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Rice Responses to Nitrogen Under High Solar Radiation and Intermittent Flooding in Peru[1]

P. A. Sanchez, G. E. Ramirez, and M. V. de Calderon[2]

ABSTRACT

The purpose of this study was to characterize the varietal responses of rice (*Oryza sativa* L.) to N fertilization in a tropical desert climate where extremely high N application rates are needed to attain maximum yields. Eight rice cultivars of contrasting plant type and growth duration were tested at applied N levels of 0 to 480 kg N/ha in a field experiment with an intermittently flooded water regime. Among the semi-dwarf cultivars, the earlier maturing 'IR8' produced a maximum yield of 11.7 ton/ha at 480 kg N/ha and the later maturing 'IR5' produced a maximum yield of 9.9 ton/ha at 400 kg N/ha. Among the tall-statured cultivars of the traditional plant type, the earlier maturing 'CEL 895' produced a maximum yield of 10.6 ton/ha at 320 kg N/ha and the later maturing 'Minabir 2' attained its highest yield of 7.9 ton/ha at 400 kg N/ha. Yield responses to N were primarily a function of effective tillering capacity and not of panicle size. Increases in dry matter production from panicle initiation to harvest were highly correlated with grain yields. A 0.85% N content in the above-ground parts at harvest was associated with maximum yields as well as a total N uptake of approximately 180 kg N/ha, suggesting the existence of an internal N requirement for rice in this environment. The apparent recovery of added N averaged 30%, which is considerable lower than in constantly flooded environments.

The results indicate that: i) the shorter the growth duration of a cultivar within a specific plant type, the higher the yields and N response; ii) the extremely high N rates required are due to high levels of N uptake and low fertilizer recovery intermittent flooding.

Additional key words: Plant type, Growth duration, N uptake, N fertilizer efficiency, Internal N requirement.

YIELD responses to N are almost universal in rice (*Oryza sativa* L.). The world-wide response in 1966 averaged 12.7 kg of rough rice per kg N applied, and the optimum rates of application ranged from 30 to 40 kg N/ha (7). Since then, a new semi-dwarf plant type has been developed which is characterized by short stature, strong culms, high tillering capacity, shorter upright leaves, and resistance to lodging. This semi-dwarf plant type contrasts sharply with the traditional plant type characterized by tall stature, weak culms, long droopy leaves, and susceptibility to lodging. Many cultivars of the new plant type have been widely planted throughout the tropics with dramatic increases in yields, N response, and optimum rates of application. Rice yields have doubled in fertilized plots, and maximum N rates in tropical Asia are now in the range of 80 to 160 kg N/ha (3, 5, 12, 16).

Rice responses to N vary widely with plant type, climate, water management, and soil properties. Among the climatic components, solar radiation is considered the most critical factor affecting N response under constantly flooded tropical conditions (6). The vast majority of tropical rice fields, however, suffer from alternate flooding and drying conditions during part of the growing season because of uneven rainfall or irrigation water distribution.

The northern coast of Peru is a high-yielding rice area where cultivars of the traditional plant type respond positively to as much as four times the conventional N rates (1, 2). Transplanted rice is grown under intermittent flooding, very high solar radiation, and relatively low temperatures for its latitude and elevation. Unlike hot tropical areas, a wide range of growth durations is found in cultivars that are sensitive or relatively insensitive to photoperiod (10). Highest yields are usually obtained with intermediate varieties (160 to 200 days from seeding to harvest).

The objective of this study was to characterize the nature of the varietal response to N of intermediate and late-maturing cultivars of contrasting plant type (semi-dwarf vs traditional) in a tropical desert climate in terms of (a) growth characteristics and duration, (b) grain yields, and (c) the efficiency of fertilizer N utilization, in order to determine why such high N rates are required in this environment.

PROCEDURE

A field experiment was conducted during the 1969-70 growing season at the Tavara Farm of the Lambayeque Experiment Station (6°42' S, 24 m elevation). An alluvial clay loam, representative of rice growing areas (pH 8.3, 1.7% O.M., 1.0 mmho/cm electrical conductivity) and adequate in all nutrients except N (1, 2, 22), was used.

Eight cultivars or selections were studied at N levels ranging from 0 to 480 kg N/ha at 80-kg intervals. 'IR8,' 'IR305-3-15,' and 'IR576-8' are semi-dwarf cultivars with intermediate growth duration. 'IR5' belongs to the same plant type but has longer growth duration. 'Minabir 2,' 'Apura,' and 'Siam Garden' are tall, late maturing, locally grown cultivars of the traditional plant type. 'CEL895-7-1-7' is also the traditional plant type but is earlier-maturing than the latter three. Due to the very similar behavior among the three semi-dwarf, intermediate-maturing cultivars and among the three traditional late-maturing cultivars, only the results of one representative of each group are presented.

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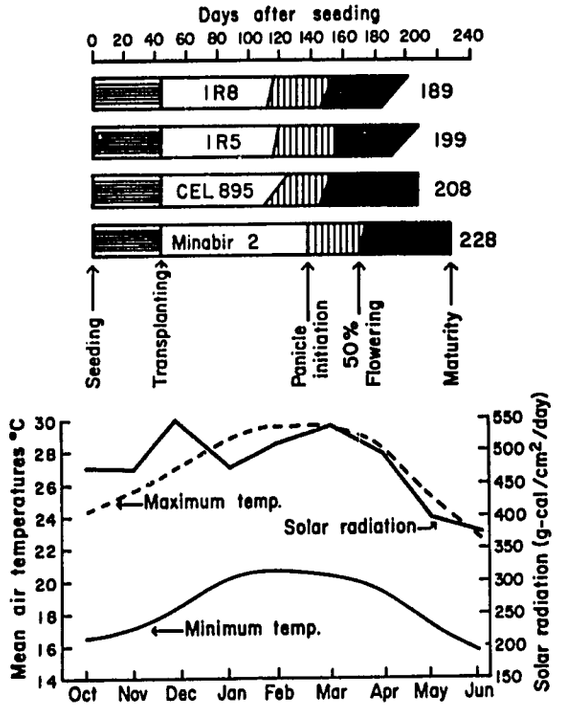

Fig. 1. Growth stage duration and climatic data. (Slanted lines represent the range in N treatments.)

A split plot design was used with N levels as main plots and varieties as subplots with three replications. Ordinary seedbeds were sown on October 20, 1969. The seedlings were transplanted 45 days afterwards in hills spaced at 25 × 25 cm with four seedlings per hill. The main plot dimensions were 12 × 20 m and the subplots 3 × 5 m. Nitrogen as urea was broadcast on a thin water layer, half the rate at 21 days after transplanting and half at panicle initiation, according to recommended practices for the area that result in maximum fertilizer N recovery (20, 21). The plots were flood-irrigated whenever water was available. The average interval bewteen water applications was 7.6 days. Most of these intervals represented a full flooding and drying cycle except after the panicle initiation stage when the valley water table had risen sufficiently to reduce water losses. Weeds were satisfactorily controlled and no incidence of pests and diseases was observed.

Plant height, tillering, dry matter production, N content, and accumulation of the above-ground parts were measured at 30 and 61 days after transplanting, at panicle initiation, at 50% flowering, and at harvest. Grain yields were determined in a 5-m²central area devoid of border effects and adjusted to 14% moisture. Grain characteristics and panicles/m² were determined in four randomly chosen hills. Spikelets per panicle, percent sterility, and 100 grain weights were determined from all panicles on one hill chosen at random. Dry matter was calculated after attaining constant weight in a draft oven at 60 to 70 C. Plant N was analyzed by the semimicro Kjeldahl method. Solar radiation and temperature data were obtained at the university observatory located about 1 km from the plots.

RESULTS AND DISCUSSION

Climate

The weather pattern during the cropping season in relation to the growth stages of the four cultivars is given in Fig. 1. Monthly temperature, solar radiation, and irrigation water supply values were normal for the valley (24). Temperatures were low at the seedling stage, increased and reached maximum values near panicle initiation and flowering stages, and decreased afterwards. Solar radiation varied little from seeding to flowering, but declined during the ripening period.

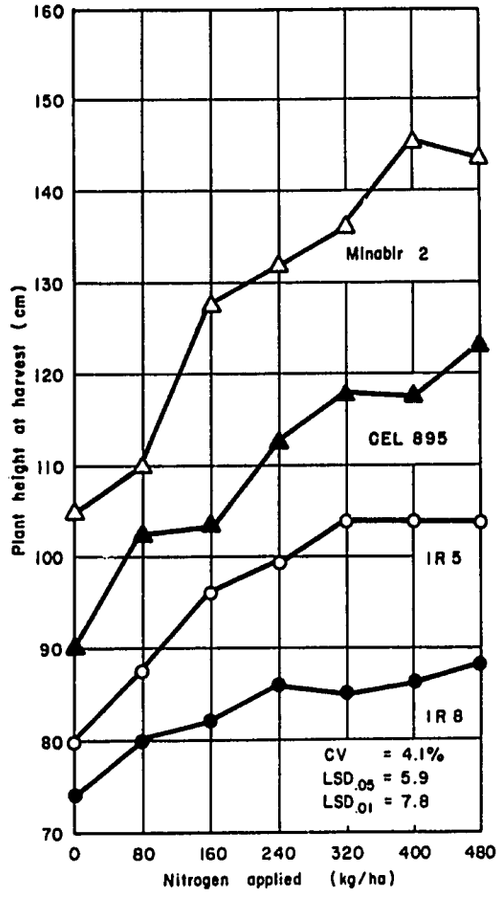

Fig. 2. Effects of N rates on plant height at harvest.

The average value for the growing season, 488 g-cal/cm²-day is approximately 19% higher than that reported for the dry season in the Philippines and 46% higher than rainy season values (6).

Growth Stages

The length of the vegetative phase averaged 115 days for IR8, 116 for CEL895, 117 for IR5, and 138 for Minabir 2. N rates significantly increased the length of the vegetative phase, but the increases were small (Fig. 1). The number of days from seeding to 50% flowering averaged 148 for IR8, 149 for CEL895, 157 for IR5, and 172 for Minabir 2. N rates had no significant influence on dates of flowering. Total growth duration differences were highly significant among cultivars and N rates. Varietal means are indicated in Fig. 1. Cultivars of the traditional plant type, regardless of growth duration, required an average of 59 days from flowering to maturity and the semidwarf cultivars required 44 days. The reasons for these differences are not understood.

Growth Characteristics

Highly significant differences in tiller and dry matter production among cultivars occurred at 30 days after planting, but no consistent trend was observed relative to plant type. At about the maximum tillering stage (61 days after transplanting) the effect of both N rate and cultivars on tiller and dry matter production was significant and remained so until harvest.

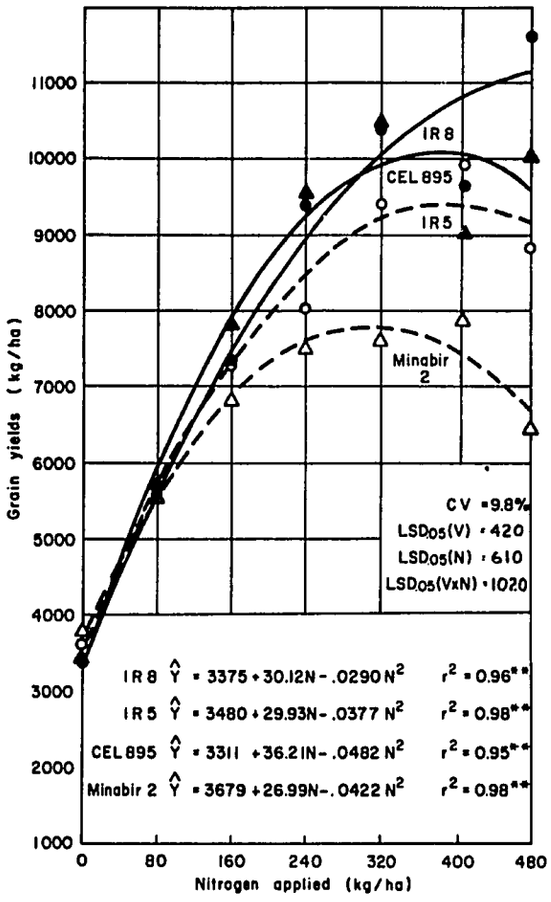

Fig. 3. Grain yield response to N applications of cultivars with contrasting plant type and growth duration.

All cultivars responded to N in terms of plant height, but the magnitude of the response was affected both by plant type and growth duration. The height response of the cultivars of the traditional plant type appears to be linearly associated with N rate (Fig. 2), reaching maximum heights at harvest of 123 and 144 cm. The semi-dwarf cultivars showed a nonlinear response in height, reaching maximum heights of 89 and 104 cm. In both sets of plant types, the later-maturing cultivars were significantly taller, which has been considered by Kawano and Velazquez (10) as a form of degeneration of plant type.

No lodging was observed in IR8 and IR5. CEL 895 lodged shortly before harvest; Minabir 2 lodged at about 2 weeks before harvest. Lodging damage was probably minimal because the grains were already formed and the soil surface was already drained.

The plant heights reported here are considerably lower than those for the same cultivars in high temperature-low solar radiation environments (15) where Minabir and CEL 895 attain heights of over 200 cm, lodge before flowering, and have very poor yields.

Grain Yields

In each cultivar from 95 to 98% of the variability in grain yield was attributable to N rate (Fig. 3). Yields at 0 and 80 kg/ha were not significantly different among cultivars. The semidwarf, earlier maturing IR8 increased sharply up to 320 kg N/ha and had a maximum yield of 11.7 ton/ha at 480 kg N/ha. The traditional, earlier maturing CEL 895 showed an almost identical response up to 320 kg N/ha and had a maximum yield of only 0.9 ton/ha less. The semidwarf, later maturing IR5 produced a sharp increase up to 320 kg N/ha with a maximum yield of 1.4 tons/ha less than IR8. Differences in maximum yields between IR5 and CEL were not statistically significant. The traditional, late maturing Minabir 2 produced a sharp response up to 160 kg N/ha and a maximum yield of 3.7 tons/ha less than IR8.

Within a specific plant type, the earlier-maturing cultivar produced a higher yield response to N than its later-maturing counterpart (Fig. 3). The excellent response of CEL 895 suggests that intermediate maturity is an important factor affecting N response in a high solar radiation environment.

These results also suggest a significant interaction between plant type and growth duration as factors affecting N response in high yielding cultivars. Similar results have been subsequently obtained with additional cultivars of the same growth duration range in the area. This relationship, however, has not been reported in the available literature, where plant type is considered the principal varietal factor affecting N response in the tropics. The relationship between long growth duration and poor N response in tall plant types has been previously established (8, 9). At Lambayeque, a multiple correlation study conducted with 127 cultivars or promising selections grown at a high N level indicated that growth duration is the most important vairetal factor affecting yield (10). The optimum growth duration appears to be within 10 days of IR8's. It is not surprising then, that both plant type and growth duration affect N responses.

Because of differences in growth duration, the cultivars were subjected to a different temperature and solar radiation regime during the reproductive phase (Fig. 1), and thus, the interpretation of these results should be limited to this particular environment. These climatic differences, however, may have been favorable to the later maturing cultivars because low night temperatures probably decreased respiration losses (26) while the decrease in solar radiation from April to May was not large enough to seriously affect photosynthesis. Furthermore, a positive correlation between grain yields and the length of the flowering to maturity period has been observed in Japan (28).

At 1970 Peruvian prices, 2.09 kg of rough rice are needed to pay for 1 kg of N as urea. The optimum N rates are 483 kg N/ha for IR8, 371 for IR5, 365 for CEL 895, and 290 for Minabir 2.

Relationship Between Grain Yields and Other Parameters

Grain:straw ratios. In terms of productivity per day, IR8 reached the highest value of 59 kg of grain/ha/day, followed by CEL with 50, IR5 with 49, and Minabir 2 with 35. Due to the longer growth duration at Lambayeque, these values are inferior to those reported in hot tropical areas (4).

One of the best measurements of plant type efficiency is the grain:straw ratio at harvest, because it is a measure of the amount of photosynthesis utilized in grain production. High values for earlier-maturing cultivars (Fig. 4) suggest that the traditional plant

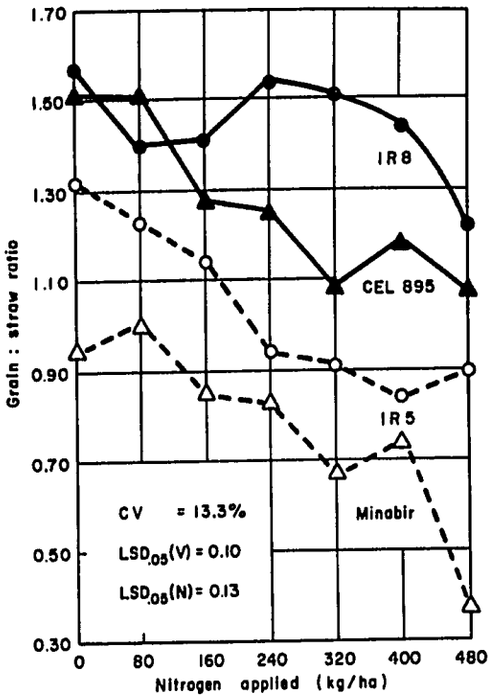

Fig. 4. Effects of N rate on grain:straw ratios.

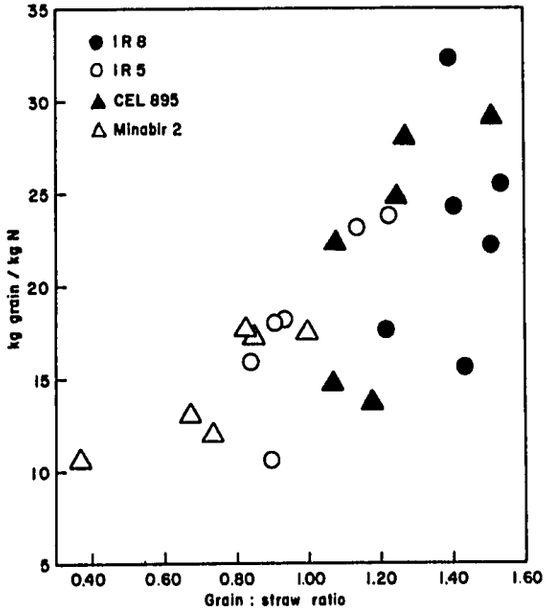

Fig. 5. Relationships between fertilizer efficiency and grain: straw ratios.

type of CEL 895 was more efficient than the semidwarf IR5. Grain:straw ratios were negatively correlated with growth duration (r = —0.76**) indicating that the earlier-maturing cultivars were more efficient than the late ones. Grain:straw ratios generally decrease with increasing N rates (26). Both IR8 and CEL 895 were able to maintain highly satisfactory grain:straw ratios at high N rates (Fig. 4). Grain: straw ratios were positively correlated with the efficiency of fertilizer applied expressed in kg rice per

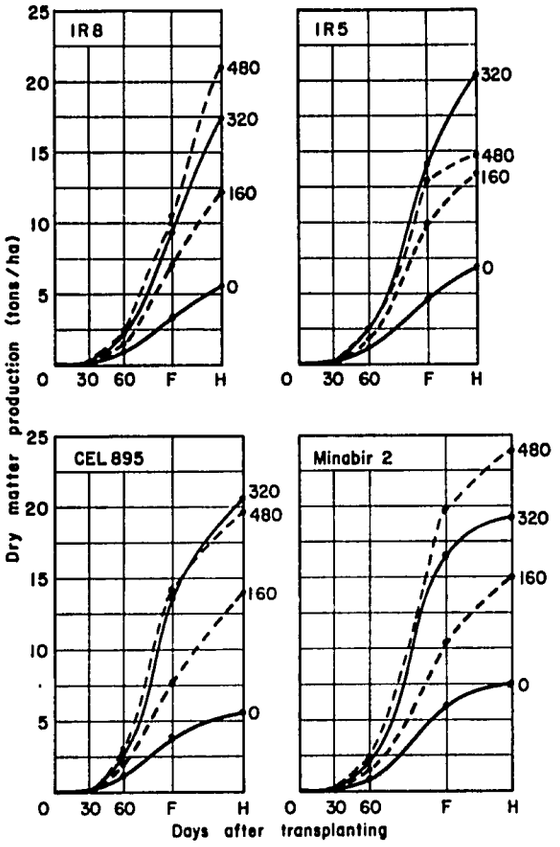

Fig. 6. Dry matter production patterns as affected by N rate.

Table 1. Linear correlation coefficients between grain yields and other growth parameters.

Dependent variable	IR8	IR5	CEL 895	Minabir	All
Total dry matter	0.99**	0.96**	0.99**	0.74*	0.83**
Dry matter increase, flowering to harvest	0.91**	0.74*	0.87**	-0.05	0.75**
Dry matter increase, panicle initiation to harvest	0.99**	0.90**	0.99**	0.77*	0.91**
N accumulated at harvest	0.98**	0.96**	0.90**	0.70	0.83**
N accumulated at flowering	0.98**	0.94**	0.84**	0.71	0.59**
N accumulation increase, 61 days to harvest	0.98**	0.92**	0.87**	-0.46	0.74**
% N at harvest	0.53	0.84**	0.61	0.48	0.58**
% N at flowering	0.75**	0.54	0.57	0.77*	0.61**
Panicles/m²	0.99**	0.95**	0.95**	0.80*	0.94**

* Significant at the 5% level. ** Significant at the 1% level.

kg of applied N (Fig. 5). The earlier-maturing cultivars clustered at the upper end and the later maturing varieties at the lower end (Fig. 5).

These three measurements of yield efficiency emphasize the importance of growth duration on N response. In hot tropical climates where growth duration varies little in cultivars not sensitive to photoperiod, these relationships are not likely to apply.

Dry matter production. The dry matter production pattern of the four cultivars at four N levels appears in Fig. 6. Unlike previous reports (5, 26), total dry matter production was highly correlated with grain yields (Table 1). The increase in dry matter from flowering to harvest was also highly correlated with yields in all cultivars except Minabir 2. The increase in dry matter production from approximately the panicle initiation stage to harvest was highly correlated with grain yields in all cultivars. This agrees with previous findings from the Philippines (5, 6) in

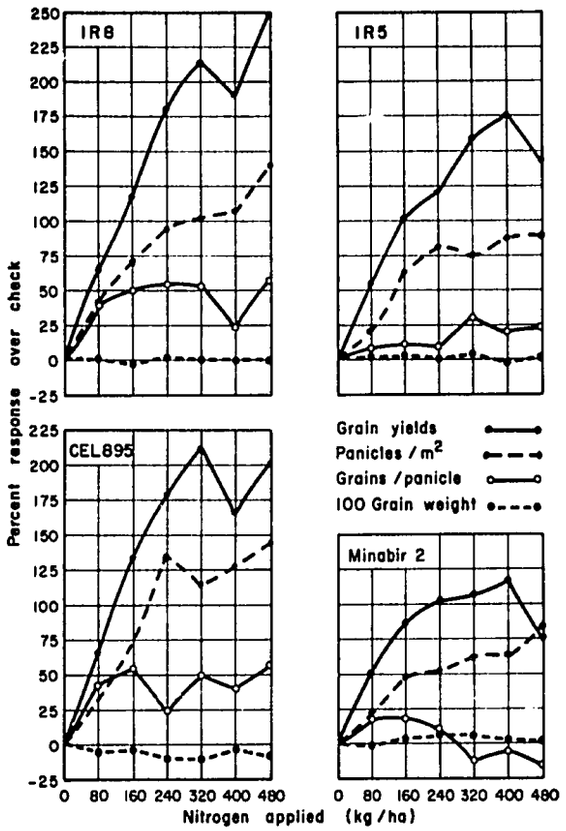

Fig. 7. Relative contributions of yield components on N response.

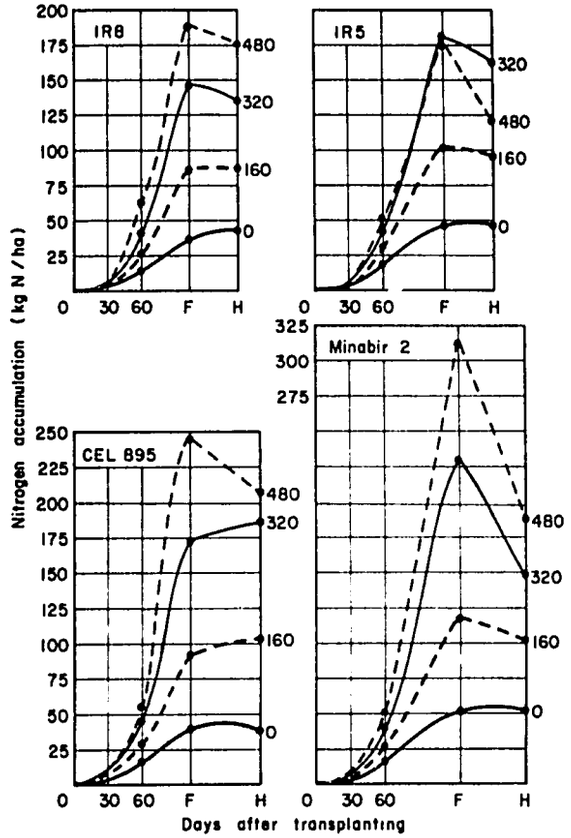

Fig. 8. Nitrogen accumulation pattern as affected by N rate.

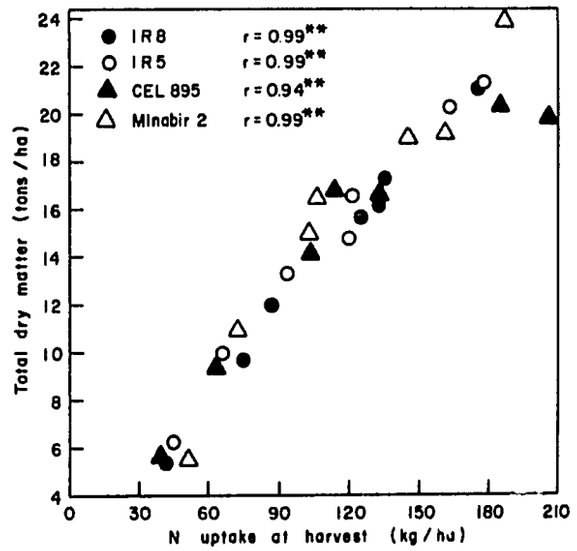

Fig 9. Correlation between total dry matter and N accumulation.

spite of the substantially longer duration of these periods at Lambayeque.

Yields components. The relative contribution of the three yield components to grain yields is illustrated in Fig. 7. Grain yields were highly correlated with the number of panicles per m² (Table 1). The number of filled grains per panicle contributed to yield increases primarily at low N levels and to yield decreases in Minabir 2 at high N levels. The 100-grain weight had little influence on grain yields, suggesting that N response is primarily a function of effective tillering capacity and that panicle size has a limited role in this environment.

Nitrogen Relations

Accumulation. The N accumulation pattern with time apears in Fig. 8. Maximum accumulation was attained at flowering. Very little change between flowering and harvest occurred at N rates that gave linear grain yield responses. Large declines in N accumulation after flowering were observed at high N rates in IR5, CEL 895, and Minabir 2. The reasons for these declines are not known. Losses of up to 30% of the maximum N accumulation have been previously reported (27) and attributed to N leaching from lower leaves by dew or rain under conditions of mutual shading. Although rainfall is negligible at Lambayeque, dew is very common in the morning.

Total N accumulated at harvest, N accumulated at flowering, and increases in N accumulated from panicle initiation to harvest were highly correlated with grain yields in all cultivars except Minabir 2 (Table 1).

Internal N requirement. Total dry matter production was highly correlated with N accumulation at harvest (Fig. 9). Maximum grain yields in each cultivar were associated with an N content at harvest ranging from 0.81 to 0.90% and averaging 0.85%. Maximum grain yields were associated with an extremely narrow range of total N accumulated at harvest, 176

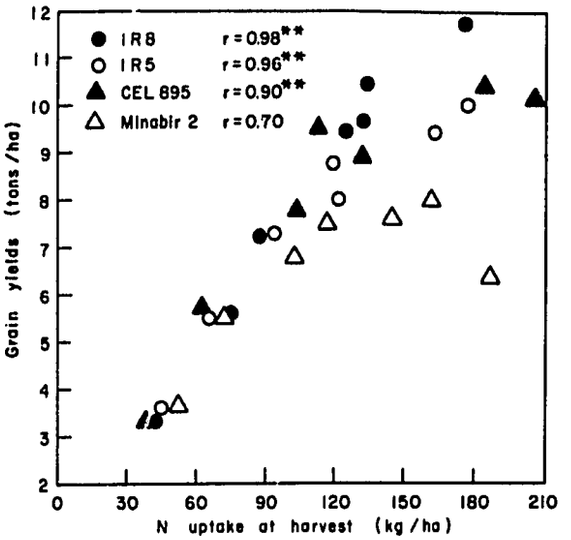

Fig. 10. Correlation between grain yields and N accumulation.

to 184 kg N/ha in all varieties except Minabir which required 162 kg N/ha (Fig. 10). The closeness of these figures suggests the existence of an internal N requirement (25) for rice at Lambayeque of 0.85% N and an optimum N accumulation of about 180 kg N/ha for maximum yields in cultivars highly responsive to N. Stanford's concept of internal N requirement as a means of better estimating N needs of crops has not been previously applied to rice data. Under Lambayeque conditions the values for rice are lower than those reported for corn (*Zea mays* L.), forage sorghum (*Sorghum bicolor* (L.) Moench.), spring wheat (*Triticum aestivum* L.) and several tropical grasses (25).

On the average, IR8, IR5, and CEL 895 required 13.8 kg of N per ton of grain yield, and the less efficient Minabir required 17.7. The overall requirement for producing one ton of dry matter averaged 7.57 kg N with little variation among cultivars or N rates. All these figures refer to N accumulation at harvest.

Recovery of fertilizer N. The total N accumulated by the unfertilized plots averaged 44 kg N/ha and ranged from 39 to 51. The linear nature of the relationship between total dry matter and N accumulation permits an estimation of fertilizer recovery based on uptake differences at harvest (25). Such calculations indicate an average recovery of 30% with a range from 15.6 to 45.5 (Table 2). Recovery values were fairly constant at rates from 80 to 320 kg/ha and declined at higher rates.

Fertilizer N losses of about 70% are higher than field estimates from constantly flooded situations, which range from 40 to 50% with adapted cultivars and adequate cultural practices (19). This could be attributed to the effect of alternate oxidation-reduction conditions, which is known to cause large N losses (17, 18). The mechanisms of N losses, although not investigated in this study, were probably denitrification and leaching of nitrates formed while the soil was oxidized. Although urea was broadcast on a soil with pH 8.3, previous reports indicate that this source is about as efficient as ammonium sulfate under conditions of alternate flooding and drying (20).

Table 2. Percent apparent recovery of fertilizer N as affected by cultivar and N rate.

N applied	IR8	IR5	CEL 895	Minabir 2	Mean
kg/ha			%		
80	40.1	27.5	29.7	26.1	30.9
160	27.7	30.9	40.1	31.8	32.6
240	34.4	32.1	31.1	23.1	30.2
320	29.0	37.0	45.5	29.2	35.1
400	22.5	33.3	23.3	27.6	26.7
480	27.9	15.6	35.1	28.4	26.7
Mean	30.3	29.4	34.1	27.7	30.4

Overall water shortages and inefficiency of distribution systems preclude the possibility of constant flooding in this rice area. The high N rates needed to attain maximum rice yields are caused by the low fertilizer N recovery. Because costs of production are high (21) and the possibility of better water management low, the best avenue to reduce fertilization costs is probably in the area of increasing the efficiency of N utilization through improved N sources, placement, and timing.

CONCLUSIONS

The varietal response to N under high solar radiation, low night temperatures, and intermittent flooding differs from that in hot tropical conditions (4, 5, 6) in both yield and rate axis, and from similar climatic conditions in temperate latitudes (11, 13) primarily in the rate axis. The importance of growth duration as a factor affecting N response is perhaps the most notable characteristic of this environment. The high yields obtained are partly due to the beneficial effects of high solar radiation (6, 14) and low night temperatures (26), which are associated with shorter plant height, high grain:straw ratios, and higher panicle production.

The high N rates required to obtain optimum yields are partly due to the high N requirement of the rice plant, 180 kg N/ha, and large losses of applied N under intermittent flooding.

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