RICE RATOONING

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ABSTRACT

Rice ratoon cropping is considered an alternative for double rice cropping. Because of its short growth duration, low water requirement, and high water use efficiency, a ratoon crop may fit well in rainfed areas on residual moisture left after wet season rice crop or in irrigated areas with limited duration of available water or growing season. Rice ratooning is practiced in several countries. Renewed interest in ratoon cropping for the Asian tropics arises from substantial advances in resistance to rice disease and insect pests. The wide variation in ratoon yields (0.1 and 8.7 t/ha) suggests an encouraging potential for ratoon cropping. This paper reviews literature on rice ratooning with emphasis on the biological mechanism and cultural factors affecting ratooning.

Ratooning ability is a potentially important but complicated varietal character. The major factors affecting ratooning ability, besides the inherent ratooning ability of the cultivars, are light, temperature, soil moisture, and fertility and management. Main-crop growth duration also affects ratooning ability and yield. Component analysis of ratoon grain yield showed that tiller number, growth duration, and 1000-grain weight are the main yield contributing characters. Ratoon crop yield in general is independent of main-crop yield and its components. Ratoon growth duration is thought to be the major factor to emphasize in the improvement of ratoon cropping because it is positively associated with grain yield. Also, precise growth duration would define necessary crop management. The mode of inheritance of ratooning ability has not been firmly established. A few studies suggested ratoon cropping as an economically viable alternative for rainfed lowlands. However, further data are needed to assess the economic feasibility of ratoon cropping. On the bases of the literature review and our own studies we summarize the various factors that determine ratooning ability directly or indirectly and discuss some points that need attention by researchers.

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RICE RATOONING

Rice is the staple food of more than half of the world’s people, and rice production must double in the next 25-30 yr to meet the food demands of a rapidly increasing population. Crop intensification and higher yields are the only way to bridge the increasing gap between food production and consumption in densely populated tropical Asia, because there is little new land available for rice cultivation.

Ratooning, the ability of rice plants to regenerate new tillers after harvest, may be one practical way to increase rice production per unit area and per unit time. Because ratooned rice has shorter duration than a new crop, it may have potential to increase productivity where cropping intensity is limited by inadequate irrigation facilities or by a second crop where the rice season is less than 180 d (94). Besides short duration, it costs less to grow a ratoon crop than a new crop. The major advantages of rice ratooning are:

- lower production cost because of savings in land preparation and plant care during early growth;
- short duration;
- efficient use of the growing seasons, especially in monsoonal climates;
- higher yield per unit area in less time;
- possible maintenance of the genetic purity of a variety or hybrid rice through several seasons; and
- low irrigation water requirements.

Rice ratooning is practiced in several countries (Table 1), and on a commercial scale in the United States of America where about 50% of the Texas rice crop is ratooned (23). Ratooning is practical in some limited areas of China, India, and Japan (71), and seems possible in Brazil, Colombia, Swaziland, Thailand, and the Philippines (68, 71). Ratooning also has been tried in the central mountains of Malagasy (M. Arraudeau, pers. comm., 1983).

In tropical Asia, rice ratooning for large-scale commercial farming has not been accepted, probably because of:

- generally low yields,
- lack of varieties with good ratooning ability,
- inferior grain quality,
- uneven maturity that makes harvest difficult,
- insect and disease problems,
- lack of assured return from investment, and
- lack of proper ratoon cultural practices.

To make ratooning more realistic, productive, and economic, inherent ratooning ability of cultivars must be improved and a suitable package of main- and ratoon-crop management practices developed. This paper reviews the literature on rice ratooning with emphasis on the biological mechanisms and cultural factors affecting ratooning.

RATOOING GRAIN YIELDS

Ratoon crop grain yields vary substantially (Table 1). An Intan ratoon crop yielded 140% of the main crop in Karnataka, India (76). With adequate moisture, the highest ratoon yield at IRRI was 3.3 t/ha with IR2058-78-1-3-2-3 (56). In Ethiopia, an IR8 ratoon yielded an unusual 8.7 t/ha (72). The japonica variety 1300 yielded 0.5-0.7 t/ha in Malagasy. In Malagasy, japonicas have better ratooning ability than indicas (M. Arraudeau, pers. comm., 1983).

Although two or three consecutive harvests can be obtained by ratooning (25), grain yields decline with each. In one instance the first ratoon yielded 54% less than the main crop and the second yielded 59% less.

The wide variation in yields suggests an encouraging potential for ratoon cropping, but much work is needed to identify the yield constraints and to minimize them.

VARIABLE RATOONING ABILITY

Many genotypic differences in ratooning ability have been reported (9, 16, 18, 29, 30, 31, 35, 42, 45, 58, 59, 60, 66, 72, 78, 80, 83, 90). To measure varietal differences in ratooning ability under field conditions or within cultivars, Samson (80) suggested the following rating scale for ratoon vigor:

- Ratoon extra vigorous
  (count basal + nodal ratoons) 1
- Ratoon normal or intermediate
  (count only basal ratoons) 5
- Ratoon very weak and few
  (no counting) 9

**Basal ratoons** - tillers that grow from the nodes of the stubble from the base up to 1 cm above the ground.

**Upper nodal ratoons** - tillers that grow from the nodes of the stubble more than 1 cm above the ground.

**Dead hills** - no ratoons.

Ratoon rating (RR):

\[
RR = (1.0 - 0.1 \text{ ratoon vigor rating}) \times \left(1.0 - \frac{\text{Missing hills/plot}}{\text{Total hills/plot}}\right) \times \left(\frac{\text{Total tillers/hill}}{16}\right)
\]
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<th>Variety</th>
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<th>Grain yield (t/ha)</th>
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*Reference(s)*
A high ratoon rating indicates less than 5% missing hills, at least 16 tillers/hill, and excellent vigor.

Genotypic differences do exist for ratooning ability. This existing variability should be exploited by suitable breeding methods to improve the ratooning ability of rice.

**RATOONING MECHANISM**

The word *ratoon* probably originated from the Latin word *retusus*, which means to cut down or mow (47). Winburne (91) defines a ratoon as a basal sucker for propagation, such as in banana, sugarcane, and pineapple.

Rice ratooning depends on the ability of dormant buds on the stubble of the first crop to remain viable. The buds exist in various stages of development (58). Axillary buds that develop at those nodes grow into ratoon tillers (Fig. 1a, 1b).

In IR5 and IR8, each of the four nodes above the ground has buds with regrowth potential (72). Tillers regenerated from higher nodes formed more quickly, grew faster, and matured earlier. When the main crop was harvested late, ratoon tillers began to develop soon after the first crop ripened. In this situation, the culms of the growing ratoon tillers were damaged because they elongated within the old leaf sheaths (86).

Different varieties produce ratoon tillers differently (87). Kaban 3 grew tillers from all nodes of the stubble, whereas Krasnodarski 424 formed tillers only from lower nodes. Dubovskii 129 developed tillers mainly from the third node. Those and similar findings indicate ratoon crops will yield well if main-crop stubble is left with 2-3 nodes.

The C:N ratio also varied with the origin of ratoon tillers. In Kagi Ban 2, C:N was 17.0 in tillers from upper nodes, 13.8 in those from the base, and 10.8 from those below the soil. Tillers from upper nodes, with higher C:N, reacted like old seedlings. Tillers from the lower nodes, with low C:N, have young-seedling characteristics. Therefore, the development of lower tillers should be encouraged because they resemble young seedlings (44).

Evaluation of 1,500 early- and intermediate-maturing cultivars showed that most regenerated tillers from higher nodes. Thirty to 40% produced tillers from higher and lower nodes (90), which is more desirable. Sixty-seven percent of the ratoon tillers developed by Mingolo were from basal nodes and 33% were from upper nodes (27). In D52-37, ratoon tillers from higher nodes appeared first, flowered sooner, and had fewer leaves than those from lower nodes (6). Ratoon tillers from lower nodes had best yield potential.

In a study on ratoon tiller development of IR44, the lengths of the growing buds at the first, second, and third nodes did not vary. Buds grew slowly for 4 d after cutting. After 5 d, the bud at the first node generally grew faster, followed by those from the second and third nodes. Maximum bud lengths were 235, 159, and 74 mm. The average bud lengths were 144, 45, and 17 mm (Table 2). Eight days after ratooning, the culms began to branch (Fig. 1a, 1b).

Several studies (17, 41, 80) show that ratoon tiller development depends on the carbohydrates that remain in the stubble and roots after the main crop is harvested. The culm of the rice plant is a vital storage organ. Thick culms may store more carbohydrate than thin culms, and probably would be reflected in ratoon potential.
We evaluated IR44 to determine the possible association between culm thickness and ratoon tillering. Culm thickness varied from 2 to 5 mm and most were 3-5 mm thick. Ratoon tillers developed irrespective of culm thickness. However, average ratoon tiller production varied with thickness. Percentage of ratoon tillers, 

\[
\text{production} = \frac{\text{Total number of ratoon tillers}}{\text{No. of ratoon producing culms}}, \\
\text{varied with thickness.}
\]

Table 2. Average length (mm) of buds at various ratoon tiller development stages, IRRI, 1983 dry season.

<table>
<thead>
<tr>
<th>Stages (d after cutting)</th>
<th>Bud position(^a) (top to bottom)</th>
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<th>(\text{III} (\text{nodes}))</th>
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<tr>
<td>0</td>
<td>5 (3-12)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5 (1-9)</td>
<td>5 (3-8)</td>
</tr>
<tr>
<td>2</td>
<td>8 (12-19)</td>
<td>8 (2-20)</td>
<td>5 (1-11)</td>
</tr>
<tr>
<td>4</td>
<td>11 (3-33)</td>
<td>11 (3-29)</td>
<td>5 (2-16)</td>
</tr>
<tr>
<td>6</td>
<td>22 (3-53)</td>
<td>15 (3-54)</td>
<td>8 (2-42)</td>
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<td>8</td>
<td>91 (20-202)</td>
<td>45 (6-155)</td>
<td>10 (5-46)</td>
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<tr>
<td>10</td>
<td>144 (50-235)</td>
<td>45 (26-159)</td>
<td>17 (5-74)</td>
</tr>
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</table>

\(a\) Usually equivalent to 4th, 5th, and 6th nodes counting downward from the node after the base of the panicle. \(b\) Figures within the parenthesis are ranges.

Early-formed ratoon tillers do not inhibit subsequent tiller production, therefore, plants with early regeneration ability produce more tillers. Early tiller regeneration actually may encourage tillering by providing the nutrients to the developing buds. Appearance of first tiller varied from 1 to 10 d after cutting. Regeneration time was negatively and significantly correlated with the number of tillers at 3 and 6 wk after cutting and at ratoon harvest (Fig. 3). Even in the greenhouse, large variability in number of ratoon tillers/plant was observed. Three weeks after cutting, tillers/plant varied substantially although the correlation remained significant (Fig. 4).
Inherent ratooning ability is important. Improving rice ratooning ability is a challenge to plant breeders. Tillering is probably the most important genetic factor affecting ratoon performance of grasses (70). Low and high tillering lines of crops do exist and this trait often determines plant spacing. Root vigor and distribution also affect ratooning. Our recent studies suggested that IR44 ratoon tillers depended on the main-crop root system for nutrients until at least 21 d after harvest. The contribution of roots from ratoon tillers to the total root mass of the ratoon crop was only 11-19%. A vigorous main-crop root system may therefore be a prerequisite for a successful ratoon crop.

Besides cultural management, light, temperature, soil moisture, and soil fertility are major factors affecting ratooning ability. Growth duration, although a genetic character, has significant impact on ratooning ability and yield.

**FACTORS INFLUENCING RATIOONING ABILITY**

**Main-crop growth duration**

Main-crop growth duration has been reported to influence ratooning ability (13, 17). Very early maturing cultivars were recommended for ratoon crops in temperate areas (22) because they do not require early seeding and also allow a favorable growth period for the ratoon crop. Cultivars of 100-d maturity, like Belle Patna, Bluebelle, and Labelle, make ratoon rice production highly successful in the Texas Gulf Coast (89). Similar results have been reported for other early-maturing cultivars (20, 28, 60, 92, 93).

Studies show that very early maturing cultivars usually produce a successful second crop, if recommended practices are carefully followed. Early-maturing cultivars do not
produce a successful second crop unless the growing period is longer than 180 d (32). However, Chatterjee et al (16) harvested a satisfactory, but low, ratoon grain yield from a wet season crop of an early-maturing variety. Medium- and late-maturing rices will not produce a consistent ratoon crop, although medium-maturing cultivars sometimes have produced satisfactory ratoon crop yields (32).

Low temperature is a major constraint in temperate areas if the growth duration of the main and/or ratoon crops is too long. In a wet season ratoon crop of late-maturing IR42, low Dec temperatures caused failure of some tillers to exert their panicles above the flag leaf sheath, and reduced grain yield (16).

A dilemma is that some cultivars with longer growth duration have better ratooning ability (35). Cultivars with intermediate to late maturity (>125 d) produce higher yields than those with early maturity (<115 d) (94). A ratoon crop of late-maturing IR42 yielded significantly more than early-maturing IR36 and medium-maturing IR38. In IR42, increased ratoon grain yield was due to higher panicle densities and filled spikelets per panicle (85). In another report (40) ratoon weight, ratoon height, and percentage of ratoon tillers were unaffected by early maturity.

Breeding for ratooning ability should emphasize medium-duration cultivars that produce large panicles and grain (94) because early-maturing varieties may not have the yield potential of longer duration cultivars.

In a study of crosses between ratooning and non-ratooning rices, F₂ segregants with 65-100 d to flowering generally had high ratooning ability (13, 17). Early-flowering F₂ segregants of day-neutral and short-day crosses also had abundant ratoon tillers (84). Within a photoperiod-sensitive cultivar, increasing growth duration equals less ratooning ability (r = -0.98**) (27). All those findings suggest that breeding lines/segregants with less than 120 d growth duration have high ratooning ability.

Main-crop growth duration was correlated with that of the ratoon crop (50, 94), and ratoon crop yield was correlated with main-crop growth duration (r = 0.803**). However, longer main-crop growth duration increases the possibility of virus disease in the ratoon crop which is a major constraint in the tropics.

**Cutting height**

Stubble height determines the number of buds available for regrowth. The effects of cutting height on ratoon vigor are variable. Some cultivars ratoon from high nodes and others produce basal ratoons that are unaffected by cutting height (87).

CH10 yielded better when cut at 15 cm than at ground level, 35 cm, or at the panicle (82). Generally, ratoon yield increased with increased cutting height (22, 29, 31, 34, 61, 81).

Bahar and De Datta (8) also found 15-cm cutting better than ground-level cutting. They harvested similar ratoon crop yields at ground-level and 15-cm cutting if plots were drained during main-crop harvesting and irrigated 12 d after harvest. However, draining the fields encouraged weeds, which severely competed with the ratoon crop. Also, reducing the cutting height from 15 to 5 cm significantly increased the number of missing hills, thereby reducing grain yield. They concluded that optimum cutting height is 15-20 cm. Other studies gave similar results (73, 80).

Our studies on bud viability after cutting the main crop at 15 cm showed there were more dead buds in the nodes closer to the ground. About 73% of the buds at the 7th node were dead (Table 5), which probably is why lower cutting produced many missing hills and reduced tillering. Different cutting heights caused significantly different grain yields, 1000-grain weight, panicles/hill, panicles/m², missing hills, and growth duration of the ratoon crop (80).

On the other hand, several reports claim that increasing cutting height decreased ratoon yields (67, 69, 72).

In other studies with Intan, 3-, 13-, or 18-cm cutting height did not significantly affect ratoon yield (77). Similar findings also have been reported (9, 43, 73, 75).

Regardless of cutting height, ratoon yields seldom are as high as main-crop yields (8, 11, 69), although there are reports of ratoon yields surpassing main-crop yields (66, 72, 76).

The number of regenerated shoots was correlated with the main-crop cutting height (31, 34, 73, 80). Ratoon tillering rates at 24-, 15-, and 6-cm cutting heights were 89, 81, and 72% (34). In similar study, ratoon tillering was 73% at ground-level cutting and 80% at 12 cm (72).

Others reported decreasing number of ratoon tillers with increased cutting height (8, 72), and still others report that
The stage of maturity at main-crop harvest affects ratoon-plant ratooned workable for most conditions, including the cultivars chosen. However, 15 cm seems among to 5 cm. However, yield was not significantly different significantly lower with

crop cutting height (73, 80) or may increase with increased heights. In sonic studies, lower cutting height delayed
growth stage. Counting tillers 15 d after cutting showed
till number increased with cutting height up to 12 cm. Beyond 12 cm, the culm was dead. Tiller count at 45 and 75 d and at harvest confirmed those findings (72).

A ratoon crop tends to grow more tillers/hill than the main crop (8, 73, 80). It produces more panicles/hill and filled spikelets/panicle, and higher 1000-grain weight at 3- and 5-cm cutting heights than at 15 cm, but grain yields were less because low cutting caused more missing hills (8, 16, 73, 80).

Main-crop cutting should leave 1.25 cm of the stem above the water because submerged stubble may rot and long stubble may produce weak tillers (44).

Ratoon plant height may not be influenced by main-crop cutting height (73, 80) or may increase with increased cutting height (31).

Ratoon crop growth duration is influenced by cutting heights. In some studies, lower cutting height delayed maturity but produced uniform growth and maturity (20, 21, 22, 31, 32, 67, 69, 72, 73, 80, 81). However, another report shows that higher cutting height increases growth duration (8).

Grassy stunt virus infection tended to be greater at higher cutting heights (7). Longer (25 cm) stubble had more stem rot (80).

Sometimes, a ratoon crop is cut two or three times after harvest. A second cutting decreased the number of tillers but increased growth duration and panicle size (34). Grain yield was 12% more with a second cutting and about 8% more with a third cutting.

Panicle harvesting by ani-ani, a small knife commonly used in Indonesia, produced more ratoons than when culms were cut (61, 73). The number of missing hills was significantly lower with ani-ani harvest than when stubble was cut to 5 cm. However, yield was not significantly different among ani-ani and 5- and 15-cm cutting heights (73).

Many factors affect the choice of cutting height to use, including the cultivars chosen. However, 15 cm seems workable for most conditions.

**Table 5. Percentage of dead buds at different positions of IR44 rice plant ratooned at 15 cm cutting height. IRRI, 1983 wet season.**

<table>
<thead>
<tr>
<th>Position of buds (top - - - bottom)</th>
<th>Dead buds (no.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>12</td>
</tr>
<tr>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>6</td>
<td>46</td>
</tr>
<tr>
<td>7</td>
<td>73</td>
</tr>
</tbody>
</table>

cutting height does not significantly affect ratooning ability (12). However, irrespective of the main-crop cutting height, the effective ratoon tillers grew from the base of the plant and not from the upper nodes (20).

The number of tillers varied with cutting height and growth stage. Counting tillers 15 d after cutting showed that tiller number increased with cutting height up to 12 cm. Beyond 12 cm, the culm was dead. Tiller count at 45 and 75 d and at harvest confirmed those findings (72).

A ratoon crop tends to grow more tillers/hill than the main crop (8, 73, 80). It produces more panicles/hill and filled spikelets/panicle, and higher 1000-grain weight at 3- and 5-cm cutting heights than at 15 cm, but grain yields were less because low cutting caused more missing hills (8, 16, 73, 80).

Main-crop cutting should leave 1.25 cm of the stem above the water because submerged stubble may rot and long stubble may produce weak tillers (44).

Ratoon plant height may not be influenced by main-crop cutting height (73, 80) or may increase with increased cutting height (31).

Ratoon crop growth duration is influenced by cutting heights. In some studies, lower cutting height delayed maturity but produced uniform growth and maturity (20, 21, 22, 31, 32, 67, 69, 72, 73, 80, 81). However, another report shows that higher cutting height increases growth duration (8).

Grassy stunt virus infection tended to be greater at higher cutting heights (7). Longer (25 cm) stubble had more stem rot (80).

Sometimes, a ratoon crop is cut two or three times after harvest. A second cutting decreased the number of tillers but increased growth duration and panicle size (34). Grain yield was 12% more with a second cutting and about 8% more with a third cutting.

Panicle harvesting by ani-ani, a small knife commonly used in Indonesia, produced more ratoons than when culms were cut (61, 73). The number of missing hills was significantly lower with ani-ani harvest than when stubble was cut to 5 cm. However, yield was not significantly different among ani-ani and 5- and 15-cm cutting heights (73).

Many factors affect the choice of cutting height to use, including the cultivars chosen. However, 15 cm seems workable for most conditions.

**Time of main-crop harvest**

The stage of maturity at main-crop harvest affects ratooning (31, 88, 92, 93). The best harvesting time for good ratooning is when the culms are still greenish (29, 67, 82). Stalks should be cut before the main crop is fully matured (9, 57) or at full maturity when the ratoon shoots have just begun to grow (86).

Delaying main-crop harvest for 44-56 d after flowering reduced ratoon crop growth duration (88). Ratoon growth duration, weight, height, and percentage of ratoon tillers declined if cutting was delayed 10-20 d after heading (40). However, ratoon traits improved slightly with cutting 30-40 d after heading. In another study, harvesting at 30, 35, 40, and 45 d after main-crop flowering did not significantly affect ratoon yields (31, 77).

Cutting the main crop to 25 cm height and harvesting 5 d earlier than optimum time was the best method of evaluating ratooning ability. Cultivar, cutting height, and harvest time were interactive (31).

**Main-crop cultural practices**

Ratooning ability is affected by plowing depth, transplanting time, spacing, crop establishment, fertilizer, and water management. Various lines/cultivars have different ratooning patterns under varying cultural practices.

**Land preparation**

Ratoon crop success is largely dependent on the thorough land preparation for the main crop (67). Deeper plowing increased culm elongation and panicles per plant. Plowing 25 cm deep gave higher grain yield than more shallow tillage. Plowing deeper than 25 cm tended to decrease ratoon crop viability (36).

Ratoon crop grain yield is significantly influenced by tillage method. Ratoon plants after zero tillage yielded least. The main crop that had been plowed and harrowed produced the highest (1.1 t/ha) ratoon crop yield (8). Plots with regular main-crop land preparation tended to grow more ratoon tillers. However, tillage did not affect number of filled spikelets/panicle and number of missing hills (80).

**Seedling age**

Main-crop seedling age did not significantly affect grain yield or other ratoon crop characteristics. However, 20-d-old seedlings tended to produce higher ratoon grain yield because they produced more panicles/unit area and filled spikelets/panicle, heavier grains, and fewer unfilled spikelets (85). The effect of seedling number/hill in the main crop on ratooning ability needs investigation.

**Planting/transplanting time**

Different planting dates expose the main and ratoon crops to different day length, temperature, and sunlight conditions, which may influence ratoon crop performance. There is little work in this area.

The effect of main-crop sowing time on ratoon growth duration and grain yield was studied using De Abriel, IR841-63-5, and IR899-55-6-4-6-1B (62). The varieties
were planted from 18 Sep to 22 Feb at 30-d intervals. The Sep seeding yielded highest for all the three varieties. IR841-63-5 and IR899-55-6-4-6-1B ratooned successfully to the Nov seeding, but grain yields declined sharply with each later seeding date. Growth duration of ratoon crop did not show any consistent trend with delay in seeding. No ratoon was obtained after Nov seeding.

In another study, Ramus and Dittrich (75) also found that sowing date affected ratoon grain yield. Their Sep seeding yielded more than the Oct seeding. Low temperatures at late main-crop growth prevented ratoon development.

Spacing
Spacing is an important ratoon-influencing factor because it determines main-crop plant population. High main-crop plant population increases tiller number/unit area, therefore increasing potential ratoon tiller number/unit area. However, that increase is not proportional to the increase in ratoon crop population because high plant density increases the number of missing hills (8).

Data suggest that 20 x 20 cm spacing produces optimum ratoon grain yield. The number of missing hills at 20 x 20 cm was significantly less than at 15 x 15 cm and equaled that at 25 x 25 cm (8). Similar spacing has also been suggested by other research (67). In another report (1), 10 x 10 cm plant spacing gave significantly higher ratoon grain yields than 20 x 20, 30 x 30, and 40 x 40 cm spacings. Closer spacing, however, requires more main-crop seed, time, and labor during planting.

Plant spacing affects the number of missing hills in the ratoon crop but grain yield may not be significantly affected (8).

Crop establishment
The effect of direct seeding and transplanting on ratooning ability has not been studied extensively, but good ratoon yields from drilled crops have been reported in Texas (21, 22). One of the advantages of direct seeding for ratoon cropping is the large number of plants per unit area, each of which will only need to grow a few ratoon tillers to produce high number of tillers/unit area.

In Indonesia, dry-seeded IR30 grew a successful ratoon crop (65), yielding 1.9-2.8 t/ha. An adjacent rice crop transplanted 4 d after the ratooned main crop was harvested suffered drought stress and yielded less than the ratoon crop. Further comparisons of dry-seeded and transplanted ratoon crop performance are necessary.

A good, uniform plant stand is a prerequisite for a productive ratoon crop, irrespective of seeding or transplanting method, but other management factors are equally important in determining ratoon grain yield.

Fertilizer management
Soil fertility may directly or indirectly affect ratoon crop growth and yield (70). N and P significantly affect ratoon growth, and P is especially important because it promotes good root development.

Fertilized plots produced better ratoon yields than no-fertilizer plots (78, 93). Timing of application, dosage, and kind of fertilizer best suited for ratoon crops need further investigation, but it is wise to select quick-acting fertilizers (44).

Applying N has been shown to increase ratoon grain yields (7, 8, 16, 20, 22, 23, 67, 73, 81, 93, 94). N should be applied immediately after harvest to promote early ratooning (7, 23, 43). Applying N fertilizer to the main crop 14 d before harvest increased sprouting rate 10%, but decreased main-crop grain yield (34).

Seventy-five percent of the recommended amount of N for the main crop should be applied immediately after harvest to achieve good ratoon yields (23), and sometimes, second and third fertilizer applications have been recommended (67). Fertilizer should be placed close to the stubble rows to ensure rapid nutrient uptake and growth (67, 70).

Fertilizer effect also depends on the inherent ratooning ability of the cultivar, and its ratooning vigor, ratoon type, and growth duration. As ratoon yields increase, N response also increases (94). Cultivars also differ in their response to N applied to the ratoon crop (9, 78).

Applying N fertilizer on ratoon crops sometimes delayed maturity (14), but other research indicates maturity was not delayed by N application (73, 81). Fertilizer application may increase ratoon tillering (34) or may not affect tillering (8).

Applying high amounts of N fertilizer to the main crop reduced ratooning viability by weakening plants due to excessive growth (36). Contrary reports showed that increasing N level (60-100 kg/ha) correspondingly increased ratoon grain yield.

Split application of 90 kg N/ha as a basal dose, and at panicle initiation, early milk stage, late milk stage, and 7-15 d before main-crop harvest did not significantly affect ratoon crop grain yield and tillers/m² (73). No significant interaction between fertilizer application time and cutting height was observed.

Besides amount of applied N, application method in the main crop affects the ratoon crop (73, 80). N deep placement in the main crop produced 15% higher ratoon grain yield and higher panicle density than split application. Split application delayed flowering and harvesting and produced lower leaf area index in the ratoon crop.

Ratoon crop plant height, panicle length, 1000-grain weight, and filled and unfilled spikelets were unaffected by ratoon crop N application method (85). N deep placement (8-10 cm) in the ratoon crop also produced significantly higher yield than an equal amount of broadcast N. Higher grain yield was associated with more panicles/plant, filled spikelets/panicle, and more vigorous ratoon plants. Increasing N also increased plant vigor but at the same N,
level, the broadcast application treatment was less vigorous than the deep placement treatment (73). Applying N by soil incorporation immediately after harvest versus top-dressing 10 d after harvest did not significantly affect the number of missing hills in the ratoon crop (80).

Applying P and K to the ratoon crop did not significantly affect ratoon grain yields. However, Chatterjee et al (16) reported that a ratoon crop yielded better with 20 kg PK/ha. A highly significant increase in ratoon yield was obtained by applying P to the main crop (20, 23, 54).

To promote early, abundant ratooning, which increases grain yield, it is important to apply fertilizer immediately after main-crop harvest. Although a ratoon crop will grow if water alone is added, grain yield is significantly higher if fertilizer is applied.

Water management

Water management before and after main-crop harvest affects ratooning ability (8, 31, 53, 72, 88).

Following is a recommended water management program (19, 44, 67): To promote ratooning, the field should be moist but not flooded for 2 wk at the end of main-crop ripening. Draining the field several days after harvest also encourages ratooning. Irrigation water must be shallow in early ratooning stages, but irrigation is essential immediately after the first fertilizer application. One week later, the field should be drained and weeded, followed by intermittent irrigation.

There was significant interaction between cutting height and rewatering time. When stubble was cut lower, delaying irrigation for 4-6 d was better than rewatering 1 d after cutting (72). Other research has confirmed those findings (8, 32, 70).

The effect of time of drainage of main crop and rewatering the ratoon crop on grain yield was evaluated (88). Grain and dry matter yields of both main and ratoon crops were increased by delayed harvest after draining the main crop. Draining the main crop increased ratoon panicles/m² and decreased the percentage of missing hills and sterile florets.

However, draining the field during main-crop harvest is not essential for good ratoon crop (7). When the ratoon crop remained flooded, yield was 2.5 t/ha at 15-cm and zero at ground-level cutting height (8). Ground-level cutting with continuous 5-7 cm flooding produced very few ratoons. If plots were drained during main-crop harvesting and irrigated 12 d after harvest, ground-level and 15-cm cutting produced comparable grain yields. The number of missing hills increased as the time between harvest and rewatering was shortened. At 15-cm or higher cutting height, it was better if fields remained flooded because continuous flooding reduced weeds.

Water management did not significantly affect percentage of ratoon tillers or ratoon height; when the crop was cut at 5 or 20 cm (38), probably because ratooning ability depends largely on food reserves in the stem base and on temperature (38). Many hills died when the crop was cut at ground level and water remained 5 cm deep. However, the effect of water management on ratoon grain yield and components was not studied (38). Ratoon tiller production did not increase 20 d after cutting.

Different main-crop water regimes, such as deep drainage, open bunds, and standing water, did not significantly affect the number of missing hills in the ratoon crop (80).

Providing shallow, permanent flooding immediately after main-crop harvest was better than flushing for 3 wk before flooding. All plots with immediate flooding yielded more than those that were flushed regardless of N application rates (53, 55). Ichii (38) did not observe rapid growth with early flooding, but Mengel and Wilson (55) reported that early flooding encouraged more rapid, uniform regrowth than delayed flooding, and produced significantly better ratoon height and yield.

More studies should evaluate the effect of the main-crop water regime on ratooning. Water depth may affect the viability of ratoon tiller buds, but in deep water rice some cultivars ratoon even if the culm has been submerged for several weeks.

Draining the main crop at harvest is generally suggested to promote ratooning and prevent death of hills due to flooding. However, under rainfed situation where water has to be retained as much as possible, the main crop should be cut at 15 cm or higher to minimize the number of missing hills in the ratoon crop (94). Water management seems to affect the ratoon crop to a considerable extent. More important is the interaction between cutting height and water management before and after main-crop harvest. The appropriate combination of cutting height and rewatering time should be considered. Flooding with very short cutting can result in poor stands by increasing the number of missing hills whereas delayed watering would result in severe weed competition to the ratoon crop.

Temperature

Only a few reports discuss the effect of temperature on ratooning ability. Plants exposed to low temperature (20/20°C) at booting stage formed 2-3 times more basal ratoon tillers than at high (35/27°C), and normal (29/21°C) temperatures (80). Under high and low temperatures, the difference between total and productive tillers did not differ significantly, but tiller number was significantly higher than under low normal temperatures. However, at 20/20°C grain yield was significantly lower because of high spikelet sterility. Ratoon grain yield (g/hill) did not differ under normal and high temperatures.

When plants were cut 10 d after heading and exposed to high (30°C) or low (20°C) temperatures, ratoon weight, height, and percentage of tillers were highest at 30°C (37). Maximum percentage of ratoon tillers was before 10 d at 30°C and before 20 d at 20°C. Percentage of ratoon tillers varied less with the temperature than did ratoon weight and height. Stem base weight 20 d after cutting was lower at 30°C compared to 20°C.
than at 20°C, but total of stem base weight and ratoon tiller weight was higher at 30 than at 20°C. Temperature also affected ratoon-crop growth duration. Maximum 96 d growth duration was at 20/20°C and minimum 56 d duration was at 35/27°C (80).

Light intensity near harvest
Shading the main crop from flowering to 7 d after harvest (28 d) caused significantly lower ratoon yields than shading at late milk stage to 7 d after harvest (24 d) or shading at harvest to 7 d after harvest. Unshaded plants yielded 72% more than shaded plants (73). Applying an extra 30 kg N/ha at early and late milk stages and 15 d before harvest in combination with different shading periods did not significantly affect ratoon grain yield.

Irrespective of growth stage, shading produced a higher percentage of hills without ratoon tillers, and shading plus N topdressing produced 22% fewer missing hills than shading without N topdressing (73).

Tiller regeneration ability was unaffected by main-crop shading. However, the number of ratoon tillers produced decreased as shading increased (27). In general, no shading and 49% shading had statistically similar effects on grain yield, spikelets/panicle, filled spikelets/panicle, 1000-grain weight, and percentage of sterile spikelets. However, 66% shading of the main crop significantly reduced ratoon grain yield, which was attributed to fewer spikelets/panicle, filled spikelets/panicle, and increased spikelet sterility (27). Panicles/hill was not significantly different among various shading treatments. However, more ratoon panicles tended to develop with less main-crop shading.

In one experiment, plants were cut 10 d after heading and placed in dark or sunlight environments. Ratoon weight and percentage of ratoon tillers were higher in the light than in the dark. About 20 d after cutting, some ratoon foliage withered in the dark. Ratoons grew taller in darkness than in light. Differences in stem base weight between sunlight and dark treatments were not apparent until 20 d after cutting, but final ratoon and stem base weights were also higher in sunlight than in darkness. Also, ratoon foliage seemed to contribute to plant growth 10 d after cutting in sunlight and 20 d after cutting in darkness (37).

In another experiment, plants grew for 2 wk before cutting in full sunlight, 50% shading or 75% shading. Percentage of ratoon tillers, ratoon height, and ratoon weight were the highest for full sunlight followed by 50 and 75% shading. Stem base weight of stubble decreased significantly and linearly as shading intensity increased, which indicates that percentage of ratoon tillers, ratoon weight, and height may be correlated with stem base traits (41).

Growth regulators
Ratoon crop plant characters differ significantly from those of the main crop. Plant height (9) and effective ratoon tillers (8) are generally lower than in the main crop. However, some ratoon crops have produced more total tillers than the main crop (8, 73, 80). Ratoon crops develop many unproductive tillers (9, 20) and axillary buds that continue metabolic activity at the cost of grain filling. To obtain higher ratoon grain yields, it is imperative that percentage of productive tillers be increased.

Growth regulators have been reported to stimulate growth and stem elongation and to inhibit lateral bud development (46), but information on their use to improve ratooning ability is meager.

Applying gibberellic acid (GA3), indole acetic acid (IAA), naphthyl acetic acid (NAA), or 2,4-dichlorophenoxyacetic acid (2,4-D) at main-crop flowering and late milk stage did not appreciably affect grain and other yield components of the ratoon crop. However, they all increased panicle number/hill (73).

The effect of benzyladenine (BA), 2-chloroethyl trimethyl ammonium chloride, GA3, kinetin, and NAA on ratoon tillering depended on their concentration and time of application (33), but all growth regulators increased ratooning. Five ppm GA3 and 100 ppm BA induced bud sprouting most effectively. In general, milk stage foliar application of growth regulators produced a higher percentage of sprouted buds than application at any other stage.

Plant growth regulators generally did not significantly affect ratoon grain yield or other yield components, except panicles per hill. Grain yield was not increased because of high ratoon crop spikelet sterility (33). Whether the sterility was caused by the growth regulators or because ratoons lack the ability to support many panicles should be further studied.

Leaf senescence and carbohydrate content
Rapid main-crop leaf senescence is assumed to be a major cause of low ratoon rice yields. Senescence or chlorophyll degradation reduces photosynthesis, depletes carbohydrate content, and decreases protein level and respiratory activity (46). Early main-crop senescence might reduce ratoon yield potential. Therefore, it is believed that if main-crop senescence could be delayed, ratoon yield potential might be considerably increased.

Delayed main-crop senescence might be an appropriate selection criterion for good ratooning ability (17). Delayed senescence is probably coupled with increased carbohydrate content of main-crop stubble, which could cause better ratoon development. Carbohydrate concentration at harvest and ratooning ability are closely associated (17, 80), which has been confirmed by clipping experiments (80). When panicles were clipped, more ratoon tillers appeared. However, clipping leaves resulted in reduced ratoon tiller number (80).

The percentage of ratoon tillers, expressed as that of the main crop, was significantly and positively correlated (r = 0.26*) with carbohydrate concentration at harvest.
Declining TNC reserves in lower plant fractions after maturity of cv. Bellemont and Vista accompanied an increase in ratoon tillers and yield. However, increasing TNC reserves for Brazos accompanied similar increases in ratoon tillers and yield. These findings suggest that besides carbohydrate content of the stubble, other factor(s) may encourage high ratooning. For example, stubble N content may be equally important as carbohydrate content for good ratoon tiller regeneration. Further investigation should be undertaken to clarify the role of stubble carbohydrate and N contents in ratooning ability.

Disease and insect pests
Insect damage can reduce or prevent ratooning (93). Ratoon crops may be heavily infested with stem borers, which can cause total crop loss (19). Heavy insect pest incidence on ratoon crop has been reported (29).

Ratoon rice often has high grassy stunt virus infection, while transplanted seedlings of the same age are virus-free (8). Ratooning virus-susceptible varieties may involve considerable risk of disease damage. In IR36, stem rot significantly reduced the number of ratoon tillers (80). Cultivars with good ratooning ability and pest resistance are needed.

GENETICS OF RATIOONING ABILITY
Breeding methods to improve or incorporate a genetic trait are largely determined by its mode of inheritance. Little is known about the inheritance of ratooning ability.

Component analysis of ratoon grain yield showed that tiller number, growth duration, and 1000-grain weight are the main yield-contributing characters (94). Cuevas-Perez (17) studied the variability and heritability of ratoon crop yield components in the F4 generation of three crosses. Heritability estimates for tiller number (0.28) and flowering time (0.56) were entirely due to additive effects. Although those estimates represented narrow sense heritability, they were low and suggested that selection should be practiced only in advanced generations when a line attains near homozygosity for ratooning ability.

High heritability estimates for percentage of ratoon tillers (0.87-0.91), height (0.83), and weight (0.98) also have been reported (40). The heritability of ratoon weight, however, varied with cutting time, which indicates the important effect of cutting time on ratoon growth and yield.

Ratooning ability is a recessive trait with simple monogenic control as suggested by the distribution pattern of the F2 population (13). Early generation selection to improve ratooning was recommended because high association was observed between ratooning ability of F2 plants and F3 lines. These findings contradict those of Cuevas-Perez (17). Efforts should, therefore, be made to learn more about the genetics of ratooning. Many crosses with diverse genotypic background should be evaluated in genetic studies of ratooning ability.
ASSOCIATION OF RATOONING ABILITY WITH OTHER PLANT CHARACTERS

Correlation studies are necessary to formulate selection criteria to simultaneously improve several traits. Close association between any physiologic, agro-ecologic, or biochemical main-crop trait and ratooning ability would make selection rapid, effective, and reliable. An association analysis of ratooning ability and some main-crop traits was done by several scientists (17, 31, 40, 94).

Ratooning grain yield was not significantly correlated with main-crop grain yield (11, 17, 18, 61, 64, 83, 94) but others reported a significant, positive correlation (31, 50). There is significant association between ratoon yield and tiller number \( (r = 0.74) \) and 1000-grain weight of ratoon crop \( (r = 0.79) \) (94). Correlation and path analyses showed that filled grains/panicle is the principal trait that determines ratoon grain yield (63). Percentage of ratoon tillers and grain yield are positively and significantly \( (r = 0.91) \) correlated (18, 31).

There was no significant association of main-crop tiller number, plant height, and grain yield with ratoon tiller number (17). Similarly, ratoon grain yield was reported to be independent of growth duration (18), but positive and significant association of those traits also was observed (31). Ratoon growth duration and tiller number were negatively and significantly correlated. Ratoon growth duration is thought to be the major factor to emphasize in the improvement of ratoon cropping because it is positively associated with grain yield. Also, precise growth duration would define necessary crop management.

Although cultivars with longer ratoon growth duration (60 d) may be selected for the breeding program, the association between ratoon tiller number and growth duration is negative and significant. The expected negative effect of such a selection on ratoon tiller number might be minimized by management practices.

The phenotypic association between percentage of ripened grains of the main crop and ratoon weight, height, and percentage of tillers was highly significant and positive (39). Ratoon weight was also positively and significantly correlated with main-crop grain yield when the crop was cut 10 d after heading. At similar cutting time, percentage of ratoon tillers was negatively and significantly associated with culm length.

Percentage of ratoon tillers was significantly and positively associated with internode and stem base weight at 20, 30, and 40 d after heading (39). Breaking strength at 20 d after heading was negatively and significantly correlated with percentage of ratoon tillers, and lodging index at 20, 30, and 40 d after heading was negatively and significantly correlated with percentage of tillers and height.

ECONOMIC FEASIBILITY

Rice ratooning cropping may save up to 60% of the labor needed for land preparation and planting and 25-30% of the production cost. Additionally, ratoon growth duration is only 45-70% that of the main crop, and it requires about 50% less irrigation water because water use efficiency is 25-30% better than that of the main crop (72).

To be successful, rice ratooning requires a good main-crop plant stand. Proper cultural management practices are necessary for both the main and the ratoon crops to produce high (3-4 t/ha) ratoon yields. Ratoon grain yield is not always lower than that of the main crop (66, 72, 76). Bardhan Roy et al (10) compared the performance of a ratoon crop of photoperiod-sensitive rices with that of the main-crop photoperiod-sensitive aman rice. The ratoon grain yield generally equaled the main crop and was higher for some varieties. Low main-crop grain yield may have been caused by drought in the reproductive phase of the transplanted crop, whereas the ratoon crop escaped drought stress because of short growth duration, therefore yielding more than the transplanted crop.

Mahadevappa (51) attributed low grain yields of the Jun-Dec main crop to heavy rains and cloudy weather during most of the crop season and also to heavy insect and disease problems. The ratoon crop season, however, (Dec-Jan to Apr-May), has long, bright sunny days and few disease and insect problems. Low temperature early in the season prolong the growth duration of the ratoon crop to more than 130 d, which produce high yields.

No systematic study has compared the costs of inputs and outputs for two short-duration transplanted crops versus a transplanted, then ratooned crop. Zandstra and Samson (94) assumed the production cost of a ratoon crop to be 55% of that of a newly transplanted crop and calculated that ratoon cropping would be preferable to transplanting a second crop if ratoon yields were to exceed 45% of the second-crop yield. In that case, a rice-ratoon sequence would yield a higher net return than a rice-rice sequence.

Where energy and labor inputs are expensive or limiting, ratoon cropping may be economical at yields less than 45% of the second rice crop (94). Bahar and De Datta (8) studied the productivity (kg/ha/d) of rice cropping systems. The productivity of 2 sequential transplanted rice crops varied from 51 to 66; for transplanted followed by direct seeded crop, 44-53; and for transplanted followed by ratoon, 37-50, which again confirms the potential of rice ratooning.

Until now, ratoon cropping experiments have used cultivars that were not bred for ratoon cropping and lacked proper management practices for ratooning. Cropping cultivars with high ratooning ability and yield potential under proper management in a particular agroclimatic condition could be economical. Chapman (15) economically analyzed ratoon cropping as an alternative technology for rainfed lowlands. His findings suggested that ratoon cropping would be economically viable and indicated that ratooning complements double-rice-cropping by freeing up scarce labor and energy resources and more efficiently
using abundant resources such as land with little double-cropping potential.

Further data are needed to assess the economic feasibility of ratoon cropping.

SUMMARY

Rice ratooning may be a practical way of increasing rice production per unit area and time. No serious, systematic attempt has been made to explore its potential and to understand the mechanism of and factors affecting ratooning ability and yield. Low grain yield and the vulnerability of the ratoon crop to insects and diseases are major constraints preventing its large-scale use in tropical Asia.

Ratooning ability is a potentially important varietal character that should be improved, but it is a complicated trait. The various factors that determine ratooning ability directly or indirectly are summarized in Figure 5. Improving ratooning ability is a difficult and challenging task because of the complex genetic architecture and predominant influence of agroclimatic conditions and management practices.

Ratooning ability differs by cultivar. Some differences that affect ratooning ability are: inherent ability to produce ratoon tillers; origin of the ratoon tillers (basal ratoon tillers preferred); delayed leaf senescence; carbohydrate accumulation ability, which might be affected by growth duration; main-crop root vigor; and viability of dormant buds.

Main-crop environment substantially influences ratooning. Low solar radiation during reproductive and ripening reduces ratoon tillers and yield. Low temperature during reproductive stage causes more ratoon tillers to form. Higher plant N and carbohydrate content also increase ratooning ability.

Main-crop cultural practices also influence ratooning. Thorough, deep plowing produces better ratoon tillers. Planting date, and therefore the effect of temperature and

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Figure 5: Factors affecting ratooning ability and grain yield.
solar radiation, also influence ratooning. Spacing only slightly affected ratoon yield, although 20 x 20 cm spacing generally is recommended. A good, uniform plant stand is essential for a good ratoon crop irrespective of seeding or transplanting method. Other factors such as N level and application and number of seedlings per hill need further studies. Water management is an important factor in ratoon tiller production, and draining fields before harvest is recommended.

Certain practices at harvest or just before can also affect ratooning. The main crop should be harvested before full maturity because delayed harvesting or cutting reduces ratoon yields. Cutting height determines the origin of the tillers and the growth duration of the ratoon crop. N should be applied immediately after harvest.

Greater efforts should be made to analyze the components of ratooning and ratoon grain yields. An ideal cultivar for rice ratoon cropping should have the following traits:

- Ratoon tiller production after and not before harvest;
- Tilling from basal, not upper, nodes;
- Sixteen ratoon tillers/hill at 20 x 20 cm spacing;
- At least 3 leaves/tiller;
- Resistance to major diseases and insects;
- Synchronized flowering and maturity;
- More than 60 d growth duration from cutting to maturity; and
- High grain yield.

More work is needed to make ratooning successful. The following points require emphasis and attention by researchers:

1. The mode of inheritance of ratooning ability has not been firmly established, therefore it is difficult to plan a breeding strategy for cultivar improvement. More information is needed about genetic aspects such as gene action, heritability estimates, and ratooning stability.

2. Temperature and growth regulator studies have produced inconsistent results and should be continued.

3. Suitable selection criteria based on main-crop characters should be identified.

4. There are many published reports on cultural practices, water management, and fertilizer use in ratoon crops. Suitable packages of cultural and management practices should be developed for specific agroclimatic conditions.

5. The economics of ratoon cropping should be further studied. The production cost of inputs and outputs for two transplanted crops or transplanted then ratooned crops should be compared for at least 4-6 seasons. Future studies should evaluate ratoon cropping not only by crop yield potential or costs and returns, but also as a cropping system with independent crop activities.

REFERENCES CITED


Other papers in this series

TITLES OF NUMBERS 1-45 ARE LISTED ON THE LAST PAGE OF NO. 46; THOSE OF NUMBERS 46-70 ARE ON THE LAST PAGE OF NO. 71-80.

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