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Validation of N-STaR Nitrogen Rate Recommendations and Evaluation of N-STaR Soil Sampling Procedures for Clay Soils in Arkansas

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ABSTRACT

The two methods for determining N-fertilizer recommendations for rice (*Oryza sativa* L.) in Arkansas are the standard N recommendation (SR) based on soil texture, previous crop, and rice cultivar, and the Nitrogen-Soil Test for Rice (N-STaR) which quantifies the potentially mineralizable-N of the soil and provides a site-specific N recommendation. The N-STaR program has recently been developed, and the validation of N-STaR for clay soils is an important step in ensuring that N-STaR predicts correct N-fertilizer rates for rice under a delayed-flood production system. Small-plot trials located across Arkansas compared the N-STaR 95 and 100% relative grain yield (RGY) N rates applied as a single preflood (SPF) and a 2-way split (2-WS) application to the SR. The N-STaR N-fertilizer rate recommendations were equal to or less than the SR at all locations with differences ranging from -224 to 0 kg N ha^{-1}. At all 13 sites, rice receiving the N-STaR 100% RGY N-fertilizer treatments yielded equal to or greater than the SR. Similar results were seen for the N-STaR 95% RGY fertilizer-N treatments, although rice receiving the 95% RGY SPF fertilizer-N rate yielded lower than the SR at three locations. The second objective was to examine potential sampling tools for their accuracy in collecting N-STaR soil samples while having the greatest ease-of-use. Alkaline hydrolyzable-N (AH-N) from soil samples collected by the N-STaR bucket and drill (BD), Kleen Hole Spade dry (KHS-D), Kleen Hole Spade lubricated with water (KHS-W), and Kleen Hole Spade lubricated with WD-40 (KHS-40) were compared against the dutch auger (DA) control. The alternative sampling methods were not statistically different in AH-N concentration from the DA, although all alternative methods had a tendency to overestimate AH-N compared to the DA and a correction value should be considered. The KHS-D showed the greatest utility in sampling clay soils and would be the best alternative method for encouraging the use of N-STaR in rice production on clay soils. In conclusion, this research validates the N-STaR N rate recommendations for rice on clay soils in Arkansas and highlights alternative sampling methods that may be employed in N-STaR soil sampling.

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DEDICATION

I dedicate this thesis to those who invested the most during my Master's degree with their time, support, and endless encouragement: to my wife, Samantha, and our son, Graham.

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INTRODUCTION

Rice (*Oryza sativa* L.) is an important crop for Arkansas and is well suited for the Arkansas Grand Prairie and the Mississippi Delta regions. In 2014, rice production directly contributed about $1.4 billion to the state's economy (USDA-NASS, 2015). Arkansas is the leading producer of rice in the United States averaging 566,560 hectares of rice in production over the last ten years (USDA-ERS, 2014a) and contributes about 46% of the total rice produced annually in the United States (USDA-ERS, 2014b). Nitrogen (N) fertilization is an important component in maintaining high rice yields. The most accepted practice for measuring N needs of a crop are by quantifying the inorganic, plant-available forms of N found in the soil (NH_4-N and NO_3-N) and adjusting fertilizer-N needs accordingly. Due to the rapidity and substantial amount of N loss associated with denitrification in rice under flooded conditions, a portion of the inorganic-N fraction available may be lost before the rice plant is able to utilize it. However, the organic-N fraction continues to mineralize during the season and can supplement plant N needs along with N fertilization. Currently, there are two N recommendations for rice in Arkansas. The standard N recommendation of 168 kg N ha^{-1} is adjusted based on cultivar, soil texture and previous crop, but does not take into consideration the N that is mineralized from the soil throughout the growing season. The Nitrogen-Soil Test for Rice (N-STaR) quantifies potentially mineralizable soil-N and provides a site-specific N recommendation.

Nitrogen fertilization can be the greatest single production expense for rice producers, and, according to the United States Department of Agriculture, N fertilizer prices have more than doubled since 2004 (USDA-ERS, 2013). Environmental pollution also continues to be a concern that adds pressure to improve N management for all crops. With proper management, rice has a high fertilizer-N uptake efficiency (FNUE), but over application of fertilizer-N lowers that efficiency and escalates N losses into the environment (Wilson, 1989).

The price of N fertilizer and increased environmental concerns encouraged the search for greater fertilizer-N efficiency during the last few decades. In the early 21st century, research in Illinois by Mulvaney and Khan (2001) was conducted on chemical methods to measure soil mineralizable-N. The research successfully correlated N response in corn (*Zea mays* L.) to the amino sugar-N fraction and was developed into a N test called the Illinois Soil Nitrogen Test (ISNT). Later, Roberts et al. (2011) developed N-STaR on silt loam soils using a direct steam distillation method to quantify the potentially mineralizable N, which was then correlated and calibrated to predict fertilizer-N needs to maximize rice yields.

The N-STaR method requires samples to be taken at the specific depth of 0-45 cm for silt loam soils. Recently, N-STaR has been calibrated for use in clay soils and the correct sampling depth has been identified as 0-30 cm (Fulford et al., 2013; Fulford, 2014). A sampling technique that collects the correct depth of soil, minimizes sample error, and is easy to use is key for the acceptance of N-STaR.

The N-STaR N rate recommendation varies according to the native soil-N. In 2013, producers that utilized the N-STaR N recommendations applied less N on average than the standard fertilizer-N recommendation (Williamson et al., 2013). Whereas lower N rates reduce the risk of N loss and decrease the cost of fertilization, concern over the economic impact of under-fertilization necessitated the validation of the N-STaR N recommendations. The N-STaR N rates for rice on silt loam soils were field validated by Roberts et al. (2013), but the recommendations for clay soils have not yet been validated. The purpose of this research is to validate the N-STaR N rates for rice grown on clay soils and evaluate alternative soil sampling techniques for clay soils. Foremost, the validation of the N-STaR N recommendations will verify the accuracy of the new soil-N test. Furthermore, the validation of N-STaR for rice on clay soils, along with a user-friendly soil sampling method, will encourage the adoption of N-STaR throughout Arkansas.

RICE PRODUCTION IN ARKANSAS

Rice was introduced in Arkansas in the early 1900's and has expanded to where Arkansas now produces approximately one-half of the rice grown in the United States (USDA-ERS, 2014b). Silt loam and clay soils account for about 96% of the rice acreage in Arkansas, with most of it managed using a direct-seeded, delayed-flood system (Wilson et al., 2009). Fields may be precision leveled to acquire benefits such as quicker drainage, uniform water depth, increased cultivated land, and better water management (Street and Bollich, 2003). Conventional and conservation tillage practices begin after harvest in the fall. With conventional tillage, the field is tilled in the fall after harvest and again in the spring to prepare a seedbed for planting. A conservation tillage system called stale seedbed planting occurs when the field is tilled the previous fall and planted in the spring. In 2009, the conventional tillage and stale seedbed planting methods were utilized on 53% and 35% of the rice acreage, respectfully, with the remainder produced in a no-till system (Wilson et al., 2009).

Rice planting begins in late March and continues to early June (Wilson et al., 2013). According to Wilson et al. (2009), about 75% of the rice in Arkansas is drill seeded with the remainder being broadcast and, to a smaller extent, water seeded. Under a drilled system, conventional varieties and hybrids are seeded with 67 to 87 kg seed ha^{-1} and 34 kg seed ha^{-1}, respectively, less than 2.5 cm deep, and on rows that range from 10 to 25 cm wide (Wilson et al., 2013). The seeding rate is increased by 20% for broadcast seeding which is accomplished using a spreader truck or an airplane and lightly disked in. Rice is flooded at the 5-leaf growth stage and maintained until 25 to 35 days after 50% heading depending on the cultivar (Henry et al., 2013).

Under a dry seeding system, levees are surveyed and marked to follow the contours of the field at a distance of 3 to 6 vertical cm and are pulled to a sufficient height for a flood depth of 7.5-15 cm (Street and Bollich, 2003). Levees are pulled with a levee disc after rice has been planted and may take many passes on clayey-textured soils to establish a levee sufficient to hold the flood water. Throughout the course of the year, an estimated 0.76 m of water is needed to sustain the 5-10 cm flood until it is drained anticipating harvest (Scott et al., 1998; Street and Bollich, 2003). According to Wilson et al. (2009), groundwater is used to irrigate 83% of the rice acreage in Arkansas and surface water irrigates the remaining acreage. Water level in the bays is controlled by levee gates set in the levee wall and are installed soon after the levees are pulled (Street and Bollich, 2003). Irrigation in Arkansas has been moving towards multiple inlet irrigation in order to conserve water and labor. Multiple inlet irrigation increased from 17% of rice acreage in 2002 to 42% in 2009 and is done by running flexible irrigation tubing across a field in order to flood all the bays in concert (Wilson et al., 2009).

Routine soil samples accompanied by soil pH values are used to monitor the need for phosphorus (P), potassium (K), and zinc (Zn) fertilizers. Little response is seen from added P when the Mehlich-3 extraction is > 26 mg P kg^{-1} at <6.5 pH or >36 mg P kg^{-1} at ≥6.5 pH. Additionally, rice rarely responds to K fertilizer when Mehlich-3 extraction values exceed 131 mg K kg^{-1}. Zinc deficiency most often appears on silt loam or sandy soils, but can be found on precision-graded clay soils. Depending on soil-test Zn, pH, and soil texture, up to 11 kg Zn ha^{-1} may be applied if the Zn source is at least 50% water-soluble (Norman et al., 2013).

The standard N recommendation in rice is not determined by a soil test, but is a blanket application which is adjusted by soil texture, rice cultivar, and the previous crop. The current unadjusted recommendation is 168 kg N ha^{-1} for silt loam soils. A new soil test, named N-STaR, has recently been developed for use in silt loam and clay soils and enables a site-specific N recommendation (Robert et al., 2013; Fulford et al., 2013; Fulford, 2014). The N-STaR takes into account the native soil N that is available to the rice plant during the season and predicts the additional portion needed to achieve optimum grain yield. The standard N recommendation and the N-STaR N recommendation are both accepted practices to determine the fertilizer-N rate for rice on silt loam and clay soils in Arkansas.

N Management In Rice

Rice is a non-legume crop and must acquire all of its N from the soil or from added fertilizer. Part of the N requirement is attained from mineralized organic matter, but for most soils, fertilizer-N must be added to consistently obtain maximum rice yields. According to Slater and Kirby (2011), 256,119 Mg of elemental N was applied in Arkansas agriculture in 2010. In a dry seeded, delayed-flood system, rice is fertilized with ammonium or ammonium-forming fertilizers in order to decrease losses from nitrification/denitrification when the permanent flood is established. Common N fertilizers used for rice include urea and ammonium sulfate. Of these, granular urea is the most common due to its high N analysis and cost—69% of N fertilizer applied in Arkansas was from granulated urea in 2010 (Slater and Kirby, 2011). Nitrogen fertilizer applied immediately prior to flooding is referred to as the preflood application. Preflood N can be applied with a spinner unit or air-flow spreader before levees are constructed or with an airplane following levee construction. The majority of the N is applied preflood (65-100%) with the remainder being applied aerially into the flood water as a midseason application near the beginning of reproductive growth (Norman et al., 2003, 2013).

When fertilizer-N is applied to a dry soil and immediately incorporated with flood water, maximum N uptake occurs by 21 days with a FNUE of 65-75% (Wilson et al., 1989; Norman et al., 2003). The midseason-N application tends to have a slightly higher FNUE than the preflood N due to plants having a more developed root system, but preflood application is of greater importance in determining rice grain yield (Wilson et al., 1989, 1998, Norman et al., 2003).

Plant uptake of midseason-N is most efficient when fertilizer-N is applied in a window between panicle initiation and panicle differentiation, and should not exceed 50 kg N ha^{-1} (Wilson et al., 1998; Norman et al., 2013). Wilson et al. (1998) found no added benefit of a midseason split application, but a split application with the second application made seven days following the first can be utilized if the midseason N need exceeds 67 kg N ha^{-1} (Norman et al., 2003, 2013).

The primary N loss mechanisms in rice are ammonia volatilization and nitrification/denitrification (Norman et al., 2003). Volatilization occurs when ammonia gas is formed whether from urea hydrolysis or from ammonium converting to ammonia. Ammonia volatilization is exacerbated by factors such as high pH, moist soil conditions, high temperature, wind, and a low cation exchange capacity (Ernst and Massey, 1960; Ferguson et al., 1984; Havlin et al., 2005). Nitrification is the conversion of ammonium to nitrate through microbial processes, and may take from days to weeks depending on the soil and environmental conditions (Havlin et al., 2005). Once the rice is flooded and the soil becomes anaerobic, the nitrate undergoes denitrification in a period of hours to days where it is reduced to a gaseous form and lost into the atmosphere. Significant loss of N through denitrification can be avoided through proper management such as the use of an ammonium-forming N source and timely flood establishment.

Since urea is cost effective per unit of N, has a high N analysis, and is ammonium forming, it is commonly used in rice production but is subject to several N loss mechanisms if not managed properly. Urea, an organic compound, is hydrolyzed into ammonia by the urease enzyme and attains an H^+ from the soil to form ammonium. Once urea is transformed into ammonium, it can adsorb to the soil cation exchange complex, yet a substantial portion may volatilize as ammonia if the urea is unincorporated. Norman et al. (2006) found that 15 and 25% of the urea-N applied to a silt loam soil was lost over five days via volatilization when applied to a dry and wet soil, respectively. On silt loam soils, urea must be applied to dry soil and the fields flooded in less than three days in order to reduce volatilization losses (Norman et al., 2006). Volatilization of ammonia on clay soils has been recorded to a lesser degree, yet incorporation of the urea should occur within seven days to avoid excessive loss (Griggs et al., 2007; Norman et al., 2007).

In cases of inclement weather or where timely floods cannot be established, the urease inhibitor, N-(n-butyl) thiophosphoric triamide (NBPT), has proven to be effective (Norman et al., 2006, 2007, 2009; Griggs et al., 2007). The NBPT slows the transformation of urea into the ammonia or ammonium form where it is more susceptible to volatilization or nitrification/denitrification losses. Norman et al. (2006) recorded that, in 5 d, <5% of urea treated with NBPT volatilized when applied on a dry silt loam soil and <15% when applied on wet soil. Similarly for clay soils, rice fertilized with NBPT treated urea produced greater yields than urea when both fertilizers were applied to dry soil 10 d prior to permanent flood (Norman et al., 2007).

Ammonium sulfate is more expensive and has additional aerial application costs per unit of N due to its low N analysis but is an additional option for reducing N volatilization loss. Griggs et al. (2007) and Norman et al. (2009) both recorded volatilization losses of <6% when ammonium sulfate was applied 10-14 d before flood establishment. Furthermore, rice fertilized with ammonium sulfate applied 10-14 d prior to flood yielded similar to urea applied one day prior to flood (Griggs et al., 2007; Norman et al., 2009). Urea and ammonium sulfate can also be blended to take advantage of the low cost of urea while limiting volatilization (Norman et al., 2009).

ILLINOIS SOIL NITROGEN TEST

While analyzing soils that received various amounts of manure, Mulvaney and Khan (2001) found an error in the steam distillation methods used in quantifying mineralizable-N during fractionation of the soil hydrolysates. This error included an incomplete conversion of amino acid-N to NH_4-N and a partial measurement of amino sugar-N and hydrolyzable NH_4 (Mulvaney and Khan, 2001). Mulvaney and Khan (2001) suggested that the error in the procedures may have been a factor in the past inability to correlate a chemical extraction of labile-N to yield. Mulvaney and Khan (2001) corrected the error by developing a diffusion method that accurately quantified the fractions of soil-N.

With the corrected techniques, Mulvaney et al. (2001) compared the NH_4-N, amino sugar-N, and amino acid-N fractions for 18 sites composed of soils where corn was either responsive or nonresponsive to N fertilization. The amino acid-N and NH_4-N values overlapped between the responsive and nonresponsive sites whereas the amino sugar-N fractions were 33% greater for the nonresponsive sites. Mulvaney et al. (2001) suggested that amino sugar-N is a key factor in the N mineralization potential of a soil. Further study of three nonresponsive sites and two responsive sites under a three month incubation showed that mineralization was greatest for the sites with the highest initial amino sugar-N concentrations and that amino sugar-N concentrations decreased as mineralization occurred. Utilizing the amino sugar-N fraction, Mulvaney et al. (2001) were able to correctly identify the sites responsive or nonresponsive to N fertilization.

The current acid hydrolysis method used to measure amino sugar-N was too time consuming and complex for use in a standardized soil-N test. Khan et al. (2001) developed a mason-jar diffusion method that was more timely and simple. The test was performed using a mason-jar with a petri dish suspended from the jar lid. The method included mixing a concentration of 2 mol L^{-1} NaOH into a soil sample which was then heated for five hours on a burner at 48-50°C. The resulting ammonium gas absorbed into the H_3BO_3 solution located in the petri dish which was then titrated to quantify the ammonium collected and subsequently the amino sugar-N concentration. Khan et al. (2001) tested the method on soil samples ground and passed through a 0.15 or 2.0 mm sieve and found that there was no difference in test values with soil aggregate size. Khan et al. (2001) surmised that the soil quickly forms a slurry when subjected to alkaline hydrolysis with 2 mol L^{-1} NaOH regardless of the soil particle size.

With the mason-jar diffusion method, Khan et al. (2001) accurately predicted the N fertilizer responsiveness for 25 sites covering a wide range of field situations. The new method was adopted as a state soil test and was called the Illinois Soil Nitrogen Test (ISNT). The development of this test increased interest in mineralizable-N and was replicated with mixed success. Williams et al. (2007a) correlated the ISNT with economic optimum N rates after the drainage classification of the soil was taken into account. In addition, Sharifi et al. (2007) found that the ISNT was a reliable source of measuring mineralizable soil-N when compared to the biological standard index developed by Stanford and Smith (1972). Alternatively, Barker et al. (2006) could not find a relationship between relative grain yield (RGY) and the ISNT values for Iowa soils and climatic conditions. Spargo et al. (2009) and Osterhaus et al. (2008) were also unable to find a correlation between the ISNT and fertilizer-N responsiveness. In several of the studies, the ISNT correlated well with total soil-N, and it was suspected that the test simply quantified a constant fraction of total soil-N (Barker et al. 2006; Bushong et al., 2008; Osterhaus et al. 2008; Spargo et al. 2009).

Direct Steam Distillation

Due to the 5 hour heating process, the ISNT is primarily limited by time when performed on a large scale. Bushong et al. (2008) compared a 7 min modified direct steam distillation (DSD) procedure and the ISNT against anaerobic incubation. While the DSD appeared more precise, both the ISNT and the DSD correlated well with the anaerobic incubation, and Bushong et al. (2008) found that there was a strong correlation between the ISNT and DSD. When the DSD was regressed against the ISNT, the slope equaled 1.08 and the y-intercept equaled 1.10. A slope and a y-intercept of near 1 and 0, respectively, suggested that the DSD and the ISNT were comparable and the DSD could be used to obtain near exact ISNT results. Moreover, the equation suggested that the DSD recovers more hydrolyzable-N than the ISNT. Yet, Bushong et al. (2008) found that the ISNT recovered a greater percentage of glucosamine-N than the DSD. The inconsistency of the DSD recovering more hydrolyzable-N while the ISNT recovered significantly greater amounts of glucosamine-N suggested that the DSD was recovering an additional N fraction other than amino sugar-N.

Roberts et al. (2009a) compared the recovery of several purified amino-N compounds and found that the ISNT recovered 10 to 22% more amino sugar-N than DSD while DSD outperformed the ISNT in recovering a significantly greater amount of transitional amino acids. The ISNT and DSD recovered <5% of the amino acids and <1% of the nucleic acids supporting previous research that amino acids and nucleic acids are not readily mineralizable (Mulvaney et al., 2001). Roberts et al. (2009a) surmised that while the ISNT recovers more amino sugar-N than DSD, the DSD recovers transitional amino-N compounds in sufficient quantity to offset the lack of recovered amino sugar-N and to report equal or greater values of hydrolyzable-N.

NITROGEN-SOIL TEST FOR RICE: N-STAR

The question prevailed of whether or not hydrolyzable-N measured by the DSD and the ISNT represented a constant fraction of total soil-N (Barker et al. 2006; Bushong et al., 2008; Osterhaus et al. 2008; Spargo et al. 2009). In response, Roberts et al. (2009b) looked at the hydrolyzable-N values across soil depths. Utilizing 16 soils with varying characteristics, Roberts et al. (2009b) took soil samples in 15 cm increments to a depth of 60 cm and tested them for total-N and hydrolyzable-N. Roberts et al. (2009b) noted that alkaline hydrolyzable-N (AH-N) varied with both depth and site indicating the influence of soil-forming factors and management such as crop rotations, mechanical operations, soil parent material, climate, etc. When AH-N was compared to total-N with consideration to sampling depth, Roberts et al. (2009b) found that the AH-N fraction of total-N fluctuated between 8 and 38%. Roberts et al. (2009b) concluded that while AH-N was significantly correlated to total-N, it was not a constant fraction. In addition, Roberts et al. (2009b) stated that sampling depth would be an important factor when incorporating AH-N in a standardized soil-N test.

The majority of rice in Arkansas is grown under flooded conditions which helps normalize the rate of mineralization. Roberts et al. (2011) measured AH-N for 24 different site-years on silt loam soils using both ISNT and DSD at 15 cm increments up to a 60 cm depth. The

DSD consistently had higher AH-N values than ISNT over all depths. Roberts et al. (2011) noted a correlation between DSD and ISNT values and total-N values, but the coefficients of determination were low which suggested variability in the fraction of total-N and reflected the previous work done by Roberts et al. (2009b) that showed AH-N to be anywhere from 8 to 38% of total-N.

Previous work done by Williams et al. (2007b) found that separating soils by texture increased the ability of the ISNT to predict N requirements. Focusing on silt loam soils, Roberts et al. (2011) was successful at correlating the ISNT and DSD to the RGY of rice. The 95% RGY coupled with a 0-45 cm sampling depth showed the greatest relationship between AH-N values and rice yield response. Roberts et al. (2011) concluded that 45 cm was the approximate rooting depth for rice. Furthermore, Roberts et al. (2011) created a calibration curve that predicted the N needs of rice using the DSD procedure and called it N-STaR. The calibration curve had an r^2 value of 0.89 for the 95% RGY at the 45 cm depth.

Roberts et al. (2013) validated N-STaR on fourteen sites apart from the sites used to develop the soil test. The study consisted of five N rates; a control, 90, 95, and 100% N-STaR RGY N rates, and the Arkansas standard N rate recommendation. The N-STaR fertilizer-N rates ranged from 22 to 252 kg N ha^{-1}, and nine of the sites were equal to or less than the standard fertilizer-N recommendation for all N-STaR rates. The other five sites had at least one N-STaR N rate greater than the standard recommendation with three sites greater for all N-STaR rates. Rice yields were statistically equal between the N-STaR 90% RGY and the standard recommendation for six sites while five sites for the N-STaR 90% RGY yielded less than the standard recommendation and three of the sites yielded more. For the N-STaR 95% RGY, the yield was statistically the same or greater than the standard recommendation for 13 of the 14 sites despite the lower N-STaR fertilizer-N rates at nine of the 14 sites. The N-STaR 100% RGY was equal to or greater than the standard recommendation for all sites while seven of the N-STaR N rates were lower than the standard N recommendation. Of the five sites that received a greater N-STaR 100% RGY N fertilizer rate than the standard N recommendation, only one site yielded higher while the remaining four sites were not statistically different. With respect to the sites that received less N yet outperformed the standard N recommendation, Roberts et al. (2013) concluded that the excess N increased lodging and disease. After comparing the N-STaR 95% and 100% RGY, Roberts el al. (2013) suggested that the N-STaR 95% RGY N rates were more economical for fertilizer-N recommendations that were above 168 kg N ha^{-1}.

The correlation and calibration of N-STaR for rice in clayey soils was conducted on 16 site years across Arkansas by Fulford (2014). Fulford (2014) found a high correlation with both N-STaR (r^2=0.79) and the ISNT (r^2=0.77) when comparing AH-N averaged over the 30 cm depth to rice yield of plots receiving no fertilizer-N. The calibration of N-STaR and ISNT to the 95% RGY also had high coefficients of determination at the 30 cm sampling depth with r^2=0.83 and r^2=0.83 respectively. While the calibration of the ISNT had a slightly higher coefficient of determination at the 0-45 cm depth, Fulford (2014) concluded that the difference was negligible (r^2=0.84 compared to r^2=0.83). The magnitude of the coefficients of determination for N-STaR decreased with increases in depth past 0-30 cm.

Soil Sampling Variability

As summarized by Petersen and Calvin (1986), the objective of a soil sample is to estimate a parameter of a specific population accurately and precisely. The estimate of the trait of interest of the population is termed a statistic. The accuracy and precision of the sample statistic to the population parameter is dependent on the error in the sample. Error arises from three basic categories; sampling error, selection error, and measurement error (Petersen and Calvin, 1986). Sampling error, or the error between the samples, occurs through the natural variability of the soil (Petersen and Calvin, 1986). The sampling variability becomes closer to the true field variability as the number of samples is increased (Dick et al., 1996). Selection error is often the result of improper sampling techniques, such as selecting for a specific field attribute or excluding a portion of the population (Petersen and Calvin, 1986). Lastly, measurement error arises when the measurement procedure provides incorrect results; the results may be consistently too high or low, or the measurement process itself may be faulty (Kempthorne and Allmaras, 1986; Petersen and Calvin, 1986). Often, selection and measurement errors are not included in the calculated sampling error and may negatively influence the accuracy and precision of the results (Petersen and Calvin, 1986).

When N-STaR was compared against the ISNT and anaerobic incubation in a lab setting, it provided similar results to the accepted standards which attested to the lack of substantial measurement error (Bushong et al., 2008; Roberts et al., 2009a). Furthermore, N-STaR recommendations were field validated in 2013 for silt loam soils by Roberts et al. (2013) and have shown through yield measurements, that the soil test accurately predicts the mineralizable-N potential of a silt loam soil. The N-STaR fertilizer-N rates for silt loam and clay soils were calculated using calibration curves developed from a specific soil sample depth, 0-30 and 0-45 cm for clayey and silt loam soils, respectively. Therefore, the volume of soil consisting of the field area to the given depth makes up the population for the N-STaR sample (Roberts et al., 2009b; Fulford, 2014). A sampling protocol that samples to an incorrect depth would fail to include a vital part of the sampling population and inflate the potential for error. According to

Petersen and Calvin (1986), only careful attention to correct procedures can keep this error at a minimum.

SAMPLE VOLUME

Sample volume can have an impact on soil sampling variability (Hassan et al., 1983; Baker et al., 1989). Hassan et al. (1983) used a soil tube probe and a bucket auger to collect two different volumes of soil in order to examine the impact of sample volume in determining salt in the soil profile. In the study, the smaller volume collected by the tube resulted in a higher variability between samples—the coefficient of variation (CV) of the sampling tube was 14% while the CV of the bucket auger was 8% (Hassan et al., 1983). In a similar study, Baker et al. (1989) examined four soil sampling probes of varying diameters and the subsequent sample volume effect on NO_3-N. The four probes included were a 1.9-cm soil probe, a 3.2-cm soil probe, a 5.1-cm Earth Auger, and a 20.3-cm power auger. Plots were classified as no-till or conventional tillage and soil samples were taken in 30 cm increments to a 150 cm depth. For the top 30 cm, the 1.9-cm probe had similar variation for residual soil-N in the no-till and conventional till plots—a CV of 47 and 45%, respectively. In comparison, the variation for residual soil-N of the 3.2-cm probe, 5.1-cm Earth Auger, and the 20.3 cm power auger were lower than the 1.9-cm probe on the no-till plots but higher on the conventionally tilled plots for the first 30 cm increment. The 3.2-cm probe recorded the highest variation for residual soil-N in the upper 30 cm of the soil profile for conventional tillage with a CV of 68% and was followed by the 5.1-cm Earth Auger with a CV of 62% (Baker et al., 1989). The data published by Baker et al. (1989) did not show any definite trends with regards to decreasing sample variation by increasing sample volume.

PROBES AND LUBRICANTS

In the event of soil sampling with a push probe, the soil is subject to friction on the inside of the probe and may cause compression of the soil sample. Compression occurs when a mechanical load is applied to the soil and causes the soil volume to decrease (Bradford and Gupta, 1986). Compression of the soil within the sample tube makes it difficult to separate the soil into separate depth increments, and soil compression below the tube may inhibit the acquisition of a correct soil sample depth (Blaylock et al., 1995). Hassan et al. (1983) recorded a lower soil bulk density for a tube probe compared to a bucket auger and attributed it to collecting a smaller amount of soil than supposed due to compression.

A study by Blaylock et al. (1995) examined the effects of various lubricants on sampling probes and the possible contamination in the soil analysis. The lubricants included in the study were WD-40, vegetable oil spray, dish-washing liquid, synthetic motor oil, and silicone spray. Blaylock et al. (1995) found that the lubricants did not significantly affect the soil analysis when testing for macronutrients, but that there is increased risk for contamination in micronutrient analysis. In addition, soil samples taken with lubricated probes tended to be less compressed although there were no significant differences in core length. Overall, the spray lubricants were easiest to apply, coated the probes evenly, and largely reduced the sampling time (Blaylock et al., 1995).

Sampling Time

In soil sampling, convenience is a notable factor in the overall acceptance and usage of a sampling probe. Stevens et al. (2002) examined the time required to sample an 8 ha field using probes selected for specific features that aid in sample collection. A Hoffer straight tube, an Oakfield foot-pedal, an M&M split tube, and an Esser Cone were included in the analysis and clogging incidences were also recorded for each probe. Overall, Stevens et al. (2002) found that the clay soil tended to take more time to sample than a silt loam or sandy loam soil. In addition, the split tube and the cone were the most time efficient probes when used on a clay soil due to the significantly less (α=0.05) number of clogging incidences for the split tube and the cone compared to the Hoffer straight tube and the Oakfield foot-pedal. Stevens et al. (2002) concluded that selecting an appropriate probe for the sampling conditions would reduce the time and labor required to obtain soil samples.

SOIL SAMPLING FOR N-STAR

During the correlation and calibration of N-STaR for silt loam and clay soils, a 5 cm Dutch Auger Probe (AMS Inc., American Falls, Idaho) was used to obtain soil samples to the depth of 30 and 45 cm for clay and silt loam soils respectively. After the introduction of N-STaR in rice production, the N-STaR bucket and drill method was adopted as a quick and sure way to obtain a soil sample at the appropriate depth on silt loam soils. A N-STaR soil sampling bucket consists of a 18.9 L bucket with a steel pipe coming up through the middle of the bucket floor. The pipe is welded to a steel plate which is screwed onto the bottom of the bucket and extends past the bucket sides to create footpads for stabilization. With the bucket and drill method, a 2.54 cm wide Ship Auger bit (Grainger, Lake Forest, IL) is attached to a drill and inserted through the pipe to collect the soil sample to the specified depth (Roberts et al., 2012). The bucket and drill method has encountered difficulties on clay soils; namely, the clay soil tends to stick in the grooves of the auger and must be manually removed, the auger is time consuming to clean, and the bucket and drill are bulky and not conducive to taking lots of samples (T.L. Roberts, personal communication, 2014). As summarized by Peck and Melsted (1967), soil sampling tools should be relatively easy to use, easy to clean, durable, provide the appropriate soil volume, and collect uniform soil samples to the accurate depth. A tool or sampling process that follows such a criteria would be instrumental towards the accuracy and precision of the N-STaR results as well as the adoption of N-STaR across Arkansas, the mid-South, and perhaps other rice-producing regions of the world. Therefore, the objectives of this research are as follows:

1. Validate the N-STaR N recommendations for clay soils through field trials.
    a. Validate the N-STaR measurement process by comparing the N-STaR-recommended fertilizer-N rates for the 95 and 100% RGY calibration curves against the standard N recommendation.
    b. Evaluate the performance of the N-STaR 95 and 100% RGY N rates under a single preflood N management system.
2. Examine alternative soil sampling techniques that are simple and easy to use in clay-textured soil while minimizing selection error due to the sample method.
    a. Ensure the alternate sampling methods are acquiring the correct soil depth by comparing the N-STaR distillation results of each sampling technique to the method used in the correlation and calibration process.
    b. Assess the ease of use and gauge the performance of each sampling method for clayey soils.

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Appendix 1.1. Definition of abbreviations.

Abbreviation or symbol	Explanation
AH-N	Alkaline hydrolyzable-nitrogen
CV	Coefficient of variation
DSD	Direct steam distillation
FNUE	Fertilizer-N use efficiency
ISNT	Illinois Soil Nitrogen Test
K	Potassium
N	Nitrogen
N-STaR	Nitrogen-Soil Test for Rice
NBPT	N-(n-butyl) thiophosphoric triamide
P	Phosphorus
RGY	Relative grain yield
Zn	Zinc

CHAPTER 2

Validation of N-STaR N Rate Recommendations for Clay Soils

ABSTRACT

The Nitrogen-Soil Test for Rice (N-STaR) provides a site-specific N rate recommendation for rice (*Oryza sativa* L.) and these N rate recommendations for rice grown on loamy soils have been validated through small plot research trials on experiment stations and production fields. The N-STaR N rate recommendations for rice on clay soils have not been validated. In this study, the N-STaR 95 and 100% relative grain yield (RGY) N rate recommendations for rice grown on clay soils were applied as either a 2-way split application (2-WS) or a single preflood application (SPF) to validate the N-STaR N recommendations under the current production practices for rice systems in the Mid-south. In 2014 and 2015, 13 small plot field trials were conducted within the rice-producing regions of Arkansas. Treatments included: a control (0 kg N ha^{-1}), the N-STaR 95% RGY SPF N rate, the N-STaR 100% RGY SPF N rate, the N-STaR 95% RGY 2-WS N rate, the N-STaR 100% RGY 2-WS N rate, and the standard N recommendation (SR) based on soil texture, previous crop, and rice cultivar. The N-STaR fertilizer-N rate recommendations were lower than the SR for all locations with differences ranging from -224 to -10 kg N ha^{-1}. At three sites, rice fertilized using the N-STaR 95% SPF produced decreased yields while rice fertilized using the N-STaR 95% 2-WS yielded lower than the SR at one site. For the N-STaR 100% RGY SPF and 2-WS treatments, rice at all sites yielded equal to or greater than the SR. At site 12, N-STaR recommended 0 kg N ha^{-1} for all treatments compared to the 224 kg N ha^{-1} as prescribed by the SR. Rice receiving the N-STaR N rate recommendation at site 12 yielded statistically higher than the SR at 3886 kg rough rice ha^{-1}. Results suggest that the N-STaR N rate recommendations accurately predict the site-specific fertilizer-N requirement of rice in Arkansas and can increase the long-term economic viability and sustainability of rice production.

INTRODUCTION

Rice is a vital component to the Arkansas agricultural sector and contributed roughly $1.4 billion to the state's economy in 2014 (USDA-NASS, 2015). Arkansas is the leading producer of rice in the United States averaging 566,560 ha of land devoted to rice production over the last 10 yr (USDA-ERS, 2014a). Annually, Arkansas contributes about 46% of the total rice produced in the United States (USDA-ERS, 2014b).

Nitrogen fertilizer is instrumental for producing maximal rice yields on most soils in Arkansas. The SR is based on cultivar, soil texture, and the previous crop and is typically 202 kg N ha^{-1} for rice grown on clayey soil following soybean (*Glycine max* L.). A test that measures the N mineralization potential of a soil has long been sought and would allow a more accurate N recommendation for rice. Bushong et al. (2008) developed a N soil test that indexed the potentially mineralizable-N of a soil. Soil texture was found to be a significant factor, and silt loam and clay soils were separated for the ensuing correlation and calibration of this newly developed soil-based N test. Sampling depth was also a significant factor, and the greatest predictability for N rate recommendations was found at a 0-45 cm sampling depth for silt loam soils (Roberts et al., 2011) and a 0-30 cm depth for clay soils (Fulford, 2014). The N test was correlated and calibrated with rice yield and called the Nitrogen-Soil Test for Rice (N-STaR) (Roberts et al. 2011). The N-STaR calibration curves were established on silt loam soils in 2010 (Roberts et al. 2011) and on clay soils in 2013 (Fulford, 2014). For N-STaR analysis, soils were identified as a silt loam or clay by having a cation exchange capacity <27 or >27 $cmol_c$ kg $soil^{-1}$, respectively. The successful calibration of N-STaR resulted in a high coefficient of determination for rice on both silt loam and clay soils (r=0.89 and r=0.83, respectively), and highlights the accuracy of N-STaR N rate recommendations.

Field validation is an important component to the introduction of a new soil test in order to ensure the accuracy of the test and provide a visual representation of the new technology. Replicated trials across various soil series, crop rotations, cultivars, native soil-N levels, and environmental conditions were instrumental in the release and adoption of N-STaR. Roberts et al. (2013) validated the calibration curves for rice on silt loam soils through small-plot field trials and concluded that N-STaR accurately predicted the site-specific N requirement to achieve maximum rice yields for rice produced on silt loam soils. While results for the validation of N-STaR on silt loam soils were overwhelmingly positive, the calibration curves for clay soils remain un-validated; therefore the validation of N-STaR N rate recommendations on clay soils is the primary purpose of this research.

Historically, fertilizer-N was applied to rice in a 3-way split application with 50% of the N applied as a preflood application and 50% as a topdress applied in two applications (Wells and Turner, 1984). A single topdress application was adopted after the introduction of short-statured cultivars that had a lower propensity to lodge. Later, research involving the uptake and partitioning of ^{15}N labeled N fertilizer showed that rice fertilized with a SPF utilized N as or more efficiently than the 2-WS application (Norman et al., 1992). Wilson et al. (1998) found that an optimum preflood-N rate increased the efficiency of the midseason fertilizer-N application and resulted in a greater uptake of native soil-N. These discoveries led University of Arkansas researchers to adopt the SPF application in the N x variety trials in 2008 (Norman et al., 2009). Research has shown that on silt loam soils, equal grain yields can be achieved with 22 to 34 kg N ha^{-1} less when applied as a SPF (Norman et al., 2002). In part, this may be a result of the SPF N rate encouraging growth of rice root biomass and enabling the uptake of sufficient soil-N later in the season. A 22 kg N ha^{-1} decrease was adopted for the SR when applied as a SPF application and no loss in grain yields have been recorded (Hardke, 2013). The magnitude of the SPF N reduction is similar for loamy and clayey textured soils under the assumption that an adjustment for clay soils was previously built into the SR.

The N-STaR soil test was developed under a 2-WS N management system with the majority of the fertilizer-N applied as a preflood application and 50 kg N ha^{-1} applied as a midseason application within 2 wk following the R0 growth stage defined by Counce et al. (2000). The SPF fertilizer-N application with the 22 kg N ha^{-1} reduction has been successful when accompanying the N-STaR N recommendations for loamy soils (T.L. Roberts, personal communication, 2014). The 22 kg N ha^{-1} reduction should be examined for clay soils as clay soils typically need additional N to achieve a similar relative grain yield.

As N prices increase and environmental concerns escalate, a site-specific N recommendation will become increasingly important. A soil-based N test that quantifies the required amount of N for a rice crop will enable fertilization practices that optimize the economic value of the rice production system (Watkins et al., 2010). Therefore, the research objective was to validate the N-STaR calibration curves on clay soils under both the 2-WS and SPF N management systems in order to verify the efficacy of this new soil-based N test and encourage its widespread use.

MATERIALS AND METHODS

Thirteen small plot validation trials were conducted on producer fields and experiment stations from 2014-2015. Sites were selected to obtain a wide range of native soil-N availability, cultivars, and cropping histories. These trials were located in plots that were placed in locations other than those used to develop the correlation and calibration curves reported by Fulford (2014). The plots were nine rows wide (18 cm spacing), 4.6 m long, and arranged in a randomized complete block design with four replications. At the experiment stations, plots were drill seeded at 112 kg of seed ha^{-1}. The rice cultivars Jupiter, Wells, CL151, and XL753 were used in the N-STaR validation trials and typically receive 202 kg N ha^{-1} when grown on a clay soil in a rice-soybean rotation. Soil data for all locations—including soil series, soil classification, and previous crop can be found in Table 2.1. Soils that were deficient or had a history of P deficiency were fertilized with 10 kg P ha^{-1} to ensure P was not limiting. Potassium and Zn deficiencies are rare on clay-textured soils, and did not occur for the 13 sites used in the study (Table 2.2).

SOIL SAMPLING AND ANALYSIS

A Dutch Auger Probe (AMS Inc., American Falls, Idaho) with a 5 cm wide inner diameter (i.d.) auger was used to collect the N-STaR samples in 15 cm increments to the required 0-30 cm depth for clay soils (Fulford, 2014). Four soil samples (n = 4) were collected for the N-STaR analysis immediately outside each block on alternating sides, and sampling was accomplished prior to the establishment of the permanent flood. Each 15 cm increment was processed separately for N-STaR and then averaged together to obtain the N-STaR value needed to generate the N recommendation. Soil from the top 15 cm depth was also analyzed for Mehlich-3 extractable nutrients, total N, total C, and pH to provide background soil chemical information and ensure no nutrients were limiting at the sites (Table 2.2). Soil samples were oven dried at 60°C, ground, and sifted through a 2 mm sieve (James and Wells, 1990). For the N-STaR analysis, a 1 g subsample was processed through the 7 min direct steam distillation method described by Roberts et al. (2009) where soil is subjected to alkaline hydrolysis using10 mol L^{-1} NaOH. The alkaline hydrolyzable-N (AH-N) was distilled and titrated to obtain the N-STaR soil-N availability index. Fertilizer-N rates for the N-STaR 95 and 100% RGY recommendations were determined using the N-STaR test values from the two calibration equations reported by Fulford (2014).

FERTILIZER-N TREATMENTS

The fertilizer-N was managed as either a 2-WS application or a SPF using urea (46 g N kg^{-1}). For the 2-WS N management, the majority of the season total N rate was applied immediately prior to permanent flood, and 50 kg N ha^{-1} was applied into the flood water at beginning internode elongation prior to the R1 growth stage (Counce et al., 2000) for pureline cultivars, and 33 kg N ha^{-1} at late boot (prior to R3) for the hybrid cultivars. Under SPF N management, all the fertilizer-N was applied immediately prior to permanent flood for both pureline and hybrid cultivars. Fertilizer-N rates were applied as follows: 0 kg N, N-STaR 95% RGY SPF application, N-STaR 95% RGY 2-WS application, N-STaR 100% RGY 2-WS application, N-STaR 100% RGY SPF application, and the SR based on the cultivar and previous crop. The SR of 202 kg N ha^{-1} for rice on clay-textured soils was increased by 22 kg N ha^{-1} when following rice and was applied using the 2-WS method at all locations. The N-STaR 95 and 100% RGY 2-WS recommendations were managed similarly unless the N treatments recommended $<$101 kg N ha^{-1} in which case an alternate N rate was provided. Under a SPF management system, research has shown that the same yield can be achieved with 22 to 34 kg N ha^{-1} less than a 2-WS system (Norman et al., 2002). Accordingly, the total N for the N-STaR 95 and 100% RGY SPF N rate recommendations were reduced by 22 kg N ha^{-1}.

Three of the 13 sites (sites 4, 7, and 12) received one or more alternate N treatments which took the place of N-STaR N rates. At site 4, the N-STaR 100% RGY 2-WS recommendation of 191 kg N ha^{-1} was nearly equal to the SR of 202 kg N ha^{-1} and an alternate N rate of 235 kg N ha^{-1} was applied in the place of the N-STaR 100% RGY 2-WS in order to verify that the N-STaR N recommendations maximize yield. The N-STaR 95% RGY 2-WS recommendation for site 7 was 95 kg N ha^{-1} and was unlikely for a producer to apply as a split application under the current pricing scheme for aerial application. With an aerial application of urea, there is a flat cost up to 112 kg urea ha^{-1} after which the rate increases incrementally for each additional kg urea ha^{-1}. A producer has little incentive to apply urea below the 112 kg urea ha^{-1} since there is no aerial application cost savings when applying a lower N rate. At site 7, the N-STaR 95% RGY 2-WS was replaced with an intermediate N rate of 146 kg N ha^{-1}. For site 12, the N-STaR 95 and 100% RGY 2-WS and SPF N rates were 0 kg N ha^{-1}, and were replaced with increasing alternate N rates of 28, 50, 84, and 101 kg N ha^{-1} in order to validate the N-STaR N recommendation and examine the possibility of a lower fertilizer-N limit. All alternate N rates were applied as a 2-WS unless the N rate was $<$101 kg N ha^{-1} where the fertilizer-N was then applied as a SPF application.

All urea-N was treated with a urease inhibitor at a rate of 0.89 g N-(n-butyl) thiophosphoric triamide kg urea^{-1} [Agrotain Ultra (285 g NBPT L^{-1}), Koch Fertilizer LLC., Wichita, KS], and the urea was applied to the plots by hand. Rice was grown to the 5-leaf stage before a permanent flood was established (5 to 10 cm depth) and maintained until physiological maturity. Throughout the season, the plots were scouted periodically for pests and were managed according to the Best Management Practices outlined by the University of Arkansas Cooperative Extension Service (Hardke, 2013).

RICE RESPONSE AND STATISTICAL ANALYSIS

The middle six to seven bordered rows of rice were harvested at physiological maturity with a small-plot combine, and grain yields were compared as kg rough rice ha^{-1} at the relative grain moisture of 120 g kg^{-1}. Sites were evaluated individually to account for factors such as cultivar, environment, planting and emergence date, and moisture. The N treatments (0 kg N ha^{-1}, N-STaR 95 and 100% 2-WS, N-STaR 95 and 100% SPF, and 202 kg N ha^{-1}) were arranged in a randomized complete block design, and yield was analyzed with a one-way ANOVA at the α = 0.05 probability level using the Fit Model platform in JMP Pro 12.0 (SAS Institute, Inc., Cary, NC). Individual means within each site were separated using *Tukey's* HSD for all pairs at α = 0.05 level.

RESULTS AND DISCUSSION

All 13 locations had N-STaR soil-N index values that were within the range reported in the correlation and calibration of N-STaR for rice on clay soils in Arkansas (Fulford, 2014). In this study, N-STaR soil-N index values ranged from 131.4 to 215.5 mg AH-N kg $soil^{-1}$ (Table 2.3) and large differences were observed between sites that were located within adjacent fields such as site 12 and 13. The large differences in N-STaR soil-N index values between neighboring fields accentuate the necessity to sample each field separately since factors that affect the native soil-N availability (tillage, cropping history, residue management, etc.) also influence the N-STaR results. The 100% RGY N rate recommendations ranged from 0 to 191 kg N ha^{-1} and 0 to 179 kg N ha^{-1} for the 2-WS and SPF management systems, respectively (Table 2.4). The N-STaR 95 and 100% RGY N rates for the SPF treatments were 22 kg N ha^{-1} less than their 2-WS N-STaR 95 and 100% RGY counterparts with the exceptions being site 12 where the N recommendations were 0 kg N ha^{-1} for all N-STaR N treatments and site 4 where the difference between the N-STaR 100% RGY 2-WS and the 100% RGY SPF was 34 kg N ha^{-1}. At site 4, the N-STaR 100% RGY 2-WS was 11 kg N ha^{-1} less than the SR. Due to the close proximity of the two N rates the SR and the N-STaR 100% RGY 2-WS treatments were combined under the SR N rate resulting in the 34 kg N ha^{-1} difference between the N-STaR 100% SPF and 2-WS N rates at site 4.

Overall, the N rate predictions for N-STaR were numerically lower than the SR. All 13 sites predicted N-STaR 95% RGY 2-WS and SPF N rates that were less than the SR of 202 kg N ha^{-1}. For the N-STaR 100% RGY 2-WS and SPF, all 13 sites predicted a lower N rate than the SR with only the N-STaR 100% 2-WS at site 4 predicted a near-equal N rate when compared to the SR.

RICE YIELD AS INFLUENCED BY NITROGEN RATE

This research was conducted to assess the ability of N-STaR in predicting the N needs for rice grown on clay soils and was similar to past research conducted by Roberts et al. (2013). The 13 sites were located across the primary rice producing areas of Arkansas on experiment stations and producer fields to examine N-STaR under various management practices and environmental conditions. Rice yield was variable across locations and treatments and ranged from 1929 to 12918 kg rough rice ha^{-1} as shown in Table 2.4.

In the event that other factors are not limiting, the yield of rice receiving no fertilizer-N is a good indicator of the native soil-N. Rice receiving no fertilizer-N produced grain yields that were statistically similar to or greater than the SR at four sites (sites 5, 6, 12, 13) and highlighted the potential for reducing fertilizer-N use when utilizing a soil-based N test (Table 2.5). Rice grown at sites 5, 6, and 12 showed no yield increase to added fertilizer-N, regardless of fertilizer-N rate. At site 13, rice that received no fertilizer-N produced a similar yield to rice fertilized with the SR but was significantly lower than rice receiving the N-STaR fertilizer-N rates (Table 2.4). Lodging greater than 50% was noted in the rice plots receiving the SR at site 12, and rice receiving no fertilizer-N yielded significantly higher than the SR. Overall, rough rice yield was maximized at 10 of the 13 sites when fertilizer-N was applied.

The rice yields for the N-STaR 95% RGY SPF treatments were statistically different from the SR at four of the 13 sites (3, 4, 9, and 12). Sites 3, 4, and 9 yielded statistically lower than the SR with yield differences between -2144 to -1162 kg rough rice ha^{-1}, and were located on the same research station (Table 2.5). In this case, the N-STaR 95% RGY SPF N rate may have been insufficient to overcome clay soil obstacles such as ammonium fixation and increased tortuosity thus resulting in N deficiency. At site 12, the N-STaR 95% RGY SPF recommended no fertilizer-N, and the unfertilized rice yielded significantly higher than the SR. A total of nine sites had no statistical yield differences between the N-STaR 95% RGY SPF and the SR (Table 2.5). The N-STaR 95% RGY SPF yielded numerically higher than the SR at only three of the nine sites that were statistically similar to the SR.

For the N-STaR 95% RGY 2-WS, there were a total of 12 site-years; site 7 did not receive a 2-WS treatment. Out of the 12 trials, sites 9 and 12 were statistically different from the SR (Table 2.4). At site 9, the N-STaR 95% 2-WS yielded significantly less than the SR with a decrease of 1875 kg rough rice ha^{-1}. Alternately, the N-STaR 95% 2-WS at site 12 recommended 0 kg N ha^{-1}, and the unfertilized rice yielded significantly higher than the SR. The N-STaR 95% RGY 2-WS yielded statistically similar to the SR for 10 of the 12 sites, and although yields varied between treatments, the average difference from the SR was -163 kg rough rice ha^{-1} (Table 2.5).

When comparing the N-STaR 95% RGY in a 2-WS versus a SPF application, the SPF was statistically different at site 4 and statistically similar at the remaining 11 sites that received the 2-WS rate (Table 2.4). The N-STaR 95% RGY SPF treatment at site 4 yielded significantly lower than the N-STaR 95% RGY 2-WS with a yield difference of -2207 kg rough rice ha^{-1}. At the 11 sites with no statistical differences between the N-STaR 95% RGY SPF and 2-WS treatments, the SPF treatments yielded an average difference of -191 kg rough rice ha^{-1} compared to its 2-WS counterpart (Table 2.5).

Yields obtained under the N-STaR 100% RGY SPF N rate ranged from 6207 to 12301 kg rough rice ha^{-1} while N rates varied between 0 and 179 kg N ha^{-1}. The N-STaR 100% RGY SPF yielded statistically similar to or greater than the SR for all 13 sites. Site 12 recommended 0 kg N ha^{-1} for the N-STaR 100% RGY SPF, and was the single site that yielded statistically greater than the SR. Twelve of the 13 sites recorded statistically similar yields between the N-STaR 100% RGY SPF and the SR, although the N-STaR 100% RGY SPF numerically out-yielded the SR at only four sites (Table 2.4).

The N-STaR 100% RGY 2-WS N rates ranged from 90 to 191 kg N ha^{-1}, and no sites had a N recommendation that was greater than the SR (Table 2.4). For all 13 sites, the N-STaR 100% RGY 2-WS yielded statistically similar to or greater than the SR. Site 12 was the single site where rice fertilized with the N-STaR 100% 2-WS N rate yielded significantly higher than the SR. In all, seven of the 13 sites yielded numerically equal to or higher than the SR when using the N-STaR 100% RGY 2-WS N recommendation (Table 2.4). This was in contrast to the N-STaR Validation for silt loam soils by Roberts et al. (2013) where the N-STaR 100% RGY rate applied as a 2-WS was statistically greater than the SR at four of the 14 sites, and all sites yielded numerically equal to or greater than the SR. A number of sites used in the N-STaR Validation for silt loam soils received a higher N-STaR fertilizer-N recommendation than the SR which could potential explain the numerically higher yields when using the N-STaR N recommendations on silt loam soils (Roberts et al., 2013). Also, silt loam soils have a lower capacity to buffer the applied fertilizer-N (Havlin et al., 2005). The negative effects of over-application of N (lodging, disease, etc) from the SR were exacerbated on silt loam soils leading to yield losses when using the SR at high native-N locations and resulted in statistically higher yields with the N-STaR N rate recommendations (T.L. Roberts, personal communication, 2016). For the validation of N-STaR N rates on clay soils, the average yield difference between the N-STaR 100% RGY 2-WS and the SR for sites that were statistically similar was -14 kg rough rice ha^{-1} and denoted the ability of the N-STaR 100% RGY 2-WS to achieve yields equal to the SR for rice on clay soils (Table 2.5).

The N-STaR 100% RGY SPF should produce yields that are equal to or greater than the N-STaR 100% RGY 2-WS with less total N fertilizer. In this study, all 13 of the sites had N-STaR 100% RGY SPF yields that were statistically similar to the N-STaR 100% RGY 2-WS with five of the N-STaR 100% RGY SPF treatments yielding numerically higher than or equal to the N-STaR 100% RGY 2-WS (Table 2.4). Overall, the N-STaR 100% RGY SPF average yield difference from the 2-WS counterpart was -135 kg rough rice ha^{-1} (Table 2.5). While the N-STaR 100% RGY SPF averaged a slight yield decrease compared to the N-STaR 100% RGY 2-WS, the N-STaR 100% RGY SPF produced near maximum yields with 22 kg N ha^{-1} less than the N-STaR 100% RGY 2-WS.

The N-STaR 100% RGY SPF N rate produced near maximum yields for all locations, and was statistically similar to the SR and N-STaR 100% RGY 2-WS (Table 2.5). On the other hand, the N-STaR 95% RGY SPF N rate accurately predicted the N requirement for rice at 10 of 13 test locations. The sites where significant yield losses did occur for the N-STaR 95% RGY SPF are cause for concern. Clay soils are known to require more N than silt loam soils in order to overcome ammonium fixation from 2:1 clays, adsorption by a greater cation exchange capacity, and a longer diffusion pathway to the plant roots (Norman et al., 2003). These factors may have played a role at sites where significant yield losses were realized for the N-STaR 95% RGY SPF N treatment. As a result, the N-STaR 95% RGY SPF adjustment may need to be decreased to overcome these additional deterrents inherent to clay soils in order to consistently obtain optimum yields.

When comparing the N-STaR 95 and 100% RGY 2-WS treatments, 11 of the 12 sites were not significantly different. Site 9 recorded the lone incidence where the N-STaR 95% RGY 2-WS yielded significantly lower than the N-STaR 100% RGY 2-WS. Out of the 11 sites that were statistically similar, only four of the N-STaR 95% RGY 2-WS yielded numerically higher than the 100% RGY 2-WS. However, the average yield difference between the N-STaR 95% RGY 2-WS and the 100% RGY 2-WS was relatively small at -195 kg rough rice ha^{-1} and portrayed the ability of the N-STaR 95% RGY 2-WS treatment to achieve near maximum yields at a lower N rate. Although the N-STaR 95% RGY 2-WS did not always return maximum yields, it may prove more economical as N prices increase. With the increased awareness of environmental pollution from agriculture, the 95% RGY 2-WS rate provides a management option that lowers the risk of N pollution by providing a site-specific fertilizer-N rate that is often lower than the SR without resulting in significant yield loss. This may become important in the event of regulations regarding fertilizer applications for rice cropping systems located in the Mississippi river watershed.

Site 12 was unique in that the N-STaR soil-N index value was extremely high at 215.5 mg AH-N kg^{-1} soil (Table 2.3) and provided a N recommendation of 0 kg N ha^{-1} across all N-STaR treatments which contrasted with the SR of 224 kg N ha^{-1}. Alternate N rates of 28, 50, 84, and 101 kg N ha^{-1} were added to verify the N-STaR fertilizer-N rate prediction and to assess the need for a lower N-STaR fertilizer-N rate limit (Table 2.4). The rice receiving no fertilizer-N obtained the highest yield at site 12 and was statistically higher than the SR at a magnitude of 3668 kg N ha^{-1} (Table 2.5). The yield decrease for the SR was a result of >50% lodging caused by the over fertilization of N. Disease and pest damage was not observed at site 12, although increased disease and pest pressure may also reduce yields when excessive fertilizer-N is applied. While the rice receiving no fertilizer-N was not significantly different from the alternate N treatments, the yields tended to decrease with increasing N, and provided evidence contrary to a lower N limit with the N-STaR N rate recommendations. However, site 12 had an extremely high N-STaR soil index value, and further research should be conducted to evaluate the potential need of a lower N limit on clay soils with moderately high N-STaR index values.

CONCLUSIONS

The purpose of N-STaR is to provide site-specific N recommendations that maximize yield. Overall, the N-STaR 95 and 100% RGY 2-WS calibration curves correctly predicted the N requirement of rice in Arkansas and reduced the fertilizer-N rate considerably while returning near maximal yields. The N-STaR 95 and 100% RGY calibration curves provide Arkansas producers the option to select the N rate that fits their N management philosophy. While the N-STaR 100% RGY 2-WS maximizes yield, the N-STaR 95% RGY 2-WS recommendation has the potential to maximize profits as N prices increase and/or policies are instituted that regulate fertilizer inputs. With regards to the SPF N management system, the N-STaR 95 and 100% RGY N applications responded differently with the N-STaR 100% RGY SPF producing maximum yields across all trials. A few of the N-STaR 95% RGY SPF trials resulted in yield losses suggesting that this treatment may need further evaluation to define the fertilizer-N rates for SPF on clay soils. However, the N-STaR 95% RGY SPF would provide the most efficient use of fertilizer-N and is recommended if fertilizer-N losses are minimized through proper water management. Overall this research indicates the ability of N-STaR to predict yield maximizing N rates for rice produced on clay soils in Arkansas and that often times yield potential can be maintained with a significant reduction in N fertilizer inputs.

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Table 2.1. Site characteristics for N-STaR clay soil validation trials in Arkansas during 2014 and 2015.

Site	Year	County	Soil Series	Soil Classification	Previous Crop	Location†
1	2014	Lonoke	Portland	very-fine, mixed, superactive, nonacid, thermic Vertic Epiaquepts	Rice	P
2	2014	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
3	2014	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean	ES
4	2014	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean	ES
5	2014	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
6	2014	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
7	2015	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
8	2015	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
9	2015	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean	ES
10	2015	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	ES
11	2015	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	ES
12	2015	Cross	Alligator	very-fine, smectitic, thermic Chromic Dystraquerts	Rice	P
13	2015	Cross	Alligator	very-fine, smectitic, thermic Chromic Dystraquerts	Rice	P

† ES, experiment station; P, production field.

Table 2.2. Selected soil chemical properties for the 0-15 cm depth at 13 N-STaR validation sites in Arkansas. All analyses represent the mean of four samples.

Site	pH¶	P†	K†	Zn†	AH-N§	Total N‡	Total C‡	Organic Matter‡
		--			$mg\ kg^{-1}$			--
1	7.4	7	353	2.1	167.4	1216	12521	44926
2	7.0	13	322	2.6	196.3	1347	15107	48068
3	7.3	44	241	4.0	155.8	1135	12307	31824
4	7.3	47	280	3.9	136.3	1113	10891	30326
5	7.3	17	366	2.2	204.4	1240	15478	49439
6	7.0	16	364	3.2	204.8	1244	12020	44590
7	6.9	13	390	1.7	188.7	1258	11896	44783
8	7.2	14	266	1.5	151.6	1197	10947	34600
9	7.4	43	351	3.4	160.7	1494	13858	32617
10	7.8	70	265	2.8	145	1051	10083	27108
11	7.8	70	265	2.8	145	1051	10083	27108
12	6.5	41	443	4.7	212.1	1211	13041	43074
13	6.9	29	410	5.3	167.2	1343	10935	35650

¶ 1:2 soil/water ratio.
† Mehlich-3 extraction.
§ AH-N, Alkaline hydrolyzable-N determined by direct steam distillation (Roberts et al., 2009).
‡ Determined by dry combustion technique (Nelson and Sommers, 1996).

Table 2.3. The alkaline hydrolyzable-N concentration at the 0-30 cm sampling depth. Means were determined from four soil samples at 13 locations in 2013 and 2014.

Site	Mean	SD†
	-------------mg kg^{-1}-----------	
1	148.2‡	14.5
2	177.4	15.8
3	149.5	6.5
4	131.4	12.8
5	175.9	39.2
6	176.5	24.8
7	170.3	12.1
8	140.2	15.6
9	154.7	11
10	135.5	12.7
11	215.5	16.1
12	152.9	21.6
13	148.2	14.5

† SD, standard deviation

‡ Alkaline hydrolyzable-N determined by direct steam distillation (Roberts et al., 2009).

Table 2.4. The standard recommendation (SR) and N-STaR N fertilizer rate recommendations and resultant rough rice yields for 13 small-plot validation studies conducted on clay soils in Arkansas during 2014 and 2015.

Treatment†	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield
	------kg ha^{-1}------									
	Site 1		Site 2		Site 3		Site 4		Site 5	
No N	0	6570 b	0	8724 b	0	1929 c	0	2043 c	0	7326 a
95% SPF	135	11550 a	62	9596 ab	112	4577 b	146	5725 b	62	8108 a
95% 2-WS	157	11954 a	84	10516 a	135	5536 ab	168	7931 a	84	7881 a
100% SPF	168	11840 a	95	10567 a	146	6207 a	168	7578 a	95	8335 a
100% 2-WS	191	12067 a	118	10680 a	168	6040 a	235‡	7906 a	118	8121 a
SR	224	12761 a	224	10869 a	202	6721 a	202	7616 a	224	7604 a
SE	399		422		451		375		332	
P value	<0.0001		0.0017		<0.0001		<0.0001		NS	
	Site 6		Site 7		Site 8		Site 9		Site 10	
No N	0	5624 a	0	6496 b	0	7492 b	0	3924 d	0	4473 b
95% SPF	56	6910 a	73	7880 ab	90	9030 a	106	8499 bc	146	8161 a
95% 2-WS	78	6456 a	146‡	8913 a	112	9371 a	129	7786 c	168	8534 a
100% SPF	90	6809 a	84	7738 ab	123	9215 a	140	9377 ab	179	8367 a
100% 2-WS	112	6368 a	106	8831 a	146	9833 a	163	8914 ab	202	8635 a
SR	224	6670 a	191	8767 a	191	9554 a	202	9661 a	224	8806 a
SE	435		490		389		308		672	
P value	NS		0.0012		0.0004		<0.0001		<0.0001	

† Treatment definitions: 95%, Nitrogen-Soil Test for Rice (N-STaR) 95% relative grain yield fertilizer-N rate; 100%, N-STaR 100% relative grain yield fertilizer-N rate; SPF, single preflood N application; 2-WS, 2-way split N application; SR, standard N recommendation.

‡ Treatments receiving alternate N rates not determined by the N-STaR recommendation: the 100% 2-WS at site 4 was similar to the SR, so a higher alternate rate was added to ensure N-STaR achieved maximum yield; the 95% 2-WS was not applied at site 7 and a middle range fertilizer-N rate was included; all N-STaR recommendations at site 12 recommended 0 kg N ha^{-1} and low increasing rates were substituted to find where yield was maximized.

Table 2.4. The standard recommendation (SR) and N-STaR N fertilizer rate recommendations and resultant rough rice yields for 13 small-plot validation studies conducted on clay soils in Arkansas during 2014 and 2015 (Cont.).

Treatment†	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield	N rate	Yield
	----------kg ha^{-1}----------									
	Site 11		Site 12		Site 13					
No N	0	5471 b	0	11163 a	0	8642 b				
95% SPF	146	11361 a	28‡	10702 a	106	10964 a				
95% 2-WS	168	12004 a	50‡	10332 a	129	10822 a				
100% SPF	179	12301 a	84‡	10819 a	140	10799 a				
100% 2-WS	202	12918 a	101‡	10069 a	163	10869 a				
SR	224	11885 a	224	7496 b	224	10148 ab				
SE	608		493		641					
P value	<0.0001		<0.0001		0.0179					

† Treatment definitions: 95%, Nitrogen-Soil Test for Rice (N-STaR) 95% relative grain yield fertilizer-N rate; 100%, N-STaR 100% relative grain yield fertilizer-N rate; SPF, single preflood application; 2-WS, 2-way split application; SR, standard recommendation.

‡ Treatments receiving alternate N rates not determined by the N-STaR recommendation: the 100% 2-WS at site 4 was similar to the SR, so a higher alternate rate was added to ensure N-STaR achieved maximum yield; the 95% 2-WS was not applied at site 7 and a middle range fertilizer-N rate was included; all N-STaR recommendations at site 12 recommended 0 kg N ha^{-1} and small increasing rates were substituted to find where yield was maximized.

Table 2.5. Summary of rice yield comparisons between the N-STaR N recommendations and the standard recommendation (SR) for small plot trials conducted in 2014 and 2015.

Comparison¶ A vs. B	A = B‡			A > B§			A < B§		
	Site-yr (Diff†)	Yield Diff	N rate Diff range	Site-yr (Diff)	Yield Diff	N rate Diff range	Site-yr (Diff)	Yield Diff	N rate Diff range
	no.	kg ha^{-1}	kg N ha^{-1}	no.	kg ha^{-1}	kg N ha^{-1}	no.	kg ha^{-1}	kg N ha^{-1}
No N vs. SR	3	-943	-224	1	3668	-224	9	-4385	-224 to -191
95% SPF vs. SR	9	-409	-168 to -78				3	-1732	-95 to -56
95% 2-WS vs. SR	10	-163	-146 to -34				1	-1875	-73
100% SPF vs. SR	12	-163	-135 to -34				-	-	-
100% 2-WS vs. SR	12	-14	-112 to 0				-	-	-
95% SPF vs. 100% SPF	11	-299	-34 to 0	-	-	-	2	-1742	-34 to -22
95% 2-WS vs. 100% 2-WS	11	-195	-34 to 0	-	-	-	1	-1128	-34
95% SPF vs. 95% 2-WS	11	-191	-22 to 0				1	-2207	-22
100% SPF vs. 100% 2-WS	13	-135	-34 to 0	-	-	-	-	-	-

¶ Treatments: SR, standard N recommendation; 95%, Nitrogen-Soil Test for Rice (N-STaR) 95% relative grain yield fertilizer-N rate; 100%, N-STaR 100% relative grain yield fertilizer-N rate; SPF, single preflood application; 2-WS, 2-way split application.
‡ No statistical differences at 0.05 level.
§ Statistical differences at the 0.05 level.
† Diff = difference A – B.

Appendix 2.1. Definition of abbreviations.

Abbreviation or Symbol	Explanation
AH-N	Alkaline hydrolyzable-nitrogen
i.d.	Inner diameter
K	Potassium
N	Nitrogen
N-STaR	Nitrogen-Soil Test for Rice
P	Phosphorus
RGY	Relative grain yield
SPF	Single preflood
SR	Standard N recommendation
Zn	Zinc
2-WS	2-way split

CHAPTER 3

Comparison of Soil Sampling Techniques for N-STaR on Clay Soils

ABSTRACT

The Nitrogen-Soil Test for Rice (*Oryza sativa* L.) (N-STaR) provides a site-specific nitrogen (N) rate recommendation for rice in Arkansas. The accuracy of the fertilizer-N recommendation is contingent on a soil sample representative of the field both horizontally and vertically through the soil profile to a depth of 30 cm for clay soils. A user-friendly sampling method for obtaining a representative N-STaR soil sample is needed, and this study was designed to evaluate the performance of several soil sampling techniques in obtaining the N-STaR sample when compared to the Dutch Auger (DA) used during the correlation and calibration phase. The alternative sampling techniques included a Kleen Hole Spade dry (KHS-D), a Kleen Hole Spade lubricated with water (KHS-W), a Kleen Hole Spade lubricated with WD-40 (KHS-40), and the N-STaR Bucket and Drill (BD). One soil sample was collected with each sampling technique from four blocks and was repeated across 14 locations. Each sample was analyzed for alkaline hydrolyzable-N (AH-N) using N-STaR and compared against the DA. Soil variability ranged from a coefficient of variation (CV) of 4.4% at site 3 to 22.3% at site 5. The AH-N at 13 of the 14 sites had no significant differences among sampling techniques. At site 14, the KHS-40 was statistically higher than the DA by 25 mg AH-N kg soil^{-1} and would correspond to a fertilizer-N rate difference of 49 kg N ha^{-1}. The KHS-D probe appears to have the greatest accuracy and precision compared to the DA, although the KHS-W, KHS-40, and the BD produce relatively similar results. However, all alternative techniques averaged a numerically higher AH-N value than the DA, therefore a correction factor may need to be considered to maintain the integrity of the N-STaR N rate recommendations when using an alternative sampling method.

INTRODUCTION

A recently developed soil-based N test called The Nitrogen-Soil Test for Rice, N-STaR, provides an index of potentially mineralizable-N that has been correlated and calibrated to rice yields in Arkansas (Roberts et al., 2011). The N-STaR procedure requires a sampling depth of 0-45 cm for silt loam soils and 0-30 cm for clay soils in order to provide correct N rate recommendations. During the development of N-STaR, soil samples were taken with a 5 cm inner diameter (i.d.) Dutch Auger (DA); however, this method is too time-consuming for widespread acceptance. The ideal sampling tool should provide a consistent, accurate sample core described as uncontaminated, reproducible, and uniform across depth (Cline, 1944; James and Wells, 1990). Furthermore, the tool must be user-friendly which is defined as easy to use, clean, and store (Peck and Melsted, 1967; James and Wells, 1990).

Few studies have been conducted that compare the accuracy and precision of different sampling tools to measureable soil characteristics such as nutrient content, soil moisture, organic matter, etc. Baker et al. (1989) observed the effects of sample volume on residual soil NO_3-N at the 30 cm sampling depth. Mixed results were seen with the smaller sample volume collected by a 1.9 cm i.d. soil sample probe recording lower precision on a no-till system and higher precision on a conventional till system compared to larger sample volumes collected by 3.2, 5.1, and 20.3 cm i.d. soil sampling tools. Furthermore, Baker et al. (1989) found that the smaller sampling volumes collected by the 1.9 and 3.2 cm soil probes tended to have a lower residual soil NO_3-N than the larger sampling volumes collected by the 5.1 and 20.3 cm soil augers. However, this volume effect may have been influenced by the fact that the 1.9 and 3.2 cm sampling tools were push probes while the 5.1 and 20.3 cm sampling tools were soil augers.

In a similar study, Hassen et al. (1983) examined the effect of sample volume on chloride (Cl) distribution in the soil profile and found that a 7.9 cm i.d. bucket auger had lower variation than a 2.1 cm i.d sampling tube with a coefficient of variation of 8.2% compared to 15.5%, respectively. They noted that the soil tended to compact below the 2.1 cm sampling tube causing the upper sample increment to mix with lower increments resulting in a smaller sampling volume and higher soil-Cl levels. Similar soil probe compaction has been reported by Cline (1944) and Blaylock and Bjornestad (1995).

Blaylock and Bjornestad (1995) examined the effect of probe lubricants on soil sample compaction and analysis. Although not statistically significant, the lubricated soil probes tended to decrease the compaction of the soil sample within the tube and also reduced overall sampling time by facilitating faster sample extraction from the soil probe tube.

Time is an additional factor to consider when soil sampling and is often related to the utility of the sampling tool. Stevens et al. (2002) compared four soil probes for clogging incidence and sampling time on silt loam and clay soils. The M&M model soil probe with the split-tube design recorded the longest sampling time on silt loam soils, but the shortest time on clay soils when compared with the other soil tube designs. This was attributed to a higher rate of clogging incidence for the straight tube design on clay soils where the sample tended to stick in the tube (Stevens et al., 2002).

The BD with a 2.54 cm i.d. ship auger bit was adopted to collect a soil sample to the 0-45 cm depth for silt loam soils (Roberts et al., 2012). The BD method has been used on clay soils, but clay soil presented difficulties in the sampling process that impeded its implementation such as clay sticking in the auger grooves. The accuracy of N-STaR initially depends on the collection of a representative sample which the BD purportedly achieves. However, the implementation of a more user-friendly tool would encourage the use and adoption of N-STaR for rice on clay soils in Arkansas.

The research objectives were to evaluate soil sampling tools and techniques in providing a uniform sample representative of the 0-30 cm sampling depth on clay soils and to assess the sampling tools for their respective ease of use and utility on clay soils.

MATERIALS AND METHODS

Sampling sites were located across major rice-producing regions of Arkansas and included Mississippi, Cross, Lonoke, and Desha counties. A total of 14 sites were sampled with five trials on experiment stations and 11 commercial production fields. The 14 sites comprised of Sharkey, Perry, Portland, Desha, and Alligator clays, and the soil series along with other site characteristics are shown in Table 3.1. Soil series information was obtained through the Web Soil Survey courtesy of the Natural Resources Conservation Service (Soil Survey Staff, 2015).

SAMPLING PROBES

Three sampling tools were utilized in this experiment; a 5 cm i.d. DA (AMS Inc., American Falls, Idaho), a 2.54 cm i.d. Kleen Hole Spade (KHS) (M&M Supply Co, Clear Lake, Iowa), and the BD with a 2.54 cm i.d. Ship Auger bit and extension (Grainger, Lake Forest, IL) as described in Roberts et al. (2012). The DA was used in the correlation and calibration of N-STaR for clay soils (Fulford, 2014) and was the control for comparison. The KHS was selected as an alternative tool that would be simple to use on clay soil. The KHS tool was marketed as fast, easy to clean, and functional in all soil textures (Anonymous, 2016). The BD has been used to take N-STaR soil samples on silt loam soils where it has been shown to collect an accurate soil sample depth (Roberts et al., 2012).

SOIL SAMPLING

Soil sampling was conducted in May and June before the clay rice fields were permanently flooded. All soil samples were taken when soil conditions coincided with the University of Arkansas Cooperative Extension Service Best Management Practices (Hardke, 2013). In the study, five soil sampling techniques were examined: 1) the DA, 2) KHS-D, 3) KHS-W, 4) KHS-40, and 5) BD. One soil sample was collected with each sampling method from four blocks for a total of 20 samples at each site (5 methods × 4 replications). In each block, soil samples were taken within 100 cm of each other in order to reduce soil variability since soil heterogeneity may be extensive even over short distances (Beckett and Webster, 1971; Cameron et al., 1971; Cipra et al., 1972; Sabbe and Marx 1987). For the DA, the 0-30 cm depth was taken in 15 cm increments to examine the fluctuation in AH-N across depth. The two DA sample depths were analyzed separately to obtain the N-STaR value and averaged for the statistical analysis. All KHS and BD samples were taken at the single depth of 0-30 cm. Before each sample, lubricant for the KHS probes—WD-40 or water—was applied liberally to the outside and inside of the sample tube. Probes were cleaned after soil samples were taken at each location to avoid site-to-site contamination. Each soil sample was placed in plastic sampling bags immediately after collection and uniquely labeled. Before N-STaR analysis, all soil samples were dried at a temperature of 40°C, ground, and passed through a 2 mm sieve (James and Wells, 1990).

SOIL SAMPLE ANALYSIS

Mehlich-III, total N, and total C analyses were conducted using soil from the top 15 cm of the DA sample to provide background soil information (Table 3.2). Soils were tested for AH-N using direct steam distillation procedures as outlined by Roberts et al. (2009). In summary, a 1 g subsample of soil was placed in a Kjeldahl flask with 10 mL of 10 mol L^{-1} NaOH. Steam distillation occurred at a rate of about 7 mL min^{-1} for 5 min, the distillate was collected in a boric acid (H_3BO_3) solution, and AH-N was quantified using acidimetric titration techniques.

Statistical Analysis

The study was analyzed as a randomized complete block design. Each site was analyzed separately, and blocks were set as random effects. The soil sample AH-N concentration for the sampling techniques were analyzed with JMP Pro 12.0 (SAS Institute, Inc., Cary, NC) in the JMP Model platform using a fit mixed analysis at the $P<0.05$ level. Individual mean comparisons were done using *Dunnet's* test with the DA as the control. Outliers were identified by a studentized residual greater than 2.5 or less than -2.5 and were removed from the analysis. Equal variances between treatments were tested by location using the *Brown-Forsyth* test. Heteroscedasticity occurred at site 6, however site 6 data was not transformed before further analysis since all other locations showed homoscedasticity. All data was normally distributed with the exception of site 3 due to an outlier. When the outlier was removed, site 3 showed a normal distribution. The accuracy of the alternative sampling methods were determined by similar AH-N concentrations to the DA control. The precision of the alternative sampling methods was determined by a low CV at the 14 locations. The AH-N values for the 0-15 cm and 15-30 cm depths collected by the DA were analyzed by location using a matched-pairs one-tailed *t*-test to determine whether the 0-15 cm depth had a greater AH-N concentration than the 15-30 cm depth.

RESULTS AND DISCUSSION

Spatial Variability

The DA was the sampling tool used in the correlation and calibration of N-STaR; therefore, the DA samples were used to estimate the AH-N means and variability at each site

(Table 3.3). For the 14 sites, the AH-N means ranged from 90 to 216 mg AH-N kg $soil^{-1}$ and the standard deviations ranged from 6.5 to 39.2 mg AH-N kg $soil^{-1}$. The CV ranged from 4.4% at site 3 to 22.3% at site 5 (Table 3.3). The average CV across the 14 sites was 10.3% and was smaller than the CV reported by Ruffo et al. (2005) when examining the variability of AH-N with the Illinois Soil Nitrogen Test on 12 fields in Illinois.

Analysis of Sampling Methods

In all, one of the 14 sites (site 14) had statistical differences among the BD, KHS-D, KHS-W, and KHS-40 compared to the DA (Table 3.4). At site 14, the KHS-40 was significantly greater than the DA at a magnitude of 25 mg AH-N kg $soil^{-1}$. The BD, KHS-D, and KHS-W were not significantly different than the DA, but the sampling techniques were all numerically greater than the DA at 12, 9, and 11 mg AH-N kg $soil^{-1}$, respectively (Table 3.4).

Sampling Method Accuracy and Precision

In regards to AH-N stratification in the soil, seven of 14 sites had a higher AH-N concentration in the 0-15 cm depth compared to the 15-30 cm depth (Table 3.5). Sites that did not have statistically different AH-N values between soil sample depths tended to show a greater numerical AH-N concentration in the 0-15 cm depth than the 15-30 cm depth (Table 3.5). Consequently, a shallow soil sample should yield an AH-N value that was greater than the DA. The set length of the KHS sampling tube limits soil sampling deeper than 0-30 cm, and samples that were greater than the DA AH-N values were expected due to soil compaction during sample collection. However, all sampling methods at sites 7 and 11 recorded a lower average AH-N value than the DA at a range of 7 to 22 and 6 to 16 mg AH-N kg $soil^{-1}$, respectfully. One potential explanation is the occurrence of human error in the DA sample through top soil contamination or collecting too shallow a sample depth. Soil variability may have factored into this phenomena but would not seem to be the primary cause since all alternative sampling methods followed the same trend. At sites 5 and 8, the KHS-D and KHS-40 had AH-N values that were numerically lower than the DA AH-N value while the BD and the KHS-W had numerically higher AH-N values than the DA. The soil variability at sites 5 and 8 was moderately high to high relative to other sites (Table 3.3). The site variability coupled with small differences between treatment means could explain why some of the alternative sampling method AH-N values were numerically lower than the DA. Sites 1, 9, 10, and 13 each had one sampling method with a numerical lower AH-N value than the DA, but the difference was approximately 1 mg AH-N kg soil^{-1} or less and was likely a result of soil variability.

A difference of 5.7 mg AH-N kg soil^{-1} equates to an 11 kg N ha^{-1} change in the N-STaR N fertilizer recommendation (Fulford, 2014). Therefore, the accuracy of the alternative sampling methods was described as the mean difference in AH-N from the DA and arranged as a relative frequency of occurrence within 5.7 mg AH-N kg soil^{-1} increments as seen in Table 3.6. A sampling tool that fell into a low mean difference range with a high degree of frequency would suggest greater accuracy. Collectively, 30% of the alternative sampling methods had an AH-N value that was less than the DA. Half of these occurrences can be ascribed to sites 7 and 11 where all the alternative sampling methods were numerically lower than the DA. From the 70% of alternative sampling methods with AH-N values numerically greater than the DA, the majority of differences occurred within the 0.0 to 5.7, 5.7 to 11.4, and the 11.4 to 17.1 mg AH-N kg soil^{-1} levels at 18, 25, and 20%, respectively. However, 4 and 5% of alternative sampling method differences were between 17.1 to 22.8 mg AH-N kg soil^{-1} and >22.8 mg AH-N kg soil^{-1}, respectively.

With the BD, 21% of sampling events had a difference from the DA that was ≤0.0 mg AH-N kg soil^{-1} (Table 3.6). This was followed by 14% of BD sampling events occurring within the 0.0 to 5.7 mg AH-N kg soil^{-1} level, 36% of sampling events in the 5.7 to 11.4 mg AH-N kg soil^{-1} level, and 21% of sampling events in the 11.4 to 17.1 mg AH-N kg soil^{-1} level. No events occurred in the 17.1 to 22.8 mg AH-N kg soil^{-1} level, but 7% of events occurred beyond the 22.8 mg AH-N kg soil^{-1} level. For the KHS-D, 41% of events had a difference from the DA that was ≤0.0 mg AH-N kg soil^{-1}. A total of 7, 21, and 28% of events occurred in the 0.0 to 5.7, 5.7 to 11.4, and 11.4 to 17.1 levels, respectively, and no events were recorded with a difference >17.1 mg AH-N kg soil^{-1}. The KHS-W recorded 21% of events ≤0.0 mg AH-N kg soil^{-1}, and 29, 21, and 14% in the 0.0 to 5.7, 5.7 to 11.4, and 11.4 to 17.1 levels, respectively. Furthermore the KHS-W had 7% of events in both the 17.1 to 22.8 mg AH-N kg soil^{-1} level and the >22.8 mg AH-N kg soil^{-1} level. The KHS-40 was similar to the KHS-W with 28% of events ≤0.0 mg AH-N kg soil^{-1}, and 21, 21, 14, 7, and 7% of events were in the 0.0 to 5.7, 5.7 to 11.4, 11.4 to 17.1, 17.1 to 22.8 and >22.8 mg AH-N kg soil^{-1} levels, respectively (Table 3.6).

The BD appeared to have the lowest accuracy when examined from a relative frequency of ≤5.7 mg AH-N kg soil^{-1} level (Table 3.6). However, all methods were similar in relative frequency at the ≤11.4 mg AH-N kg soil^{-1} level. Overall, the KHS-D appeared to have the highest accuracy of the alternative sampling methods due to a large frequency of events ≤0.0 mg AH-N kg soil^{-1} and no events >17.1 mg AH-N kg soil^{-1} when compared to the DA AH-N values. The BD, KHS-W, and KHS-40 sampling methods recorded AH-N values in the 17.1 to 22.8 or the >22.8 mg AH-N kg soil^{-1} levels which is a concern when using the N-STaR N rate recommendations. A method that returns an AH-N value of 17.1 mg AH-N kg soil^{-1} higher than the actual field average would recommend approximately 34 kg N ha^{-1} less than the N rate required to maximize rice yield. Such a large discrepancy in N-STaR N recommendation would be detrimental for producers and generate a lack of trust in the N-STaR N recommendations. Therefore, accuracy in the soil sampling method is a vital component to the continued success of N-STaR.

Precision was evaluated using the CV of the AH-N concentration for each sample method by site (Table 3.7). Contrary to previous studies (Hassan et al., 1983; Baker et al., 1989), the soil sample collected by the narrower 2.54 cm i.d. BD auger and KHS probes did not increase the AH-N variability in the samples compared to the 5 cm i.d. DA which would collect a larger soil sample volume. In this instance, the KHS-W had the lowest average CV at 8.9% compared with the DA at 10.3%. The KHS-40 recorded the highest variability possibly due to the collection of inconsistent sample cores as the lubricant often worked too well and samples tended to slip out of the probe upon extraction from the soil profile. Overall, the CV appeared similar for all sampling methods, but the KHS-W had the greatest consistency with only three sites reporting a CV over 10% (Table 3.7).

Mechanical Factors Affecting Precision, Accuracy, and Ease of Use

The observed moisture content of the soil varied among locations, however, no soil samples were taken on saturated soil conditions. Often, the clay soil would have a dry, cracking crust on the surface with moist conditions 2 to 3 cm below the surface.

With the DA, the 0-30 cm sample depth was taken in two 15 cm increments. In the process of removing the 0-15 cm increment, the hard crust of the top soil would fall into the hole and potentially contaminate the second sample similar to reports by Hassan et al. (1983) when using a bucket auger. The holes were cleaned by reinserting the DA and removing the loose soil. The tendency for soil to fall into the hole and contaminate the 15-30 cm sample depth may have contributed to the variability observed with the DA and to the instances where the AH-N values for the DA were higher compared to the alternative soil sampling methods. The DA was the most difficult tool to use in collecting clay soil samples. The major negative aspect was the time required to auger into the clay soil, hand remove the clay from the auger, and fit a large sample into the soil sampling box. On the other hand, cleaning the DA took relatively little time, and the tool was easy to carry while sampling and easy to store during periods of non-use.

The BD collected the same depth as the DA on silt loam soils and was expected to perform similarly on clay soils since compaction was not likely with the Ship Auger bit attachment (Roberts et al., 2012). Therefore, the BD was expected to perform similar to the DA in terms of accuracy and precision. Yet, the BD was not similar to the DA and often showed the lowest accuracy and precision when compared to the other sampling methods. Once past the dry soil crust, the moist clayey soil would fill the grooves of the auger bit and require hand removal. The 2.54 cm pipe in the center of the N-STaR bucket was meant to hold the Ship Auger bit vertical and assist in taking a uniform soil core. To avoid hand removal of the soil, the bit could be pressed against the top lip of the pipe as the drill was pushed downward which would cause the clay soil in the Ship auger bit to fall loose. The action of pressing the bit to the side of the pipe may have caused the bit to collect soil laterally from the upper portion of the sampling profile resulting in the decreased accuracy and precision of this method. Furthermore, the BD required the most time to clean due to clay coating the inside of the auger bit grooves. The bulkiness of the BD and the large number of component parts made it difficult to carry in the field and store during non-use and thus lowered its utility. The drill may also be a detrimental aspect for crop consultants who sample thousands of acres since it would require numerous spare batteries or a power generator.

The primary concern with the three KHS sampling methods was that the clay soil would compact below the tube and the shallow sample depth would lead to an erroneous N-STaR recommendation. Visual evidence of compaction was seen with the KHS probes in that the soil core was nearly always shorter than the 30 cm sampling tube. In severe cases, the sample cores were <15 cm in length. Soil compaction when sampling with push probes has been stated in previous reports (Cline, 1944; Hassan et al., 1983). The KHS probes also had difficulties with the soil cores slipping out of the tube when extracting the KHS probe from the soil. Both compaction and sample slippage in the tube resulted in a short soil core and prompted resampling in extreme cases. While all KHS methods had occurrences of compaction and sample slippage, the KHS-D appeared to have the least slippage which may have resulted in the greater accuracy of this method. The lubrication on the KHS-W and KHS-40 seemed to accentuate samples slipping out of the tube especially on soil where water content was near field capacity below the surface crust, although the lubricant visually appeared to lessen problems with compaction. Although Blaylock and Bjornestad (1995) did not report soil cores slipping out of the sampling probe when using lubricants, they did see a similar decrease in sample compaction within the tube.

Surprisingly, the KHS probes frequently outperformed the BD on accuracy and precision and may be a result of certain sampling tool characteristics. These characteristics for the KHS probe included a smaller diameter for the probe's cutting edge than the probe's tube which may have reduced friction between the soil and the tube sides. Also, the tube length measured at 31.75 cm, and may have mitigated the effects of compaction by sampling slightly deeper than 30 cm. The foot pedal on the KHS probes made it easy and fast to collect the soil sample, and the soil was simple to extract from the split-tube opening. This coincides with data from Stevens et al. (2002) who found the split-tube probe to be more time efficient than straight tube probes on clayey textured soils. One detriment to the split-tube was the tendency of the soil core to flip out of the tube when it was opened. This was a potential source of contamination as the core would collect top soil and debris. Cleaning the soil probe was quick, especially for the KHS-W and KHS-40 which required minimal effort due to the lubrication effect of water and WD-40. Overall, the KHS probe was the easiest alternative method to use, clean, and store.

SAMPLING METHOD RECOMMENDATION

Although not statistically different, all alternative sampling methods tended to have numerically greater AH-N values than the DA. It may be appropriate to include a correction factor between -11.4 to -5.7 mg AH-N kg^{-1} when using one of these alternative methods to ensure a sufficient N recommendation to achieve the desired yield goal. This may be especially important on soils with high N availability where the N rate is reduced significantly by using the N-STaR recommendation in place of the SR. Correction factors can vary by location due to the actual depth of soil collected and the distribution of AH-N down the soil profile, so a universal correction factor may be difficult to determine. The appropriate adjustment for these alternative sampling methods is an area for further research. The KHS-D was best suited as an alternative method for the DA when soil sampling for N-STaR because of its relatively high and consistent accuracy when compared to the other alternative sampling methods. The KHS-W and KHS-40 may be used to provide similar results, but care must be taken to avoid collecting samples where half of the core has slipped out of the tube. The BD may also be used to sample for N-STaR, but a correction factor is recommended since the BD was >5.7 mg AH-N kg $soil^{-1}$ compared to the DA at 64% of the locations (Table 3.6). The BD was previously thought to have high accuracy compared to the DA, and additional research is needed to discover why the BD performed poorly in this study and what part of the sampling process should be altered to ensure an accurate sample.

CONCLUSIONS

The N-STaR program has potential to transform the N recommendations for rice in Arkansas, yet an accurate, user-friendly soil sampling method is needed to encourage its adoption on clay soils. The KHS-D was the best alternative option to fill that need. However, a correction factor may be required to safeguard against insufficient N rate recommendations caused by shallow samples from soil compaction or sample slippage from the probe. The KHS-W, KHS-40, and BD all performed similar to the KHS-D and should provide comparable results. When subjectively ranked from the easiest to most difficult to use, the sampling methods were arranged as follows: KHS-40, KHS-W, KHS-D, BD, and DA. Although, any differences among the three KHS methods were of minor consequence. The ability to collect an N-STaR soil sample with a variety of tools allows for greater acceptance of this relatively new soil-N test and will encourage its use on clay soils in Arkansas.

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Table 3.1. Site characteristics for N-STaR clay soil validation trials in Arkansas during 2014 and 2015.

Site	County	Soil Series	Soil Classification	Previous Crop	Location†
1	Lonoke	Portland	very-fine, mixed, superactive, nonacid, thermic Vertic Epiaquepts	Rice	P
2	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
3	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean‡	ES
4	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean	ES
5	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
6	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
7	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
8	Lonoke	Perry	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	P
9	Mississippi	Sharkey	very-fine, smectitic, thermic Chromic Epiaquerts	Soybean	ES
10	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	ES
11	Desha	Sharkey/Desha	very-fine, smectitic, thermic Chromic Epiaquerts	Rice	ES
12	Cross	Alligator	very-fine, smectitic, thermic Chromic Dystraquerts	Rice	P
13	Cross	Alligator	very-fine, smectitic, thermic Chromic Dystraquerts	Rice	P
14	Cross	Alligator	very-fine, smectitic, thermic Chromic Dystraquerts	Soybean	P

† ES, experiment station; P, production field

‡ *Glycine max L.*

Table 3.2. Alkaline hydrolyzable-N (AH-N), total soil-N, total soil-C, and organic matter for the top 0-15 cm at 14 sites across Arkansas. All analyses represent the mean of four samples collected by the Dutch Auger.

Site	AH-N§	Total N‡	Total C‡	Organic Matter‡
	-----------------	--------mg kg^{-1}--------	-----------------	-----------------
1	167.4	1216	12521	44926
2	196.3	1347	15107	48068
3	155.8	1135	12307	31824
4	136.3	1113	10891	30326
5	204.4	1240	15478	49439
6	204.8	1244	12020	44590
7	188.7	1258	11896	44783
8	151.6	1197	10947	34600
9	160.7	1494	13858	32617
10	98	542	6902	23877
11	145	1051	10083	27108
12	212.1	1211	13041	43074
13	167.2	1343	10935	35650
14	166.9	935	12278	38908

¶ 1:2 soil/water ratio.
† Mehlich-3 extraction.
§ Alkaline hydrolyzable-N determined by direct steam distillation (Roberts et al., 2009).
‡ Determined by dry combustion technique (Nelson and Sommers, 1996).

Table 3.3. Alkaline hydrolyzable N concentration and variability for 14 soil sampling sites in 2014 and 2015. Mean, median, standard deviation (SD), and coefficient of variation (CV) were determined from four samples (*n*=4) taken by the Dutch Auger at the 0-30 cm depth within a 12 by 25 m plot.

Site	n	Mean	Median	SD	CV
		-----------------	mg kg^{-1}	-----------------	%
1	4	148†	148	14.5	9.8
2	4	177	177	15.8	8.9
3	4	150	149	6.5	4.4
4	4	131	131	12.8	9.7
5	4	176	178	39.2	22.3
6	4	177	177	24.8	14.0
7	4	170	172	12.1	7.1
8	4	140	140	15.6	11.2
9	4	155	155	11.0	7.1
10	4	90	90	10.3	11.5
11	4	136	134	12.7	9.4
12	4	216	214	16.1	7.5
13	4	153	155	21.6	14.1
14	4	148	149	10.5	7.1

† Alkaline hydrolyzable-N determined by direct steam distillation (Roberts et al., 2009).

Table 3.4. Statistical comparison of alkaline hydrolyzable-N concentration from soil samples collected by the Dutch Auger (DA), N-STaR Bucket and Drill (BD), Kleen Hole Spade dry (KHS-D), Kleen Hole Spade lubricated with water (KHS-W), and Kleen Hole Spade lubricated with WD-40 (KHS-40). Samples (*n*=4) were collected from a 0-30 cm depth.

Sampling Method	Site 1		Site 2		Site 3		Site 4		Site 5		Site 6		Site 7	
	Mean	SD†	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	mg kg^{-1}													
DA	148.2	14.5	177.4	15.8	149.5	6.5	131.4	12.8	175.9	39.2	176.5	24.8	170.3	12.1
BD	147.4	9.6	188.9	24.2	153.9	22.6	139.9	15.8	186.6	19.3	206.4	18.1	163.4	16.4
KHS-D	158.2	9.9	194.1	20.7	161.2	3.8	143.6	17.5	168.6	23.2	185.2	16	161.6	7.5
KHS-W	162.8	12	201.6	10.7	160.6	2.4	148.9	27.6	179.1	16.7	176.8	21.5	148.2	10.6
KHS-40	159.8	10.8	197.6	13.6	157.1	11.4	142.7	12.1	164.4	30.2	178.4	15.5	162.1	12.9
P value	NS‡		NS		NS		NS		NS		NS		NS	

Sampling Method	Site 8		Site 9		Site 10		Site 11		Site 12		Site 13		Site 14	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
	mg kg^{-1}													
DA	140.2	15.6	154.7	11	90	10.3	135.5	12.7	215.5	16.1	152.9	21.6	148.2 b§	10.5
BD	145.2	24.8	164.2	14.8	98.2	12.2	129.6	18.2	221	21.8	158.7	12	160.7 b	12.6
KHS-D	138.9	25.8	157.1	8.5	89.9	20.5	124.3	17.4	227.6	18.6	152.5	6.5	157 b	3
KHS-W	141.7	29.9	153.4	13.4	100.6	4.4	118.7	11.1	226.9	12.9	153.2	10.9	159.4 b	10.7
KHS-40	135.2	15	157.9	13	97.8	18.8	125.6	16.1	227.4	31.4	156	19.5	173.4 a	15.5
P value	NS		NS		NS		NS		NS		NS		0.042	

† SD, standard deviation.
‡ NS, not significant at the 0.05 probability level.
§ Individual comparisons were performed with *Dunnet's* test with the DA as the control.

Table 3.5. Differences in alkaline hydrolyzable N between the 0-15 and 15-30 sampling depths. Means were calculated from four soil samples using the Dutch Auger.

	Sample Depth				
	0-15 cm		15-30 cm		
Site	Mean	SD	Mean	SD	Student *t* ratio†
	mg kg-1				
1	167.4	24.3	128.9	11	3.18*
2	196.3	18.2	158.5	15.4	6.53**
3	155.8	10.7	143.2	12.8	1.29
4	136.3	7	126.6	20.4	1.17
5	204.4	53	147.5	27.1	3.69*
6	204.8	29.7	148.3	22.2	6.56**
7	188.7	16.1	151.8	13	4.5*
8	151.6	22.9	128.7	13	2.27
9	160.7	11.8	148.7	13.6	1.88
10	98	10	81.9	16.6	1.78
11	145	9.7	126	20.4	1.96
12	212.1	9.1	218.9	27.8	-0.52
13	167.2	30	138.6	14.1	3.14*
14	166.9	12.1	129.4	14.4	4.59**

† Statistical analysis performed using a matched-pairs one-tailed *t*-test.
* Significant at the 0.05 probability level.
** Significant at the 0.01 probability level.

Table 3.6. Accuracy of the N-STaR Bucket and Drill (BD), Kleen Hole Spade dry (KHS-D), Kleen Hole Spade lubricated with water (KHS-W), and Kleen Hole Spade lubricated with WD-40 (KHS-40) compared to the Dutch Auger using 14 sites in 2014 and 2015.

Range§	BD†	KHS-D†	KHS-W†	KHS-40†	All‡
mg kg^{-1}			--------%--------		
< -22.8	0	0	0	0	0
-22.8 – -17.1	0	0	14	0	4
-17.1 – -11.4	0	0	0	7	2
-11.4 – -5.7	14	21	0	14	13
-5.7 – 0.0	7	21	7	7	11
0.0 – 5.7	14	7	29	21	18
5.7 – 11.4	36	21	21	21	25
11.4 – 17.1	21	28	14	14	20
17.1 – 22.8	0	0	7	7	4
> 22.8	7	0	7	7	5

§ Range is subdivided into 5.7 mg alkaline hydrolyzable-N (AH-N) kg soil^{-1} levels.

† Values in each column represent the frequency of the mean difference between the alternative sampling methods and the DA (**$\bar{x}_x$-$\bar{x}_{DA}$**) that fall within each interval. A high frequency within intervals close to zero and a low frequency within intervals distant to zero would suggest a greater degree of accuracy.

‡ Averaged across all methods.

Table 3.7. The precision of five sampling techniques in sampling for alkaline hydrolyzable-N (AH-N) using the coefficient of variation (CV). The CV for the Dutch Auger (DA), N-STaR Bucket and Drill (BD), Kleen Hole Spade dry (KHS-D), Kleen Hole Spade lubricated with water (KHS-W), and Kleen Hole Spade lubricated with WD-40 (KHS-40) was determined from four soil sample cores (*n*=4) collected from the 0-30 cm depth at 14 locations across Arkansas.

Site	DA	BD	KHS-D	KHS-W	KHS-40	All†
	--------	--------	--------	%	--------	--------
1	9.8	6.5	6.3	7.4	6.8	7.4
2	8.9	12.8	10.7	5.3	6.9	8.9
3	4.4	3.4	2.4	1.5	7.3	3.8
4	9.7	11.3	12.2	18.5	8.5	12
5	22.3	10.3	13.8	9.3	18.4	14.8
6	14	8.8	8.7	12.2	8.7	10.5
7	7.1	10	4.6	7.2	7.9	7.4
8	11.2	17.1	18.6	21.1	11.1	15.8
9	7.1	9	5.4	8.8	8.2	7.7
10	11.5	12.4	22.8	4.4	19.3	14.1
11	9.4	14	14	9.4	12.9	11.9
12	7.5	9.9	8.2	5.7	13.8	9
13	14.1	7.6	4.2	7.1	12.5	9.1
14	7.1	7.8	1.9	6.7	9	6.5
All†	10.3	10.1	9.6	8.9	10.8	9.9

† CV averaged across sites or sampling methods.

Appendix 3.1. Definition of abbreviations.

Abbreviation or Symbol	Explanation
AH-N	Alkaline hydrolyzable-nitrogen
BD	N-STaR bucket and drill
CV	Coefficient of variation
DA	Dutch auger
i.d.	Inner diameter
KHS	Kleen Hole Spade
KHS-D	Kleen Hole Spade dry
KHS-W	Kleen Hole Spade lubricated with water
KHS-40	Kleen Hole Spade lubricated with WD40
N	Nitrogen
N-STaR	Nitrogen-Soil Test for Rice

CHAPTER 4

Conclusions

CONCLUSIONS

The purpose of this research was to ensure the accuracy of the Nitrogen Soil-Test for Rice (N-STaR) through proper validation of the N-fertilizer rate predictions and to evaluate sampling techniques that would encourage N-STaR soil sampling. A two-year validation was performed using small-plot trials on producer fields and experiment stations with a total of 13 site-years. The N-STaR 100% relative grain yield (RGY) N rate recommendation accurately predicted the site-specific N requirement at all locations under a single preflood (SPF) and a 2-way split (2-WS) N management system. The N-STaR 95% RGY N rate recommendations were accurate at 11 of 12 sites when applied as a 2-WS and 10 of 13 sites when applied as a SPF. The N-fertilizer rate recommendations predicted by N-STaR ranged from 224 to 11 kg N ha^{-1} less than the standard N recommendation and highlighted the economic and environmental benefits of N-STaR. A study of alternative soil sampling techniques for N-STaR was conducted jointly with the validation, and encompassed 14 locations over a two-year period. Overall, the N-STaR Bucket and Drill and all method variations of the Kleen Hole Spade were not significantly different in AH-N from the Dutch Auger (DA) control and could be used in sample collection. However, the tendency for numerically higher AH-N values for all alternative techniques compared to the DA may necessitate the inclusion of a correction factor when using the alternative methods to ensure accurate N-STaR N rate recommendations. Out of all techniques, the Kleen Hole Spade had the greatest utility and was the best alternative sampling tool when sampling for N-STaR.