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PERFORMANCE OF IMPROVED RICE VARIETIES IN THE TROPICS WITH SPECIAL REFERENCE TO TILLERING CAPACITY

By SHOUICHI YOSHIDA AND F. T. PARAO

*The International Rice Research Institute**

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SUMMARY

The growth of improved short varieties of rice with low and high tillering capacities was compared under a wide range of nitrogen levels and spacings. A high tillering variety performed better than a low tillering one under the experimental conditions tested. Leaf area index values as high as 10 to 12 were not detrimental to grain production unless the crop lodged.

Rice varieties differ in their tillering capacity, high-tillering varieties being usually preferred in countries where transplanting is common, e.g. the variety Hoyoku in Japan, Taichung Native 1 in Taiwan, and IR8 in the Philippines. On the other hand, where direct sowing is generally practised, low-tillering varieties are preferred, such as Century Patna 231 in the U.S.A. Holliday (1960), Yamada (1961), and Matsuo (1964) have reviewed the literature on interactions between plant characters, spacing, and nitrogen. Matsuo stated that the yields of short, heavy-tillering varieties are greatly affected by nitrogen and, to a lesser degree, by spacing. Irrespective of tillering capacity, the yields of tall varieties are less responsive to nitrogen, presumably because they lodge.

In transplanted rice, close spacing and heavy application of nitrogen are indispensable for achieving sufficient leaf area development for high yields. Leaf area development in transplanted rice is primarily determined by the number of tillers per unit land area, number of leaves per tiller, and average leaf size, of which attributes the tiller number is the most variable. Leaf area development of a rice variety is therefore closely related to its tillering capacity at conventional spacing.

A high tillering variety tends to have vigorous vegetative growth, which has been thought to lead to detrimental mutual shading, and eventually to low grain yields. For this reason a medium tillering capacity was believed to be a desirable trait for high-yielding varieties (Beachell and Jennings, 1962). In addition there have been indications that an optimum spacing (Tanaka *et al.*, 1964) and an optimum leaf area index (Tanaka and Kawano, 1966) exist for rice varieties in the tropics.

If vigorous tillering tends to create detrimental mutual shading, a low-tillering variety, when sown directly at high seeding rates, should perform better than a high-tillering variety provided the other characters of the two varieties are the

* Present address: The International Rice Research Institute, M.C.C. P.O. Box 1300, Makati, Rizal D-708, Philippines.

same. Direct seeding usually creates a much higher plant density than transplanting.

IR8, released in 1966 by the International Rice Research Institute, is short, high tillering, and resistant to lodging. It is highly responsive to nitrogen (De Datta *et al.*, 1966, 1968) and performs well under diverse climatic conditions (IRRI, 1966), suggesting that a high tillering capacity is desirable for a commercial variety. Under the low-level management commonly practised by farmers in tropical Asian countries, insufficient leaf area development or an insufficient number of panicles tend to limit grain yields, so high tillering capacity seems desirable.

Among the rice varieties that were available in the tropics at the start of this study, none were both short and low tillering. High-tillering varieties are either tall or short, but low-tillering varieties are usually medium to tall. Therefore, the varieties with different tillering capacities, whose performance was to be examined, also had different plant heights. As a result the degree of lodging always made it extremely difficult to draw any definite conclusions, particularly when close spacings and high nitrogen levels were used.

This discussion points the need for critical evaluation of the tillering capacity of new rice varieties under a tropical environment, and the paper describes the growth performance of new, improved varieties under a wide range of spacings and nitrogen levels.

MATERIALS AND METHODS

Experiment 1. Preliminary observation trial

Seeds of twenty varieties or experimental lines (the word 'variety' is used hereafter to refer to either lines or varieties), provided by the varietal improvement department of the International Rice Research Institute, were sown in seed boxes on 3 March 1967. Two weeks later seedlings were transplanted at spacings of 20 × 20 cm. (20 m.^{2} plot) and 100 × 100 cm. (70 m.^{2} plot), on plots that had received 150 kg./ha. N, with two replications. Twenty hills at 20 × 20 cm. and 10 hills at 100 × 100 cm. were randomly staked for weekly counts of tillers.

Experiment 2. Response to different spacings

Six varieties were selected, based on the results of Experiment 1, and planted on 6 July in the wet season and on 13 December in the dry season. Eighteen-day-old seedlings were transplanted with 0 or 100 kg./ha. N at five spacings, 10 × 10 20 × 20, 30 × 30, 40 × 40 and 50 × 50 cm. Tiller density (number of tillers divided by the cross-sectional area in square centimetres 15 cm. from the ground) was measured in two varieties.

Experiment 3. Response to nitrogen application

The same six varieties used in Experiment 2 were planted at 20 × 20 cm with 0, 30, 60, 90 or 120 kg./ha. N.

Experiment 4. *Performance in direct seeding*
IR8 and IR154-45-1 were broadcast at 50, 100 and 200 kg./ha. with 100 kg./ha. N on 15 January 1968 (dry season) and 3 July 1968 (wet season). Forty days after seeding they were top-dressed with 30 kg./ha. N. Samples for yield components were taken with a 50 × 50 cm. wooden quadrat and samples for grain yield with a 2 × 3 m. wooden quadrat.

Experiment 5. *Leaf area index and grain yield*
Data on grain yield and leaf area indices (LAI) of IR8 at flowering were collected from various field experiments. These experiments, conducted in the wet and dry seasons from 1966 to 1969, included nitrogen levels ranging from 0 to 200 kg./ha. N and spacings from 10 × 10 cm. to 100 × 100 cm. The data from lodged plots were discarded.

All the plots in all experiments received 40 kg./ha. P_2O_5 and 40 kg./ha. of K_2O. Seedlings were transplanted at one plant per hill, with the customary procedures at the Institute for disease, pest, and rat control. Except in Experiment 1, each plot was 40 $m.^2$ in size and each treatment was replicated three times in a split-plot design. Leaf area was measured with an automatic area meter (Murata and Hayashi, 1967). Data on grain yields were collected from an area of 6 $m.^2$ and reported as rough rice at 14 per cent moisture. The climatic environment of the experimental site is described in annual reports of the International Rice Research Institute (IRRI, 1966, 1967, 1968, 1969).

RESULTS

Preliminary observation trial
In the preliminary observation trial the coefficients of variation of panicle number for twenty varieties were 20 per cent at 20 × 20 cm. spacing and 31 per cent at 100 × 100 cm. (Table 1). Since greater variability was found at the wide spacing than at the close spacing, the tillering capacity of a variety is better assessed at the wide spacing. At 100 × 100 cm. spacing, 90 to 99 per cent of the tillers bore panicles, so, the number of panicles was approximately equal to the total number of tillers produced. Grain yield was closely related to panicle number at the wide spacing: the larger the panicle number, the greater the grain yield. Thus a high tillering variety is better suited to the wide spacing than a low tillering one.

Table 1. *Range of grain yields, average panicle weights, and panicle numbers of twenty varieties at wide and close spacings*

	Yield (t./ha.)		Average panicle weight (gm)		Panicles (no./hill)	
	20 × 20 cm	100 × 100 cm.	20 × 20 cm.	100 × 100 cm.	20 × 20 cm.	100 × 100 cm.
Minimum	3·32	0·82	1·6	1·1	10	44
Maximum	7·2[illegible]	2·56	2·4	4·4	20	135
Means	5·52	1·53	2·0	2·5	15	83
C.V. (per cent)	21	29	20	30	20	31

The average panicle weight had greater variation coefficients at the wide spacing than at the close spacing (Table 1), the coefficients in turn being

Table 2. *Growth characteristics of the selected six varieties grown at 100 × 100 cm. spacing with 150 kg./ha. N*

Variety	Tillering capacity: Panicle number	Tillering capacity: Grade	Height (cm.)	Growth duration (days)
IR154-45-1	48	Low	103	103
IR165-34-2	58	Medium	98	114
IR154-68-3	58	Medium	99	108
IR154-30-3	64	Medium	98	103
IR8	94	High	106	120
IR154-18-2	94	High	104	106

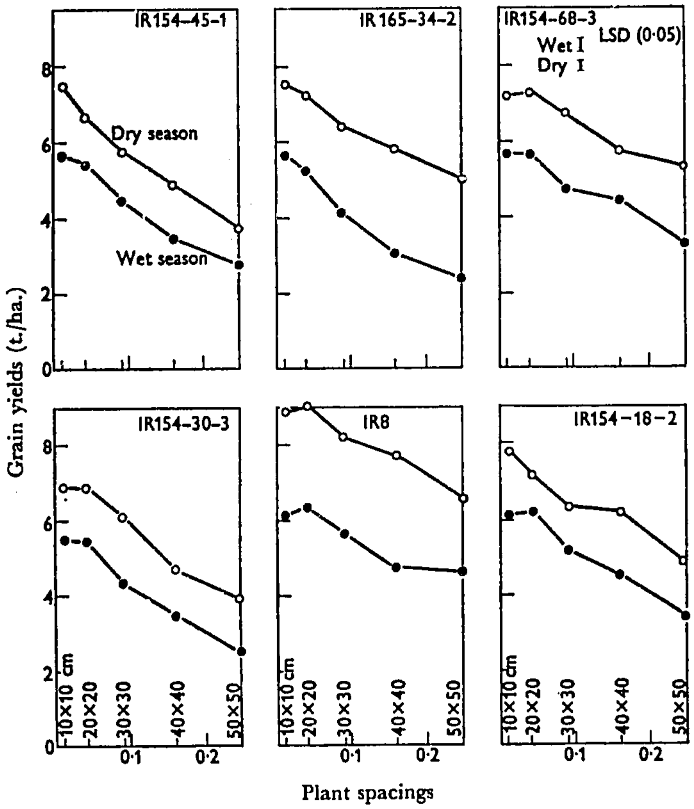

Fig. 1. Response of six rice varieties to different spacings (wet and dry seasons 1968).

associated with greater variation in panicle number. At 100 × 100 cm. spacing the average panicle weight was inversely related to panicle number. Low-tillering varieties tended to produce few heavy panicles and high-tillering varieties many light ones.

Guided by our observations on tillering capacity and other characters such as yielding ability, plant height, disease resistance, and growth duration, we selected

Table 3. *Yields of six varieties in relation to spacing and nitrogen application (means of two seasons)*

Variety	Grain yield (t./ha.) 50×50 cm.	Grain yield (t./ha.) 10×10 cm.	Increase (per cent)	Grain yield (t./ha.) 0 N	Grain yield (t./ha.) 120 kg./ha. N	Increase (per cent)
IR154-45-1	3·27	6·60	102	3·56	5·96	67
IR165-34-2	3·67	5·59	52	3·49	5·60	60
IR154-68-3	4·27	6·46	51	3·86	6·32	64
IR154-30-3	3·22	6·22	93	3·59	5·89	64
IR8	5·59	7·50	34	4·76	7·26	53
IR154-18-2	4·10	6·98	70	4·09	6·70	64

Table 4. *Changes in tiller density at about panicle initiation stage as affected by spacing*

Spacing (cm.)	Tillers (no./cm.²) IR8	Tillers (no./cm.²) IR154-18-2
10×10	0·85	0·80
20×20	0·59	0·80
30×30	0·51	0·79
40×40	0·51	0·71
50×50	0·41	0·63

six varieties for subsequent studies (Table 2). All six had erect, dark-green leaves, were 100 to 110 cm. tall, resistant to lodging, and matured in 100 to 120 days.

Response to spacing

Yields of all six varieties responded to spacings up to 20 × 20 cm. and some responded to the 10 × 10 cm. spacing (Fig. 1 and Table 3). The low-tillering variety, IR154-45-1, responded with the highest per cent increase while the high-tillering variety, IR8, responded with the lowest. The relatively high response of IR154-18-2 to spacing was possibly due to its compact tiller arrangement, since even at wider spacings it maintained a relatively compact tiller arrangement whereas IR8 spread its tillers (Table 4). The excessively compact tiller arrangement of IR154-18-2 increased shading within the hill and reduced the average photosynthetic activity per tiller, so at wider spacings its high tillering capacity was not a great advantage. Both tillering capacity and tiller arrangement play a role in determining the response of a variety to spacing.

When planted at 20 × 20 cm. with 100 kg./ha. N the leaf area of the high-tillering variety, IR8, developed faster and was larger (LAI = 8·5 at heading) than that of the low-tillering variety IR154-45-1 (LAI = 5 at heading). At conventional spacing (20 × 20 to 30 × 30 cm.) all the tillers produced do not necessarily bear panicles and a low percentage of effective tillers (i.e. the ratio of number of panicles to the maximum number of tillers produced) is often considered an indication of poor performance and a cause of low grain yields.

IR8 had a smaller percentage of effective tillers at the close spacing than at the wide spacing, i.e. 55 per cent at 10 × 10 cm. and 76 per cent at 20 × 20 cm. The grain yields, however, were about the same, indicating that the difference in effective tiller percentage did not affect grain yields. At 10 × 10 cm. with 100 kg./ha. N the high-tillering variety (IR8) had a much smaller proportion of effective tillers (59 per cent) than the low-tillering variety (IR154-48-1) with 84 per cent. Within the range observed, a low percentage of effective tillers may not necessarily be related to low yield if enough tillers or panicles are maintained.

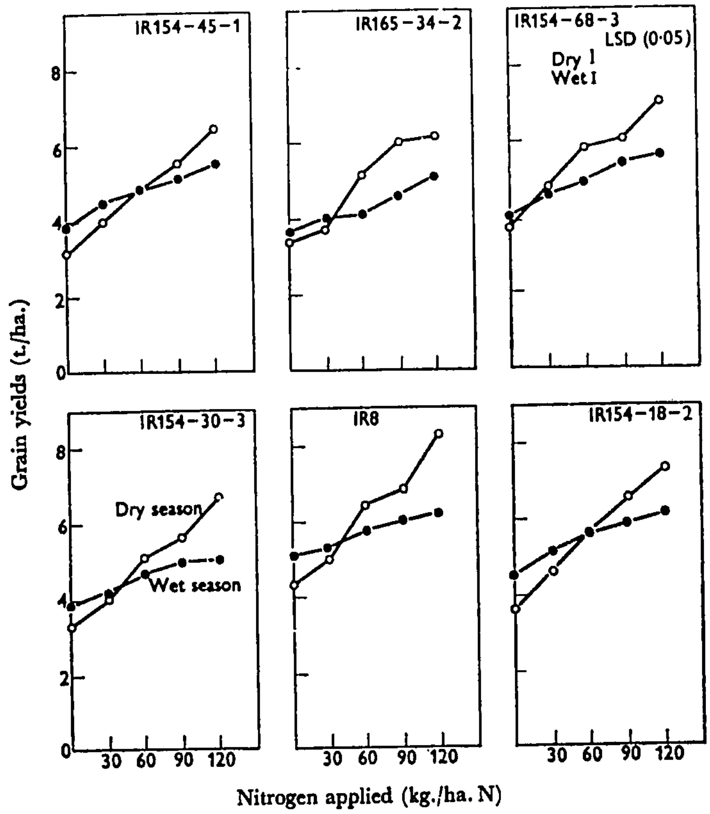

Fig. 2. Response of six rice varieties to different levels of nitrogen (wet and dry seasons, 1968).

Table 5. *Response of low-tillering short variety (IR154-45-1) and high-tillering (IR8) to different seed rates in direct seeding, wet and dry seasons,* 1968

Seed rate (kg./ha.)	Number of plants/m.² (dry season) IR154-45-1	IR8	Panicles (no./m.²) IR154-45-1 Wet	IR154-45-1 Dry	IR8 Wet	IR8 Dry	Yield (t./ha.) IR154-45-1 Wet	IR154-45-1 Dry	IR8 Wet	IR8 Dry
50	205	129	585	530	595	555	4·32	7·27	5·20	7·57
100	416	241	610	662	680	645	4·54	7·34	5·33	7·44
200	800	503	740	667	670	644	4·42	6·81	5·04	7·68

Analysis of variance (grain yield)	Wet L.S.D. (0·05)	Wet C.V. (X) per cent	Dry L.S.D. (0·05)	Dry C.V. (X) per cent
Seed rates (*D*)ⁿˢ	—	—	—	—
Variety**	0·30	—	0·22	6·6
V × *D*ⁿˢ				

Response to nitrogen application

The yield of the six varieties responded similarly to nitrogen application (Fig. 2), the percentage of yield increase attributable to nitrogen application ranging from 53 to 67 per cent (Table 3). The high-yielding variety IR8 showed the lowest percentage of increase in yield, because its yield was high even at 0 N. Yield response to nitrogen was greater in the dry season than in the wet season.

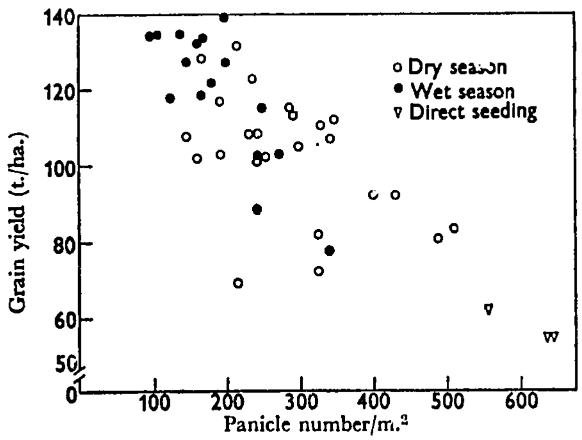

Fig. 3. Relations between panicle number and grain yield.

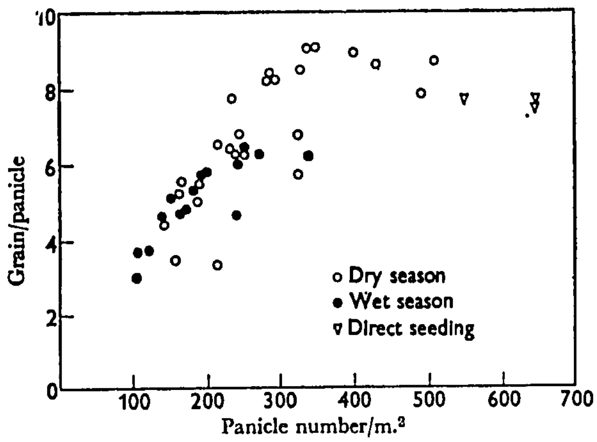

Fig. 4. Relations between panicle number and number of grains per panicle.

Performance in direct seeding

The yields of low- and high-tillering varieties were compared when direct-seeded at different rates (Table 5). Apparently, high seeding rates did not affect the grain yields of either the high-tillering variety (IR8) or the low-tillering variety (IR154-45-1). In other words, the rice plant is extremely tolerant to high plant densities.

Analysis of yield components

Data collected from Experiments 2 to 4 showed that grain yield was closely related to panicle number per square metre up to about 350 to 400 sq. m., beyond which, grain yield was not necessarily related to panicle number (Fig. 3). The number of grains per panicle was inversely related to the number of panicles per square metre, i.e. the more panicles per unit area the fewer grains per panicle. For example, the direct-seeded crop produced more panicles but less grains per panicle than the transplanted crop (Fig. 4).

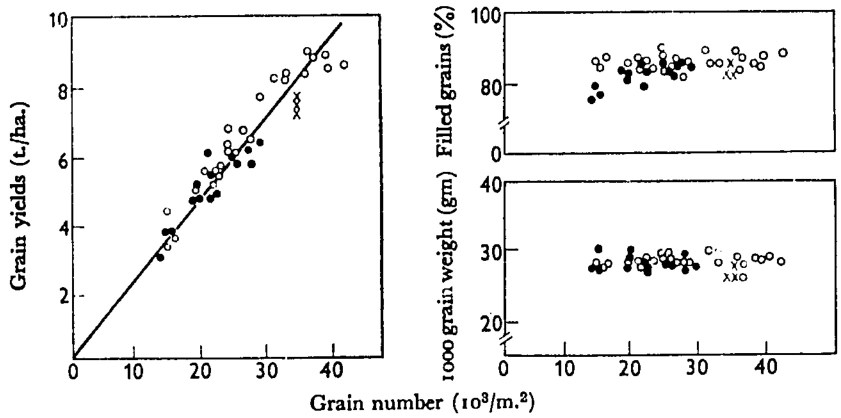

Fig. 5. Relations between grain yield, filled grain percentage and grain weight, Variety IR8. (○ = dry season; ● = wet season; × = direct-seeding.)

Since the number of panicles per square metre and the number of grains per panicle tend to compensate each other, neither is an adequate measure of grain yield under diverse cultural conditions. However, the product of the panicle number per square metre and the grain number per panicle (i.e., the total number of grains per square metre) is linearly related to grain yield (Fig. 5). The dry-season crop produced more grains per square metre than the wet-season crop, and this increase resulted in higher grain yield.

The linear relationship indicates that the total number of grains per square metre is the major factor limiting grain yield and that two other yield components, filled grain percentage and grain weight, do not appreciably affect grain yield within the observed range. In fact, the percentage of filled grains and the 1000-grain weight remained fairly constant regardless of the total number of grains per square metre (Fig. 5).

Relationship between leaf area index and grain yield

The grain yield increased almost linearly with increasing LAI and reached a plateau when LAI value was about 6 (Fig. 6). This indicates that when LAI is below 6, the grain yield of IR8 is closely associated with LAI, and it appears that large LAI values are not detrimental to grain yield.

At low LAI values there was no significant difference between grain yields in the dry and wet seasons but at high LAI values the dry season crop gave much higher yields than the wet season one. Higher grain yields in the dry season have been attributed to higher amounts of solar energy in the dry season (Tanaka *et al.*, 1964; De Datta and Zarate, 1970).

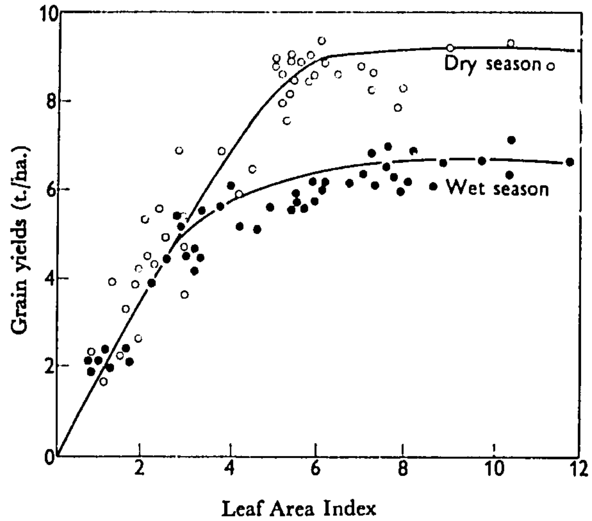

Fig. 6. Relations between grain yield and LAI at flowering in IR8 (wet and dry seasons 1966–9)

DISCUSSION

Our data show why high-tillering rice varieties have an advantage over low-tillering ones in transplanted rice cultivation. A high-tillering capacity makes it easy for the plant to produce enough tillers, or a leaf area index high enough, to enable it to reach maximum yield under a given condition. A high-tillering capacity also enables the plant to compensate for missing hills that may be caused by poor management.

The data also indicate that vigorous growth or a large leaf area of a high-tillering variety is not detrimental to grain yield, as shown by the plateau-type response of grain yield to leaf area index. Data obtained on IR8, a short and erect-leaved variety, indicate that leaf area index values as high as 10 to 12 are not detrimental to grain production unless the crop lodges. The fairly constant percentage of filled grains, regardless of the total number of grains per unit land area, also indicates that a large leaf area index is not detrimental to grain filling. Since at present 9 to 10 t./ha. is the maximum yield we can expect from farmers, high tillering capacity can be considered a desirable trait for high-yielding commercial rice varieties in the tropics.

The absence of any detrimental effects of a large leaf area index on the grain yield of improved varieties may be attributed to the characteristic short stiff culm, high resistance to lodging, and erect leaves which permit efficient penetration of incident light into the leaf canopy. In particular the improved variety IR8 is able to maintain the erect leaf habit even at high nitrogen levels and throughout growth (Yoshida *et al.*, 1969).

Whether the high tillering capacity is still a desirable trait for increasing rice yield further remains to be examined. Both Donald (1968) and Duncan (1969), for different reasons, believe that tillering is undesirable for the maximum yield of cereal crops. A major reason for Donald's advocacy of uni-culm varieties is that the main shoot would have a larger panicle than the tiller, but this appears to be a misconception about panicle size of a crop. It is true that the main shoot has a larger panicle than a tiller within the hill, but the average panicle size of a crop is largely affected by total number of panicles per unit area and does not appear to be affected by whether the panicle is produced by the main shoot or the tiller. Increasing plant density means increasing the number of panicles per square metre produced by the main shoot. For instance, in the direct-seeding experiment, the main shoot of IR8 in the dry season produced 23 per cent of the panicles at the seeding rate of 50 kg./ha. and 78 per cent at the seeding rate of 200 kg./ha., though, the grain yields of these two crops were about the same. If the main shoot always produces a larger panicle than the tiller, the high seeding rate should have produced a higher grain yield than the lower one.

A crop of uni-culm plants would have a more even distribution than a crop of tillered plants, and thus could use incident light better. However, at high plant densities a multi-culm (tillered) variety would approach the uni-culm plant in tillering, and the advantage of a uni-culm variety with even distribution of stands could also be achieved by planting a multi-culm variety at high density. Thus, in rice, high tillering capacity appears to have many advantages.

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