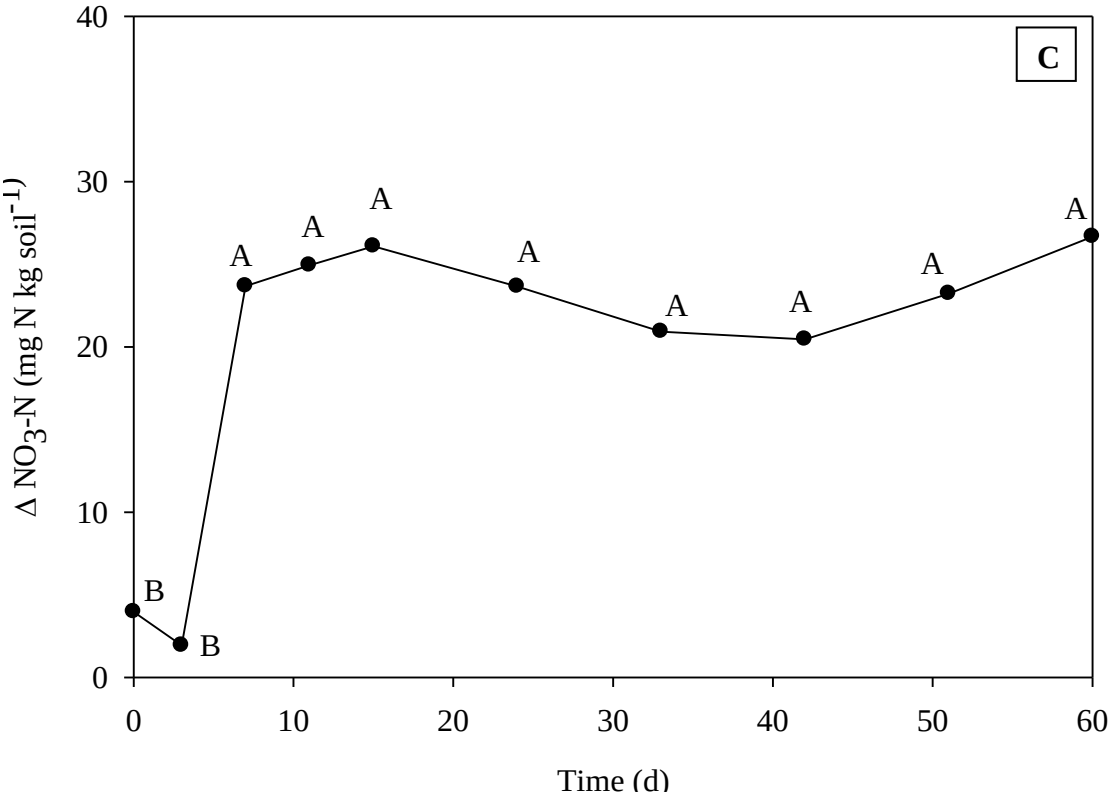

Figure 3.6. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration for C) fresh litter-3. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.9 mg N kg soil^{-1}. N

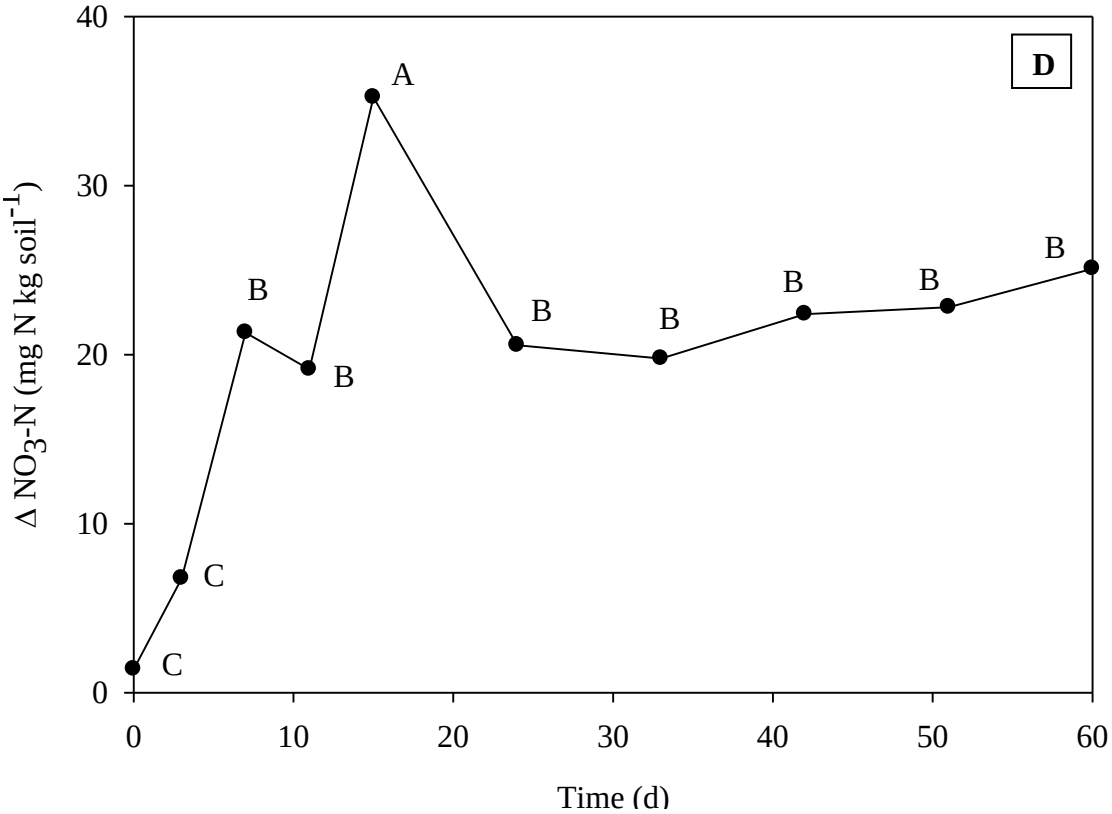

Figure 3.6. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration for D) fresh litter-4. Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.9 mg N kg soil^{-1}.

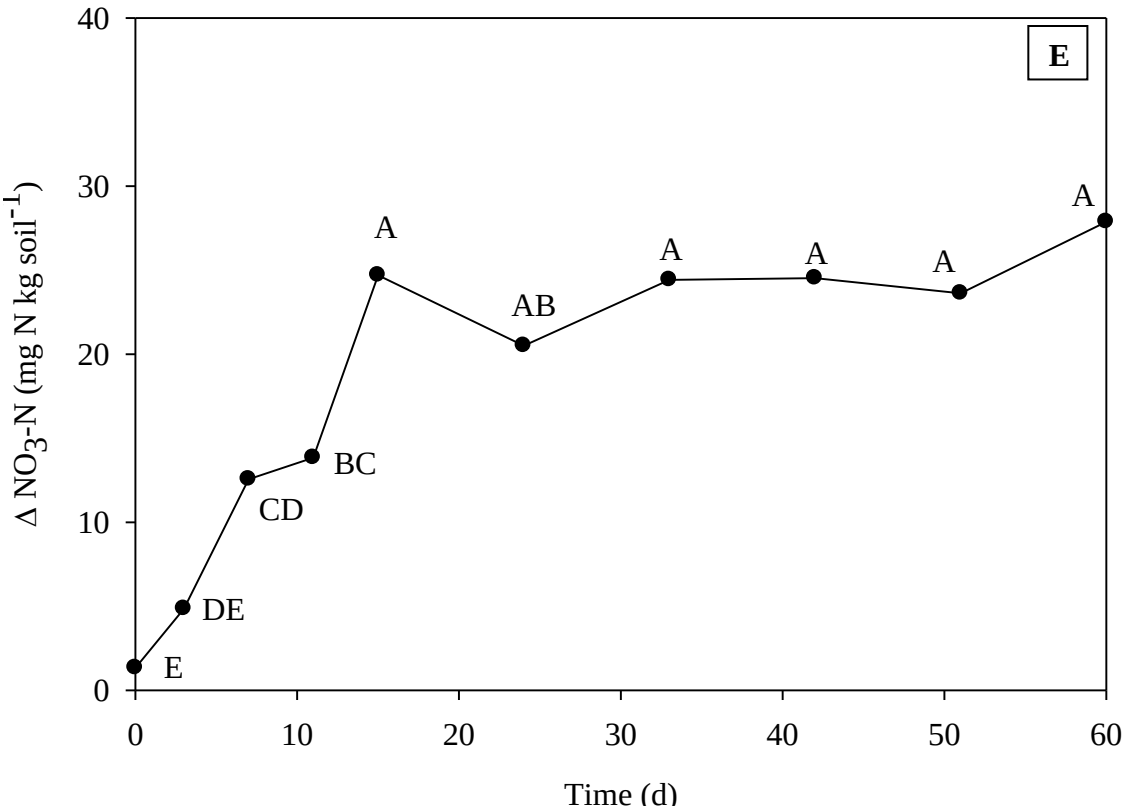

Figure 3.6. Influence of poultry litter (PL) source and extraction time on the net change in NO_3-N concentration for E) pelletized PL (PPL). Means with the same letter are not significantly different at the $P<0.05$ level. LSD 0.05 to compare within a PL source across time is 7.9 mg N kg soil^{-1}.

CHAPTER FOUR

Conclusions

The focus of these studies were to identify changes in AH-N values within soil that has received a PL application, identifying if the standard N-STaR N recommendation can be used following a PL application or to what extent the N-STaR recommended N rate needs to be adjusted to prevent an over- or under-fertilization with N fertilizer. The overall goal is to ensure that the N-STaR N recommendation following a PL application is accurate and improve how Arkansas rice producers manage N fertilizer inputs to improve profitability and long-term sustainability. Results of this 2-yr field study and 60-d laboratory incubation study indicated that AH-N is significantly influenced by a PL application prior to the collection of soil for N-STaR analysis. A PL application can also significantly increase rice grain yield and decrease the N-STaR N recommendation. Changes in AH-N following a PL application ranged from 0 to 29 mg N kg soil^{-1} in the incubation study, but the field study displayed a change in AH-N of 7 mg N kg soil^{-1} between the untreated control and the highest PL application rate when soil samples are collected from the recommended 45 cm soil depth. The N-STaR has the ability to identify small changes in potentially mineralizable-N that are statistically significant.

Alkaline hydrolyzable-N is significantly influenced by a PL application, however from a practical standpoint the influence is insignificant when variability in the field, fertilizer application, and environment are considered. Poultry litter minimally influences N-STaR soil test values because we are applying and incorporating PL in the top 15 cm of the soil surface, but the N-STaR uses a 45 cm deep soil sample. Evaluating the influence of PL on N-STaR soil test values across time allows us to ensure that the proper N recommendation is determined using N-STaR following a PL application. When applying PL before the collection of N-STaR soil samples, it is important to wait until AH-N values stabilize to collect soil samples as a result of large fluctuations in AH-N values being identified immediately following the application of PL.

The results presented suggest that the N-STaR is a reasonably good indicator of potentially mineralizable-N from PL. Indicating that producers applying PL need to wait at least 15 d following a PL application before collecting soil samples for N recommendations in rice using the N-STaR program.