Effect of Panicle Size on Grain Yield of IRRI-Released Indica Rice Cultivars in the Wet Season

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Abstract: Grain yield under wet season (WS) conditions has gradually received more attention due to looming scarcity of irrigation water, which limits the area for planting to flooded lowland rice in the dry season in the tropics. This study was conducted to determine (1) grain yield of IRRI (International Rice Research Institute)-released rice cultivars under WS conditions and (2) if panicle size (spikelet number per panicle) is an important trait that influences grain yield in the WS. Field experiments were conducted at the IRRI farm in the 2000 WS and 2001 WS using 14 IRRI-released conventional and two F1 hybrid cultivars under irrigated lowland conditions. Grain yield and yield-related traits were measured at maturity. Grain yield of tested cultivars ranged from 4.5 to 7.0 t ha⁻¹ in the 2000 WS and from 4.1 to 5.6 t ha⁻¹ in the 2001 WS. Large differences in panicle number and panicle size were observed among cultivars. All cultivars had small to intermediate panicle size ranging from 63 to 114 spikelets per panicle. Among all the measured yield-related traits, panicle size had the most consistent and closest positive correlation with grain yield. These results suggest that it is possible to improve maximum attainable yield in WS by breeding cultivars with larger panicle size. However, whether other cultivar groups such as the tropical japonica with large panicles (150-200 spikelets per panicle) would confer high yield in WS remains to be studied.

Keywords: Grain yield, Panicle size, Solar radiation, Rice, Wet season.

The area for planting to flooded lowland rice in the dry season (DS) is largely limited by irrigation. Due to the looming scarcity of water, rice production in the wet season (WS), therefore, may be an important practice. In WS, however, cloudiness with resulting lower solar radiation is very common. At the International Rice Research Institute (IRRI) farm, 20-year weather data (Climate Unit, IRRI) showed that the average solar radiation is 10.9% lower in WS than in DS. This difference could reach as high as 18% in a year. Because the yield potential of rice crop is determined by solar radiation at the reproductive stage (Yoshida and Parao, 1976; Evans and De Datta, 1979; Seshu et al., 1989; Mitchell et al., 1998), low solar radiation has been considered one of the major yield constraints in WS (Yoshida, 1972).

Adaptability to low solar radiation level varies with the genotype. Under WS condition when solar radiation is limiting, the suitable plant type may differ from that under DS conditions. Increase of yield in the low-radiation environments by using suitable plant type has been pointed out (Horie et al., 1997; Ponnuthurai et al., 1984). However, information regarding the plant type that is suitable for WS cropping is scarce. Singh et al. (1988) reported that 30-60% of yield losses occur primarily in medium to long duration rice cultivars under cloudy conditions. Early maturing cultivars and those with a lower leaf area and higher chlorophyll content were efficient under low light intensities (Singh et al., 1988).

It is known that productive tiller percentage and panicle numbers are largely influenced by total solar radiation (Yoshida, 1981). Under a high-yield environment without stress, increasing sink size or the number of spikelets per unit land area can be achieved either by increasing panicle number or panicle size (spikelet number per panicle) (Takeda, 1984). However, when radiation is limited such as in WS, it is difficult to improve grain yield by increasing panicle number because solar radiation has large effect on tillering capacity and productive tiller percentage (Peng et al., 2000). This suggests that grain yield in WS may be improved by increasing panicle size. This study was conducted to determine the plant type that would be most suitable for WS conditions using IRRI-released indica rice cultivars and F1 hybrids having small to intermediate panicle size.

Materials and Methods

1. Plant materials

Field experiments were conducted at the IRRI farm in the 2000 and 2001 WS. Pregenerated seeds...
were sown on seedling trays to produce uniform seedlings. In the 2000 WS, 14-day-old seedlings of 14 IRRI-released conventional indica-type and two indica-indica F1 hybrid cultivars for lowland rice were transplanted on 21 June 2000 at a hill spacing of 20×20 cm with four seedlings per hill. The same cultivars (excluding IR64) at the same seedling age were transplanted at the same hill spacing on 6 June in the 2001 WS. Those cultivars were chosen because they were released after 1983 and had a large variation in the number of spikelets per panicle in previous studies conducted at the IRRI farm. In both experiments, cultivars were laid out in a randomized complete block design with four replicates. The plants received a basal fertilizer supply of 15 kg P ha⁻¹, 20 kg K ha⁻¹, and 5 kg Zn ha⁻¹ incorporated 1 d before transplanting. Total N fertilizer was 70 kg ha⁻¹ applied in the form of prilled urea and in three splits: 20 kg ha⁻¹ 1 d before transplanting, 20 kg ha⁻¹ at midtillering, and 30 kg ha⁻¹ at panicle initiation (PI) based on the growth stage of IR72, a standard check variety. Midtillering is the midpoint between transplanting and PI. Standard cultural management practices were followed in both field experiments. To avoid yield loss, pests were intensively controlled using recommended pesticides. Fields were flooded 4 days after transplanting and a water depth of 5 to 10 cm was maintained until 7 d before physiological maturity of each cultivar when fields were drained.

2. Yield and yield components
At physiological maturity, grain yield (rough rice) was measured from a 5-m² area and adjusted to 14% grain moisture content. Aboveground total dry weight and yield components were determined from 0.48-m² area (12 hills). Height was measured from the base of the plant to the flag leaf tip and panicles were counted. Plant samples were separated into straw and panicles. Panicles were hand-threshed and the filled spikelets were separated from unfilled spikelets by submerging them in tap water. Dry weight of each component was determined by oven-drying at 70°C to constant weight to calculate total dry weight, harvest index (HI) and 1000-seed weight. Filled and unfilled spikelets were counted to calculate spikelets per panicle and grain filling percentage (100×filled spikelet/total spikelet number). Daily weather records were obtained from the weather station adjacent to the experimental site.

3. Data analysis
Analysis of variance was performed for each year and error variance was analyzed for heterogeneity. The error variances of two years were homogeneous in all parameters. Therefore, combined analysis of variance across years using mixed model was carried out (SAS, 1982). Year, replications within year, and cultivar × year were considered as random effects. Cultivar means per year were compared based on the Tukey-Kramer Least Significant Difference Test (LSD) at the 0.05 probability level. The relationships between yield and yield components and other growth parameters were determined by correlation analysis.

Results
Table 1 shows the daily solar radiation, minimum and maximum temperatures from June to October in 2000 and 2001. July and October 2000 and August 2001 had lower average radiation than other months. Daily minimum and maximum temperatures were less variable across month compared with solar radiation.
On the average, temperatures from June to October were 0.5°C higher in 2001 than in 2000. Growth duration of tested cultivars ranged from 104 to 124 d in 2000 WS and from 100 to 125 d in 2001 WS (Table 2). On the average, the growth duration was 3 d longer in the 2000 WS than in the 2001 WS. Analysis of variance revealed that year and cultivar interaction was significant for all parameters measured. Significant differences in plant height, total dry weight, and HI were observed among the cultivars (Table 2). PSBRc30 and PSBRc72H produced the highest biomass, which was significantly different from the lowest biomass in IR58 and PSBRc10. Average HI was higher in the 2000 WS than in the 2001 WS (Table 2). Across the two years, the average HI was highest in PSBRc10 and lowest in PSBRc30 with the difference being significant (Table 2). Average plant height and total dry weight across cultivars were similar between the two years. However, across years only slight cultivar differences were observed in total dry weight compared with that of plant height (Table 2).

Large differences in panicle number and panicle size were observed among the cultivars (Table 3). IR58 and IR60 produced about 40% more panicles than PSBRc54 and PSBRc80. All cultivars had low to intermediate panicle size ranging from 63 to 114 spikelets per panicle and no difference was observed between the two years. PSBRc26H, PSBRc72H, and PSBRc80 produced highest yield in the 2000 WS and PSBRc26H and PSBRc80 produced highest yield in the 2001 WS. Average grain yield across cultivars was 11% higher in the 2000 WS than in the 2001 WS.

Correlations between the 2000 WS and 2001 WS were statistically significant in yield and yield-related traits of tested cultivars (Table 4). Differences in 1000-seed weight, plant height, growth duration, and grain filling percentage among the cultivars were very consistent across the two years. Cultivar means of total dry weight, HI, panicle number and spikelets per panicle in the 2000 WS were also highly correlated to those in the 2001 WS. However, variability in grain yield across the two years was greater than in the yield-related traits.

Growth duration, plant height, total dry weight and 1000-seed weight were significantly correlated with grain yield only in the 2000 WS (Table 5). Grain filling percentage was not correlated with grain yield in either year. Panicle number was negatively correlated with grain yield in the 2001 WS. Positive and significant correlation was observed between HI and grain yield in both years. Spikelets per panicle exhibited the most consistent and closest relationship with grain yield (Table 5, Fig. 1) compared with other yield-related traits. Among the yield-related traits, growth duration was positively correlated with plant height, total dry weight and spikelets per panicle but negatively correlated with HI and grain filling percentage (data not shown). Plant height was positively correlated with total dry weight and spikelets per panicle. **Significant at the probability level of 0.01.**

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**Table 3.** Yield components and grain yield of IRRI-released rice cultivars grown at the IRRI farm in the 2000 and 2001 wet seasons.

| Cultivars’ | Panicle number (m²) | Spikelets per panicle (%) | Grain filling (%) | 1000-seed weight (g) | Grain yield (t ha⁻¹) |
|-----------|---------------------|---------------------------|-----------------|---------------------|-------------------|
| 2000      |                     |                           |                 |                     |                   |
| IR58      | 417.2               | 63.0                      | 82.2            | 20.2                | 4.49              |
| IR60      | 371.9               | 98.4                      | 67.5            | 19.2                | 5.19              |
| IR66      | 320.5               | 75.8                      | 78.1            | 24.6                | 4.47              |
| IR67      | 357.8               | 106.3                     | 75.8            | 20.1                | 5.65              |
| IR72      | 368.2               | 77.8                      | 69.5            | 20.6                | 4.56              |
| PSBRc04   | 345.1               | 79.2                      | 82.6            | 21.8                | 5.01              |
| PSBRc10   | 316.5               | 95.7                      | 71.6            | 22.6                | 5.43              |
| PSBRc20   | 392.9               | 98.2                      | 79.7            | 21.3                | 5.65              |
| PSBRc26H  | 396.2               | 108.1                     | 73.2            | 22.3                | 6.04              |
| PSBRc28   | 333.3               | 89.4                      | 78.5            | 22.4                | 5.62              |
| PSBRc30   | 361.5               | 85.4                      | 71.1            | 23.6                | 5.48              |
| PSBRc32   | 367.2               | 90.9                      | 72.7            | 19.9                | 5.54              |
| PSBRc54   | 265.5               | 112.3                     | 73.0            | 21.9                | 5.25              |
| PSBRc72H  | 312.9               | 109.4                     | 67.9            | 25.7                | 6.38              |
| PSBRc80   | 299.5               | 110.0                     | 75.9            | 23.1                | 6.19              |
| Mean      | 306.9               | 92.3                      | 74.5            | 22.6                | 5.46              |
| LSD (0.05) | 40.8              | 8.8                     | 5.1             | 0.5                 | 0.53              |

**Table 4.** Correlation between 2000 wet season and 2001 wet season in growth and yield components of IRRI-released rice cultivars grown at the IRRI farm.

| Parameter | Correlation coefficient (r) |
|-----------|-----------------------------|
| Growth duration | 0.99**                     |
| Plant height | 0.94**                     |
| Total dry weight | 0.81**                     |
| Harvest index | 0.83**                     |
| Grain filling percentage | 0.86**                     |
| Panicle number | 0.76**                     |
| Spikelets per panicle | 0.82**                     |
| 1000-seed weight | 0.95**                     |
| Grain yield | 0.90**                     |

*All cultivars are indica inbreds, except for PSBRc26H and PSBRc72H, which are F1 indica-indica hybrids.
per panicle but negatively correlated with HI and grain filling percentage. There was a positive correlation between HI and grain filling percentage but a negative correlation between panicle number and spikelets per panicle.

**Discussion**

Maximum attainable rice yield in the tropical irrigated system is 5-6 t ha\(^{-1}\) in WS and 9-10 t ha\(^{-1}\) in DS (Yoshida, 1981). Large variation in WS grain yield was observed among IRRI-released indica rice cultivars in this study, suggesting that it is possible to further improve the maximum attainable grain yield in WS. PSBRc26H, an indica/indica \(F_1\) hybrid, produced nearly 7.0 t ha\(^{-1}\) although PSBRc80, a conventional indica cultivar, yielded 6.2 t ha\(^{-1}\) in the 2000 WS. In 1994 WS, PSBRc52, a conventional indica cultivar, produced 7.2 t ha\(^{-1}\) and IR66877H, an indica/indica \(F_1\) hybrid, yielded 7.1 t ha\(^{-1}\) in the 1997 WS (unpublished data). Climatic data also supports our view that the maximum attainable grain yield in WS should not differ from that in DS by 4 t ha\(^{-1}\) as reported by Yoshida (1981). Long-term weather data from 1979 to 2001 indicate that the average solar radiation in DS was only 13% higher than that in WS (Table 6). In 1996, average solar radiation in WS was even slightly higher than that in DS, respectively. If disease and pest can be controlled effectively and lodging will not occur, on the basis of the difference in solar radiation in the long-term weather data, the difference in grain yield between DS and WS would be 2.0-2.5 t ha\(^{-1}\).

Yield potential of irrigated rice cultivars has been stagnant at the level of 10 t ha\(^{-1}\) in DS since the release of IR8 in the 60’s (Flinn et al., 1982; Akita, 1994; Peng et al., 1994). Efforts have been devoted to develop new plant type (NPT) at IRRI with the goal of breaking the yield barrier since late 1980’s and early 1990’s (Khush and Peng, 1996). However, NPT lines have not yet yielded over 10 t ha\(^{-1}\) under tropical irrigated condition in DS. We argue that closing the yield gap between DS and WS could be a more effective approach to increase rice production in the tropics compared with improving the yield potential of rice cultivars in DS, especially in the rice growing areas where water is limiting.

Our study indicates that the cultivars with intermediate panicles (100-115 spikelets per panicle) produced higher grain yield than the cultivars with small panicles (60-80 spikelets per panicle). It is unknown if increasing panicle size over 115 spikelets per panicle can further increase grain yield in WS.
observed that the relative performance of the NPT lines with 150-200 spikelets per panicle was better in WS than in DS (Visperas et al., 2000). However, large panicle is not always associated with high yield in WS. Large panicle often results in reduced panicle number and poor grain filling percentage. Cultivars with large panicles also have greater plant height (Visperas et al., 2000), and longer growth duration (Akita, 1988), which are undesirable traits in relation to lodging resistance.

Why would cultivars with larger panicles perform better than the cultivars with small panicles in WS? Firstly, cultivars with larger panicles produced fewer tillers than the cultivars with smaller panicles (Ise, 1992; Peng et al., 1994; Khush and Peng, 1997). We speculate that the rice crop with fewer tillers will have a better canopy structure for light interception than the one with more tillers. The fewer tiller is an important characteristic for maintaining a high canopy photosynthetic rate when light is a limiting factor. Secondly, solar radiation has a large effect on tillering capacity and productive tiller percentage (Yoshida, 1981). The yield of cultivars with small panicles depends heavily on panicle number, which is largely reduced under limited radiation such as in WS. On the other hand, cultivars with an extremely high number of tillers would have greater consumption of stored materials by excessively bigger sink size (Yoshida and Parao, 1976; Khush and Peng, 1996; Lee and Ha, 1999). Consequently, these stored materials, which are important under a low solar radiation condition (Laza et al., 2003), will be reduced and less will be translocated to the grains. In addition, increases in tiller number cause overgrowth and mutual shading during the vegetative stage (Akita, 1988), which could be detrimental to leaf area index (LAI) and crop growth rate. Excessive LAI could lead to increase in percentage of unfilled grain especially when solar radiation is low (Takeda, 1985) as in the WS condition.

On the other hand, rice crops with intermediate tillers would have reduced LAI necessary for intercepting solar radiation and would allow even distribution of light in the canopy (Murata, 1995).

Grain yield in the 2000 WS was 0.6 t ha⁻¹ greater than that in the 2001 WS. This yield difference was associated with HI but not with total dry weight (Table 5). Sink formation (spikelets and panicle numbers) and 1000-seed weight were also similar between the two years and cultivar differences across years were significant (Table 5). Grain filling percentage was generally greater in the 2000 WS than in the 2001 WS. This difference could be explained by the differences in weather conditions between the two years (Table 6). Although the average radiation from transplanting to maturity was slightly higher in the 2001 WS, solar radiation and sunshine hours during the grain filling period between flowering and maturity was 4% higher and 15% longer, respectively, in the 2000 WS than in the 2001 WS. These differences could partly explain the higher grain filling percentage in the 2000 WS.

In conclusion, the difference in grain yield among the tested cultivars was attributed mainly to the variation in spikelets per panicle whereas the difference in grain yield between the two years was associated with the grain filling percentage. IRRI-released rice cultivars can produce as high as 7 t ha⁻¹ under a WS condition in the tropical irrigated rice system. The positive relationship between grain yield and panicle size (Fig. 1) in this study suggests that it is possible to improve maximum attainable yield in WS by breeding cultivars with larger panicle size. Further study is underway to determine other morphophysiological traits that confer high yield in WS using other cultivar groups such as tropical japonica with large panicles (150-200 spikelets per panicle) and low tillering capacity.

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