Published May, 2000

Effects of Salinity on Grain Yield and Yield Components of Rice at Different Seeding Densities

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ABSTRACT

One possible management option for growers in dealing with decreases in rice (*Oryza sativa* L.) production caused by salinity is to compensate yield reduction by increasing seeding density. Our objectives were to investigate the effects of salinity and seeding density on grain yield and yield components, and analyze the relationships of the yield components to final grain yields at different seeding densities under salinity. Plants were grown in the greenhouse in sand irrigated with nutrient solutions. The treatments included seeding densities of 400, 600, and 720 seeds m^{-2} and salt levels of 1.0, 3.9, and 6.5 dS m^{-1}. Salinity effects were highly significant on grain yield, plant stand, seed weight per plant, seed weight per panicle, and spikelets per panicle, but not significant on panicle density, kernel weight, and shoot weight per plant at seeding densities tested. Grain yield was not significantly increased with an increase of seeding density. Plant stand and panicle density were significantly increased, while seed weight per plant, fertility, and harvest index were significantly decreased with increases of seeding densities. The density-dependent seed weight per plant under salinity was explained by the competition within and among plants at high-density populations affected by salinity. Seed weight per panicle accounted for 62% of total variation and contributed more than panicle density to the grain yield under salinity. It was concluded that yield loss under moderate salinities may not be compensated for by increasing seeding density above normal density levels.

Rice is grown in many regions under slightly to moderately saline conditions. In California, the direct water-seeded cultural system is dominant in rice production. Thus, rice plants are grown in continuously flooded and flow-through fields in this system (Hill et al., 1992). It was reported that salt levels increased in the standing water of rice fields due to irrigation practices that are commonly used during the early growing season (Scardaci et al., 1996). Since rice is recognized as a salt-sensitive crop (Maas and Hoffman, 1977), there was a serious concern that plant stand (i.e., seedling survival) and the development of yield components were affected by water salinity. Based on salt tolerance studies under greenhouse conditions on 'M-202', a commonly used rice cultivar in California, the lowest effective salinity levels in nutrient solutions affecting seedling growth and survival, and yield components were found to be lower than or close to the salt levels in irrigation water of some direct water-seeded rice fields in California (Zeng and Shannon, 2000). Substantial loss in plant stand and final yield reduction were also observed in the salt-affected rice fields in California (Scardaci et al., 1996; Shannon et al., 1998). Salinity problems in salt-affected rice fields might be relieved by developing appropriate management options for rice growers. One possible management option in dealing with salinity-induced decreases in rice production is to compensate yield reduction by increasing seeding density.

There have been extensive studies on the relationships between yield and plant density in rice under nonstressed conditions. The relationships varied with different planting systems in rice production. In transplanted cultural systems, maximum grain yield can be reached at a plant density of about 200 plants m^{-2} (Nguu and De Datta, 1979; Akita, 1982). In drill-seeded cultural systems, grain yield can be maximized at plant densities between 161 and 215 plants m^{-2}, which can be achieved with seeding densities between 90 and 112 kg ha^{-1} (Huey, 1984). In continuously flooded, direct water-seeded cultural systems that are common in California, grain yield was maximized at a broad range of plant densities between 221 and 451 plants m^{-2} (Miller et al., 1991). A compensatory relationship between yield components and plant density has been observed. It was shown that panicle density significantly increased with increases of seeding densities, while filled spikelets per panicle were reduced significantly (Wells and Faw, 1978; Counce, 1987; Jones and Snyder, 1987a and 1987b; Gravois and Helms, 1992). Tillers per plant and spikelets per panicle increased with decreases of plant density in direct-seeded rice (Wu et al., 1998).

Salinity effects on plants are complex. The general effects of salinity are the results of both osmotic and ionic stresses (Greenway and Munns, 1980). The initial and primary effect of salinity, especially at moderate salinity concentrations, is due to its osmotic effects (Munns and Termaat, 1986; Jacoby, 1994). At the whole plant level, ion concentrations in plant tissues increase as a result of salinity stress. Ion toxicity or nutrition deficiency will be caused by the overdominance of a specific ion (Bernstein et al., 1974). The measurable or visible effects of salinity on plants can include reduced growth rate, damage of meristems in growing shoots, reductions in yield components, or typical symptoms of nutritional disorders under osmotic and ionic stress. Grain yield reduction of rice under stress of root-zone salinity can be caused by injuries at both seedling and maturity stages. In most commonly cultivated rice cultivars, young seedlings were very sensitive to root-zone salinity (Pearson and Bernstein, 1959; Kaddah, 1963; Flowers and Yeo, 1981; Heenan et al., 1988). Yield components related to final grain yield were also severely affected by root-zone salinity. Primary branches per

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Published in Agron. J. 92:418–423 (2000).

Abbreviations: EC, electrical conductivity; FT, fertility; KW, kernel weight; PD, panicle density; SP, spikelets per panicle; SWP, seed weight per panicle; YD, grain yield.

panicle, panicle length, spikelets per panicle, number of filled spikelets, and seed weight per panicle were significantly reduced by salinity (Sajjad, 1984; Heenan et al., 1988; Khatun et al., 1995).

Although there have been extensive studies on salinity effects on seedling and yield components, little or no information has been reported on the interrelationships between grain yield and yield components at different seeding densities in rice under salinity. Our objectives were to investigate the effects of salinity and seeding density on grain yield and yield components, analyze the relationships of the yield components to final grain yields at different seeding densities under salinity, and determine if the yield loss under salinity would be compensated for by increasing seeding density above normal density levels.

MATERIALS AND METHODS

The experiment was conducted in a greenhouse at Riverside, CA (33°58′24″ N latitude, 117°19′12″ W longitude) in the summer of 1998. One medium-grain, early-maturing, semidwarf, and salt-sensitive cultivar, M-202, was cultured in nutrient solution (Yoshida et al., 1976) in sand tanks (122 by 61 by 46 cm deep) filled with sand (#12, Cisco, Corona, CA)[1] with an average bulk density of 1.4 g cm^{-3}. Irrigation solutions were prepared in reservoirs of 2000 L each and pumped to provide irrigation to sand tanks. Drainage from the sand tanks returned to the reservoirs through overflows by gravity. Each reservoir irrigated six sand tanks (replicates). Seeds were soaked for 32 to 48 h and hand-broadcast into an area of 0.55 m^2 within each sand tank as a seeding plot. The water depth was controlled at 5 to 8 cm. Air temperature was controlled between the ranges of 25 and 33°C during day and 18 and 23°C during night. Relative humidity ranged from 40 to 80%. Light averaged 1074 μmol m^{-2} s^{-1}, with a minimum of 244 and a maximum of 1417 μmol m^{-2} s^{-1} at noon.

The experimental design was a randomized block. This factorial experiment consisted of three salt levels and three seeding densities with six replicates in all combinations between salt and density levels. Salt and seeding density levels were considered fixed effects. There were three seeding densities, 400, 600, and 720 seeds m^{-2}, which were approximated to 100, 150, and 180 kg ha^{-1}, respectively. The seeding densities of 100 and 150 kg ha^{-1} were considered to be within the range of normal seeding densities in direct-seeded cultural systems (Huey, 1984; Jones and Snyder, 1987a; Scardaci et al., 1996). NaCl and $CaCl_2$ (5:1 molar concentration) were added to the nutrient solutions in three steps at the first, third, and fifth day after planting. Electrical conductivity (EC) in nutrient solutions was measured twice each week and averaged 1.0, 3.9, and 6.5 dS m^{-1} over the growing season for the three EC levels.

An area of 0.32 m^2 at the center of each seeding plot was measured as an inner-plot. Prior to harvest, 15 plants were randomly collected from each of the inner-plots to measure shoot dry weights and yield components. The shoots and panicles of each of these plants were bagged individually and dried at 70°C for 1 wk. Main stems were not distinguished from tillers. All the panicles from an individual plant were measured and averaged. Yield components were analyzed based on the measurements from these plants to determine the spikelets per panicle, fertility (i.e., percentage of filled spikelets per panicle), seed weight per panicle, seed weight per plant, kernel weight, and harvest index (i.e., seed weight per plant/total aboveground biomass per plant). Data were averaged over the 15 subsamples. Grain yields were estimated on an unit area basis. Plants were harvested in July 1998. All the plots were harvested in one week when most panicles had matured. Panicles were cut from the unsampled plants in each inner-plot. The numbers of panicles in each inner-plot were counted and recorded as panicle density (panicles m^{-2}), and then bulked, hand-threshed, and oven-dried. Seed dry weights from panicles in each inner-plot were measured as final grain yield (g m^{-2}). Plants in each inner-plot were harvested by pulling up with roots. Plants were carefully separated, counted, and recorded as plant stand (plants m^{-2}).

The data were analyzed using general linear models with SAS (version 6.12) and the procedures were described by SAS (SAS Inst., 1994). The measurements of treatments were compared and grouped using Duncan's multiple range tests at the 0.01 significance level (Ott, 1993). The comparisons were made only between the lowest salt or seeding density levels and the other treatment levels. The relative importance of yield components was analyzed using multiple linear regression. The significance of yield components was determined by stepwise regression analysis.

RESULTS

Plant Stand and Panicle Density

Based on the analysis of variance, the overall effect of salinity was highly significant ($P < 0.01$) on plant stand, but not significant on panicle density (significant at $P = 0.10$) (Table 1). The overall effect of seeding density was highly significant ($P < 0.01$) on plant stand and panicle density (Table 1). The interaction between salinity and seeding density was not significant for plant stand and panicle density (Table 1). These two variables were further analyzed based on Duncan multiple range tests at the 0.01 significance level. Mean values of plant stand and panicle density were compared with those at the lowest salt level as the controls. Plant stand was significantly reduced by salinity at 3.9 and 6.5 dS m^{-1} (Table 2). Panicle density was not significantly reduced

[1] Mention of trade names or commercial products in this article is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the USDA.

Table 1. Mean squares for grain yield and yield components at different seeding density under salinity.

Source	df	Grain yield $\times 10^{-2}$	Plant stand $\times 10^{-2}$	Panicle density $\times 10^{-2}$	Seed wt. per plant	Seed wt. per panicle	Kernel wt.	Spikelets per panicle	Fertility	Shoot wt. per plant	Harvest index $\times 10^2$
Salt (S)	2	5017**	349**	325	3.53**	1.45**	20.17	3361**	597**	2.43**	5.69**
Density (D)	2	75	1866**	1186**	1.24**	0.11	5.24	11	235**	1.92*	0.68**
S × D	4	73	25	50	0.32*	0.02	8.06	27	50	1.12	0.03
Replication	5	69	36	79	0.64**	0.14*	4.13	1276**	88*	2.07**	0.40**
Error	40	99	25	106	0.10	0.04	7.83	154	27	0.45	0.07

*, ** Significant at the 0.05 and 0.01 probability levels, respectively.

Table 2. Effect of salinity on seed yield and relative parameters with mean values averaged across seeding density levels.

	Salt levels (dS m^{-1})		
Parameters	1.0	3.9	6.5
Grain yield (g m^{-2})	606a†	451b	273c
Panicle density (no. m^{-2})	649a	565a	595a
Plant stand (no. m^{-2})	404a	325b	330b
Seed wt. per plant (g)	1.57a	1.09b	0.68c
Seed wt. per panicle (g)	1.04a	0.73b	0.47c
Spikelets per panicle	69.2a	52.6b	42.1b
Fertility (%)	70.4a	70.6a	60.5b
Kernel wt. (mg seed^{-1})	20.7a	19.5a	18.6a
Shoot dry wt. per plant (g)	3.48a	3.39a	2.80a
Harvest index	0.30a	0.24b	0.19c

† Within rows, means followed by the same letter are not significantly different at 0.01 probability level based on Duncan multiple range tests.

Table 3. Effect of seeding density on seed yield and relative parameters with mean values averaged across salt levels.

	Seeding density (seeds/m^2)		
Parameters	400	600	720
Grain yield (g m^{-2})	429a†	434a	467a
Panicle density (no. m^{-2})	512b	628a	669a
Plant stand (no. m^{-2})	249c	358b	452a
Seed wt. per plant (g)	1.41a	1.03b	0.91b
Seed wt. per panicle (g)	0.84a	0.70a	0.70a
Spikelets per panicle	55.5a	54.3a	54.0a
Fertility (%)	71.1a	66.3ab	64.1b
Kernel wt. (mg seed^1)	20.1a	19.0a	19.6a
Shoot dry wt. per plant (g)	3.59a	3.13a	2.95a
Harvest index	0.27a	0.24ab	0.23b

† Within rows, means followed by the same letter are not significantly different at 0.01 probability level based on Duncan multiple range tests.

by salinity (significant at $P = 0.05$) (Table 2). Mean values of plant stand and panicle density were compared with those at the lowest density level as the controls. Plant stand and panicle density increased significantly with the increase of seeding density (Table 3).

Grain Yield and Other Relative Variables

Based on the analysis of variance, the overall effect of salinity was highly significant ($P < 0.01$) on grain yield, seed weight per plant, seed weight per panicle, spikelets per panicle, fertility, shoot weight per plant, and harvest index, but not significant on kernel weight (Table 1). The overall effect of seeding density was highly significant ($P < 0.01$) on seed weight per plant, fertility, and harvest index, significant ($P < 0.05$) on shoot weight per plant, but not significant on grain yield, seed weight per panicle (significant at $P = 0.09$), spikelets per panicle, and kernel weight (Table 1). The interaction between salinity and seeding density was not significant on most variables except on seed weight per plant (significant at $P = 0.05$).

These variables were further analyzed based on Duncan multiple range tests at the 0.01 significance level. Mean values of the variables were compared with those at the lowest salt level as the controls. Grain yield, seed weight per plant, seed weight per panicle, spikelets per panicle, and harvest index were significantly reduced by salinity at 3.9 and 6.5 dS m^{-1} (Table 2). Fertility was significantly reduced by salinity at 6.5 dS m^{-1}, but not at 3.9 dS m^{-1} (Table 2). Kernel weight and shoot weight per plant were not significantly reduced by salinity, although there was a strong tendency of reduction for shoot weight per plant ($P = 0.05$) (Table 2). Mean values of these variables were compared with those at the lowest density level as the controls. Grain yields did not significantly increase with increases of seeding densities, although there was a slight increase at 6.5 dS m^{-1} ($P = 0.25$) (Table 3). Seed weight per plant, fertility, and harvest index significantly decreased with increases of seeding densities (Table 3). Seed weight per panicle, spikelets per panicle, kernel weight, and shoot weight per plant did not significantly decrease with increases of seeding density (Table 3), with a strong tendency of reduction for seed weight per panicle and shoot weight per plant ($P = 0.10$).

Relationship of Grain Yield and Yield Components

The relative importance of yield components to grain yield (YD) was evaluated based on the variables in Eq. [1]

$$\mathrm{YD} = \mathrm{PD} \times \mathrm{SWP} \quad [1]$$

where PD is panicle density and SWP is seed weight per panicle. PD was used as a component of yield predictors because it is a direct function of plant stand and tillering. Similarly, SWP was used as another component of yield predictors because it is a direct function of spikelets per panicle (SP), fertility (FT) and kernel weight (KW). The significance of yield components was determined based on the order of their addition into the multiple regression model. At each salt level, the variation to YD contributed by PD was more than or close to that contributed by SWP. Overall, when data were combined across salt levels, SWP accounted for 62% of variation of YD and PD accounted for 28% of variation of YD (Table 4).

The relationships between SWP and other yield components (i.e., SP, FT, and KW) were also evaluated based on the variables in Eq. [2]:

$$\mathrm{SWP} = \mathrm{SP} \times \mathrm{FT} \times \mathrm{KW} \quad [2]$$

At each salt level, SP accounted for the most variation of SWP. Overall, when data were combined across salt levels, SP still contributed the most variation (56%) to SWP (Table 5).

DISCUSSION

The grain yield and most yield components at the three different seeding densities used in this study were significantly reduced by salinity at moderate salt levels of 3.9 and 6.5 dS m^{-1}. This provided further evidence of the severity of salinity problems in rice production. The results were consistent with those previously reported (Akbar et al., 1972; Khatun et al., 1995) and with our previous studies, which showed severe salinity effects and the low measurable salinity thresholds on the yield components (Zeng and Shannon, 2000). The nonsignificant salinity effect on kernel weight in rice cultivar M-202 might be due to the moderate salt levels used in this study and the confounding effects of salinity

Table 4. Contributions of yield components to variation in grain yield of rice under salinity.

YD = PD × SWP†

Yield components	Salt levels (dS m^{-1}) 0.01	3.9	6.5	Overall
	R^2‡			
PD	0.23	0.68	0.87	0.28
SWP	0.42	0.02	0.30	0.62
SWP + PD	0.63	0.68§	0.92	0.76
df (error)	16	16	16	51

† Grain yield was the product of panicle density and seed weight per panicle. YD, grain yield; PD, panicle density; SWP, seed weight per panicle.
‡ The significance of yield components to grain yield was determined by stepwise regression analysis. The yield components with the higher R^2 values were the first to add to the regression model. The next yield components were added to the model at $P = 0.05$.
§ The last variable to add to the regression model was not significant at $P = 0.05$.

Table 5. Contributions of yield components to seed weight per panicle in rice under salinity.

SWP = SP × FT × KW†

Yield components	Salt levels (dS m^{-1}) 1.01	3.9	6.5	Overall
	R^2‡			
KW	0.16	0.01	0.30	0.18
FT	0.01	0.18	0.31	0.24
Sp	0.23	0.70	0.55	0.56
SP + KW	0.45	0.77	0.84	0.69
SP + KW + FT	0.45§	0.80	0.84§	0.71
df (error)	16	16	16	51

† Seed weight per panicle was the product of spikelets per panicle, fertility, and kernel weight. SWP, seed weight per panicle; SP, spikelets per panicle; FT, fertility; KW, kernel weight.
‡ The relationship between seed weight per panicle and other yield components was determined by stepwise regression analysis. The yield components with the highest R^2 values were the first to add to the regression model. The next yield components were added to the model at $P = 0.05$.
§ The last variable to add to the regression model was not significant at $P = 0.05$.

reduction and compensation between yield components due to the reduction of spikelets under salinity, which caused an alteration of source–sink ratio.

The nonsignificant but marginal salinity effects on panicle density at salt levels used in this study can be explained by the high competition among plants. In populations with normal plant densities, secondary and tertiary tillering was suppressed due to a limited light intensity. The loss of plant stand under salinity at early plant establishment increased space between plants, stimulated secondary tillering and complicated salinity effects on panicle density. The plasticity of tillers per plant as responses to plant spacing has been observed in transplanted rice (Counce et al., 1989) and drilled-seeded rice (Wu et al., 1998). This phenomenon has also been observed in salinity-affected rice fields in California (S. Scardaci, personal communication, 1997).

Spikelet number per panicle was determined to be more important to grain yield than fertility and kernel weight. In our previous studies, spikelets per panicle was the most salt-sensitive yield component; fertility and kernel weight were less sensitive to salinity (Zeng and Shannon, 2000). Because spikelets per panicle can be visually estimated, it should be a desirable and rapid selection criterion for screening a large number of plants for salt tolerance. However, its heritability in selection for salt tolerance has yet to be determined.

It was reported that panicle density was the most important component of yield in direct water-seeded rice under nonstressed conditions (Miller et al., 1991). In this study, it appeared that panicle density was more important than seed weight per panicle to total grain yield when salt level remained fixed. However, when data were combined across salt levels, seed weight per panicle contributed more variation to total grain yield than panicle density. This provided an insight into the relationships between the yield components and total grain yield of rice under salinity. An increasing gradient of salt levels from top to bottom basins was typical in salt-affected rice fields with flow-through irrigation systems (Scardaci et al., 1996). The variability of salinity levels among basins in rice fields would make panicle density less important than seed weight per panicle for total grain yield at normal seeding densities. As a result, total grain yield could depend more on panicle weight than on panicle density within a certain range of seeding densities in salt-affected rice fields. The application of this influence to other rice production systems depends on the variability of salinity levels in rice fields, which can be determined based on soil texture, irrigation water source, planting methods, and topography of fields.

Although there was a slight increase of total grain yield with increases of seeding densities in this study, the overall effect of seeding density on grain yield was not statistically significant. The lack of a significant increase in grain yield with an increase of seeding density above normal density levels was also observed in spring wheat under root-zone salinity (Steppuhn, 1997). Under nonstressed conditions, the responses of yield to the changes of plant densities were determined by a compensatory relationship between plant density and yield components. The compensatory relationship within populations determines a maximum yield above which the grain yield per unit area will not increase with the further increase of plant density. Plant stand and panicle density increased with increases of seeding densities. However, the increases of plant stand and panicle density were offset by the reduction in seed weight per plant and fertility with the increases of seeding densities (Counce, 1987; Counce et al., 1989; Miller et al., 1991; Gravois and Helms, 1992; Wu et al., 1998). Under normal conditions, this compensatory relationship results from a combination of competition among plants and environmental factors such as light (Evans and De Datta, 1979), row spacing (Jones and Snyder, 1987a; Counce et al., 1989), and N levels applied (Counce and Wells, 1990). Under salinity, the changes of the size and seed yield of individual plants result from a combination of the competition within and among plants in populations and salinity stress. Within plants, a source–sink relationship determines the partitioning of carbohydrates between vegetative and reproductive growth. The elongation of the culm, which occurs at the same time as panicle initiation and development, can cause strong competition for carbohydrate supply (Murata and Matsushima, 1975; Pattanaik and Mohapatra, 1988). Under nonstressed conditions, according to Pattanaik and Mohapatra (1988), carbohydrates were utilized in internode growth before anthesis and extra supply was reserved and remobilized to filling grains at the postanthesis stage. Therefore, the shoot growth was suppressed by the growing panicles at the postanthesis stage. In M-202 under salinity stress, the reduction in spikelet number per panicle due to salinity was highly significant, whereas the reduction in shoot dry weight per plant was not highly significant. The reduction in yield sink sites changed the source–sink relationship and the partitioning of carbohydrates between vegetative and reproductive growth. It was hypothesized that a higher proportion of carbohydrates were utilized to shoot growth in the postanthesis stage under salinity than under normal conditions because of the reduction of yield sink sites. At high density, carbohydrate supply was limited because of shading among plants, and the competition between shoot growth and panicle growth was enhanced. This resulted in the reductions in harvest index with the increases in seeding densities under salinity in M-202. Reduction in fertility with increases in seeding densities under salinity in M-202 resulted from a combination of salinity and plant density effects. It was known that salinity reduced pollen viability and seed set (Khatun et al., 1995). The supply of carbohydrate to developing florets was limited in high-density populations because of shading and caused spikelet sterility in rice (Murty and Murty, 1981) and wheat (Mishra and Mohapatra, 1987). The reduction in fertility at high density was one of the causes for the reduction of seed yield per plant with the increase of seeding density.

The possibility of compensation to yield loss due to salinity by increasing seeding density could be better determined by studies with a wider range of seeding densities and salt levels in order to determine the optimum density under salinity and, if possible, thresholds of salinity effect on yield at different plant densities. We were successful in determining interrelations among yield components at different density populations under salinity. Under continuous salinity stress, the loss of grain yield under salinity resulted from a combination of reductions in plant stand, spikelet number per panicle, fertility, and harvest index. The increase of seeding density could partially compensate for the loss of plant stand. However, the density-dependent seed yield of individual plants under salinity indicated that the expected yield compensation will be offset by the reduction of seed yield per plant with the increase of seeding density. Thus, the management option of increasing seeding density will not be economically feasible. It is concluded that the increase of seeding density above normal density levels may not compensate for yield loss under salinity. In order to prevent final yield loss, it is necessary to develop other management options to control salinity levels below thresholds or to avoid salinity stress at critical development stages at which plants are most sensitive. Experiments on the effects of salinity stress and relief during different development stages are being conducted in our laboratory in order to quantify salinity effects at critical stages. The genetic improvement of salt tolerance can be another strategy in dealing with salinity problems, considering the cost and applicability of field management options.

ACKNOWLEDGMENTS

This research was supported by Agricultural Technology Utilization and Transfer (ATUT) Project No. 263-240. We thank Dr. C.W. Johnson (Rice Experiment Station, Biggs, CA) for providing rice seeds; Dr. S.R. Grattan and Dr. G.B. Gregorio for critiquing this manuscript; S. Lesch and P. Nash for statistical analysis; and J. Poss, T. Donovan, and J. Draper for their excellent technical assistance.

REFERENCES

Akbar, M., T. Yabuno, and S. Nakao. 1972. Breeding for saline-resistant varieties of rice. Jpn. J. Breed. 22:277–284.

Akita, K. 1982. Studies on competition and compensation of crop plants: XI. Effects of planting density on the yield component in rice plant. Sci. Rep. Fac. Agric. Kobe Univ. 15:17–21.

Bernstein, L., L.E. Francois, and R.A. Clark. 1974. Interactive effects of salinity and fertility on yields of grains and vegetables. Agron. J. 66:412–421.

Counce, P.A. 1987. Asymptotic and parabolic yield and linear nutrient content responses to rice population density. Agron. J. 79:864–869.

Counce, P.A., K.A. Moldenhauer, and D.B. Marx. 1989. Rice yield and plant yield variability responses to equidistant spacing. Crop Sci. 29:175–179.

Counce, P.A., and B.R. Wells. 1990. Rice plant population density effect on early-season nitrogen requirement. J. Prod. Agric. 3:390–393.

Evans, L.T., and S.K. De Datta. 1979. The relation between irradiance and grain yield of irrigated rice in the tropics, as influenced by cultivars, nitrogen fertilizer application and month of planting. Field Crops Res. 2:1–17.

Flowers, T.J., and A.R. Yeo. 1981. Variability in the resistance of sodium chloride salinity within rice (*Oryza sativa* L.) varieties. New Phytol. 88:363–373.

Gravois, K.A., and R.S. Helms. 1992. Path analysis of rice yield and yield components as affected by seeding rate. Agron. J. 84:1–4.

Greenway, H., and R. Munns. 1980. Mechanisms of salt tolerance in non-halophytes. Annu. Rev. Plant Physiol. 31:149–190.

Heenan, D.P., L.G. Lewin, and D.W. McCaffery. 1988. Salinity tolerance in rice varieties at different growth stages. Aust. J. Exp. Agric. 28:343–349.

Hill, J.E., S.R. Roberts, D.M. Brandon, S.C. Scardaci, J.F. Williams, C.M. Wicks, W.M. Caneuari, and B.L. Weir. 1992. Rice production in California. Pub. 21498. Coop. Ext. Univ. California, Div. of Agric. and Natural Resources, Oakland.

Huey, B.A. 1984. Seeding. p. 8–12. *In* Rice production handbook. Ser. MP 192. Univ. of Arkansas Coop. Ext., Stuttgart.

Jacoby, B. 1994. Mechanisms involved in salt tolerance by plants. p. 97–123. *In* M. Pessarakli (ed.) Handbook of plant and crop stress. Marcel Dekker, New York.

Jones, D.B., and G.H. Snyder. 1987a. Seeding rate and row spacing effects on yield and yield components of drill-seeded rice. Agron. J. 79:623–626.

Jones, D.B., and G.H. Snyder. 1987b. Seeding rate and row spacing effects on yield and yield components of ratoon rice. Agron. J. 79:627–629.

Kaddah, M.T. 1963. Salinity effects on growth of rice at the seedling and inflorescence stages of development. Soil Sci. 96:105–111.

Khatun, S., C.A. Rizzo, and T.J. Flowers. 1995. Genotypic variation in the effect of salinity on fertility in rice. Plant Soil 173:239–250.

Maas, E.V., and G.J. Hoffman. 1977. Crop salt tolerance: Current assessment. J. Irrig. Drain. Div. Am. Soc. Civ. Eng. 103(IR2): 115–134.

Miller, B.C., J.E. Hill, and S.R. Roberts. 1991. Plant population effects on growth and yield in water-seeded rice. Agron. J. 83:291–297.

Mishra, S.P., and P.K. Mohapatra. 1987. Soluble carbohydrates and

floret fertility in wheat in relation to population density stress. Ann. Bot. (London) 60:269–277.
Munns, R., and A. Termaat. 1986. Whole-plant responses to salinity. Aust. J. Plant Physiol. 13:143–160.
Murata, Y., and S. Matsushima. 1975. Rice. p. 75–99. *In* L.T. Evans (ed.) Crop physiology. Cambridge Univ. Press, London.
Murty, P.S.S., and K.S. Murty. 1981. Effect of low light at anthesis on spikelet sterility in rice. Curr. Sci. 50:420–421.
Nguu, N.V., and S.K. De Datta. 1979. Increasing efficiency of fertilizer nitrogen in wetland rice by manipulation of plant density and plant geometry. Field Crops Res. 2:19–34.
Ott, L.R. 1993. An introduction to statistical methods and data analysis. 4th ed., Duxbury Press, Belmont, CA.
Pattanaik, P.K., and P.K. Mohapatra. 1988. Role of assimilates and phosphates in the control of internode elongation in tall and dwarf indica rice varieties. J. Exp. Bot. 39:1367–1380.
Pearson, G.A., and L. Bernstein. 1959. Salinity effects at several growth stages of rice. Agron. J. 51:654–657.
Sajjad, M.S. 1984. Effect of increased salt stress on yield and yield components in rice. Pak. J. Sci. Ind. Res. 27:292–294.
SAS Institute. 1994. SAS/STAT user's guide. Version 6. 4th ed. SAS Inst., Cary, NC.
Scardaci, S.C., A.U. Eke, J.E. Hill, M.C. Shannon, and J.D. Rhoades. 1996. Water and soil salinity studies on California rice. Rice Pub. 2. Coop. Ext. Univ. California, Colusa.
Shannon, M.C., J.D. Rhodes, J.H. Draper, S.C. Scardaci, and M.D. Spyres. 1998. Assessment of salt tolerance in rice cultivars in response to salinity problems in California. Crop Sci. 38:394–398.
Steppuhn, H. 1997. Increasing plant density in spring wheat to ameliorate the effects of salinity on grain yield. Trans. ASAE 40: 1599–1606.
Wells, B.R., and W.F. Faw. 1978. Short-stature rice response to seeding and N rates. Agron. J. 70:477–480.
Wu, G., L.T. Wilson, and A.M. McClung. 1998. Contribution of rice tillers to dry matter accumulation and yield. Agron. J. 90:317–323.
Yoshida, S., D.A. Forno, J.H. Cock, and K.A. Gomez. 1976. Laboratory manual for physiological studies of rice. 3rd ed. IRRI, Los Baños, Philippines.
Zeng, L., and M.C. Shannon. 2000. Salinity effects on seedling growth and yield components of rice. Crop Sci. (in press).

TURFGRASS MANAGEMENT

Using Near Infrared Reflectance Spectroscopy to Schedule Nitrogen Applications on Dwarf-Type Bermudagrasses

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ABSTRACT

Due to the high rates of N fertility necessary for producing high-quality turfgrasses, quick, reliable methods of determining the N status of turfgrasses would be valuable management tools. The first objective of this study was to evaluate the use of near infrared reflectance spectroscopy (NIRS) to schedule N fertilization on two dwarf-type bermudagrasses [*Cynodon dactylon* (L.) Pers. × *C. transvaalensis* Burtt Davy]. The second objective was to test the accuracy of NIRS-predicted mineral tissue concentrations. The third objective was to study the effect of N fertility on thatch development. 'Tifdwarf' and 'FloraDwarf' bermudagrasses grown on sand–peat (9:1 by volume) were subjected to five treatments using time, NIRS-predicted N thresholds, and a visual quality rating threshold to schedule applications of $(NH_4)_2SO_4$ for 20 wk per growing season in 1997 and 1998. There were positive linear relationships between total Kjeldahl nitrogen (TKN) and NIRS-predicted N in 1997 ($r^2 = 0.76$; slope = 0.96) and 1998 ($r^2 = 0.92$; slope = 1.06). NIRS-scheduled fertility resulted in similar quality with less fertilizer than time or visual quality-based fertility. The NIRS mineral concentration predictions for K, Ca, Mg, Fe, Zn, Mn, and Cu were positively correlated with traditional laboratory methods, but there was not sufficient precision in measurements to use NIRS for determination of these nutrients. Thatch development and yields were greater in treatments receiving higher rates of fertilizers, suggesting that excessive growth rates due to high rates of applied fertilizer may have contributed to thatch development.

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Published in Agron. J. 92:423–427 (2000).

Near infrared reflectance spectroscopy analysis is a nondestructive method for measuring the chemical composition of materials with simple sample preparation. NIRS technology is based on near infrared absorption properties, which can be measured and used to differentiate one compound from another in a tissue sample (Marten et al., 1985). NIRS has been in development for 30 yr, and new uses for this technology are being developed as it is refined. NIRS techniques have been used to measure such forage quality criteria as digestibility, energy intake, and botanical composition as accurately as conventional laboratory analyses (Eckman et al., 1983; Moore et al., 1990) and to evaluate moisture, oil, and starch concentrations in many food commodities (Halgerson et al., 1995; Hattey et al., 1994; Roy et al., 1993). Research has also shown the potential of using NIRS to accurately predict the response of corn (*Zea mays* L.) to fertilizer and to the N-supplying capability of a soil (Fox et al., 1993). Mineral analysis of Ca, P, and K in forages using NIRS has been proven to be reliable ($r^2 > 0.74$) (Clark et al., 1987). NIRS has been shown to significantly decrease time and labor involved in measuring total nonstructural carbohydrates (TNC) in several turfgrasses (Shepard et al., 1990), with a correlation of $r^2 = 0.86$ between laboratory TNC and

Abbreviations: NIRHi, high NIRS N-threshold; NIRLow, low NIRS N-threshold; NIRS, near infrared reflectance spectroscopy; SCHHi, scheduled high N; SCHLow, scheduled low N; TKN, total Kjeldahl nitrogen; TNC, total nonstructural carbohydrate(s); VIS, fertilized based on visual rating.