Vol. 24, No. 5 Research Report August 2009

Impact of Nitrogen Rate on the Performance of Three Rice Cultivars Seeded at Varying Densities

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Introduction

Rice grown under field conditions does not function as a homogeneous population of plants (Wu et al. 1998). Rather, it is comprised of a population of tillers formed at different times and having specific growth characteristics. The rice plant's ability to tiller is an important characteristic because tillering impacts panicle production (Miller et al. 1991), which is highly correlated with grain yield (Counce and Wells 1990; Miller et al. 1991; Gravois and Helms 1992). Miller et al. (1991) reported that rice grain yield in a continuously flooded, water-seeded cultural system was dependent on final tiller density, with rice grain yield increasing as final tiller density increased up to 65 tillers per square foot.

Plant population density is a principal factor affecting tiller production (Counce et al. 1992; Schnier et al. 1990), and the plant population density required to produce optimum rice grain yield is affected by cultivar and seeding rate (Gravois and Helms 1992). Counce (1987) reported optimum plant populations for non-semidwarf rice cultivars grown in a drill-seeded cultural system in Arkansas to be 12–15 plants per square foot. No significant rice grain yield losses occurred in that research with higher plant populations. Excessive plant population densities can lead to greater plant height and weaker culms, increasing the potential for losses due to lodging and disease (Dofing and Knight 1994).

Nitrogen (N) is one of the most yield-limiting nutrients in lowland rice production, and proper N management is essential for optimizing rice grain yields (Fageria et al. 1997). However, N fertilizer is one of the most expensive inputs for rice production, and N deficiencies are widely reported in lowland rice soils (Fageria and Baligar 1996; Kundu et al. 1996). Nitrogen recovery efficiency for lowland rice grown in the tropics is typically 30–50% of applied N (De Datta 1986; Fageria and Baligar 2001). Research in the southern United States examining the influence of application timings and N management strategies on N use efficiency reported N recovery of 17–61% of the applied N at rice maturity depending on N management strategy (Norman et al. 1989; Westcott et al. 1986).

Rice cultivars commonly grown in the United States require and respond to large amounts of N (Bollich et al. 1994; Norman et al. 2003; Wells and Johnston 1970). Nitrogen use efficiency in a delayed-flood, drill-seeded cultural system is optimized when N is applied in a single preflood application under optimum conditions and intensive management (Bollich et al. 1994; Norman et al. 1999). This single preflood application is made to a dry soil when rice

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is at the four- to five-leaf stage and before flood establishment (Bollich et al. 1994; Bollich et al. 1999; Wilson et al. 2001). Furthermore, the N fertilizer rate producing maximum grain yield also produced the highest head rice (whole milled rice) yield (Bond and Bollich 2007; Jongkaewwattana et al. 1993).

Extensive work has been conducted in the southern U.S. rice-growing region to examine the response of rice cultivars to seeding rates or nitrogen rates. However, few of these studies have examined the interaction between these two factors. One experiment examined a single semidwarf cultivar planted into a silt loam soil in Arkansas in 1972 and 1973 (Wells and Faw 1978). A second report compared semidwarf and conventional-height cultivars grown on a clay soil in Arkansas from 1983 to 1985 (Counce et al. 1992). Cultivars examined in previous research have all been replaced with more vigorous, high-yielding cultivars. Therefore, the objective of our research was to characterize the relationship between rice seeding rate and N rate utilizing three long-grain rice cultivars currently in cultivation in Mississippi.

Materials and Methods

An experiment to evaluate the response of three rice cultivars to different seeding rates and N fertilizer rates was conducted in 2005 and 2006 at the Mississippi State University Delta Research and Extension Center in Stoneville, Mississippi. Soil at Stoneville was a Sharkey clay (very-fine, smectitic, thermic Chromic Epiaquerts) with a pH of 8.2 and 2.1% organic matter. Plots were drill-seeded on April 20, 2005, and May 10, 2006. Rice was grown in an upland condition until the five-leaf growth stage, at which time preflood N rates were broadcasted onto dry soil within 2 days before flood establishment. Standard agronomic and pest management practices were used during the growing season according to state recommendations (Miller and Street 1999). At maturity, plots were drained approximately 2 weeks before harvest. Rice was harvested with a small-plot combine at a moisture content of approximately 20%.

Treatments were arranged in a randomized complete block with a factorial arrangement of three rice cultivars, four seeding rates, and three preflood N application rates with four replications. Cultivars were semidwarf 'Cheniere' and 'CL131' and conventional-height 'Wells.' Each cultivar was seeded at 7.5, 15, 30, and 60 seeds per square foot. N rates of 60, 120, and 180 pounds per acre as urea were applied within 2 days before flood establishment. All experiments were drill-seeded with a small-plot grain drill equipped with double-disk openers and press wheels with 8 inches between each row. Individual plots consisted of seven rows measuring 15 feet in length.

The number of seedlings per square foot was measured 10–14 days after seedling emergence by counting the main stems in the center two rows from an area 8 feet in length in each plot. When rice grain reached approximately 20% moisture content for each cultivar and treatment, a randomly selected area of 11 square feet from each plot was hand-harvested to determine yield components (panicle density, filled grains per panicle, and 1,000-grain weight) and head rice yield. The remaining area in each plot was harvested with a small-plot combine to determine rough rice yield after all yield component and head rice yield subsamples had been collected. Rough rice yield was adjusted to 12% moisture content. The total number of panicles in each hand-harvested sample was counted to determine panicle number per square foot (panicle density). Ten rice panicles were then randomly selected from each hand-harvested sample and threshed. The number of filled grains was counted to determine the average number of filled grains per panicle for each treatment. The remaining portion of the hand-harvested samples was then threshed with a plot thresher, combined with grain from the l0-panicle subsamples, and dried to approximately 12% moisture content. Five 1,000-grain subsamples were then weighed to determine 1,000-grain weight. Head rice yield was estimated using the procedure outlined by Adair et al. (1972).

All data were subjected to ANOVA (SAS 2003) with year being used as a random-effect parameter testing all interactions of cultivar, seeding rate, and N rate. Years, replications (nested within years), and all interactions containing these effects were considered random effects; all other factors (cultivar, seeding rate, and N rate) were fixed effects. Least-square means were calculated, and mean separation ($P \leq 0.05$) was produced using PDMIX800 in SAS, which is a macro for converting mean separation output to letter groupings (Saxton 1998).

Results and Discussion

Seedling Density

Seedling density was influenced by a main effect of seeding rate (Table 1). Seedling density increased with seeding rate up to 22 seedlings per square foot at a seeding rate of 60 seeds per square foot (Table 2). Counce (1987) reported optimum plant populations for non-semidwarf rice cultivars to be 12–15 plants per square foot. Bond et al. (2005) reported seedling densities of 15–20 plants per square foot after a seeding rate of 30 seeds per square foot when rice was seeded in a silt loam soil under stale seedbed conditions. In this research, plant densities within the range suggested by Counce (1987) were attained after a seeding rate of 30 seeds per square foot. Wells and Cheniere were included in the research of Bond et al. (2005), and they reported seedling densities for Cheniere and Wells to be 16 and 18 seedlings per square foot, respectively, when seeding rate was 30 seeds per square foot. However, the work of Bond et al. (2005) was conducted on silt loam soil under stale seedbed conditions. This research was done on Sharkey clay soil under conventional tillage. Differences in soil texture and tillage system may explain the apparently conflicting results.

Rough Rice Yield

The main effect of cultivar and all interactions containing cultivar were not significant for rough rice yield at $p = 0.05$ (Table 1). The main effects of rice seeding rate and N rate were significant for rough rice yield (Table 1). Pooled across cultivar and N rate, rough rice yield was greatest when a minimum of 30 seeds per square foot was planted (Table 2). When pooled across cultivar and seeding rate, rough rice yield increased with N rate up to 7,370 pounds per acre at 180 pounds of N per acre (Table 3).

These data suggest that currently grown cultivars have a seeding rate response similar to that seen in older cultivars evaluated in conventional tillage and/or water-seeded systems (Counce 1987; Jones and Snyder 1987; Miller et al. 1991). Yield data presented here show the ability of rice to overcome low plant densities and produce satisfactory yield (Wells and Faw 1978; Counce and Wells 1990; Gravois and Helms 1992; Wu et al. 1998).

In previous research, Norman et al. (1999) found that short-stature and semidwarf cultivars are more responsive to N than older, conventional-height cultivars and generally require 120–180 pounds of N per acre for maximum grain yield. Results of our research also confirm this to be true for CL131, Cheniere, and Wells.

Head Rice Yield

The main effect of rice seeding rate and a cultivar-by-N rate interaction were significant for head rice yield (Table 1). Pooled across cultivar and N rate, head rice yield decreased when the seeding rate was increased from 15 to 60 seeds per square foot (Table 2). Gravois and Helms (1996) reported that head rice response to seeding rate should be assessed on a cultivar basis. Data from our research indicate that head rice yield varies with seeding rate regardless of cultivar.

Table 1. Significance (p value) of the main effects of cultivar (cv), seeding rate (sr), and N rate (nr) and interactions among the main effects pooled across years.

Effect	Density	Rough rice yield	Head rice yield	Panicle density	Filled grain	Grain weight
cv	0.4431	0.1273	0.1079	0.0938	0.0173	0.0459
sr	0.0102	0.0155	0.0143	0.0001	0.0238	0.0439
nr	0.9722	0.0033	0.1151	0.1157	0.0982	0.0962
cv*sr	0.2653	0.3219	0.1533	0.3954	0.6252	0.4967
cv*nr	0.3506	0.5934	0.0071	0.8465	0.9356	0.9736
sr*nr	0.8619	0.3702	0.3670	0.1508	0.9885	0.3578
cv*sr*nr	0.9958	0.6416	0.1808	0.0964	0.9633	0.7327

Table 2. Effect of seeding rate on rice yield and yield components in Mississippi in 2005 and 2006.[1]

Target seeding rate	Seedling density	Rough rice yield	Head rice yield	Panicle density	Filled grain	Grain weight
seeds/ft²	*seedlings/ft²*	*lb/A*	*%*	*panicles/ft²*	*no./panicle*	*g/1,000 seed*
7.5	3 c	5,550 c	50 a	24 d	128 a	22 b
15	5 c	6,140 b	49 ab	28 c	114 ab	23 ab
30	13 b	6,700 a	47 bc	33 b	107 bc	24 a
60	22 a	6,730 a	46 c	39 a	97 c	24 a

[1]Data pooled over cultivar and N rate. Means followed by same letter for each parameter are not significantly different at $p \leq 0.05$.

Table 3. Effect of N rate on rough rice yield in Mississippi in 2005 and 2006.[1]

N rate	Rough rice yield
lb/A	*lb/A*
60	5,020 c
120	6,470 b
180	7,370 a

[1]Data pooled over cultivar and seeding rate. Means followed by same letter are not significantly different at $p \leq 0.05$.

Pooled across seeding rate, head rice yield of Cheniere and Wells increased when the N rate was increased from 60 to 180 pounds per acre. Only 120 pounds of N was required to improve head rice yield of CL131 over that observed after application of 60 pounds (Table 4). However, regardless of cultivar, head rice yield was optimized after 120 pounds of N. Head rice yield of Cheniere was 11–19% greater than CL131 and 23–24% greater than Wells at N levels of 60 and 120 pounds per acre. However, at 180 pounds, CL131 and Cheniere produced similar head rice yields, which were both greater than that of Wells. Jongkaewwattana et al. (1993) reported that head rice yield was highest after the N rate producing maximum grain yield. Rough rice yield in our study increased with N rate up to 180 pounds per acre (Table 3), regardless of cultivar. Head rice yield of CL131, Cheniere, and Wells did not increase with N rates higher than 120 pounds (Table 4).

Average milling yields for Cheniere were within the range reported by Linscombe et al. (2006); however, the whole milled rice percentages for Wells reported by Moldenhauer (2001) were approximately 10% greater than what was measured in this study. Based on Moldenhauer (2001) and Linscombe (2006), the genetic potential for whole milled rice for Cheniere and Wells are very similar. Grain weights for Cheniere and Wells are also similar (Linscombe et al. 2006; Moldenhauer 2001; Kanter et al. 2006); however, Wells produces a longer, narrower grain compared with Cheniere's shorter, wider grain (Linscombe et al. 2006; Moldenhauer 2001). Fissuring in rice grain is caused by absorption of water into the endosperm of kernels, which produces stress fractures in the grain before harvest. During the milling process, fissuring can reduce head rice yield by increasing the proportion of broken kernels. It can be implied from these data that greater fissuring could have been caused in Wells because of the grain shape.

Yield Components

Panicle density, filled grains per panicle, and grain weight were influenced by the main effect of seeding rate (Table 1). Pooled across cultivar and N rate, panicle density increased with seeding rate up to 39 panicles per square foot at a seeding rate of 60 seeds per square foot, but filled grains per panicle and grain weight were highest at a seeding rate of 15 seeds per square foot (Table 2). Yield compensation between panicle density and filled grains per panicle may explain the effect of seeding rate on filled grains per panicle. Other researchers have reported similar trends in panicle density and filled grains per panicle (Gravois and Helms 1992; Jones and Snyder 1987; Wells and Faw 1978). Panicle density had the highest effect on rice grain yield, even at low seeding rates where filled grains per panicle increased to compensate for decreased panicle density (Gravois and Helms 1992). The relationship between panicle density and filled grains per panicle may explain the rough rice yield response to seeding rate (Table 2). Although panicle density increased up to the highest seeding rate, filled grains per panicle and rough rice yield reached their maximum at seeding rates 15 and 30 seeds per square foot, respectively.

The main effect of cultivar was significant for filled grains per panicle and grain weight (Table 1). Cheniere produced 31% and 49% more filled grains per panicle than CL131 and Wells, respectively, regardless of seeding or N rate (Table 5). Although Cheniere produced 49% more filled grain per panicle than Wells, grain weight for Wells was higher than that for Cheniere or CL131 (Table 5).

Table 4. Effect of cultivar and N rate on head rice yield in Mississippi in 2005 and 2006.[1]

N rate	CL131	Cheniere	Wells
lb/A	%	%	%
60	36 ef	55 bcd	31 f
120	49 cd	60 ab	37 ef
180	56 abc	62 a	45 de

[1]Data pooled over seeding rate. Means followed by same letter are not significantly different at $p \leq 0.05$.

Table 5. Effect of cultivar on filled grains and grain weight in Mississippi in 2005 and 2006.[1]

Cultivar	Filled grain	Grain weight
	no./panicle	*g/1,000*
Cheniere	137 a	22 b
CL131	92 b	23 b
Wells	105 b	25 a

[1]Data pooled over seeding rate and N rate. Means followed by same letter for each parameter are not significantly different at $p \leq 0.05$.

CONCLUSIONS

The objective of this research was to determine the relationship between rice seeding rate and N rate for different long-grain rice cultivars seeded in a clay soil. Research conducted in the 1970s and 1980s in Arkansas showed that more N was required at lower rice seeding rates. Wells and Faw (1978) reported no differences in rice grain yields among seeding rates of 6, 12, and 28 seeds per square foot at low N levels (60 pounds per acre), but lower seeding rates produced significantly higher rice grain yields at high N levels (180 pounds per acre). Under high N fertility, the negative impact of excessive vegetative growth before anthesis limited rice grain yields under dense populations. Counce et al. (1992) observed that 30–60 pounds per acre more N was required to achieve maximum rice grain yields with very low rice plant populations than with adequate rice plant populations. Our research indicates that seedling density, rice yield, and rice yield components are functions of seeding rate. Furthermore, rough rice yield and head rice yield (dependent on cultivar) were influenced by N rate. However, in contrast to the results of Wells and Faw (1978) and Counce et al. (1992), no interaction between seeding rate and N rate was detected in our research, although seeding rate and N rate individually influenced the parameters studied. Our results do agree with those of Mariot et al. (2003) in that they also reported that rice grain yields responded to N fertilization independent of seeding rate.

The differences in agronomic characteristics and yield potential between cultivars in our research and those used in earlier research are the most likely explanation for the different seeding rate and N rate responses. Relative to seeding rate, panicle density in our research increased with seeding rate up to 60 seeds per square foot; however, grain yield did not increase when seeding rate was increased beyond 30 seeds per square foot. The grain yield plateau could be attributed to the fact that filled grains per panicle was greatest at 15 seeds per square foot.

Cultivars tested in this research were semidwarf or stiff-strawed, conventional-height cultivars with high yield potential. These newer cultivars respond differently to inputs than older cultivars. Grain yield of CL131, Cheniere, and Wells responded to seeding rates and N rates independently when planted into clay soils, and producers should employ seeding and N rates that maximize yield potential.

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