Rice Nitrogen Management- Rates and Timing of Urea Fertilizer
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Managing nitrogen fertilization can be a challenge due to potential N losses from urea volatilization before flooding and denitrification after flooding. Extension recommendations for preflood N (PFN) rates in rice are usually based on empirical N field tests and adjustments are made for specific varieties, crop rotation, and soil texture. To help reduce rice N deficiency stress from early season N losses and supply N needs during grain-filling growth stages, midseason N (MSN) by aerial topdressing on rice can be applied near panicle differentiation (R1) growth stage. Measurements such as leaf area index, biomass accumulation, Y-leaf (most recently fully expanded leaf) N concentration, and whole-plant N concentration have been used to estimate midseason plant N sufficiency for determining whether topdressing is likely to increase rice yields.

Plant area measurements with a rice gauge have also been used to predict midseason N need. The rice gauge has two main components: (1) a vertical wooden board (1.5 inch wide X 40 inch tall) with centimeter digits for measuring plant height and (2) a height adjustable inverted trapezoid (15 inch across the top) with centimeter digits along the top edge for measuring canopy spread. The vertical board is positioned in the center of a rice drill row, and the trapezoid is slid to the top of the canopy. Then a person visually estimates the rice plant height and width at the sample location. These numbers are used in a formula to calculate plant area. Scientists in Arkansas found that plant area values from a rice gauge were a good estimator of rice dry matter and a more reliable estimator of total N accumulation than Y-leaf N concentrations and SPAD readings. Although use of the rice gauge for predicting rice need for midseason N has been widely promoted by state extension services in the upper Mississippi Delta region, very few rice consultants or farmers use it because of the labor required. Much of the rice in the Delta region is scouted by a single person walking across a field checking for disease, insect, weed, and nutrient problems. For monitoring rice plant midseason N status with a rice gauge, one person must carry a clip board and pencil to record numbers, slide and lock the trapezoid in place, prevent the vertical shaft from falling over in the mud while backing away to estimate height and width, and then move to another sample location in a field.

The objective of this study was to develop thresholds using visual and digital image measurements for predicting rice yield response to MSN applications at R1 growth stage. In 2004-2007, we conducted experiments to determine if plant area estimates based on plant height or numbers visible on a yardstick floating on floodwater between rice rows were reliable predictors of rice need for MSN applications. In 2005-2007, percent green pixels in digital images from rice plots recorded with a digital camera were evaluated as a predictor of rice need for MSN.

MATERIALS AND METHODS
Rice field experiments were conducted at Glennonville, Missouri on a Dewitt silt loam soil, and at Portageville, Missouri on a Sharkey clay soil. Plots were shifted to a new location each year to maintain a soybean-rice rotation. Rice plots were drill seeded (7.5 inch row spacing) with ‘Francis’ and ‘Cheniere’ varieties in 2004-2006. Cocodrie was substitute for Cheniere in 2007 because of a ban on Cheniere planting due to Liberty
Link genes being found in the seed supply. A split-plot design with four replications was used with rice varieties in main plots and N treatments in subplots. N treatments were urea N applied 0, 35, 70, 105 and 140 lb N acre$^{-1}$ before flooding at V4 to V5 growth stage with no additional N at midseason and the same PFI rates with MSN applied 30 lb N acre$^{-1}$ urea at R1 growth stage followed by 30 lb N acre$^{-1}$ urea again at R1 +7d. Each subplot was 12 feet wide by 25 feet long.

In this study, MSN rates of 30 lb N acre$^{-1}$ at R1 growth stage followed by 30 lb N acre$^{-1}$ one week later were used because this topdressing program has been the standard practice in the Delta region for many years. Recently, many rice farmers began making a single midseason application of 45 to 60 lb N acre$^{-1}$ to reduce aerial application costs. This system may change the magnitude of yield change from midseason N, but in-season diagnostic indicators predicting rice response to additional N will continue to be needed.

Clomazone herbicide (0.50 lb a.i. acre$^{-1}$) was applied premergence for weed control at each site. Quinclorac (0.30 lb a.i. acre$^{-1}$) and propanil (2.5 lb a.i. acre$^{-1}$) were applied postemergence before flooding grass and broadleaf control. In 2005 on the Dewitt silt loam, an infestation of duck salad developed after flooding and bensulfuron (0.05 lb a.i. acre$^{-1}$) was applied for control.

Plots were mechanically harvested with a combine and adjusted to 13% moisture. Rice yields for each pre-flood N rate subplot without midseason N were subtracted from yields in pre-flood N rate subplots with midseason N.

Three methods of measuring midseason plant area per plot were evaluated 1-2 d before R1 growth stage. For the first method, a yardstick was floated on floodwater between two center drill rows and the numbers visible were counted. Inch digits on the yardstick were approximately 2.0 mm tall. Standing between adjacent rows and leaning over the sampling rows, we counted the inch numbers showing on the yardstick (not hidden by rice leaves) out of 36 numbers possible (Figure 1). When a rice leaf obstructed the view of one digit in a two-digit number to the point that the whole number was not recognized, we did not count that number. For the second method, plant height was measured at the same sample location in each plot. One location per plot was sampled.

For the third method, digital images were collected 1 to 3 days before midseason N applications with a camera mounted on 5-ft rod held above the plot in 2005-2007. This method was not used in 2004. The camera was positioned level with the soil surface and recorded a plot area of 32 inches X 45 inch (Figure 2). A computer macro program developed at University of Arkansas was used with Sigma Scan™ Pro 5.0 image software to determine the percentage of green pixels in each photo. We defined green color in Sigma Scan as 52 to 110° hue on the color wheel and a saturation of 35 to 100%.

The statistical analyses of plant height, yardstick numbers showing, percent green pixels, and rice yield were performed using Proc Mixed from Statistical Analysis System. This procedure provided Type III $F$ values but did not provide mean square values for each source of variation within the analysis or the error terms. Mean separation was evaluated through a series of pair-wise contrasts among all treatments. Probability levels greater than 0.05 were categorized as non-significant. Excel™ 2000 spreadsheet software was used to graph and develop regression equations for yardstick number showing and percent green pixels relative to rice yield changes from midseason N.

In 2007, we also evaluated additive to urea and soil release N sources on rice at the Missouri Rice Research Farm and Delta Center Lee Farm. Treatments included four
preflood rates of urea applied with and without Agrotain, applications of ESN, ammonium nitrate, Scotts slow release N, calcium thiosulfate, and NutriSphere-N. Soil conditions were managed to promote volatilization by scheduling applications after a rain and 1 week before establishing a permanent flood.

RESULTS AND DISCUSSION

Although Francis variety rice plants grew taller and matured 3 to 5 days later than Cheniere, we found no consistent rice yield pattern indicating that one variety should be fertilized with more or less N than the other variety on a specific soil (Tables 1 and 2). However, rice varieties did not always respond the same to N treatments in different weather and soil environments. Only in 2 out of 12 cases (Francis, Sharkey clay, 2004; and Francis, Dewitt silt loam in 2006), did a variety with 105 lb N acre\(^{-1}\) PFN produce statistically lower yields than the same rice variety with 140 lb N acre\(^{-1}\) PFN. A significant yield response to N was not found on either soil in 2007 (Figure 3).

The wind conditions from the aftermath of Hurricane Katrina on August 30, 2005 at Portageville provided a unique opportunity to study the effect of MSN fertilization on rice lodging. Although applying MSN is an important management tool for relieving N-deficiency stress in rice, plants may be more likely to lodge. By chance, the rice drill rows in plots were planted east to west because of the field grade. Weather records indicate the wind gusts were strongest from 3 to 6 am CDT when wind was blowing straight from the east in the row direction. Rice plants prone to lodge fell towards the alleys rather than an adjoining plot on the right or left. We observed plots without midseason N that were completely standing from border to border. Often these plots were immediately adjoining plots with high PFN rates and MSN that sustained 60 to 80% lodging. One explanation for the high lodging in MSN plots is that midseason N fertilization may have produced plants with heavier panicles which is desirable for increasing grain yields but makes the plant top heavy and more likely to lodge in high winds.

Preflood Nitrogen

An important factor to consider before applying MSN is the amount of N that was applied preflood. The small plots in this study were managed with ideal cultural practices for minimizing N losses from urea volatilization. We were able to completely flood plots within 4 hr of applying preflood urea and maintained the flood for the rest of the season. Unfortunately, farmers may need several days to flood a field and they may be uncertain of how much PFN was lost due to N volatilization. Nevertheless, preflood N remains one of the best predictors of whether yield increases are likely to occur from MSN.

Regression analyses were performed after removing Sharkey clay 2005 yields from the dataset. This was done because of the problems with soil disturbance from land leveling and high winds at harvest. Solving for zero yield increase from MSN application (YLD=0), we found that 107 lb N acre\(^{-1}\) preflood was predicted to produce rice yields with no additional response to midseason N topdressing. This is 28% less N than the current University of Missouri total N recommendation to farmers for Francis and Cheniere varieties (150 lb N acre\(^{-1}\)), but is much closer than predictions with Sharkey clay 2005 results included in the analyses. On an actual rice farm in the Delta, more urea N may be required than our predictions to compensate for N losses from volatilization.
and denitrification. Since it is difficult to know how much N is lost in a given field, developing one or more in-season plant indicators for predicting N response to MSN is needed.

**Plant Measurements**

Although plant height is used as an input for estimating rice crop canopy with the rice gauge, we found little value for this measurement for predicting rice N status at midseason. Regression coefficients of determination for plant height and rice yield change from midseason N applications were very low.

Most modern rice varieties have been selected for vertical leaf orientation for the uppermost leaves. This change in leaf orientation improves light penetration into the canopy compared to the more horizontal leaf position of older varieties. Cheniere and Francis are high-yielding rice varieties bred to maximize photosynthesis using vertical leaf orientation. Yardstick numbers showing and percent green pixels in digital images are indicators of crop leaf canopy closure and can be influenced by leaf orientation. Yardstick numbers visible and % green pixels were significantly affected by preflood N rates but did not have a variety x preflood N interaction. This is important because it indicates that the systems might be used for N management with both Cheniere and Francis, and perhaps across other varieties with vertical leaf orientation, without major adjustments.

Plant area measurements were made with yardstick and digital image systems on the Dewitt silt loam in 2005 and 2006 and Sharkey clay in 2005 and 2006. We found that an inexpensive low-resolution digital camera (640 x 480 pixels) produced similar green pixel percentages as more expensive digital cameras. Also low resolution images from a cheap camera can be processed faster in Sigma Scan than large high resolution files. As expected, a strong coefficient of determination ($R^2=0.73$) was found between the two monitoring systems (Figure 4). The main difference between the systems is that yardstick numbers indicate the outward overlapping of rice leaves from rows into the center of row middles in contrast to the green pixel method which evaluates the entire rice leaf area including the rows.

An infestation of aquatic weeds developed after the permanent flood was established on the silt loam soil at Glennonville in 2005. Digital images on the loam site in 2005 were not useable and were excluded from Figure 5 because of small duck salad weeds growing between the drill rows after flooding. An application of bensulfuron killed the weeds but Sigma Scan software could not distinguish between green pixels produced by rice plants and green pixels from the slowly dying aquatic weeds at the water surface. Fortunately, the duck salad was small enough that the plants did not interfere with our ability to place the yardstick between rice rows and collect visual inch-number-showing data.

Yardstick number showing, used as an independent variable with regression analysis did not perform as well as PFN rate for predicting yield change from topdressed MSN application. The best fit equation correlating yield change from MSN with yardstick digits was a quadratic equation (Figure 6). Although MSN can help reduce deficiency, it is only a supplement to a good preflood N program. Rice rows with 30 to 35 yardstick numbers showing were severely deficient of N, and tillering was poor. Applying N at R1 growth stage on these plots was often too little N applied too late.
Using the regression equation for yardstick numbers in Table 4 with Sharkey clay 2005 data excluded, no yield response to MSN was produced when less than 13 inch numbers were showing. When the clay 2005 data were removed from the regression analysis because of the lodging problem, 64% pixels was the critical level for no yield response to MSN (YLD= -25.38 %PIXEL +1630.3, R²=0.418).

Costs for equipment, software, and labor will influence which plant N-monitoring system are used by rice farmers, crop consultants or scouts. Commercial cost for Sigma Scan Pro 5.0 image software is approximately $1375. A wooden yard stick can be purchased for less than $5. A yardstick is lighter to carry than a pole and camera across muddy rice fields. Also, when using digital photography, image file names and field names must be matched, images processed in a computer, and aquatic weeds can make results unusable. However, using aerial digital photography of whole fields combined with scouting for weeds would minimize some of these problems.

Tests evaluating nitrogen fertilizer additives did not show a significant benefit for increasing rice yields in 2007 (Figures 7 and 8).

SUMMARY

No significant yield increase was produced from MSN when 105 lb N acre⁻¹ was applied preflood with small plot water management. However, in large rice grower fields managing to reduce volatilization and denitrification losses is more difficult. Critical plant area thresholds values for R1 growth stage rice were developed using visual and digital image measurements for predicting rice yield response to MSN. No yield response was produced from MSN when fewer than 13 numbers were showing on a yardstick floating between drill rows or more than 64% of the pixels in digital images of plots were green. Information about this study and other crop production research at the Delta Center is posted at http://www.plantsci.missouri.edu/deltacrops.
## Table 1. Rice grain yields from Francis and Cheniere varieties grown on Dewitt silt loam and Sharkey clay with preflood and midseason N treatments in 2004-2006.

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†Within soils and years, rice yield values followed by the same letter were not significantly different at the 0.05 probability level.
Figure 2. Illustration of rice leaves blocking the overhead view of inch numbers on a yardstick floating in floodwater parallel and halfway between two rice 7.5-inch spaced drill rows. In this example, 2, 7, 11, 12, 16, 20, 25, 28, 31, 33, and 35 would not be counted as showing.

Figure 3. Example images (left to right- low PFN to high PFN,) collected at R1 growth stage with a digital camera from 32 inch X 45 inch areas in rice plots. Values in the lower left corner of photos were the proportion of green pixels in images.
Figure 1. No significant rice yield response to preflood or midseason N was found in 2007 on Dewitt silt loam or Sharkey clay soils.

Figure 4. Relationship between visible numbers showing on yardstick and percent green pixels in digital images measured at R1 growth stage before midseason nitrogen was applied in 2005 and 2006 on Francis and Chenihere varieties.
Figure 5. Rice yield response to midseason N applications relative to percentage of green pixels in digital images recorded at R1 stage from Francis and Cheniere varieties in 2005 and 2006 on Sharkey clay and 2006 on Dewitt silt loam soil.

\[ \text{YLD} = 1933.8 - 35.208 \% \text{PIXEL} \]

\[ R^2 = 0.4603 \]
Figure 6. Rice yield response to midseason N applications relative to visual number of numbers showing on yardstick at R1 growth stage from Francis and Cheniere varieties in 2005 and 2006 on Sharkey clay and 2006 on Dewitt silt loam soil.
Figure 7. Rice yield response on Sharkey clay to urea applied with and without Agrotain, or applications of ESN, ammonium nitrate, Scotts slow release N, and NutriSphere-N.

Figure 8. Rice yield response on Dewitt silt loam to urea applied with and without Agrotain, or applications of calcium thiosulfate, calcium thiosulfate with Agrotain, calcium thiosulfate with NutriSphere-N, and NutriSphere-N.