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Effect of Nitrogen and Harvest Grain Moisture on Head Rice Yield

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ABSTRACT

In rice (*Oryza sativa* L.) production, both grain yield and milling quality play an important role in determining the grower's income. Nitrogen input is essential in maintaining a desirable yield, but its effect on rice milling quality is less clear. This study examined optimal N input for rice milling quality and the combined effect of N and grain moisture at harvest on both grain yield and head rice yield. Experiments were conducted in California at the Rice Experiment Station, Butte County, on three cultivars (S201, M201, and L202) during the 1987 and 1988 growing seasons to determine the effects and optimum levels of N and grain moisture at harvest on milling quality. Results showed that the optimal harvest grain moisture to produce the maximum head rice yield depended on the levels of N applied and ranged between 220 and 270 g kg^{-1} for S201, 210 to 270 g kg^{-1} for M201, and 200 to 250 g kg^{-1} for L202. The optimal N level for maximum head rice yield was 125 kg ha^{-1} for S201, 112 kg ha^{-1} for M201, and 130 kg ha^{-1} for L202. These optimum N rates fell within the lower half region of the required N for 0.95 confidence of producing the maximum grain yield. Thus, optimum N inputs for head rice yields are also likely to produce maximum grain yields for the cultivars studied. These findings will greatly simplify the management requirement on N application for California rice farming.

SELECTION of the most appropriate rate of N fertilization is a major concern affecting both economic viability of the crop production and the impact of agriculture on the environment. Traditionally, the optimum rate of N fertilization has been the rate that results in maximum economic yield.

In rice production, however, both grain yield and milling quality, expressed in terms of head rice (whole milled grain), play an important role in determining the grower's income. This is because the market value of rice is based on head rice recovered from each unit of rough rice or paddy.

Many factors influence rice milling quality. These include (i) plant factors, such as genotypic (Juliano, 1972) and grain characteristics (Khush et al., 1979); (ii) postharvest factors, such as drying methods (Wright and Warnock, 1983), milling systems (Camacho et al., 1978; Dilday, 1989; Esmay et al., 1979), and rice processing (parboiling) (De Datta, 1981); and (iii) cultural practices, such as grain moisture content at harvest (Berrio and Cuevas-Perez, 1989; Calderwood et al., 1980; Counce et al., 1990; Geng et al., 1984) and N applications (Kunze et al., 1988; Jongkaewwattana and Geng, 1991). Published results on the effect of N on rice milling quality have not been consistent. Rhind (1962) reported that N adversely affected head rice yield, but Kester (1959) and Schroeder and Evatt (1963) reported that N had no effect on rice milling quality. In a later study, Fagade and Ojo (1977) reported that N applied at 75 kg ha^{-1} improved head rice of the cultivar IR8 by 7% when compared with the nonfertilized treatment. Nangju and De Datta (1970) showed that increasing N fertilization up to 120 kg ha^{-1} increased head rice yield of one of the chalky cultivars.

In a recent study, Jongkaewwattana and Geng (1991) found that late drainage tends to increase head rice recovery, and the impact on rice milling quality is increased with an increased rate of N application. Thus, there is an interaction effect of the N application and the grain moisture content on rice milling quality. This interaction effect may have contributed to the conflicting results reported in previous studies.

Rice growers worldwide prefer growing nonchalky and N-responsive cultivars; thus, it is important to obtain unambiguous information on the response of rice milling quality of these cultivars to N fertilization at variable harvest times. This information can be used to determine the optimal rate of N fertilization for grain yield and head rice yield.

Our objectives were to (i) determine the effect of N on rice milling quality of cultivars of differing grain types and (ii) estimate optimal ranges of N fertilization for producing both maximum grain yield and maximum head rice yield.

MATERIALS AND METHODS

Field Experiments

Field studies were conducted during the 1987 and 1988 growing seasons at the Rice Experiment Station, Butte County, California (39° 26′ N, 121° 49′ W). Three nonchalky early-maturing cultivars (S201, M201, and L202, representing short, medium, and long grain types, respectively) were planted in a split-plot design with four replications, with N as the main plot and cultivars as subplots. Nine equally spaced levels of N were incorporated as $(NH_4)_2SO_4$ in the 1987 experiment (from 0 to 224 kg ha^{-1}) and eight levels in the 1988 experiment (from 0 to 235 kg ha^{-1}) prior to flooding.

Seed was sown in 3.05- by 6.10-m plots on 18 May in 1987 and 3.05- by 8.24-m plots on 25 May in 1988. In each plot, an area 1.52 by 3.05 m at the perimeter was marked and reserved for hand-harvested milling samples.

Sampling Procedures

Panicle samples from 0.75 m^2 and 10 individual panicles (for moisture testing) were hand-harvested weekly from the reserved area, beginning at ≈300 g kg^{-1} grain moisture. The first samples were collected in the second week of September for both years. Grain moisture was determined immediately after each harvest from the 10 extra panicle samples, using an oven-dried method. Panicle samples from the 0.75-m^2 sampling area were threshed and cleaned (separating leaves, stem, and other foreign materials from rough rice grains). Clean rough rice was dried at room temperature to ≈140 g kg^{-1} moisture, and a 125-g sample was dehulled in a McGill sample sheller. Brown rice samples were weighed, and percent hull was calculated. Brown rice samples were subsequently milled in a McGill No. 2 miller (Rapsilver Supply, Brookshire, TX). Milled rice samples were weighed and separated into head rice and broken rice by different sieve sizes in an automated sizing device. Weight of head rice samples was obtained, and percent head rice and total milled rice were calculated. The final harvest was conducted on 20 October in 1987 and 15 October in 1988. Grain yields were obtained.

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Data Analysis

Analysis of variance procedures were applied for the analysis of data obtained on each cultivar. Moisture curves were fitted to the head rice yield data for each of the N levels when N × harvest date interaction was determined significant ($P < 0.05$) in the analysis. In this case, a second-degree regression model was used,

$$Y = a + bX + cX^2 ,$$

where Y represents the percent head rice, a, b, and c are the regression coefficients, and X is the grain moisture at harvest. The maximum percent head rice and the corresponding optimal grain moisture at each N level were then estimated from the moisture response curve. The estimated maximum percentages of head rice were used to determine the N effect on the head rice yield. The N effect was evaluated from a fitted linear-plateau model (Anderson and Nelson, 1975), and the optimum N level was calculated from the model and defined as the lowest N level to produce the maximum percent head rice. Regression models were also used to estimate the optimal yields of the cultivars.

RESULTS AND DISCUSSION

Results of the overall analysis of variance showed a significant N × harvest date interaction ($P < 0.05$) for all cultivars. Because of the interaction, regression models were used to estimate the moisture and the N effects. The regression models were fitted better for data of higher N levels. The R^2 values ranged between 0.96 to 0.99 for the highest levels of N, but ranged between 0.26 to 0.71 for the control levels (0 N). The moisture response curves for the extreme N levels and a middle level are shown in Fig. 1. Similar results were also reported by Nangju and De Datta (1970). The quadratic curve is a reasonable description of the relationship between harvesting moisture and head rice yield, because grain moisture is directly related to the maturity of the crop. Early harvest, while grain moisture is high, can result in a decrease in milling quality due to a high proportion of immature grain. Late harvest, when grain moisture content has dropped too low, may also reduce milling quality due to fissures developed in the grain (Ranganath et al., 1970; Srinivas et al., 1978). Clearly, as illustrated in Fig. 1, the response of head rice yield to grain moisture is affected by the amount of the N applied.

Optimal grain moisture contents at harvest for maximum head rice were determined from the quadratic response functions. The ranges for optimal harvest grain moisture were 220 to 270 g kg^{-1} for S201, 210 to 270 g kg^{-1} for M201, and 200 to 250 g kg^{-1} for L202. These results are consistent with our previous findings based on farmers' records (Geng et al., 1984). Thus, the optimal moisture content in grain at harvesting time is between 200 and 270 g kg^{-1} for a wide range of grain types and cultural practices in California. Because there did not exist a detectable relationship between the optimal grain moistures and N levels, moisture content between 200 to 270 g kg^{-1} represents a general measure of maturity for harvesting.

The maximal head rice estimates obtained from moisture curves within N levels represent the best head rice recovery that can be attained at each of the N levels. These maximal head rice estimates are then used to determine the N effects. The linear-plateau model (Anderson and Nelson, 1975) fitted the data very well, and the smallest R^2 value for the three fitted curves was 0.84 (Fig. 2, 3, and 4).

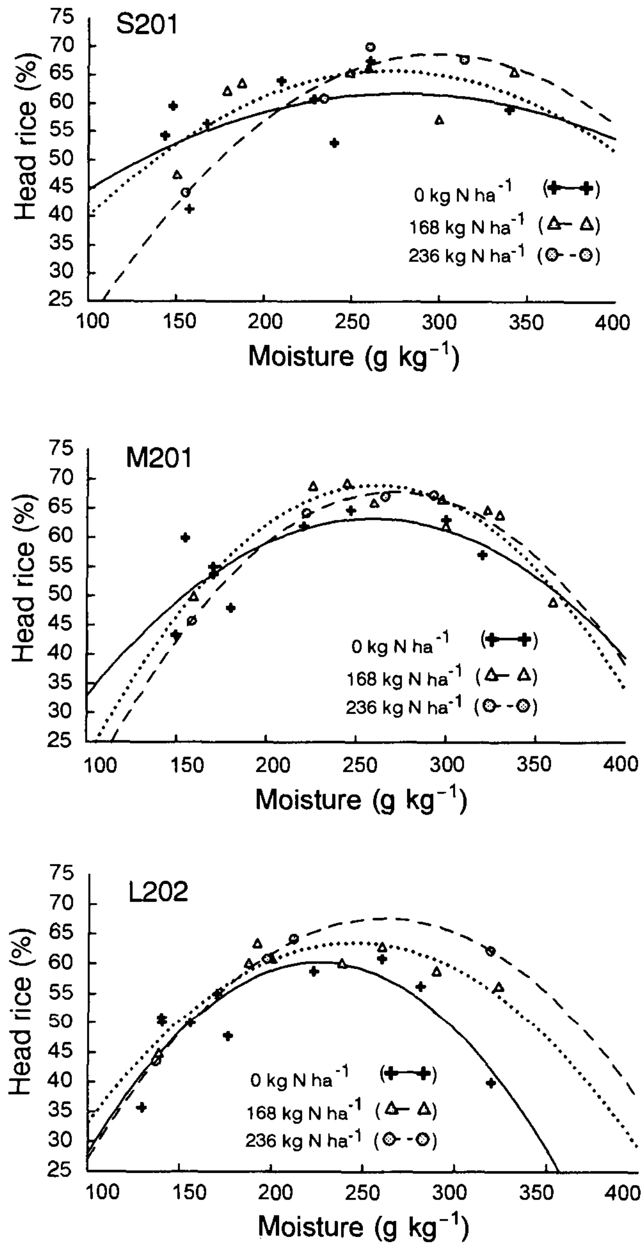

Fig. 1. Illustration of quadratic response of percent head rice and harvest grain moisture contents at three N rates.

These linear-plateau models provide estimates of the minimum N level (125 kg ha^{-1} for S201, 112 kg ha^{-1} for M201, and 130 kg ha^{-1} for L202) that will produce the maximum head rice. The corresponding maximum head rice yields are 68% for S201, 67% for M201, and 64% for L202. Nangju and De Datta (1970) found a significant relationship between head rice and N rates in one chalky cultivar, but no N effect on head rice was detected in three other cultivars. They suggested that the increase in head rice in the chalky cultivar as a result of N application was due to an increase in the protein content of brown rice and a decrease in chalky kernels. They suggested that protein bodies functioned as a binder oc-

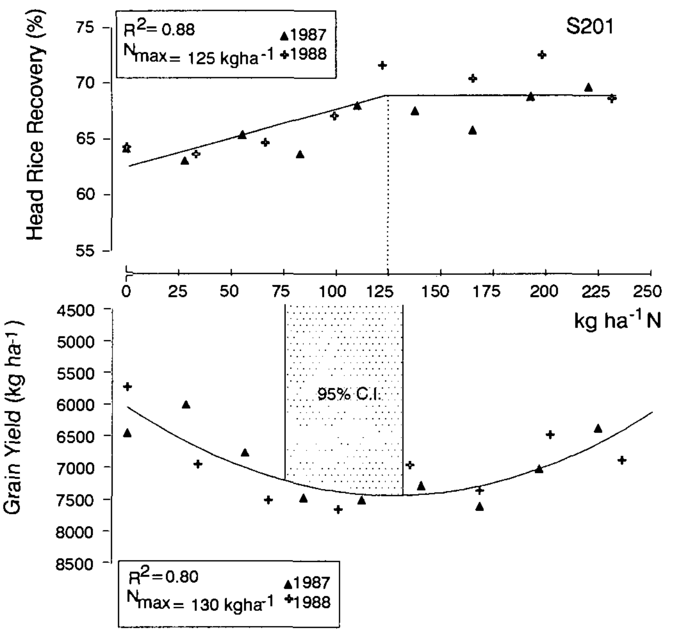

Fig. 2. Optimal N requirements for maximum yield and percent head rice of cultivar S201. 95% C.I., 0.95 confidence interval.

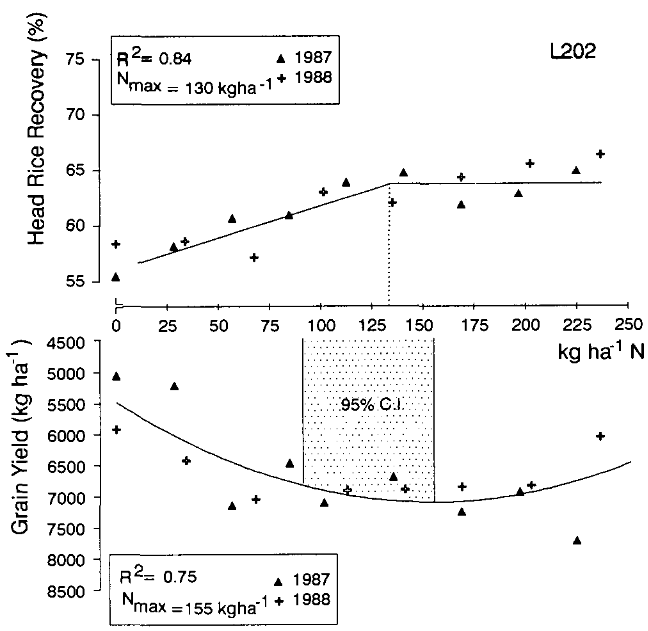

Fig. 4. Optimal N requirements for maximum yield and percent head rice of cultivar L202. 95% C.I., 0.95 confidence interval.

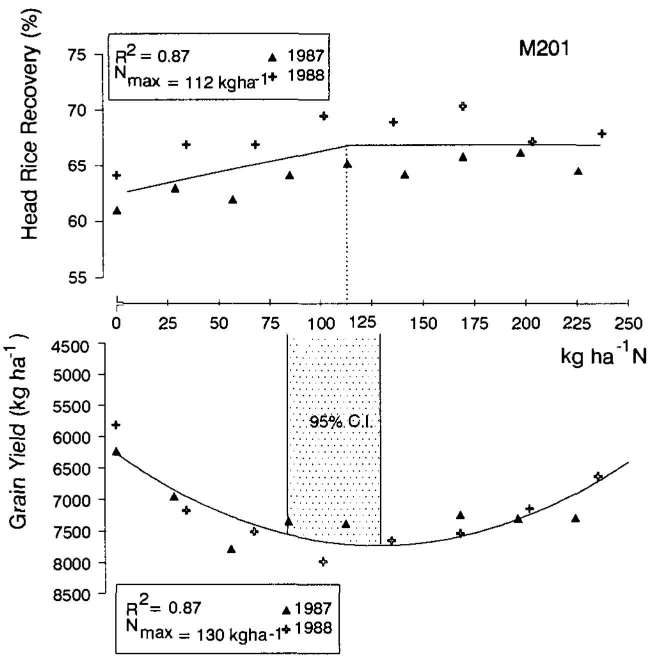

Fig. 3. Optimal N requirements for maximum yield and percent head rice of cultivar M201. 95% C.I., 0.95 confidence interval.

cupying the space between unpacked starch granules, which resulted in increased resistance of rice grain to breakage during milling.

Percent hull and total milled rice did not respond to N fertilization for any cultivar and these traits remained fairly constant throughout the harvest period. The average percent hull was 19% for S201, 21% for M201, and 22% for L202. The average percent total milled rice was 70% for S201, 69% for M201, and 68% for L202. Similar results were also reported by Fagade and Ojo (1977), who found that N did not significantly affect total milled rice.

Grain yield of all cultivars declined at high levels of N due to lodging (Fig. 2, 3, and 4) The N levels that produced maximum grain yields were 130 kg N ha^{-1} for S201, 130 kg N ha^{-1} for M201, and 155 kg N ha^{-1} for L202.

Maximum grain yield for each cultivar was achieved at a slightly higher N level than was required for maximum head rice. The optimum N rates for maximum head rice, however, lie within the lower half of the 0.95 confidence intervals (shaded area of Fig. 2, 3, and 4) of the maximum grain yield for all cultivars. Thus, there is a high confidence that grain yield will not be sacrificed if a lower N input is used to maximize the head rice yield.

This experiment provided data that separates the effects of grain moisture at harvest and the N level on rice milling quality as measured by percent head rice. The level of grain moisture at harvest is shown to be critically important for head rice recovery, and it should be determined for each commercial cultivar. The optimal N level that produces the highest head rice yield will also, with high probability, produce maximum grain yield for California cultivars. Results of this study help eliminate a practical problem of N management in rice farming, which would otherwise be required to optimize different economic traits and balance the grain yield and milling quality concerns.

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