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Evaluation of Soybean Maturity Group and Planting Date in a Soybean-Rice Rotation on Overall Crop Productivity

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Evaluation of Soybean Maturity Group and Planting Date
in a Soybean-Rice Rotation on Overall Crop Productivity

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ABSTRACT

Little is known about the effects of soybean (*Glycine max* L.) management techniques on soil-nitrogen (N) credit development and its impact on the subsequent rice (*Oryza sativa* L.) crop's success. This study was conducted to determine how soybean maturity group (MG) and planting date effect overall soybean productivity and its influence on the following rice crop. Various soybean planting dates (optimum and late) and MGs (3.5, 4.7, 5.4, and 5.6) were grown and followed in rotation with a rice crop. Six rates of pre-flood fertilizer-N (0, 44, 89, 134, 179, 224 kg N ha^{-1}) were applied to the rice crop. Soybean grain yield was significantly different amongst MGs in both 2016 ($P = 0.0012$) and 2017 ($P = 0.0004$), with the 4.7 relative MG consistently yielding the highest. Soybean total N uptake (TNU) increased with increasing grain yield ($P = 0.0167$) when all site years were analyzed together. The net N returned to the soil through biomass residue was not significantly influenced by planting date ($P = 0.7796$) or MG ($P = 0.3475$).The rice grown in clay soil produced a higher grain yield when following a 5.4 MG soybean ($P < 0.0001$). On a silt loam soil the interaction of both planting date and MG of the previous soybean crop influenced the maximal grain yield achieved of the rice crop ($P < 0.0001$) and the N rate needed to achieve 95% relative grain yield ($P = 0.0007$). At an optimum planting date, soybean MG had little effect on the rice crop but should be selected to achieve the highest soybean grain yield. However, when the soybean crop is planted late, a determinate cultivar should be selected to achieve the highest rice crop TNU, maximal grain yield, and require the lowest rate of fertilizer-N to achieve 95% relative grain yield. Soybean crop management decisions can be highly influential when producing a soybean-rice rotation in Arkansas to maximize overall crop rotation productivity and profitability.

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Introduction and Literature Review

Soybean (*Glycine max* L.) is a common crop grown in rotation with rice (*Oryza sativa* L.) in Arkansas. The United States is the world's top producer of soybean (Coats and Ashlock, 2000), while Arkansas is the United States' largest producer of rice (Hardke, 2016). Although these crops have different soil and water requirements (Anders and Hignight, 2009), this rotation system is relied on very heavily throughout the mid-south. The natural nitrogen (N) fixation which soybean plants provide through a symbiotic relationship between the plant root and soil bacteria, *Bradyrhizobium japonicum*, is one of the benefits of this rotation. Maturity group (MG) and planting date affect the time spent in vegetative growth stages. Manipulating these factors may impact the amount of N fixed by the soybean crop and the degree of benefits provided to the subsequent rice crop. Maturity groups IV and V are the most common cultivars grown in Arkansas. These MGs are well suited to the Arkansas climate and often perform well in grain production.

Although N is an essential mineral nutrient for plant growth, much is still unknown about the N cycle and its many loss pathways in the soil. Through the use of a legume crop in rotation the N recommendation for the following crop is reduced. Nitrogen fertilizer is often the largest input cost for a rice producer (Roberts et al., 2012), further increasing the importance of understanding of the influence of soybean growth and performance on N credits and N dynamics in a soybean-rice rotation. The complexity of the N cycle poses many threats to the potential loss of N within the soil due to its mobility, large range of oxidation states, and multiple chemical forms. Understanding how the previous soybean crop's management influences the soil-N will allow for a more specific fertilizer-N recommendation to the subsequent rice crop. The objective of this study was to determine the impact of different soybean management practices on soil-N credits developed and adjust fertilizer-N recommendations accordingly. It is theorized that the management of a soybean crop will have a direct impact on the amount of soil-N credits developed and the fertilizer-N recommendation for a following rice crop.

LITERATURE REVIEW

Traditionally in Arkansas, MG IV soybean is grown for grain and thought to supply N to the soil system. The high grain yields achieved reveal high productivity and adaptiveness of these soybean cultivars. Over 72 percent of rice grown in Arkansas in 2015 was grown in rotation with soybean, a number that increases each year (Hardke, 2015). The idea that different soybean management techniques, such as MG and planting date, could provide a different amount of N to the soil and improve the grain yield of a following rice crop began through an informal extension interview with an Arkansas rice producer. Understanding the dynamic relationship between N_2 fixation, soybean yield potential, and soil-N credits can help producers better select soybean management techniques to achieve both immediate and long-term benefits.

AGRICULTURE AND NITROGEN IMPORTANCE

As the world population is ever increasing, so is the demand for food and the importance of reducing nutrient pollution. In an average year, two-thirds of crop land in the United States does not meet the criteria for good N management, allowing excess N applied to increase the price of crop production and damage the environment (Ribaudo et al., 2012). The benefits of a N soil test that can accurately predict N fertilizer needs are not solely about optimizing economic or agronomic returns, but include making environmentally sound N fertilization decisions (Roberts et al., 2012). This is not always excessive application of fertilizer, but can also include under-application leading to low yields, poor management practices such as timing and use of fertilizer, and other management factors. There are many ways to improve the management of N fertilizers, including relying on biological N fixation (BNF) of legume crops within a crop rotation system.

Soybean is a major crop grown in the US and internationally, providing benefits through its leguminous properties. Several long-term studies have demonstrated the benefits of crop rotation on soil organic matter and crop productivity (Havlin et al., 1990). To ensure the correct fertilizer-N rate for a rice crop, the N contribution from the previous crop residue must be delineated (Norman et al., 1990). This applies to all crops, with N credits an important factor in a soybean-rice rotation system.

Fertilizer-N use efficiency (FNUE) continues to gain importance as the environmental implications of N fertilizer misuse are discovered. Recent issues within the Gulf of Mexico have raised concerns with the continued growth of a hypoxic zone. Large loads of inorganic-N carried by the Mississippi river, particularly during the spring, are the primary cause of nutrient enrichment generating hypoxic waters (Ribaudo et al., 2005). Nonpoint sources of pollution significantly outnumber the point sources in most regions. Agricultural nonpoint sources are estimated to contribute more than 65% of the N loads to the Gulf of Mexico in the outflow of the Mississippi River. Arkansas' proximity to the Mississippi river and the Gulf of Mexico make this issue critical for our long-term sustainability and continues to increase the importance of fertilizer-N research and correct application by producers.

Nitrogen fertilizer and application costs account for 15% of production costs for Arkansas rice producers in 2018 according to University of Arkansas Extension Service Rice Comparative Budget (University of Arkansas, 2018). Although the exact cost will fluctuate with fertilizer prices, it continually represents the single largest expense for rice production in Arkansas (Roberts et al., 2015). The potential to reduce this cost would result in net profit for Arkansas rice producers and allow for a more lucrative season overall.

As well as the largest input expense for producers, fertilizer-N is also the most extensively applied fertilizer for agronomic crop production in Arkansas (Roberts et al., 2015). The danger in over-applying fertilizer rests in the economics and environment, with the emphasis on efficient nutrient management now greater than ever. Estimating the nutrient removal is an important part of a farm nutrient management plan. This management technique allows for an accurate estimate of fertilizer recommendations and yield predictions. There are two known ways to determine fertilizer-N rates for rice in Arkansas, the standard method and the Nitrogen Soil Test for Rice (N-STaR). The standard method is the traditional approach based on cultivar, soil texture, and previous crop. N-STaR is a new method allowing for site-specific N rates to be determined based on the soil's ability to supply N (Roberts et al., 2013b). Direct steam distillation is used to quantify ammonium, amino sugars, and amino acids as potentially mineralizable-N and predict field specific fertilizer-N needs with this new method (Roberts et al., 2009).

SOYBEAN PRODUCTION IN ARKANSAS

Soybean is the top commodity crop grown in Arkansas in both hectares produced and cash receipts (Coats and Ashlock, 2000). Soybean is grown in more than 41 of Arkansas' 75 counties according to the Arkansas Soybean Promotion Board (Arkansas Soybean Promotion Board, 2016). These counties are mostly located along the eastern side of the state in the Mississippi delta region. This area is primarily flat and well suited for row crop production and irrigation. Soybean is also produced in the Arkansas River Valley in the west and the Red River Valley in the southwest corner of the state. Arkansas is a state with six distinct regions and is ranked as the 10^{th} largest soybean producing state in the U.S. by the Arkansas Farm Bureau. In terms of value added, soybean production is the number one crop production industry in Arkansas with a statewide value of production of $1.74 million in 2017 (USDA-NASS, 2018).

Leguminous crops have the unique ability to collaborate with rhizobia bacteria in the soil and biologically fix atmospheric N_2 into ammonia-NH_3. No fertilizer-N is needed in a legume cropping system. If inorganic fertilizer-N is applied to a legume crop, the BNF will cease and the plant will only use the N applied available to it. Legume crops have a high N demand and therefore it is not economically feasible to produce legumes using inorganic fertilizer-N. Majority of the plant N is allocated to the grain and removed at harvest leaving only a small portion of the N in the remaining biomass. The residue-N left behind by the legume crops following harvest is often referred to as N credits. The quantity of N credits supplied by the legumes depends on the species and yield of the legume (Purcell et al., 2014). The effect of growing a legume crop on residual soil-N depends on the total quantity of the plant's N (concentration and biomass), and the distribution in the plant (Goss et al., 2002). All of these factors, as well as environmental factors, must be considered when estimating the amount of N credits produced by a soybean crop to establish the best fertilizer recommendation for the following crop.

Research demonstrates the benefits of rotating soybean with rice, grain sorghum (*Sorghum bicolor* L.), corn (*Zea mays* L.) or cotton (*Gossypium hirsutum* L.). This rotation increases soybean yield potential due to breaking the cycles of primary soybean pests such as diseases, weeds, and insects and by a general increase in soil productivity (Ashlock et al., 2000). Both mineral and fixed N are essential to maximize soybean yield and N content (Goss et al., 2002). Soybean production in Arkansas is highly successful as demonstrated by the grain yields, N credits produced, and rotational benefits in the whole production system.

MATURITY GROUP SELECTION

Soybean cultivars are classified into different MGs based on the day length requirement, recommended planting date, and time spent in different vegetative and reproductive stages. Cultivars of different MGs produce grain yields that vary considerably based on planting date, geographic location, and timing of adequate soil moisture, especially through reproductive stages of plant development (Purcell et al., 2014). One of the most important decisions a producer must make is the soybean MG selection. By choosing a MG well suited to the temperature, day length, and available moisture in the field, the crop is set up for the highest yield potential. Soybean is a short day plant, meaning the physiological development is accelerated by more time spent in dark hours. Aligning the soybean's need for short days with the reproductive stages of development optimizes yield. Soybean cultivars with low MG numbers are typically grown in more northern areas with longer days in the summer and shorter growing seasons, while the cultivars classified with higher numbers are grown in more southern regions. Figure 1-1 shows a map of the United States soybean production which indicates the more northern states such as Minnesota are best suited for MG 00 or 0, Arkansas is well-suited for MG IV, V, or VI, and Florida is well suited for MGs VIII or IX. These differences are due to the day length, temperature, and soil moisture regime. Soybean cultivars of higher relative MGs have a longer growing season compared to lower relative MG soybean plants (Wegerer et al., 2015). This difference in time needed to reach maturity and length of growing season shows differences in physical growth characteristics, with lower relative MG soybean measuring lower in height and size than higher MG soybean. This size difference between MG leads to a difference in the amount of N contained in above ground residue (Mastrodomenico and Purcell, 2012) which will change the amount of N credits accumulated in the soil system. Soybean genotypes of late MGs accumulate larger amounts of N in vegetative tissue than early MG soybean cultivars.

Maturity group of soybean is correlated with the growth habit: determinate, semi-determinate or indeterminate. Traditionally, determinate cultivars have been MG V to X, and indeterminate cultivars have been from 000 to IV (Purcell et al., 2014). This distinction has become less clear over the years, and there are numerous MG IV cultivars that are determinate and MG V that are indeterminate. Determinate cultivars stop vegetative growth and production of nodes on the main stem soon after flowering starts, while indeterminate cultivars continue producing nodes on the main stem until the beginning of seed fill. Within the state of Arkansas, MG IV is the most commonly grown throughout the state, classifying the Arkansas soybean production system as predominately indeterminate. However, MG V are not uncommon in Arkansas and some determinate cultivars are grown. The soybean used in this study are both determinate and indeterminate to encompass all Arkansas soybean production. The distinction between determinate and indeterminate soybean is not always clear, as there are some soybean cultivars classified as semi-determinate. These are plants which do not clearly represent either group and are typically MG IV or V.

BIOLOGICAL NITROGEN FIXATION

As previously mentioned, soybean is a member of the legume family with the ability to supply biologically fixed N through a symbiotic relationship with rhizobia bacteria. Legumes are very important both ecologically and agriculturally. A substantial part of the global flux of N from atmospheric N_2 to fixed forms such as ammonium, nitrate, and organic-N is a result of legumes (Zahran, 1999). Nodules form on the roots of a soybean plant and facilitate this phenomenon. Nodules are small growths on the root system of the plants and form this symbiotic relationship with *Bradyrhizobium japonicum* bacteria in soil. However, if a field has not been in rotation with soybean within the past few years it is important to inoculate the soybean seed with the bacterium to ensure the soil appropriate bacterium is present. Different legumes coincide with different soil bacteria, increasing the importance of inoculation. The ability for soybean plants to fix N_2 allows the crop to grow in vegetative stages and reproduce viable seed without any fertilizer-N input. Soybean plants can distribute N differently, as much as 88% of the seed N at maturity was biologically fixed through the root nodules of the plant (Mastrodomenico and Purcell, 2012).

The different stages in the soybean life cycle involve vegetative and reproductive stages, with vegetative focusing on the growth of the soybean plant while the reproductive stages involve bloom and seed fill (Purcell et al., 2014). In the *Rhizobium*-legume symbiosis, which is a N_2 fixing system, the process of biological N_2 fixation is strongly related to the physiological state of the plant (Zahran, 1999). It has yet to be determined within which of these growth stages the root nodules fix the most N, or if a correlation exists. Typical environmental stress faced by the legume nodules and bacteria may include photosynthetic deprivation, water stress, salinity, soil nitrate, temperature, heavy metals, and biocides. These stresses will also affect which growth stages N_2 is primarily fixed within the plant life cycle because of the strong correlation between plant health and amount of N fixed. There is considerable discrepancy concerning the time, course, and duration of the N_2 fixation process within the growth stages. Different MGs of soybean invest different amounts of time in vegetative versus reproductive growth, which may in turn affect the amount of N a plant fixes throughout the growing season.

The exact correlation between soybean plant growth and N_2 fixation is unknown. Termination of N_2 fixation is likely near the end of seed fill, indicating N_2 fixation may continue late into the reproductive stages (Mastrodomenico and Purcell, 2012). Late MGs have an extended crop growth cycle in relation to early MGs, mainly during the vegetative stages (Divito et al., 2016). Late maturing cultivars also have greater biomass and N content (Mastrodomenico and Purcell, 2012). The longer growing season and higher N content recorded indicates a potentially larger quantity of N_2 fixation in late MGs. Biological N fixation requires a large quantity of carbon (C) and energy use by the soybean plant. Soybean crops derive between 25 to 75% of their total N from N_2 fixation allowing for the assumption that under conditions without excess N in the soil, a soybean which fixes more N may yield higher, as it has a higher N availability to promote growth.

RICE PRODUCTION IN ARKANSAS

Rice is the largest single source of calories for over 3.7 billion people in the world today with rice cultivation as the single largest use of land for food (Adviento-Borbe et al., 2016). Arkansas is the number one rice producing state in the United States, with 442,321 hectares harvested in 2017 (Hardke et al., 2018). The state average yield is 8288 kg rough rice ha^{-1}. Some of the main factors of rice production include selecting an appropriate cultivar, fertilization, irrigation, disease control, and weed control. There are many options for producers within each of these factors which can contribute to successful management and maximal rice crop yields.

A rice plant has nine major stages in growth and development, including germination, emergence, pre-tillering, tillering, and panicle initiation as the vegetative growth stages. Panicle differentiation, heading, grain fill and maturity comprise the reproductive stages (Moldenhauer et al., 2013). Maturity is described as approximately 20% grain moisture, while the grain is not considered dry until it reaches 12% moisture.

Optimum N application timing contributes significantly to successful rice production (Wilson et al., 1998). When managed correctly, rice production can have some of the highest FNUE of all crops, measuring up to 80-90% efficiency. However, this can also drop to one of the lowest FNUE values when managed improperly (Norman et al., 2003). Rice FNUE in developing countries can be very low, generally 30 to 50% (Miah et al., 2016). Rice cultivars differ in the amount of fertilizer-N required to produce optimum grain yields (Roberts et al., 2013b). Multiple rice cultivars studied continually require more fertilizer-N to maximize grain yields on the clay soils compared to the silt loam soils (Norman et al., 2002). Nitrogen fertilizer can be applied through urea (46-0-0) or by ammonium sulfate (21-0-0-24) and can be applied as a single pre-flood treatment or as a spilt treatment. Traditionally, most rice producers in Arkansas have applied fertilizer-N using a two-way split application with majority of the fertilizer-N applied pre-flood and the remaining fertilizer applied at midseason or boot. Applying all of the N pre-plant is not successful in dry seeded rice because most of the N applied is converted into NO_3-N during the time between seeding and flooding. After flooding, the NO_3-N can be lost through denitrification in an anaerobic condition. Many producers striving to increase their N management efficiency are interested in implementing a single pre-flood N application, which can be further reduced with a higher N credit provided by a successful soybean crop the previous year. This could significantly reduce the input cost of a rice crop to the producer and in turn assist in producing a successful and profitable rice crop.

The differences in N use efficiency among rice production systems are attributed to the management of loss pathways including ammonia-NH_3 volatilization, denitrification, leaching, immobilization, N loss from rice foliage, and surface runoff (Norman et al., 1992 and Miah et al., 2016). The N lost as ammonia volatilization from a flooded rice field can be as high as 50% of the applied N in a poorly managed system, making the correct fertilizer-N application crucial to a profitable season for the producer and for the environment. Improved fertilizer-N management practices can increase rice yields and mitigate global warming potential through the reduction of these loss pathways (Adviento-Borbe et al., 2016). Fertilizer placement is one factor that can be managed to improve FNUE; as fertilizer placement depth is increased, the N recovery diminishes because the proximity to the root system decreases (Roberts et al., 2013a). Majority of N recommendations are based on yield goal approaches; however, applying N based on maximizing profit may lead to a more efficient use of N in rice production compared to yield maximization (Watkins et al., 2010). The same study showed the profit maximizing yields were within 0.1 to 2% of maximum yield across multiple locations, with the variability due to N price.

Arkansas has a soil test specific to N in rice production systems known as the Nitrogen-Soil Test for Rice, or N-STaR. This is a soil test that quantifies the amount of N that will become available to the rice crop during the growing season, or potentially mineralizable-N (Roberts et al., 2011). The two primary types of organic-N in the soil quantified by N-STaR are amino acids and amino sugars, which are the two forms most likely to be mineralized by soil microbes and provide plant available N for crop uptake (Roberts et al., 2013b). This test requires that soil samples be collected deeper than the standard soil test samples of 0-10 cm for P, K and Zn. N-STaR requires soil samples be collected at either 30 to 45 cm depending on the soil texture (silt loam vs. clay). This produces a field-specific fertilizer-N recommendation based on the potentially mineralizable-N in the soil instead of using the cultivar and previous crop to estimate a N rate recommendation. While N-STaR is a pre-season soil test, there is also an in-season test using the Trimble Greenseeker hand held device. This test is designed to inform a producer if applying midseason N to a rice crop will produce a significant profit increase. The sensor emits brief bursts of red and infrared light and measures the quantity of each light type reflected back. A reference strip area which has received an over application of fertilizer-N is compared to the whole field using the normalized difference vegetative index (NDVI). An average response index less than 1.2 indicates relative grain yield would not benefit from additional midseason N application. This is a great advancement in soil fertility as the majority of our current analytical tests can only expose application rate at the end of the growing season.

Fertilizer management goes beyond N; it is important to keep all 16 essential nutrients in mind when creating a fertilizer plan for a rice crop. N-STaR soil tests and standard soil tests should be done regularly on each field. The best time to collect soil samples is during the winter or early spring and should be taken at a consistent time each year. Consistency is important in the soil sampling and testing process as nutrient cycles fluctuate greatly with soil moisture (Roberts et al., 2013b). Soil samples should always be collected before fertilizer, manure, or bio solids are applied, and should be collected at an appropriate depth. Roberts et al. (2011) determined the need to sample soil over the entire rooting depth of the crop for an accurate measure of plant available N.

One important factor of yield is panicle and tiller number. Rice yield is positively related with panicle number per unit land area (Wang et al., 2016). Nitrogen applications can be critical to increase the number of tillers per unit area. Beyond fertilizer management, cultivar selection is another important factor in a profitable crop. It is important to select cultivars for specific fields, considering the conditions and history associated with each field (Wilson et al., 2013). All of the following factors should be considered: field history of disease and cultivar ratings, field history of weed species, soil texture and seedling vigor, seeding method, susceptibility to lodging, relative maturity and seeding dates, grain and milling yield performance, irrigation capacity, and geographic location. Selecting rice cultivars with a high FNUE is the best approach to reduce fertilizer-N need in rice production.

Irrigation is another important factor in growing a successful rice crop. There are many different irrigation systems used in Arkansas including zero grade, precision grade, non-precision grade, multiple inlet, sprinkler/center pivot, and furrow irrigated rice (Henry et al., 2013). Furrow irrigated rice is increasing in popularity because of the environmental benefits of less water use; however, its implications of NFUE have not been determined. Each of these irrigation systems supplies a different amount of water to the rice crop (Hardke, 2015). Roughly 75% of the crop production systems are irrigated with ground water with the remaining irrigated with surface water sources. If a producer is unfamiliar with the quality of the water supplied, the groundwater should be tested and considered as a factor in the fertilization plan. For flooded rice, the permanent flood should be applied to the rice crop at the fifth vegetative leaf, or first tiller stage, and kept until it fits the conditions of both time and maturity. These conditions include 25-30 days past 50% heading and 2/3 straw colored kernels on silt loams or 1/3 straw colored panicles on clay soils.

NITROGEN CYCLE IN SOYBEAN-RICE ROTATION

Many studies have examined the benefits of using a crop rotation system containing a legume. Traditional belief that legumes improve the soil productivity is supported by many studies (Lory et al., 1995). Documented rotation effects from legumes include: contribution of the legume-N, recycling of mineralized soil-N, interruption of pest cycles, positive and negative soil moisture effects, negative allopathic effects, and improved soil physical properties. Rice is a member of the grass family *Poaceae*, while soybean is a member of the legume family, *Fabaceae*. This is beneficial in breaking up pest and disease cycles within the rotation system. These crops have different nutrient requirements to achieve a high grain yield and productivity.

Soybean is a dominate legume crop used worldwide, credited for a significant portion of the global N_2 fixed annually. It has been calculated that the soybean crop fixes 16.4 Tg N each year, representing 77% of the N_2 fixed by legumes (Herridge et al., 2008). This N_2 fixed by the soybean crop is then available for use by the current soybean plant for growth. The N is allocated within the plant to grain production or biomass. The grain-N is removed from the soil system at harvest while the biomass-N remains in the system. The biomass-N is released through residue decomposition and either mineralized or immobilized within the soil system. The fate of the biomass-N depends on the C:N ratio, which is typically low (15:1) promoting mineralization (Norman et al., 1990). The mineralized N derived from the biomass residue and any unused fixed N makes up the soil-N credits.

A similar study found that a substantial amount of soybean residue N was mineralized and lost (Norman et al., 1990). Mineralization occurs any time after crop harvest and is not related to the following crop's nutrient demand cycle. It is very difficult to quantify the amount of N mineralized from the crop residue during the growing season because the efficiency of the crop residue-N is unknown. Returning the biomass of the crop back into the soil system is a common practice, either by tillage or decomposition of the residue left aboveground. Residue left on the soil surface decomposed slower than buried residue (Gilmour et al., 1998). The nutrient content of the residue contributes to the rate of decomposition. The higher the carbon (C) to N ratio and the lower the amount of N in the crop residue allows for more of the residue-N to be recovered into the soil.

NITROGEN CREDITS IN SOIL

Nitrogen credit is the fertilizer-N replacement value obtained in a crop rotation sequence compared with a continuously grown crop, usually referring to a legume component in a crop rotation (Lory et al., 1995). There are two different ways to calculate the N credit in a soil. One method uses a fertilizer response curve comparing an unfertilized non-legume crop grown in rotation without a legume, compared to one with a legume crop in the rotation. The second way to quantify an N credit considers the economic returns of the production system. This defines N credits as the difference between the economic N rates of conventionally fertilized non-legume and of the non-legume in rotation, and is determined directly from a fertilizer response curve of the non-legume in rotation. This estimate of N credit may change with prices of fertilizer and harvested product. The first method, termed the traditional method, must be carefully considered as to not include any non-N rotation effects in the measurement.

There are five major ways to measure the N_2 fixation that occurs in a soil (Herridge et al., 2008). These include 1) detecting and quantifying the gas ethylene after exposure of root and nodules to acetylene, 2) using the total N-balance method assuming the plant/soil system will accumulate N over time if there is a net input of N_2 fixation, 3) comparing total N accumulated by legumes to the total N of a reference crop that does not fix N_2, 4) measuring the heavy isotope on N, ^{15}N by a N_2 fixing crop, and 5) the ureide method measuring the total ureide N to total N in xylem sap. Within these different ways of measurement, various quantitative values can be found increasing the importance of using the same method for consistency.

Nitrogen credits in the soil system are extremely valuable to a producer and should be maximized when possible to reduce the need to fertilize the soil. Rice FNUE is the highest of all major crops when managed correctly, allowing for a lower input cost and a higher profitability. The loss pathways denitrification and ammonia volatilization pose the threat of a large input cost for very little gain to a producer and heavy environmental impacts. The use of natural BNF allows a reduced loss potential and an increase in yield and soil health.

OBJECTIVES

Many researchers have studied differences in MGs of soybean, but no one has investigated the topic of N cycling in a soybean-rice crop rotation concerning soybean management practices. The primary purpose of this study was to determine the influence of soybean management techniques including MG and planting date on soil-N credits developed. These management techniques were also evaluated for the impact on a following rice crop's fertilizer-N recommendation rate. Five site years of data were used to assess these management techniques on silt loam and clay soils in Arkansas. Four MGs (3.5, 4.7, 5.4, and 5.6) were used to represent Arkansas soybean production cultivars. Two relative planting dates were evaluated as management practices, optimum and late. Optimum planting date was classified as early May sowing. Late planting date was classified as June or July sowing. N-STaR soil tests were taken from each soybean treatment to measure the plant available N at rice emergence, termed soil-N credits. The rice response to the soybean treatments was measured through the TNU, grain yield, and N rate needed to achieve 95% relative grain yield.

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APPENDIX

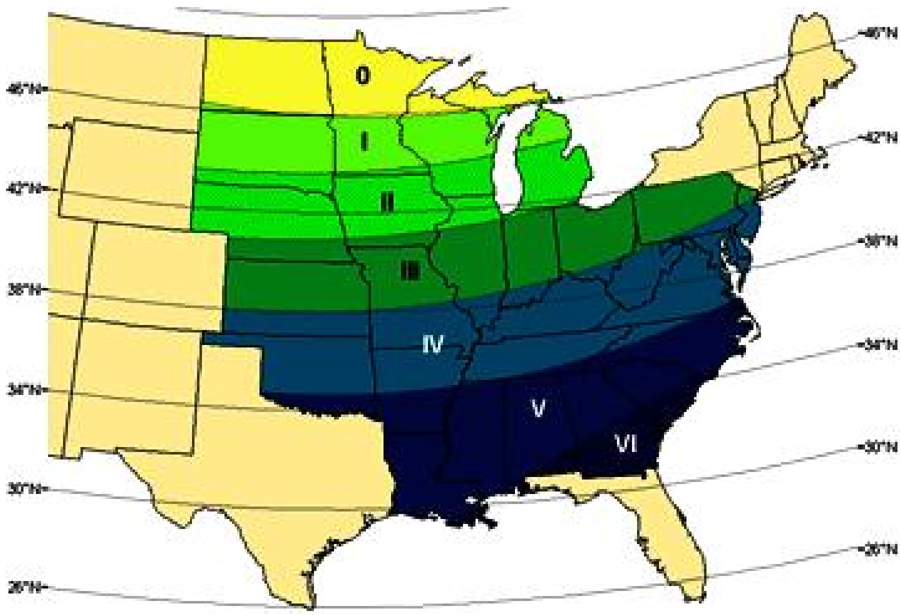

Figure 1-1. Map of the well adapted areas of soybean maturity groups in the United States (Zhang et al., 2007).

CHAPTER TWO

Evaluation of Soybean Management on Total Nitrogen Uptake, Grain Yield, and Net Nitrogen Returned to the Soil System

ABSTRACT

Management of a soybean (*Glycine max* L.) crop can influence the amount of soil-nitrogen (N) credits generated, which may significantly impact the amount of fertilizer-N needed for the success of a subsequent crop. Manipulation of soybean maturity group (MG) and planting date may help increase the productivity and yield of a soybean crop while simultaneously influencing the soil-N credits. Four soybean MGs (3.5, 4.7, 5.4, and 5.6) were evaluated at optimal and late planting dates in Arkansas. Grain yield was significantly different amongst MGs in both 2016 (P = 0.0012) and 2017 (P = 0.0004), with the 4.7 relative MG consistently yielding the highest. Plant total aboveground N uptake (TNU) increased with increasing grain yield (P = 0.0167) when all site years were analyzed together and was significantly higher when planted in an optimal planting window (P = 0.0004). The N removed from the cropping system by soybean grain harvest was significantly different between MGs in 2016 (P < 0.0001), and in 2017 was significantly influenced by the interaction of planting date and MG (P = 0.0397). The net N returned to the soil through biomass residue was not significantly influenced by planting date (P = 0.7796) or MG (P = 0.3475); however, net N returned to the soil decreased as grain yield increased (P = 0.0522). An optimum planting date of a well-adapted soybean MG produces the highest grain yield, TNU, and N removed from the cropping system identifying a relationship which allows producers to achieve maximum profitability while minimizing inputs to the whole farm system.

INTRODUCTION

Relative MG of soybean describes the growth habit, day length response, and overall length of the growing season. Soybean MG also characterizes where a cultivar is best adapted without limiting the locations it can be grown (Lersten and Carlson, 2004). Soybean cultivars differ in the amount of time spent in vegetative growth before the plant blooms, which is influenced by soybean MG and planting date. Manipulating MG selection as well as planting date may result in a significant response in soybean yield. Legume crops, such as soybean, can provide N credits to the soil system through the N remaining in the unharvested biomass, thus allowing for a decreased N fertilization rate for a successive crop. A survey found ~$440,000,000 was spent on fertilizer in Arkansas during 2017 (USDA-NASS, 2018). Lowering this input cost through an optimized crop rotation system allows the producer to increase potential overall profit. Agricultural systems which involve biological N fixation (BNF) as a major source of N tend to have a lower N surplus; therefore, less nitrate is lost resulting in a lower potential for environmental impacts (Syswerda et al., 2012; Blesh and Drinkwater, 2013). In soybean, high yield is directly related to high nutrient uptake with N demand satisfied by a combination of BNF and soil-N supply (Tamagno et al., 2017). Nutrient uptake and partitioning is closely related to dry matter accumulation with about 68% of the plant TN provided by BNF (Peoples et al., 1995; Herridge et al., 2008; Bender et al., 2015). Biological N fixation continues at a constant daily rate throughout the growth stages from when the trifoliate leaves unroll and plants are in full bloom until the leaves begin to senesce and discontinue photosynthesis (Hanway and Weber, 1971) otherwise known as late seed fill (Mastrodomenico and Purcell, 2012). Different MGs will spend various amounts of time in vegetative growth and therefore will reach full seed at different times, resulting in separate levels of BNF, N uptake, and N distribution within the plant. These variations coupled with different yield potentials may produce different amounts of N returned in the unharvested biomass.

Planting date is another important decision in addition to soybean MG, as planting dates can affect the total length of the vegetative period, flowering, pod-set, and to a lesser degree the seed-fill period (Salmerón et al., 2016). Photoperiod and temperature are the two main factors when delineating the MG best adapted to the location and its environmental conditions (Mourtzinis et al., 2017). Earlier planting dates allow for much of the reproductive seed development to occur prior to the hot, dry August weather (Sweeney et al., 1995). Timing of this reproductive growth appears to be more important than total growth duration in determining overall yield (Steele and Grabau, 1997). Planting date adjustments may provide an optimal environment during seed-fill allowing for maximal yield return. If planted at a suboptimal time, the soybean yield potential is reduced and does not represent the full potential of the cultivar (Zhang et al., 2007). Planting date and soybean MG decisions can greatly affect yield and composition, TNU, and net N returned significantly impacting overall farm profitability.

Crop rotations which involve legumes often refer to a reduced N rate as a ‘N credit’; however, soybean does not result in a net N input to the soil system through N_2 fixation as this term suggests (Salvagiotti et al., 2008). Instead, the addition of N to the soil system is derived from the decomposition of unharvested biomass. Soybean residue generally contains a low C:N ratio (15:1) (Norman et al., 1990), allowing for rapid mineralization of soybean residue-N and enhanced mineralization of soil organic matter. This increases the plant available-N in the soil system for the following crop without any N fertilizer input to the soybean crop. Through careful selection and management of the soybean used in rotation, maximal N credits may be achieved. Many influential factors go into this consideration including: soybean MG, planting date, fertilization, and irrigation (Gelfand and Robertson, 2015). The quantity of N credits established by each MG is dependent on many factors including environmental and physiological characteristics. The goal of this research was to investigate the productivity of different MGs when grown within similar environments to establish relationships among soybean MGs and planting dates. The TNU, grain yield, N removed, and net N returned were evaluated between planting dates and MGs to develop a relationship between soybean management and overall productivity.

MATERIALS AND METHODS

SITE DESCRIPTIONS

Field trials were conducted at two locations, which primarily differed in soil properties, during 2016 and 2017. The locations selected had an agronomic field history which represent typical Arkansas crop production rotations. To ensure that a broad spectrum of production settings were represented, both silt loam and clay textured soils were used in this study. Two of the fields at Pine Tree Research Station (PTRS) near Colt, Arkansas were a Calhoun (fine-silty, mixed, active, thermic Typic Glossaqualfs) silt loam soil (PTRS-16L and PTRS-17O) while the third field at PTRS was a Calloway (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) silt loam soil (PTRS-17L). The two fields at the Southeast Research Station (SEREC) near Rohwer, Arkansas were Sharkey (very-fine, smectitic, thermic Chromic Epiaquerts) and Desha (very-fine, smectitic, thermic Vertic Hapludolls) complex clay soil (SEREC-17O and SEREC-17L). All field history can be found in Table 2-1. Each location included two planting dates, one representing an optimal planting date for soybean and one representing a late planting date in Arkansas. The optimal planting dates were planted in early May while the late planted fields were planted in June or early July (Egli and Cornelius, 2009).

Routine composite soil samples were taken from each field near planting, in April or May, to assess preliminary soil characteristics as shown in Table 2-2. Five or more soil cores were randomly taken with a 0-10 cm cone sampler and mixed together as a single composite sample. Each sample was oven-dried at 70°C and ground to pass through a 2 mm sieve and submitted to the Agricultural Diagnostic Laboratory in Fayetteville, AR for nutrient analysis. The soil tests conducted assessed pH as a 1:2 v:v soil:water ratio (Thomas, 1996), total N (TN) (Bremner, 1996), total carbon (TC) (Nelson and Sommers, 1996), organic matter via loss on ignition (LOI) (Schulte and Hopkins, 1996), and Mehlich 3 extractable nutrients, phosphorus (P), potassium (K), and zinc (Zn) (Helmke and Sparks, 1996).

For all sites within the PTRS location, soil test K fell within the medium soil test category and 67 kg K_2O ha^{-1} was applied and incorporated prior to planting. The soil was tilled to a 10 cm depth prior to drill seeding the soybean crop with five rows at a 38 cm row spacing at all site years. Due to complications with the planter in the SEREC-17O field, the soybean crop was double planted and resulted in an above average plant population. Two years of data were collected to replicate the study across locations and planting dates to encompass differing environments.

The computer program SOYMAP was used to predict the growth stages and grain yield for each location and planting date. SOYMAP is a soybean maturity analysis and planning software created by the University of Arkansas developed to help plan and compare the growth stages and yield projections of various soybean MGs (Popp et al., 2016). Due to the various MGs, planting dates, and locations, SOYMAP was useful in estimating the distinct growth stages to help plan the sampling of soybean total aboveground biomass. This program considers the location, planting date, MG, soil texture, and soil water holding capacity. These factors project the estimated yield, date plants will reach important growth stages, irrigation requirements, and an overall economic analysis. SOYMAP estimates the date of the following growth stages: R1 (beginning bloom), R5 (beginning seed), and R8 (maturity) based on the characteristics previously listed. These estimates show the wide variety of time spent in vegetative growth stages between MG and planting date and are presented in Table 2-3.

SOYBEAN MATURITY GROUP STUDY

Four soybean cultivars were planted in 45.7 meter strips of the field, where each cultivar was randomly assigned to one strip in each replication. In 2017, an additional strip was added to each replication and left fallow to act as the untreated check, or control, for the future rotation analysis. Each strip was divided into six subplots, each 7.62 meters long for precise aboveground sampling and analysis of the future crop rotation. Each field contained four replications of the study. The cultivars used in 2016 were all Pioneer (Corteva Agriscience™, Midland, MI) seed with the glyphosate tolerant trait. These cultivars included: P35T48 (3.5 MG), P47T36 (4.7 MG), P54T94 (5.4 MG), and P56T12 (5.6 MG). In 2017, the indeterminate cultivars remained the same while the determinate cultivars changed to University of Arkansas cultivars, due to difficulty obtaining seed of the appropriate MG. The cultivars planted in 2017 were P35T58R (3.5 MG), P47T36R (4.7 MG), UA 5414RR (5.4 MG), UA 5612 (5.6 MG). The 3.5, 4.7 and 5.4 MG were glyphosate tolerant, and the 5.6 MG was a conventional cultivar. The cultivars and their predominate characteristics are listed in Table 2-4. The soybean seed planted in 2016 was untreated, but all soybean seed planted in 2017 was treated with CruiserMaxx® Beans (Syngenta, Research Triangle Park, NC). All cultivars were planted on the same date within each site year as indicated in Table 2-3. Plant population was measured by taking plant stand counts during vegetative growth at approximately the V5 growth stage, where number of plants were counted in 5.3 m of row and extrapolated to determine an average plant population on a per hectare basis.

The fields were managed using University of Arkansas recommendations for all nutrients and pests (Ross, 2000). The SEREC-17L field was impacted by a rare species of snails (*Gastropoda*) near the R5 growth stage. The same field measured a low stand count and showed symptoms of a possible chloride (Cl^-) toxicity later in the growing season, around the R6 growth stage. Plant samples were taken from the affected leaves and indicated a possible Cl^- toxicity level, ranging from 759 to 2070 mg Cl^- kg^{-1}. Cox et al. (2018) reported this same level of Cl^- in an excluder cultivar would result in ~92.7% relative grain yield. The wet weather during the vegetative and early reproductive growth stages kept the clay soils extremely wet, not drying out until mid-September. The well water used to irrigate the experiment may have introduced a high Cl^- level to the cropping system which damaged the plants. The soil samples taken at planting were also analyzed for extractable Cl^- (Cotlove et al., 1958). The field which exhibited symptoms, SEREC-17L, ranged from 54.4 to 103.3 mg Cl^- kg^{-1}, while the neighboring field which did not exhibit toxicity symptoms, SEREC-17O, measured only 38 mg Cl^- kg^{-1}.

ABOVEGROUND BIOMASS SAMPLING AND ANALYSIS

All cultivars were irrigated, managed identically within location, and tracked using the SOYMAP program to predict and record the growth stages. The aboveground biomass sampling procedures in 2016 and 2017 were slightly different. In 2016, five random plant samples were taken from bordered rows in two subplots within each MG strip at full seed. These subplots did not receive any different treatment in the first year of the study, both were sampled for replication. Similar to Bender et al. (2015), ten whole plant samples were taken from each strip, for a total of 160 soybean plants per field. The plant samples were collected in burlap bags, labeled, and dried at 60°C until the plants reached a constant weight. The plants were then removed from the dryer and weighed to determine the total dry matter weight. Each bag of five whole plant samples was separated into biomass and grain, with each subsample weight recorded. The biomass was ground to pass through a 1 mm sieve and a representative subsample was taken. At maturity, each plot was harvested using a small plot combine and yield data were collected and adjusted to 13% moisture content. The grain from each plot was weighed and subsampled. The subsample was ground in a KitchenAid (Whirlpool Corporation, Benton Harbor, MI) coffee grinder for about one minute until a consistent, fine texture was achieved.

In 2017 the sampling procedure involved two rows, 1-m in length at the late full seed growth stage (R6.5). This totals 0.76 m^2 of whole plant samples taken from each sampled subplot. These samples were from bordered rows in two subplots within each MG strip. These subplots did not receive any different treatment; both subplots were sampled for replication. The sampled plants were weighed in the field to get a total wet weight of the whole sample. From the whole sample, five random plants were collected and weighed again to record a subsample wet weight. These five plants were then placed in a burlap bag, dried to a constant moisture, and weighed again to get a dry biomass weight. The ratio of the subsample dry weight to wet weight was used to extrapolate the whole sample wet weight into a dry matter weight per hectare. Sampling was conducted according to the predicted R6.5 growth stage, to achieve the best estimate of aboveground TNU possible. The sampling history is presented in Table 2-3. Yield and sample processing were conducted exactly the same as presented earlier.

All plant sample analysis was conducted at the Agricultural Diagnostic Laboratory in Fayetteville, AR. At the full seed growth stage (R6) the soybean plant has accumulated the majority of the N (Bender et al, 2015) and has not yet begun to senesce the leaves. At this stage, whole plant samples were taken to measure TNU. In 2016, the whole plant samples were separated between biomass and grain and analyzed separately. The biomass was analyzed only for TN through combustion with Elementar Rapid N III Nitrogen analyzer (Bremner, 1996). In 2017, the whole plant samples were ground together to pass a 2 mm sieve and TN was measured using the same combustion method. The mature grain samples were analyzed the same in both 2016 and 2017, which measured the amount of N removed from the cropping system at harvest. The remaining biomass was not sampled for TN, but was estimated by subtracting the grain-N from the total plant-N measured at full seed. The 2016 soybean samples were also analyzed for TC using the combustion with Elementar Variomax method (Nelson and Sommers, 1996).

Following harvest at each site-year, the remaining biomass residue from the harvested soybean was spread evenly throughout each individual subplot to allow for an even distribution of nutrients through decomposition of biomass. The fields were then left fallow to minimize disturbance until planted with the rotation crop the following spring.

STATISTICAL ANALYSIS

The 2016 site year was analyzed separately from the 2017 site years due to differing sampling methods and different cultivars within two of the MGs. The 2016 site year (PTRS-16L) was analyzed as a randomized complete block with MG as a fixed effect and block as a random effect. The 2017 site years were analyzed as a split plot design with location and planting date as whole plot factors and MG as a split plot factor. An abbreviated analysis of variance table is listed in Table 2-5. Location and planting date were nested within block and included as a random effect. A location by planting date interaction and MG by planting date interaction were included as random and fixed effects, respectively. Variance components of random effects are shown in Table 2-6. In 2017, a fallow strip was added into each block as a control for the following study within the crop rotation, but was not included as a treatment in analysis. Normality was assumed for all data. All five site years of data collected included four blocks within each field. Each block included one large plot (45.7 x 2.1 meters) for each MG.

Mean separation was carried out using Tukey's HSD test for those effects having significant F-tests. Comparisons were done at the $\alpha = 0.05$ significance level to evaluate differences. Tukey's HSD was used on all means comparisons to produce fewer false differences in the outcome. Outliers were identified using the studentized residual plots as any data point exceeding an absolute value of three standard deviations. One data point was excluded from the 2016 data for an unusually high TNU recorded and thus, this datum was excluded from analysis in all response variables. This was a 3.5 MG on the edge of the field. Two additional data points were excluded from the 2017 data for unusually high N removal values. These data points belonged to the 3.5 and 5.4 MG treatments and were excluded from analysis of all response variables.

Total N uptake, grain yield, N removed, and net N returned were all response variables analyzed for statistical significance. The N returned to the soil system was found using a difference method of total N accumulation at full seed minus the grain-N at maturity. The difference represents the biomass-N returned to the soil system, contributing to potential N credits. The following equation was used:

$$\textit{Biomass-N} = (\textit{kg N ha}^{-1} \textit{ at R6.5}) - (\textit{kg grain ha}^{-1} \textit{ x \%N in grain at maturity})$$

This is assuming all N has entered the aboveground plant system at full seed, which a portion may have accumulated after this point. However, this assumption is leaning on the conservative side; if more N is taken up into the plant in the later growth stages, this evaluation is underestimating the N returned.

The degrees of freedom and *P*-value of each statistical model are listed in Table 2-5. All site years of data were combined to investigate a correlation between grain yield and TNU, as well as grain yield and N returned. These relationships were considered to determine if an overall correlation across all planting dates, environments, and MGs exists. All statistical analyses were performed using JMP Pro 13 (SAS Institute, Cary, NC).

RESULTS AND DISCUSSION

SAMPLING DATES

All soybean cultivars were planted on the same day within each site year, shown in Table 2-3. The different MGs, planting dates, and locations of the experiment resulted in a large span of sampling times for the data collection at full seed and maturity. The earlier planted treatment was sampled and harvested before the later planted treatment across all locations and MGs. The indeterminate MGs had a shorter growing season and were sampled prior to the determinate MGs within each planting date and location. This is because of the shortened vegetative growth period in the indeterminate cultivars.

SOYMAP estimates the date of growth stages R1 (beginning bloom), R5 (beginning seed), and R8 (maturity) based on the factors previously listed. These estimates show the wide variety of time spent in vegetative growth stages across the MGs and planting dates included in this trial. For example, the first field planted in PTRS on May 7, 2017 had a range of expected dates for the four MGs to reach R1 from June 6 for the 3.5 MG to June 26 for the 5.6 MG. All predicted dates are in Table 2-3 for comparison. The relative amount of time spent in vegetative and reproductive growth stages is important because if the soybean plants are in vegetative growth longer, they are expected to be assimilating N for a longer period of time. Late planting dates will result in a reduction in the length of the vegetative growth period as well as time spent in crucial reproductive stages, including seed fill (Salmerón et al., 2016). Nitrogen fixation continues until late seed fill and supplies nearly all of the seed N to the plant (Mastrodomenico and Purcell, 2012). Both planting date and MG affect the progression from seed development (R5) to seed fill (R7) (Mourtzinis et al., 2017). Therefore, shortening the season and time spent in the early growth stages may reduce the amount of N supplied by the legume because of a reduced quantity of biomass produced, hence a reduction in the amount of N returned post-harvest.

TOTAL NITROGEN UPTAKE

The TNU of the soybean crop at the full seed growth stage (R6.5) ranged from 83 to 378 kg N ha^{-1}, with averages by MG and planting date presented in Table 2-7. Sampling occurred immediately prior to leaf senescence, when the majority of the season total N had accumulated (Bender et al., 2015). No significant differences were observed between MGs in 2016 (P = 0.2971) or 2017 (P = 0.05487), presented in Table 2-7. However, planting date significantly influenced the season TNU in 2017 (P = 0.0004), with a greater TNU for the optimum planted soybean crop than the late planted crop. Total N uptake for the optimum planting date averaged 242 kg N ha^{-1} across locations, while TNU for the late planted soybean crop averaged 145 kg N ha^{-1}. There was no significant MG by planting date interaction (P = 0.0575), further defining planting date as the management decision having the greatest impact on soybean plant TNU. Gaspar et al. (2017) found TNU was affected by the environment, but not the cultivar. Location did not affect the TNU (P = 0.4854), which agrees with the conclusion that environment is manipulated by planting date.

Gaspar et al. (2017) also concluded that peak uptake rates for N occurred between R4 and R5, depending on yield level. After the R5.5 growth stage ~69% of vegetative N was remobilized to the seed. This supports our assumption that the measurements taken at R6.5 captured the peak soybean TNU and after the N redistribution to the seed began. Mastrodomenico and Purcell (2012) found that N_2 fixation could supply up to 86 and 90% of total N required by the soybean plant. George et al. (1988) found the proportion of N derived from fixation and average N assimilation rates were similar among MGs. With this assumed constant, and soil-N mineralization consistent within site year, the near significant differences observed between MGs ($P = 0.0549$) may be related to the overall yield potential.

SOYBEAN GRAIN YIELD

Grain yield ranged from 1076 to 5312 kg ha^{-1} and mean treatment data is presented in Figure 2-1 separated by MG. The data set includes one very low yielding site year, SEREC-17L, and one very high yielding site year, PTRS-17O. Both of the optimum planting date site years had high yields, with all four MGs achieving yields above the state average of 3295 kg ha^{-1}. In all three of the late planted site years the grain yield did not reach the state average in any of the four MGs considered. Gaspar et al. (2017) found higher yields were associated with greater late season accumulation of dry matter, specifically after R5.5. This accumulation of dry matter would have been more significant in the optimum planted site years which allowed a longer dry matter accumulation period. Total N uptake required to produce a given grain yield varies between environments but increases as yield increases.

Maturity group significantly influenced grain yield in 2016 ($P = 0.0012$) and 2017 ($P = 0.0004$) across all planting dates, shown in Table 2-7. The MG 4.7 cultivar was the highest yielding in both 2016 and 2017; however, the MGs had different degrees of significance by year, shown in Figure 2-1. In 2016, the MG 4.7 cultivar yielded the highest and was significantly higher than the MG 3.5 and MG 5.6 cultivars. In 2017 there was no significant difference between the MG 4.7, 5.4, and 5.6 cultivars; however, all yielded significantly higher than the MG 3.5 cultivar. There was not a significant difference in grain yield between growth habits (indeterminate vs. determinate) in either 2016 ($P = 0.0811$) or 2017 ($P = 0.3329$).

Although the planting date factor was not significant ($P = 0.0850$), a strong trend was seen between grain yield and planting date. All MGs yielded higher in the May planting dates than the June or July planting dates. The interaction between MG and planting date ($P = 0.0851$) highlights the differences seen between MG in the optimum planted site years and indicates the importance of choosing the correct MG when planting during the optimum window. These data indicate that a MG is not a critical factor in yield when soybean is planted late, since all MGs resulted in a similarly low yield when grown in suboptimal conditions (i.e. late planting date). This yield reduction in late planted soybean may be attributed to the reduced vegetative growth (Carter and Boerma, 1979; Weaver et al., 1991) caused by premature flowering due to the shortening day length as the season progresses (Board and Hall, 1984; Board, 1985). Data also indicate that the total flowering period (R1 to R5) is decreased by late planting and this is a reason for low yields.

In all but one site year (SEREC-17L), the 3.5 MG yielded the lowest of all MGs considered. This field was very low yielding across all MGs, with the highest yield at 1726.7 kg ha^{-1}. A possible Cl^- toxicity was observed at the R6 growth stage, affecting the field in circular patterns. The average plant population of this field was measured in the early vegetative growth at 231,000 plants per hectare. All other fields measured an average of 436,000 plants per hectare, just above the desired plant population of 420,000 plants per hectare (Robinson and Conley, 2007). This entire field was affected by snails which fed on the leaves and pods of the soybean late in the season at approximately the R5 growth stage. The different yield trend seen may have been because the MG 3.5 cultivar was much further along physiologically at the onset of potential Cl^- toxicity and pest impact compared to the other MGs.

Across all site years, the MG 4.7 or 5.4 cultivars had the overall highest yield, shown in Figure 2-1. The planting of these relative MGs are common practice in Arkansas, as MG IVs and early MG Vs are well suited for the environment (Mourtzinis et al., 2017). The optimum planted site years showed higher indeterminate yields of the MG 3.5 and 4.7 cultivars, while the late planted site years showed higher determinate yields of the MG 5.4 and 5.6 cultivars. The day length may have contributed towards these differences, as the late planted site years only experienced shortening days, which may have triggered early flowering. Consequently, planting date has a practical importance on grain yield of a soybean crop and should be considered as a management technique to maximize profitability.

GRAIN YIELD x TOTAL NITROGEN UPTAKE

As TNU increased, the grain yield increased ($P = 0.0167$) across all MGs, planting dates, and locations (Figure 2-2). The higher N uptake supported an increased grain production. This relationship between TNU and grain yield was significant within each MG except 5.4 ($P = 0.7039$) when all site years were considered (3.5 MG $P = 0.0022$, 4.7 MG $P = 0.0031$, 5.6 MG $P = 0.0022$). The model explained very little of the variability ($r^2 = 0.073$); therefore this relationship cannot be used to predict the grain yield from the TNU data and it is only applicable in general trends. A soybean with a high TNU will not always result in a high grain yield. A plant may take up high amounts of N but not successfully distribute it into the grain, resulting in a low yield and high N returns to the soil through biomass residue following harvest.

The variability in this relationship lies in the high TNU plants, which did not all produce an equally high grain yield. High yielding soybean had a small variability in TNU values, indicating a high yielding soybean is possible only through a high TNU. Low yielding cultivars have a much greater variability in TNU, indicating a high TNU does not exclusively guarantee a high grain yield. This is because of differing seed composition of N, as the soybean yield-composition relationship is very complex, but well defined. Seed yield is often correlated to total N assimilated and protein content (George et al.,1988, Mourtizinis et al., 2017). Seed composition is controlled by breeding, environmental conditions, and geographic location of production. The data points with a high TNU and disproportionally low grain yield were late planted MG 5.4 and 5.6 cultivars. These determinate cultivars thrive in long growing seasons with extensive vegetative growth stages. This generally couples with a high TNU to support a high grain yield; however, if the reproductive growth was condensed due to the environmental conditions, the plants would have a large amount of N with an unbalanced distribution of N into the grain. The uneven variances violate an assumption made in statistical analysis; therefore, the relationship is limited to practical use and should not be used to base decisions on. A producer with high yields can roughly estimate the TNU of the crop, knowing the yield and TNU are related.

NITROGEN REMOVED

The N removed from the production system is related to the grain yield and is calculated as the grain yield multiplied by the N concentration within the grain. Although a relationship between grain yield and soybean MG exists, further trends were identified when N removal is considered due to this measurement also considering the distribution of N. A range from 53 to

276 kg N ha^{-1} were removed from the cropping system in the harvested grain, and the means are presented in Table 2-7.

The effect of MG on N removed in the grain was significant in both 2016 (P = 0.0012) and 2017 (P = 0.0004), presented in Figure 2-3. The determinate cultivars removed more N from the cropping system than the indeterminate cultivars in both 2016 (P = 0.0028) and 2017 (P = 0.0036). Figure 2-3 shows the net N removal for each MG in both years. Across all site years the MG 5.4 cultivar had the highest N removal, while the MG 3.5 cultivar removed the least N. This is explained by the grain yield and N distribution within the plant. General trends show the higher yielding MGs removed the most N in the grain, while the low yielding MGs removed the least. More significant differences were seen between MGs for N removal than for grain yield, because the internal allocation of N was considered as well as the plant productivity. The raw data of percent of N in the sampled grain shows a normal distribution ranging from 5.16 to 7.29 % N. The MG 3.5 cultivar was on the lower end of this range coupled with lower grain yields, attributing to the low removal observed, which was caused by the lowest grain yield and the least N allocated to the grain from the biomass.

Planting date was not a significant factor in N removal rates (P = 0.1124), nor was location (P = 0.9493). However, there was a significant interaction between MG and planting date (P = 0.0397). The optimum planted MG 5.6 cultivar removed the most N from the cropping system at 243 kg N ha^{-1}, followed by the remaining three optimum planted MGs, data presented in Figure 2-3. All late planted MG cultivars removed less than the optimum planted MGs, yet the late planted 3.5 and 4.7 MGs were the only late planted cultivars that removed significantly less than the optimum planted 3.5 MG. The present findings do agree with the observations of

Weaver et al. (1991) that considerable variation in yield components is present between soybean cultivars when planted late.

NET NITROGEN RETURNED TO THE SOIL

The net N returned to the soil system after harvest in the crop residue was not significantly different between MGs in 2016 (P = 0.2625) or 2017 (P = 0.3475). There was also no significant difference among planting dates (P = 0.7796) or location (P = 0.5474). Norman et al. (1990) found various N concentrations in unharvested biomass between species, promoting differences in potential N loss pathways during the winter season which lead to a difference in N recovered by a following rice (*Oryza sativa* L.) crop.

The amount of net N returned to the soil after harvest ranged from -107 to 192 kg N ha^{-1}. The data were calculated as the N removed by the grain subtracted out of the TNU to estimate the amount of N remaining in the biomass which was not relocated into the grain and returned to the soil in the unharvested crop soybean biomass. The sampling method used allows for a small quantity of negative values reported due to the assumptions that were drawn. Sampling for TNU was completed at full seed instead of maturity to avoid leaf senescence; however, this estimate only considers approximately 90% of the season TNU (Bender et al., 2015). Although it is known that negative values cannot be returned to the soil, it is relative to the other estimations produced from this method. This allows for the negative values to be kept in the data set and used for comparisons within site year, as it is assumed all MGs were equally affected.

This estimation of the biomass-N is what the crop will potentially contribute to the soil-N pool as N credits. The mineralization of the residue-N provides one of the rotational benefits to the following crop, rather than the BNF (Smith and Sharpley, 1990; Green and Blackmer, 1995). Crops with lower C:N ratios provide more benefits to the cropping system through mineralization and quick decomposition (Gilmour et al., 1998). Alfalfa (*Medicago sativa* L.) increased soil-N mineralization by 30-40% when compared to soybean (Carpenter-Boggs et al., 2000) because of the very low C:N ratio of around 13:1. The C:N ratio of the residue biomass remaining in the cropping system after harvest determines the fate of the remaining N. Low C:N ratio residue will result in an increased plant available N pool through mineralization, while high C:N residue will immobilize the N and result in a reduced level of plant available N. The fate of the remaining N was determined using an estimated C:N ratio of 15:1 (Norman et al., 1990). All soybean plots involved in the study resulted in a net increase in plant available N through mineralization, ranging from 2.7 to 98.0 kg N ha^{-1} added to the soil.

GRAIN YIELD X NITROGEN RETURNED

As grain yield increased the N returned to the soil system decreased (P = 0.0522) across all MGs and planting dates, presented in Figure 2-4. The higher yielding soybean plants had sufficient N uptake and were successful in redistributing the N from the biomass to the grain, leaving less N behind after harvest. Little significance was found when the relationship was broken down by MG. The MG 5.6 cultivar was the only significant cultivar when analyzed individually (P = 0.0217). No relationship was seen within the MG 4.7 (P = 0.5053), the 3.5 (P = 0.9610), or the 5.4 (P = 0.2184) cultivars.

This overall relationship is loosely significant; however, the model explains very little of the variability (r^2 = 0.049) shown in Figure 2-4. Grain yield cannot be used to predict the N returned to the soil by a soybean crop. Only general assumptions can be drawn from the relationship. A high yielding soybean crop will typically return less N credits to the soil because of the elevated N removed in grain at harvest. The highest level of N credits will typically be achieved following a low yielding soybean crop due to the reduced amount of N removed in grain at harvest.

CONCLUSION

The results of this trial focused on N accumulation, N removal and N returned to the soil by various MGs of soybean across optimal and late planting dates. The results indicate that the most important aspects of soybean management in Arkansas are the selection of a well-suited MG and planting during the optimum planting window. These decisions, which are crucial for a successful soybean crop, must be made based on the environment, seed technology, and whole farm considerations. There is no single MG or planting date guaranteed to provide the highest yield and N credits, so it is best to plant in an early to optimum time and choose a well-suited MG for the environment. Planting early allows the soybean crop to achieve maximum biomass accumulation and N uptake thus preparing to produce a high grain yield with adequate N allocated in the grain. This also allows the possibility of a replant should the soil crust or poor stand establishment occurs, minimizing risk. Arkansas soybean producers should avoid planting any MG below group IV due to the significant yield reduction seen in the 3.5 MG across environments within this study. Maturity group selection is the paramount management decision when achieving a high grain yield is the objective. Relative MGs of high group IV to mid group V are well-suited maturities for the climate in Arkansas (Mourtzinis et al., 2017). Producers must also consider the intended end use of the crop when determining what cultivar will be used. Various uses of soybean prefer different N concentrations, which is heavily controlled through both MG selection and planting date. Maturity group selection is most important when planting at an optimum time for grain-N allocation. The cultivar selection importance decreases when the crop is planted after the optimum time due to the resultant decrease in overall yield potential with later planting dates. Late planted soybean result in less significant differences between N removed at harvest among MGs. Management of the planting date or MG had no influence on the net N returned to the soil through the biomass residue; however, additional research is needed to investigate the long term effects of MG and planting date on soybean N credits returned. Additional MGs of an extreme relative maturity would add useful information to this study, as well as multiple cultivars within each MG. Incorporating a group VI or group VII would allow a comparison of well-suited cultivars to MGs not previously considered in this study. Mastrodomenico and Purcell (2012) found the later maturing cultivars (MG VI) did not fully allocate N to the grain as other MGs (IV and V) did, allowing for the potential for mature biomass N concentration to vary among MG in these higher MG cultivars.

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APPENDIX
TABLES AND FIGURES

Table 2-1. Selected soil and agronomic information for soybean trials conducted in 2016 and 2017.

Site ID	Location	Relative Planting Date	Soil Texture	Soil Series	Previous Crop†	Soybean Year
PTRS-16L	PTRS	Late	Silt Loam	Calhoun	Soybean	2016
PTRS-17O	PTRS	Optimum	Silt Loam	Calhoun	Soybean	2017
PTRS-17L	PTRS	Late	Silt Loam	Calloway	Rice	2017
SEREC-17O	SEREC	Optimum	Clay	Sharkey & Desha	Rice	2017
SEREC-17L	SEREC	Late	Clay	Sharkey & Desha	Rice	2017

†- Soybean, *Glycine max* L.; rice, *Oryza sativa* L.

Table 2-2. Selected soil chemical property information for soybean trials conducted in 2016 and 2017.

	pH	P	K	Total N	Total C	LOI
Site ID		mg kg soil^{-1}		%		
PTRS-16L	7.2	27	97	0.06	0.79	2.11
PTRS-17O	7.8	22	69	0.12	1.21	2.41
PTRS-17L	7.5	53	120	0.08	0.96	2.02
SEREC-17O	7.8	67	215	0.05	0.78	2.69
SEREC-17L	7.8	55	177	0.05	0.78	2.12

The soil tests conducted assessed pH (1:2 v:v soil:water ratio) (Thomas, 1996), Mehlich 3 extractable nutrients, phosphorus (P) and potassium (K)(Helmke and Sparks, 1996), total nitrogen (TN) (Bremner, 1996), total carbon (TC) (Nelson and Sommers, 1996) and organic matter via weight loss on ignition (LOI) (Schulte and Hopkins, 1996).

Table 2-3. Important agronomic dates including soybean planting and emergence, as well as the projected R1 growth stage using SOYMAP, and the sampling date of full seed measurements for the trials conducted in 2016 and 2017.

Site ID	Planted	Emerged	Projected R1 Beginning Bloom — Maturity Group 3.5	4.7	5.4	5.6	R6.5 Full Seed Sample Dates — Maturity Group 3.5	4.7	5.4	5.6
PTRS-16L	9-Jun	13-Jun	11-Jul	15-Jul	25-Jul	27-Jul	31-Aug	6-Sep	14-Sep	14-Sep
PTRS-17O	7-May	13-May	6-Jun	12-Jun	23-Jun	26-Jun	16-Aug	30-Aug	6-Sep	6-Sep
PTRS-17L	4-Jul	8-Jul	25-Jul	29-Jul	6-Aug	7-Aug	20-Sep	27-Sep	4-Oct	4-Oct
SEREC-17O	10-May	15-May	10-Jun	15-Jun	26-Jun	28-Jun	15-Aug	29-Aug	5-Sep	5-Sep
SEREC-17L	7- Jul	11-Jul	24-Jul	27-Jul	4-Aug	6-Aug	13-Sep	27-Sep	27-Sep	27-Sep

Table 2-4. Soybean cultivar comparisons using information obtained on the seed distributors website (DuPont Pioneer, 2017; University of Arkansas, 2018).

Year	Cultivar	Seed Company	Relative Maturity	Growth Habit†	Chloride Sensitivity‡	TechnologyFꞘ	Pod Color
2016 & 2017	P35T48	Pioneer	3.5	Ind	-	R	Brown
2016 & 2017	P47T36	Pioneer	4.7	Ind	8	R	Brown
2016	P54T94	Pioneer	5.4	De	9	R	Brown
2016	P56T12	Pioneer	5.6	De	-	STS, R	-
2017	UA 5414	University of Arkansas	5.4	De	Ex	R	Tan
2017	UA 5612	University of Arkansas	5.6	De	-	C	Tan

†Ind, indeterminate; De, determinate.

‡ Numeric ratings, 9=Excellent; 1=Poor; Blank= Insufficient data or cultivar not tested. Ex, excluder.

Ꞙ R, Glyphosate Tolerant; STS, ALS inhibitor herbicides; C, Conventional.

Table 2-5. Abbreviated analysis of variance tables for individual 2017 fixed effect variables.

	Total Nitrogen Uptake				Grain Yield			
	NDF	DDF	F Ratio	*P*-value	NDF	DDF	F Ratio	*P*-value
Planting Date	1	29.8	16.255	0.0004*	1	1.4	20.135	0.0850
Maturity Group	3	39.6	2.758	0.0549	3	41.1	7.606	0.0004*
MG x PD	3	39.6	2.716	0.0575	3	41.1	2.363	0.0851
	Nitrogen Removed				Net N Returned			
	NDF	DDF	F Ratio	*P*-value	NDF	DDF	F Ratio	*P*-value
Planting Date	1	1.4	13.793	0.1124	1	6.7	0.0875	0.7796
Maturity Group	3	40.9	5.936	0.0019*	3	39.8	1.1326	0.3475
MG x PD	3	40.9	3.038	0.0397*	3	39.8	1.1718	0.3326

*Significant at the $\alpha=0.05$ level.

Table 2-6. Variance components of individual random variables for 2016 and 2017 data analysis.

		Total Nitrogen Uptake		Grain Yield		Nitrogen Removed		Nitrogen Returned	
	Effect	Estimate†	Percent of Total	Estimate	Percent of Total	Estimate†	Percent of Total	Estimate	Percent of Total
2016	Block	403.8	31.4	3903.0	9.9	67.6	87.9	559.4	37.6
	Residual	855.6	68.6	35215.0	90.1	9.2	12.1	926.7	62.4
	Total	1289.5	100.0	39118.1	100.0	76.8	100.0	1486.1	100.0
2017	Location	2651.7	51.9	47735.6	15.9	46.1	3.6	967.7	25.5
	Loc x PD	<0.1	<0.1	122573.4	40.8	645.4	50.9	119.6	3.2
	Block (Loc, PD)	< 0.1	<0.1	10323.9	3.4	<0.1	<0.1	80.9	2.1
	Residual	2455.8	48.1	120274.2	39.9	576.6	45.5	2624.2	69.2
	Total	5107.5	100.0	300907.2	100.0	1268.1	100.0	3792.6	100.0

†Negative estimates were compared to the standard errors and found not significantly different from zero

Table 2-7. Least Square Means by maturity group (MG) and planting date (PD) for 2016 and 2017 data within each response variable.

	Grain Yield		Total N Uptake		Nitrogen Removed		Net Nitrogen Returned	
	2016	2017	2016	2017	2016	2017	2016	2017
	kg ha^{-1}		kg N ha^{-1}					
MG								
3.5	2361 bc	2647 b	218	193	147.0 c	148 b	71.7	47.1
4.7	2975 a	3232 a	261	191	187.0 b	167 ab	74.7	26.1
5.4	2831 ab	2993 a	223	201	200.7 a	176 a	24.0	26.5
5.6	2067 c	3059 a	239	236	181.3 b	183 a	58.3	52.7
PD								
Optimum		3539		242 a		201		51.4
Late		1756		145 b		96		42.8

Means not sharing the same letter within a column are significantly different (HSD, $P < 0.05$).
Not significant at the $\alpha = 0.05$ level if letters are not present.

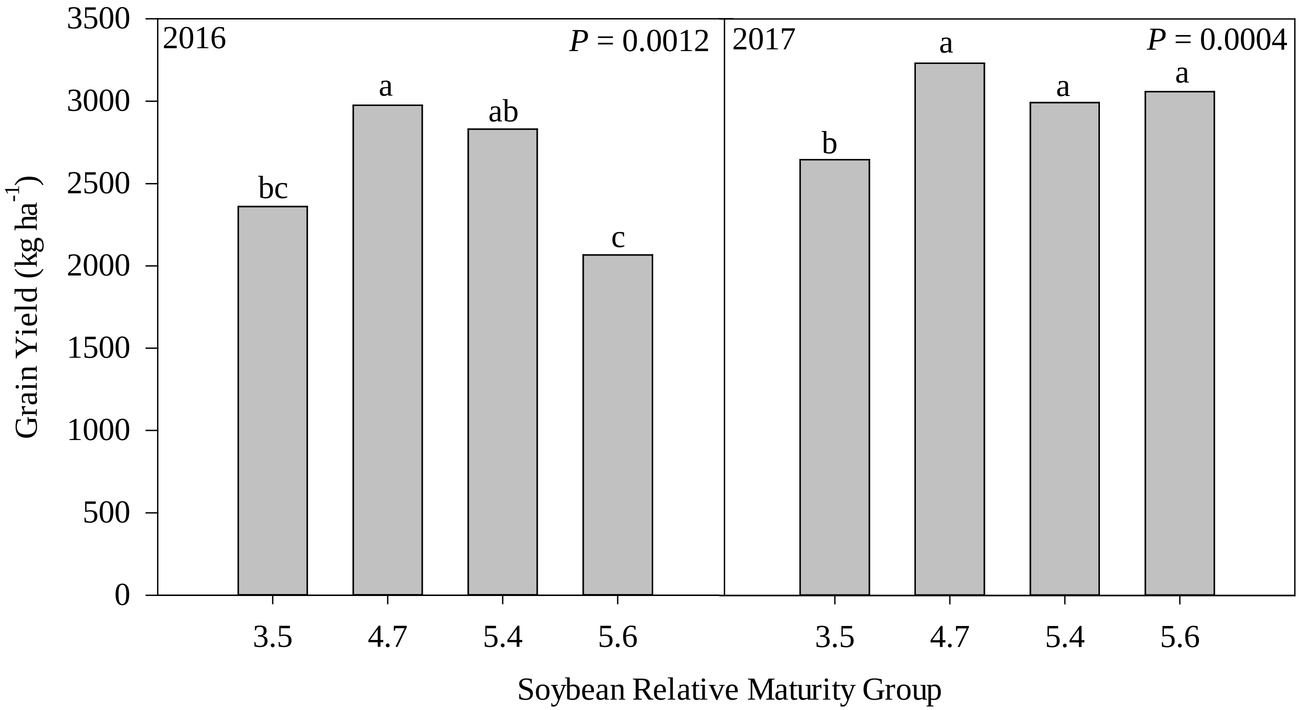

Figure 2-1. Soybean grain yield as influenced by maturity group, PTRS-16L (left). All four 2017 site years analyzed together shown in the right graph. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

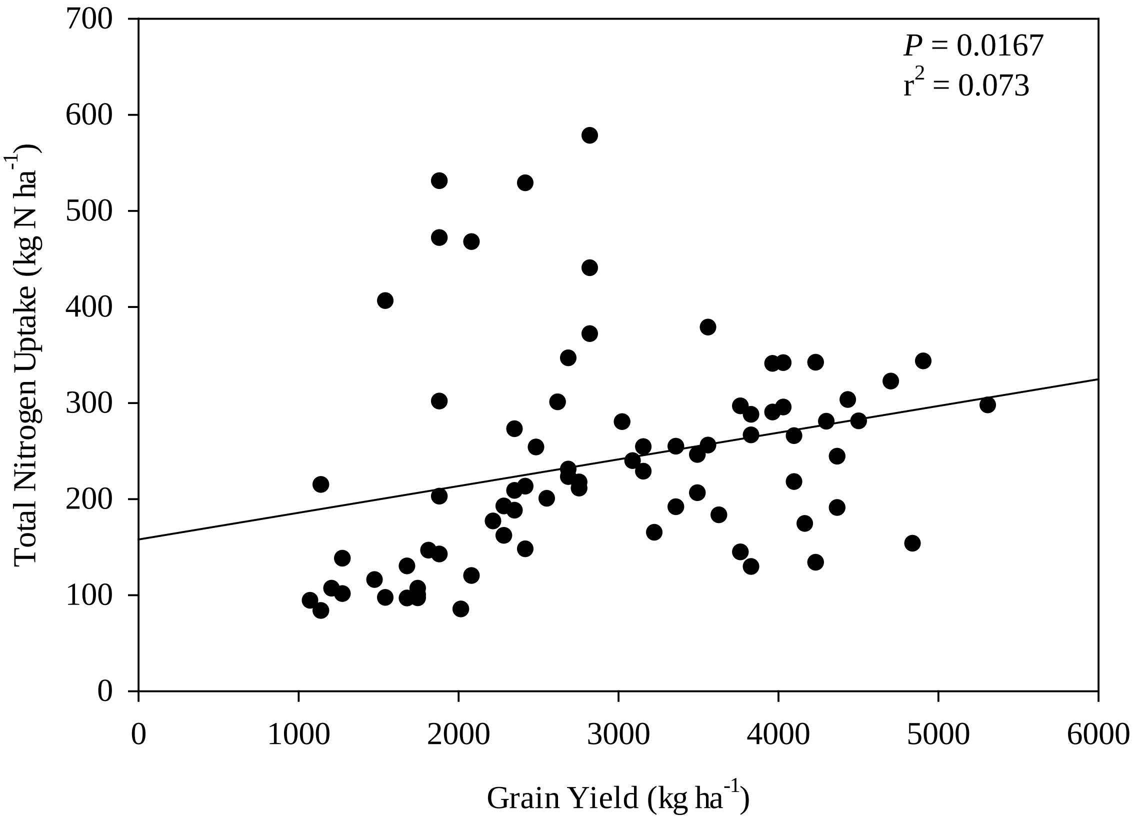

Figure 2-2. Relationship between total N uptake (TNU) and soybean grain yield across all site years.

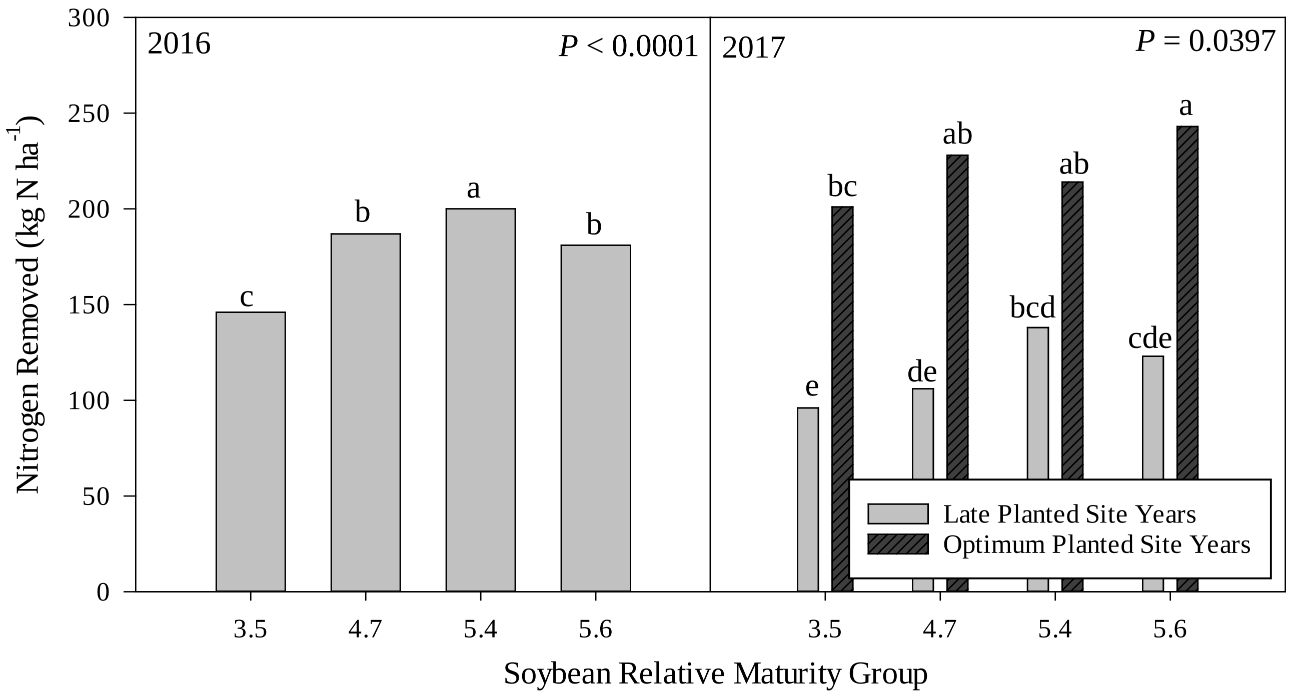

Figure 2-3. Nitrogen removed by grain at harvest by soybean maturity group in PTRS-16L (right). Interaction between planting date and maturity group of all four 2017 site years combined (left). Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

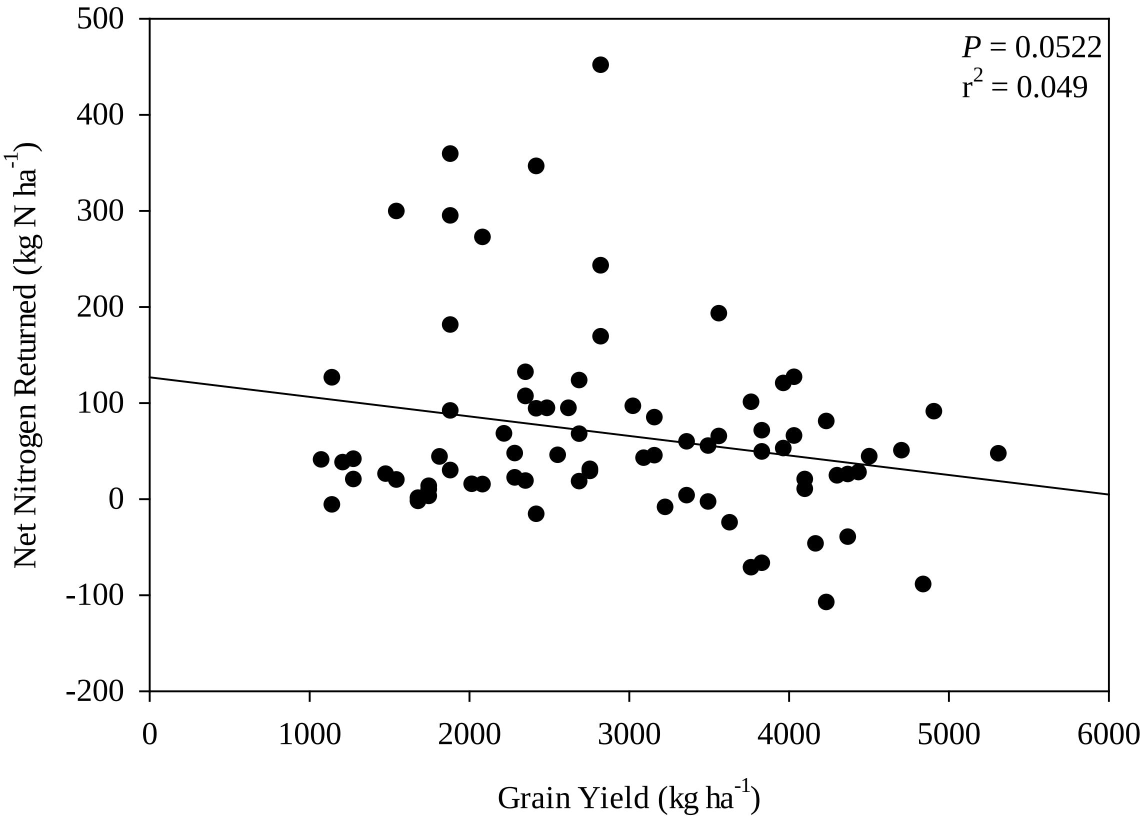

Figure 2-4. Relationship between net N returned and soybean grain yield across all site years.

CHAPTER THREE

Influence of Soybean Management Decisions on the Subsequent Rice Crop's Response to Nitrogen

ABSTRACT

Little is known about the effects of soybean (*Glycine max* L.) management practices on the subsequent rice (*Oryza sativa* L.) crop's success. This study was conducted to determine rice response to different soybean maturity groups (MGs) and planting dates, where various soybean planting dates (optimum and late) and MGs (3.5, 4.7, 5.4, and 5.6) were grown and followed with a rice crop. Six rates of pre-flood nitrogen (N) fertilizer (0, 44, 89, 134, 179, and 224 kg N ha^{-1}) were applied to the rice crop. The results differed by soil texture, with the planting date and MG selection of the previous soybean crop more important in a silt loam soil than a clay soil. Rice grown on a clay soil produced a higher grain yield when following a 5.4 MG soybean ($P < 0.0001$), whereas the planting date of a previous soybean crop influenced the soil-N credits measured at rice emergence ($P = 0.0129$). On a silt loam soil the interaction of both planting date and MG of the previous soybean crop influenced the maximal grain yield achieved by the rice crop ($P < 0.0001$). When soybean is planted during an optimum planting date, soybean MG has little effect on the successive rice crop. However, when the soybean crop is planted late, a determinate MG should be selected to achieve the highest rice crop total N uptake (TNU), maximal grain yield, and reduce the rate of fertilizer-N needed to achieve 95% relative grain yield (RGY). Management techniques should be considered when implementing a soybean-rice rotation in Arkansas to maximize rice grain yield and overall farm profitability.

INTRODUCTION

In the United States, Arkansas has been the top rice producing state since 1973 in both hectares planted and total kg of rough rice produced, growing approximately 48% of the country's rice (Hardke, 2017). Nitrogen fertilizer costs account for as much as 30% of all rice input costs and often is the largest single item input cost associated with the production system (Roberts et al., 2013). Soybean is commonly grown in rotation with rice providing N credits to the soil system, breaking up pest and weed cycles, and allowing for a reduced fertilizer-N rate for the subsequent rice crop. The traditional Arkansas rice fertilizer recommendations are based on the assumption that soybean was the previous crop; therefore, fertilizer-N rate should be adjusted in all other scenarios (Hardke, 2017). When rice follows grain sorghum (*Sorghum bicolor* L.), wheat (*Triticum aestivum* L.), or corn (*Zea mays* L.) the fertilizer-N adjustment rate is an additional 11 kg N ha^{-1}. When following rice or cotton (*Gossypium hirsutum* L.) the recommended fertilizer-N rate increases by 22 kg N ha^{-1}. The base rate decreases by 11 kg N ha^{-1} when following a previously fallowed field to account for the increased N mineralization potential. These adjustment factors were established based on the crop residue nutrient composition and mineralization potential as well as cultivar by N rate trials located across the state. Management of soybean MG and planting date influences the residue accumulation and mineralization following soybean harvest, which may result in differing amounts of plant available soil-N (PAN). Consequently, the recommended fertilizer-N rate required to maximize rice grain yield could be affected.

Soil texture influences the mineralization of added residue-N (Hassink, 1997) as well as the nutrient availability. It is very difficult to quantify the amount of mineralized-N from the crop residue during the growing season because the uptake efficiency of the crop residue-N is unknown (Norman et al., 1990). The nutrient content of the residue contributes to the rate of decomposition, with rapid decomposition within the first two weeks followed by a reduced rate thereafter (Gilmour et al., 1998). Legume crops have relatively high N concentrations in their unharvested biomass compared to other agronomic crops, promoting quick mineralization of residue and increasing PAN in the soil system. Returning the biomass residue back into the soil system is a common practice, either by tillage or decomposition of the residue left aboveground. Residue left on the soil surface will decompose slower than incorporated residue and can potentially delay N mineralization.

Fertilizer-N use efficiency (FNUE) in direct-seeded, delayed-flood rice can be very high due to the controlled anaerobic conditions eliminating loss pathways such as denitrification through the prevention of nitrification. Norman et al. (1992) found 79% of the fertilizer applied pre-flood was taken up by panicle differentiation and was significantly higher than other cereal crops. The reported worldwide FNUE in cereal production is estimated to be 33% (Raun and Johnson, 1999). This is reported as 42 and 29% FNUE in developed and developing countries, respectively. This increased FNUE in the delayed-flood system results in an increased TNU of the rice crop from both the N applied and the PAN in the soil. The elevated TNU of the rice plant supplies sufficient N to achieve higher grain yields (Fitts et al., 2014). The absorption of N during the vegetative growth stage contributes to rice development during reproductive and grain filling stages through translocation, resulting in an increase in grain yield and quality (Bufogle et al., 1997). This increase in grain yield as well as the reduced amount of N lost through ammonia volatilization and denitrification are essential components of a profitable rice and environmentally friendly rice production system.

A study was initiated to determine how management of a soybean crop influenced the fertilizer-N recommendations for the subsequent rice crop. The objectives of this study were to quantify the differences seen in rice TNU, rice grain yield, and N rate to achieve near maximal rice grain yield of a direct-seeded, delayed-flood rice crop when grown following different MGs and planting dates of soybean.

MATERIALS AND METHODS

SITE DESCRIPTIONS

Field studies were conducted during the 2017 and 2018 growing seasons at the University of Arkansas Division of Agriculture Southeast Research and Extension Center (SEREC) near Rohwer, AR and the Pine Tree Research Station (PTRS) near Colt, AR. The study was conducted on a Calhoun silt loam soil (fine-silty, mixed, active, thermic Typic Glossaqualfs) and a Calloway silt loam soil (fine-silty, mixed, active, thermic Aquic Fraglossudalfs) at PTRS. At SEREC the study was conducted on a Sharkey (very-fine, smectitic, thermic Chromic Epiaquerts) and Desha (very-fine, smectitic, thermic Vertic Hapludolls) clay soil complex. All fields followed soybean, with additional agronomic field history listed in Table 3-1. Routine composite soil samples were taken from each field near planting, in April or May, to assess preliminary soil characteristics, shown in Table 3-2. Five or more soil cores were randomly taken with a 0-10 cm cone sampler and mixed together as a composite sample. The composite soil samples were oven dried at 70°C and ground to pass through a 2 mm sieve. The soil tests conducted assessed pH as a 1:2 v:v soil:water ratio (Thomas, 1996), total N (TN) (Bremner, 1996), total C (TC) (Nelson and Sommers, 1996), organic matter via loss on ignition (LOI) (Schulte and Hopkins, 1996), extractable NH_4-N and NO_3-N (Miller and Sonon, 2014), and Mehlich 3 (1:10 ratio) extractable nutrients, phosphorus (P), potassium (K), and zinc (Zn) (Helmke and Sparks, 1996). At the PTRS location, soil tests indicated that some soil nutrients were below optimal and P, K, and Zn were applied pre-plant at the recommended rates of 67 kg P_2O_5 ha^{-1}, 101 kg K_2O ha^{-1}, and 11 kg Zn ha^{-1}.

The previous soybean crop involved four MGs grown in 2.13 x 45.72 meter strips within each replication. Specific details of the soybean trial are listed in Chapter 2. A single late soybean planting date was considered in the 2016-2017 soybean-rice rotation at PTRS. Each location in the 2017-2018 rotation included one field as an optimum soybean planting date and one field as a late soybean planting date. Two indeterminate (3.5 and 4.7 MGs) and two determinate (5.4 and 5.6 MGs) cultivars were grown and measured for TNU, grain yield, N removed, and net N returned to the soil (data presented in Chapter 2). The soybean residue was spread evenly on the soil surface within the plot of origin after harvest to best represent mineralization and soil content while considering each subplot as its own system. Nitrogen Soil Test for Rice (N-STaR) soil samples were taken from each MG strip the following spring to quantify the soil-N credits accumulated at the start of the rice crop season. Soil samples were taken at a depth of 0-45 cm to quantify the season PAN to the rice crop for the silt loam soils at PTRS (Roberts et al., 2009). Soils with a clayey texture were sampled from 0-30 cm at the SEREC field locations. These different sample depths for each texture category were selected because they represent the recommended soil sample depth for the alkaline-hydrolyzable N soil test used to predict field-specific N rates for flood-irrigated rice. Soil samples collected in the fallow strip represent the field control, when no soybean growth preceeded the rice crop and allows assessment of the soybean MG and planting date influence on rice growth and productivity. The soil collected for N-STaR analysis was dried and ground to pass through a 2 mm sieve. A representative subsample weighing one g was analyzed by direct steam distillation and titration to quantify the N content in mg kg^{-1} (Roberts et al., 2011).

NITROGEN RESPONSE TRIAL

Rice cultivars used in this trial were 'LaKast' (PTRS-17L), 'Diamond' (SEREC-18O and SEREC-18L), and 'CL 153' (PTRS-18O and PTRS-18L), which were selected to represent well-adapted southern long-grain, pureline cultivars. All rice cultivars were seeded on 19 cm row spacing and at the following seeding rates; LaKast- 81 kg seed ha^{-1}, Diamond- 91 kg seed ha^{-1} and CL 153- 75 kg seed ha^{-1}. Respective planting dates are presented in Table 3-1.

Five N response trials were conducted to determine the optimum N rate for direct-seeded, delayed-flood rice following soybean fields with MG and planting date manipulated. Nitrogen, as urea (460 g N kg^{-1}), was hand applied onto a dry soil surface at rates of 0, 44, 89, 134, 179, and 224 kg N ha^{-1} as a single pre-flood application when the rice reached the four- to five-leaf stage. Urea applied pre-flood was treated with the urease inhibitor N-butyl-thio-phosphoric triamide (NBPT) at a rate of 0.89 g kg^{-1} urea (Agrotain Ultra [285 g NBPT L^{-1}], Koch Agronomic Services, LLC., Wichita, KS). The combination of the previous soybean MG, planting date, and urea application rate form the individual treatment within each subplot. Within each MG strip, each of the six subplots was randomly assigned a N rate from the previously listed treatments. Following the pre-flood N application, a 5 to 10 cm flood was established and maintained until rice crop maturity and the flood was released prior to harvest. Plots were managed to be weed and pest free following the University of Arkansas Cooperative Extension Service's recommended practices for drill-seeded, delayed-flood rice (Hardke, 2017).

Above ground biomass samples of rice tissue were collected at 50% heading from all plots to measure TNU (Guindo et al., 1994). A one m section of a bordered row was sampled in each plot (Norman et al., 1992). Tissue samples were oven dried at 60°C to a constant weight, weighed, and ground to pass a 1 mm sieve. A subsample was analyzed for TN by combustion

(AOAC 993.13) (Campbell, 1992) using either an Elementar Rapid N III (Elementar, Ronkonkoma, NY) in 2017 or a LECO CN 628 C and N analyzer (LECO, Saint Joseph, MI) in 2018. Total aboveground N uptake was determined as the product of the plant TN concentration in the rice tissue and the dry weight and extrapolated to an area basis (kg N ha^{-1}) (Roberts et al., 2011). This was analyzed at an optimal and suboptimal N rate to further evaluate trends in the plant TNU. Optimal N rate was defined as the N rate within the previously listed applied six rates which consistently achieved 95% RGY. The suboptimal N rate was defined as the N rate within the six applied rates below this optimal rate which did not consistently achieve 95% RGY. The optimal N rate was 224 kg N ha^{-1} on clay soils and 179 kg N ha^{-1} on silt loam soils. The suboptimal N rate was 179 kg N ha^{-1} on clay soils and 134 kg N ha^{-1} on silt loam soils. At maturity, each plot was harvested using a small plot combine and yield data were collected and adjusted to 12% moisture content.

STATISTICAL ANALYSIS

For each location and year the design was a split plot with four blocks in each field. Previous soybean planting date was treated as the whole plot factor and previous soybean MG was treated as the split plot factor. Both were analyzed as fixed effects. An interaction between the previous soybean planting date and MG was considered as a fixed effect. Block was nested within previous soybean planting date and included as a random effect, variance components are shown in Table 3-3. The whole plot error was considered random as the blocks with previous soybean planting date nested within. In the 2016-2017 rotation each block included four N response strips each following a soybean MG treatment. In the 2017-2018 rotations a fifth strip was added in each block as a fallow treatment the previous year. The overall analysis of variance involved five site years of data analyzed by year and location, abbreviated analysis of variance tables listed in Table 3-4. The analysis was divided into these categories because of each location having a different soil texture, environment, and rice cultivar grown. Normality was assumed in all distributions. All statistical analyses were preformed using JMP Pro 14 (SAS Institute, Cary, NC).

Response variables considered included N-STaR soil sample results, rice TNU at suboptimal and optimal N rates, maximal grain yield, and N rate needed to achieve 95% RGY. All response variables were analyzed as the previous MG strip acting as one plot, similar to the statistical analysis of Chapter 2. One N-STaR soil sample was taken in each previous MG strip, representing it as a whole. Within each previous MG strip, six different N rates were applied to the rice crop, the highest grain yield of these was recorded as the maximal grain yield response variable representing the whole strip. From this value, a 95% RGY was calculated. Within each field, the grain yield of the four replications of the same previous soybean MG treatment were regressed by N rate to compute a significant quadratic equation. This equation was used to calculate the precise N rate needed to achieve the 95% RGY value of each previous MG strip. Figure 3-1 shows the raw rice grain yield at PTRS following an optimum planted soybean by fertilizer-N rate with the corresponding regression curve plotted by previous soybean MG. From the calculated N rates needed to achieve 95% RGY the treatments were categorized into optimal and suboptimal N rates for each soil texture. The TNU was analyzed separately at the suboptimal and optimal rates for each location and year. Differences between the suboptimal and optimal rates were not statistically compared.

Means separation was carried out using Tukeys HSD (honestly significant difference) test for those effects having significant F-tests. Comparisons were done at the $\alpha = 0.05$ significance level to evaluate differences. Tukeys HSD was used on all means comparisons to produce fewer false differences in the outcome. Outliers were identified using the studentized residual plots as any data point exceeding three standard deviations. One data point was identified as an outlier in the PTRS 2018 data set and was excluded from analysis of maximal grain yield and N rate to achieve 95% RGY. This data point did not act as an outlier in the analysis of N-STaR soil samples or TNU and was not excluded in these response variable analyses.

RESULTS AND DISCUSSION

MAXIMAL GRAIN YIELD

Significant differences in rice grain yield appeared on both silt loam and clay soils in 2018, *P*- values presented in Table 3-4. The CL 153 rice grain yield at PTRS in 2018 ranged from 10037 to 12004 kg ha^{-1} with an average of 10921 kg ha^{-1}, presented in Table 3-5. The Diamond rice grain yield at SEREC in 2018 ranged from 8826 to 10743 kg ha^{-1} with an average of 9733 kg ha^{-1}, presented in Table 3-6. Both locations in 2018 were significantly different between previous soybean MG treatments. The 2017 rice trials did not have significant differences between previous MG grown and maximal rice grain yield ($P = 0.8119$). Previous soybean planting date and its interaction with previous soybean MG was significant in 2018 at PTRS ($P < 0.0001$) but not at SEREC ($P = 0.0571$). Differences in these outcomes may have been caused by the different soil textures, environments, or rice cultivars grown and supports the previous assumption that these should be analyzed separately.

Previous soybean MG selection significantly affected the following rice crop grain yield at SEREC on a clay soil across both relative planting dates considered ($P < 0.0001$), shown in Figure 3-2. The significantly highest rice grain yield followed the 5.4 MG soybean which yielded an average of 2799 kg ha^{-1} at SEREC across planting dates in 2017. This soybean MG was not outwardly productive in any of its measured variables; however, it did have the highest plant population of all the MGs considered. An average plant population of 497299 plants ha^{-1} was measured in the 5.4 MG. Ennin and Clegg (2001) found plant population may influence the soybean residual N contributed to the soil system. Doubling the soybean population may increase average N_2 fixation from 44 to 69 kg N ha^{-1} (Bello et al., 1980). This increase in N_2 fixation potential may support both a high soybean yield and a high residual N level. The trend seen in the 2018 rice grain yield among previous soybean MG follows the same general trend which the 2017 soybean crop plant population took. Although there were no significant differences in plant population between MGs (P = 0.8375) in the 2017 SEREC soybean crop, differences may have developed when also considering overall soybean productivity. The lowest rice grain yield in 2018 was measured following the 3.5 MG soybean and the fallow strip. The 3.5 MG soybean measured the lowest in plant population in 2017 with an average of 426874 plants ha^{-1} and produced the lowest grain yield of all MGs. The low overall productivity of the 3.5 MG soybean crop did not produce the magnitude of N credits or rotational benefits in this highly smectitic clay soil.

The two fields of soybean-rice rotation grown at PTRS in 2017-2018 support the hypothesis that the combined management of both MG selection and planting date of the previous soybean crop significantly influences the grain yield of the following rice crop in silt loam soil (P < 0.0001), shown in Figure 3-3. Of the rice that followed an optimum planted soybean treatment, none of the previous MGs were significantly different than the fallow strip in the field. This indicates the MG selection does not significantly influence the following rice crop grain yield when the soybean crop is planted at an optimum time. Regardless, soybean MG selection when planted at an optimum time is important for the overall system productivity due to the significant soybean crop grain yield differences between MG in 2017 (P = 0.0004)

(Chapter 2). The previous soybean crop planted at an optimum time at PTRS recorded a difference of 1193 kg ha^{-1} in average grain yield between the 4.7 and 3.5 MGs.

The rice which followed the late planted 5.6 MG or 3.5 MG soybean treatment produced the statistically highest rice grain yield overall ($P < 0.0001$), presented in Figure 3-3. However, the late planted 5.6 MG soybean produced significantly higher soybean grain yields than late planted 3.5 MG soybean crop in 2017 ($P = 0.0026$). The late planted 5.6 MG soybean crop yielded 2639 kg ha^{-1} while the 3.5 MG only yielded 1950 kg ha^{-1}. Although these two previous MGs did not result in significantly different grain yields in the following rice crop, the 5.6 MG soybean produced 689 kg ha^{-1} more soybean grain than the 3.5 MG. Therefore, when planting a soybean crop late the MG selection is an important factor in the overall success of the crop rotation. The late planted 5.6 MG soybean provided the most profit to the overall system when considering a late soybean planting date as it resulted in a relatively high soybean yield and the overall highest rice grain yield at this location.

TOTAL NITROGEN UPTAKE AT OPTIMAL AND SUBOPTIMAL NITROGEN RATES

The rice crop above ground TNU was significantly influenced by the previous soybean management in 2018 on the silt loam soil but not on the clay soil. For the rice planted to a silt loam soil there were no significant differences between previous soybean MGs in above ground TNU for 2017 at either optimal N rates ($P = 0.8009$) or suboptimal N rates ($P = 0.8186$), presented in Table 3-5. The soybean-rice rotation fields at PTRS in 2018 had significantly different TNU levels between the main effect previous soybean planting date at a suboptimal N rate ($P = 0.0358$) and at an optimal N rate ($P = 0.0155$), presented in Figure 3-4. Previous soybean MG only significantly influenced the following rice crop TNU when a suboptimal N rate was applied ($P = 0.0438$), presented in Figure 3-5, which is where one would expect to see differences that were potentially influenced by the previous soybean crop management. There was no significance in the TNU interaction between previous MG and planting date in either level of N rate. The increased significance of previous soybean management reported under suboptimal N conditions is explained by the rice root system more fully exploiting the native soil-N when insufficient fertilizer-N was applied. This suboptimal fertilizer-N level was able to support the development of an expansive root system which was better able to assimilate N from the previous soybean residue (Norman et al., 2013). When fertilizer-N was applied at an optimal rate any differences between previous soybean crop management in the rice crop TNU were diluted by the high fertilizer-N taken up. The differences in TNU between location and year are due to the different levels of native soil-N and the different cultivars grown.

The rice following a late planted soybean crop consistently took up significantly more N than when following an optimum planted soybean crop at PTRS in 2018, shown in Figure 3-4. This may be associated to the soybean data presented in Chapter 2 showing the optimum planted soybean crop produced significantly higher TNU than the late planted soybean crop (P = 0.0004). The apparent N fertilizer recovery (ANFR) of the rice crop increased when following late planted soybean at both suboptimal and optimal N rates. At a suboptimal N rate, the rice crop following an optimum planted soybean measured 61% ANFR while the rice crop following late planted soybean measured 80.5% ANFR. The same trend appeared when an optimal N rate was applied with the ANFR increasing from 59.5 to 84% when following a late planted soybean. Rice that received no fertilizer-N took up 98.04 kg N ha^{-1} after an optimum planted soybean crop and 102.92 kg N ha^{-1} after a late planted soybean crop. The difference of 4.86 kg N ha^{-1} represents the residual N differences between fields and is negligible. The optimum planted field and late planted field were geographically separate and had different soil series. The optimum planted field was a Calhoun silt loam soil while the late planted field was a Calloway silt loam soil. These soils do not have any extreme differences but may be causing this gap in ANFR due to differing soil characteristics. Although not statistically significant, the N-STaR soil test values in the two fields did show a higher residual N level of 6 kg N ha^{-1} in the late planted field compared to the optimum planted field, shown in Table 3-5.

The highest rice TNU on a silt loam soil under suboptimal N conditions followed a 5.4 MG soybean treatment. Under the same conditions, the previous 3.5 MG soybean treatment produced the significantly lowest rice TNU. The previous soybean 4.7 MG, 5.4 MG, and fallow treatments were not significantly different than the previous soybean 5.6 MG nor 3.5 MG treatments, shown in Figure 3-5. The previous 5.4 MG soybean crop at PTRS in 2017 was not outwardly productive in any of the measured variables. The soybean crop TNU and N removed by grain increased with increasing MG, measuring 251 kg N ha^{-1} and 193 kg N ha^{-1}, respectively, for the 5.4 MG at PTRS in 2017 (Chapter 2). No differences were observed in net N returned between MGs in 2017 (P = 0.3475). The higher determinate cultivars may have mineralized in a more rapid or efficient manner during the winter season due to differences in growth habit leading to these differences in the following rice crop. This is related to the N rate needed to achieve 95% RGY, which is reduced when following determinate soybean cultivars because of the high TNU achieved.

SOIL-NITROGEN CONTENT

The N-STaR soil test measuring potentially mineralizable soil-N at rice emergence did not find any differences between previous soybean MG at either location in 2018 or 2017 (P = 0.7045). The soil test ranged from 43 to 85 mg N kg^{-1} in silt loam soils and 57 to 126 mg N kg^{-1} in clay soils. Previous soybean planting date did provide a significant difference in soil test values on a clay soil (P = 0.0129) as shown in Figure 3-6; however, no significant differences were seen on a silt loam soil. The previous soybean crop performed very differently based on its planting date. The optimum planted soybean at SEREC produced an average grain yield of 3959 kg ha^{-1} and was harvested by MG between late September and mid-October, whereas the late planted soybean yielded an average of only 1529 kg ha^{-1} and was harvested between early to late October. This large gap (2430 kg ha^{-1}) in previous soybean productivity and harvest dates resulted in differing amounts of residue and time of decomposition. The optimum planted soybean residue had much more time to decompose in the fall before microbial activity ceased. The different levels of residue and length of the off season resulted in different soil-N levels the following spring.

Each N-STaR measurement was used to produce a fertilizer-N recommendation for each rice plot. The fertilizer-N rate recommendations produced from N-STaR soil tests do not exceed 184.9 kg N ha^{-1} for silt loam soils or 201.7 kg N ha^{-1} for clay soils. Over 85% of the recommendations given to the rice in silt loam soil were the maximum rate. Over 92% of the recommendations to the rice in clay soil were the maximum rate. All of the reduced N recommendations on clay soils followed the optimum planted soybean treatment because of the increased biomass level and mineralization potential. The high fertilizer-N recommendations established through the N-STaR soil test results may be indicating a net N deficit at the time of soil sampling. Assuming 5% of the soil organic matter is organic N and that 2% is mineralized on an annual basis (Fernandez et al., 2012), each percent of soil organic matter will supply an estimated 22.5 kg N ha^{-1} in the upper 17 cm of the soil profile (Bender at al., 2015). The soils considered ranged from 2.02 to 2.69% soil organic matter (Table 3-2), producing an estimated 45.45 to 60.52 kg N ha^{-1} annually through mineralization. The previous soybean N removed ranged from 147 to 200 kg N ha^{-1} depending on MG and year. Given these assumptions, the result would be a net N deficit by as much as 154.55 kg N ha^{-1}.

No differences were seen between previous soybean crop management and the N-STaR soil test results on silt loam soils in 2017 or 2018. The large gap in previous soybean productivity that occurred at SEREC also occurred at PTRS. The optimum planted soybean at PTRS yielded an average of 1660 kg ha^{-1} more than the late planted soybean at PTRS in 2017. At rice emergence, no differences in PAN existed in the silt loam soil. Differences appeared later in the rice productivity and may be due to the fact that this was managed as a no-till system and the soybean residue had not yet decomposed and mineralized when the N-STaR soil samples were taken. A similar study which focused on soybean-corn rotation also found the soybean residue N mineralization was not complete by the following spring on the two silt loam soils (Bundy et al., 1993). The soil was not plowed or disturbed between rotational crops, slowing the mineralization process through microbial contact and climate exposure. The end result of mineralization is ammonium-NH_4^+, amino acids, and amino sugars which is measured in the distillation procedure of N-STaR soil tests. The residue at SEREC may have mineralized faster because of the warmer climate experienced between cropping systems and the higher soil microbial activity of the clay soil. The average high temperature in SEREC remained above the average high temperature in PTRS by 2.8°C throughout the entire fallow season (October through April). The average low temperatures at SEREC also remained above the average low temperatures in PTRS by 1.4°C. Monthly average temperatures for both locations are reported in Table 3-7. Although this is not a large difference in temperature, it may have led to more mineralization throughout the season resulting in the accumulated differences seen at SEREC and not at PTRS. Microbial activity ceases at any temperature below 17.9°C resulting in no net mineralization of residue-N (Cassman and Munns, 1980). The average high temperature in November and March reached 17.9°C at SEREC but not at PTRS. These two months may have allowed for increased microbial activity and mineralization to accumulate throughout the winter season at SEREC but not PTRS.

NITROGEN RATE NEEDED TO ACHIEVE 95% RELATIVE GRAIN YIELD

Significant differences were observed between the N rates needed to achieve 95% RGY on silt loam soils; however, not on clay soils. The interaction between previous soybean planting date and MG was significant (P = 0.0007) in the 2017-2018 rotation at PTRS, shown in Figure 3-7. The rice following optimum planted soybean had no significant differences between the previous MG treatments and the fallow control. However, the rice following the late planted determinate soybean (5.4 and 5.6 MGs) needed significantly less N to achieve 95% RGY than the fallow control. The previous late planted 5.4 and 5.6 MGs reduced the fertilizer-N rate by 54 and 52 kg N ha^{-1}, respectively, when compared to the fallow strip. The two treatments which needed the most N to achieve 95% RGY were the optimum planted 4.7 MG and the fallow control, requiring 166 and 165 kg N ha^{-1}, respectively. All other treatments reduced the rate of N needed for the following rice crop. These fertilizer-N rates which achieved 95% RGY were lower than the recommended rates through N-STaR because of the continued mineralization of soybean residue throughout the rice season. The late planted 5.6 MG provided the following rice crop with the highest TNU, maximal grain yield, and needed the lowest rate of N to achieve 95% RGY. Values as high as 89 kg N ha^{-1} have been reported as N credits derived from a previous soybean crop on silt loam soil (Hanson et al., 1988). Although this magnitude was not measured in the presented data, maximizing the N credits established through management techniques has the potential to increase the profitability of the whole farm system on a silt loam soil.

The optimum planted 4.7 MG produced the highest average soybean grain yield of 4774 kg ha^{-1} at PTRS in 2017; however, this treatment resulted in some of the lowest rice yields and highest N rate needed, presented in Table 3-5. This soybean MG was 689 kg ha^{-1} higher than the next highest yielding MG, the 5.6 MG. The optimum planted 5.6 MG required 26 kg N ha^{-1} less than the optimum planted 4.7 MG to achieve 95% RGY in the subsequent rice crop. Determining which MG was more profitable overall when planted in an optimum window depends on the current price of fertilizer-N, soybean grain and rice grain. When considering a late planting date, the 5.6 MG provided the highest soybean grain yield by 84 kg ha^{-1}, highest rice grain yield by 262 kg ha^{-1}, and required the significantly lowest fertilizer-N to achieve 95% RGY in the subsequent rice crop. Therefore, when planting a late soybean crop on silt loam soil in Arkansas the 5.6 MG provides the most profit to the cropping system.

No differences were observed in N rates needed to achieve 95% RGY in 2017 (P = 0.6535) on clay soils in 2018, presented in Table 3-6. Rice grown in clay soils all required high N rates to achieve 95% RGY. The average N rate needed to achieve 95% RGY was 181 kg N ha^{-1} on a clay soil and 144 kg N ha^{-1} on a silt loam soil. This increase of 37 kg N ha^{-1} on the clay textured soil mimics the state recommendations for rice fertilizer-N which would recommend an automatic increase of 33.6 kg N ha^{-1} when grown on a clay soil (Hardke, 2017). The clay soils reported an elevated soil organic matter when compared to the silt loam soils (Table 3-2), indicating an increased mineralization rate may occur annually. However, the reduced drainage and wetter winter climate (Table 3-7) increases the loss potential for any mineralized N. This would negate any differences established through mineralization resulting in no change in management recommendations on a clay soil. The increased rice grain yield recorded when following a 5.4 MG soybean can be explained by the elevated soybean plant population instead of the crop management.

CONCLUSION

The research presented here expands on the previously known N credits developed by a soybean crop providing additional information on their managerial impact. Prior knowledge was solely crop specific with additional information needed. Rice yield was consistently higher when rice followed a soybean treatment rather than a fallow strip, validating the presence of soil-N credits and other potential rotational benefits. Although the previous soybean crop may have resulted in a net N deficit when measured the following spring, as mineralization continued throughout the rice growing season additional PAN was taken up by the rice crop. More differences were seen in the rice following soybean grown in silt loam soil than in clay soil. Clay soil requires a higher rate of N because of its higher CEC, potential for ammonium fixation, the tortuous nature of N movement in clay soils, lower mineralizable-N value, and a higher stabilization of soil organic matter (Ros et al., 2011). These factors appear to have diluted the potential differences established by the previous soybean crop except for rice grain yield. The differences seen in soil-N credits at rice emergence between previous soybean planting date on a clay soil may have been due to the larger quantity of residue, longer time span for mineralization to occur, and the warm winter climate experienced at SEREC. The previous soybean MG provided significant differences to the rice crop grain yield, proving MG selection to be an important management factor in a soybean-rice system on a clay soil.

On a silt loam soil, both previous soybean planting date and MG are important management factors. When the soybean crop is planted at an optimum time MG selection is not critical for maximizing rice grain yield but should be considered to maximize soybean yield and overall profit. However, when the soybean crop is planted late the MG selection becomes a very influential factor for the subsequent rice crop success. The previous 5.6 and 3.5 MG treatments produced the highest rice grain yield of the late planted treatments. Within this system, the 5.6 MG soybean produced 689 kg ha^{-1} more soybean grain yield and needed 10 kg N ha^{-1} less to achieve 95% rice RGY than the previous late planted 3.5 MG. The use of soybean management techniques to maximize the grain yield throughout the crop rotation and reduce the input costs may be very profitable. Future research involving a larger array of soybean MGs with various crop rotation cycles is needed to further identify these trends. Quantifying the soybean residue dry matter and C:N ratio to further investigate the mineralization developments would also provide valuable information. A several year study would allow the cumulative effects of soybean MG and planting date on soil-N mineralization potential and differences in soil-N credits to be quantified.

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APPENDIX

TABLES AND FIGURES

Table 3-1. Selected soil and agronomic information for crop rotation trials conducted in 2017 and 2018.

Site ID	Location	Prev. Soy Relative PD	Soil Texture	Soil Series	Cultivar	Planting Date	Rice Year
PTRS-17L	PTRS	Late	Silt Loam	Calhoun	Lakast	April 27	2017
PTRS-18O	PTRS	Optimum	Silt Loam	Calhoun	CL 153	May 2	2018
PTRS-18L	PTRS	Late	Silt Loam	Calloway	CL 153	May 2	2018
SEREC-18O	SEREC	Optimum	Clay	Sharkey & Desha	Diamond	April 27	2018
SEREC-18L	SEREC	Late	Clay	Sharkey & Desha	Diamond	April 27	2018

PTRS, Pine Tree Research Station; SEREC, Southeast Research and Extension Center.

Table 3-2. Selected soil chemical property information for soybean-rice rotation trials conducted in 2017 and 2018.

	pH	Total N	Total C	LOI	P	K	Zn	NO_3-N	NH_4-N
Site ID	——	%			mg kg soil $^{-1}$				
PTRS-16L	7.2	0.06	0.79	2.11	27	97	8	-	-
PTRS-17O	7.8	0.12	1.21	2.41	22	69	2	1.2	32.7
PTRS-17L	7.5	0.08	0.96	2.02	53	120	6	2.6	22.5
SEREC-17O	7.8	0.05	0.78	2.69	67	215	2	8.4	11.9
SEREC-17L	7.8	0.05	0.78	2.12	55	177	2	7.1	7.5

The soil tests conducted assessed pH (1:2 v:v soil:water ratio) (Thomas, 1996), Mehlich 3 extractable nutrients, P, K, and Zn (Helmke and Sparks, 1996), total nitrogen (TN) (Bremner, 1996), total carbon (TC) (Nelson and Sommers, 1996), organic matter via loss on ignition (LOI) (Schulte and Hopkins, 1996), and KCl extractable NH_4-N and NO_3-N (Miller and Sonon, 2014).

Table 3-3. Variance components of individual random variables for 2017 and 2018 data analysis by location.

Year	Location	Effect	N-STaR Estimate	N-STaR Percent of Total	Maximal Grain Yield Estimate	Maximal Grain Yield Percent of Total	Nitrogen Rate to Achieve 95% RGY Estimate	Nitrogen Rate to Achieve 95% RGY Percent of Total
2017	PTRS	Block	45.7	32.1	<0.1	<0.1	4.8	0.3
		Residual	97.1	67.9	421075.7	>99.9	1686.7	99.7
		Total	142.8	100.0	421075.7	100.0	1691.5	100.0
2018	PTRS	Block (PD)	19.9	28.2	27361.4	56.4	118.2	41.6
		Residual	50.7	71.8	21142.4	43.6	166.0	58.4
		Total	70.6	100.0	48503.8	100.0	284.2	100.0
2018	SEREC	Block (PD)	58.5	33.9	964.4	0.9	<0.1	<0.1
		Residual	113.8	66.1	102173.9	99.1	572.5	>99.9
		Total	172.3	100.0	103138.3	100.0	572.5	100.0

Year	Location	Effect	Total Nitrogen Uptake, *Suboptimal N Rate* Estimate	*Suboptimal N Rate* Percent of Total	Total Nitrogen Uptake, *Optimal N Rate* Estimate	*Optimal N Rate* Percent of Total
2017	PTRS	Block	<0.1	<0.1	413.1	32.2
		Residual	301.1	>99.9	868.9	67.8
		Total	301.1	100.0	1282.0	100.0
2018	PTRS	Block (PD)	<0.1	<0.1	<0.1	<0.1
		Residual	1424.8	>99.9	3022.8	>99.9
		Total	1424.8	100.0	3022.8	100.0
2018	SEREC	Block (PD)	531.5	16.7	1106.7	42.5
		Residual	2640.6	83.2	1494.6	57.5
		Total	3172.1	100.0	2601.4	100.0

PTRS, Pine Tree Research Station; SEREC, Southeast Research and Extension Center; PD, planting date.

Table 3-4. Abbreviated analysis of variance tables for individual 2018 fixed effect variables: previous soybean planting date (PD), previous soybean maturity group (MG), and the interaction of both previous soybean management practices (MG x PD).

		N-STaR				Maximal Grain Yield				N Rate to Achieve 95% RGY			
Location	Effect	NDF	DDF	F Ratio	*P*-value	NDF	DDF	F Ratio	*P*-value	NDF	DDF	F Ratio	*P*-value
PTRS	PD	1	6	2.3525	0.1760	1	6.0	56.0878	0.0003*	1	6.0	3.9625	0.0931
	MG	4	24	1.3725	0.2730	4	23.1	7.5475	0.0005*	4	23.1	7.4796	0.0005*
	MG x PD	4	24	0.6847	0.6095	4	23.1	14.9898	<0.0001*	4	23.1	7.0785	0.0007*
SEREC	PD	1	6	12.2335	0.0129*	1	6	1.5460	0.2601	1	6	0.0058	0.9417
	MG	4	24	1.9632	0.1325	4	24	20.4036	<0.0001*	4	24	1.7192	0.1786
	MG x PD	4	24	0.6898	0.6061	4	24	2.6632	0.0571	4	24	1.1412	0.3611

		Total Nitrogen Uptake							
		Suboptimal N Rate				*Optimal N Rate*			
Location	Effect	NDF	DDF	F Ratio	*P*-value	NDF	DDF	F Ratio	*P*-value
PTRS	PD	1	6	7.2591	0.0358*	1	6	11.1818	0.0155*
	MG	4	24	2.8905	0.0438*	4	24	0.1598	0.9566
	MG x PD	4	24	0.7096	0.5933	4	24	0.4535	0.7689
SEREC	PD	1	6	0.5754	0.4769	1	6	0.2667	0.6241
	MG	4	24	1.3645	0.2757	4	24	1.7592	0.1701
	MG x PD	4	24	0.7127	0.5914	4	24	0.4902	0.7429

*Significant at the α 0.05 level.

PTRS, Pine Tree Research Station; SEREC, Southeast Research and Extension Center.

Table 3-5. Least Square Means by maturity group (MG) and planting date (PD) for Pine Tree Research Station in 2017 and 2018 within each response variable, *P*-values previously listed in Table 3-3.

		N-STaR	Maximal Grain Yield	N Rate to Achieve 95% RGY	Total Nitrogen Uptake	
					Suboptimal N	*Optimal N*
Year	Factor	mg N kg^{-1}	kg ha^{-1}	kg N ha^{-1}		
2017	MG					
	3.5	62.7	10400	171	91	113
	4.7	56.7	9984	157	101	109
	5.4	64.7	10085	151	100	125
	5.6	62.0	10249	185	95	105
2018	PD					
	Optimum	59.2	10486 b	150	180 b	204 b
	Late	65.2	11429 a	129	211 a	253 a
	MG					
	3.5	58.2	11148 a	139 ab	178 b	241
	4.7	60.8	10875 bc	148 ab	184 ab	221
	5.4	64.8	10837 c	129 ab	184 ab	223
	5.6	61.7	11083 ab	127 b	234 a	227
	Fallow	65.3	10844 c	154 a	197 ab	232
	MG x PD					
	3.5 O	57.7	10680 de	154 ab	155	230
	4.7 O	56.5	10541 ef	166 a	168	206
	5.4 O	62.5	10554 ef	147 ab	175	189
	5.6 O	56.0	10289 f	140 ab	205	185
	Fallow O	63.5	10365 ef	143 ab	197	212
	3.5 L	58.7	11616 ab	123 ab	201	252
	4.7 L	65.2	11209 cd	131 ab	200	237
	5.4 L	67.2	11121 cd	111 b	192	257
	5.6 L	67.5	11878 a	113 b	263	269
	Fallow L	67.2	11323 bc	165 a	198	252

Means not sharing the same letter within a column are significantly different (HSD, $P < 0.05$).
N, nitrogen; RGY, relative grain yield; MG, maturity group; PD, planting date; O, optimum planting date; L, late planting date.

Table 3-6. Least Square Means by maturity group (MG) and planting date (PD) for Southeast Research and Extension Center in 2018 within each response variable, *P*-values previously listed in Table 3-3.

Year	Factor	N-STaR	Maximal Grain Yield	N Rate to Achieve 95% RGY	Total Nitrogen Uptake	
					Suboptimal N	*Optimal N*
		—mg N kg^{-1}—	— kg ha^{-1} —		kg N ha^{-1}	
2018	PD					
	Optimum	102.7 a	9669	181	135	158
	Late	80.4 b	9797	181	152	172
	MG					
	3.5	88.6	9249 c	169	115	162
	4.7	84.2	9904 b	190	142	168
	5.4	93.4	10415 a	184	150	190
	5.6	93.4	9898 b	169	174	165
	Fallow	98.1	9198 c	192	138	139
	MG x PD					
	3.5 O	101.5	9280	174	103	153
	4.7 O	91.5	9822	194	157	177
	5.4 O	104.2	10478	188	143	180
	5.6 O	102.7	9520	153	147	149
	Fallow O	113.5	9242	197	125	130
	3.5 L	75.7	9217	165	127	171
	4.7 L	77.0	9986	185	126	158
	5.4 L	82.5	10352	180	157	199
	5.6 L	84.0	10276	185	201	181
	Fallow L	82.7	9154	188	151	148

Means not sharing the same letter within a column are significantly different (HSD, $P < 0.05$).
N, nitrogen; RGY, relative grain yield; MG, maturity group; PD, planting date; O, optimum planting date; L, late planting date.

Table 3-7. Monthly average weather data at Pine Tree Research Station (PTRS) and Southeast Research and Extension Center (SEREC) during the winter months of 2017 to 2018 off season. The average monthly high (max) and low (min) temperatures in Celsius and precipitation in cm are reported. National Oceanic and Atmospheric Administration (NOAA) weather data collected from Marianna, Arkansas and Rohwer, Arkansas.

		2017				2018				
		Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
PTRS	Max °C	29.3	24.9	17.7	10.4	6.0	13.2	17.6	18.7	31.0
	Min °C	16.5	11.0	5.4	0.0	-3.8	2.6	6.6	6.5	19.3
	Precip. (cm)	1.7	6.5	4.1	19.7	6.4	30.8	14.5	11.6	9.9
SEREC	Max °C	28.8	24.4	18.3	12.2	7.7	14.4	18.3	19.4	30.0
	Min °C	17.7	11.1	7.7	2.2	-1.6	4.4	7.7	8.3	19.4
	Precip. (cm)	11.2	3.1	3.3	19.6	7.2	37.2	18.6	20.1	3.4

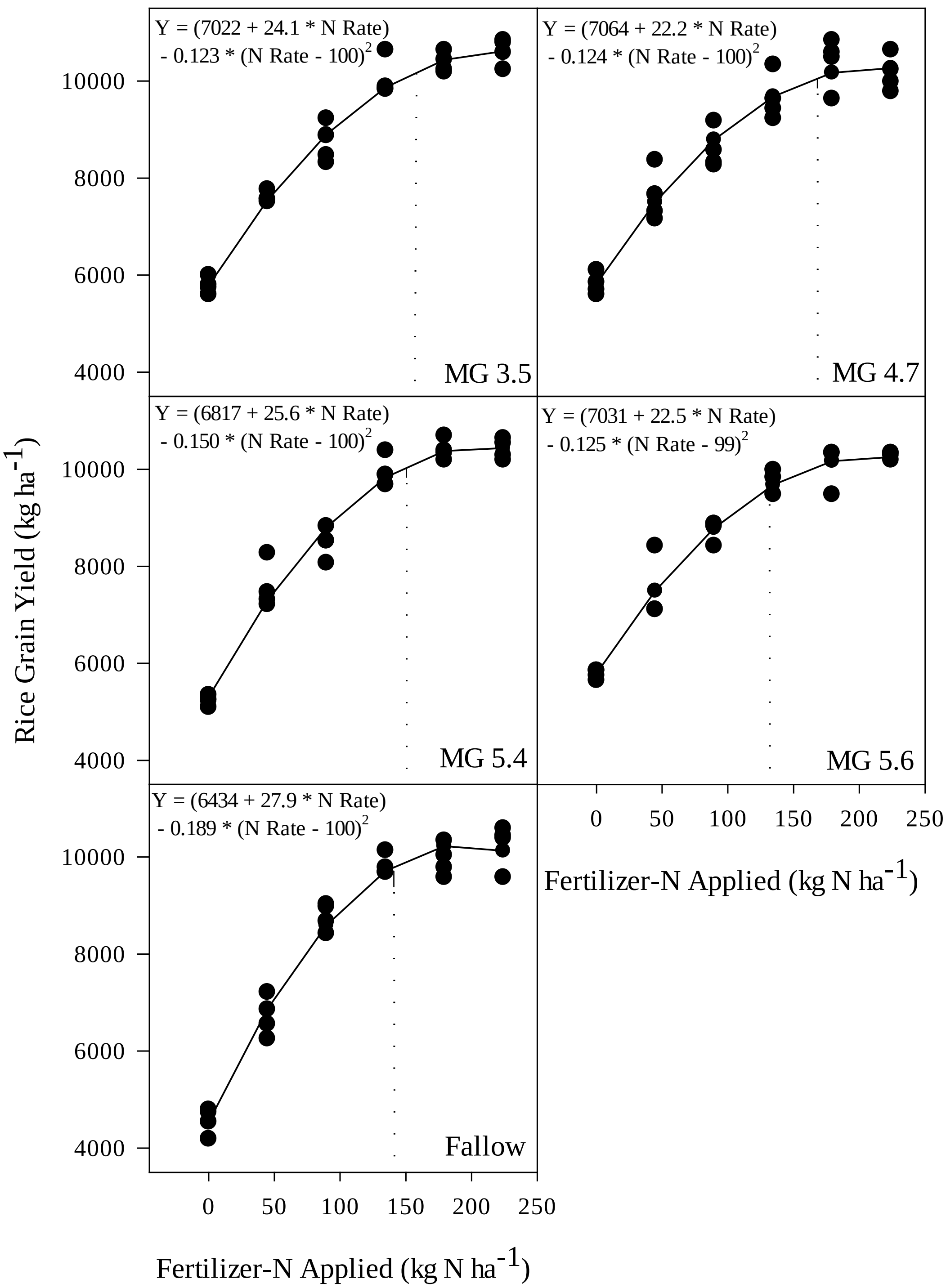

Figure 3-1. Regression equations used to relate rice grain yield to fertilizer-N response of each treatment in the optimum planted site year at Pine Tree Research Station (PTRS) in 2018. The vertical dashed line indicated the N rate required to produce 95% relative grain yield (RGY). Exact fertilizer-N rates calculated are presented in Table 3-5.

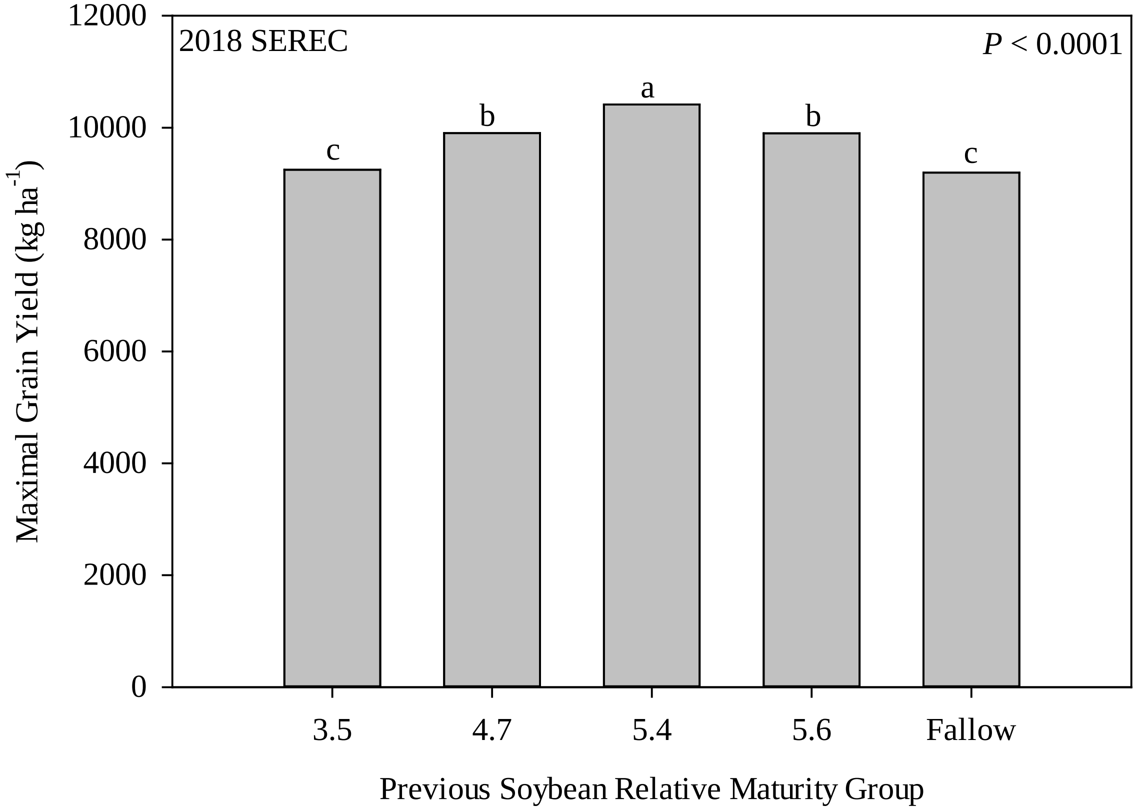

Figure 3-2. Maximal rice grain yield at the Southeast Research and Extension Center Station 2018 fields between previous soybean relative maturities. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

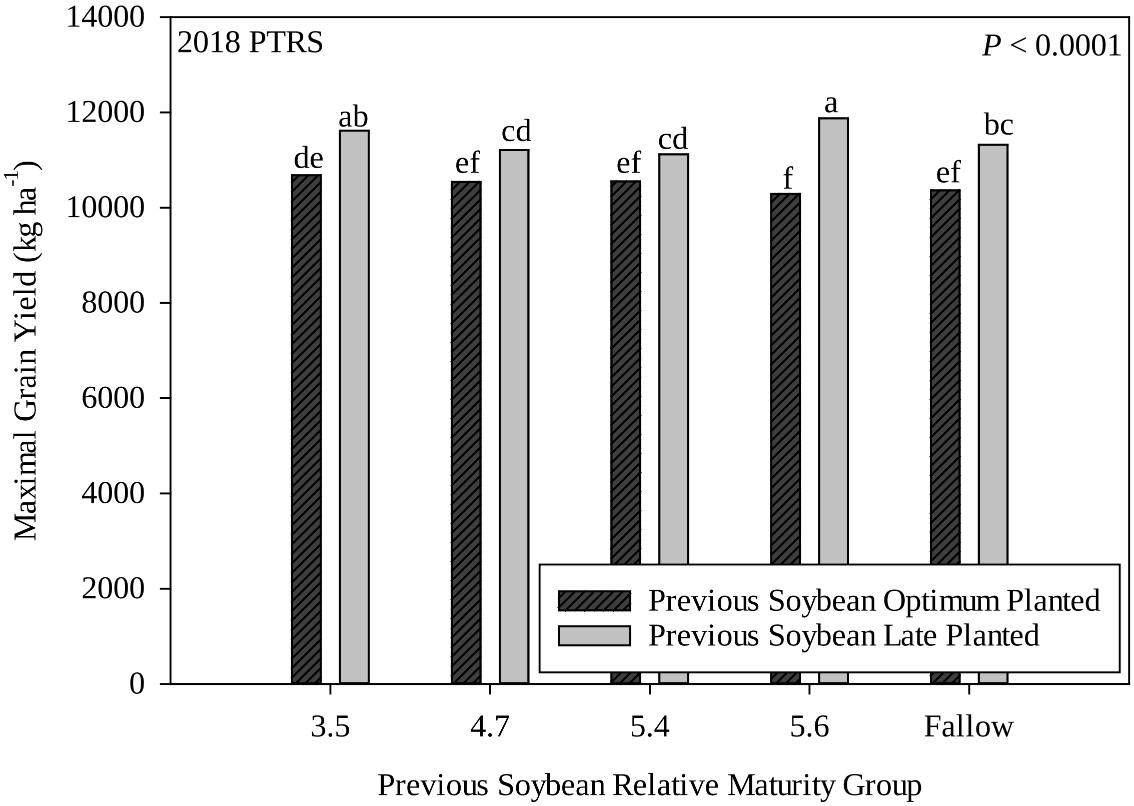

Figure 3-3. Maximal rice grain yield at Pine Tree Research Station 2018 fields between previous soybean relative maturities and planting dates. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

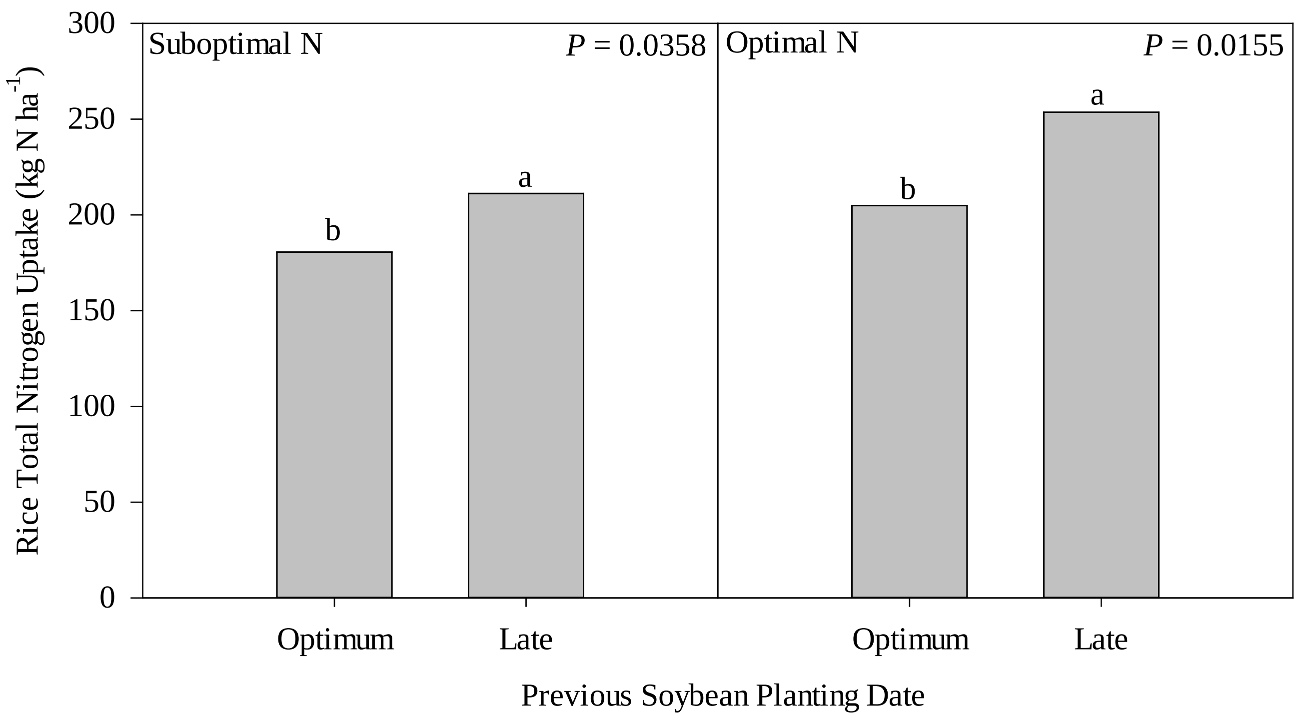

Figure 3-4. Rice total nitrogen (N) uptake at a suboptimal N rate (left) and an optimal N rate (right) at Pine Tree Research Station 2018 fields between previous soybean planting dates. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

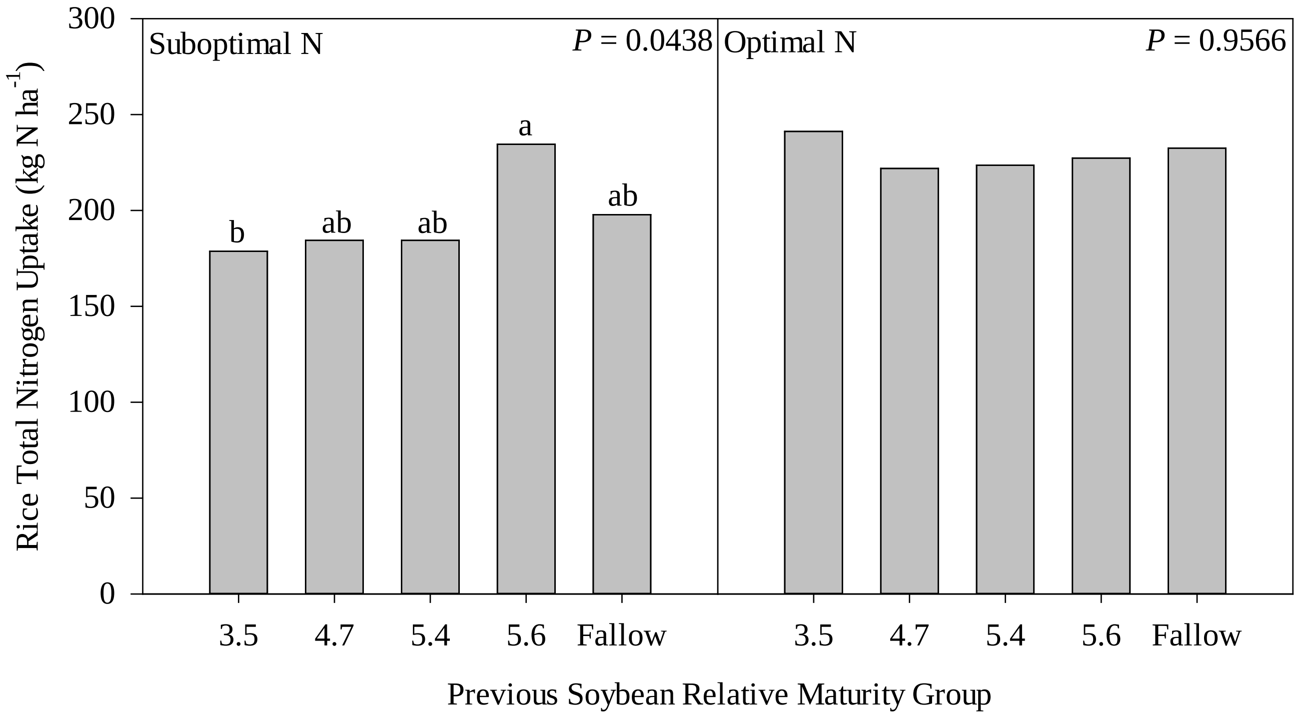

Figure 3-5. Rice total nitrogen (N) uptake at a suboptimal N rate (left) and an optimal N rate (right) at Pine Tree Research Station 2018 fields between previous soybean relative maturities. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

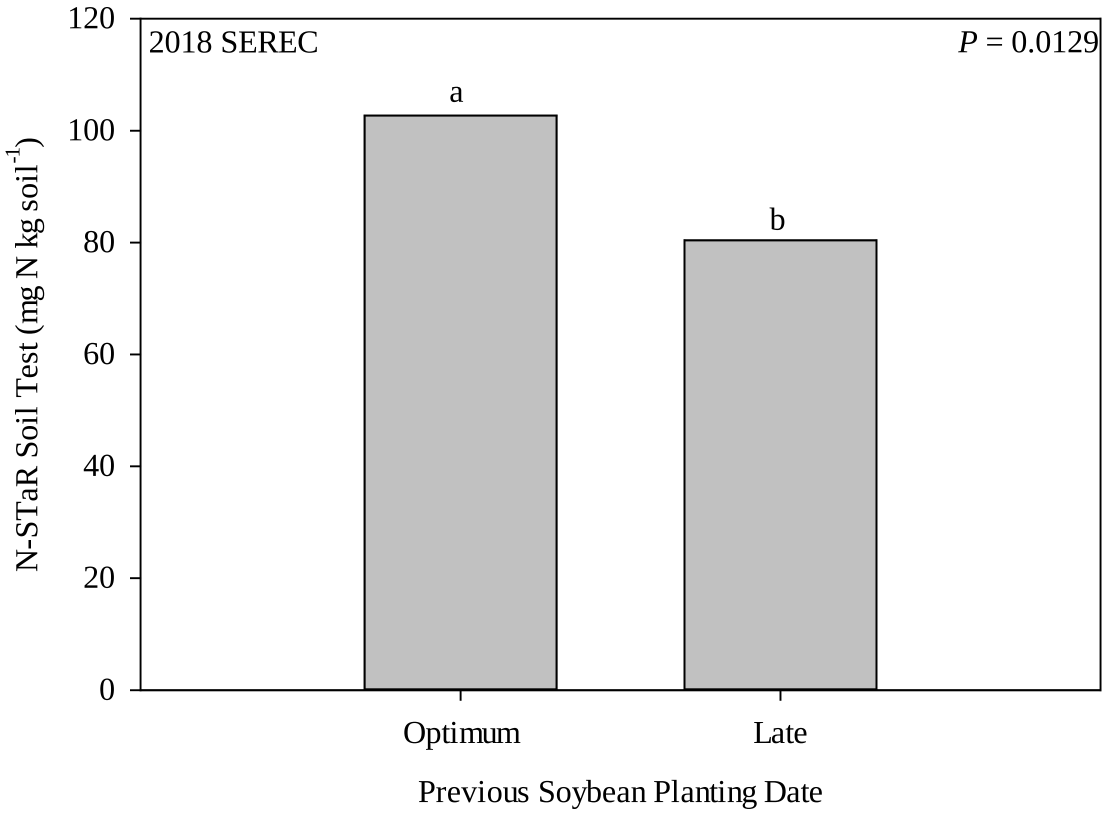

Figure 3-6. Nitrogen Soil Test for Rice (N-STaR) soil test levels at rice emergence at the Southeast Research and Extension Center Station 2018 fields between previous soybean planting dates. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

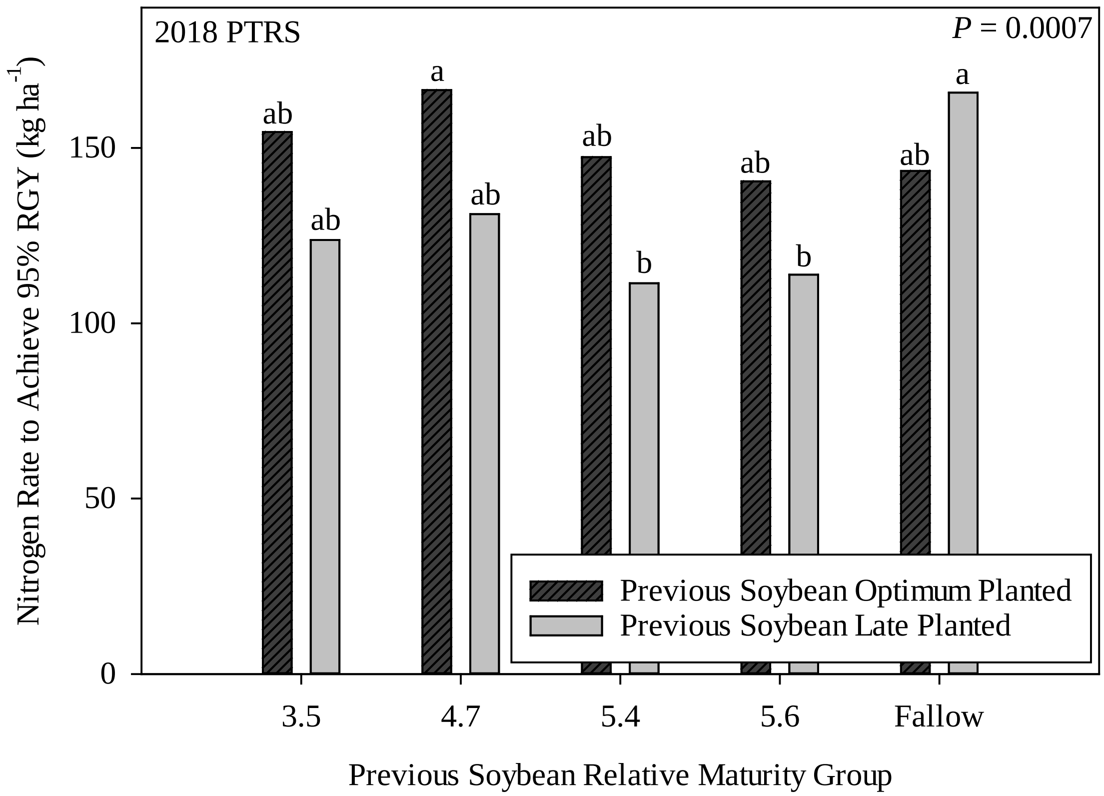

Figure 3-7. Nitrogen rate needed to achieve 95% relative grain yield (RGY) at Pine Tree Research Station 2018 fields between previous soybean relative maturities and planting dates. Means not sharing the same letter are significantly different (HSD, $P < 0.05$).

CHAPTER FOUR

Conclusions

The purpose of this study was to quantify the benefits provided by various management practices of a soybean crop to a soybean-rice rotational system. The results indicated that the planting date and maturity group (MG) of a soybean influence both the overall soybean productivity and the subsequent rice crop productivity. The management decisions must be made based on environment, seed technology, and associated costs. There is no single MG or planting date guaranteed to provide the highest yield and nitrogen (N) credits, so it is best to plant at an optimum time and choose a well-suited MG for the environment. No differences were seen in the net N returned to the soil system from the soybean crop in 2016 or 2017. Norman et al. (1990) found differences in mature biomass C:N compositions coupled with differing harvest dates among species, leading to differences in N recovered by a following crop. The current findings agree with these conclusions, with the addition of soybean planting date differences in N credits on clay soil the following spring. The major differences in rice productivity were found later in the growing season on both clay and silt loam soils.

The soybean MG did not significantly affect the subsequent rice crop grain yield or N rate needed to achieve 95% relative grain yield (RGY) when planted at an optimum time. Therefore, when planting in the optimum window any well suited soybean MG can be selected to achieve the highest soybean grain yield increasing the cropping system's overall profitability. However, when planted late, the soybean MG has a significant influence on following rice crop's productivity. The late planted 3.5 and 5.6 MGs provided the highest grain yield in the subsequent rice crop. Meanwhile, the late planted 5.6 MG soybean crop out yielded the 3.5 MG by 689 kg ha^{-1} and required 10 kg N ha^{-1} less for the subsequent rice crop to achieve 95% RGY. The findings reveal that a 5.6 MG provided the most benefits of all MGs when planted late. These merits, when combined, indicate that there can be significant differences in overall crop rotation productivity between soybean management decisions when the whole rotation is considered.

REFERENCES

Norman, R.J., J.T. Gilmour, and B. R. Wells. 1990. Mineralization of Nitrogen from Nitrogen-15 Labeled Crop Residues and Utilization by Rice. Soil Sci. Soc. Am. J. 54:1351-1356. doi:10.2136/sssaj1990.03615995005400050025x