RICE RATOONING

INTERNATIONAL RICE RESEARCH INSTITUTE

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Contents

Foreword
Welcome 1

Overview

Rice ratooning as an alternative to double cropping in tropical Asia **3**
K. Krishnamurthy
Economic perspectives of rice ratooning **17**
J. C. FIinn and M. D. Mercado

Morphology and physiology of rice ratoons

Morphology and physiology of ratoon rice **31**
B. S. Vergara, F. S. S. Lopez, and J. S. Chauhan
Some factors influencing the growth of rice ratoon **41**
M. Ichii

Rice ratooning in practice

Breeding and testing for superior ratooning ability of rice in Texas **47**
C. N. Bollich, B. D. Webb, and J. E. Scott
Utilization of rice ratooning by farmers in Rio de Janeiro State, Brazil **55**
W. E. de B. Andrade, S. Amorim Neto, A. B. de Oliveira, and G. M. B. Fernandes
Rice ratooning in the Dominican Republic **61**
Federico Cuevas-Pérez
Rice ratooning practices in India **69**
M. Mahadevappa
Ratooning in China **79**
Xu Xue-Bin, Zhang Jong–Guo, and Jiang Xian-Xiang
Rice ratoon crop management in the hilly region of Karnataka **87**
T. Gopala Reddy and M. Mahadevappa
Production practices for ratoon rice in Tungabhadra River Project **97**
K. S. Prakash, K. Krishnamurthy, Y. C. Panchal, and B. G. Prakash
Ratoon rice research in Karnataka, India **105**
M. Mahadevappa, T. Gopala Reddy, and Nagaraju

Evaluation and potential of rice ratooning

Status of and potential for rice ratoon cropping in Tamil Nadu **111**
A. Palchamy and G. Soundrapandian
Scope for rice ratoon cropping in the northeastern hill region of India **119**
T. Ahmed and G. R. Das
Scope for rice ratoon cropping in the central and northern belts of India **123**
B. K. Singh
Potential of rice ratooning in Madagascar **129**
B. B. Shahi and Jeanine Raharinirian
Potential for rice ratooning in eastern India, with special reference to photoperiod-sensitive rices for deepwater areas **135**
S. K. Bardhan Roy, J. Mondal, B. N. Chatterjee, S. Bhattacharya, P. Debnath, and B. and B. Mondal
Ratooning in Bangladesh: prospects and potentials **143**
M. M. Hossain and A. K. M. Farooq
Use of ratooning in hybrid rice **151**
J. S. Chauhan
Ratooning with rice hybrids **155**
Sun Xiaohui, Zhang Jingguo, and Liang Yujiu

Cultural practices

Agronomic principles and practices of rice ratooning **163**
S. K. De Datta and P. C. Bernasor
Rice ratooning: breeding, agronomic practices, and seed production potentials **177**
M. Mahadevappa and H. S. Yogeesha
N fertilizer management for maximum ratoon crop yields **187**
Fred T. Turner and W. O. McIlrath
Insect pests and their natural enemies in ratoon rice **195**
C. G. dela Cruz and J. A. Litsinger
Diseases and disease management in rice ratoon crops **209**
T. W. Mew and N. G. Fabellar
Yellow dwarf disease in ratoon rice **219**
V. Muniyappa, Nagaraju, M. Mahadevappa, and K. T. Rangaswamy
Rice ratooning and ratoon-based system in Kerala **227**
K. Karunakaran, N. Rajappan Nair, and C. A. Rosamma
Disease and insect pests and their control in rice ratooning systems **233**
A. K. Nagaraju, Chakravarthy, and M. Mahadevappa

Genetics and varietal improvement

Inheritance of ratooning ability in Chinese rice varieties [*O. sativa* subsp. *xian* (or indica)] **239**
Li Shifen and Chen Tingwen
Varietal improvement for rice ratooning: traits, procedures, collaboration **247**
D. HilleRisLambers
Commercial ratoon rice production in Texas, USA **257**
C. N. Bollich and F. T. Turner
Screening rice genotypes for ratooning ability in the Tungabhadra River Project of Karnataka **265**
K. S. Prakash and B. G. Prakash

Recommendations **270**
Participants **273**
Varietal index **275**

Foreword

Ratooning, the ability of the rice plant to regenerate new panicle-bearing tillers after harvest, could be a practical way to increase rice production per unit area and per unit time. Because ratoon rice has a shorter growth duration than a newly planted crop, it can increase productivity where cropping intensity is limited by inadequate irrigation or by low temperature late in the cropping season. However, until the 1970s, ratooning was not explored in a systematic way; it was practiced by farmers more as an afterthought than as an integral component of crop management.

For that reason the Workshop on Rice Ratooning was held 21-25 April 1986 at Bangalore, India, under the sponsorhip of the International Rice Research Institute (IRRI), the Indian Council of Agricultural Research, and the University of Agricultural Sciences, Bangalore. The Workshop objectives were to discuss the prospects and economics of rice ratooning, identify the cultural methods to manage the ratoon crop, and initiate collaborative testing of varieties known to have good ratooning ability.

The papers presented focused on the advantages of the rice ratoon crop—its lower production cost, greater productivity, and reduced irrigation water requirements. Disadvantages, too, came under scrutiny—generally low yields, lack of varieties with good ratooning ability, uneven maturity, susceptibility to insects and diseases, and the lack of cultural practices for the ratoon crop.

The papers included in this volume constitute a comprehensive review of present knowledge on rice ratooning. The recommendations provide a framework of exploiting the advantages of rice ratooning and a strategy for overcoming the inherent problems in this rice cultural practice.

The success of the Workshop was due in large part to the efforts of the organizing committee: M. D. Pathak, chairman; B. S. Vergara and K. Krishnamurthy, convenors; and committee members S. K. De Datta and D. HilleRisLambers.

This book was edited by W. H. Smith and Vrinda Kumble with the assistance of Emerita P. Cervantes.

Klaus J. Lampe
Director General

Welcome

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Vice-Chancellor
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It gives me immense pleasure to associate myself with this international Rice Ratooning Workshop and extend to you a warm and cordial welcome. IRRI has taken a lead in organizing the Workshop through cosponsorship with ICAR. Dr. M.S. Swaminathan has been the guiding spirit behind this. The University is grateful to him for selecting Bangalore as the venue for this workshop. This has provided a rare opportunity for our Indian scientists, particularly those of the University of Agricultural Sciences, to contribute papers and participate in the workshop.

Scientists participating in the workshop have come from different countries and from different states in India. I hope they will have a very productive and pleasant time in Bangalore, which is known both as the garden city and the science city of India. I extend to them a warm and cordial welcome.

Rice is an important food crop of the world. About 386 million tons of rice are produced annually on about 144 million hectares worldwide. East Asia accounts for 44% of the total; Southeast Asia, 20%; and South Asia, 27%.

In rice research, our attention so far has been on plant breeding, soil and water management, plant protection, and weed control. A new dimension of our research has been added with greater awareness of the potential of ratooning rice. The idea itself is not new, but with the availability of fertilizer-responsive, semidwarf, modern varieties and increasing costs of labor and fertilizer, there has been renewed interest in rice ratooning. In areas where rain or irrigation water is available for raising a second or even a third crop of rice each year, there appears to be good potential for rice ratooning.

The excellent ratooning ability of certain varieties has inspired our scientists to initiate research on ratoon cropping. The growth of the main crop may range from 85 to 175 days in many varieties, whereas the duration of the ratoon crop ranges from 40 to 135 days—indicating that the ratoon crop may take about 1 month less for maturity. Grain yields from ratoon crops range from 6 to 140% of those of the main crop, indicating considerable scope for selection of varieties for ratoon cropping.

Ratoon tillers develop from basal auxiliary buds that exist on the stubble of the main crop plant. The growth and vigor of ratoon tillers depend on carbohydrate reserves of the stubble and the root system after harvest of the main crop. It is therefore evident that management of the ratoon crop begins with management -of

the main crop. Harvest time, cutting height, fertilizer application, irrigation management, plant protection, and weed control for the main crop naturally have a great bearing on the growth and yield of the ratoon crop. So in developing practices for the ratoon crop, special practices required for the main crop need to be worked out as well.

I am glad IRRI has demonstrated keen interest in organizing this international symposium at Bangalore. It is in this District of Bangalore where, as early as 1943, a farmer harvested 2 t of rice/ ha just by weeding and irrigating stubble of the first crop of a traditional variety, S684. Further, in 1980-81, officers of the Department of Agriculture and scientists of the University of Agricultural Sciences discussed research results, developed a package of practices for ratoon cropping, and included the package in the joint recommendation book *Package of practices for high yields.* One of the recommendations was to grow Intan rice on monocropped valley slopes and lowlands where they have been adopted readily, not only with the recommended variety Intan but with some local varieties. In India, of the 40 million hectares under rice, about 18.9 million hectares constitute the lowland where ratooning is possible. Some of the area grown to irrigated rice could also be put under ratoon cropping.

Several problems in ratoon cropping need to be tackled immediately. Varietal improvement, incorporating ratooning ability, and resistance to diseases and insect pests is of prime importance. The varieties need to be of desired growth duration for specific growing conditions. Fertilizer management for ratoon cropping as a whole needs to be worked out to regulate desired growth at different stages. Water management techniques have to be solved for the system to bring about greater water use efficiency. Chemical weed control has a place in ratoon cropping because chemicals control weeds over longer periods and would help considerably to reduce labor costs. The economic feasibility needs to be worked out with a suitable package of practices for the system to achieve reduced overall cost of rice production.

I am sure this select group of eminent scientists will deliberate on various aspects of rice ratooning and generate ideas and strategies for intensifying research in this important area, which no doubt will have a great bearing on increasing rice production to feed the growing population of the world.

I am glad that the group is visiting some areas in Kodagu and Chikkamagalur districts to see where ratooning is practiced. This will no doubt give participants a greater insight into the problems.

I once again extend a warm welcome to you all and thank you for traveling long distances to be here with us today.

Rice ratooning as an alternative to double cropping in tropical Asia

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Rice is cultivated in tropical Asia (South and Southeast Asia) over an area of about 88.7 million ha, with an annual total production of nearly 183.8 million tons of rough rice, an average productivity of 2.7 t/ ha (Table 1). Only 14% of the rice area in tropical Asia supports 2 crops of rice per year under irrigation. The remaining riceland is entirely rainfed, with varying water regimes.

AREA OF SUITABILITY

In areas where adequate water is available after the main crop season, rice ratooning could be practiced as an alternative to double-cropping. It is particularly suited to areas where monocropping is practiced and resources go to waste in the off-season, because no crops other than rice can be grown under the climate and moisture limitations.

Such situations exist widely in hills and valleys in the tropical heavy-rainfall mountainous regions of the world.

ADVANTAGES OF RICE RATOONING

Rice ratooning is not a new practice with farmers. Its usefulness has been studied in many countries such as India, Japan, USA, Philippines, Brazil, Colombia, Swaziland, Thailand, and Taiwan. However, only in Texas, USA, is it practiced on a commercial scale on 50% of the rice area. The advantage of rice ratooning is that in areas where rice is the main crop, a double crop of rice can be grown for additional returns. The ratoon crop matures earlier and requires less labor and water inputs. Water use efficiency is high.

Rice ratoon cropping systems on a commercial scale have not been developed in tropical Asia chiefly because of a lack of cultivars specially suited to ratoon cropping and with built-in resistance to insect pests and diseases, and because of lack of appropriate agronomic practices. Location-specific strains and suitable agronomic practices need to be developed to fit the tropical monsoon climate.

This paper gives an overview of the status of rice ratooning and indicates the lines of research that need immediate attention to make rice ratooning a profitable

Table 1. Area, production, and productivity of tropical monsoon, South and Southeast Asian countries, 1978.

Country	Area (million ha)	% of world total	Production (million tons)	% of world total	Yield (t/ha)	% of world mean
South Asia						
Pakistan	1.99	1.4	4.78	1.2	2.40	89
India	39.79	27.6	77.78	19.3	1.90	70
Nepal	1.25	0.9	2.28	0.6	1.80	67
Bhutan	0.04	–	–	–	1.10	–
Bangladesh	10.23	7.1	19.95	5.2	1.90	70
Sri Lanka	0.78	0.5	1.94	0.5	2.50	93
	54.08		106.73			
Southeast Asia						
Burma	4.75	3.3	10.57	2.7	2.2	81
Thailand	9.44	6.6	17.25	4.4	1.8	67
Laos	0.69	0.5	0.97	0.3	1.4	52
Cambodia	1.30	0.9	1.35	0.4	1.0	37
Vietnam	5.40	3.7	10.20	2.6	1.9	70
Malaysia	0.68	0.5	1.89	0.5	2.8	104
Singapore	–	–	–	–	–	–
Indonesia	8.91	6.2	27.27	7.1	3.1	115
Philippines	3.52	2.4	7.58	2.0	2.2	81
	34.69		77.08			
Total/mean	88.77		183.8		2.70	

Source: USDA 1978-80 data.

alternative to doublecropping in monsoon areas and to further augment rice production in Asia.

LITERATURE ON RICE RATOONING

The earliest reports on rice ratooning in India, by Mukhejee (13) and Ramaiah (19), have indicated it is possible to doublecrop rice through ratooning. The first report in Karnataka, which dates back to 1942-43, stated that S-684, a rice cultivar developed at Nagenahalli (Mysore taluk), Karnataka, gave a main crop yield of 2.75 t/ha and a ratoon crop yield of 1.01 t/ha. Days to maturity of the ratoon crop were 65% less than the main crop. About 174 reports on rice ratooning have since been published. Most of these reports, however, cover rice ratooning research under irrigation. Reports on the feasibility of a rice ratooning system in rainfed lands that could be fitted in after main crop harvest are few.

RESEARCH REQUIREMENTS

Rice genotypes need to be screened for ratooning ability; adaptation to soil, climate, and topography; pest tolerance; and response to fertilizer.

The genetics of inheritance of ratooning ability is yet to be properly studied for breeding. Studies on ratooning ability of cultivars suggest that varieties with wild gene characters (such as pigmentation, sturdiness of culms, awns, etc.) are most suitable for rice ratooning (16).

CROP IMPROVEMENT

Choice of variety

The varietal choice for ratooning in a given area is determined by the geography and the climate. Early-maturing cultivars are reported to perform well as ratoon crops in the Texas Gulf and temperate areas; however, studies indicate intermediate- to late-maturing cultivars are required for raising a good ratoon crop in tropical hills and valleys.

The success of a good ratoon crop depends on the care with which the main crop is cultivated in the growing season. Agronomic practices and the care with which the main crop is protected against insect pests and diseases determine the success of ratooning and crop yields in ratoonable cultivars.

The best time to cut the main crop for good ratooning is when the culms are still green (9) and physiologically viable for ratoon tillering.

Low temperature at postmaturity of the main crop will reduce the tillering ability and yield performance of the ratoon significantly.

Blast incidence on the main crop could carry over to the ratoon, resulting in total failure. Such cases have been recorded in experiments with Intan at Ponnampet, Karnataka.

Hence, there are no set rules with regard to choice of cultivar for ratooning. A good agronomic cultivar of the area could also be a good ratooner, like Intan in Karnataka.

Several cultivars have given ratoon grain yields of more than 2 t/ ha (Table 2). Some of the important cultivars discussed in this paper are D52-37 (l), IR28 (2), C3810 (6), Labelle (12), IR8 (20), Intan (21), IET 7191, IET 9667, IET 9668, and IET 9670 (17), IR42, and IR2058-78-1-3-2-3.

Ratooning ability

Varieties differ greatly in their ratooning ability. Hence, the genetic inheritance of ratooning ability could be exploited. A high ratoon rating indicates less than 5% missing hills and at least 16 tillers/hill with excellent vigor.

In Malagasy, japonica varieties have better ratooning ability than indicas. Japonica/indica crosses such as Mahsuri have shown high ratooning (16) in experiments at Mandya, Karnataka.

Varietal differences also exist with respect to emergence of ratoon tillers from different nodes of the stubbles. The tillers may emerge from all nodes of the stubbles or from only the lower nodes or from any specific node number. Many findings suggest that the ratoon crop will yield better if the main crop stubble is cut with 2-3 nodes left.

Variations in soil, water, light, and temperature greatly influence ratooning ability. Their interactions need to be properly studied for manipulating ratooning ability agronomically.

Tiller development is highly influenced by the carbohydrates that remain in the stubbles and roots after harvest and by nitrogen in the soil. Plants with thick culms store more carbohydrate than those with thin culms.

Table 2. Rice varieties with ratoon yield potential of more than 2 t/ha found promising in tropical Asia,

Location	Variety	Yield (t/ha)	Authority	Year
Victoneta, Philippines	Milbuen 5	3.4-5.6	Parag (1960)	1956-57
IRRI, Philippines	IR28	2.1	Bahar and De Datta (1977)	1973-75
IRRI, Philippines	IR2061-632-3-1	2.1	Bahar and De Datta (1977)	1973-75
Cuttack, India	CRM 10-3628	3.3	Anonymous (1977)	1976
Karnataka, india	Intan	2.3-7.7	Raddy et al	1977-78
IRRI, Philippines	IR4722-36-1	2.1	Nadal et al	1978
IRRI, Philippines	IR2058-78-1-3-2-3	2.6	Nadal et al	1978
IRRI, Philippines	IR2863-28-1-2	2.3	Nadal et al	1978
Karimganj, India	C3810	2.1	Das and others	DS
Kalyani, India	IET3629	2.7	Nayak and others	1980-81
Chinsurah, India	SR26B	2.5	Bardhan Roy and others	1981-82
Chinsurah, India	FR13A	3.0	Bardhan Roy and others	1981-82
Chinsurah, India	Tillakkachari	5.0	Bardhan Roy and others	1981-82
Chinsurah, India	Achra 108/1	4.8	Bardhan Roy and others	1981-82
IRRI, Philippines	IR42	2.9	Hou	1982

[a] Source: Chauhan et al (3).

The C-N ratios also vary between tillers that emerge from different nodes. Tillers from lower nodes will have a lower C:N than tillers from higher nodes. The lower tillers resemble young seedlings. Such healthy tillers generally emerge from lower nodes and will have the best ratoon yield potential (3).

There is scope to vary the carbohydrate as well as the C-N ratio to promote the development of healthy tillers from lower nodes for potential yields. This factor needs further attention by research workers. Similarly, the effect of micronutrients in promoting proper root development and on the initial establishment of the ratoon tillers, and their influence on vigor should be considered for future research.

Growth duration

The duration of the main crop is reported to correlate positively with ratooning ability. The available literature suggests that early-maturing varieties perform well in temperate areas and in the Texas gulf coast; cultivars such as Bellepatna, Bluebelle, and Labelle give good ratoon crop yields in temperate areas. However, reports on choice of duration of main crop for tropical Asia differ. The general trend is that intermediate- to late-maturing varieties produce higher ratoon yields than early-maturing varieties.

A ratoon crop of late-maturing IR42 yielded significantly higher (1.5 t/ ha) than early-maturing IR36 (0.5 t/ ha) (15). Similarly, the ratoon of very late-maturing Intan (165 d) has yielded about 140% of the main crop in the hill valleys of Chikkamagalur District in Karnataka (22).

These findings suggest that the choice of duration of the main crop is important in relation to the location of and the climatic factors (temperature, elevation, light intensity, longitude, and latitude) that prevail in a region. This area should be studied carefully for future research.

Ratoon yield performance

An analysis of 126 reports (1942-82) on the potential of ratoon rice summarized by Chauhan et al (3) suggests the following.

Table 3. Mean grain yield potential and growth duration of ratoon rice - estimates from 126 published reports (1942-82). [a]

Year	Maturity (d)			Grain yield (t/ha)		
	MC	RC	% of MC	MC	RC	% of MC
1942-82						
Range	85-174	40-113	31-78	0.8-8.0	0.1-8.7	—
Mean	122-52	67-13	54-79	3.97	1.54	38.8

[a] MC = main crop, RC = ratoon crop. Source: Chauhan et al (3).

Table 4. Main crop and ratoon crop grain yield and crop duration performance of six semidwarf rice cultivars.

Cultivar	Grain yield (t/ha) [a]		Duration (d)	
	Main crop	Ratoon crop	Main crop	Ratoon crop
C-3810	4.1	2.1 (51.1)	124	54
Ratna	3.9	1.8 (46.5)	125	50
TNAU 13613	3.5	1.6 (44.9)	121	49
CR 220-66	2.6	1.5 (56.5)	123	48
OR 100-25	3.9	1.3 (34.3)	122	49
CR 157-22-1900	4.0	1.4 (34.9)	123	52
Mean	3.66	1.6	123	50.33
S. Em±	0.13	0.09	—	—

[a] Figures in parentheses are percentages of main crop yield. Source: (6).

Wide variation exists among rice cultivars in their genetic potential for ratooning and yield levels. On an average, ratoon rice can give a yield roughly equivalent to 40% that of the main crop, with 40% reduction in crop duration (Table 3). However, there could also be cultivars that can give ratoon grain yields as high as 140% of the main crop, as reported from Karnataka (21), with variety Intan. In Ethiopia, a ratoon crop of IR8 yielded an unusual 8.7 t/ ha. The highest yield obtained by scientists at IRRI with cultivar IR2058-78-1-3-2-3 was 3.3 t/ha.

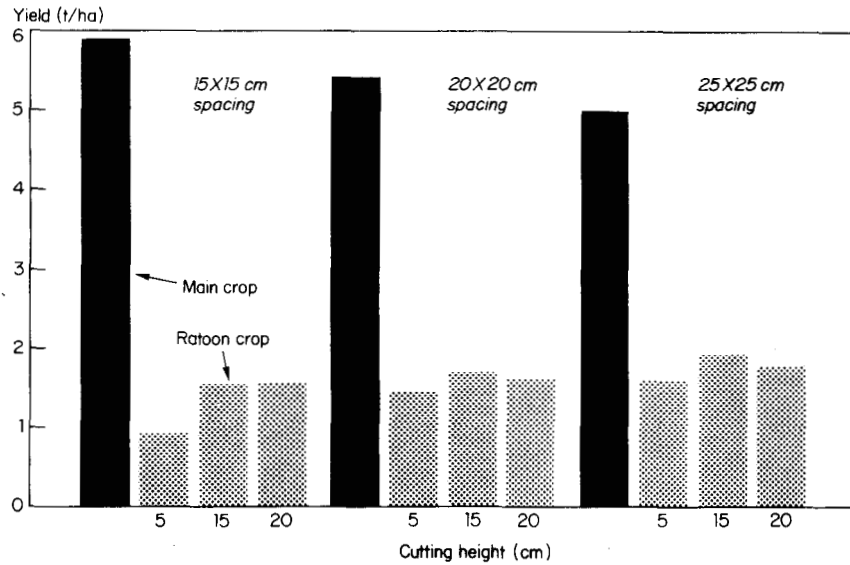
In a set of 6 semidwarf rice varieties, Das and Ahmed (6) noted that the ratoon crop produced, on an average, a yield equivalent to 43% of the main crop, with 60% reduction in duration. In this study, cultivar C3810 was rated as having the highest potential, with a ratoon yield of 2.1 t/ ha (Table 4).

These large variations in yield suggest genetic divergence among the cultivars, which could be exploited through breeding and management for ratooning ability. The donors specific to the location should be carefully earmarked for future use.

AGRONOMIC PRACTICES

Spacing

The effect of spacing on grain yield of the main and ratoon crops was studied in IR28 (2). Main crop yield was not altered significantly by different levels of spacing (Fig. 1). However, at 20 × 20 cm spacing, the number of missing hills was significantly lower than at 15 × 15 cm and equal to that at 25 × 25 cm spacing. In this study, the optimum spacing for the best ratoon yield was 20 × 20 cm.



1. Effect of spacing and cutting height on yield performance of main crop and ratoon crop (2).

Table 5. Effect of early irrigation (El) and delayed irrigation (Dl) on ratoon crop grain yield and plant height at different N levels. [a]

N level (kg/ha)	Plant height (cm)		Rough rice yield (t/ha)	
	El	Dl	El	Dl
0	71.6	70.3	1.4	1.o
22	78.6	71.0	1.7	1.1
45	81.6	74.3	1.9	1.2
67	84.0	73.3	2.0	1.4
90	87.3	77.6	2.3	1.4

[a] Source: Mengel and Wilson (12). Early irrigation = shallow, continuous flooding; delayed irrigation = a series of short-term floodings.

These studies indicate that different cultivars respond differently to spacing which, in combination with cutting height, determines ratoon yield. Hence, no general conclusions could be drawn.

Cutting height

The effect of cutting height on ratoon grain yield performance varies. Saran and Prasad (24) noted that cutting the main crop at ground level gave lower ratoon yields than cutting at 50% of the height of the main crop. Cutting the plants 35 cm above ground level (50% of the height of the main crop) gave maximum yield, 566 kg/ha as against 68 kg/ ha of plants cut close to the ground (Table 5).

Bahar and De Datta (2) observed 15-20 cm as the optimum cutting height above ground. Reducing the cutting height from 15 to 5 cm increased the number of

missing hills significantly, from 12% to 37%, and the growth period of the ratoon crop from 73 d to 86 d.

In studies with cultivar Intan in Karnataka, cutting the plants at 8, 13, and 18 cm did not affect ratoon yield (21).

However, interactions between cultivars and cutting height do exist; some cultivars tiller better when cut high above ground, while others produce better tillers when cut at lower levels.

Because of the genetic variability among cultivars, there is scope to fix the cutting height to realize the optimum yield specific to cultivar and site, rather than to depend on general findings.

Time of harvest

The best time to harvest the main crop for raising a good ratoon crop is when its culms are still green (24). Stalks should be cut before the main crop is fully matured.

In Brazil, Oliveira and Neto (18) studied the effect of sowing date on ratoon crop yield. They planted 3 cultivars — De Abrill, IR841-63-5, and IR889-55-6-4-6 at 30d intervals 18 Sep to 18 Feb. The September-seeded crop gave the best ratoon crop yield. Grain yields decreased with each successive seeding date, and no ratoon could be obtained with the November seeding.

Seedling age and the effect of number of seedlings per hill of the main crop on ratooning ability need thorough investigation.

Sowing time, temperature, daylength, and other factors, have a profound influence on main crop duration. Harvest date of the main crop and its effect on rice ratooning also vary. Very little work has been done on this aspect.

The work done at Mandya and in Ponnampet (Karnataka) has shown that low temperature (below 18 °C) will prolong main crop duration. Hence, any delay in planting the main crop will delay harvest and affect ratoon crop yields as well. These factors need further research.

Water management

Bahar and De Datta (2) noted that irrigating the fields immediately after harvest may cause the stubbles to rot, especially where plants are cut close to the ground, resulting in missing hills. Studies suggest that fields should not be flooded until the new ratoon tillers are 10-15 cm high.

However, Mengel and Wilson (12), in their studies on the effect of irrigation and N requirement on the grain yield and milling quality of the ratoon crop of cultivar Labelle, observed that shallow irrigation given as continuous flooding immediately after main-crop harvest gave better grain yields and plant characters than short-term delayed flooding (Table 5).

Indepth studies on water management of ratoon rice are needed because of contradictory reports on the subject.

Fertilizer management

Evatt and Beachell (7), in their studies on fertilizer requirement for ratoon rice, noted that ratoon crop yields were high at nitrogen levels of 75% of the main crop.

However, no significant increases in the ratoon yields could be recorded for P and K. Earlier, Ganguli and Ralwani (8), in their experiments on N requirements of ratoon rice, noted little difference in ratoon yields between plots fertilized with 22 kg N/ha and those fertilized with 44 kg N/ha. However, the ratoon plots not fertilized with N recorded a 25% yield reduction.

Szokolay (25) obtained findings similar to those of Evatt and Beachell (7). Evatt and Beachell also found that P and K did not significantly affect the ratoon grain yield when the main crop was supplied with adequate P and K fertilizers. Studies on the time of application of fertilizers to the ratoon crop showed that fertilizer application 20 d later, or at the panicle stage, gave the highest grain yields. Yields decreased with delay in application. They suggested earliest application of N for better yields.

However, the effect of P on plant characters like ratoon rice root development, grain filling, etc., and the effect of K in inducing tolerance for insect pests and diseases have not been reported by a majority of the workers. These factors need further study.

PLANT PROTECTION

Insects

Chen and Ko (5), working with green leafhopper, noted that this insect vector not only multiplied faster on the ratoon crop but also acquired the rice yellow dwarf inoculum from the ratoon rice plants and transmitted the virus to the main crop. Joshi et al (11) studied the level of infection of gall midge on ratoon rice. The development of the insect was continuous on the ratoon crop, although the level of infestation was lower than on the main crop. The average length of the gall was 9.2 cm in the ratoons as against 15.5 cm in the main crop. Up to 37.8% parasitism by *Platygaster* sp. was recorded in the ratoon crop.

In studies on the incidence of insects on the ratoon crop of IET 7191 at Ponnampet, Gubbaiah et al (10) noted high incidence of orange headed leafhopper which damaged the crop considerably. The literature on insect pests affecting the ratoon rice yield is scanty.

The ratoon rice crop will favor multiplication of insects (borer, gall midge, leafhopper) during the off-season and thus serve as an alternative host for maintaining a continuous insect population. This factor needs consideration when recommending ratoon cropping. Varieties bred for ratooning should possess insect resistance to minimize the cost of plant protection chemicals. In addition, economic plant protection schedules must be developed for maintaining higher yields.

Diseases

The ratoon rice crop is more prone to disease than the main crop. Grassy stunt virus infection in the ratoon crop tended to be greater with increasing levels of cutting. Longer stubbles had more stem rot than the main crop (2). Similarly, Chen and Ko (4) observed that the ratoon crop had a higher incidence of rice yellow dwarf virus than the main crop.

Table 6. Grain yield and blast reaction performance of three semidwarf rice varieties, main and ratoon crops, Ponnampet, Karnataka, 1986.[a]

Variety	Main crop			Ratoon crop			Blast rating of main crop	
	Days to 50% flowering	Plant height (cm)	Yield (t/ha)	Days to 50% flowering	Plant height (cm)	Yield (t/ha)	Leaf blast (plant crop)	Neck blast
IET 9667	86	133	.083	36	99	1.7	2	90
IET 9668	89	125	nil	38	96	1.7	0	100
IET 9670	94	114	111	41	91	1.6	1	90
Mean	89	124	–	38	95	1647	–	–
% height reduction	–	46.6	% reduction in days to flowering			–	42.6	

[a]Source: Naidu et al (17).

In the cultivar reaction to blast at Ponnampet, Naidu et a1 (17) noted that of 57 entries in the National Screening Nursery, which suffered 100% blast incidence on main crop, 3 — IET 9667, IET 9668, and IET 9670 — could regenerate a vigorous ratoon crop. They produced an average yield of 1.64 t/ ha, compared to negligible or no yield for the main crop, with a 42.6% reduction in duration. Plant height was also reduced 46.6% (Table 6). No effect on seed viability and germination was recorded

However, in the same experiment, cultivar Intan, used as control, suffered 100% blast incidence and could not establish itself as a ratoon crop because the ratoon rice was also attacked by leaf blast.

These findings suggest that there could be cultivars that have a disease in the main crop but can withstand it in the ratoon crop and produce satisfactory grain yields.

In studies on yellow dwarf disease of rice, Muniyappa and Ramakrishnan (14) observed that infestation level was much higher (1.05-35.89%) on the ratoon crop than on the main crop (0.33-22.5%). They also noted variability in resistance to yellow dwarf among the cultivars studied; cultivars CH2, CH45, CR126-33-11, IR127-80-1-10, and MR278 had zero incidence in both main and ratoon crops.

Weeds

Weeds are reported to cause as much as 11% rice grain yield loss in Asia. Many devices have been worked out for effective control of weeds in irrigated rice under various climates, soil types, weed flora, etc. Such studies are limited to ratoon rice weed management. However, the effects of tillage practices on both main and ratoon crops were studied by Bahar and De Datta (2). Tillage clearly helps produce higher ratoon crop yields. Plowing followed by harrowing gave the highest yields of main and ratoon crops, the most panicles/ m^2, and the lowest percentage of unfilled grains. Thus, weed management is essential for better yields. More studies are necessary to work out cheaper weed management practices.

SEED QUALITY

Reddy and Pawar (23) observed that seed from the ratoon crop of a number of cultivars showed no defect in productive capacity or viability. Several studies

relating to seed viability are available, but cooking quality and nutritive value of seed of ratoon rice are yet to be studied.

RATOONING IN RICE-BASED CROPPING SYSTEM

In an analysis of double-cropping yield potential of three cropping sequences, Bahar and De Datta (2) observed the following yields: 1) 11.7 t/ ha for transplanted - transplanted rice cropping sequence; 2) 11.4 t/ ha for transplanted - direct seeded; and 3) 7.6 t/ ha for transplanted - ratooned. Although the ratoon crop gave a lower yield, it matured earlier (Table 7) and required less water, input, and labor cost. The system appeared useful for increasing production with limited resources.

It is also essential to work out yield performance under a system of direct-seeded rice followed by transplanted rice. It is expected that the system will give higher yields by reducing missing hills per unit area and produce maximum number of tillers.

In studies on nitrogen fixation by blue-green algae (BGA), Watanabe et a1 (26) noted that BGA could fix nitrogen more efficiently in ratoon rice than in the main crop. There is need for intensive research on BGA and other biofertilizers to reduce dependency on nitrogen, an expensive chemical input.

ECONOMICS OF RICE RATOONING

The average yield of lntan in the blast-free areas in the Coorg District (Karnataka) is estimated at 3.5 t/ha. The levy rate of rice in 1986 was Rs.1650/t (US$114/t). If ratoon cropping is to be economical, it should yield at least 50% of the main crop. Total returns per ratoon crop would then be Rs.2887.50/ha (about US$199/ha). The farmer will realize a net profit of Rs. 1382.50, or US$95.70, which is significant (Table 8).

More detailed studies on the economics of rice ratooning as a whole are needed to determine whether ratooning will be a profitable enterprise in rice-based cropping system areas.

Table 7. Double-cropping grain yield performance of six semidwarf rice varieties in three cropping systems.[a]

Cultivar	Grain yield (t/ha)			Field duration (d)			Production (kg/ha per d)		
	T-T	T-DS	T-R	T-T	T-OS	T-R	T-T	T-OS	T-R
IR206l-464-2	10.2	9.3	6.4	183	197	163	56	47	39
IR1561-228-3	11.7	10.4	7.6	177	197	153	66	53	50
IR74782-6	8.7	7.6	5.1	165	174	135	53	44	38
IR28	11.8	9.6	8.7	183	197	167	62	49	52
IR2061-465-1	9.1	8.9	6.4	177	197	172	51	46	37
IR2061-632-3-1	9.4	8.7	7.3	180	197	142	52	44	-

[a]T = transplanted, DS = direct-seeded, R = ratooned. Source: Bahar and De Datta (2).

Table 8. Costs of rice ratooning — an estimate for Intan rice grown in Coorg District of Karnataka, India, in 1986.

Expenditure/ha	cost	
	Rs	US $
Nitrogen fertilizer (75 kg N/ha)	375.00	25.90
Irrigation (at 4 irrigation/mo)	52.50	3.60
10 mo 5 laborers		
Weeding twice at 15 laborer/ha	315.00	21.70
30 laborers		
Plant protection chemicals	250.00	17.20
Harvesting charges - 25 laborers	262.50	18.10
Threshing, winnowing, and other postharvest charges	250.00	17.30
Total cost of cultivation/ha	1505.00	103.80

[a] Labor charge/day for 8 h work is Rs. 10-50 or US$0.72/individual.

CONCLUSION

The available literature on ratoon rice to date is only suggestive rather than definitive. Systematic research on ratoon cropping, its adoption, and economics is needed to make this unique cropping system a practical and paying enterprise.

There is significant scope to adopt this technology, particularly in the tropical monsoon areas where rice is the principal crop. Where rice is cultivated mostly as a monocrop, resources go to waste during the off-season. The area that could be put under a ratoon system could be roughly estimated as 30% of the rice area in tropical Asia, or about 26.63 million hectares (as of 1978). The average yield of rice in tropical Asia is 2.7 t/ ha. The data available on ratoon rice indicate that yields up to 50% of the main crop are possible.

Assuming that the entire lowland rice area can be put under ratooning, the total production from ratoon cropping could be as high as 35.95 million tons annually.

FUTURE DIRECTIONS

1. Most of the work on ratooning so far has dealt with irrigated rice. Research on ratooning under residual moisture (rainfed), which is much more important, is scanty. There is need to know the prospects of ratooning in rainfed conditions to tide over moisture stress during later growing phases of the crop.
2. The genetics of inheritance of ratooning has not been properly understood. This should be given major emphasis, and systematic breeding efforts should be undertaken to synthesize cultivars specially for ratooning.
3. Cultivars suitable for different climates, altitude, and purposes should be identified to optimize ratoon rice yields.
4. Studies on control of tillering and growth analysis should be initiated to determine the physiological phenomenon involved in tiller regulation and crop growth.

5. Cultivars that have so far proved better (yielding more than 50% of the main crop) should be pooled as genetic stocks and temporarily used for breeding.
6. Ratoon rice suffers from insect pests and diseases and would act as alternate host for perpetuation of the pest to the main crop. Efforts should be made to screen for ratooning ability of rice resistance to insect pests and diseases. Tolerance for low temperature, especially during the seedling stage, and for drought during the later stages of the crop (because the crop is ratooned in off-season) should also be considered.
7. Development of low-cost technology in terms of use of biofertilizer, weed management, etc., to minimize cultivation costs is necessary to make ratoon rice a profitable enterprise. Suitable agronomic practices covering sowing date/cutting time, cutting height, and fertilizer and water management should be worked out for a given cultivar in various sites.
8. Areas suitable for successful growing of ratoon rice should be identified and the practice popularized to augment rice production.
9. Postharvest technology, including seed viability, quality, and milling quality, should be studied.

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Economic perspectives of rice ratooning

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A computer-aided search of IRRI's library identified 120 papers key-worded to ratooning. Although this may not be an exhaustive survey of the literature, fewer than five addressed economic aspects of rice ratooning, and in only one was economic analysis the main theme (3). We also did not discover any systematically reported national data on area or yield of ratoon rice. This means the relative importance of ratooning compared to seeded rice could not be examined.

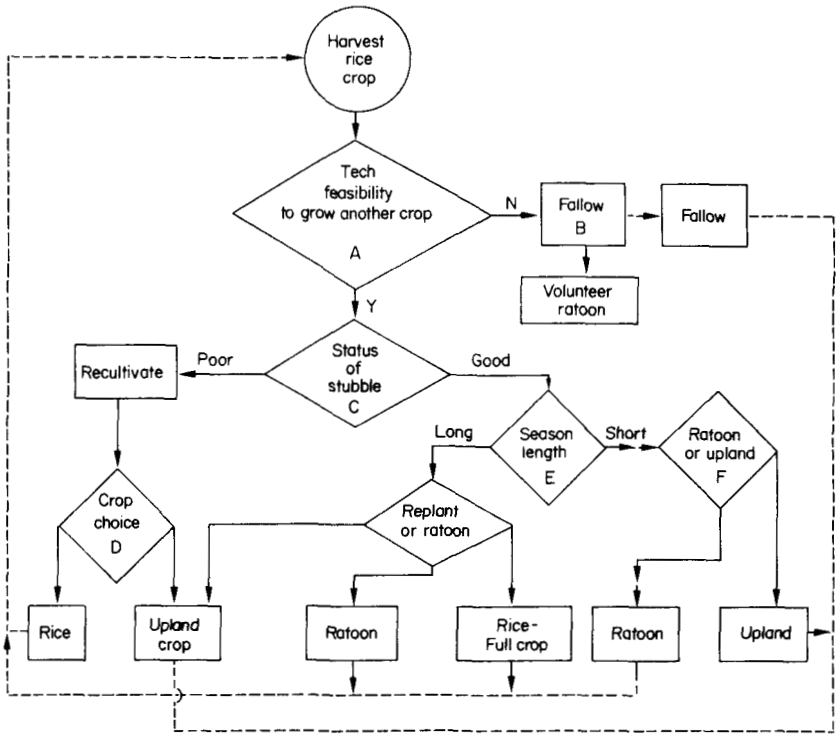
Given the lack of background, our discussion is not based on accumulated insights into economic aspects of ratooning. Even if references had been plentiful, the methodology would have been more interesting than the results. Economic analyses tend to be time-bound to prices and technology. Location-specific methodology can be adapted to analyze specific sites. Our contribution to this proceedings is a review of methods which may help evaluate rice ratooning economically. This analysis is divided into three steps:

- First, a system framework is sketched to help judge whether rice ratooning is advantageous in a particular ricefield, at a given point in time;
- Second, budgeting methods are presented which permit evaluation of the profitability of rice ratooning versus other uses of land;
- Third, a structure is presented to help judge the benefits of investing in rice ratooning research.

RICE RATOONING IN A SYSTEMS CONTEXT

Rice ratooning is visualized as a competitive form of land use (Fig. 1). When the main rice crop is harvested, the farmer must decide whether it is *technically feasible* to grow another crop on that piece of land in that cropping year. This is decision point A. Technical feasibility will be judged by:

- expectations about the weather (e.g. temperature, daylength) during the growth period of proposed crops and at harvest;
- prospects for a future water supply (irrigation or rainfall): how much, for how long, and how distributed;
- the crop maturation time; and
- fertility and pest status of the field and surrounding fields and the likely pest dynamics over the course of the crop's growth.



1. Framework for visualizing ratooning within a cropping pattern context.

Clearly, technical feasibility is crop specific: it may be technically feasible to grow a ratoon rice crop. It may not be feasible to grow a seeded rice crop or an upland crop.

If the farmer judges it is not technically feasible to grow another crop, including a purposefully managed rice ratoon, the choice is to fallow the land (decision B). Indeed, in the Philippines at least, ratoon rice is the rice that regenerates from stubble if rainfall persists or if irrigation water is available later than expected. It is a nonmanaged crop. It is not surprising that ratoon yields are often low and regarded by farmers as a windfall gain.

Given technical feasibility, the farmer must choose which crop(s) to grow under which management system. The crop and technology choice will depend on two sets of factors: first, the managerial feasibility of alternatives, and second, the socioeconomic viability of alternative crops and ways to produce them. An important decision is whether a purposeful ratoon crop is feasible and more profitable than alternative uses of the land.

Management factors (node C) which may influence a farmer's decision to ratoon a rice crop, rather than to cultivate the field, may include:

- the condition of the stubble (field conditions, stand density, etc), and
- anticipated disease/weed/insect problems which may occur with or follow a ratoon crop.

Should the farmer feel that ratooning is not managerially feasible, the field is recultivated, with the choice made between planting another rice crop or an upland crop (node D).

Assume, however, that a ratoon rice crop is technically and managerially feasible (node E). On technical grounds (e.g., the length of the remainder of the growing season) the farmer may face two options.

If the season is too short to permit a seeded rice crop to mature, the choice is between a rice ratoon and an upland crop (node F).

If the remaining season is somewhat longer, a seeded rice crop also enters the decision framework (node G).

Technical factors influencing the farmer's choice at node F will include water status of the field, suitability of the soil for an upland crop, and anticipated decline and end of rains or the irrigation season.

Managerial factors will include availability of power and labor to recultivate the field or to prepare it for an upland crop; availability of seeds and other inputs to grow other crops; availability of cash or credit to purchase inputs; and expected weather conditions, labor supply, etc., including during harvesting, threshing, and processing the crop.

If the expected season length is longer (node G), the choice may be between a second full duration rice crop, a ratoon rice crop, or an alternate upland crop.

Crop choice and crop management practices are determined by economic and household considerations. Household factors may include a desire to produce a particular crop or variety to meet social obligations, a preference for consumption or a requirement for livestock feed, a desire to remain independent from the market to assure the household's food supply, and a desire for personal labor flexibility to allow acceptance of off-farm work, if and when available.

Economic considerations will include costs of inputs and credit to purchase inputs; perceived yields and prices, the profits at harvest; and the relative riskiness of each crop which competes for land use.

In summary, choosing a ratoon crop over other land uses depends on three sets of factors (6):

1) technical/ agronomic adaptation (how fully are crop-physical requirements met under farm conditions),
2) managerial feasibility (does the farmer have the resources and skills to cope with the necessary cultural practices), and
3) economic viability (can the proposed practice compete with current land use).

Valid answers to these questions can only be obtained through on-farm research designed with a farming systems perspective.

ECONOMIC EVALUATION OF RATOONING

The economic advantages of rice ratooning include (4, 5):

- lower production costs resulting from savings in land preparation, transplanting or direct seeding, and crop maintenance during early growth;

- short duration, providing the possibility for growing another crop in the same cropping year; and
- freeing up resources (power, labor, cash) for other uses.

The economic disadvantages include:

- uneven maturity, which makes harvest difficult and expensive; and
- uneven grain quality, with possibly a lower market value, and generally low and uncertain yields.

The ratio of advantages and disadvantages helps determine whether or not ratooning is an economically viable proposition.

Ratoon vs seeded rice crop

The cost of a full duration rice crop and that of a hypothetical ratoon rice crop (we have no field data on purposefully managed ratoons) are compared in Table 1. Data for the full duration rice crop is from Central Luzon, Philippines. In this example, ratooning may save up to 60% of the labor used and most of the power, largely because land preparation and transplanting are avoided with ratooning. Of course, labor savings and costs would have been less if the rice crop was direct seeded, a practice gaining popularity in South and Southeast Asia as the real cost of herbicides falls. Irrigation costs are not included in this example because they are fixed per season, independent of the quantity of water supplied and the crop duration. However, where a farmer has to pay actual pumping costs for water, savings with a ratoon crop could be substantial; 50% less irrigation water may be used by a ratoon than by a full duration rice crop (8).

Assuming all inputs are valued at their market price, the full cost of ratooning was $96/ ha, 70% less than the cost of a full duration rice crop. This saving is consistent with other estimates (10).

Such rules of thumb must, of course, be used with caution. Savings will depend on the cost of land preparation and crop establishment in proportion to total costs, in addition to differences in costs of levels of managed inputs (e.g. fertilizer) between the main crop and the ratoon crop.

Where farmers have no alternative use for their labor and power, they may not consider it realistic to value their own resources at hired rates. In this case, the cash-cost comparison of a newly transplanted crop and a ratoon rice crop may be the more appropriate comparison from the farmer's viewpoint. The cash cost and full cost of transplanted and ratoon rice crops are compared in the last two rows of Table 1. In this example, savings on a cash-cost basis was $199, because the farmer rented the tractor used for land preparation.

Break-even yields

A recurring concern in the rice ratoon literature is the uncertainty of the ratoon crop yield. One way to address this problem is to determine the "break-even" ratoon crop yield which would be necessary to make this crop competitive with a full duration rice crop. In principle, if the reduction in benefits from a ratoon crop (i.e. yield difference by price) is less than the added cost of producing a second rice crop, then ratooning appears to be a profitable option.

That is, given the data in Table 1, adopt ratooning when

$$(1-h)\,(Y-R) * P_y, 229$$

where Y is yield of the main rice crop,
R is yield of the ratoon rice crop,
h is the harvester's share, and
P_y is the farmer-effective price of paddy rice.

The harvesters' and threshers' share, h, is included in the equation because, in the Philippines at least, his yield dependent. Harvesters demand a larger share of the crop as payment when yields are low, which often is the case with a ratoon rice crop.

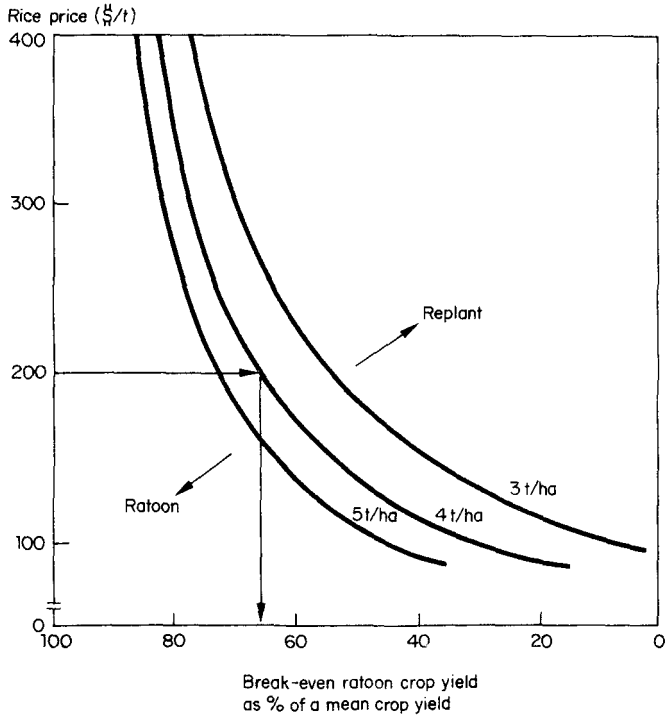
The equation is graphed for the full-cost case in Figure 2. For simplicity, h is assumed to be constant at one-sixth of gross yield over all yield levels. At a full-crop yield of 4 t/ha and a rice price of $200/t, the ratoon crop would need to yield at least 66% of the main crop (i.e., 2.6 t/ha) to be as profitable as the main crop (assuming there was no option to plant another crop after the ratoon crop).

At ratoon crop yield and price combinations that lie above a yield isoquant, replanting is more profitable; at those combinations that lie below the isoquant, ratooning is advantageous. As main crop yields and rice prices decrease, the break-even ratoon yield also decreases; as main crop yields increase, ratoon yields as a percentage of main crop yields also increase, to generate equal profitability.

Table 1. Cultivation costs of a second full duration rice crop and a ratoon rice crop.

	Unit/ha	Cost/unit	Second full duration rice crop		Ratoon	
			Level	Value ($)	Level	Value ($)
Costs						
Labor						
Land preparation	d	1.75	8.5	14	–	–
Transplanting	d	1.35	19.5	26	–	–
Crop maintenance/management	d	1.50	20.5	30	13.5	20
Harvesting/threshing	d	[a]	24.0	94	15.0	50
Postharvest	d	1.50	3.5	5	2.0	3
Subtotal			76.0	170	30.5	73
Power						
Carabao	c days	3.50	3.0	5	–	–
Tractor	t days	15.00	4.0	27	–	–
Subtotal				32		
Other inputs						
seeds	kg	0.30	75	23	–	–
N fertilizer	kg	0.47	55	26	30	14
P/K fertilizer	kg		20	13	–	–
Insecticide	($)			10		3
Herbicide	($)			4		1
Fuel and oil	li	0.30	47	14	–	–
Repair/maintenance	($)			3	–	–
Subtotal				92		18
Interest on cash costs	%/season		20	31	20	5
Cash cost basis	($)			281		82
Full cost basis	($)			325		96

[a]Harvester/thresher's share is 1/6 of total harvest.
Note: Power cost without cost of operator's labor, fuel, oil, repair and maintenance. Those are incorporated in other cost components.



2. Relationship between rice price and break-even yield of a ratoon crop and main rice crop.

Evaluating rice ratoon patterns

An advantage of ratooning, other than lower production cost, is its short duration compared to a planted rice crop. Zandstra and Samson (10) recorded growing season requirements of between 195 and 245 d, depending on the method of first crop establishment (i.e., transplanted or direct seeded) and whether the second crop was transplanted or ratooned (Table 2). A ratoon crop may provide the opportunity for a second rice harvest in a short wet season, or the possibility of an upland crop following the rice ratoon.

It is instructive to evaluate the profitability of patterns as opposed to crops in isolation. A better sense of the benefits of ratooning would be gained by comparing the productivity of two short duration transplanted rice crops (TPR - TPR), a transplanted rice crop followed by a ratoon crop (TPR - ratoon) or an upland crop (TPR - ULC), or possibly a three crop pattern (TPR - ratoon - ULC). Clearly, the technical viability of each pattern depends on the length of the growing season, as well as on the characteristic rainfall at the onset and termination of the monsoon.

Few data sets were available which permit such an analysis. While dated, the most useful for our purpose was that of Bahar and De Datta (2). They compared the productivity of three rice patterns: TPR - TPR, TPR - WSR, and TPR - ratoon. In these experiments, the first crop (TPR) was planted in the 1974 dry season, the

Table 2. Approximate growing season[a] requirements (d) for rice-rice and rice-ratoon cropping patterns (10).

Cropping pattern[b]	Crop duration (d)	Turnaround time	Growing seaso[c] offset	Growing season requirement
DSR_s - TPR_s	100 + 80	20	0	200
WSR_s - TPR_s	100 + 80	20	20	220
TPR_s - TPR_s	80 + 80	20	40	220
DSR_s - Ratoon	100 t 60	0	0	160
WSR_s - Ratoon	100 + 60	0	20	180
TPR_s - Ratoon	80 + 60	0	40	180
DSR_m - TPR_s	125 t 80	20	0	225
WSR_m - TPR_s	125 + 80	20	20	245
TPR_m - TPR_s	100 + 80	20	40	240
DSR_m - Ratoon	125 t 70	0	0	195
WSR_m - Ratoon	125 + 70	0	20	215
TPR_m - Ratoon	100 + 70	0	40	210

[a] Growing season = from day on which 75 mm rain was received and day after which 100 mm rain remains to be received. [b] DSR = rice seeded into dry soil, WSR = rice seeded onto puddled soil, TPR = transplanted rice: s = short maturity (100 d) variety, m = medium maturity (125 d) variety. [c] Time between start of growing season and planting time.

second crop (TPR, WSR, or ratoon) grew and matured into the 1975 wet season (WS).

Pattern yields and inputs applied are summarized in Table 3. Ratoon yields in 1975 WS were low, from 33% (TPR) to 43% (WSR) of the yield of the full duration (TPR) crop with which it competed. This low yield resulted in the TPR - ratoon being less profitable than the TPR - TPR and TPR - WSR patterns. Indeed, the ratoon yield would need to be more than 60% of the second TPR crop yield to make it equally profitable, given current rice prices in the Philippines.

Incorporating risk in ratoon analysis

The economic analysis so far presented implies that a farmer's objective is to maximize profits. More realistically, farmers are also concerned with stability of income (and yields) and may be unwilling to follow a practice which, while it increases expected returns, also increases, even if only occasionally, the possibility of large losses. Most farmers are risk averse and subjectively trade off higher average returns against variability of returns. The more risk averse a farmer, the greater will be the reduction in average returns he will accept in exchange for a specified reduction in variance.

Many models have been developed to assess a farmer's willingness to trade off level of income against dependability of income (1). However, in practice, little quantitative information on the degree of risk aversion of farmers is available. In this situation, a simplified rule of thumb may be evoked (I): moderately risk averse farmers are prepared to accept additional risk (as measured by the standard deviation of profit) provided the increase in risk is less than twice the increase in net benefit resulting from the increased use of that input. That is, crop i (say ratooning) will be preferred to crop j (say an upland crop) if

Table 3. Estimated net benefits of three cropping patterns: transplanted rice -transplanted rice, transplanted rice - wet seeded rice, and transplanted rice - ratoon.

	Unit/ha	TPR (1st crop)		TPR (2d crop)		WSR (2d crop)		Ratoon (2d crop)	
		Level	Value ($)	Level	Value ($)	Level	Value ($)	Level	Value ($)
Cost									
Labor input									
Land preparation	d	9.5	17	8.0	14	8.0	14	–	–
Transplanting	d	19.5	26	19.5	25	2.5	3	–	–
Crop maintenance/management	d	20.5	30	20.5	30	20.5	30	13.5	20
Postharvest	d	3.5	5	3.5	5	3.5	5	2.0	3
Subtotal		53.0	78	51.5	75	34.5	53	15.5	23
Power input									
Carabao	c days	9.5	17	8.0	14	8.0	14	–	–
Other inputs									
Seeds	kg	75	23	75	23	100	30	–	–
N fertilizer	kg	90	42	40	19	40	19	40	19
P/K fertilizer	kg	40	20	40	20	40	20	40	20
Insecticide	($)		10		10		10		3
Herbicide	($)		4		4		4		1
Subtotal			98		75		82		43
Interest on cash costs	%/season	20	28	20	23	20	20	20	10
Cash cost basis	($)		167		139		121		62
Full cost basis	($)		221		188		170		76
Return									
Gross yield	t	5.5	825	4.5	678	3.5	530	1.5	230
Net yield	t	4.6	688	3.8	565	2.9	441	1.3	191
Net return (of pattern)									
Cash cost basis	($)				947		841		650
Full cost basis	($)				844		738		582

Note: Harvester/thresher's share is 1/6 of total harvest. Cost/unit is same as in Table 1.
Data sources:
a) Rice yields and input levels (2).
b) Labor inputs and prices (field data collected by authors in Laguna, Philippines, 1985-1986, unpublished).

$$(S_i - S_j) - 2\,(B_i - B_j) < 0 \qquad (2)$$

where S_i and S_j are the standard deviations of profits and B_i and B_j are the mean levels of profit (benefits) of crop alternatives i and j.

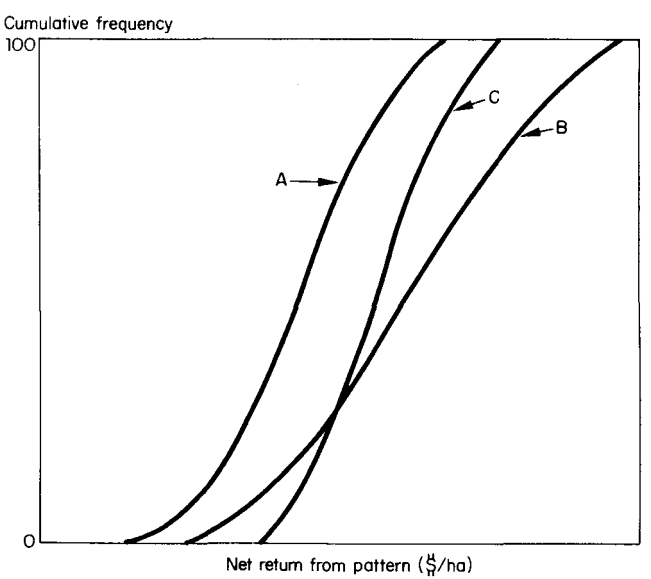
This rule basically helps determine whether the difference in mean profits between treatments is large enough to compensate for the differences in profit variability.

An immediate problem with this model is that statistically defensible estimates of yield variability may not be available. A working approximation in this case is to estimate (it may be based on expectation) the mean yield (M) and the anticipated lower (L) and upper (U) yield limits. The standard deviation of this distribution is approximated by

$$0.24\,(U-L)\,(9) \qquad (3)$$

This rule assumes that yields (and net benefits) are symmetrically distributed. A more general approach, particularly useful when management practices, including ratooning, are being evaluated in multilocation tests, is to plot the cumulative frequency distribution (CDF) of the proposed ratooning practice and the practice it would replace. The rules of sparse data analysis (1) provide a means of estimating CDFs from a limited number of points. This approach makes no assumptions about the nature of the underlying distribution function.

A hypothetical example of the CDFs of a ratoon rice crop and an alternative crop are sketched in Figure 3. Three CDFs are displayed. Curve A depicts a cropping pattern that includes a ratoon rice crop grown under management system



3. Hypothetical cumulative frequency distributions of net returns of three cropping patterns, A, B, and C.

A; curve B, a pattern with a ratoon crop grown under system B; and curve C, a pattern that includes a full duration rice crop, followed by a ratoon or a competitive upland crop. From the frequency distribution for each pattern, it is possible to directly read:

a) the probability of the profitability of any pattern reaching a target value;
b) the minimum level of profit expected for any selected probability level; and
c) the probability of net benefits falling within a desired range.

Of greater current interest is the comparison of the entire probability distributions of alternative practices. This comparison underlies the concept of stochastic dominance, which provides a means of identifying technologies which have a greater probability of a higher net benefit than alternative technologies (1).

Thus, in Figure 3, pattern C, at all levels of cumulative frequency, has a higher profit than pattern A. (The cumulative frequency distribution of C always lies to the right of A.) For this reason, C is "risk efficient" compared to A, and is preferred. The CDFs cross over in many situations, as is the case with pattern B. In this case, a risk-averse farmer may prefer C because the chance of low income is less, although the mean net return of pattern B is greater than that of pattern C.

Ratoon-main crop relations

It would be advantageous, when deciding whether or not to purposefully ratoon a rice crop, to be able to use the condition of the previous crop to help determine the expected yield of the ratoon crop. Chauhan et al (4) discuss the importance of management practices in the main crop and cultural practices at harvest which influence ratooning ability and ratoon yields. However, they and others have observed that ratoon yields vary substantially between cultivars and within cultivars over space and time (4,5).

Mahadevappa (5) shows that ratoon yields correlate with main crop yield and field duration of the ratoon crop. It is interesting to extend our analysis to separately relate ratoon yields of local/improved (LV) and modern varieties (MV). Chauhan et al (4) have provided the data that allow us to do this.

Ratoon crop yields were significantly related to main crop yields for LV, but not for MV (Table 4). Within the range of the data, for each 1 t/ha increase in LV yields, ratoon yields increased by 0.5 t/ha. However, there was no systematic

Table 4. Least squares estimates of ratoon rice yield (t/ha) as a function of main crop yield (t/ha) and ratoon crop duration (d).[a]

	Variety		Difference	
	Local	Modern	Value	t-test
Constant	1.7785	–0.0242	–	–
Main crop yield	0.4875**	0.0718^{ns}	0.4157	2.57*
Ratoon duration	0.0258*	0.0140*	0.0118	1.08^{ns}
R^2	0.47	0.11		
F-ratio	11.58**	3.47*		
n	29	58		

[a]** = significant at 5% level, * = significant at 1% level, ns = not significant. Data sources: Chauhan et al (14), Table 1.

relationship between the main crop yield and the ratoon crop yield among the MVs evaluated.

Ratoon yields were significantly related to ratoon duration among both LV and MV. A 1-d increase in ratoon duration, on average, increased LV ratoon yields by about 25 kg/ha; among MV, by about 14 kg/ha. However, the last column of Table 4 shows that the duration-yield effect did not differ significantly between LV and MV, due to the enormous variability in the data.

The poor, and often unpredictable, ratooning ability of modem rices clearly provides opportunity to select varieties and associated cultural practices that will increase both the level and dependability of ratoon rice yields. However, in doing so, scientists and policymakers should consider:

a) the trade-off between increasing ratoon yields and increasing the yield, or yield dependability, of the main crop, and
b) the trade-off of investing scarce scientific talent and funds in research on rice ratooning against the gains which may be achieved if these same resources are directed toward solving other problems.

EVALUATING RATOONING RESEARCH

Several authors argue that ratooning is little practiced by farmers because yields are low. Yields are low because cultivars have not been bred for ratooning and because management practices that will assure high ratoon yields have not been developed (4).

Why has ratoon research such low priority in rice research portfolios? One reason seems to be that ratooning ability is a complicated trait, so that it is difficult to genetically improve rice ratoon yields. Broadly interpreted, researchers seem to predict that the gains (benefits) from ratooning may not be adequate, given the research investment necessary to achieve the gains.

Under what circumstances might ratoon technology be more attractive to farmers? A current belief is that the real price of rice will continue to fall as per capita rice production increases (7) and that the cost of purchased inputs and labor, compared to rice, will continue to increase. If this scenario is credible, then cost-reducing technology, such as ratooning, will gain relevance as an option to planting a second rice crop, provided farmers are confident they can realize reasonable ratoon yields.

This same scenario will also increase the competitiveness of higher-valued upland crops grown after rice. Therefore, when considering opportunities for research investment, profitability of upland crops also must be compared with that of ratoon rice crop.

A simplified version of the investment formula provides a mental guideline for trying to obtain some rough idea about the relevance of alternative research investments. The expected net benefits of investing in research alternative a is calculated as:

$$Ka = \sum_{j=0}^{N} \frac{Pab \cdot Ba}{(1+r)^n} - \sum_{i=0}^{N} \frac{Pac \cdot Ca}{(1+r)^m}$$

where Pab = subjective expectation of obtaining benefit Ba. (If the researcher believes there is a 50:50 chance of increasing ratoon yields on 100,000 ha from 1.5 to 1.8 t/ha, then Pab is 0.5);

j = first year of benefits derived from the research, given research investment a;

Ba = estimate of benefit which the national economy (or the farmers) will derive in a given year as a result of the application of results from research alternative a. B measures net crop benefits, i.e., additional value (100,000 × 0.3 × rice price minus value of additional inputs);

r = rate of discount;

n = years with benefits;

m = years with costs;

Pac = expectation of having a cost, c, amounting to Ca in year i (n > m);

i = years of research expenditure; and

Ca = cost of research alternative a in year i.

If Ka is positive, then research investment a is profitable. However, the benefits of research alternative a should be compared with the benefits of other research alternatives. The optimum research strategy will be the one with the highest K.

Normally, this will imply a mixed research portfolio. If there is only one research alternative, then the optimum investment level would be when

$$\text{when } DKa = DCa \text{ or when } DKa/DCa = 1.0$$

where DKa = the increment in expected net benefits, given

DCa = the increment in investment cost.

If funds are scarce, the ratio will be DKa/ DCa > 1.0.

In practice, there may be a number of research alternatives, with different added benefit to cost ratios. For example,

$$DKa/DCa = 2.0$$
$$DKb/DCb = 1.5$$
$$DKz/DCz = 1.2$$

In this case, more research funds might be invested in alternative a than in alternative b to push the ratio toward alternative z. When research funds are limited, it is optimal to allocate funds in such a manner that the ratio of added benefits to added costs is equal between investment alternatives. In the above example, this would imply spending less on z and more on a.

Research in general is highly uncertain. It is rather courageous to estimate P — particularly Pab — because budgets, and therefore costs, are often determined outside the system at levels lower than researchers would choose. But in fact, most agricultural scientists do have some idea about the chances for success of research alternatives and an estimate of the time involved. If the statement that ratooning is a complex trait is correct, it may be difficult to make progress, in which case Pab may be quite small.

The same logic applies to benefits. Most research workers have some idea of the increase in output that may be obtained and the area over which the technology is relevant. If productivity gains are expected to be modest, net benefits/ ha will be, too.

It is unrealistic to imply that researchers here should attempt to arrive at Ka's for alternative investments in ratooning, or for other uses of scarce research funds, manpower, and facilities. The value of the formulae lies in the approach, which highlights the need for ordering expectations, benefits, and costs. Such an exercise may well lead to ranking ratooning research against other research alternatives. That, after all, is what is required.

In practice, the benefits of food crop research investments are strongly influenced by the area (domain) over which the technology is adopted. However, a large part of the area effect may occur because cultivars and technology are transferrable from one country to another. From a national viewpoint, these spill-over effects may be of little interest because they are not captured by those funding the research. (Indeed, spillover effects may be regarded as a detriment from the investing country's viewpoint, if the adoption of the technology by other countries decreases the first country's trade or production advantage). Where individual country benefits are small, but spillover effects between countries are large, the advantages of undertaking the work cooperatively between countries or by regional and international institutes concerned with the problem make eminent sense.

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Morphology and physiology of ratoon rice

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The morphology of the ratoon plant differs significantly from that of the main crop plant. Usually, plant height (3) is lower and effective tillers (2) are fewer in the ratoon than in the main crop. However, some ratoon crops have produced more total tillers than the main crop (2, 33, 37). Ratoon crops also developed many unproductive tillers (3, 10) and axillary buds that continued metabolic activity at the cost of grain filling.

Rice ratooning depends on the ability of dormant buds on the stubble of the first crop to remain viable. The buds may be at different stages of development (27) or similar in length (7). Axillary buds that developed at those bud nodes grew into ratoon tillers (Fig. la, b). Tillers regenerated from higher nodes formed more quickly, grew faster, and matured earlier (32). They usually had fewer leaves (1). The panicles from ratoons coming from lower nodes produced more grains per panicle than those from upper nodes, but the fertility percentage decreased (41). Panicles from upper nodes contributed more to ratoon grain yields than those from lower nodes (41).

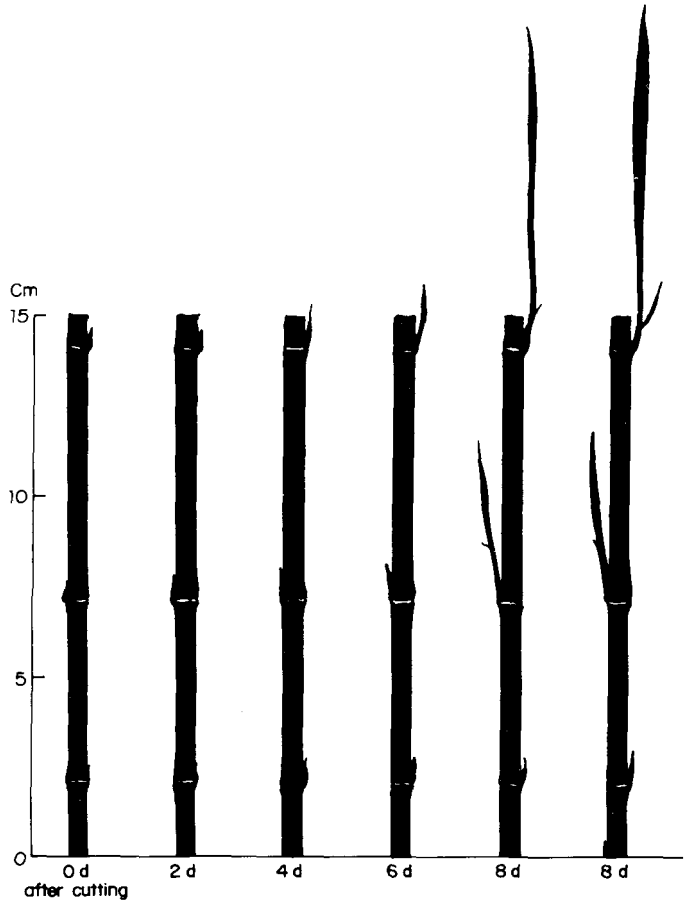
Different varieties produced ratoon tillers differently (43). Some grew tillers from all nodes of the stubble, others formed tillers only from lower nodes or mainly from the third node. These findings indicate that ratoon crops will yield well if main crop stubble is left with 2-3 nodes.

Tillers from upper nodes, with high C:N, reacted like old seedlings. Tillers from the lower nodes, with low C:N, had young seedling characteristics. The development of lower tillers should be encouraged because they resemble young seedlings (22).

In IR44, the lengths of the growing buds did not vary. After 5 d, the bud at the first node generally grew faster, followed by those from the second and third nodes (Table 1). Eight days after ratooning, the ratoon tillers began to branch (Fig. la,b).

Ratoon tiller development depends on the carbohydrates that remain in the stubble and roots after the main crop is harvested (8, 20, 37). The culm of the rice plant is a vital storage organ. Thick culms may store more carbohydrate than thin culms; this probably would be reflected in ratoon potential.

In IR44, culm thickness varied from 2 to 5 mm; most were 3-5 mm thick. Ratoon tillers developed, irrespective of culm thickness. Average tiller production varied from 1.33 to 2.90 and was higher for thick culms. Origin and time of tiller development were not influenced by culm thickness (7).



la) Developmental stages of IR44 ratoon tillers.

Ratoon tillers that form early do not inhibit subsequent tiller production; plants with early regeneration ability produced more tillers. Early tiller regeneration actually may encourage tillering by providing nutrients to the developing buds. Appearance of first tiller varied from 1 to 10 d after cutting. Regeneration time correlated negatively with number of tillers at 3 and 6 wk after cutting and at ratoon harvest. Three weeks after cutting, tillers per plant varied substantially, although the correlation remained significant (7).

FACTORS INFLUENCING RATOONING ABILITY

Inherent ratooning ability is important. A vigorous main crop root system may be a prerequisite for a successful ratoon crop. Cultural management, light, temperature, soil moisture, and soil fertility are major factors affecting ratooning ability. Growth duration, although a genetic character, has a significant impact on ratooning ability and yield.

b) Variations in IR44 ratoon tillering 10 d after cutting.

Table 1. Average length (mm) of buds at ratoon tiller development stages. IRRI, 1983 dry season.

Stages (d after cutting)	Bud position [a] (top to bottom)		
	I	II	III
0	5	5	5
2	8	8	6
4	11	11	5
6	22	15	8
8	91	45	10
10	144	45	17

[a] Usually equivalent to 4th, 5th, and 6th nodes, counting down from the 1st node under the base of the main crop panicle.

Cutting height

Stubble height determines the number of buds available for regrowth. The effect of cutting height on ratoon vigor varies: some cultivars ratooned from high nodes, others produced basal ratoons that are unaffected by cutting height (43).

When bud viability was assessed after the main crop was cut, there were more dead buds in the nodes closer to the ground (7, 41). This is the reason lower cutting produces many missing hills and reduces tillering.

More shoots were regenerated initially with higher main crop cutting height (14, 17, 32, 33, 37). Others have reported that cutting height did not significantly affect ratooning ability (4). However, irrespective of the main crop cutting height, the effective ratoon tillers grew from the base of the plant, not from the upper nodes (10). The optimum cutting height reported is 15-20 cm (2, 33, 37).

Ratoon crops produced more panicles per hill, filled spikelets per panicle, and higher 100-grain weight at 3- and 5 cm cutting heights than at 15 cm, but grain yields were less because low cutting resulted in more missing hills (2, 6, 33, 37).

Main crop cutting height should leave 1.25 cm of the stem above the water; submerged stubble may rot, longer stubble may produce weak tillers (22).

Ratoon crop growth duration is influenced by cutting height. Lower cutting height delayed maturity but produced uniform growth and maturity (10, 11, 14, 15, 29, 30, 32, 33, 37, 38). Higher cutting height increased growth duration (2).

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 (17). Grain yield was 12% more with a second cutting and about 8% more with a third cutting.

Generally, ratoon yield increased with increased cutting height (2, 14, 17, 28, 38). On the other hand, several reports claim that higher cutting heights decreased ratoon yields (29, 30, 32). In other studies, cutting height did not significantly affect ratoon yield (3, 21, 33-35).

Time of main crop harvest

The stage of maturity of the main crop at harvest affected ratooning (14, 44, 45). The best harvesting time for good ratooning was when the culms were still greenish (29, 39), before the crop fully matured (3, 26), or at full maturity when the ratoon shoots had just begun to grow (42).

Delaying main-crop harvest to 44-56 d after flowering reduced ratoon crop growth duration (44). Harvesting at 30, 35, 40, and 45 d after main crop flowering did not significantly affect ratoon yields (14, 35).

Main crop cultural practices

Ratooning ability is affected by plowing depth, transplanting time, spacing, crop establishment, and fertilizer and water management. While different cultivars have different ratooning patterns under different cultural practices, only cultural practices are discussed.

Spacing. Spacing determines main-crop plant population. A high main crop plant population increased the tiller number/ unit area, increasing potential ratoon

tiller number/unit area. But high main plant density increased the number of missing hills in the ratoon crop (2).

Fertilizer management. Applying N increased ratoon grain yields (2, 6, 10, 12, 29, 33, 36, 38). N should be applied immediately after harvest to promote early ratooning (12, 21). Applying N fertilizer to the main crop 14 d before harvest increased ratoon sprouting 10%, but decreased main crop grain yield (17).

Fertilizer applied to the ratoon crop should be placed close to the stubble rows for rapid nutrient uptake and growth (29, 31). Cultivars differ in response to N applied to the ratoon crop (3, 36).

Applying N fertilizer on ratoon crops has been reported to delay maturity (5); in other reports, it did not (33, 38). Fertilizer application may (17) or may not (2) increase ratoon tillering.

Applying high amounts of N fertilizer to the main crop reduced ratooning viability by encouraging excessive growth with weaker plants (18).

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 tillers per m^2 or ratoon crop grain yield (33). No significant interaction between fertilizer application time and cutting height was observed.

Ratoon crop plant height, panicle length, filled and unfilled spikelets, and 1,000-grain weight were not affected by main crop N application method (40). Deep-placed N produced significantly higher yield in the ratoon crop than did broadcast N. Higher grain yield was associated with more vigorous ratoon plants, more panicles per plant, and more filled spikelets per panicle. Increasing N also increased plant vigor. But at the same N level, plant vigor was less with broadcast application than with deep placement (33). Application method did not significantly affect the number of missing hills in the ratoon crop (37).

Applying P and K to the ratoon crop did not significantly affect ratoon grain yields (6). Applying P to the main crop produced a highly significant increase in ratoon yield (10, 12, 24).

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 with only water added, grain yield is significantly higher if fertilizer is applied.

Water management. Water management before and after main crop harvest affected ratooning ability (2, 14, 23, 32, 44). To promote ratooning, the field should be moist but not flooded for 2 wk at the end of the main crop. Draining the field several days after main crop harvest encouraged ratooning (9, 22, 29). Draining the main crop increased ratoon panicles per m^2 and decreased the percentage of missing hills and sterile florets (44).

When stubble was cut low, delaying irrigation was better than rewatering 1 d after cutting (2, 15, 31, 32).

If plots were drained during main crop harvesting and irrigated 12 d after harvest, ground-level and 15-cm cutting produced comparable grain yields (2). Many hills died when the crop was cut at ground level and water remained 5 cm deep or the field was immediately irrigated (2, 19). The number of missing hills increased as the time between harvest and rewatering shortened.

Early flooding encouraged more rapid, uniform regrowth than delayed flooding and produced significantly better ratoon height and yield (25).

Draining the main crop at harvest is suggested to promote ratooning and prevent death of hills due to flooding. However, under rainfed conditions where water needs to be retained, the main crop should be cut at 15 cm or higher to minimize the number of missing hills in the ratoon crop and to reduce weed growth.

Temperature

Only a few reports discuss the effect of temperature on ratooning ability. Plants exposed to low temperature (20/20 °C) at the booting stage of the main crop formed 2-3 times more basal ratoon tillers than those exposed to high (35/27 °C) and normal (29/21 °C) temperatures. Low temperature prolonged ratoon crop growth duration (37).

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 the late milk stage to 7 d after harvest (24 d) or shading at harvest to 7 d after harvest. Unshaded plants yielded 7% more than shaded plants (33). Applying extra N at early and late milk stages and at 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 missing hills. Shading plus N topdressing produced 22% fewer missing hills than shading without N topdressing (33).

Tiller regeneration ability was not affected by main crop shading. The number of ratoon tillers produced decreased as shading increased (13). In general, no shading and 49% shading had similar effects on grain yield, spikelets per panicle, filled spikelets per panicle, 1,000-grain weight, and percentage of sterile spikelets. However, 66% shading reduced ratoon grain yield, which was attributed to fewer spikelets per panicle, fewer filled spikelets per panicle, and increased spikelet sterility (13). Panicles per hill was not signficantly affected by shading. More ratoon panicles tended to develop with less main crop shading.

Percentage of ratoon tillers, ratoon height, and ratoon weight were highest in full sunlight, followed by 50 and 75% shading 2 wk before cutting. Stem base weight of stubble decreased as shading intensity increased, indicating that percentage of ratoon tillers, ratoon weight, and height may be correlated with stem base traits (20).

Growth regulators

Plant growth regulators did not significantly affect ratoon grain yield or other yield components, except panicles per hill (16, 33). Promotion of ratoon tillering was dependent on growth regulator concentration and time of application.

Leaf senescence and carbohydrate-nitrogen content

Rapid main crop leaf senescence is assumed to be a major cause of low ratoon rice yields. 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 (8). 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 (8, 37).

The percentage of ratoon tillers correlated positively (r=0.26*) with carbohydrate concentration at harvest (8). However, actual number of ratoon tillers appeared to be independent of carbohydrate concentration at harvest. Percentage of ratoon tillers, ratoon weight, and ratoon height correlated positively with stem base weight. Total nonstructural carbohydrate (TNC) may limit ratoon regrowth (20).

Growth regulators were applied to delay main crop senescence, allowing more carbohydrate to accumulate through photosynthesis (33). Their limited effect on ratoon rice indicated that the original hypothesis, that ratooning ability is associated with plant carbohydrate content at harvest, might not be correct.

In the cultivar BPI76, carbohydrate content correlated positively (r=0.88**) with main crop growth duration (13). However, ratooning ability was associated negatively with growth duration. Carbohydrate concentration was 48% less in short growth duration plants (117 d) than in 177-d plants, but the short-duration plants had higher ratooning ability. The 100% stubble regeneration of short-duration plants could not be attributed to reserve carbohydrate content. High regeneration in short-duration plants might have been due to the high N concentration in the stubble. High N is associated with profuse tillering.

N content of the main crop stubble correlated negatively (r=-0.98**) with growth duration (13). In Mingolo, carbohydrate content in the stubble correlated with the number of ratoon tillers.

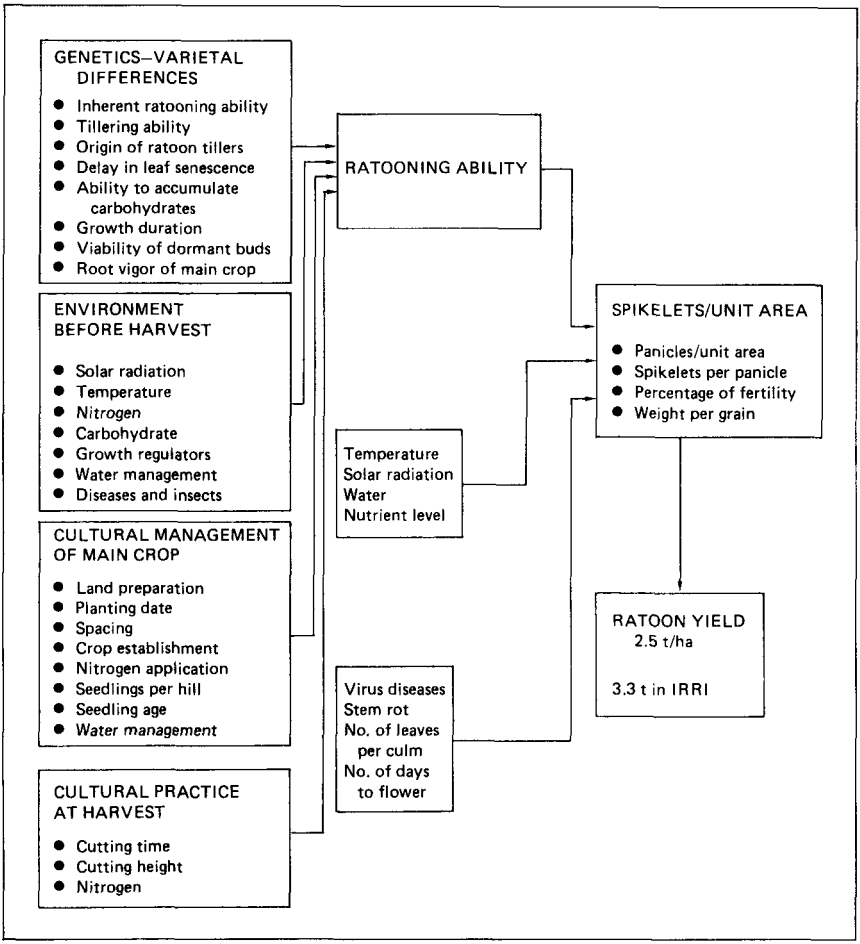
Carbohydrate content of the main-plant stubble correlated negatively with degree of shading, which probably explains why plants ratoon poorly if the main crop is shaded (13). C:N was highest at no shading and lowest at 66% shading. However, C:N in BPI76 increased with longer growth duration; growth duration was negatively associated with ratooning ability. These data contradict the assumptions about the role of carbohydrates in ratooning ability.

These findings suggest that in addition to carbohydrate content of the stubble, other factors may encourage high ratooning. For example, stubble N content may be as important as carbohydrate content for good ratoon tiller regeneration. The role of stubble carbohydrate and N content in ratooning ability needs to be clarified.

SUMMARY

Ratooning ability is a potentially important varietal character. But it is a complicated trait. Improving ratooning ability is difficult because of the complex genetic architecture and dominating influence of agroclimatic conditions and management practices.

No serious, systematic attempt has been made to identify the factors and to understand the mechanisms affecting ratooning ability and yield. The factors known to determine ratooning ability directly or indirectly are summarized in Figure 2.



2. Factors affecting ratooning ability and grain yield.

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 stages reduces ratoon tillers and yield. Low temperature during the reproductive stage causes more ratoon tillers to form. Higher plant N and carbohydrate content also increase ratooning ability.

Main crop cultural practices can influence ratooning. Spacing only slightly affected ratoon yield. Factors such as N level and application and number of seedlings per hill need further study. Water management is important in ratoon tiller production, draining fields before harvest is recommended.

Practices at or just before harvest also affect ratooning. The main crop should be harvested before full maturity, delay reduces ratoon yields. Cutting height determines the origin of the tillers and the growth duration of the ratoon crop.

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Some factors influencing the growth of rice ratoon

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ABSTRACT

Ratoon growth varies according to the internal and external environments of the stubble. The effects of temperature, soil fertility, and reserves of the main crop stubble were determined.

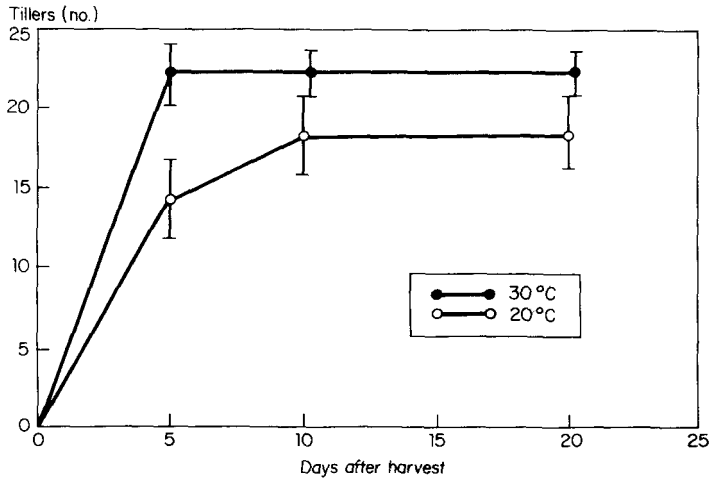
Grain yield and the other agronomic characters in the rice ratoon crop differ significantly among cultivars (1, 6, 7). Ratoon growth, however, may vary according to internal and external factors affecting the stubble. These factors include temperature, soil fertility, and reserves contained in the stubble. This paper presents the effects of these factors on ratoon growth.

TEMPERATURE

High temperature causes vigorous ratoon growth. The higher the temperature, the more tillers are formed, the higher their rate of increase, and the higher the foliage weight of the ratoon plant. Tiller number varied with temperature and reached the maximum 5-10 d after main crop harvest (Fig. 1).

Over 20 d, ratoon plant foliage weight increased linearly and stem base weight decreased. In sunlight and at higher temperature, foliage weight increased exponentially and stem base weight decreased linearly. In darkness, foliage weight and stem base weight decreased linearly. These facts indicate that ratoon growth is activated by photosynthesis of ratoon foliage. Moreover, it is inferred that substances in the stem base play an important role in the growth and respiration of the ratoon plant.

Figure 2 shows changes in the sum of stem base weight and foliage weight of the ratoon plant for 20 d. The sums remained almost constant for the first 10 d, then foliage weight and stem base weight of the ratoon plants in the high-temperature, sunlit environment increased significantly. This suggested that ratoon foliage contributed its photosynthetic products to its own growth. That the sums in dark environments were almost constant throughout the period suggested that substances in the stem base were consumed for respiration.



1. Changes in tiller numbers of ratoon plants. Vertical line represents standard deviation.

SOIL FERTILITY

The grain yield of the ratoon crop increased when manure was applied to the main crop between early ripening and harvest (1, 9, 14). Su(11) showed that the earlier the application of N fertilizer to the ratoon crop, the higher the grain yield. The effects of macronutrients on ratoon growth were examined for the amount, kind, and time of application.

Rice plants were grown in nutrient solutions and subjected to different treatments for 20 d before and after main crop harvest to determine the effect of macronutrients on ratoon growth. Ratoon growth responses to macronutrient application 10 d before harvest to 10 d after harvest are shown in Table 1. In the preharvest treatments, there were no significant differences in tiller number and foliage weight of ratoon plants, indicating that fertilizer application 10 d before harvest had little influence on ratoon growth. In the postharvest treatments, tillers and the foliage weight of ratoon plants increased as macronutrients increased. Tiller number in macronutrient-deficient application 10 d after harvest was still far less than that in the standard application, even though ratoon plants were all cultured in the same solution beginning the 10th day after harvest. This means that ratoon tillering is determined most by the amount of nutrients available the first 10 d after main crop harvest.

The effects of N, P, or K deficiency on ratoon growth are also shown in Table 1. An apparent decrease of tillers and foliage weight was observed in N- and P-deficient applications, but a statistically significant decrease occurred only in the N-dseficient application. Potassium deficiency influenced foliage weight slightly, but not tiller number. These results underscore the importance of N to the ratoon crop, because foliage weight and tiller number are directly related to ratoon crop yield.

Table 1. Traits of ratoon plant grown in different macronutrient solutions at 10 d before and 10 d after main crop harvest.

Treatment no.	NPK[a]		Tiller no.[b]	Foliage wt[b] (g/hill)
	10 d before harvest[c]	10 d after harvest[c]		
1	000	111	19.1 a	4.60 a
2	111	111	19.6 a	4.67 a
3	222	111	20.2 a	4.54 a
4	111	000	15.9 b	3.68 b
5	111	222	22.1 c	5.02 a
6	111	011	16.3 b	3.59 b
7	111	101	17.9 ab	4.11 c
8	111	110	20.0 a	4.42 ac

[a]1 = standard Kimura's B solution, 2 = double the nutrients, 0 = zero nutrient (5). [b]Means followed by same letter are not significantly different at 5% level. [c]Harvest 10 d after heading.

Bahar and De Datta (1) and Mengel and Wilson (10) reported significant yield increase in the ratoon crop plant when N was applied after main crop harvest. The same results were shown in sorghum (4, 12).

Our results were obtained from solution culture in which fertilizer response is faster than in soil. Applications of N and P fertilizers 1 wk before main crop harvest are most effective for ratoon rice cropping.

RESERVE SUBSTANCES

The effects of some external environments on ratoon growth of rice were investigated in the preceding section. However, it is obvious that ratoon growth must be affected also by the internal environment of the stubble and roots such as the amount of reserve substances and the number and vigor of resting buds. Ehara et a1 (2) reported that in herbage plants, the dry weight of new tops increased with the increase of reserves in the stubble. This may be true of the rice plant. We studied the effect of reserves in the stem base of the rice plant on ratoon growth.

To regulate the amount of reserves in the stem base, potted rice plants were grown 2 wk under 3 environments, full sunlight, 50% sunlight, and 25% sunlight. Immediately after main crop harvest, the plants were transferred to a dark environment.

Traits of main crop plants on the day of harvest, and of ratoon plants after 40 d in darkness are given in Table 2. Stem base weight and total available carbohydrates (TAC) and two ratoon plant traits (tiller number and foliage weight) increased linearly with sunlight intensity. This tendency was statistically verified by the results shown in Table 3, which indicated that every one of the correlation coefficients between stem base weight and TAC in the stem base at harvest and the two ratoon plant traits was positive and significant.

These results suggest that ratoon growth of rice in darkness depends largely on the amount of reserves, especially on TAC in the stem base. Ehara et al (3) reported

Table 2. Characteristics of main crop and ratoon plant.

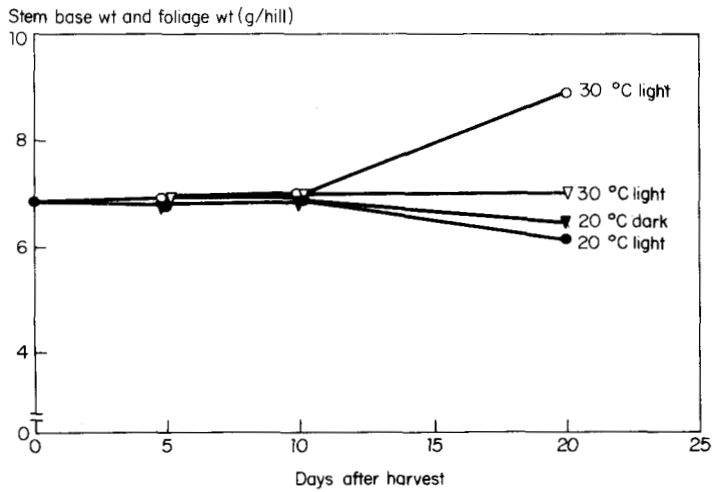
Trait	Full sunlight[a]	50% sunlight[a]	25% sunlight[a]
Stem base wt[b] (g/stem)	0.303	0.215	0.185
TAC wt in stem base[b] (g/stem)	0.185	0.109	0.085
Tiller no.[c]	18.0	14.3	8.8
Foliage wt[c] (g/hill)	0.86	0.39	0.14

[a]Treatment was for 2 wk before harvest. [b]Of main crop plant on day of harvest. [c]Of ratoon plant 49th day after main crop harvest.

Table 3. Correlation coefficients between stem base and ratoon plant traits.

Trait	Tiller number	Foliage wt
Stem base weight	0.793**	0.902**
TAC wt in stem base	0.760**	0.900**

**: Significant at 1% level, Correlation coefficients calculated from 18 points.



2. Changes in sum of stem base weight and foliage weight of ratoon plants.

that in herbage plants of Gramineae, ratoon growth depended on the amount of reserves in stem base and roots. According to Yoshida and Takahashi (15), rice plant roots do not serve as a storage organ. Weinmann (13) found that plant reserves were composed mainly of TAC. It appears that ratoon growth of rice depends on the amount of TAC in the stem base alone, at least at the early growth stage. The large amount of TAC required to produce many tillers would be achieved by high cutting the main crop, because the amount of TAC in stubble increases with cutting height (8).

Ratoon growth after the early stage was affected not only by the amount of reserves in the stem base but also by photosynthetic products in foliage (Fig. 2).

However, the dependence on photosynthesis in foliage is of far less importance in determining tiller number than it is in determining foliage weight, because tiller number became constant far more rapidly than foliage weight after main crop harvest (Fig. 1). Ratoon plants should have sufficient tillers in the early stage after main crop harvest to achieve high yields. Cultivars and culture practices, including cutting height and fertilizer management, which provide a large quantity of reserves at harvest, may be advantageous for rice ratooning.

CONCLUSION

Temperature, soil fertility, and reserves are important to the successful ratooning of a rice crop.

Temperature. The higher the temperature, the higher the tiller number and rate of increase. Photosynthetic products in the ratoon plant contribute to its growth the ratoon plant consumes only small amounts of reserves in the stem base for respiration.

Soil fertility. Macronutrient application before main crop harvest had no significant influence on tiller number and foliage weight of the ratoon plant, but those traits varied considerably with the amount applied after main crop harvest. Tillers and foliage weight decreased most with N deficiency, followed by P deficiency. No significant effect was detected with K deficiency.

Reserve substances. Every one of the correlation coefficients between stem base weight and TAC weight in the stem base on the day of main crop harvest, and tiller number and foliage weight of the ratoon plant was positive and significant. Therefore, ratoon growth reflects the amount of reserves at the time of main crop harvest, at least at the early ratoon stage.

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Breeding and testing for superior ratooning ability of rice in Texas

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ABSTRACT

Commercial ratoon cropping contributes significantly to rice farmers' income on the Gulf coast of Texas and Louisiana. Ratooning ability has been an important breeding objective. A primary basis for releasing cultivars Belle Patna and Labelle was superior ratooning ability. Research in the United States on ratooning has been relatively limited in the United States and has focused primarily on cultural practices. In the breeding program in Texas, advanced selections are routinely tested for ratooning ability but no early-generation selection criteria are available. The field plot techniques are reliable but relatively labor intensive. Ratoon crop yield appears to be independent of main crop yield. Carbohydrate reserves in the culm at maturity generally have a positive but low relationship with ratoon crop yield. Average ratoon yields in research plots have remained relatively constant for 30 yr. Preliminary indications are that, with good management, newly developed high-yielding semidwarf cultivars like Lemont and Gulfmont can produce significantly higher ratoon crop yields on the Gulf coast than current nondwarf cultivars. Superior ratooning ability is receiving increased breeding emphasis in Texas because it offers the potential to significantly reduce the per unit cost of production.

Rice ratooning on a commercial scale in the Southern United States was established in 1962 with the release of the very-early maturing cultivar Belle Patna. Before the release of Belle Patna, no U.S. rice cultivars were sufficiently early maturing for reliable ratoon crop production, although some ratooning was practiced on a limited scale. In 1959, only 4,000-8,000 ha of rice were ratoon-cropped in Texas (5).

Research on ratoon cropping initiated in Texas in 1956 included studies of the effect of cutting height, cultivars, and fertilizer rates on ratoon production (2, 4). At that time, the development of cultivars with superior ratooning ability became a breeding objective. Belle Patna was released primarily on the basis of its high yield potential through the production of a ratoon crop (1). The widespread popularity of Labelle, the leading cultivar in the U.S. for a number of years, was due to a large extent to its superior ratoon crop yields (6).

Evaluations of the ratooning potential of promising early-maturing selections in the breeding program at Beaumont are conducted in replicated field plots. The same plots are used to measure main crop yields and ratoon crop yields. Standard

plot size is 6 rows × 6.1 m with 17.8 cm row spacing. Plots are drill-seeded at 112/kg ha and standard cultural practices are followed. From the 2 center rows, 4.88 m are harvested by hand to determine yield. Following the main crop harvest, the border rows are discarded, leaving a uniform stubble with a height about 70% that of the main crop. The stubble is topdressed with 67 kg N/ha. Ratoon plots are flooded to harvest. The same 2 rows used to measure main crop yield are used to measure ratoon yield.

The ratoon crop shows considerably more variability in grain yield than the main crop. Table 1 presents coefficients of variation for main crop yield, ratoon crop yield, and total yield in the Regional Uniform Rice Nurseries at Beaumont for 1977, 1978, 1981, and 1982. In most years for most groups, the coefficients of variation for the ratoon crop tended to be double or triple those for the main crop. The inherently higher ratoon crop yield variability may be caused by main crop lodging; diseases; bird, rodent, and weather damage; soil nutrient deficiencies; and low temperature.

Despite the high variability in ratoon data, the tests tend to identify superior ratooning lines. The correlation coefficient between 1977 and 1978 ratoon yields was 0.508; between 1981 and 1982, it was 0.824. An example of the range of main and ratoon crop yields in the very-early-maturing group of the 1978 Regional Uniform Rice Nurseries is presented in Table 2.

Although ratooning ability is an important objective of the rice breeding program in Texas, the primary emphasis is on main crop yield. The main crop, which constitutes the major portion of the total yield, generally has better milling quality and is more stable and reliable than the ratoon crop. If a superior ratooning line is identified, it will be of value only if it is combined with satisfactory main crop yielding ability and with other important attributes required in a successful cultivar.

When superior main and ratoon crop yielding abilities are combined in a cultivar, extraordinarily high total yields are possible and the cost per unit of production is reduced significantly. In 1985, a combined main and ratoon crop yield of 13.6 t/ha was obtained with the semidwarf cultivar Lemont in research plots in Louisiana (3). In commercial production, a total main and ratoon crop yield of 11.8 t/ha (12% moisture) was obtained on a 160-ha field of Lemont in Texas. The

Table 1. Coefficients of variation for main and ratoon crop yields in groups of the Regional Uniform Nurseries at Beaumont, Texas.

	Group I	Group II	Group III	Group IV	Group V	Av
1977						
Main crop yield	5.4	4.2	7.8	4.2	5.0	5.3
Ratoon crop yield	11.3	16.6	–	27.3	–	18.4
1978						
Main crop yield	7.7	5.3	14.3	9.9	13.6	10.1
Ratoon crop yield	34.3	21.3	–	37.9	–	31.2
1981						
Main crop yield	11.2	9.0	7.7	–	7.9	8.9
Ratoon crop yield	8.3	11.1	19.3	–	10.8	12.4
1982						
Main crop yield	12.3	–	–	–	5.8	9.0
Ratoon crop yield	17.4	–	–	–	23.8	20.6

main crop yielded 8.2 t and the ratoon crop 3.6 t/ha. Table 3 presents additional evidence of the contribution a ratoon crop can make to total yield.

Most of the research relative to ratooning at Beaumont consists of data from the annual Regional Uniform Rice Nurseries. The nurseries are primarily performance trials of advanced breeding lines from Texas, Louisiana, and Arkansas. The emphasis is on main crop yields, milling and cooking quality, disease reaction, lodging resistance, and maturity. Ratoon yields generally have been obtained only in the early-maturing groups in Texas.

Although these nurseries were not designed to study ratooning in any fundamental way, they provide a relatively large body of data that can contribute valuable information relative to the association of ratooning ability with other important agronomic characteristics and climatic factors in the Gulf coast area of Texas and Louisiana. Some of the important associations in a breeding program for

Table 2. Main and ratoon crop yields for selections in the very early group (Group I) of the Regional Uniform Rice Nurseries, at Beaumont, Texas, 1978.

Selection	Yield (t/ha)[a]		
	Main crop	Ratoon crop	Total yield
RU7802003	6.9 a	1.8 bcd	8.8 a
RU7801011	6.8 ab	1.4 def	8.2 abcd
RU7602015	6.6 abc	1.6 cde	8.2 abcd
RU7801004	6.6 abc	1.7 bcde	8.3 abc
RU7603009	6.4 abcd	1.0 gh	7.4 def
Labella	6.3 abcde	2.1 b	8.4 ab
RU7703008	6.3 abcde	0.8 h	7.0 ef
RU7802010	6.1 bcde	2.0 bc	8.1 abcd
RU7801001	6.1 bcde	1.3 efg	7.4 def
RU7703005	6.1 bcde	1.3 efg	7.4 def
RU7701014	5.9 cdef	1.6 cde	7.5 cdef
RU7802013	5.9 cdef	1.2 fgh	7.0 f
RU7703012	5.8 def	1.6 cde	7.4 def
RU7801007	5.8 def	2.1 b	7.9 bcde
RU7502006	5.6 ef	2.7 a	8.2 abcd
RU7702016	5.3 f	2.1 b	7.4 def
Mean	6.1	1.6	7.8

[a]In a column, values followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 3. Main and ratoon crop yields for indicated cultivars at Eagle Lake, Texas, 1985.

Cultivar	Yield (t/ha)[a]			Plant type
	Main crop	Ratoon crop	Total yield	
Lemont	8.7 a	2.3 bc	11.0 a	Semidwarf
Gulfmont	8.3 ab	2.9 a	11.3 a	Semidwarf
Rexmont	7.4 b	1.9 cd	9.3 b	Semidwarf
Skybonnet	6.0 c	2.8 ab	8.8 b	Normal
Newrex	5.9 c	2.2 c	8.2 b	Normal
Lebonnet	4.9 d	1.7 d	6.6 c	Normal

[a]In a column, values followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test.

improved ratooning ability are 1) the relationship of main and ratoon crop yields, 2) ratoon yield anti plant height, and 3) ratoon yield and days to heading or maturity.

Because of time constraints, we only analyzed data from selected years. We also limited the number of characters analyzed. Analyses were of data from 1977, 1978, 1981, and 1982. Ratoon yields were determined for 36 selections in 1977, 52 selections in 1978, 68 selections in 1981, and 56 selections in 1982.

The ratoon crop was harvested only from those plots that appeared to have an estimated minimum yield of about 0.5 t/ ha. Ratoon yields above the minimum level usually are produced only by selections in the very early or early maturity groups of the Regional Uniform Rice Nurseries. Yields of later maturing entries often are reduced by low temperatures and declining daylengths.

Within the 4 yr studied, for all groups combined, none of the principal agronomic characters included in the analyses correlated (Table 4). From the breeder's standpoint, that lack of strong associations indicates that very early or early cultivars can be developed for the Gulf coast that combine the semidwarf plant type with superior main crop and ratoon crop yielding ability. Initially, we were fearful that semidwarf types might lack the ratooning potential of taller types. Although no significant correlations were found among all groups combined within any year for the characters analyzed, there were some significant correlations within some groups in some years.

Although superior ratooning ability has been an important breeding objective in Texas for the past 30 yr, we have had no criteria on which to base early-generation selection for improved ratooning. Not until the most promising selections have been entered into advanced yield trials, usually the Regional Uniform Rice Nurseries, are ratooning evaluations conducted. By that time, the selections are relatively homozygous. In effect, there is no direct selection for improved ratooning, only evaluation of selections after they are essentially homozygous for the character. The only characteristic that influences ratooning potential that we consciously emphasize in an early generation is early maturity. Early maturity is essential for reliable ratoon production before cool autumn temperatures occur on the Texas and Louisiana Gulf coast.

To develop selection criteria for superior ratooning ability that could be applied to earlier generations, in 1977 we initiated studies of the relationship of

Table 4. Simple correlation coefficients between ratoon crop yield and main crop yield, main crop plant height, and main crop days to heading.

Variables	n	r
1977 Main crop yield and ratoon crop yield (all groups)	36	–0.202 ns
1978 Main crop yield and ratoon crop yield (all groups)	52	0.025 ns
1981 Main crop yield and ratoon crop yield (all groups)	68	0.041 ns
1982 Main crop yield and ratoon crop yield (all groups)	56	0.091 ns
1981 Main crop height and ratoon yield (all groups)	68	0.179 ns
1982 Main crop height and ratoon yield (all groups)	56	0.162 ns
1981 Days to heading and ratoon yield (all groups)	68	–0.093 ns
1982 Days to heading and ratoon yield (all groups)	56	–0.090 ns

reserve carbohydrates (total nonstructural carbohydrates [TNC]) in the culms at maturity with ratoon yield (3). At main crop maturity, subsamples of plants were harvested from all plots to be ratooned. The panicles were removed, samples dried and ground, and TNC percentage determined.

As with ratoon yields, TNC appears to be inherently highly variable. The mean coefficient of variation for TNC ranged from 11.2 to 27.3 among the Regional Uniform Nursery groups in 1977 and from 16.2 to 29.5 in 1978. For all groups combined, the correlation coefficient between TNC percentage in 1977 and 1978 was 0.208, a low but statistically significant value. For the individual groups, the correlation coefficients for groups I through V were 0.307, 0.020, -0.493, -0.066, and 0.619. Despite the high degree of variability in TNC values, statistically significant differences among selections were common in all regional nursery groups in both 1977 and 1978. An example of the range in TNC values within a regional nursery group is presented in Table 5.

Correlations of TNC with main crop yields and ratoon yields in 1977 and 1978 are presented in Table 6. Although TNC and ratoon yields correlated significantly in some test groups, the levels appear to be too low to have much practical value as a selection criterion in breeding for superior ratooning ability. Although we intentionally used the simplest approach in our investigation of TNC as a possible selection index for ratooning, the time required for sample preparation and laboratory evaluation was probably too great for TNC to ever be developed as a routine screening procedure. In our opinion, any technique that would require extensive labor for sampling, sample preparation, and carbohydrate determinations would limit the number of selections that could be tested to an ineffective level. However, newly developed laboratory equipment, such as near-infrared (NIR) reflectance, might allow almost instantaneous evaluation of carbohydrate levels in dried culm samples with minimal cost and labor.

Table 5. Average TNC percentage in mature culms of selections in Group I of the Regional Uniform Nurseries, Beaumont, Texas, 1977.

Selection	(%) TNC[a]
RU7702010	15.4 a
RU7502006	12.1 b
RU7702003	11.2 b
CI 9857	10.1 bc
RU7701021	9.6 bcd
RU7703008	8.8 bcde
Labelle	7.7 cdef
RU7401011	7.1 cdefg
RU7701014	6.9 cdefg
Skybonnet	6.6 defg
RU7603009	6.0 efgh
RU7701001	5.9 efgh
RU7703012	5.5 efgh
RU7601007	5.3 efgh
RU7702016	4.8 fgh
RU7701004	3.8 gh
Newrex	2.5 h

[a]In the column, values followed by a common letter are not significantly different at the 5% level by Duncan's multiple range test.

Table 6. Simple correlation coefficients between TNC percentage and main crop and ratoon yields in the Regional Uniform Nurseries, Beaumont, Texas, 1977-78.

Test		Main crop yield	Ratoon yield
1977			
Group I	% TNC	-0.439**	-0.243
Group II	% TNC	-0.365*	0.262
Group III	% TNC	-0.351**	–
Group IV	% TNC	-0.016	0.347**
Group V	% TNC	-0.261*	–
Combined Groups	% TNC	-0.305**	0.094
1978			
Group I	% TNC	0.015	0.462**
Group II	% TNC	–0.167	0.279*
Group III	% TNC	0.116	–
Group IV	% TNC	-0.044	0.219
Group V	% TNC	-0.315**	–
Combined Groups	% TNC	-0.239**	0.289**

*Significant at the 5% level of probability, **significant at the 1% level of probability.

Although our investigations indicate that TNC percentage in the straw at main crop harvest generally is not an effective indicator of ratooning potential under the cultural practices and climatic conditions common to the U.S. Gulf coast, we believe that the subject merits further testing. It may be that a different sampling time, or nitrogen level, or variations in cultural practice other than those under which our study was conducted might provide more satisfactory results.

Since the establishment of ratoon cropping with the release of Belle Patna in 1961, average ratoon crop yields in both research plots and farmers' fields have remained relatively constant in Texas and Louisiana. However, preliminary indications are that the newly released, high-yielding semidwarf cultivars Lemont and Gulfmont may have significantly better ratoon crop potential under a high level of management than Labelle and other current nonsemidwarf cultivars. The previously cited 1985 data from Louisiana (7), data in our other paper presented here, and new data from other disciplines at Beaumont support this projection. The semidwarf cultivars may not have inherently higher ratoon crop yielding ability, but their high nitrogen-responsiveness and extreme lodging resistance may allow them to be fertilized for maximum yield expression without the lodging that frequently occurs with nonsemidwarf cultivars at high fertility rates.

The development and release of Lemont and other semidwarf long-grain rice cultivars have resulted in significant yield increases across the Southern U.S. rice area. To maximize the high yield potential of the new cultivars, a higher level of management is being applied, with emphasis on reduced unit cost of production rather than yield per se. Preliminary economic analyses indicate that ratoon cropping can dramatically reduce per unit production cost of the total crop. As a result of this finding, research on all aspects of ratoon cropping is being expanded, with emphasis on breeding for superior, stable ratoon crop yields combined with high main crop yields, and on developing cultural practices that will maximize productivity. The goal is to raise average yields in Texas to 8.5 t/ha by 1991.

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Utilization of rice ratooning by farmers in Rio de Janeiro State, Brazil

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Irrigated rice in Rio de Janeiro State, Brazil, is planted on 33,000 ha, with an average yield 3.3 t/ha, for a total production of about 100,000 t—20% of the state's need. Although rice represents only 2% of the national economy, it is very important in the state economy, as it contributes 12% of agricultural income and employs a 20,000-person labor force.

Considering the economic importance of intensive utilization of lowlands, the Rio de Janeiro Agricultural Research Corporation (PESAGRO-RIO) started research on rice ratooning to try to increase production and to employ more labor.

LITERATURE REVIEW

Studies by Oliveira et al (5) showed that rice ratooning had been adopted by some farmers in the Norte Fluminense region, but usually without success. The problem is that traditional cultivars have long growth durations, so that the flowering stage of the ratoon crop occurs at low temperatures, causing low grain yield. With the introduction of such modern cultivars as P899 and IR841, it has become feasible to utilize this new technology in the region. Using the new cultivars, some farmers have obtained ratoon yields higher than the main crop yields of traditional cultivars (4).

Ramos et al (7) found that sowing date and cultivar growth duration influence the date of main crop harvest, while cutting height and vigor of ratoon tillers influence ratoon yield.

Ishikawa (3) and Balasubramanian et al (2) reported that cutting height of the main crop did not affect the ratoon crop yield. But Parago (8) suggested that the main crop should be cut at or close to ground level. Saran and Prasad (8), however, reported that cutting at ground level produced lower ratoon yields than did higher cutting.

Ratooning may be a satisfactory agronomic practice. Some farmers using modern cultivars have had rice ratoon yields higher than the main crop yields of traditional cultivars (1, 5).

Table 1. Mean monthly data in Campos Agricultural Experiment Station, September 1975 to July 1978.

Month	Mean Temperature (°C)			Rainfall (mm)	Insolation (mm)
	Max	Min	Mean		
Sep	25.9	17.4	21.6	74.5	136.0
Oct	27.0	18.8	23.4	119.5	185.0
Nov	28.1	20.6	24.7	178.5	114.0
Dec	29.7	21.0	25.7	152.2	154.0
Jan	31.3	21.9	26.9	82.7	177.3
Feb	31.5	21.2	26.8	48.5	139.2
Mar	32.4	19.9	26.7	41.2	198.3
Apr	29.0	18.7	24.2	66.0	160.1
May	27.3	16.5	22.7	77.2	210.0
Jun	26.1	15.7	21.4	20.2	143.5
Jul	26.1	15.0	20.9	66.9	155.7

Source: Campos Agricultural Experiment Station (PESAGRO-RIO).

MATERIALS AND METHODS

Two experiments at Campos Agricultural Experiment Station, 14 m altitude, 21°41'S, 4l°20'W, tested sowing dates and height of main crop cutting on ratoon yield and grain quality. In the Norte Fluminense Region, the climate is classified as dry and wet, with a summer rainy season (Table I). The first trial in 1979-80 studied ratoon yields of two modern and one traditional varieties across six sowing dates.

Sowing dates were from September to February. Traditional variety De Abril and modern cultivars IR841-63-5 and P899-55-6-4-61B were transplanted 30 days after seeding at a spacing of 30 cm between rows and 20 cm between hills using 5 seedlings/ hill in a split plot design with 3 replications. The main crop was fertilized with 50 kg N, 50 kg P_2O_5/ ha, and 50 kg K_2O/ ha; 1/3 N and all P_2O_5 and K_2O were applied as basal and 2/3 N was broadcast at panicle initiation. The ratoon crop was fertilized with 30 kg N/ ha soon after the main crop harvest.

For the main crop, cutting height was 12-15 cm above ground level. Sufficient soil moisture was maintained to the end of tillering, then plots were flooded to 15 cm until grain maturity initiation of the ratoon crop.

The second trial in 1983-84 used 10 cultivars and varieties in a split plot design with 3 replications to test cutting height (10, 20, and 30 cm). The 14.4 m^2 plots were direct seeded at 100 kg/ ha with 30 cm spacing between rows.

The soils of the two trial fields were Paraiba alluvial, with low organic content and clay texture. The main crop was fertilized with 50 kg N and 60 kg P_2O_5/ha; 1/3 of the N and all the P_2O_5 and K_2O were applied as basal and 2/3 N was broadcast at panicle initiation. The ratoon crop was fertilized with 20 kg N/ ha soon after harvest of main crop.

RESULTS AND DISCUSSION

In the first trial, improved varieties performed better at all sowing dates (Table 2). However, yields from October, September, and November sowings were higher. In

Table 2. Mean grain yield and growth duration of main crop and ratoon crop of three rice cultivars sown on different dates. 1978-79.

Sowing	Cultivar[a]	Growth duration (d)		Yield (t/ha)		
		Main crop, emergence to ripening	Ratoon, first harvest to ratoon crop flowering	Main crop	Ratoon[b]	Total
18 Sep 1978	De Abril	185	87	3.9	1.3 (34)	5.3
	IR841-63-5	154	73	5.4	3.4 (63)	8.9
	P899-55-6-4-6-1B	157	76	5.7	3.3 (58)	9.0
20 Oct 1978	De Abril	161	78	5.4	0.8 (16)	6.2
	IR841-63-5	146	74	6.1	3.0 (49)	9.1
	P899-55-6-4-6-1B	145	74	7.8	3.2 (41)	11.0
21 Nov 1978	De Abril*	150	–	4.4	–	–
	IR841-63-5	149	82	6.5	0.4 (6)	6.9
	P899-55-6-4-6-1B	146	80	7.4	0.5 (6)	7.9
21 Dec 1978	De Abril*	145	–	3.7	–	–
	IR841-63-5*	140	–	5.2	–	–
	P899-55-6-46-1B*	141	–	5.9	–	–
23 Jan 1979	De Abril*	135	–	4.9	–	–
	IR841-63-5*	142	–	4.6	–	–
	P899-55-6-4-6-1B*	140	–	5.8	–	–
22 Feb 1979	De Abril*	142	–	2.2	–	–
	IR841-63-5*	154	–	2.0	–	–
	P899-55-6-4-6-1B*	154	–	2.8	–	–

[a]* = no ratoon yield from crop sown on this date. [b]Figures in parentheses are percentages of main crop yield. Source: EEC, PESAGRO-RIO.

the main crop, the improved varieties also had the best yields, except in the late sowings, where the yield of the traditional cultivar equaled those of the improved cultivars IR841 and P899. The best performance of the ratoon crop occurred in September and October. IR841 yields decreased with sowing dates from September to November. Usually the harvest of cultivars with growth durations of 140-150 d will occur in April, when the mean low temperature is about 18 °C. Because the rice ratoon crop flowering stage will occur at low temperature, decreases in grain yield due to spikelet sterility can be expected.

In the second trial (Tables 3, 4, and 5), cultivar P899 and varieties Metica I and L-5738 had the best yields, up to 5 t/ha. Cutting at 10 cm above ground level lowered the ratooning ability of all cultivars and varieties tested — maximum yield was 16.8% that of the main crop in the variety MG209. The best ratoon yields were with a cutting height at 30 cm above ground: the best responses were from PESAGRO-101, P899, De Abril, and Metica 1 — the yields doubled at 20 cm cutting height.

P899 had the highest total yield (main crop + rice ratoon), more than 7 t/ha. Metica 1 and L-5738 also showed a high potential for rice ratooning with total yields more than 6 t/ ha at 30 cm cutting height. The lowest yields were with the traditional cultivar De Abril (Table 3).

The low total yield in the second trial was due to the low soil fertility, with only 2% organic matter.

In the main crop, growth duration ranged from 144 to 166 d. For all cultivars and varieties, growth duration of the ratoon crop was about 60 d (Table 4).

Table 3. Yield of main crop and ratoon crop of 10 irrigated rice cultivars at 3 cutting heights, PESAGRO-RIO 1984.[a]

Cultivar	Yield (t/ha)						
	Main crop	Ratoon crop[b]			Total		
		10 cm	20 cm	30 cm	10 cm	20 cm	30 cm
IR841-63-5	3.9	0.6 (17)	0.7 (17)	1.1 (28)	4.6	4.6	4.7
PESAGRO 101	3.6	–	0.4 (11)	0.9 (24)	3.6	4.0	4.5
PESAGRO 102	4.2	0.4 (9)	0.5 (12)	0.4 (10)	4.5	4.7	4.6
PESAGRO 103	4.9	0.3 (5)	0.6 (11)	0.6 (12)	5.2	5.5	5.6
MRI IR22	4.8	0.3 (6)	0.7 (16)	0.7 (15)	5.1	5.5	5.5
Metica 1	5.5	0.2 (4)	0.3 (6)	0.7 (12)	5.8	5.9	6.2
L-5738	5.5	0.3 (5)	0.7 (13)	1.0 (17)	5.8	6.2	6.5
P899-55-6-4-6-1B	5.7	0.9 (15)	0.7 (12)	1.7 (30)	6.5	6.4	7.4
MG209	3.6	0.6 (17)	0.4 (12)	0.7 (20)	4.2	4.1	4.4
De Abril	3.5	–	0.2 (4)	0.3 (9)	–	3.6	3.8

[a]* = mean of 3 replications. [b]Figures in parentheses are percentages of main crop yield.

Table 4. Plant height and growth duration of main crop and ratoon crop of 10 irrigated rice cultivars at 3 cutting heights, Campos Agricultural Experiment Station, PESAGRO-RIO.

Cultivar	Main crop		Ratoon [a]					
	Plant height (cm)	Growth duration (d)	Plant height (cm)			Growth duration (d after first cutting)		
			10 cm CH	20 cm CH	30 cm CH	10 cm CH	20 cm CH	30 cm CH
IR841-63-5	80	145	55	46	56	60	60	60
PESAGRO 101	130	160	55	56	55	60	60	60
PESAGRO 102	84	144	60	62	60	60	60	60
PESAGRO 103	104	158	56	59	64	62	62	48
MRI-IR22	125	160	57	66	67	60	60	60
Metica 1	100	146	64	60	64	60	60	60
L-5738	86	144	60	60	63	60	60	60
P899-56-6-4-6-1B	99	144	68	70	70	60	60	60
MG209	140	147	–	–	–	–	–	–
De Abril	139	163	–	–	–	–	–	–

[a]CH = cutting height.

The best milling quality was from the main crop; the ratoon crops of IR841, PESAGRO 102, L-5738, and Metica 1 had the highest grain translucency (Table 5).

CONCLUSIONS

1. The best sowing dates for rice ratooning are September-October;
2. IR841 showed the highest potential for rice ratooning, with yields corresponding to 62% of the yield of a main crop sown in September;
3. Ratoons of P899 and IR841 performed better than ratoons of De Abril;
4. No crop successfully ratooned when sowing was after November;
5. Cutting the main crop at 10 cm was detrimental to ratooning;
6. Cutting at 30 cm resulted in the best ratooning performance in all cultivars;

Table 5. Milling quality grain translucence, and 1,000 grain weight of main crop and ratoon crop of rice cultivars at 3 cutting heights, 1984.[a]

		Main crop				Ratoon			
Cultivar	Cutting height (cm)	MR (%)	HG (%)	GT (%)	1,000-GW (g)	MR (%)	HG (%)	GT (%)	1,000-GW (g)
MG209	10	63	50	73	23	55	42	89	21
	20	66	60	66	22	61	48	87	22
	30	59	52	74	22	51	49	84	21
P102	10	64	52	76	21	49	36	91	21
	20	63	36	77	22	55	43	89	18
	30	67	50	79	21	61	60	88	20
IR841	10	63	54	89	26	54	50	95	24
	20	65	51	86	25	56	49	91	24
	30	63	43	89	26	59	55	93	24
P101	10	63	55	86	26	–	–	–	–
	20	62	57	71	26	46	32	87	22
	30	58	42	76	26	50	39	89	21
L-5738	10	63	54	93	26	50	40	96	22
	20	67	54	81	25	58	51	96	22
	30	66	54	84	25	57	49	94	22
P899	10	60	50	71	25	57	35	78	23
	20	60	32	77	24	54	29	75	24
	30	63	38	74	26	60	40	66	24
Metica 1	10	61	52	86	25	57	41	92	20
	20	63	49	81	23	59	46	88	21
	30	65	53	80	25	58	40	93	21
De Abril	10	59	42	40	31	–	–	–	–
	20	59	45	41	28	59	45	41	28
	30	58	42	41	25	53	44	41	25

[a]Mean Of three replications for each cutting height. MR = milled rice, HG = head grain, GT = grain translucence, GW = grain weight.

7. Cutting height did not influence grain quality of the main crop or of the ratoon crop;
8. Ratooning may be a satisfactory agronomic practice, requiring less labor and costs than growing another conventional rice crop.

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Rice ratooning in the Dominican Republic

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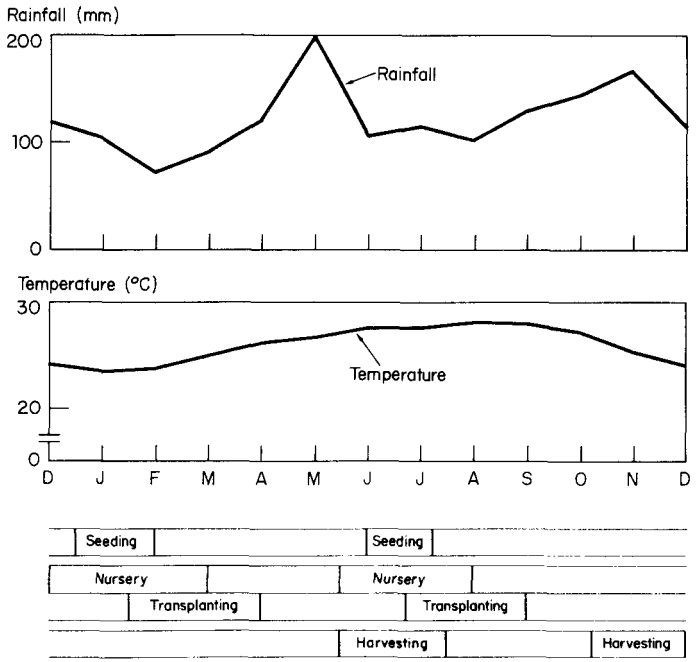
ABSTRACT

Rice ratooning is a common means of obtaining a second rice crop in the Dominican Republic. During the second half of 1981, 12,000 ha were ratooned while an estimated 10,000 ha were double-cropped. Farmers manage the ratoon crop by recutting the stubble after main crop harvest to a height of 10 cm and begin flushing stubble with water 2 wk later, until the regrowth withstands flooding. Fertilizer is applied two or three times, usually after hand weedings. An average of 91 kg N/ha, 10 kg P/ha, and 1.3 kg K/ha are used. Ratoon crop yields during the second half of 1985 averaged 3.0 t/ha in Jicomé and Castañuelas, where ratooning is the first option for the second half of the year. The rice crop planted during the same period averaged 3.9 t/ha. The cost of production under ratooning was significantly lower in both sites, US$94.40/t vs US$247.90/t in Jicomé and US$113.70/t vs US$163.10/t in Castañuelas. The ratoon crop yield per day was the same as the planted crop in Jicome, about 30 kg/ha per day, but it was lower in Castañuelas (25 vs 33 kg/ha per day). Economic as well as logistical reasons partly explain the popularity of rice ratooning.

With hectarage varying from 100,000 to 120,000 ha per year, rice ranks fourth in area harvested among crops in the Dominican Republic. Because the crops with larger harvested areas are for export, i.e. sugarcane, coffee, and cacao, rice represents the major locally produced food crop. Most rice is planted in irrigated lowlands, making it second only to sugarcane in the use of irrigated lands.

The general goal of Dominican agricultural authorities is to obtain two crops of rice per year, which is a feasible target considering the climate. To double-crop, the first crop should be planted, either transplanted or direct seeded, before the middle of February and harvested before the end of June (Fig. 1). The general recommendation is to plant the second crop before the end of August to 1) escape low night temperatures (below 20 °C) and cool winds during flowering, which usually begin in early December, and 2) avoid disturbing the first crop the following year. The first crop is the spring crop and the second is the winter crop.

Lack of credit and machinery and water deficits prevent farmers from following the double-cropping system every year. For example, in 1981 the total area planted to rice at any time was 90,000 ha, whereas total harvested area amounted to 112,000 ha, a cropping intensity of 1.24 (2).



1. Double-cropping of rice in the Dominican Republic (7).

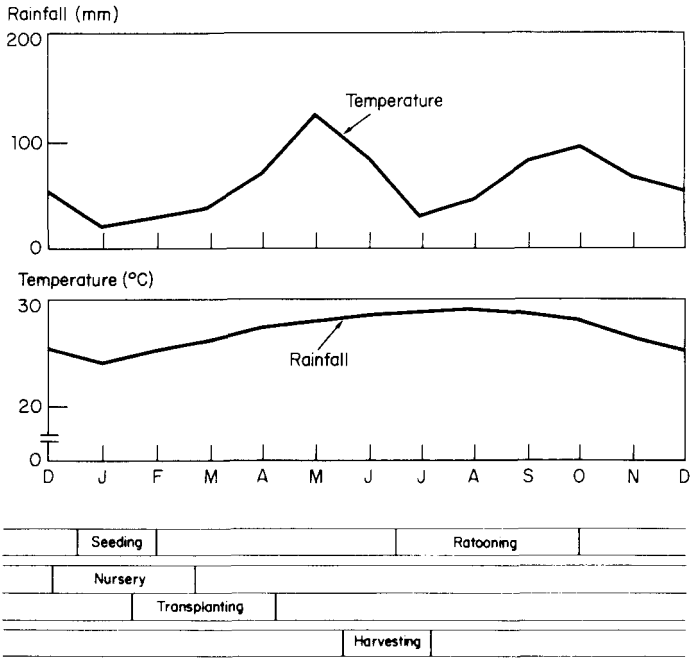
Double-cropping then is more the exception than the rule, a fact not often realized. 1981 data on harvested area showed 61,700 ha of spring crops and 50,300 ha of winter crops. These data could give the impression of a cropping intensity of 1.8. The truth is, however, that some of the area planted during the second half of the year was not planted in the previous half and vice versa.

Difficulties associated with double-cropping mean that Dominican farmers have traditionally obtained a ratoon crop, which reduces the need for machinery, land preparation, and time required to harvest a second crop (Fig. 2).

This paper describes ratooning in the Dominican Republic and compares its profitability to a second planted crop. The literature on ratooning in the Dominican Republic is reviewed and the results of a 1985 second-semester survey at two sites where ratooning is preferred over a second planted crop are summarized.

RATOONING AS A SECOND CROP

Of the 50,300 ha harvested as winter crop in 1981, 12,100 ha came from the ratoon crop, or one-fourth of the area harvested during the second half of the year. However, if we subtract the area ratooned from the 112,000 ha harvested during the year, the planted area amounts to only 100,000 ha. Considering that the total area planted to rice is 90,000 ha, the actual area double-cropped is 10,000 ha. These figures indicate that ratooning and second planting were equally popular during the second half of 1981.



2. The spring crop and the ratoon of rice in the Dominican Republic (7).

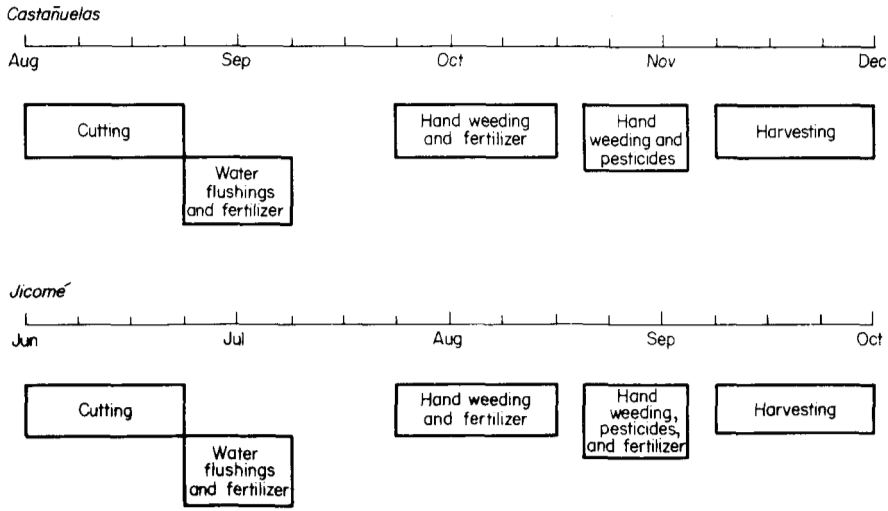
The ratoon crop in the Dominican Republic is managed as a specific crop, with the objective of increasing its productivity. It is not simply left in the field for whatever rice it yields. In fact, when the main crop stubble is left in the field without applying additional inputs, farmers call the crop *riso* to distinguish it from the *retoño* (ratoon) that requires a second cutting after main harvest (5).

The riso system is usually practiced by farmers who grow a photoperiod-sensitive cultivar which they do not believe would yield a second crop if the stubble is recut lower after main crop harvest. They seem to be aware that lower buds have not been affected by photoperiodic cycles with the same intensity as the higher buds. These farmers are happy with whatever riso crop they harvest, usually in about 60 d.

The first activity in ratooning is to recut the stubble as soon as possible after harvest. Cutting heights vary within and among locations. During the second half of 1985, 14 of 16 farmers in Jicomé cut the stubble at 10 cm or lower. In Castañuelas, farmers recut as high as 17.5 cm. In general, more than half of the farmers recut stubble at heights of 10 cm or less.

After cutting, the stubble is allowed to regrow for 2 wk, after which it is first irrigated and fertilized (Fig, 3,4). The stubble is flushed with water until the regrowth can withstand continuous flooding. The first fertilizer application is usually a complete formulation, but sometimes K is not used. After 1 mo, the field is hand weeded and additional fertilizer is applied. Most farmers use only N, as urea or ammonium sulfate, for the second application.

Just before flowering (about 65 d after cutting), a second hand weeding is usually done followed by pesticide application — mainly insecticides against stink



3. Rice ratooning crop sequence in Jicomé. and Castañuelas. Dominican Republic. 1985 (7).

Table 1. Fertilizer applied (kg/ha) to the ratoon and second planted crop in two sites in the Dominican Republic, 1985.[a]

Fertilizer	Jicomé	Castañuelas
	Ratoon crop	
N	88	94
P	13	7
K	2	0.8
	Second planted crop	
N	107	157
P	43	3.4
K	0	3

[a]Based on a survey of 400 ha of ratoon crop in each site, and 15 ha in Jicomé and 20 ha in Castañuelas of second planted crop. [b]Formulas used included 15-15-15, 16-20-0, and 12-24-12. Urea and ammonium sulfate were also used.

bugs, *Oebalus* sp. Eight of 14 farmers in Jicomé did a third fertilizer application at this stage. Total fertilizer applications in the ratoon crop and second planted crop in 1985 in Jicomé and Castañuelas are shown in Table 1. The K applied reflects its use as part of a complete formulation in the first application. Farmers applied 81% as much N to the ratoon as they applied to the second planted crop.

The ratoon crop is harvested 100–110 d after cutting. The 1985 ratoon crop was harvested before December in both sites, which made it possible to start the spring crop on time the following year.

Ratoon vs planted crop

Several authors have tried to compare ratoon vs planted crop, usually relating ratoon yields and growth duration to those of the main crop. A recent review showed that ratoon yields varied from 0 to 140% of the main crop, and days to maturity

varied from 31 to 102% (1). Although the data comparing the main crop with the ratoon crop are interesting, we believe a more valuable comparison would be second crop-ratoon. These crops represent mutually exclusive alternatives for the farmer, under similar environmental conditions.

The analyses by Cuevas-Pérez and Nuñez Jimenez (3), De Groot (4), and Doorman and Cuevas-Pérez (6) discuss the costs of ratoon and second planted crop in the Dominican Republic. Cuevas-Pérez and Nuñez Jiménez (3) used data from production cost surveys to compare yields, production costs, and efficiency (yields per time) of the main crop vs ratoon crop. Ratoon yields varied from 61 to 80% of the main crop, cost per kilo of paddy from 36 to 71%, and efficiency from 95 to 120%. Although ratoon yields were lower, the crop could produce rice in less time and was always cheaper.

On one farm, which was double-cropped and ratooned in consecutive years, the ratoon crop was cheaper than the second crop, although the ratoon crop yielded lower and was less efficient (3). The ratoon produced rice at a cost of US$l00/ t; the planted crop US$190/t. The second crop yielded 82% of the main crop during the first year, whereas the ratoon yield was 60% of the main crop in the second year. The efficiency of the planted crop was 28 kg/ ha per day and that of the ratoon crop was 26 kg/ ha per day.

De Groot (4) made similar comparisons using data from the ratoon crop of two rice farms and estimating second crop yields. He concluded that additional rice produced by a second planted crop would cost more than the selling price of paddy. Doorman and Cuevas-Pérez (6) used data from 184 farms for the first crop and from 36 farms for ratooning to compare the profitability of the ratoon crop with that of a second planted crop. By estimating second planted crop yields as 90% of first crop, they observed that benefits from ratooning would be US$598 whereas from second crop they would be only US$408.

In 1985 we studied second crops and ratoon crops growing at the same time in two sites, where ratooning is a common practice, to determine the reason for farmers' preference for ratooning. In Jicomé, 16 of the 18 farmers studied practiced ratooning and 2 planted a second crop (Table 2). Although the farms in Castañuelas were smaller, the total area under ratooning was the same.

Table 2. Characteristics of the ratoon and second planted crop farms studied in two sites in the Dominican Republic, 1985.[a]

System	Jicomé	Castañuelas	Total
Ratoon			
Farm (no.)	16	42	58
Area (ha)	400	400	800
Variety	Mingolo[b]	Mingolo	–
Second planted crop			
Farm (no.)	2	5	7
Area (ha)	150	20	170
Variety	ISA-21[c]	ISA-21 ISA-40[c]	–

[a]Based on a survey of 400 ha of ratoon crop in each site, and 15 ha in Jicomé and 20 ha in Castañuelas sf second planted crop. [b]Traditional tall variety. [c]Improved semidwarfs.

Table 3. Yield, production costs, and profits from ratoon and second planted crop at two sites in the Dominican Republic, 1985.

Crop	Yield	Production cost		Gross income[a]	Gross profit	
	(t/ha)	($/ha)	($/t)	($/ha)	($/ha)	($/t)
			Jicomé			
Ratoon	3.5	330	94	805	475	136
Second	3.8	953	248	874	(79)	–
			Castañuelas			
Ratoon	2.5	281	114	575	294	118
Second	4.7	755	163	1081	326	69

[a]Calculated using a selling price of $230/t.

Table 4. Productivity of ratoon and planted crops in two sites in the Dominican Republic, 1985.

System	Productivity (kg/ha per d)	
	Jicomé	Castañuelas
Ratoon crop	30.8	24.5
Second planted crop	27.8	32.8
LSD 0.5	10.1	1.6

Ratoon yields in Jicomé were 92% of the second planted crop yields (3.5 vs 3.8 t/ha), whereas in Castañuelas the ratoon crop yielded only 52% (2.5 vs 4.7 t/ha) (Table 3). Ratoon yields are lower than those of a second crop, so the farmers' preference for ratooning is probably associated with factors other than yield.

Variable costs of production were similar across locations, ratoon crop costs being one-third those of the planted crop (Table 3). Total costs in Jicomé tended to be higher than in Castañuelas, but costs per ton of paddy were much lower for the ratoon crop (US$94.40) than for the planted crop (US247.90) in Jicomé. The same was true in Castañuelas, although the cost advantage of the rice produced under the ratoon cropping system was not as big (US$113.70/t vs US$163.10/t). This was expected because ratoon yields in Castaiñuelas were only 50% of the planted crop compared with 92% in Jicomé.

The minimum fixed price per ton of paddy for the second half of 1985 was US$230.00, about $47.00 lower than the cost to produce a ton under the planted crop in Jicomé.

Table 4 summarizes the production efficiency of the ratoon and the second planted crop in the two sites studied. In Jicomé both crops produced about 30 kg paddy/ha per day whereas in Castañuelas the planted crop produced significantly more rice per day than the ratoon crop.

DISCUSSION

Two types of farmers practice ratooning in the Dominican Republic. One group obtains a ratoon crop only when a second planting is difficult, mainly due to time constraints. Another group grows a ratoon crop every year and begins the crop-year

with ratooning in mind. Farmers of the first type are represented in the analysis of a farm which ratooned 1 yr after planting a second crop the previous year (3) and in the riso cropping system (5).

Farmers who ratoon every year are common in Jicomé and Castañuelas. There does not seem to be any time constraint for Jicomé farmers to plant a second crop because they finish their first crop early June. In Castañuelas the first crop is harvested late, which makes it difficult for farmers to harvest a second crop before the end of the year. The time constraint in Castañuelas seems to be frequent inasmuch as farmers indicated that ratooning is their second crop choice every year.

The farmers in Jicomé do not make money with a second planted crop, but can produce ratoon rice profitably. Although farmers in Castañuelas produce rice cheaper under ratooning, their profit from the second planted crop is greater. For example, from the ratoon crop they would make US$116.30/t of paddy, that with a yield of 2.5 t would give a total profit of US$290.75. In the second planted crop, the profit would be US$66.90/t, but with a yield of 4.7 t, the total profit would be US$314.43. The real issue is whether it is worthwhile to make an additional investment of US473.40 (US754.60 - US$281.20) to grow a second planted crop to obtain a profit of US$23.68, which amounts to a 5% return on investment.

We do not think that farmers' decisions are made by analyzing the numbers that way, especially small farmers such as those in Castañuelas. A more reasonable explanation for choosing ratooning, in addition to time constraint, is the scarcity of money. Interest charges in Castañuelas were much higher than those in Jicomé. For farmers who grow a ratoon crop, interest charges in Jicomé were half of those in Castañuelas, while for those who planted double crop, the value was about one-eighth. Interest charges on money borrowed for the planted crop were higher probably because the money was kept longer.

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Rice ratooning practices in India

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ABSTRACT

Rice ratooning in India — its introduction, adoption in various states, and research on various aspects of the system — is reviewed and discussed by state. Although attempts to introduce this practice were begun in eight states as early as 1915, there was no continuity in the research to develop suitable varieties and agronomic and plant protection practices, and no sound technology was developed. Interest in rice ratooning was revived in the 1970s, with the photoperiod-sensitive variety Intan in the valleys of the hilly regions of Karnataka, South India; simultaneously, renewed research was begun in eight other states. The latest research results on varieties, seasonal requirements, planting times, stage and method of main crop harvest, water and fertilizer management, pest incidence, and quality of ratoon crop grain and seed as compared with that of the main crop are reviewed. The research and extension gaps to be filled in exploiting the potential of this practice are discussed.

Rice ratooning offers special scope for increasing production without expanding land area, particularly where moisture and growing season are inadequate for planting a second crop of rice. Ratooning is practiced on a commercial scale in the Dominican Republic and in Texas, USA. In Asia, however, although practiced in isolated small pockets, ratooning is not established to any appreciable extent.

In India, a notable beginning has been made in the hilly regions of Karnataka and, to some extent, rice ratooning has been adopted in other states (Table 1). However, progress is slow. Because of lack of suitable varieties and a dependable production technology, rice farmers are skeptical of the success of the system. But spectacular ratoon yields realized with Intan on several private farms in Karnataka and at several experimental stations have encouraged the practice to a considerable extent. This paper reviews the rice ratoon crop practices that have been researched and tried, and that are being adopted in various parts of India.

Ratoon cropping in a small way has been reported in India almost from the start of this century (10, 14, 16). However, in the late 1970s and early 1980s, i.e., after a gap of about 2 decades, research in this line has been speeded up in the states of Andhra Pradesh, Assam, Bihar, Karnataka, Kerala, Orissa, Tamil Nadu, Uttar Pradesh, and West Bengal. The research results are briefly reviewed by state.

Table 1. Ratoon crop practices and yields in eight states of India.[a]

State	Location	Year	Variety	Maturity (d)[a]			Grain yield (t/ha)			Special points	References
				MC	RC	% of MC	MC	RC	% of MC		
Andhra Pradesh	Rajendranagar	1956-57	Basumathi	143	72	50	0.9	0.8	89		(16)
	Rajendranagar	1956-57	Jeerigesanna	145	72	50	0.9	1.0	111		(16)
	Rajendranagar	1956-57	Kakirekkalu	145	73	50	1.0	0.3	30		(16)
	Rajendranagar	1956-57	Sugadas	145	73	50	1.6	0.1	6		(16)
Asram	Karimganj	1981	C 3810	124	54	44	4.1	2.1	51	Main crop normally fertilized + RC 30 kg N/ha top-dressed, growing period saved. Per day and per unit area production high.	(4)
	Karimganj	1981	Ratna	123	50	41	3.9	1.8	47		(4)
	Karimganj	1981	(11 genotypes)	114-127	40-52	35-41	2.6-4.0	1.3-1.8	72		(4)
Bihar	Dholi	1981	(6 genotypes)	134-143	59-68	44-48	3.2-4.1	0.3-0.8	9-20 33,39	MC normally fertilized, no treat-ment to RC. T 21 was top in combined yield.	(20)
	Dholi	1981	NP 97	120	60	50	1.8	0.6, 0.7 000.8	44	MC fertilized, RC i) not fertilized ii) 10 kg N and iii) 20 kg N/ha topdressed.	(11)
	Dholi	1981	NP 125	–			–	0.4-0.7			(11)
Kerala	Pattambi	1981	(20 genotypes)	103-119	45-61	38-59	3.2-4.9	0-0.5	0-11	MC fertilized normally, RC nil; only 38 rainy days during RC period.	(9)
Orissa	Cuttack	1976	CRM 10-3628	–	–	–	2.7	3.3	122	June 1st planting gave the lowest yield and June 30th planting the highest.	(2)

Tamil Nadu	Coimbatore	1968	ADT 27	–	–	42	3.8	0.5	13	Both MC and RC were fertilized.	(5)
	Coimbatore	1968	CO 32	–	–	43	4.7	1.5	32	Fertilizer to RC	(5)
	Coimbatore	1968	IR8	–	–	40	4.4	1.4	32	increased only	(5)
	Coimbatore	1968	JS	–	–	43	3.1	1.3	42	straw yield without	(5)
	Coimbatore	1969	IR8	146	69	47	3.0	1.4	47	significant increase in grain yield.	(15)
Uttar Pradesh	Karimganj	–	(14 genotypes)	114-124	40-54	31-43	2.6-4.1	1.3-2.1	33-67		(4)
West Bengal	Kalyanl	–	(9 genotypes)	–	60-70	–	–	0.2-0.5	–	No cultural manage-	(8)
	Kalyanl	1980-81	IET 3629	140	95	68	4.8	2.7	56	ment of fertilizer	(8)
	Kalyanl	1980-81	IET 4555	140	95	68	4.7	2.1	45	application – only	(8)
	Kalyanl	1980-81	(6 genotypes)	130	101	78	3.1-4.5	0.4-1.8	13-46	Supplemental irriga tion provided. In another experiment RC responded to fertilizer application.	(8)
	Chinsurah	1981-82	SR26B	–	–	–	–	2.5	–	Ratoon cropping is	(6)
	Chinsurah	1981-82	FR13A	–	–	–	–	3.0	–	suitable for lowland	(6)
	Chinsurah	1981-82	Tilakkachari	–	–	–	–	5.0	–	areas where flood or	(6)
	Chinsurah	1981-82	Achra 108/1	–	–	–	–	4.8	–	sudden water stag- nation hampers fresh planting during wet season.	(6)

[a]MC = main crop, ratoon crop.

ANDHRA PRADESH

Basumathi, Jeerige sanna, Sugadas, and Kakirekkalu rices studied in 1956 at Rajendranagar, Hyderabad, produced ratoon yields 6-111% of the main crop yield in half the main crop duration, the highest ratoon yield being 1 t/ ha, in Jeerige Sanna (16). Fertilized plots yielded higher than unfertilized ones and the varieties responded differentially to N levels.

ASSAM

Das and Ahmed (4) evaluated 89 photoperiod-insensitive semidwarf varieties at Karimganj, Assam, for main and ratoon crop yields. The main crop received complete fertilizer at 60 kg N, 13.2 kg P, and 24.90 kg K/ha but the ratoon crop received only N at 30 kg/ ha, topdressed immediately after cutting the main crop at 30 cm stubble height. The ratoon crop yields ranged from 9.4 to 68.1% of main crop yields with an average of 37.2%; the average ratoon crop duration was 39.6% of the main crop. The best performing C 3810 produced the highest main crop yield (4.1 t/ ha in 124 d) and the highest ratoon crop yield (2.1 t/ ha in 54 d), followed by CR 220-60 and CR 156-5021-307.

BIHAR

As reviewed earlier (11), two experiments were carried out to determine the yields obtainable from ratoon crops of rice and the effect of date of transplanting and rate of manuring on ratoon crops. In the first experiment, NP 97 rice yielded 1.8 t/ ha in 120 d (Table 1). The ratoon crop harvested in 60 d yielded 0.6 t/ha without N; addition of 10 and 20 kg of N/ ha produced 0.7 and 0.8 t of grain/ha. In a second experiment the same year, NP 125 rice was transplanted to manured fields on 1, 15, and 30 Jun. The highest yield from the ratoon crop (0.7 t/ha) was obtained from plants transplanted on 1 Jun and the lowest (0.4 t/ ha) from those transplanted on 30 Jun, indicating regression of ratoon crop yield on the planting time of the main crop.

KARNATAKA

In Karnataka, the first report on ratooning, published in 1943 (1), stated that the variety S 684 gave a main crop yield of 2.7 t/ ha in 174 d and a ratoon crop yield of 1 t/ ha in 113 d, the ratoon crop taking 65% of the main crop duration but producing 37% of the main crop yield (Table 2). Subsequent reports in the 1970s mostly emphasized the success of this system on hill valley bottoms and midlands, where seasonal inadequacies (short interval of rice fallows and moisture) prevented raising an upland crop or a newly planted rice crop. The excellent ratooning ability of Intan

Table 2. Ratoon crop practices and yields in Karnataka, India.[a]

Location	Year	Variety	Maturity (d)[a]			Grain yield (t/ha)			Special points	Reference
			MC	RC	%of MC	MC	RC	%Of MC		
Near Bangalore	1942-43	S 684	174	113	65	2.7	1.0	37	No additional fertilizer, irrigated	(1)
Madikeri	1975-76	Intan	166	109	66	2.2	1.7	77	No additional fertilizer and with residual moisture	(12)
Chikkamagalur District	1977-78	Intan	174	126	72	2.0-5.5	2.3-7.7	115-140	RC topdressed at 20-50 kg N/ha after 25 days	(17)
	1977-78	Intan	–	–	–	2.0	7.0	350		(22)
	1977-78	Intan	–	–	–	2.1-5.5	2.3-7.0	110-127	RC topdressed at 20-50 kg N/ha after 25 days	(19)
	1979-80	Intan	173-200	131-147	76	1.1-7.7	0.7-4.6	60-64	RC topdressed at 20 kg N/ha	(19)
	1980-81	Intan (UAS)	169	128	76	6.1	3.7	61	RC topdressed at 20 kg N/ha after 25 days	(18)
	1980-81	lntan (IRRI)	155	126	81	4.7	3.2	68	RC topdressed at 20 kg N/ha after 25 days	(18)
	1980-81	Mingolo	162	117	72	5.8	1.0	17	RC topdressed at 20 kg N/ha after 25 days, low temperature injury	(18)
	1980-81	Range of 24 genotypes	147-169	76-128	52-76	2.4-6.3	0.2-3.7	1-59	RC topdressed at 20 kg N/ha after 25 days, low temperature injury	(18)
	1980-81	Range of 45 genotypes	128-1 95	75-93	48-57	0.9-8.3	0.1-0.6	7-11	No fertilizer, low temperature injury	(18)
Bangalore	1983-84	Mangala	118	85	72	–	1.8	–	No fertilizer to RC. water management only	(7)
	1983-84	CT 1351	127	100	79	–	0.9	–	No fertilizer to RC, water management only	(7)
	1983-84	S 317	136	105	77	–	0.9	–	No fertilizer to RC, water management only	(7)

[a]MC = main crop, RC = ratoon crop, * = MC not fertilized, RC with 50 kg N.

rice observed at the University as well as on private farms of two hill zone districts (Kodagu and Chikkamagalur) impelled rice researchers to take up varietal, agronomic, and plant protection studies in collaboration with the International Rice Research Institute (IRRI), Philippines.

Ratoon yields ranging from 77 to 140% of the main crop yield in 66-72% of the main crop duration were realized in the hill region with Intan rice (Table 2). In Bangalore, Mangala planted in August and harvested at the end of November produced the highest ratoon yield (7) (Table 2). Short-duration varieties such as CH 45, CT 1351, S 705, Mangala, and Intan mutant also showed moderate ratoon yields in Bangalore (21).

Two experiments conducted at Kodemadkal Government Farm, Mudigere, Chikkamagalur District, to screen and evaluate 69 genotypes showed ratoon crop yield ranging from 76 to 350% of main crop yields (19). On an average, the ratoon crop had 24% shorter growth duration.

Data gathered from several private farms in the Chikkamagalur District revealed wide fluctuations in ratoon crop yields (0.74.6 t/ha) compared with main crop yields (1.1-7.8 t/ha). Probable causes were time of main crop harvest, stubble height, and fertilizer applied to the ratoon crop. The early-cut ratoon plots (November to mid-December) exhibited maximum yield fluctuations in the ratoon crops, flowering under low winter temperatures which prevented proper panicle exsertion and caused high spikelet sterility.

Failure of ratoon crops also has been observed in plots with soil affected by iron and aluminum toxicity and phosphorus deficiency, where even the main crop stand was below normal (personal observation of T. G. Reddy and A. Manjunath).

The ratoon cropping practices recommended now are

- use only Intan variety,
- select only plots with good main crop stand,
- dry the field for 8-10 d,
- cut main crop to stubble height of 7.5-10 cm,
- resume light irrigation when ratoon growth becomes visible, and
- weed and topdress ratoon crop with 50 kg N/ha 1 mo after cutting of main crop (3).

These general recommendations need to be refined to fit varying main crop cutting times, topographic situations, and soil conditions; studies with genotypes of varying growth duration for different planting dates are needed. In Chikkamagalur District, with the introduction of ratoon cropping with Intan rice, farmers have themselves selected one more local variety — Aluvbatta, which occupies a sizable area between Mudigere and Chikkamagalur — for ratoon cropping. This variety needs to be evaluated for its potential as a main crop for direct use and its worth in a breeding program. An introduction from the Dominican Republic, Mingolo, has been identified as equivalent to Intan in all respects (plant height, virus and blast resistance, ratooning ability, and grain quality) except growth duration. This is being evaluated for late main crop harvests and the variety is fast being adopted by farmers.

CHIKKAMAGALUR

The conditions favoring high ratoon yields in the Chikkamagalur area are better sunlight in the season (December to April); longer daylength than in main crop season; lower disease and insect pressure; low relative humidity; low wind velocity; and low temperatures during early ratoon growth, favoring high net assimilation and higher yields. More disease and pest problems and high humidity in the monsoon may reduce main crop yields, while the favorable weather in the ratoon crop season (dry season) accounts for ratoon yields in Chikkamagalur area.

The photoperiod-sensitive varieties, if planted in the dry season, do not flower in Bangalore because of long days. But a main crop of photoperiod-sensitive Intan planted in July and ratooned during December-January normally flowers during March-April. This is an indirect advantage of ratoon cropping.

The possible damage by insect pests (leafhoppers and planthoppers, stem borers, leaf roller) and diseases (brown leaf spot, stem rot, mycoplasma-like organisms [MLO]) is minimized by following the plant protection schedule recommended for the main crop. The currently cultivated Intan and Mingolo, which is in prerelease testing, are resistant to viruses and MLOs. Because birds are active during the ratoon crop period (February-May), bird damage has been a major obstacle to taking ratoon crops in isolated areas where day roosts are available and the main roosts are nearby (S. Subramanya, pers. comm.).

KERALA

Kerala has a tradition of mixed-cropping rice varieties of different growth durations, where the late variety is harvested in the vegetative stage, along with the early-maturing companion variety. The late variety regenerates and gives normal crops of both grain and straw. In 1981, 20 varieties of the Ninth International Rice Yield Nursery planted in the wet season and fertilized at 70 kg N/ ha, 15 kg P/ ha, and 29 kg K/ha was cut at 15 cm stubble height; ratoons were grown without fertilizer or pesticides, with only 625 mm of rainfall spread over 38 rainy days. The average ratoon yield was only 6% (0.225 t/ha) of the main crop yield (3.59 t/ha); ratoon duration was 54 d, nearly 50% of the main crop duration of 110 d. Varietal differences were significant (9).

ORISSA

The culture CRM 10-3628, a Mahsuri mutant studied at the Central Rice Research Institute, Cuttack, in 1976 produced encouraging ratoon crop grain yield of 3.3 t/ ha, or 122% of main crop yield (2.7 t/ ha) (2). The ratooning ability is inherited from the parent, Mahsuri, as with the Intan mutant (from Intan) in Karnataka (21).

TAMIL NADU

Balasubramanian et a1 (5) studied at Coimbatore the growth attributes and yield of main and ratoon crops of four varieties, 27, CO 32, IR8, and JS. They reported that 1) varieties differed significantly in ratooning and ratoon grain production abilities; 2) ratoon crop duration, growth, and yield were lower than those of the main crop; 3) productive tillers were of the same order in both main crop and ratoon crop; and 4) N fertilization increased ratoon grain and straw yields. Ramaswami and Haws (15) ratooned IR8 in 4 successive crops and realized in the ratoon crop 46% of the main crop yield in 47% of the main crop duration. Palchamy and Kolandiswamy (13), studying varieties Vaigai and Bhavani, reported that the principal trait determining ratoon grain yield was number of filled grains/panicle.

UTTAR PRADESH

Fourteen cultivars, including Patna and IR36, in trials at Kumarganj, produced ratoon crop yields ranging from 1.3 to 2.1 t/ ha, or 33-67% of the main crop yield; ratoon crop duration was 40-54 d (31-43% of main crop duration). The most promising variety was C3810 — it gave the highest ratoon main crop yields. This variety should be further evaluated under the new system (4).

WEST BENGAL

In field studies on ratooning of five cultures in Kalyani from main crops of two seasons (wet season: July-October; dry season: January-May) managed without any care after the main crop harvest, except for supplemental irrigation to keep the field moist, ratoon yields ranged from 0.2 to 1.0 t/ ha in 60-70 d. Ratooned variety Ratna with 15 kg N/ha yielded 1.2 t/ha (8). In another study at Chinsurah (6), ratooned and freshly sown SR26B, FR13A, Tilakkachari, and Achra 108/ 1 were compared. Ratooned Tilakkachari and Achra 108/1 yielded more (5.0 and 4.8 t/ha, respectively) than the main crops (3.8 and 3.9 t/ ha). In general, the mean yield of ratooned rice varieties equaled that of main crops, indicating the suitability of the ratoon cropping system in lowland areas where flood or sudden water stagnation hampers the freshly planted crop during the wet season.

CONCLUSION

Ratoon crop yields up to 7.7 t/ha and up to 350% of the main crop yield (in an extreme case) suggest high potential for ratoon cropping. Continuous ratoon cropping of Intan and maintenance of KMS-1, KMS-4, and KMS-5 male-sterile lines through vegetative propagation for more than 30 yr in Karnataka indicate strong sources of genetic resistance to virus and MLOs in rice. Thus, fears of possible virus and MLO epidemics under ratoon cropping appear unfounded. Ratoon cropping has been more frequent and relatively better established in low-

temperature areas (high and medium elevations), although good ratoon yields have also been harvested in warmer climates.

The ratoon-cropped area in the hill and transition belts of Karnataka is fluctuating; lack of appropriate varieties and production technology for specific situations and lack of effort to transfer available technology are reasons which need research attention. Stray cattle, birds, and uncertainty of residual moisture due to periodic droughts are problems faced by farmers who are otherwise inclined toward ratoon crop production.

Missing hills, uneven flowering, weed growth, inefficient water management, and errors in main plot selection have contributed to frequent low ratoon yields. Because ratoon crop production is relatively more complicated, it needs careful decisions at various stages. A great handicap is lack of awareness among farmers, extension workers, and administrators of the potential of the rice ratoon cropping system. It will be rewarding to intensify research under diverse climatic conditions to select priority regions for this system. Economic viability analysis is also an important prerequisite to introducing ratoon cropping of rice over a larger area.

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Ratooning in China

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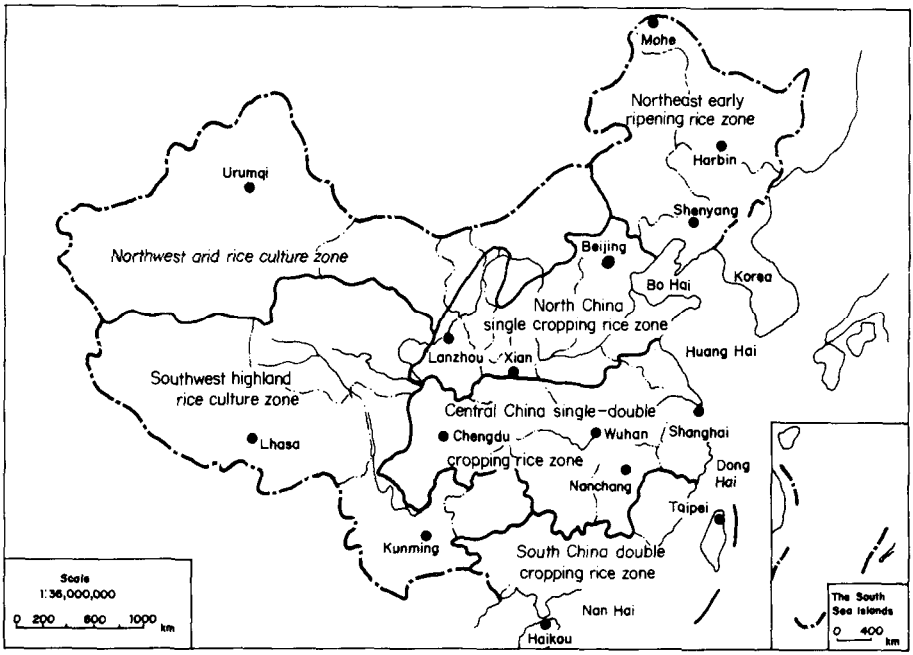
ABSTRACT

Rice ratooning in China is concentrated mainly in the middle and lower reaches of the Yangtze River. Semidwarf and hybrid ratoon rices were developed in the 1970s with a record yield of 8.7 t/ha obtained in Guangdong Province. A total yield equal to that of double-cropped rice is possible with the variety 40-1, a medium-duration rice with good ratooning ability. This may expand ratoon culture in Hubei Province. In southeast Sichuan, the medium-duration hybrid Zai Sheng You produced a total yield (main crop plus ratoon crop) on winter flooded fields 26% higher than that of single-cropped medium-duration rice.

Rice is grown on 33 million hectares in China. The area extends from 18°9'N in the south to 53°20'N in the north and from as far east as Taiwan to as far west as Xinjiang, Uygur Autonomous Region. Rice is grown as low as in the tidal-swamp lowlands along the southeast coast and as high as 2,400 m or higher in the southwestern highlands (4).

In such a wide rice area, the climatic and physical conditions for rice culture, varieties, and cropping systems are very complex. Hence, the rice-growing area in China is divided into six regions (Fig. 1).

Among the six zones, the central China single-double cropping rice zone is the largest. Ratoon rice is also concentrated in that area, particularly near the margin of the double-cropped rice zone (i.e. double cropping early rice and late rice). Medium-duration and long-duration rice prevail in the single-cropping area of this zone. Generally, after the harvest of medium-duration rice, the temperature is high enough for a ratoon crop. Rape, barley, wheat, or green manure is grown as a winter crop. However, changes in cropping systems or improvement of cultivars may affect the cultivation of ratoon rice. For example, sometimes late-season rice or double cropped rice takes the place of the medium-duration rice. After their harvest, the temperature is too low for a ratoon crop.



1. Rice-growing regions of China (5).

Ratoon rice in China in the 1950s

Ratoon rice could be seen in every province in the middle and lower reaches of the Yangtze River in the 1950s (3). For example, in 1953, there were 133,000 ha of ratoon rice in Hubei Province. In Wuchang county, Hubei Province, ratoon rice occupied 20,000 ha, about 51% of the total rice area. In Liuan Prefecture of Anhui Province, there were 7,333 ha of ratoon rice. Although the highest ratoon yield reached 2.25 t/ ha, the average yield was 0.75 t/ ha. During this period, the best cultivars for ratooning were Sheng Li Xian and Wan Li Xian.

In 1954, the Ministry of Agriculture considered growing ratoon rice one of the important measures to increase rice yield per unit area to achieve an adequate supply of food grain. For this purpose, a book entitled *How to grow a ratoon rice crop* was compiled and published.

In 1958, the late professor Yang Kai Qu (Sichuan Agricultural College) revised his papers on ratoon rice research from 1937 to 1941 (18). This is the earliest systematic study on biological behavior and cultural techniques of ratoon rice.

The above information involves ratoon rice of tall-stature cultivars.

Ratoon rice in China in the late 1970s

As short-stature cultivars and hybrid rice with large root systems and better ratooning ability became popular, renewed interest in ratooning arose. Many institutes (province, prefecture, or county research institutes) of the Central China single-double rice cropping zone and the South China double-cropping zone conducted experiments on ratooning. In some provinces, the area for ratoon rice

Table 1. Reports on yields of rice main crop (MC) and ratoon crop (RC) during the 1970s.[a]

Location	Year	Variety or hybrid	Maturity (d)		Grain yield (t/ha)		Cuttlng height (cm)	Reference
			MC	RC	MC	RC		
Nanchang Jiangxi	1976	Shan You 2	164	70	6.0	5.2	23.3	(13)
Lingling Hunan	1979	Yang Xian 203	132	62	7.7	5.0	16.6-20.0	(10)
Jianglin Sichuan	1977	Nan You 2	140-150	50-60	7.0	4.7	45.6	(11)
Wuchang Hubei	1977	IR 29	137	54	7.2	3.8	46.6	(9)
Chengdu Sichuan	1977	Shu Feng 1	115-125	60	7.3	3.4	30.0	(2)
Jingmen Hubei	1976	IR 29	120	54	5.6	3.2	26.6	(8)
Foshan Guangdong	1977	IR 24	170[b]	92	8.4	8.7	1.6-3.3	(7)
Forhan Guangdong	1979	Xiaojiahuo	192[b]	103	9.8	8.4	1.6-3.3	(7)
Foshan Guangdong	1974	Guangerai	154[b]	92	7.5	5.5	1.0-2.0	(6)
Foshan Guangdong	1975	IR 24	157[b]	85	6.4	4.9	1.0-2.0	(6)
Zhaoqlng Guangdong	1975	Zhenzhuei/ IR 661	155	69	8.0	3.6	G round level	(20)
Chengdu Sichuan	1977	Shu Feng 1	130	70	5.8	3.1	5.0	(15)

[a]Records of grain yield over 3.0 t/ha with data needed were adopted. Most of them were obtained from small areas. [b]Complementary data from the original author, agronomist, Huang, Dao-You, Foshan Prefecture Agricultural Research institute, Guangdong Province.

also expanded; in Sichuan Province, for instance, 16,000 ha were planted to ratoon rice in 1977, 18,666 ha in 1978.

Important information was obtained from those studies (Table 1):

1) Some varieties and hybrid rices were promising for ratooning. These included Yang Xian 203, IR24, and Shu Feng 1 and the hybrids Ai You 1, Nan You 2, and Shan You 2.
2) High yield records were set. The IR24 ratoon crop yielded 8.73 t/ha; including the main crop, yield totaled as high as 17.15 t/ha in Foshan Prefecture Agricultural Research Institute, Guangdong Province, in 1977. Ai You 4 and other varieties yielded 6.57-8.17 t/ha for the main crop and 5.07-5.88 t/ha for the ratoon crop. Two crops yielded 11.66-14.20 t/ha in Fujian, Jiangxi, Guangdong, and Sichuan Provinces (12).

There were two main patterns of ratooning:

1. Low cutting (below 4-5 cm) height. Low cutting-height ratoon with high yielding potential (4.5-8.2) t/ha and long growth duration (about 90-100 d) can be grown only in conventional double-cropping rice areas. Very sensitive cultivation is an essential prerequisite for its success.

2. High cutting height (17-30 cm). High cutting-height ratoon with high yield (about 7.5 t/ha) and 55-60 d ratoon growth duration can fully utilize the rice-growing season to get a higher yield from the two crops. Such a ratoon could fit well with single crop mediumduration rice. Single crop medium-duration hybrid rice ratoon is promising.

Intensive water management is needed for a low cutting-height ratoon crop; otherwise, an increase in number of missing hills and a decrease in regeneration rate would reduce grain yield considerably. In addition, severe weed competition, low fertilizer efficiency, and widespread occurrence of insect pest incidence contribute to greater loss. Since high cutting-height ratoon did not fully use the available growing season in the double rice cropping area, low yield was obtained.

Experiments on and production of ratoon rice in the conventional double-cropping areas were discontinued in the late 1970s.

On the other hand, in the single-crop, mediumduration rice area, the prospect of good ratoon varieties and hybrids and high yield was still attractive to rice workers. A new breeding program was started to develop high-yielding varieties or hybrids for main crop and ratoon ratoon yields, which would fit in well in the midseason ratoon cropping system. For example, a ratoon collaborative experimental network was set up in 1979; more than 2,000 varieties were screened and evaluated for the breeding program.

With this approach to line selection, it is possible to get good ratoon varieties with high yield for main crop and high inherent ratooning ability. On the other hand, evaluating ratooning ability according to tillering after cutting has not led to the successful development of a good ratoon variety (14). High sterility in the main crop may result in high tillering in the ratoon crop. In such cases, the main crop yield is too low to get a high yield for both main and ratoon crops.

From this research it was learned that

- ratooning ability should be evaluated when the main crop is at the ripening stage and shows high yield traits.
- number of germinating buds on stubble and elongating length (3-6 cm or above) rather than tillering after harvest should be used to identify ability.

In the meantime, some physiological and cultural studies on ratooning were carried out in Guangdong, Hubei, and Yuanan Provinces: *(Studies on the distribution of photosynthetic products and the absorption of nitrogen nutrients in regenerative rice by using isotopes* ^{14}C *and* ^{15}N (19), and others.)

All such research served as foundation for ratoon rice development in the succeeding years.

The above information involves research and utilization of short-statured varieties and hybrid rice ratooning in the 1970s.

Trend toward expansion of ratoon culture

A new ratoon variety. 40-1 is an early medium-duration hsien (indica) variety developed by the Food Crop Research Institute, Hubei Academy of Agricultural Sciences. Its growth duration is 132 d for the main crop and 60 d for the ratoon crop (1). When the main crop ripens, the buds at ground level and above elongate or grow out of the leaf sheaths. The main crop still set well (filled grain = 87%,

Table 2. Rice variety 40-1 ratoon yield performance (1).

Year	Location	Area (ha)	Yield (t/ha)		
			Main crop	Ratoon crop	Total
1984	FCRI[a]	0.076	7.81	4.67	12.48
1985	Huang Gong County	13.3	7.20	4.16	11.36

[a]Food Crop Research Institute, Hubei Academy of Agricultural Sciences, Wuchang County.

1,000-grain weight = 25.4 g). High grain yields are obtained in both main and ratoon crops (Table 2).

The total grain yield of main and ratoon crops of the variety 40-1 equaled that of double-cropped rice. In addition, the labor force required is substantially reduced and the seedbed from which a certain amount of grain can be obtained is saved, for a total saving of 0.6 t grain/ ha (1).

Plant heights of main and ratoon crops of the variety 40-1 were 94 cm and 64 cm, respectively; the variety also had high tillering, large culms, and a strong root system. The panicles of the main crop were large (106 filled grains/panicle). The uppermost bud of the stubble was 24 cm above ground level, cutting height was about 30 cm. Each of the buds above and at ground level might regrow. The 40-1 ratoon crop produced 465 panicles/m^2 and 46 filled spikelets (89%) per panicle and grain quality was good, surpassing that of the main crop.

A plan for ratoon cultivation of some 5,333 ha may be carried out to confirm the performance of the varieties and cultural techniques in Hubei Province in 1986.

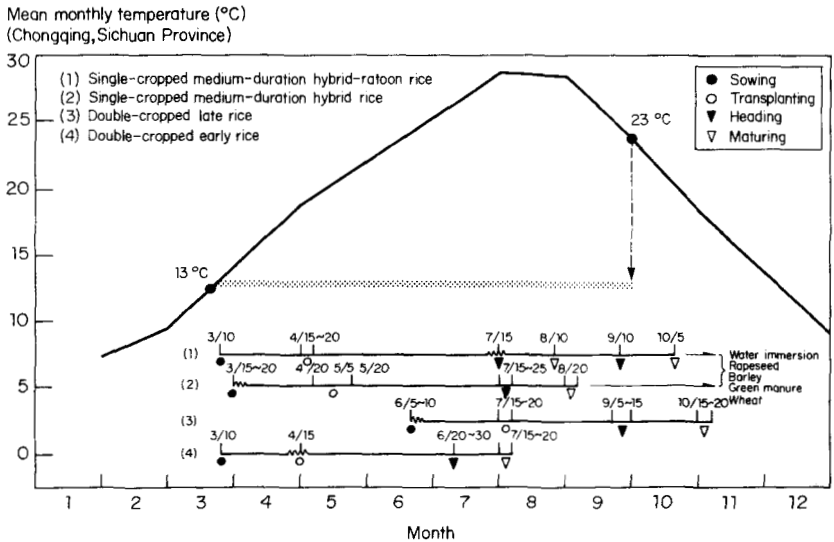
Medium-duration hybrid rice. Cooperative experiments on growing medium-duration hybrid ratoon rice were conducted in southeast Sichuan Province by 12 institutes and colleges from 1983 to 1985. Demonstration fields of 1,346 ha showed that, on an average, the main crop yielded 7.9 t/ha and the ratoon crop 1.8 t/ha. Grain yield was 25.9% higher than that of the local medium-duration hybrid rice (17). This hybrid ratoon rice may be planted on 10,000 ha in southeast Sichuan Province in 1986. It is reported that Jiangjin county has 53,000 ha of medium-duration rice, of which 6,666 ha will be used for a ratoon crop. To carry out this project, a videotape recording made of the ratoon demonstration field in 1985 was broadcast repeatedly over a countywide television network to acquaint farmers with ratoon crop cultural techniques. Cultural practices recommended for medium-duration rice ratooning in southeast Sichuan Province are

1. Use Zai Sheng You, Ai You 1, Shan You 63, for hybrid ratoon rice (Table 3). The hybrid Zai Sheng You (Choayang lA/Taiguodao Xuan) was developed by Sichuan Agricultural University. Its growth duration is 155 d for the main crop and 55-60 d for the ratoon crop.
2. Fertilize for ratoon tiller sprouting. Apply 35-70 kg N/ ha to the main crop 14 d before harvest to increase sprouting rate and promote early and vigorous ratoon crop growth.
3. Use a main crop cutting height of 30 cm. The buds at the second, third, and fourth nodes will regrow. For such a high-cut ratoon crop, weeding is not necessary.

Table 3. Yield trial[a] of varieties for ratoon (17).

Type	Variety	Yield (t/ha)[b]		
		Main crop	Ratoon crop	Total
Hybrid rice	Zaisheng You	8.0 a	3.0 a	11.0 a
Hybrid rice	Ai You 1	6.8 b	1.7 bc	8.5 bc
Hybrid rice	Ai You 1	6.7 b	2.6 ab	9.3 b
Hybrid rice	Shan You 2	7.6 a	1.3 c	8.9 bc
Conventional	Zaisheigai	5.2 c	2.7 ab	7.9 c
Conventional	Luke 3	6.3 b	2.0 bc	8.3 bc

[a]Randomized complete block design, three replications. [b]Figures within a column followed by the same letter(s) show no significant difference at the 5% level (LSR method).



2. Growth stages of medium-duration midseason hybrid-ratoon rice in relation to temperature.

4. Sow and transplant early. Early sowing and transplanting of the main crop ensures safe heading of the ratoon (16). The safe growing season in southeast Sichuan is about 190-195 d. (The critical low temperatures are 13 °C for sowing and 23°C for heading [Fig.2]). That is long enough for some medium-duration hybrids, such as Zai Sheng You, and the ratoon crops.

Thus, hybrid vigor can be exploited twice to produce high yields from the main and ratoon crops.

In southeast Sichuan, an area of 533,000 ha consists of rainfed fields, where water has to be reserved after the rice season every year to avoid drought in the next growing season. Generally, these winter waterlogged fields are fertile; however, because of the limited duration of the growing season, only one rice crop can be grown. Farmers used to grow a single crop of medium-duration varieties. Now a medium-duration hybrid and its ratoon may take its place, and higher total grain yields obtained.

China is now implementing her Seventh Five-Year-Plan for economic development. The cultivated land will be gradually concentrated on the skilled farmers as the reformation of the rural economy goes on. Rice ratooning, as a labor saving and high-yielding measure, is expected to be further developed.

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Rice ratoon crop management in the hilcly region of Karnataka

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ABSTRACT

Rice ratoon cropping systems offer considerable potential for increasing rice production and utilizing seasonally idle land and labor as well as residual moisture in the hilly region of Karnataka State. Studies on ratoon crop management showed that neither cutting the main crop 35, 40, and 45 d after 50% flowering nor stubble heights cut 8, 13, and 18 cm above ground at main crop harvest caused significant differences in ratoon yields. Experiments with cutting-time intervals and cutting height are suggested. The ratoon crop yields ranged from 76 to 350% of the main crop yields. The ratoon crop had 24% shorter growth duration and 59% higher mean yield than the main crop in an experiment at Karemane. Topdressing with 50 kg N/ha 30 d after main crop cutting gave the highest ratoon yield. In farmers' fields, ratoon yields ranged from 0.68 to 4.58 t/ha, compared with 1.10-7.75 t/ha main crop yields. Research is suggested on stabilizing ratoon crop yields and developing suitable varieties, management. and plant protection practices.

Fifty-four percent of the cultivated area of the hilly region of Karnataka is planted to rice; it forms one-third of the total rice area in the state. Because rice is traditionally monocropped and other important crops are perennial plantations (coffee, cardamom, citrus, etc.) in the hill slopes, land and labor are not fully utilized from January to May. In some small pockets a second (dry-season) rice crop is cultivated through fresh plantings. But residual moisture is not enough for a newly planted second rice crop in the midlands and lowlands of hill valleys, which are left unexploited. Sometimes the growing season is too short for a newly planted crop even if water is available, because preblossom showers start early and upland crops are often not preferred.

The newly introduced rice ratoon cropping system is aimed at utilizing residual moisture and the short season to increase rice production at a relatively low cultivation cost. The system also provides work to otherwise idle laborers (1, 2, 4, 5). The rainfall pattern and temperature regimes (Table 1) are conducive to high ratoon yields.

Table 1. Average monthly rainfall and temperature in the hilly region of Karnataka (Uttara Kannada, Belgaum, Shimoga, Chikkamagalur, Dharwad, Coorg, and Hassan districts). Values represent average of 6 yr, 1978-83.

Month	Rainfall (mm)	Temperature (°C)	
		Max	Min
January	2.2	25.9	14.5
February	2.5	28.1	15.5
March	9.6	29.9	17.1
April	51.7	29.4	18.5
May	96.7	27.9	18.9
June	438.5	23.5	18.1
July	914.2	21.5	17.8
August	509.6	21.9	17.9
September	166.6	23.3	17.5
October	155.2	24.9	17.5
November	50.8	24.9	16.3
December	22.1	24.0	14.3

Ratoon crop management involves specialized practices from the time the main crop is cut until harvest. The adoption of this technology in the hilly region of Karnataka started with the excellent ratooning ability of Intan observed at the University experimental station Madikere, as well as on private farms. This prompted the University scientists in 1976 to initiate some agronomic investigations on the private farms of Chikkamagalur District. Since then, research on varietal and agronomic aspects has been carried out in a small way. An experiment was also conducted in collaboration with IRRI in the Philippines during 1981-82.

This paper summarizes past studies on rice ratoon crop management in the hilly region of Karnataka and suggests future prospects for agronomic research to improve and stabilize ratoon yields.

RATOON CROP MANAGEMENT EXPERIMENTS

Cutting of main crop: time and stubble height

Two replicated experiments were conducted during 1977 to determine the effect of cutting time and height on ratoon crop yields. A third experiment continued the yield performance study conducted in 1978. All studies were conducted with the stubble of the 1978 wet-season harvest at Sringeri, Chikkamagalur District, which is representative of the hilly region.

In the first experiment, cutting time was fixed at 35, 40, and 45 d after 50% flowering (40 d is the normal harvest time). Plot size was 10 m^2, with 3 replications in a randomized complete block design. The main crop, seeded on 30 Jun and cultivated with prevailing farmers' practices, was cut to a 13-cm stubble height on 13, 18, and 23 Dec. The entire experimental area was topdressed with 50 kg urea/ ha (44.0%) 30 d after cutting the main crop (18 Jan 1979).

In the second experiment, also a randomized complete block design with 4 replications, cutting heights were 8, 13, and 18 cm above ground. Plot size was a direct seeded 2-m row. The main crop, seeded on 30 Jun and managed with farmers' practices, was cut on 23 Dec 1978 and topdressed with 50 kg urea/ ha 30 d later. The third experiment, at Balehonnur, repeated the 1977 experiment.

The main crop seeded in June 1978 was harvested in December and the ratoon was topdressed 40 d later at 40 kg urea/ ha. The ratoon was harvested on 21 Apr 1979. Other practices followed were local. All 3 experimental crops lost an estimated 35% to birds because there were no rice plots around the experiments.

Neither cutting time nor cutting height influenced grain yield (Table 2). A 5-d interval after harvest seems to be too short to cause significant yield difference because the main and ratoon crops have long growth durations (171 and 130 d); longer cutting intervals may improve ratoon yields. Similarly, yield differences attributable to cutting height were not significant. But treatments differing by 10 cm or more may produce large differences. With the late-maturing variety Intan, minor differences in cutting time and height of the main crop appear to have no significant influence on yield. Cutting heights with larger differences might induce variation, as has been observed in nonreplicated experiments where no yield data could be recorded systematically. Studies on varieties suitable for ratoon cropping, with virus resistance and good regrowth ability, are needed.

The ratoon crop yields (Table 3) in the third experiment were attractive, an average 2.9 t/ ha, ranging from 42 to 61% of the main crop. But their yields were much lower than those of 1977-78. Bird damage contributed to some extent to the observed discrepancy.

Table 2. Effect of cutting time (days after 50% flowering) and cutting height of the main crop on grain yield of ratoon crop of rice variety Intan.

Days after 50% flowering	Grain yield (t/ha)	Cutting ht from ground (cm)	Grain yield (t/ha)
35	3.0	8	2.8
40	3.1	13	2.9
45	3.1	18	2.6
CV %	13	–	21

Table 3. Yield of main and ratoon crops of rice variety Intan at Balehonnur, Karnataka, India, at different fertilizer levels, 1978-79.

Main crop treatment	Grain yield (t/ha)	
	Main crop	Ratoon crop[a]
N_0 P_0 K_0	4.2	2.1 (50)
N_{40} P_0 K_0	5.2	2.6 (50)
N_{80} P_0 K_0	5.3	2.7 (51)
N_{120} P_0 K_0	5.9	2.5 (42)
N_{40} P_{20} K_0	5.3	2.7 (51)
N_{80} P_{40} K_0	5.7	2.8 (49)
N_{120} P_{60} K_0	6.0	2.9 (48)
N_{40} P_{20} K_{20}	5.4	2.8 152)
N_{80} P_{40} K_{40}	5.7	2.8 (49)
N_{120} P_{60} K_{60}	5.7	3.5 (61)
N_{120} P_{60} K_{40}	6.1	3.4 (56)
N_{120} P_{60} K_{40} + $ZnSO_4$	6.2	3.1 (50)
Mean	5.6	2.8 (50)

[a]Figures in parentheses are percentages of main crop yield.

Table 4. Yield of main and ratoon crops of rice at Karemane village, Karnataka, India, 1977-78.

Main crop		Ratoon crop		
Treatment[a]	Grain yield (t/ha)	N applied (kg/ha)	Grain yield (t/ha)	Grain yield % of main crop
F_0 N_0	2.1	0	2.3	110
F_0 N_0	2.0	50	7.0	350
F_0 N_{120}	3.0	25	6.5	217
F_0 N_{120} P_{26}	4.6	25	6.3	137
F_0 N_{120} P_{26} K_{50}	5.5	0	4.2	76
$F + N_0$	3.1	50	7.7	248
$F + N_0$	3.3	0.5	6.1	185
$F + N_0$	3.3	12.5	4.2	127
$F + N_{60}$	3.3	12.5	5.2	158
$F + N_{90}$	4.2	12.5	4.6	110
Mean	3.4	–	5.4	159

[a]F_0 = no farmyard manure (FYM), F = 12 t FYM/ha.

Fertilizer and grain yield

Another study of rice ratoon cropping patterns with Intan was conducted on a private farm in Chikkamagalur District in the 1977-78 wet season. The experiment was seeded in June 1977, transplanted on 16 Jul, and harvested on 12 Dec. The ratoon crop was ready for harvest on 24 Apr 1978, but was harvested on 2 May because it was maintained as a demonstration crop for visitors. Main and ratoon crop yields obtained in the experiment at Karemane village, Karnataka (1977-78), are given in Table 4.

The ratoon crop, which matured in 133 d, generally yielded more than the main crop (Table 4). Ratoon crop yields ranged from 76 to 350% of the main crop yields. As with N applied 30 d after cutting main crop, at 0 kg N/ha yields averaged 93% of main crop yield; at 12.5 kg N/ha, 132%; at 25 kg N/ha, 180%; and at 50 kg N/ ha, 300%. The ratoon crop had 24% shorter growth duration and 59% higher mean yield than the main crop. This good yield does not represent an average farm situation and needs clarification.

Because the main crop treatments were not originally planned for a ratoon crop study, lack of replications limits the data's value. But the treatment that received the recommended dose of N-P-K in the wet season and N in the ratoon crop may be close to an average farm situation. Interestingly, ratoon yields were high even in plots where the main crop yields were low.

PERFORMANCE IN FARMERS' FIELDS

Data on main and ratoon crop yields and on crop duration were collected from 14 randomly selected private farms (Table 5). The ratoon crops showed a wider range of yields than did the main crops. Yields ranged from 0.68 t/ha to more than 4 t/ha. However, mean yields are encouraging and suggest that the system has high potential. But more research is needed to stabilize yields by developing varieties suitable for ratoon cropping and optimum management practices.

Table 5. Performance of main and ratoon crops of rice variety Intan in farmers' fields, Chikkamagalur District, Karnataka, 1979-80.

Location	Trial area (ha)	Duration (d)		Grain yield (t/ha)	
		Main crop	Ratoon crop	Main crop	Ratoon crop
Havandur, Koppa	0.13	173	146	6.5	4.2
Addada, Koppa	0.08	174	145	5.6	3.8
B. Kanebur, N. R. Pura	2.40	187	147	7.8	3.8
Bandihatti, N. R. Pura	2.60	-	-	-	3.0
Bannur, N. R. Pura	1.00	-	-	-	2.5
Kamalapur, N. R. Pura	0.80	-	-	-	2.8
Madabur, N. R. Pura	1.00	-	-	-	2.5
Madabur, N. R. Pura	1.00	-	-	-	2.5
Bigganahalli, Chlkkamagalur	0.32	190	139	3.8	4.6
Bigganahalll, Chlkkamagalur	0.11	192	131	1.1	0.7
M. D. Halli, Chikkamagalur	0.16	190	132	5.5	3.9
Kelagur, Mudigera	0.10	180	140	4.8	3.6
Lalitha Estate, Mudigere	0.40	200	137	3.2	1.5[a]
Vijayalli, Mudigere	0.80	200	136	3.7	2.9

[a]Suffered very heavy wild boar damage.

General observations in the region revealed that in early-planted rice harvested in November, the ratoon crop will flower in midwinter and is subject to cold damage. But main crops cut in December and January flower after winter, leading to successful ratoon crop production. This suggests that we should develop varieties suited for cutting in different months, depending on the planting time of the main crop and ratoon crop potential of specific situations. Cold tolerance in the ratoon or flowering of the ratoon crop after winter are the criteria to be adopted.

The cultural practices currently followed need to be refined after adequate investigation and the fertilizer requirement of the ratoon crop determined separately for lowlands and midlands, since lowlands have a problem of iron toxicity. Phosphorus deficiency is common in both lowlands and uplands. The report (3) that in some genotypes the seed quality of the ratoon crop is as good as that of the main crop is encouraging; seed production from the ratoon crop may thus be possible. Planting value and stability of ratoon crop seed are worth studying to determine the seed production potential.

Some incidence of gall midge insect was observed in ratoon crops, although there was none in the preceding main crop. Care should be exercised to study its possible intensification and necessary control.

RESEARCH NEEDS AND ADVANTAGES OF RATOON CROPPING

Varietal Choice

The experiment with 25 breeding lines in 1980-81 showed that the cultivars that matured late in both the main and the ratoon crops (Intan UAS, Intan IRRI, Mingolo) escaped low-temperature damage in the ratoon crop and produced

Table 6. Summary of observations on 45 rice cultivars studied for the combined performance in the main and ratoon crops at the Regional Research Station, Mudigere, 1980-81 kharif and rabi.

Cultivar	Main crop			Ratoon crop			Combined		
	Plant ht (cm)	Days to maturity	Grain yield (t/ha)	Plant ht (cm)	Days to maturity	Grain yield (t/ha)	Days to maturity	Grain yield (t/ha)	Per day production (kg/ha)
1. IR19794-2-2-2	74	129	6.4	70	81	0.5	210	6.9	32.9
2. IR19794-3-2-2	71	129	3.9	65	78	0.4	207	4.2	20.5
3. IR19796-14-2-2	64	131	3.6	60	76	0.2	207	3.9	18.7
4. IR19799-17-3-1	80	140	2.2	60	81	0.1	221	2.3	10.4
5. IR9201-101-2-2-7	60	132	5.4	60	83	0.2	215	5.5	25.8
6. IR9209-48-3-2	71	131	8.3	70	84	0.5	215	8.8	41.0
7. IR9828-41-2-1	74	140	4.3	72	84	0.6	224	4.9	21.9
8. IR13214-99-2-2-3	84	149	5.2	80	81	0.4	231	5.6	24.4
9. IR13429-305-3	70	129	6.9	70	85	0.5	214	7.4	34.5
10. IR9209-81-2-3-2-2	74	137	7.1	75	84	0.6	221	7.7	55.1
11. IR9940-11-2-3	77	136	3.7	65	91	0.3	227	4.0	17.7
12. IR13240-15-3-3-2	63	138	6.7	60	84	0.4	222	7.1	31.9
13. IR11248-227-1-2-2	65	147	4.3	60	90	0.4	237	4.7	19.8
14. IR11248-8-242-3-1-1	73	128	1.4	60	84	0.1	212	1.6	7.4
15. IR9129-417-1-3	72	128	4.9	60	90	0.2	218	5.1	23.2
16. IR9209-49-1-2-1-2	65	128	1.4	60	83	0.4	211	1.8	8.7
17. IR975-303-3-1-3-2-3	63	132	3.9	60	83	0.3	215	4.2	19.6
18. IR9846-256-3-1	65	131	2.8	60	78	0.4	209	3.1	15.0
19. IR13368-4-3	70	129	4.5	50	83	0.1	212	4.6	20.2
20. IR13371-86-1	57	130	5.6	50	86	0.2	216	5.8	26.9
21. IR15675-74-1-3	65	129	4.8	60	85	0.2	214	5.0	23.5
22. IET3127	83	137	5.7	65	87	0.2	224	5.9	26.4
23. IET4094	83	195	3.9	70	83	0.3	228	4.2	18.3
24. IET405	74	134	5.3	70	80	0.4	214	5.7	26.5
25. Double Dwarf	59	120	3.9	60	83	0.4	203	4.4	21.5
26. IR2055-462-3-2	75	150	6.4	75	76	0.6	226	7.0	31.0
27. Carreon	76	149	2.5	60	77	0.1	226	2.6	11.7
28. Ram Thulasi	109	139	0.4	80	80	0.1	219	0.5	2.3
29. Thilalek Chanian	82	137	4.1	70	79	0.3	216	4.5	20.7
30. IR13641-4	64	168	6.4	60	79	0.3	217	6.7	30.9
31. IR13641-20	67	131	0.9	65	89	0.4	220	1.4	6.2

32. IR19362-62	70	140	5.1	65	91	0.4	231	5.5	23.8
33. C 23-3-1	78	144	2.6	75	93	0.4	237	3.0	12.7
34. IR10167-87-3-3	70	141	5.4	60	87	0.2	228	5.7	25.0
35. IR10198-21-1-3	75	139	6.5	75	78	0.4	217	6.9	31.7
36. Karekagga 78	88	142	6.3	65	77	0.2	219	6.5	29.1
37. IR7682-135-3-2-2-2	83	141	2.7	70	81	0.4	222	3.0	13.6
38. IR13047-76-1	72	141	2.7	60	83	0.2	224	2.9	12.9
39. Gulfrose	70	131	1.2	60	83	0.2	214	1.5	6.9
40. Milbumum	85	151	3.3	75	80	0.4	231	3.7	16.0
41. RPKN 2	85	141	6.8	75	83	0.3	224	7.1	32.1
42. IR10167-129-3-4	73	140	4.3	75	77	0.5	217	4.8	21.9
43. IR5857-4-IE-6	87	141	2.5	80	81	0.5	222	3.1	13.8
44. IR8460-180-2-1-3	67	129	1.4	60	87	0.2	217	1.7	7.7
45. IR9940-11-2-3	46	129	4.9	45	84	0.2	213	5.0	23.6

Table 7. Combined performance of main and ratoon crops of 25 genotypes at the Regional Research Station, Mudigere, 198081 kharif and rabi.

Entry	Main crop		Ratoon crop		Combined		
	Days to maturity	Grain yield (t/ha)	Days to maturity	Grain yield (t/ha)	Days to maturity	Grain yield (t/ha)	Per day grain production (kg/ha)
IR9209-48-3-2	163	3.7	87	0.6	250	4.3	17.0
IR9758-150-3	153	3.0	76	0.4	229	3.4	14.8
IR9129-393-2-6-2-2	163	2.4	77	0.5	240	2.9	12.2
IR9209-217-1-2-2	153	4.5	80	0.6	233	5.2	22.1
IR9752-71-3-2	151	3.2	88	0.5	239	3.7	15.3
IR9761-40-3-2	160	6.3	81	0.6	241	6.9	28.8
IR15324-117-2-2-3	163	5.5	93	0.5	256	6.0	23.5
Intan (UAS)	169	6.1	128	3.7	297	9.8	33.0
IR9782-111-2-1-2	151	3.9	82	0.3	233	4.1	17.7
IR9846-23-2	147	5.4	78	0.5	225	5.9	26.3
IR9129-209-2-2-2-3	163	4.6	81	0.5	244	5.0	20.6
IR9129-457-2-2-1-2	149	3.6	84	0.4	233	4.1	17.5
IR9224-223-2-2-2-1	155	5.1	88	0.5	243	5.6	23.0
IR9224-22-2-2-2-3	154	5.6	78	0.6	232	6.2	26.8
IR9698-16-3-3-2	152	5.8	81	0.4	233	6.2	26.9
IR13423-71-2-2	155	4.7	86	0.7	241	5.4	22.1
IR9852-19-2	153	5.0	83	0.4	236	5.4	22.8
IR36	157	4.9	80	0.6	237	5.5	23.2
Intan (IRRI)	155	4.6	126	3.2	281	7.9	28.0
Mingolo	162	6.1	117	2.9	279	9.0	32.3
IR17525-8-12-3-3-2	159	5.8	80	1.0	239	6.8	28.5
IR23057-247-2-2-3	156	5.4	83	0.4	239	5.8	24.1
IR8608-76-3-2	160	6.1	80	0.4	240	6.6	27.4
IR9814-14-3	159	5.5	77	0.4	236	5.8	24.8
IR8608-75-3-1-3	158	5.2	85	0.2	243	5.4	22.3

attractive yields (Table 6, 7) because they flowered after winter. Also, because the flowering of ratoon crops coincided with that of early-sown (early-maturing) summer crops, bird damage was minimized.

The cultivars IR9209-217-1-2-2, IR9761-40-3-2, IR15324-117-2-2-3, Intan (UAS), IR9846-23-2, 1R9224-223-2-2- 1, IR9224-22-2-2-2-3, IR13423-71-2-2, IR9852-19-2, IR36, Intan (IRRI), Mingolo, IRI 7525-8-12-3-3-2, and IR23057-247-2-2-3 could be tried under delayed planting, since their low ratoon yields were due to cold and bird damage. This would reveal whether ratooning with these cultivars is practicable and economical.

Advantages of ratoon cropping

The cost of cultivation for the ratoon crop is considerably lower than that of sowing a second crop, because of reduced labor costs for land preparation and transplanting. Also, the land, otherwise idle during January-May, is profitably used and therefore the cost per unit production should be cheaper. The rice straw also has substantial value in the hilly region and is an additional point in favor of ratoon cropping.

The likely area to be covered under this system in the hilly region of Karnataka is estimated at 50,000 ha. However, because the system is new, studies are needed to determine suitable varieties, planting time, and management practices for the main and the ratoon crops.

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Production practices for ratoon rice in Tungabhadra River Project

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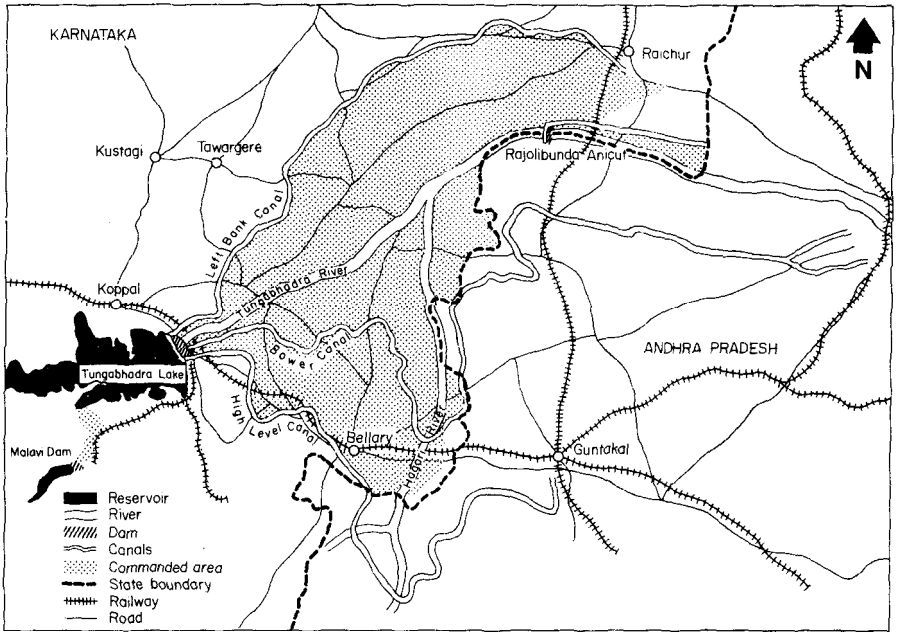
About 0.2 million hectares of the irrigated area of northern Bellary and Raichur districts, Karnataka, are fed by the Tungabhadra River Project (TRP) canals (Fig. 1). The climate is characterized by high temperatures, adequate solar radiation, and low rainfall (Table 1). The climate is ideal for cultivating irrigated rice. Rice is grown mainly in autumn and summer. The autumn crop is normally a long-duration variety. The summer crop is a medium-duration variety which can be harvested before the canal is closed, normally by the end of April. Until recently, rice was thought to be a problem-free crop providing farmers stable income. Blast disease is relatively unknown, but recent outbreaks of brown planthopper (BPH) have caused great losses to the rice crop.

Need for rice ratooning in the TRP area

In 1985, insufficient rain in the catchment area lowered water in the Tungabhadra reservoir. Silting, frequent breaches in canals, and improper water management have accentuated the scarcity of irrigation water, particularly during summer. In 1985, the canals were reopened late in the season in July, and little time was left for cultivating a second crop. Rice growers were cautioned not to plant a second rice crop because of receding water in the reservoir. However, the unsuitability of ricelands for alternative crops forced farmers to grow a second crop despite repeated warnings. Consequently, there was an increased demand for shortduration rice varieties in the summer of 1986, even though their grain quality is inferior and yields are low.

For these reasons, we are exploring ratooning the autumn main crop instead of planting a second rice crop. Zandstra and Samson (3) indicated that ratooned rice, which has a shorter duration than the main crop, has the potential to increase yields where cropping intensity is limited by inadequate irrigation. It also costs less to grow a ratoon crop than a new crop. Mahadevappa (2) reported that an Intan ratoon crop yielded 140% of the main crop. This cultivar, however, is not recommended for irrigated northern areas of Karnataka. Ratoonable genotypes must have good grain quality to meet standards of rice mills.

Rice ratoon cropping was summarized by Chauhan et al (1). Successful ratoon cropping requires proper cultural management for the main and the ratoon crops. Although heavy insect pest incidence reduces ratoon crop yields, no suitable



1. The Tungabhadra River Project.

chemical control measures have been recommended. BPH survives in stubble so its incidence may decrease ratoon growth and yields in this region. Weed management in rice is an important production practice, which is usually coupled with water management. Severe weed population at ratooning may inhibit ratoon regeneration and reduce crop yields. Reports of chemical weed control in ratoon rice are lacking.

CULTURAL PRACTICES FOR RICE RATOONING

We conducted experiments to develop cultural practices for rice ratooning in the TRP area.

Effect of nitrogen source

The soils of the TRP command area are deep Vertisols. To determine the effect of N source on ratoon yields, pot and field experiments were conducted. In the pot experiment, Pusa-l50, Rasi, 1ET7575, and BPT-5204 were used. The first set of treatments consisted of 50 kg N/ha as urea, *Azolla* only at 2.5 t/ha, and zero N. The second set consisted of 50 kg N/ha as urea, *Azolla* only at 2.5 t/ha, 25 kg N/ha + *Azolla,* and zero N. The first main crop in all these pots was continuously supplied with *Azolla* in addition to its continuous growth in pots. In the pot experiment, the ratoons of the 4 genotypes treated with *Azolla* only and *Azolla* + 25 kg N/ha remained green and vigorous and more tillers were regenerated. *Azolla* remained green and grew vigorously until the first week of March. We could not summarize

Table 1. Weather parameters in the Tungabhadra River Project area.

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Maximum temp (°C)	30.2	33.7	37.0	38.8	42.3	35.1	32.6	32.2	32.1	32.1	30.6	29.3
Minimum temp (°C)	16.0	18.6	31.8	24.4	24.7	23.1	22.2	21.7	21.7	20.8	18.0	15.3
Av rainfall (mm)	1.8	4.3	4.4	13.9	33.9	89.2	121.8	118.2	155.0	95.6	22.0	4.3
Av sunshine hours	9.9	10.6	10.4	10.2	9.5	6.2	4.5	5.1	6.4	7.8	9.2	8.7
Potential evapo-transpiration	136.4	154.0	186.0	204.0	218.8	192.0	173.6	181.2	147.0	139.5	129.0	124.0

Table 2. Effects of sources of nitrogen and different insecticides on ratoon crop of Sona Mahsuri, Tungabhadra River Project.

Treatment	Regenerated tillers (no.)	Stem girth (cm)	1 mo of ratooning		2 mo after ratooning		Postharvest observations					
			Shoot wt/plant (g)	Root wt/plant (g)	Shoot wt/plant (g)	Root wt/plant (g)	Plant ht (cm)	Tillers/ plant	Panicles/ plant	% sterility	Yield (t/ha)	Harvest index
N_0I_0	10.9	0.36	5.3	4.1	6.6	1.5	43.9	12.7	10.0	2.15	0.92	0.44
N_0I_1	9.4	0.39	8.3	4.6	3.2	1.2	47.7	11.3	7.7	4.72	0.90	0.49
N_0I_2	12.8	0.34	8.5	4.0	8.8	0.8	49.0	14.7	11.7	2.71	1.23	0.49
N_0I_1	22.3	0.40	11.2	10.5	11.3	2.5	63.9	20.1	20.9	2.11	2.22	0.44
N_1I_1	22.1	0.37	15.8	12.0	15.8	4.5	64.3	26.3	20.0	1.25	r.92	0.41
N_1I_2	18.0	0.35	12.8	14.2	13.7	2.5	60.0	24.0	17.3	0.93	1.93	0.44
N_2I_0	14.0	0.33	11.5	10.2	7.0	2.1	50.4	17.4	13.3	2.72	1.68	0.50
N_2I_1	12.6	0.32	13.9	10.4	7.2	2.0	48.8	14.2	11.4	1.27	1.17	0.41
N_2I_2	14.6	0.35	14.4	14.8	8.6	1.8	48.3	13.3	10.9	1.50	0.74	0.40
N_3I_0	17.7	0.34	10.1	10.3	8.0	2.3	56.6	20.7	16.9	1.32	2.02	0.52
N_3I_1	20.8	0.38	8.2	8.3	11.1	2.8	53.3	23.6	14.5	1.80	1.47	0.45
N_3I_2	23.3	0.37	10.5	9.0	11.8	3.6	56.8	19.8	17.5	1.21	1.35	0.45
SE±	1.25	0.01	2.2	1.46	1.8	0.42	4.2	6.7	4.5	0.22	0.46	0.05
CD (0.05)	4.26	0.02	5.75	3.46	3.5	1.60	7.8	0.98	9.4	0.52	0.74	0.09

the results of pot experiments because in all the treatments, *Azolla* was applied to the main crop. We stopped applying *Azolla* to the ratoon crops with zero N and 50 kg N/ ha treatments. During the autumn-winter months when the main crop was grown, the temperatures were favorable for the multiplication and development of *Azolla*. Probably, the decomposition of *Azolla* resulted in green and vigorous ratoon plants in all the pots. Even in those pots where *Azolla* was maintained in the ratoon crop, the multiplication of *Azolla* slowed in March when the temperatures started rising. Hence, application of *Azolla* to the ratoon crop in this region may not be beneficial.

We did field insecticidal trials with a ratoon crop of Sona Mahsuri. We used four fertilizer treatments and two insecticides with a control. The treatments are summarized in Appendix 1.

Azolla could not be uniformly maintained in the field because of fluctuating water level and snail damage. The higher temperatures during the ratoon crop season may also be the reason for its poorer development and multiplication particularly in March-April. Soil salinity (pH = 8.3) may be another reason. The 50 kg N/ ha treatment gave the most regenerated tillers/plant and the highest ratoon yields. The ratoon tillers were vigorous and green, and exhibited delayed flowering. Tillering was poor in the control and better in plots treated with *Azolla* only (Table 2).

Applying *Azolla* immediately after ratooning may not benefit the ratoon crop because *Azolla* N is not available to the plants until the *Azolla* decomposes. In the pot experiment, *Azolla* N was continuously available to the ratoon crop treated with *Azolla* only. This partially explains inconsistencies between pot and field experiments, but more experiments are required for conclusive results.

Insecticide - nitrogen source interaction

There was no significant interaction between nitrogen source and insecticide application in relation to ratoon growth and development because there was no pest pressure in either crop. In the summer crop of Sona Mahsuri grown in farmers' fields, we observed BPH incidence. The canopy of the ratoon Sona Mahsuri crop in our experiment was not as thick as the farmers' crop.

There was significant variation in number of regenerated tillers, shoot and root weight, panicles/ plant, and yield. Mineral nitrogen at 50 kg/ ha gave the highest mean yield, 2.02 t/ha, in Sona Mahsuri (Table 2).

Application of chemical herbicides

In one herbicide experiment, chemical weedicides were applied to main and ratoon crops of Tellahamsa. Six weedicides were used at three concentrations, along with an unweeded check plot. The other two treatments were hand weeding twice during the crop growth and maintaining the plot weed-free. The treatment was repeated 1 wk after ratooning (Appendix 2). Rice seedlings germinated from the fallen grains and competed with the ratoon crop as weeds. Hand weeding was the most effective weed control method in the main and ratoon crops. Among weedicides, however, pendimethalin at all three concentrations checked weeds in both crops. Ratoon

Table 3. Effect of weedicide application on main and ratoon crops of Tellahamsa.

Treatment		Main crop			Ratoon crop				
		Weed no.	Weed wt (kg)	Yield (t/ha)	Weed no.	Weed wt (kg)	Regenerated tillers (no.)	Stem girth (cm)	Yield (t/ha)
1. Pendimethalin	0.75	128.0	0.108	4.56	37.3	0.3	9.7	0.36	1.86
2. Pendimethalin	1.0	127.0	0.104	4.36	45.0	0.93	9.20	0.35	1.76
3. Pendimethalin	1.5	133.0	0.118	4.14	62.1	0.64	14.3	0.34	2.04
4. Oxadiazon	0.25	121.3	0.119	4.46	50.6	0.3	7.4	0.36	1.14
5. Oxadiazon	0.50	133.6	0.133	3.97	106.6	0.99	7.5	0.30	1.04
6. Oxadiazon	0.75	148.6	0.120	4.26	226.0	1.33	10.2	0.34	1.44
7. Butachlor	1.00	142.3	0.123	4.18	207.3	1.3	6.4	0.35	0.94
8. Butachlor	1.25	152.3	0.127	4.0	235.8	0.87	10.1	0.32	1.15
9. Butachlor	1.5	150.0	0.17	3.41	179.0	0.67	9.6	0.32	1.02
10. Amilophos	0.40	144.0	0.120	3.92	119.0	1.64	1.8	0.32	1.25
11. Amilophos	0.50	147.7	0.125	3.66	159.3	1.37	10.4	0.35	1.44
12. Amilophos	0.60	126.6	0.120	4.04	156.7	1.51	10.9	0.36	1.15
13. Oxifluorfen	0.08	130.3	0.142	4.29	148.3	0.93	8.0	0.34	1.42
14, Oxifluorfen	0.10	131.6	0.125	4.05	117.0	0.82	8.1	0.35	1.32
15. Oxifluorfen	0.12	156.7	0.122	3.88	115.7	0.95	9.7	0.32	1.53
16. Unweeded		185.7	0.324	3.62	56.7	0.89	6.5	0.37	0.95
17. Hand weeded twice		116.7	0.056	5.84	52.3	0.28	6.60	0.36	1.56
18. Weed free		25.67	0.020	8.25	51.3	0.03	8.6	0.34	1.75
SE±		5.67	0.008	0.14	10.9	0.08	0.4	0.01	0.10
CD (0.05)		16.4	0.05	0.48	25.4	0.24	2.6	0.04	0.39

regeneration was suppressed in the unweeded plot. The yield levels were higher in the plots treated with pendimethalin at three concentrations and in weed-free plots. Pendimethalin suppressed some of the perennial monocot weeds, which became a problem in the ratoon crop treated with other herbicides and in the unweeded plot (Table 3).

In another weedicide experiment on a ratoon crop of Sona Mahsuri (Appendix 3), hand weeding and pendimethalin at 3 liters/ha effectively controlled weeds and increased ratoon regeneration and shoot and root weights. The herbicide controlled dicot plants, annual grasses, and some perennial weeds. As Table 4 shows, number of weeds and weed weight were less in the hand weeding treatment. Tillers/plant, panicles/plant, and grain yield were significantly higher in hand weeding and pendimethalin treatments than in the other treatments. We conclude that pendimethalin is suitable for ratoon rice crops.

CONCLUSION

Fertilizer nitrogen applied at 50 kg/ha immediately after ratooning increased tiller number and dry matter accumulation in roots. Higher nitrogen levels may benefit the ratoon crop, and effects of various levels of mineral nitrogen must be studied. If we are to use *Azolla* as a nitrogen source for the ratoon crop, we should start by applying it to the main crop. Applying *Azolla* long before ratooning allows it to decompose in time to benefit the ratoon crop. It may not, however, replace mineral nitrogen and its complementarity with mineral nitrogen must be investigated. Hand weeding is a more efficient method of weed control and should be used wherever

Tabla 4. Effect of weedicide application in ratoon Sona Mahsuri.

Treat-ments	No. of re-generted tillers	No. of weeds/plot (monocots + dicots)	Weed dry wt (kg/plot)	1 mo after ratooning		2 mo after ratooning		Plant ht (cm)	Tillers/ plant	Panicles/ plant	% of sterility	Yield /ha
				Shoot wt /plant (g)	Root wt /plant (g)	Shoot wt /plant (g)	Root Wt /plant (g)					
w_0	21.53	310.00	5.60	8.9	2.4	8.3	2.5	55.9	12.7	10.6	1.3	10.88
w_1	25.6	131.6	2.14	5.3	3.6	10.0	4.3	63.8	15.4	14.2	2.1	13.5
w_2	25.0	146.6	2.7	9.1	4.6	9.2	3.0	56.7	15.2	13.1	1.7	10.6
w_3	20.0	231.6	3.6	10.3	4.6	11.9	6.5	61.5	13.8	12.2	1.4	13.7
w_4	29.6	123.3	1.7	7.0	4.2	12.4	6.2	58.8	16.8	14.4	2.7	18.2
w_5	25.3	48.3	0.8	7.7	4.4	10.6	3.6	63.6	15.7	15.4	1.2	19.6
SE±	1.64	4.2	0.42	0.5	0.2	0.86	0.3	1.24	0.56	0.51	0.46	0.92
CD (0.05)	2.05	25.44	0.84	1.4	1.8	2.8	0.7	7.48	1.46	1.02	0.75	1.53

labor is economical. Among the chemical weedicides, pendimethalin at 3-5 liters/ha controlled weeds most effectively in main and ratoon crops and encouraged ratoon regeneration.

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Appendix 1. Source of nitrogen X insecticidal trial in ratoon Sona Mahsuri, Tungabhadra River Project.

Genotype: Sona Mahsuri
Oats of sowing: 16 Jul 1985
Date of ratooning: 17 Feb 1986
Plot size: 6 m X 2 m

Treatments:

Nitrogen

1. N_0 = Control (0 N)
2. N_1 = 50 kg N/ha as urea
3. N_2 = *Azolla*
4. N_3 = *Azolla* + 25 kg N/ha

Insecticide

1. I_0 = Control
2. I_1 = Monocrotophos 36EC 0.5 kg al/ha
3. I_2 = Chlorpyrifos 20 EC 0.3 kg al/ha

Date of nitrogen application: 20 Feb 1986
insecticidal application: 20, 45, and 65 d after ratooning
Azolla application: once in a week

Appendix 2. Chemical weed control in main and ratoon crops of Tellahamsa, Tungabhadra River Project.

Genotype: Tellehamsa
Date of sowing: 25 Jul 1985
Date of weedicide application to the main crop: 25 Aug 1985 (5 d after planting)
Date of ratooning: 31 Dec 1985

Treatments	*Active ingredient (kg/ha)*
1. Pendimethalin	1.8
2. Pendimethalin	2.5
3. Pendimethalin	3.7
4. Oxadiazon	0.6
5. Oxadiazon	1.2
6. Oxadiazon	1.8
7. Butachlor (50 EC)	2.5
8. Butachlor	3.1
9. Butachlor	3.7
10. Amilophos (Arozin)	1.0
11. Amilophos (Arozin)	1.2
12. Amilophos (Arozin)	1.5
13. Oxifluorfen	0.2
14. Oxifiuorfen	0.2
15. Oxifluorfen	0.3
16. Unweeded check	
17. Hand weeded twice	
18. Weed free	

Date of harvest: 7 Apr 1986

Appendix 3. Weedicide trial in ratoon crop of Sona Mahsuri, Tungabhadra River Project.

Genotype: Sona Mahsuri
Date of sowing: 16 Jul 1985
Date of ratooning: 17 Dec 1985
Date of weedicide application: 24 Dec 1985
Plot size: 4 m X 2 m

Treatments

W_0	: Unweeded check	
W_1	: Butachlor (50% EC)	2.5 liters/ha
W_2	: Benthiocarb	1.6 liters/ha
W_3	: 2,4-D	2.5 kg/ha
W_4	: Pendimethalin	3.0 liters/ha
W_5	: Hand weeding	

Date of harvest: 5 Apr 1986

Ratoon rice research in Karnataka, India

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ABSTRACT

Rice ratoon cropping can increase rice production without increasing land use where moisture, inputs, and seasonal conditions are too short to raise a second crop. Published data on ratooning are meager and discontinuous, resulting in slow adoption of this system. Varieties differ widely in ratooning ability, type of tillers produced, growth duration, grain quality, and yield. Occurrence of yellow dwarf/grassy stunt diseases on the ratoon crop of several genotypes screened warns breeders of the need to evolve varieties with resistance. Intan, Mingolo, and Intan mutant currently under experimentation in Karnataka possess resistance to those virus diseases. Work on selecting genotypes with cold tolerance, ratoonability, and desirable growth duration at Bangalore helped identify seven genotypes that possess all three characters.

On riceland where moisture, soil, and seasonal inadequacies prevent raising an upland crop or a newly planted rice crop, rice ratoon cropping is suggested as a way to increase rice production without increasing land area. Hill valley bottoms in Karnataka, India, were identified as potential areas for a ratoon cropping system and research was initiated at the Agricultural University Research Stations at Madikeri and Mandya in the 1970s (9, 10). The excellent ratooning ability of Intan rice encouraged researchers to initiate trials in research stations and in farmers' fields simultaneously. Ratoon crop yields were 2-3 t/ ha (19-24). We review here the results of that research, including collaboration with IRRI, and suggest future lines of research.

VARIETAL DIFFERENCES

Rice genotypes exhibit considerable variation in such characters as ratooning ability, types of ratoon tillers produced, ratoon growth duration, ratoon grain quality, and ratoon crop yield. Wide varietal differences have been reported for one or more of these characters in studies involving more than 3,000 genotypes (9).

Ratooning ability and inheritance

Haque (6) reported zero to 60% ratooning ability in the IRRI lines he studied. Some varieties produced nodal ratoons, others produced the desirable basal ratoons,

independent of the harvest cutting height of the main crop (28). Among the varieties screened in Karnataka for ratooning ability and type of tillers, Intan, Mingolo, Intan mutant, Mahsuri, and some experimental hybrids produced more basal tillers than nodal tillers. Although many other genotypes tended to put up ratoon growth, they had more nodal tillers than basal tillers. Cutting height and number of nodal tillers produced are positively correlated (r = 0.867).

At Ponnampet Farm, IET7191 (RPS 32/Pankaj) showed very good ratoon growth (25). In a preliminary study (1983-85) at the Bangalore Research Station, removing early tillers helped attain uniform flowering and maturity of the ratoon crop of varieties Mangala, CH2, and KMS-I . In fact, cutting back early tillers on KMS-1 plants produced on stubble delayed flowering, so that flowering synchronized with flowering of a newly planted Intan mutant-I. Cutting back two times helped synchronize flowering with newly planted Intangouri (14). When uncut, single-cut, and twice-cut tillers were allowed on a single plant, the plant could supply pollen for 22 d. This could be of use in hybrid seed production.

In 20 crosses of 8 parents in different generations, the recessive and heterotic nature of the genes governing inheritance of ratooning ability was identified (18).

Growth duration

Varieties with longer growth durations tend to have stronger ratooning ability. Growth of the main crop was 85-175 d and that of the ratoon crop was 40-135 d (9). Growth duration and grain yield correlated strongly. The ratoon crop production of late-maturing Intan and Mingolo in Karnataka supports this finding. Good ratooning ability of shortduration varieties CH45, PTB-10, N22, CT1351, S705, Mangala, and Intan mutant has also been reported (1-3). This suitability of medium- and early-maturing varieties for ratoon cropping needs to be investigated. Zandstra and Samson (28) have indicated that high ratoon yields may require selecting varieties for a ratoon crop with durations longer than 70 d.

Plant and grain characters

Except for seed viability, all other characters (plant height, panicle length, spikelet size, number of productive tillers, and grain setting) were less pronounced in the ratoon crop than in the main crop (16, 17). Grain quality is of great concern. Reddy and Pawar (16) and Saran and Prasad (17) reported ratoon crop seed viability and productivity as good as that of the main crop. Webb et a1 (26) reported that the ratoon crop of some varieties had relatively fewer uniform kernels. Protein content tended to be considerably higher in ratoon crop grains than in main crop grains, although it varied greatly. Gelatinization temperature and viscosity values were consistently lower in ratoon crop grain samples. Gay (4) reported that the ratoon crop grain of Gulfrose variety graded No. 1. Nadal and Carangal (11) observed that the grains produced by the second ratoon were superior to those produced by the first ratoon. Nagaraja and Mahadevappa (12) noted that the seed quality of main and ratoon crops varied with variety and that viability in ratoon crop seeds deteriorated faster than it did in main crop seeds. However, field performances of a variety raised from the seeds obtained from the main crop and from the ratoon crop did not differ.

Grain yield and related characters

Varietal differences in grain yield and other related characters are also quite large. Ratoon crop yields of 6-140% of main crop yields have been reported. Main crop yields ranged from 0.8 to 7.5 t/ ha, the related ratoon crop yields ranged from 0.1 to 8.7 t/ha. Average yields of main and ratoon crops were 3.7 and 2.1 t/ha. In a few cases, ratoon crop yields exceeded main crop yields.

In 1985-86, IET9667, IET9668, and IET9670 produced ratoon crop yields of 1.7 and 1.6 t/ha at Ponnampet Farm; the main crop failed due to low or high temperature (25). Higher ratoon crop yields also have been reported in sorghum and cotton (15). Others (7, 13, 27) reported ratoon crop yields 20-60% of main crop yields. Haque (6) reported ratoon crop yields of 65 IR lines ranging from 7 to 720 kg/ha, accounting for 0.33-13% of the main crop yields. Main crop plus ratoon crop yieids in Karnataka ranged from 2.9 to 9.8 t /ha, main crop 2.44-6.11 t/ ha, and ratoon crop 0.23-3.22 t/ ha. Per day production in main crop plus ratoon crop was 14.8-33.0 kg/ha, which could be increased through improved management (5).

Ratoon crop yield was more variable than main crop yield (6). It is possible to reduce high fluctuations in ratoon crop yields by breeding stable ratooning and uniformly flowering varieties and adopting improved management practices. In a planting date study at Bangalore (India), Basavaraju et al(1) reported that Mangala planted in August and harvested at the end of November produced the highest ratoon yields among early maturing Mangala, CT1351, and Halubbalu. Jones (8) reported that cultivar selection had more effect on ratoon crop yields than did cutting height.

RESISTANCE TO STRESS

Varieties susceptible to virus diseases are not suitable for ratoon crops. At Bangalore, only 15 of 260 genotypes tested were unaffected by yellow dwarf or grassy stunt in the ratoon growth; the rest had to be immediately plowed under, even if they possessed ratooning ability. In the cold tolerance nursery, 86 of 232 genotypes tested in the 1984-85 winter were unaffected by viruses in ratoon growth. Among the affected ratoon growths, incidence was 5.0-20.0%. Diseases like blast, brown leaf spot, and glume blight occurred at the same intensity on both main and ratoon crops. Resistance to viruses is a requirement of varieties to be fitted into a rice ratoon cropping system.

Varieties currently under study for their suitability for ratoon cropping in India are those that are resistant to viruses (Intan, Mingolo, Intan mutant, Mangala). Recent work at the Main Research Station, Bangalore, to select genotypes combining cold tolerance, ratooning ability, and desirable growth duration for planting the main crop in Sep-Oct and harvesting the ratoon crop in April, identified seven that possess all three characters: KBCPI, CT51, NR10073-167-3-1-1, IR18476-55-2, IR15599-135-3, B2983-6-SR-85-3-24, and CT19. These genotypes have been screened for several seasons for different stresses and are being advanced to prerelease farm trials in southern Karnataka.

Cultivars that flower before the end of winter (night temperature less than 18 °C) may fail even if they have good ratoon potential unless cold tolerance is bred

into them. Breeding for cold tolerance at ratoon flowering, identifying suitable varieties for different planting dates, and developing a suitable package of agronomic practices for optimum yields are the needed research lines.

Criteria to be considered in a breeding program are ratooning ability with more basal tillers, resistance to insects and virus diseases, growth duration, and desirable grain characteristics.

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Status of and potential for rice ratoon cropping in Tamil Nadu

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ABSTRACT

In Tamil Nadu, rice ratoon cropping is not ordinarily practiced by farmers except in isolated pockets of Cumbum Valley and Chingleput District. Twenty-five percent of the area under rice is monocropped under canal- or tank-fed irrigation systems, where water is available for 190 d. A single crop of rice maturing in 130-135 d is raised either transplanted or direct-seeded. There is scope for raising a ratoon crop in the single-crop wetlands of Tamil Nadu, where surplus irrigation water is available for 55 d. Experiments were conducted during 1967-68 to 1984-85 to study the ratooning ability of different short- and medium-duration varieties superimposed with the treatments such as stubble height, nitrogen levels, and irrigation regimes. Cv Bhavani was found consistently superior to the rest as a ratoon crop, recording the maximum ratoon crop yield, accounting for 58% of the main crop yield. Harvesting the main crop at physiological maturity stage, leaving a 20-cm stubble height, and applying 120 kg N/ha in split doses to the ratoon crop produced the maximum grain yield. The ratoon crop of Bhavani matured in 70 d and the main crop in 135 d.

In Tamil Nadu, rice ratoon cropping is not ordinarily practiced by farmers, except in isolated pockets of Cumbum Valley and Chingleput District. Twenty-five percent of the area under rice is grown with a single crop of medium-duration varieties under canal- and tank-fed irrigation systems. Isolated studies on ratooning of rice in Tamil Nadu have shown promise for utilizing the surplus irrigation water potential in 2.25 million hectares of double-cropped and single-cropped lowlands (Table 1).

Water is available for irrigation in the double-cropped lowlands for 210-240 d, of which surplus water is available for nearly 30 d after the harvest of the second crop, depending upon the monsoon rains. Cropping intensity can be increased in the doublecropped areas — where shortduration varieties are followed by medium-duration varieties — either by reducing the duration of the second crop from 130-133 d to 100-110 d to fit in a third ratoon crop, or by efficient water management in selected pockets in the head zones of the command areas in different canal systems, such as the Cumbum Valley in Tamil Nadu.

The ideal situation for ratoon cropping in Tamil Nadu, however, is the single-cropped lowland areas (0.72 million hectares) in the canal- and tank-fed systems, where water is available for 190 d, depending upon the monsoon rains

Table 1. Area and irrigation sources for rice crops in Tamil Nadu.

Area (thousand ha)						
Irrigation source						
Government canals	Private canals	Tanks	Tube wells	Wells	Other	Total
763	1	517	143	815	15	2254

Source: Tamil Nadu - An Economic Appraisal 1984-85, Tamil Nadu.

Table 2. Season and area of irrigated rice grown in Tamil Nadu.

Area (thousand ha)			
First crop (Jun-Jul)	Second crop/ single crop (Sep-Oct)	Third crop (Feb-Apr)	Total
957	715	36	1708

Source: Season and crop report of Tamil Nadu, 1979-80. Department of Statistics, Government of Tamil Nadu.

(Table 2). Farmers traditionally cultivate a single crop of rice with medium-duration (130-135 d) varieties, either followed by a short-duration crop (legumes and millets) or left fallow. The surplus water available for 55-70 d in the single-cropped lowlands can be economically utilized for a ratoon crop after main crop harvest.

The climate also favors ratoon cropping. The main crop is sown in August and harvested in November-December. The northeast monsoon (October to mid-December) brings about 448 mm (50 yr average) rainfall as supplemental irrigation for the ratoon crop. The maximum and minimum average temperatures of 37 °C and 24 °C favor maximum productivity of the rice crop. Pest and disease incidence is low or almost nil, another point favoring the raising of a ratoon crop of rice.

Ratoon cropping trials and experiments in Tamil Nadu have tested: 1) tiller regeneration ability, 2) fertilizer management, 3) stubble height, 4) crop duration, 5) per day productivity, and 6) water management.

RATOONING ABILITY OF CULTIVARS

Genotypic differences in tiller regeneration ability have been reported among the 30 varieties studied at the rice research stations at Ambasamudram, Madurai, Coimbatore, Tirur, and Aduthurai in Tamil Nadu (1-11). The ratoon crop grain yields ranged from 0.75 to 4.8 t/ha; ratoon crop yield as a percentage of the main crop yield ranged from 7.5 to 115.3 (Table 3).

In six trials, Bhavani (Peta × BPI 76) with a maturity period of 135 d showed the best tiller regeneration ability, with 4.9 t/ha ratoon crop yield during the 1979 second crop season (68.4% of the main crop yield) and 4 t/ha during the 1985 second crop season (58.0% of the main crop yield) at Madurai center. In the 1984 trial at the

Table 3. Ratoon crop yields of rice in Tamil Nadu. 1967-85.

Research center	Year	Variety	Maturity (d)			Grain yield (t/ha)			Per day productivity (kg/ha)		Reference
			MC	RC	% of MC	MC	RC	% of MC	MC	RC	
Ambasa-mudram	1967-68	IR8	*	93	*	*	3.9	*	–	42.1	(9)
Tirur	1975-76	IR8	138	104	75.4	2.1	1.6	67.3	15.5	13.9	(10)
		IR20	135	104	77.0	2.1	0.75	35.3	15.7	7.2	(10)
		Ponni	135	103	76.3	4.7	1.5	32.3	34.6	14.6	(10)
		Ehavani	135	87	64.4	7.0	2.4	33.9	52.2	27.5	(10)
		ADT 29	138	121	87.7	4.6	1.3	28.6	33.1	10.8	(10)
		ADT31	108	67	62.4	2.1	1.6	77.1	19.6	24.4	(10)
		TKM 8	138	121	87.7	3.3	1.2	35.1	24.0	9.7	(10)
Coimbatore	1970	ADT 27	115	67	58.3	3.8	0.48	12.6	32.8	7.1	(1.2)
		Co32	135	77	57.1	4.7	1.2	31.5	34.7	19.2	(1,2)
		IR8	135	82	60.7	4.4	1.3	29.5	32.9	16.0	(1,2)
		Jeeragasamba	140	81	57.9	3.1	1.3	41.7	21.9	15.8	(1,2)
Coimbatore	1970	IR8	137	69	50.36	3.0	3.5	115.3	22.2	50.7	(8)
Aduthurai	1977	ADT 30	105	55	52.4	4.3	4.4	101.6	41.3	80.0	(11)
		ADT 31	110	55	52.4	7.9	2.8	35.0	71.8	25.2	(11)
		CR146-224	110	55	52.4	10.2	3.3	31.9	90.3	59.4	(11)
		RP1045-5-6-2	130	60	46.2	9.4	4.8	51.1	72.3	80.0	(11)
		RP1045-10-6-2-1	130	60	46.2	6.1	3.7	60.4	46.7	61.1	(11)
		IET2885	135	60	44.4	11.2	4.0	35.6	83.2	66.6	(11)
		GMRl3	130	60	46.2	7.7	4.5	58.2	59.5	75.0	(11)
		IR1529-680-3	130	60	46.2	6.4	3.4	49.5	52.8	56.7	(11)
Aduthurai	1977	IR20	130	60	46.2	5.5	2.7	49.7	42.3	45.6	(11)
		CR1001	135	60	44.4	7.6	3.5	49.7	56.1	58.9	(11)
		Ponni	135	60	44.4	6.9	4.0	58.2	51.3	67.2	(11)
		AD 54-1	130	60	46.2	7.6	3.7	52.1	54.5	61.1	(11)
		AD 2774	135	60	44.4	5.2	3.3	62.4	38.8	54.5	(11)
Ambasa-mudram	1977	Bhavani	135	70	51.9	*	3.0	*	*	42.6	(7)
		Ponni	140	94	67.1	*	2.9	*	*	30.3	(7)
		IR20	135	85	63.0	*	1.8	*	*	20.9	(7)
Madurai	1979	Vaigai	107	70	65.4	6.5	3.3	50.4	61.1	47.1	(6)
		Bhavani	133	74	55.6	7.1	4.9	68.4	53.3	65.6	(6)
Madurai	1982	IR20	130	75	58.0	5.6	0.70	12.3	43.4	9.3	(3)
		Bhavani	130	70	54.0	5.6	1.6	29.2	43.3	23.5	(3)
		Co42	135	65	48.0	4.8	1.2	25.1	35.7	18.6	(3)
Madurai	1984	Ehavani	128	78	60.9	2.5	2.2	86.6	19.5	27.8	(4)
		Ponni	138	88	63.8	1.6	0.43	22.2	11.4	4.9	(4)
		Puduvai Ponni	138	66	47.8	2.4	0.77	31.5	17.6	11.6	(4)
		IR20	128	77	60.2	3.0	0.92	30.7	23.3	11.9	(4)
		ACM 8	120	88	48.3	0.85	0.68	80.0	87.1	11.7	(4)
		ACM 9	104	81	71.9	3.5	1.2	34.5	33.8	15.0	(4)
		ACM 10	104	81	77.9	2.9	1.6	54.3	27.7	19.3	(4)
		Co 43	135	69	51.1	2.6	0.67	25.9	19.0	9.6	(4)
		Co 44	120	81	67.5	2.0	0.92	46.6	16.4	11.3	(4)
		MDU2	138	77	55.8	2.6	0.47	17.9	18.8	6.0	(4)
Madurai	1985	Bhavani	130	71	54.6	7.0	4.0	58.0	53.6	56.9	(5)
		Ponni	137	79	57.7	6.3	1.3	21.1	46.1	16.8	(5)
		IR20	130	71	54.6	6.8	0.51	7.5	52.3	7.2	(5)

MC = main crop, RC = ratoon crop, l = not reported.

Agricultural College and Research Institute, Madurai, Bhavani recorded the highest percent ratoon yield, 86.6% of the main crop yield.

Varieties RP 1045-5-6-2, GMR 13, ADT 30, and IET 2855 (4.8, 4.5, 4.4, and 4.0 t/ha; 51.1, 58.2, 101.6, and 35.6% of the main crop yield) showed some potential for ratooning. IR20 was not promising in its tiller regeneration ability — it yielded

only 7.5-49.7% of the main crop yield in the 6 trials conducted in Tamil Nadu. IR8 recorded the maximum of 115.3% of the main crop yield, accounting for 3.5 t/ha against 3.0 t/ha of the main crop yield.

Thus, considerable variability exists among the genotypes in tiller regeneration ability, which can be further exploited through suitable breeding methods.

FERTILIZER MANAGEMENT

Different genotypes responded differently in their tiller regeneration ability in terms of grain yield to different levels of fertilizer N, P, and K (1-9). Nine varieties were evaluated at 3 sites — Ambasamudram, Coimbatore, and Madurai - under various levels of N ranging from 40 to 150 kg/ ha.

The most responsive variety was Bhavani, which gave ratoon yields of 0.82-5.3 t/ha at various levels of N (50-125 kg/ha). The maximum ratoon crop grain yields of 5.3 and 5.0 t/ ha were recorded at 150 and 120 kg N/ ha, applied in split doses, at Madurai center (Table 4).

IR20 did not respond favorably to the N levels; it recorded only 0.19-2.0 t/ ha of ratoon crop yield at N levels ranging from 50 to 125 kg N/ha. Short-duration variety Vaigai (110d) responded favorably to 120 and 150 kg N, with ratoon crop yields of 3.4 and 3.7 t/ha, respectively (51.9 and 57.0% of the main crop yield). The ratoon crops of varieties ADT 27, Jeeragasamba, Ponni, and Co 42 showed poor response to different levels of N.

Apparently, the response of ratoon crop to different levels of N depends on the fertilizer dose. There was no consistency in the performance of different genotypes at the same level(s) of N in different years and locations. Further critical analysis on the fertilizer requirements of the ratoon crop is needed with highly responsive genotypes in different agroclimatic regions of Tamil Nadu; various levels, times, and methods of application of N, P, and K, should be tested.

STUBBLE HEIGHT

Stubble heights are important in maintaining good ratoon growth, because enough buds are needed on stems or crown tissue to produce rapid-growing shoots or tillers. Eight varieties were evaluated at Ambasamudram, Coimbatore, and Madurai for their tiller regeneration ability at different stubble heights ranging from close to ground level to 30 cm, at intervals of 5 and 10 cm (2, 4, 8, 9). Again, the variety most responsive to different stubble heights was Bhavani, and the next best was Vaigai (Table 5). Most varieties performed well at 20 cm stubble height. IR8, on the contrary, yielded the maximum (2.9 t/ ha) when cut close to the ground. IR20 and Ponni gave low yields when cut at 15 cm.

Tiller regeneration ability in relation to different stubble heights apparently varies with the genotype. Further detailed studies are needed, especially under the varied rice-growing conditions of Tamil Nadu.

Table 4. Fertilizers and grain yield of ratoon rice crop in Tamil Nadu.

Research center	Year	Fertilizer for ratoon crop (kg/ha)	Variety	Grain yield (t/ha)[a]			Reference
				MC	RC	% of MC	
Ambasamudram	1967	100 kg N	IR8	•	3917	•	(g)
Coimbatore	1970	40 kg N	IR8	4.5	1.2	26.3	(1, 2)
			ADT 27	3.8	0.41	10.8	(1, 2)
			Co 32	4.7	1.1	24.1	(1, 2)
			Jeeragasamba	3.1	0.95	31.0	(1, 2)
		80 kg N	IR8	4.4	1.4	30.8	(1, 2)
			ADT 27	3.8	0.49	12.9	(1, 2)
			Co 32	4.7	1.5	31.3	(1, 2)
			Jeeragasamba	3.1	1.3	44.0	(1, 2)
		120 kg N	IR8	4.4	1.5	32.7	(1, 2)
			ADT 27	3.8	0.52	13.8	(1, 2)
			Co 32	4.7	1.8	39.0	(1, 2)
			Jeragasamba	3.1	1.5	50.2	(1, 2)
		50-35-35 NPK	IR8	•	3.5	•	(8)
Ambasamudram	1977	50-25-25 NPK	Bhavani	•	3.0	•	(7)
			Ponni	•	2.9	•	(7)
			IR20	•	1.8	•	(7)
		65-25-25 NPK	Bhavani	•	3.0	•	(7)
			Ponni	•	2.0	•	(7)
			IR20	•	2.0	•	(7)
Madurai	1979	90-50-50 NPK	Vaigai		2.8	42.3	(6)
		120-50-50 NPK	Vaigai	6540	3.4	51.9	(6)
		150-50-50 NPK	Vaigai		3.7	57.0	(6)
		90-60-60 NPK	Bhavani		4.2	57.0	(6)
		120-60-60 NPK	Bhavani	7095	5.0	70.1	(6)
		150-60-60 NPK	Bhavani		5.3	75.3	(6)
		100-50-50 NPK (single dose)	Bhavani	5639	1.5	26.9	(3)
			IR20	5633	0.61	10.8	(3)
			Co 42	4823	1.1	23.3	(3)
		100-50-50 NPK (split dose, 7 and 20 d)	Bhavani	5639	1.8	31.5	(3)
			IR20	5633	0.78	13.9	(3)
			Co 42	4823	1.6	34.1	(3)
Madural	1984	50-50-50 NPK	Bhavani	2410	0.82	33.9	(8)
		75-50-50 NPK	Bhavani	2900	0.83	28.6	(8)
		100-50-50 NPK	Bhavani	3500	1.1	31.1	(8)
		125-50-50 NPK	Bhavani	2937	1.0	35.4	(8)
		50-50-50 NPK	Ponni	2453	0.61	24.8	(8)
		75-50-50 NPK	Ponni	2517	0.61	28.2	(8)
		100-50-50 NPK	Ponni	2338	0.49	20.8	(8)
		125-50-50 NPK	Ponni	2810	0.55	19.7	(8)
		50-50-50 NPK	IR20	3937	0.26	6.6	(8)
		75-50-50 NPK	IR20	3827	0.26	6.7	(8)
		100-50-50 NPK	IR20	3934	0.28	7.1	(8)
		125-50-50 NPK	IR20	3804	0.36	9.5	(8)
Madural	1985	50-50-50 N P K	Bhavani	6.7	2.2	32.4	(5)
		75-50-50 NPK	Bhavani	6.1	2.4	39.6	(5)
		100-50-50 NPK	Bhavani	7.1	3.5	49.5	(5)
		125-50-50 NPK	Bhavani	6.9	3.8	55.1	(5)
		50-50-50 NPK	Ponni	6.6	1.3	10.8	(5)
		75-50-50 NPK	Ponni	7.1	1.2	16.9	(5)
		100-50-50 NPK	Ponni	6.3	1.3	19.8	(5)
		125-50-50 NPK	Ponni	6.4	1.4	21.0	(5)
		50-50-50 NPK	IR20	6.9	0.25	3.7	(5)
		75-50-50 NPK	IR20	7.1	0.19	2.7	(5)
		100-50-50 NPK	IR20	6.4	0.35	5.4	(5)
		125-50-50 NPK	IR20	6.7	0.45	6.7	(5)

[a]MC = main crop, RC= ratoon crop, • = not reported. Main crop received normal recommended dose of N:P:K except Madurai 1985.

Table 5. Relation of stubble height to grain yield in rice ratooning trials, Tamil Nadu.

Research center	Year	Variety	Stubble height (cm)	Grain yield (t/ha)[a]			Reference
				MC	RC	% of MC	
Ambasamudram	1969	IR8	15 (no N)	*	1.7	*	(9)
		IR8	Close to the ground	*	2.9	*	(9)
Colmbatore	1970	ADT 27	10		1.8	47.3	(2)
		ADT 27	20	3.8	1.9	50.2	(2)
		ADT 27	30		2.4	64.4	(2)
		Co 32	10		2.5	52.8	(2)
		Co 32	20	4.7	3.1	66.7	(2)
		Co 32	30		3.8	82.1	(2)
		IR8	10		1.5	34.7	(2)
		IR8	20	4.4	1.4	31.2	(2)
		IR8	30		1.6	36.2	(2)
		Jeeregasamba	10		2.9	96.3	(2)
		Jeeregasamba	20	3.1	3.3	107.0	(2)
		Jeeragasamba	30		3.5	115.6	(2)
Ambasamudram	1977	IR20	15	*	1.8	*	(8)
		Ponni	15	*	2.9	*	(8)
		Bhavani	15	*	3.0	*	(8)
Madural	1979	Vaigai	10	*	3.4	*	(4)
			15	*	3.1	*	(4)
			20	*	3.6	*	(4)
		Bhavani	10	*	4.5	*	(4)
			15	*	4.8	*	(4)
			20	*	5.4	*	(4)

[a]MC = main crop, RC = ratoon crop, * = not reported.

RATOON CROP GROWTH DURATION

The ratoon crop growth duration of the 30 varieties reported (1-11) ranged from 55 d in short-duration (105-110 d) varieties ADT 30, ADT 31, and CR146-224 to 121 d in the medium-duration (138 d) varieties ADT 29 and TKM 8 (Table 3). The growth duration of the ratoon crop accounted for 44.4-87.7% of that of the main crop, which ranged from 104 to 140 d. In Bhavani, the ratoon crop duration ranged from 70 to 87 d, as against 128-135 d for the main crop; however, IR20 matured in 60-105 d (3-5, 7, 10, 11), accounting for 46.2-77.0% of the main crop growth duration (130-135 d).

These variations in the maturity period of the ratoon crop may have been influenced by the main crop growth duration and location, as well as by soil, water, season, nutrition, and stubble height.

PER DAY PRODUCTIVITY

Per day productivity of the ratoon crop of 30 of the test varieties varied widely, from 6 kg in MDU 2 to 80 kg in ADT 30 (a short-duration crop). Per day productivity of the main crop ranged from 7 kg in ACM 8 to 90 kg in CR146-224. This wide

variation may be due to such factors as variety, location, soil, water, season, and management practices. The ratoon crop of the promising variety Bhavani yielded 23.5-65.6 kg/ha per d as compared with 19.5-53.6 kg/ha per d recorded by the corresponding main crop (4-7, 10).

WATER MANAGEMENT

Water management before and after harvest of the main crop affects ratooning ability. The reported results on water management for the ratoon crop of rice from Ambasamudram (8,9) and Madurai (5) are based on a limited range of treatments. However, irrigation to 5 cm depth 1 d after disappearance was best for the ratoon crop and varieties Bhavani, Ponni, and IR20. Bhavani responded best, with 3.1 t/ ha grain yield (5). The trials at Ambasamudram showed that variety Bhavani, irrigated 5 times at 12-d intervals, yielded 3.0 t/ha of grain (8). Further detailed studies on water management under the various canal systems of Tamil Nadu are needed for effective management of the ratoon crop with economic utilization of the surplus water available in the single-crop lowlands.

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Scope for rice ratoon cropping in the northeastern hill region of India

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ABSTRACT

Rice-growing conditions in the northeastern hill region are evaluated. There is considerable scope for ratooning ahu rice (April/May-July). However, growing a ratoon crop from sali (July-Nov) rice is not feasible because of drought and low temperature in the ratoon crop season. Lowland boro (Dec-May) rice also cannot be ratooned because of water stagnation. Work needed includes surveys of potential areas for ratoon rice, development of high ratooning varieties for particular land types, and evolution of location-specific agronomic practices.

The northeastern hill region of India, comprising seven states — Arunachal Pradesh, Assam, Meghalaya, Manipur, Nagaland, Mizoram, and Tripura — has diverse rice-growing situations. This paper gives background on rice cultivation and evaluates the scope for ratoon cropping in the region.

THE TERRAIN

In the hilly terrain of the northeastern region, rice is usually grown in valley bottoms and on the lower terraces of the hill slopes with fair moisture regimes. Maize is grown on the middle terraces with low moisture regimes, *ragi* (finger millet) and sesame on the upper terraces with poor moisture regimes, and forests on the hill tops. In other areas of northeastern India such as Assam, extensive plains are available for growing lowland rice. Some of these areas are flood-prone, but most of the plains are flood-free and sometimes suffer drought. Even in low-lying areas depending on the distribution of monsoon rain, drought prevails in the premonsoon and postmonsoon periods.

RICE GROWING SEASONS

Normally there are three well-defined rice growing seasons in the plains of this region:

Ahu rice - from March/April to July
Sali rice - from June/ July to November
Boro rice - from November to May

On the lower terrains and on steep slopes in the hilly areas, boro rice is not grown because of severe drought and low temperatures. Both ahu and sali crops are grown in varying proportions, depending on the topographic situation, climatic conditions, and local preferences.

Monocropping with rice

In the entire northeast region of India, rice is mainly grown once a year; 2 crops of rice are grown, following the ahu-sali sequence, on only about 20% of the plains area.

In hilly regions, ahu rice is more important. Sowing is usually from mid-April to mid-May, using premonsoon showers. Before April, temperatures are very low and timely rainfall is not assured, discouraging earlier sowing. Such delayed sowing of ahu rice makes it difficult to grow a sali rice crop after it on the same field. Thus, single-cropping of rice, either ahu or sali, prevails in the hilly regions. Table 1 lists area, production, and yields of rice in the northeastern hill region.

RICE VARIETIES AND LAND TYPES

Jhum land

In hilly areas where *jhum* (slash-and-bum) cultivation is practiced, local varieties such as Pawnbuh in Mizoram; Jatri, Popy, Soiki, and Yabar in Arunachal Pradesh;

Table 1. Area, production, and yields of rice in northeastern India, 1979-80.[a]

State		Ahu rice (Mar-Jul)	Sali rice (Jun/July-Nov)	Boro rice (Nov-May)	Total
Arunachal Pradesh	A	56.7	–	–	56.7
	P	78.0	–	–	78.0
	Y	1.38	–	–	1.38
Assam	A	513.9	1579.8	33.9	2127.6
	P	277.0	1562.3	37.1	1876.4
	Y	0.54	0.99	1.09	0.89
Manipur	A	33.0	122.2	–	155.2
	P	46.5	181.0	–	227.5
	Y	1.41	1.48	–	1.47
Meghalaya	A	30.5	70.1	1.6	102.2
	P	27.6	94.3	3.0	124.9
	Y	0.90	1.34	1.87	1.22
Mizoram	A	22.0	41.2	–	63.2
	P	6.8	12.7	–	19.5
	Y	0.31	0.31	–	0.31
Nagaland	A	37.3	35.6	–	72.9
	P	34.5	42.0	–	76.5
	Y	0.92	1.18	–	1.05
Tripura	A	80.0	140.9	33.4	254.3
	P	82.0	166.8	42.4	291.2
	Y	1.02	1.18	1.27	1.14
Total	A	773.4	1989.8	68.9	2832.1
	P	552.4	2059.1	42.4	2694.7
	Y	0.71	1.03	1.27	0.95

[a]A = area (thousand ha), P = production (thousand t), Y = yield (t/ha).

and CR 238-3-2-99 in Meghalaya, Manipur, and Sikkim are grown at altitudes of 200-1,000 m.

Valleys

Rice varieties grown in the valleys vary with altitude:

Up to 800 m	*800-1,300 m*	*Above 1,300 m*
Jaya, IR8, IR24, Rasi, CR 142-3-8, IR36, Sattari, Ngoba, Subhadra, Pijum, and BM 2060	Pusa 33, Ch 1039, Ch 988, IR238-3-249, ITB 2, Pawnbuh, AP-30, Ngoba, and Phulbuh	Khonorullu Local promising varieties Immo Elang, Qat Pyapu, and Impoare

Plains

On the plains, for example, in Assam, both local and high-yielding varieties are grown.

POSSIBILITY OF RATOON CROPPING

For hilly regions, where low temperatures prevail, the main crop should be harvested not later than August, so that a ratoon crop can be harvested in another 2 or 2-1/2 mo. But, where photoperiod-sensitive and long-duration varieties are grown to be harvested by the end of November, ratoon cropping from sali stubble is not possible because of drought and cold.

Boro rice is grown in low-lying areas where winter water is available for irrigation whenever needed. In such areas, premonsoon showers, particularly in April-May, cause water stagnation, which precludes the possibility of ratoon cropping from boro stubble.

In the plains, where temperatures are high and photoperiod-insensitive varieties are grown in normal or late-sown ahu rice, ratoon rice could be successfully grown, provided the main crop is harvested no later than September.

CONDITIONS FAVORING RATOON CROPPING

In areas where only ahu rice is grown, as in Arunachal Pradesh, there is a distinct possibility of raising a ratoon crop from the stubble.

In the entire northeastern rice areas of Assam, ratoon culture from ahu stubble may form an alternative rice production strategy. During the monsoon (Jul-Aug), land preparation for the sali crop is very difficult because postharvest operations of the ahu crop overlap land preparation and transplanting of the sali crop. Ratoon cropping from ahu stubble would free more labor during peak demand for such activities as threshing, drying, etc.

Farmers of the northeastern hill region are generally poor. Because of a shortage of bullock power, double-cropping is difficult. Ratoon cropping of rice may be an alternative.

EXPERIMENTS ON RATOON CROPPING

In areas where the ahu-sali sequence is maintained, the sali crop yield is very low, rarely exceeding 2 t/ha.

But our studies (3) revealed that the most promising ratoon variety, C-3810, a derivative of Manila × IR22, produced a yield of 4 t/ha for the main crop and 2 t/ha for the ratoon crop in 179 d. Further studies the following year confirmed the stability of the ratoon yield for this variety.

Thus, ratooning the ahu crop would be more profitable, giving higher total yields of main plus ratoon crop, than late-planting a sali crop. Moreover, ratoon yields would be obtained at little added labor cost.

On the other hand, early harvest of the ratoon crop would allow for timely planting of dry-season crops like wheat, rapeseed, and legumes in the same field. Such a three-crop sequence might be difficult with a sali main crop of rice in the sequence.

Studies on cutting heights for ratoon cropping showed that ratoon yields remained about the same for cutting heights from 15 to 45 cm; below 15 cm, ratoon yields declined drastically.

CONCLUSION

On the whole, there appears to be distinct scope for rice ratoon cropping in the northeastern region. However, we need to

- survey the areas where ratoon cropping can be fitted profitably into the cropping sequence of the region;
- identify suitable high-ratooning varieties for different types of land, emphasizing conversion of single-cropped ahu rice to double-cropped areas; and
- evolve location-specific agronomic measures for stabilizing ratoon yields at a high level.

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Scope for rice ratoon cropping in the central and northern belts of India

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ABSTRACT

The prospects for rice ratoon cropping in the central and northern belts of India are assessed in light of two critical requirements: water and suitable temperatures. Experimental evidence indicates the possibility of growing a ratoon crop of summer rice, which at present is grown only in small areas due to lack of irrigation. In areas following the sequence summer rice - kharif (rainy season) rice - wheat, kharif rice may be replaced, at least partially, by a ratoon crop of the summer rice. A summer rice ratoon crop could also be taken between the two rice crops by shifting the transplanting of kharif (photoperiod-sensitive) rice to a later date, using a system known locally as *kharuhan* (where seedlings are transplanted from the first nursery into a second nursery before final transplanting in the field) or older healthy seedlings. Where land needs to be vacated by September for early planting of winter crops (early potatoes, chillies, *Brassica campestris* var. *toria,* berseem or *Trifolium alexandrinum* chillies, sugarcane, winter maize), a summer rice ratoon may find a place in the cropping system. Ratoon rice cropping of early-maturing kharif rice also appears feasible, provided varieties possess some cold tolerance at heading. Rice varieties harvested in November-December cannot be ratooned because of low winter temperatures and demand on the land for wheat cultivation. Ratoon cropping of boro (November-May) rice grown in flood-affected low-lying areas and the mid-lowlands of Katihar and Purnea Districts of Bihar and parts of West Bengal and northeastern India needs to be tried. Cropping patterns involving ratooning must, to be successful, give the farmer advantages over existing ones in terms of better profits and reduced labor requirements.

Rice ratoon cropping is not practiced in the central and northern belts of India at present. Reports on rice ratoon cropping in the literature are scarce. Although sporadic attempts have been made to study the possibility of rice ratoon cropping in northeastern India, no systematic and sustained efforts have been made so far to explore the feasibility of introducing rice ratooning in these areas. However, on the basis of prevailing rice farming practices and limited experimental data on rice ratooning, this paper suggests areas where rice ratooning might be possible.

EXPERIMENTS ON RICE RATOONING

Ratoon of summer rice

Saran et al (2) tested the performance of photoperiod-insensitive varieties during the summer season (March to July) at Dholi, in northern Bihar, and observed that immediately after the harvest in July, all these varieties developed fresh vegetative growth. They allowed the tillers to grow and recorded the yields. Taichung Native-1 as a summer main crop gave significantly higher yield than SL016 and N22 (Table 1). Taichung Native-1 gave yields 4.7% higher than NC1626, 8.8% higher than T21, and 12% higher than N136. But the same set of varieties behaved differently in the ratoon culture, where T21 was significantly superior in yield to the other varieties. Ratoon duration of the ratoon crop was less than half that of the main crop. However, ratoon crop yields were poor compared with main crop yields.

My associates and I conducted a trial on summer rice varieties Pusa 221, Pusa 33, CR44-35, NC1626, IET 1444, and C8585 at the Rajendra Agricultural University Farm, Pusa (North Bihar), in 1979 and studied the tiller regeneration ability of these varieties. The soil of the experimental plot was calcareous silt loam of medium fertility, pH 8.7, and EC 1.20 mmhos/cm at 25 °C. Seed was sown on 16 Mar and seedlings transplanted at 15 × 15 cm spacing on 19 Apr. The main crop received 120-18-17 kg NPK/ha. C8585 was harvested on 16 Jul, NC1626 on 19 Jul, leaving a 15 cm stubble from ground level. Other varieties were harvested 1 wk earlier. The ratoon crop was hand weeded 15 d after the main crop was harvested and topdressed with 20 kg N/ha. The field remained saturated with occasional flooding. Only the ratoon crops of NC1626 (intermediate) and C8585 (semidwarf) were harvested: the other varieties showed poor tiller regeneration ability and their yields were not recorded.

The C8585 ratoon yielded 31% of the main crop yield; NC1626, 24% of the main crop (Table 2). Total main and ratoon crop yields, however, were higher in NC1626. The height of the ratoon crop was 25% shorter than that of the main crop. Panicle-bearing shoots/ hill of the ratoon seemed to be positively correlated with the number of panicle-bearing shoots/ hill of the main crop. The reduction in number of ripened grains/panicle of the ratoon was more pronounced (20-26%) than panicle

Table 1. Grain yield and duration of photoperiod-insensitive summer rice varieties and their ratoons, Dholi (North Bihar), India, 1969.

Variety	Grain yield (t/ha)			Days to maturity	
	Summer crop	Ratoon crop	Total	Summer crop	Ratoon crop
NC1626	3.93	0.76	4.69	137	59
T21	3.76	1.54	5.30	143	68
SL016	3.17	0.34	3.51	143	59
N22	3.38	0.71	4.09	138	59
N136	3.63	0.53	4.16	134	59
Taichung Native-1	4.13	0.63	4.76	138	59
Mean	3.66	0.75	4.41		
CD (0.05)	0.59	0.29			

Table 2. Grain yield, yield attributes, and other plant characters of main and ratoon crops of two shortduration summer rices, Pusa (North Bihar), India, 1979.

Variety	Grain yield (t/ha)	Plant ht (cm)	Panicles/m^{2a}	Grains/ panicle	Panicle lenth (cm)	1000-grain weight (g)	Duration (d)
NC1626 main crop	4.1	131	444 (10)	95	20.5	21.6	125
NC1626 ratoon crop	1.0	102	222 (5)	76	18.2	20.5	54
C8585 main crop	3.5	90	488 (11)	84	19.1	19.8	122
C8585 ratoon crop	1.1	65	311 (7)	62	17.5	19.2	52

[a]Figures in parentheses indicate number of panicles/hill.

length reduction (8-11%). The ratoon crop matured 70 d earlier and had lower grain weight than the main crop.

Ratoon of autumn rice

Saran and Prasad (1) conducted experiments at Sabour (South Bihar plain) to determine the height at which the autumn rice should be harvested for a good ratoon. The photoperiod-insensitive variety, CH10, was harvested at different heights (Table 3) on 8 Oct. Soon after the harvest, the plots were irrigated and weeded and tillers were allowed to grow. Except the shoots which developed from the first node and those which came up from the underground nodes, all others in the various treatments flowered in about 2 wk from harvest. Flowering in shoots from the first and underground nodes was irregular and grain setting was poor. The ratoon crop was harvested on 17 Nov to vacate the land for wheat sowing. The duration of ratoon of winter rice was only one-third (40 days from date of sowing) that of the main crop.

The highest ratoon yield — 0.57 t/ ha, or about 3 1% of the main crop yield - was obtained with the main crop harvested at half its height (Table 3). Plant height, panicle length, spikelet size, number of fertile shoots, and grain setting were all lower in the ratoon crop, but seed viability was unaffected.

SCOPE OF RICE RATOON CROPPING

The most important requirements for ratoon cropping are assured irrigation and optimum temperature; the scope for rice ratoon cropping in central and northern belts of India must be assessed with these requirements in view.

In kharif (the rainy season), medium- and long-duration (photoperiod-sensitive) varieties are grown on upland, medium land, and lowland, respectively, mostly under rainfed conditions. Only 20-30% of the rice area has irrigation facilities.

The bulk of the rice area in these regions falls under aman rice, which is generally transplanted in July and harvested in December, when temperatures drop much lower than are suitable for a ratoon crop (Table 4). Besides, the land vacated by aman rice is planted to wheat; thus, there is no possibility of taking a ratoon crop of aman rice in these areas.

Table 3. Effect of stubble height of main rice crop (CH10) on the yield of its ratoon, Sabour (Bihar), India, 1952.

Treatment	Grain yield (t/ha)	
	Main crop	Ratoon crop
Harvested close to ground	1.83	0.07
Harvested at 15 cm above ground (height at which crop is ordinarily harvested)	1.79	0.27
Harvested at half the crop height about 36 cm above ground)	1.81	0.57
The panicles were picked Only panicles were harvested	1.82	0.50

Table 4. Normal mean daily maximum and minimum temperatures and mean daily relative humidity at 0830 h on the Bihar plains, India.

Month	Temperature (°C)		Relative humidity (%)
	Max	Min	
Jan	23.2	9.3	75
Feb	25.6	11.6	72
Mar	32.1	16.1	57
Apr	37.1	21.5	52
May	37.1	24.7	53
Jun	34.8	26.1	75
Jul	32.5	26.2	82
Aug	31.9	26.0	83
Sep	32.0	25.5	81
Oct	31.3	21.6	72
Nov	27.9	14.5	68
Dec	24.2	9.8	69

The high-yielding varieties of medium- and long-duration (130-150 d) rice are generally harvested by 15 Nov. Tillers do regenerate but die out with a fall in temperature.

However, early-maturing varieties (100-115 d), transplanted in July and harvested the first week of October (autumn rice), have produced ratoon tillers which yielded around 31% of the main crop yield (Table 4). It might be possible to take a ratoon crop (40-45 d) of transplanted early rice varieties under irrigation before wheat sowing. The rice varieties, however, should possess some cold tolerance at heading.

Experimental results indicate that ratoon cropping after summer rice has good promise (Table 1, 2), because temperatures remain favorable for crop growth (Table 4). Irrigation costs on the ratoon crop would be reduced substantially by monsoon rain. Such a ratoon cropping would also relieve pressure on labor during the peak transplanting period in July and permit timely transplanting of the remaining rice area with the limited manpower available.

Unfortunately, the area under summer rice is hardly 2-4% (or even less) of the total rice area. With improvement in power supply and canal water supply, the area under summer rice would increase and this in turn may brighten the prospects for rice ratooning.

In case of continuous rains in July, the grains of summer rice germinate on the panicle itself. Evolving summer varieties with at least 15 d seed dormancy would be a step toward increasing the area under summer rice and thereby increasing the scope for rice ratooning.

I explored the possibility of growing three consecutive crops of rice followed by wheat in a multiple cropping sequence in north Bihar. Three crops of rice were taken in succession between April and November. The first crop (CR44–35) was transplanted on 6 Apr using 35-d-old seedlings; harvested on 30 Jun, it yielded 4 t/ha. The second crop (Pusa 33), transplanted on 4 Sep, yielded 3.5 t/ha. For the third crop, 60-d-old normal and double-transplanted seedlings of BR8 (photoperiod-sensitive) were transplanted at closer spacing (15 × 10 cm). The crop was harvested on 30 Nov (vacating the land for the succeeding wheat crop) and the double transplanted *(kharuhan)* rice crop yielded about 4 t/ha.

The farmers' acceptance of the new cropping pattern rice (summer) -rice (early kharif) -rice (late kharif) - wheat is, however, yet to be ascertained. Ratoon cropping after summer rice may replace the transplanted early kharif rice and make the above newly developed cropping pattern less labor-intensive and acceptable to farmers.

In some areas, a rice (summer) - rice (kharif) -wheat rotation is followed: here, ratoon cropping of summer rice may replace kharif rice, provided yields and economics of the two remain comparable. In another situation, farmers wish to get their land vacated by September for early planting of winter crops like early potato, chillies, autumn-planted sugarcane, winter maize, pea, toria *(Brassica campestris* var. *toria),* berseem (Egyptian cloves), and winter vegetable. They often do so by advancing the date of sowing/ transplanting of early kharif rice by a month or so. Growing of summer rice and its ratoon in such a situation would increase the total rice production without affecting timely planting of winter crops.

Summer rice and its ratoon may also find place in flood-affected areas like West Champaran District in Bihar. Seedlings of newly transplanted tall indica rice get uprooted by the swift current of the floodwater from rivulets originating from the nearby mountains. A rice ratoon crop, because of its good anchorage, may resist uprooting by the swift current.

There are some winter rice (locally called boro) areas in which ratoon cropping might be possible. In Purnea and Katihar Districts of Bihar and parts of West Bengal, winter rice (photoperiod-insensitive) is becoming popular. There are some waterlogged areas in this belt where kharif and rabi (winter-spring) crops are not feasible. In these areas, seeds of winter rice are sown in the nursery-bed in October, when temperatures are favorable for seedling growth. Seedlings are allowed to remain in the nursery-bed until December and transplanted in January. The seedlings pick up growth with the rise in temperature, and the crop matures by the end of May. It is possible to take a ratoon of this winter rice between June and July, before the land is again flooded. In these areas, winter rice is being taken even on medium lowlands. Seedlings of winter rice are transplanted in January-February and harvested in May-June and then tall indica rice is transplanted in standing water in July. Hence, it might be possible to take a ratoon crop of winter rice in between two rice crops.

In multiple cropping areas, working out the economics of rice ratoon cropping alone would not be enough; rather, each cropping pattern that will involve rice ratoon needs to be compared (as a whole) with existing cropping patterns in these areas, to assess the scope for increasing ratoon rice cropping.

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Potential of rice ratooning in Madagascar

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ABSTRACT

Madagascar has some excellent environments for ratoon cropping. Because the per capita consumption of rice is one of the world's highest and because there is need for higher rice production to feed the growing population and to decrease rice imports, ratoon cropping may play an important role. In the high plateau where low temperature prevails after main crop harvest, farmers are interested in ratoon straw yield for cattle fodder. In some areas of Mananjary on the east coast, farmers use a variety called Mampana for ratoon cropping. Some research work done in the past is reported in this paper. Potential local and introduced germplasm are also given.

Madagascar is the fourth biggest island in the world, about 600,000 m^2 in area. It is situated between 12° and 26º south of equator and 43° and 55° east. It is about 400 km east of African coast. Rice is the staple food of the people. It has played a most important role in the socioeconomic development of this country. About 1.2 million hectares are under cultivation and average yield is 1.8 t/ha. The population, which is about 9.5 million, is growing rapidly, resulting in a shortage of rice in the local market. The per capita consumption of rice in Madagascar is the world's highest, about 150 kg. From a rice exporting country, Madagascar has become a net importing country since 1973.

Rice has been cultivated for centuries in Madagascar and has a complex history of introduction, adoption, and dissemination from the coastal area to the high plateau with very specialized type of cultivation. Wild rice species such as *Oryza sativa* Linn (red rice), *O. longistaminata* A. Chev., *O. perennis* Moench., and *O. barthii* A. Chev. occur naturally in the Alaotra, Marovoay, and East coast regions, and were certainly not introduced by immigrants to this country.

The extremely wide diversity of eco-edaphic regions, climatic variations, cropping systems, and cropping seasons has led to a correspondingly broad variability within the traditional rice varieties in Madagascar. Rice planting and harvesting are a continuous phenomenon from the coastal area to the high plateau. This has resulted in the absence of a clearly defined rice harvesting season. The different season crops are locally called *asara, atriatry, jeby, aloha, siha,*

vakiambiaty, hosy, vatomandry, gondra, tsipala, ririnina, and *asarake* in different regions of Madagascar and generally different varieties and different lands are used. These local terms can be broadly translated as first, intermediate, and second-season rice crops; slash-and-bum type (tavy); and upland rainfed (tanety) rice crops.

Madagascar has tremendous potential for increasing rice production and could become a top exporter of rice in Africa in the future.

PREVIOUS WORK ON RICE RATOONING

Although little work has been done on ratoon cropping in Madagascar, literature is available in report form from Lac Alaotra region (786 m), where testing for ratoon cropping was carried out by Arraudeau and Dechanet (1) from 1960 to 1963. They tested some varieties during a 3-yr period. No. 34 (Makalioka local selection) and Chianung 8 were kept as control without ratooning and Taichung 150, Kameji, No. 1300, Shinei, Tomoe Masari, Toyokekari, and Shintsu were ratooned in replicated trials. Ratoon crop yields ranged from 301 kg/ha for Toyokekari to 961 kg/ha for Taichung 150. The main crop and ratoon crop yields of these varieties could not surpass the yields of Chianung 8 (5.3 t/ha) and No. 34 (7.4 t/ha). Other studies showed that short-duration (122-146 d) Taiwanese and japonica varieties produced higher ratoon yields. than long-duration checks Chianung 8 (153 d) and No. 34 (176 d). The total yield ranged from 2.0 t/ha for Shintsu to 7.4 t/ha for No. 34. Taichung 150 gave a total yield (main crop and ratoon crop) of 5.03 t/ha.

Arraudeau and Dechanet concluded that the role of short-duration varieties is important because harvest is in March when rice is scarce and expensive as compared with No. 34 which is harvested in April-May. These early varieties can be used for ratoon yield. However, the ratoon crop yields were not superior to those of No. 34 in quality and quantity, and bird damage was considerable.

Dobos (3) also studied ratooning of rice at Lac Alaotra. He used 6 varieties, in 5 replications, 2 cutting heights of main crop, and 100 kg N/ha for the main crop and 40 kg N/ha for the ratoon crop.

He concluded that 5 cm cutting height produced more homogeneous and synchronous ratoons than 30 cm. Kaoshung 21 was best for fodder crop yield.

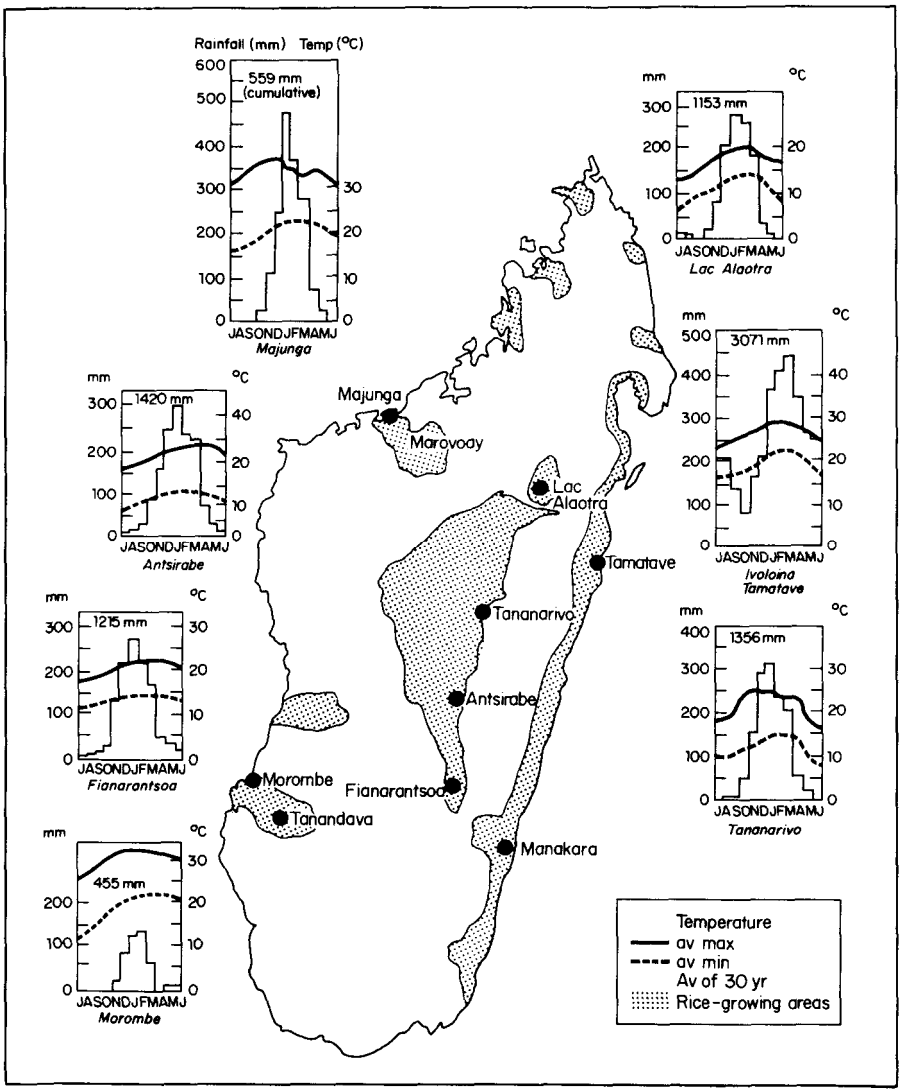
Denton (2) mentioned that local variety Mampana is used for ratoon cropping in Marozafy village in Mananjary area in the southeast coast. The variety is seeded in November and December, transplanted in February, and harvested in April and May.

POSSIBLE AREAS

There are several areas where ratoon cropping can be practiced in Madagascar (Fig. 1) but the following three areas could be more important in near future, with proper varietal selection.

1. Marovoay region. Total rice area in this region is about 30,000 ha. Three types of rice culture are grown in the area.

a. Asara, grown during December to May when rainfall is high and many areas are flooded. Although altitude is low (20 m) and temperatures are favorable, main constraint is water management.
b. Atriatry, grown between February and August. The ratoon crop could suffer from drought.
c. Jeby, grown between April and October. With appropriate varieties, a ratoon crop which can mature before heavy rain comes could be grown. With varietal selection for deep water tolerance and tiller regeneration



1. Rainfall distribution and temperature range in several major rice-producing areas of Madagascar.

ability, a ratoon crop is possible during this season. Average maximum and minimum temperatures throughout the year remain between 24.3 and 29.3 °C.

2. High plateau. This is a large area of about 300,000 ha. Some intermediate hill valleys can grow a ratoon crop of rice, especially in an area around the national capital, where they grow a first crop called varyaloha (April-February). An additional ratoon crop could be possible with Taiwanese and japonica type varieties. The main problem is excessive water accumulation in low-lying areas and low temperatures. In some valleys in the high plateau, especially in the Manjakandriana area, farmers demand ratooning varieties for animal feed. Lowland fields are mostly monocropped because of poor drainage. It seems that the demand for palatable rice ratoon fodder is growing and this can be met to a certain extent by selecting vigorous ratooning types. In this area temperature is not enough for panicle formation because the rice crop is harvested during April and temperature goes down fast beginning in May.

Animal population in Madagascar is around 10 million, mostly zebu (cattle). Only with the varyaloha crop which is harvested during February is a ratoon crop possible because the temperature is right for panicle maturity. Average maximum and minimum temperatures range between 14.9 and 21.1 °C and reasonable vegetative growth of ratoons can be maintained.

3. East Coast. The East Coast is blessed with good temperature and heavy rainfall. Annual rainfall is about 3,500 mm in 241 d per year and it gradually decreases toward the south; in Manankara it is about 2,700 mm. Average maximum and minimum monthly temperatures range between 21.6 and 26.3 °C. Farmers grow excellent crop of vary-tavy (slash-and-burn upland) where there is no moisture stress. The area under different systems of culture is about 250,000 ha. This includes a vatomandry or rainy-season crop grown between December and May and a dry-season crop hosy grown between June and November in Manankara and Mananjary region in the east-south coast. In Manankara, Soanierana-Ivongo, Sainte-Marie, Ivoloina, Brick-a-ville, and Mahanoro in the Tamatave region, two crops of lowland rice are grown. They are the rainy-season crop called asarake, grown between October and April, and ririnina, grown between May and November. Often, the second-season crop or the dry-season crop of some varieties is left for ratooning. The east coast region can indeed be a good crop growing area with appropriate varieties and management practices. The east coast is also dotted by slash-and-burn (vary-tavy) upland rice; generally small hillocks (shifting cultivation) are used where water does not accumulate. Conventional upland rice is also grown on level surfaces.

POSSIBLE VARIETIES

Varietal requirements for the high plateau, the west coast, and the east coast differ because of different ecological conditions in the regions. Cold-tolerant, short-duration, blast-resistant varieties with good ratooning ability are needed for the high

Table 1. Main and ratoon crop yields and green straw yields of six rice varieties at Lac Alaotra, Madagascar (adapted from Dobos [3]).

Variety	Yield (t/ha)	Ratoon crop yield (t/ha)	Duration of ratoon crop (d)	Yield of green straw (t/ha)
Kaoshung 21	5.6	–	81	3.4
Nahda-11	3.9	2.2	94	1.6
No. 1300 (1 cal)	2.4	1.2	99	2.2
No. 1300/Taichung-150	2.9	1.6	94	2.0
No. 1300/Shinei	2.5	1.7	94	2.0
IR356-1-46B-4-6-18	3.2	5.0	99	3.0

Table 2. Ratooning ability of three rice varieties grown in varyaloha (Apr-Feb) season around Antananarivo (average of 10 hills in farmer's field).

Variety	Tillers (no.)	Ratoons (no.)
Rojofotsy (local)	10.5	8.0
Rojofotsy mixture	6.8	3.8
No. 1300 (japonica type)	19.4	20.1

Table 3. Local varieties mentioned as good for ratooning in different regions.

Variety	Region	Culture type
Rojofotsy	Antananarivo	Varyaloha
Mangakely	Antananarivo	Varyaloha
Botohavana	Antananarivo	Varyaloha
Chianung-8	Antananarivo	Vakiambiaty
Tsipala	Marovoay	Jeby
Kalila	Marovoay	Jeby
Andramota	Marovoay	Jeby
Mampana	Mananjary (East coast)	Hosy
Tsimatahotrosa	Mananjary (East coast)	Jeby
Eengiza	Mananjary (East coast)	Jeby

plateau. Not all areas in the high plateau can grow a ratoon crop, but some mid-altitude (800-1,200 m) valleys can grow ratoon crops as fodder for animals. Varieties mentioned in Tables 1 and 2 can be used with proper management practices.

Varieties for Marovoay region should have deepwater tolerance and good ratooning ability for the jeby season culture. Some local varieties such as Tsipala, Kalila, and Andramota can be used and some new tropical varieties such as IR44, TNAU 13613, CR 156-5021-207, and IET 3600 can be tested. Some of these varieties are mentioned in Table 2.

Varieties for the east coast need special consideration because rainfall is higher toward the north than the southeast. The temperature is most ideal for rice cultivation. In some areas a ratoon crop could produce as much as the main crop with fertilizer management and varietal selection. Varieties should have strong dormancy, and disease and insect resistance. The east coast is known for pests and

iron toxicity. As mentioned earlier, Denton (2) observed some local varieties being grown in ratoon cropping in Madagascar. There is need to survey these areas in greater detail. Some of the local varieties mentioned in Table 3 can be used with newly introduced varieties and supplemented by the following varieties — CICA-4, IR2061-462-2, IR2061-632-3-1, Intan, Labelle, IR4722-36-1, Milbuen 5, and IR2058-78-1-3-2-3.

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Potential for rice ratooning in eastern India, with special reference to photoperiod-sensitive rices for deepwater areas

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ABSTRACT

Ratooning photoperiod-sensitive rice varieties in deepwater areas of eastern India may reduce crop loss from frequent floods or rainwater accumulation. Rice varieties suitable for these areas should have photoperiod sensitivity, semidwarf plant type with elongation ability or flood tolerance, fertilizer responsiveness, tolerance for moisture stress, and good ratooning ability. In experiments at Chinsurah and Kalyani, West Bengal, India, the ratoon crop of photoperiod-sensitive rice grown in the dry season yielded well in the wet season. The F_2 segregates of a few crosses indicated that ratoon characters may be accumulated in high yielding varieties. Although the ratoon crop yielded less than the main dry season crop, its growth and yield were equal to those of a normally sown crop in the wet season. Maximum yields of main crop and ratoon crop were obtained when complete fertilizer was applied at 100 kg N, 22 kg P, and 42 kg K/ha. Cold temperatures in December reduced yields of the wet season ratoon crop harvested from November to February.

Rice cultivation on 1,599,000 ha of lowland deepwater areas (70-100 cm) in eastern India is unpredictable because sudden floods or water accumulation damages the crop in various growth phases. Ratooning of photoperiod-sensitive rice varieties, which can be grown twice a year in identical photoperiods, may greatly reduce the crop loss on about 500,000 ha. A suitable ratoon variety for the area should have the following characteristics (1):

- photoperiod sensitivity with a high yielding background,
- fertilizer responsiveness with main crop yield of 4-5 t/ha in the dry season,
- photoperiod-sensitive ratoon that remains in the vegetative stage from April to August,
- good ratooning ability and vigorous growth during premonsoon rains,
- some degree of drought and submergence tolerance or elongation ability for the ratoon, and
- resistance to viral diseases.

At the Rice Research Station, Chinsurah (22° 52'N), and Bidhan Chandra Krishi Viswa Vidyalaya, Kalyani (23 °N), experiments were conducted to determine the possibility of ratoon cultivation for lowland, deepwater areas. This paper discusses the results of those experiments.

FLOWERING BEHAVIOR

Photoperiod-sensitive rice during dry season

Most of the photoperiod-sensitive rice varieties flower at the end of March or April when they are sown in November. The flowering behavior of a few tall, photoperiod-sensitive varieties grown at Chinsurah from 1980 to 1985 showed considerable variation in heading time. During 1983-84, varieties FR13A, SR26B, Achra 108/1, and Tillakkachari did not flower (Table 1) because of low temperature (9.8-12.9 °C) that prevailed from 22 Feb to 7 Mar. A high degree of flowering stability with various photoperiod sensitivity-low temperature interactions is an essential trait for dry-season, photoperiod-sensitive varieties.

Ratooned photoperiod-sensitive varieties

Six photoperiod-sensitive, traditional, lowland varieties (NC365, FR13A, Achra 108/1, Nagra 41/14, SR26B, and Bansmoti aman) were sown the first week of November 1980. All flowered between late March and early April. Each variety was ratooned at maturity in May. The ratoon crop of FR13A, SR26B, and Achra 108/1 showed a burst of flowering in early June. NC365 and Bansmoti aman ratoon crop did not flower until October. Nagra 41/14 ratoon crop flowered irregularly throughout the growing period (Fig. 1). All the other varieties showed further vegetative growth and flowered the third week of October. The same varieties sown in July also flowered during the same period (Table 2).

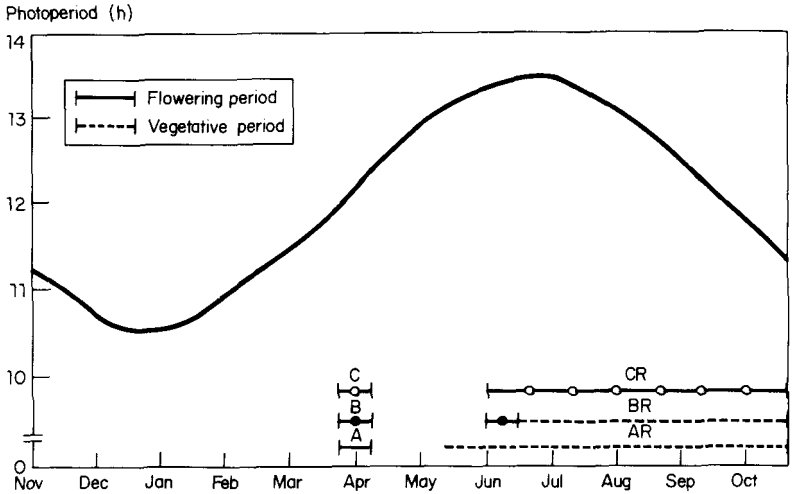
Ratoon of F_2 segregates

The flowering behavior of F_2 generations of FR13A, Achra 108/1, IR36, and IR50 crosses was tested under November sowing and October ratooning.

Table 1. Flowering behavior of some lowland photoperiod-sensitive rice varieties during dry season, Chinsurah (22°52'N).

Variety	Flowering date				
	1980-81	81-82	82-83	83-84	84-85
NC365	28 Mar	30 Mar	27 Mar	9 Apr	25 Mar
Bansmoti aman	24 Mar	3 Apr	24 Mar	13 Apr	3 Apr
FR13A	6 Apr	8 Apr	3 Apr	NF	9 Apr
SR26B	4 Apr	6 Apr	9 Apr	NF	7 Apr
Achra108/1	10 Apr	13 Apr	9 Apr	NF	14 Apr
Tillakkachari	17 Apr	17 Apr	12 Apr	NF	18 Apr
Bhasamanik	–	27 Apr	20 Apr	25 Apr	–
Nagra 41/14	8 Apr	12 Apr	11 Apr	14 Apr	–
Kumargore	7 Apr	5 Apr	28 Mar	NF	8 Apr

NF = did not flower.



1. Flowering behavior of photoperiod-sensitive rice varieties and their ratoon crops under different photoperiods, A = NC 365, B = ACHRA 108/1, C + NAGRA 41/14, R = ratoons.

Table 2. Flowering behavior of photoperiod-sensitive rice varieties and their ratoon crops.

Variety	Main crop 50% flowering	Ratoon flowering 1st flush	Growth phase (Jun-Sep)	Ratoon flowering, full 2nd flush	Normal sown (July) full flowering
NC365	28 Mar	nil	Vegetative	24 Oct	25 Oct
Bansmoti aman	24 Mar	nil	Vegetative	22 Oct	22 Oct
SR268	4 Apr	1-7 Jun 90%	Vegetative[a]	22 Oct	25 Oct
Achral08/1	6 Apr	1-7 Jun 30%	Vegetative[a]	22 Oct	24 Oct
FR13A	6 Apr	6-15 Jun	Vegetative[a]	22 Oct	24 Oct
Negra 41/14	8 Apr	Jun-Oct irregular	Flowering	–	23 Oct

[a]= after flowering, 1st flush showed further vegetative growth.

The pregerminated seeds of the crosses were sown 15 Nov 1983 and transplanted mid-January 1984. Plants that flowered by April were ratooned in May. Plants still at the vegetative stage in April were uprooted. Plants showing intermediate flowering between July and September and those that flowered in October were separated (Table 3). Thirty-six to fifty percent of the plants obtained from different crosses flowered twice under similar daylength (11 h, 30 min, excluding twilight). The prospect of obtaining those types of plants is almost similar in short daylength sensitive crosses or in short daylength sensitive - insensitive crosses. Crosses between two insensitive types faded to produce desirable plants.

RATOONING ABILITY

Photoperiod-sensitive rice varieties

The prospect of a successful ratoon cultivation depends largely on the ratooning ability of a variety. Among the F_2 segregates of crosses between ratooning and

Table 3. Flowering behavior of F_2 segregates and their ratoons.

Crosses	Total plants	Plants flowering in Mar-Apr (no.)	Ratoon plants flowering in Oct		Plants flowering in intermediate months (July through September)	
			No.	%	No.	%
FR13A/Achra108/1	106	88	44	50	44	50
FR13A/IR36	106	102	42	41	60	59
FR13A/IR50	106	103	48	47	55	53
Achra108/1/IR36	106	96	35	36	61	63
Achra108/1/IR50	106	102	40	39	62	61
IR36/IR50	106	106	–	–	–	–

Table 4. Ratooning ability of some rice varieties, Chinsurah 1981-82.

Variety	Photoperiod sensitivity[a]	Hills with ratoons (%)	
		8 cm	12 cm
SR26B	S	97	97
NC1263	S	92	96
NC365	S	94	92
Achra108/1	S	97	88
Tillakkachari	S	96	85
Bhasamanik	S	94	87
Bansmoti aman	S	88	89
Latisail	S	76	85
FR13A	S	86	76
Kumargore	S	71	52
IR36	i	61	61
	Mean	87	83
	CD (0.05)	27	28
Pooled variety		587.25**[b]	
Pooled cutting height		200.0*	
Pooled variety cutting height		45.67	
Pooled error		35.64	

[a]S = photoperiod-sensitive, I = photoperiod-insensitive. [b]Two asterisks indicate significance at the 1% level.

nonratooning rices, segregates that flowered in 65-100 d and late-maturing segregates had higher ratooning ability (1, 4). The ratooning ability of 10 photoperiod-sensitive rice varieties at cutting heights of 8 and 12 cm aboveground was studied at Chinsurah during 1981-82 dry season.

Pregerminated seeds were sown 14 Nov 1981 and transplanted 4 Jan 1982. Main crop harvest was completed by May. Ratooning ability was scored 15 d after harvest at available soil moisture. Photoperiod-sensitive varieties had higher ratooning ability and cutting height did not significantly affect ratooning ability (Table 4). Prashar (5) reported ratoon tillers increased when the main crop was cut from ground level up to 12 cm, but declined at cutting height beyond 12 cm. This genotypic variability for ratooning could be utilized for improving the ratooning ability of rice (3).

RATOON YIELDS

Yield-contributing characters

The yield of ratoon crop compared to the main crop is another important criterion for ratoon cultivation. The total yielding ability (main crop and ratoon crop) of three photoperiod-sensitive rice varieties, namely, FR13A, SR26B, and Achra 108/1, were studied along with yield components such as plant height, tiller number, and panicle length. The main crop was sown 15 Nov in 1980 and in 1981. The late main crops were harvested in May and the ratoon crops were harvested in December. Plant height was higher in the ratoon crop than in the main crop in all varieties, but differences in effective tillers and panicle length were small (Table 5). There was no association between main crop yield and ratoon crop yield. Low mean yield of the main crop during 198 1-82 was caused by severe drought during flowering and grain filling (Table 6).

Ratooned rice and normal sown aman rice

Ratooned and normal sown aman rice–varieties were compared. Photoperiod-sensitive rice varieties SR26B, FR13A, Tillakkachari, and Achra l08/1 were sown 14 Nov 198 1 and harvested in May 1982. Ratooned tillers were allowed to dry in the field. The same varieties were sown 17 Jul 1982 and their performance was compared with that of the ratoon crop. Ratooned Tillakkachari and Achra 108/1 yielded more than the aman-sown crop (Table 7). The mean yield of the ratoon crop equaled that of the sown crop, indicating the suitability of wet season ratooning in lowlands where sudden floods or water stagnation hinders growth of the freshly planted crop.

Table 5. Average plant height, tiller, number and panicle length in main (M) and ratoon (R) crops of three photoperiod-sensitive rice varieties, Chinsurah, 1980-82.

Variety	Plant ht (cm)		Tillers (no.)		Panicle length (cm)	
	M	R	M	R	M	R
FR13A	120	154	9	9	28	25
SR26B	136	172	9	7	26	27
Achra108/1	129	185	8	8	26	28

Table 6. Yield of main (M) and ratoon (R) crops of four photoperiod-sensitive rice varieties.

Variety	1980-81 yield (t/ha)		1981-82 yield (t/ha)	
	M	R	M	R
Tillakkachari	–	–	2.6	4.4
Achra108/1	4.9	3.1	2.6	4.7
SR26B	4.3	3.0	2.8	3.2
FR13A	3.2	2.5	1.6	3.0

Table 7. Comparison of photoperiod-sensitive ratoon crop and normal aman rice crop.

Variety	Aman-sown rice				Ratoon crop			
	Plant ht (cm)	Panicle length (cm)	Tiller (no.)	Yield (t/ha)	Plant ht (cm)	Panicle length (cm)	Tiller (no.)	Yield (t/ha)
SR26B	146	22	7	3.7	158	24	11	2.5
FR13A	113	22	8	3.8	146	25	11	3.0
Tiliakkachari	142	24	9	3.8	170	26	13	5.0
Achra108/1	132	25	7	3.9	170	27	11	4.8
Mean	133	23	8	3.7	161	26	12	3.8

FERTILIZER RESPONSE OF MAIN AND RATOON CROPS

A field experiment was conducted at Bidhan Chandra Krishi Viswa Vidyalaya, West Bengal, in dry season (ratoon crop in 1983-84), to study the effect of major nutrients on growth and yield of the main crop and the ratoon crop of some photoperiod-sensitive traditional types and photoperiod-insensitive HYVs.

Growth

The varieties IR36, IR50, CR1014, and Kumargore were transplanted in January with four fertilizer treatments: 100 kg N/ha, 100 kg N and 22 kg P/ha, 100 kg N and 42 kg K/ha, and 100 kg N, 22 kg P, and 42 kg K/ha. Immediately after main crop harvest, all plots received 20 kg N/ ha followed by an additional 10 kg N/ha 60 d later.

Main crop yields of Kumargore and CR1014 were appreciably lower than those of IR50 and IR36 in the dry season (Table 8). This was because the number of matured panicles was lower in the photoperiod-sensitive Kumargore and CR1014 than in the photoperiod-insensitive IR36 and IR50. The ratoon crop yields of IR36 and IR50 were appreciably lower than their main crop yields but the ratoon yields of CR1014 and Kumargore were only slightly lower. The IR50 ratoon crop yielded more than IR36; on par with Kumargore and CR1014. Panicle initiation in IR50 and IR36 was 30 d after main crop harvest. Yield was recorded as the sum total of matured panicles collected at 15-20 d intervals. Kumargore and CR1014 partially lodged in wet season after 30 kg N/ha was applied after main crop harvest. The number of grains per panicle and 1,000-grain wt of IR36 and IR50 were appreciably reduced in the ratoon crop, but not as much as in the CR1014 and Kumargore ratoon crop.

Ratoon cropping of the dry season crop of IR36 and IR50 was not feasible agronomically because of staggered maturity of the panicles. The yields of Kumargore and CR1014 were also less than those of the HYVs. The residual effect of phosphorus was not significant in the dry-season crop. There is, however, a need for varieties and management practices to raise total yield of the ratoon and the main crops in West Bengal lowlands, where fields are waterlogged for long periods in the wet season and a dry season crop is possible by tapping nearby water resources.

Table 8. Effect of different fertilizer combinations and varieties on the growth and yield of main and ratoon rice crops, Kalyani, 1983-84.

Treatment	Grain yield (kg/ha)	Panicles /m^2	Grains/ panicle	1000-grain wt (g)	Duration (days)		
					Vegetative	Reproductive	Total
Main crop (dry season)							
100 kg N/ha	3194.0	251	74	19.90			
100 kg N/ha, 22 kg P/ha	3757.0	313	85	20.56			
100 kg N/ha, 42 kg K/ha	3315.0	244	76	19.99			
100 kg N/ha, 22 kg P/ha, 42 kg K/ha	3936.0	327	91	20.62			
SE ±	119.3	14.1	2.3	0.09			
CD (0.05)	413.7	48.7	7.9	0.31			
IR50	5314.0	417	89	21.70	93	60	153
IR36	5073.0	399	83	20.93	93	60	153
CR1014	1620.0	197	90	14.97	113	60	173
Kumargore	2195.0	284	84	23.48	113	60	173
SE ±	73.8	13.2	2.1	0.16			
CD (0.05)	215.3	38.4	6.2	0.46			
Ratoon crop (wet season)							
100 kg N/ha	1457.0	272	62	18.51			
100 kg N/ha, 22 kg P/ha	1826.0	325	76	19.36			
100 kg N/ha, 42 kg K/ha	1617.0	278	66	18.56			
100 kg N/ha, 22 kg P/ha, 42 kg K/ha	1800.0	319	74	19.04			
SE ±	312.0	18.2	3.2	0.22			
CD (0.05)	107.90	–	–	–			
IR50	1736.0	312	51	18.59	30[a]	60	90
IR36	1403.0	302	49	18.37	30[a]	60	90
CR1014	1737.0	292	91	16.01	110	60	170
Kumargore	1679.0	288	87	22.49	110	60	170
SE f	719.1	11.4	3.4	0.24			
CD (0.05)	57.6	–	9.9	0.71			

[a] Flowering began 30 d after main crop harvest; however, bulk harvesting was 90 d after main crop harvest.

Yield

In lowlands of West Bengal, two transplanted crops (one in the wet season and one in the dry) are usually grown. No crop is grown for the 2-3 mo (November-February) between the two rice crops. Ratooning provides the potential for another crop during that short period.

Yield and yield components in ratoons of HYVs were tested in the wet and dry seasons at Bidanchandra Krishi Viswa Vidyalaya. Short-duration varieties in wet-season ratoon yielded little and the late-maturing IR42 yielded nothing because of the low December temperature (Table 9). Yield components such as panicles per hill and filled grain wt were nearly equal to those of the wet season crop (2).

CONCLUSION

Ratooning rices in the semideep and deepwater areas has a potential for high yield with low cultivation cost. Further studies are needed on:

Table 9. Grain yield and yield components of ratoon rice.[a]

Variety	Grain yield (t/ha)		Panicled hill		Filled grains/ hill		1000-grain wt (g)	
	WS	DS	WS	DS	WS	DS	WS	DS
IET2683	0.2	0.3	3	7	22 (9)	52 (71)	22.8	20.1
IET1444	0.2	0.4	3	7	22 (9)	35 (74)	21.0	20.5
IR579	0.2	0.4	6	7	19 (45)	43 (79)	20.4	20.0
IR36	0.2	0.4	7	9	23 (57)	41 (62)	21.4	20.8
IR42	–	0.5	4	4	39 (36)	42 (57)	21.4	21.7
SE ±	90	50	0.4	0.8	1.4	3.4	0.6	0.7
CD (0.05)	–	150	1.2	2.3	4.2	9.9	1.9	2.0

[a] WS = wet season, DS = dry season. Figures in parentheses are percentages of filled grain.

- breeding and isolation of photoperiod-sensitive HYVs tolerant of low temperature in their vegetative and reproductive stages,
- lodging resistance under fertilizer application,
- cost-benefit ratio of supplemental irrigation to the ratoon crop, and
- ratoon crop insect pests and diseases.

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Ratooning in Bangladesh: prospects and potentials

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ABSTRACT

Agroecological conditions in Bangladesh are divided into three distinct rice cropping seasons, with cropping patterns to fit particular agroclimatic regions. Rainfed and irrigated rice-based cropping systems have developed where monthly total rainfall is favorable and in locations with assured irrigation. Crop intensification by ratoon cultivation is one way to secure more food production in Bangladesh, but its prospects are restricted by unfavorable weather during the boro season. However, prospects for ratoon cultivation during aus, after the boro harvest, as well as during transplanted aman after aus harvest might be feasible. High-yielding, good-ratooning boro and aus varieties are needed. Pajam II and IR50 produced good numbers of ratoons and yielded 1.1-2.4 t/ha after boro and aus. Traditional deepwater rice areas are converting to irrigated boro followed by fallow, late-seeded, or transplanted deepwater rice. If deepwater rice varieties with good ratooning ability could be developed, with the capability of producing high yields for boro cultivation followed by ratooning, deepwater rice areas presently fallow could be brought into production.

The cultivable land in densely populated tropical Asia is already being farmed. In fact, the agricultural land area is gradually decreasing as land is diverted to nonagricultural uses. At the same time, rapid population growth is increasing day-to-day food demands. To meet these increasing demands, food production will have to increase by intensifying land use and by increasing yields.

Rice ratooning saves time and production costs and could increase productivity where irrigation facilities are limited or when a fallow period exists between crops.

In recent years, farmers in many countries have begun rice ratooning. The practice can be successful if soil moisture is available for at least a month after the main crop harvest (7). Ratoon growth will vary with internal and external conditions (4): food reserves in the stubble, number and vigor of resting buds, number and condition of rice plant roots, mineral nutrient status in the field, and water management. External conditions, such as agroclimatic factors, also affect rice ratooning capacity.

CLIMATE OF BANGLADESH

Bangladesh is situated between latitude 20.50°N and 26.20°N and longitude 88.50°E and 92.50°E. The significant variation in temperature, humidity, rainfall, and solar

radiation is typical of such subtropical locations. During winter (Nov-Feb), minimum temperatures are about 9 °C and maximums about 27 °C. Relative humidity remains fairly low during winter, but is often above 95% during summer. Average annual rainfall is 2,100 mm, with significant variation by district, month, and year.

In the northern region (Rajshahi, Pabna, Dinajpur, Rangpur, and Bogra districts), average high temperatures are 33-38 °C April-May; average rainfall is 234.4 mm during June. In the eastern region (Comilla, Sylhet, and Chittagong districts), average temperatures are 27-31°C during April-May and average rainfall is 379 mm during June-July.

In the southern region (Sonagazi, Barisal, and Khulna districts), average high temperatures are 32-36 °C during April-May; rainfall is 724 mm at Sonagazi and 399 mm at Barisal in August.

RICE CULTIVATION IN BANGLADESH

Rice is cultivated on about 10.6 million ha (Table 1). Modern varieties are grown on about 2.79 million ha (26.3%). Pajam is grown on 0.6 million ha (5.7%) and local varieties (including b. aman) are grown on the remaining 7.21 million ha (68%).

Rice is cultivated in three seasons: boro (Nov-Apr), aus (Apr-Aug), and t. aman (Jul-Nov). About 1.21 million ha (77%) of boro land, 0.65 million ha (22.1%) of aus land, and 0.93 million ha (20.9%) oft. aman land are planted to MVs.

Broadcast aman (deepwater rice) is grown on about 18% of the total riceland. As the irrigated land area increases (Table 2), the deepwater rice area is decreasing, from 1.82 million ha in 1975 to 1.3 million ha in 1985 (2).

Table 1. Area planted to modern rice varieties, Bangladesh, 1985.

Season	Area planted (million ha)			
	MVs	Local	Pajam	Total
Boro	1.21	0.54	0.15	1.90
Aus	0.65	2.29	–	2.94
T. aman	0.93	3.07	0.45	4.45
Total	2.79	5.90	0.60	9.29
B. aman	–	1.31	–	1.31

Table 2. Distribution of total irrigated lands under rice cultivation and total broadcast aman, by season, Bangladesh, 1980-83.

Year	Total cropped area (ha)	Total irrigated area (ha)			Total broadcast aman area (ha)
		Boro	Aus	T. aman	
1979-80	–	1,008,806	91,919	128,650	1,615,789
1980-81	9,565,992	998,988	119,749	140,498	1,595,546
1981-82	9,587,854	1,042,123	113,089	184,387	1,586,640
1982-83	9,613,765	1,140,399	125,350	194.352	1,547,368

Source: Bureau of Statistics.

RATOON CULTIVATION CONSTRAINTS

Rice ratooning has not yet been accepted in Bangladesh. The major constraints are:

- lack of good ratooning varieties,
- lack of dependable irrigation water sources,
- poor grain quality,
- low yields of ratoon crops,
- insect and disease problems,
- low temperature following t. aman harvest,
- higher labor costs for harvesting a main crop that will be ratooned, and
- lack of attractive income potential from ratooning.

POTENTIAL FOR RATOONING THE BORO MAIN CROP

Ratooning of the boro crop offers the most attractive opportunity. Boro is generally harvested in April and May, when the average minimum temperature is about 27 °C and the maximum 37 °C, and when total rainfall varies from a minimum of 200 mm to a maximum of 800 mm/mo (Fig. 1).

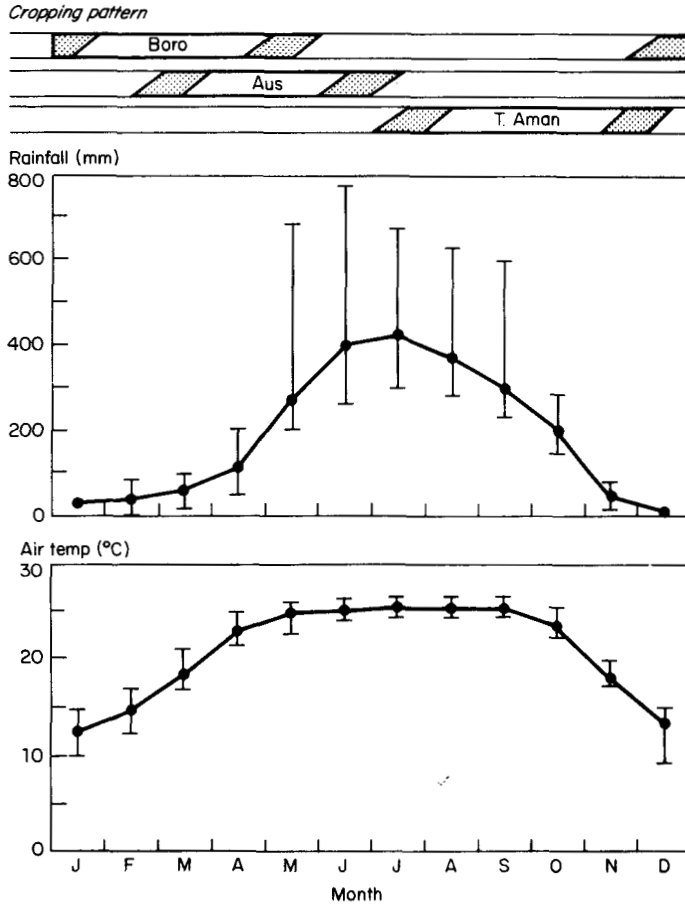
Rainfall after the boro harvest is an important determinant of ratooning potential. All boro rice is irrigated, with the water usually delivered on contract. After boro harvest, the irrigation contracts end when pumps and tubewells are decommissioned. Then, land is either prepared for transplant aus rice, planted to green manure, transplanted to b. aman, or kept fallow for a single t. aman crop (Table 3). Farmers could grow ratoon rice on flood-free sites as an alternative to green manure or fallow during the early aus season, if a good-ratooning, high-yielding boro variety were available.

A recent study of the grain yield potential of main crop, relay crop, and ratoon crop in boro and aus examined the total productivity of a given area. Combinations

Table 3. Agroeconomic productivity of long-term irrigated rice-based cropping patterns at different agroclimatic regions of Bangladesh.

Boro	Aus	T. aman	Total field duration (d)	Yield (t/ha)			Total net return (Tk/ha)[a]
				Boro	T. aus	T. aman	
			Joydebpur				
BR3 –	Green manure	– BR4	288	5.2	–	4.4	28887
Gram –	BR3	– BR11	308	0.8	4.9	4.6	44200
Wheat –	BR1	– BR10	308	3.1	2.8	4.7	43775
BR3 –	Fallow	– Pajam	245	4.5	–	3.8	24780
			Rajshahi				
BR1 –	BR1	– BR10	273	3.1	2.8	4.2	42968
Wheat –	BR1	– BR10	316	3.4	3.6	4.5	56956
BR3 –	Green manure	– BR11	238	6.0	–	5.0	50997
			Comilla				
BR3 –	Fallow	– BR11	–	6.0	–	5.2	25673
Gram –	BR9	– BR11	–	0.5	3.1	4.7	10983
Wheat –	BR9	– BR11	–	1.1	3.5	4.4	10651

[a]Price of crops at time of harvest: BR1 = Tk.5.30/kg, BR3 = Tk.5.35/kg, BR4 = Tk.5.80/kg, BR10 = Tk.580/kg, BR11 = Tk.5.80/kg, Pajam = Tk.6.00/kg, Wheat = Tk.5.40/kg, Gram = Tk. 10.00/kg. 1 US$ = Tk.30.35 (as of July 1986).



1. Rice cropping season based on monthly average maximum rainfall and minimum air temperature in lowland areas.

of main, relay, and ratoon crops of BR3, Pajam II, and Baspati varieties were tested. When ratooning was tested, the main crop was harvested at 15 cm stubble height.

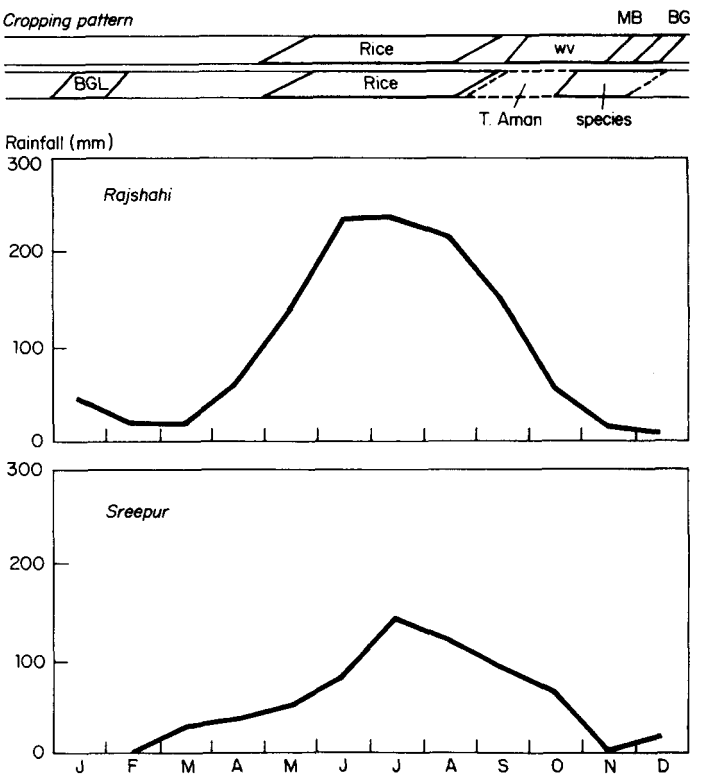
The combination of main boro crop followed by ratoon crop produced the lowest yield. But, it occupied the field only 130 d. Main crop with no ratoon produced the highest yield, followed by combinations of main crops ratooned, then relayed (Table 4). Highest ratoon yield (2.4 t/ha) was obtained from Pajam II (improved variety), followed by Baspati (local variety) (1). Two main crops during boro and aus do not allow optimal t. aman yields. Boro, ratoon aus, and t. aman might be a good pattern with boro and t. aman as the main crops.

POTENTIAL FOR RATOONING THE AUS MAIN CROP

After aus harvest, about 85% of the cultivated land is transplanted to aman rice (Fig. 1, 2). There is little scope for ratooning the aus crop because the crop itself generally has a low yield.

Table 4. Grain yields of main crop and ratoon crop grown during boro and aus seasons.

Cropping pattern			Grain yield (t/ha)				Growth duration (d)
Boro		Aus	Boro	Aus	Ratoon	Total	
BR3	–	BR3	6.7	3.7	–	10.4	245
BR3	–	Ratoon	6.1	–	0.0	6.1	130
BR3	–	Ratoon + BR3 relayed	6.3	1.8	0.0	8.1	253
Pajam	–	Pajam	6.3	3.4	–	9.7	270
Pajam	–	Ratoon	5.9	–	2.4	8.3	221
Pajam	–	Ratoon + Pajam relayed	5.7	1.7	1.8	9.2	260
Baspatl	–	Baspati	4.3	2.6	–	6.9	257
Baspatl	–	Ratoon	4.9	–	1.6	6.5	202
Baspatl	–	Ratoon + Bsspati	4.2	0.8	1.2	6.2	244



2. Rice-based cropping patterns based on monthly average maximum rainfall in upland areas.

Ratooning of BRI and IR50 grown as main aus crops, followed by relay-transplanted BR11 and IR50 varieties during aman under rainfed conditions, was studied. The aus main crop was harvested in August, leaving 15 cm stubble. Early in September, aman seedlings were transplanted between the ratoon hills, as a relay crop (Table 5). The highest ratoon yield (1.1 t/ha) was obtained with IR50. The single t. aman yield (without relay with ratoon) was higher than the ratoon crop with

Table 5. Average yields of ratoon rice, ratoon + t. aman relayed, and single t. aman late planted after aus harvest.

Cropping pattern	Aus harvest date	Ratoon		Ratoon + t. aman relayed		Single t. aman	
		Duration (d)	Yield (t/ha)[a]	Yield (t/ha)	Production cost (Tk./ha)[b]	Yield (t/ha)	Production cost (Tk/ha)[b]
Boro – Aus – Ratoon + t. aman							
Fallow – BR1 – BR11	25 Aug	61	0.2	2.6 (a) A	3,531	2.7 (a) A	3,714
Fallow – IR50 – BR11	15 Aug	55	0.8	2.1 (B) B	3,361	3.4 (a) A	3,714
Fallow – BR1 – IR50	8 Sep	56	0.2	1.8 (b) B	3,531	2.7 (a) E	3,714
Fallow – IR50 – BR11	3 Aug	52	0.1	2.1 (a) B	3,381	2.2 (a) E	3,714

[a]In a column, figures followed by the same capital letter are not significantly different. In a row, figures followed by the same lowercase letter are not significantly different. [b]US$ = Tk.30.35.

t. aman relay (Table 5). The antagonistic relationship between ratoon yield and t. aman yield perhaps was because high ratoon growth suppressed growth of t. aman, reducing the aman yield.

In flood-free situations, where farmers plant early, high-value winter season crops after the aus harvest, ratooning modern variety, high-yielding aus rices may be possible (Fig. 2). Relatively high ratoon yields would be necessary to justify farmers' delaying the establishment of winter season vegetable crops.

NO POTENTIAL FOR RATOONING T. AMAN

Ratooning t. aman rice is not possible, because of low November-January temperatures and minimum December-January rainfall (Fig. 2). In the low December temperatures, some ratoon tillers failed to exert panicles above the flag leaf sheath (3). Also, ratooning during this period would encourage overwinter survival and multiplication of rice hispa populations, a serious insect pest of the aus crop.

POTENTIAL FOR RATOONING DEEPWATER RICE

As irrigation availability increases, the area planted for boro production is increasing and the deepwater rice area is decreasing. A large proportion of traditional deepwater riceland is being converted to irrigated boro rice. Transplanting b. aman or direct seeding pregerminated deepwater rice into the maturing boro crop is being practiced in many of these areas. However, these practices risk deepwater crop establishment (6).

High-yielding deepwater rice varieties are being tested during the boro season, with the expectation that subsequent ratooning could produce an effective stand capable of elongating as floodwaters rise during June and July. Initial results indicate that this strategy offers considerable potential. It may be possible to develop varieties with attractive boro yields that can produce an adequate number of ratoon tillers with elongating capability to establish a deepwater crop. This use of ratooning seems to offer potential for increasing production of deepwater rice after boro, recovering some of the production lost to reduced hectarage during recent years.

OTHER FACTORS AFFECTING RATOONING POTENTIAL

A ratoon crop usually attracts more insect pests than the main crop. Insects may find the succulent growth of the ratoon plant attractive, especially when alternative foods are not available.

When a crop to be ratooned is harvested, it is important to avoid damaging the roots. This precaution may increase labor costs. For a successful ratoon crop, a vigorous main crop root system may be a prerequisite (5).

About 0.6 million ha (40% of the total boro area) could be considered flood free and the rice crop could be ratooned. But the question is whether the total 0.6 million ha are really in rice. About 20% of that area every year is planted to crops other than rice (wheat, gram, etc.). About 480 thousand ha is subdivided into different agroclimatic regions that are not equally suitable for rainfed rice crops. The cultivable lands available for ratooning are about 32% of the total boro land (4.5% of the total), limiting the prospect of rice ratooning with available varieties and production practices.

CONCLUSION

Of the three rice seasons in Bangladesh, ratooning the boro harvest seems most attractive and feasible. Good-ratooning, high-yielding boro varieties must be identified, developed, and made available to farmers.

Pajam II and IR50 might be used as boro and aus season varieties with ratoon potential. In flood-free boro areas where boro and t. aman are the current main crops, a ratoon crop after boro harvest might provide additional yield without hampering t. aman cultivation.

Deepwater varieties for boro main crop which can produce an adequate number of ratoon tillers with elongating capacity to establish a ratoon crop would increase production and recover some of the production from hectarage lost during recent years.

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Use of ratooning in hybrid rice

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ABSTRACT

The adoption of hybrid rice depends on the relative cost of the hybrid seed versus the economic gain obtained by cultivating a hybrid instead of a nonhybrid variety. A ratoon crop has short growth duration and low production costs and needs less irrigation water. Ratooning male-sterile, maintainer, and restorer lines would result in increased seed yield that could help reduce initial seed cost. Ratoon cropping then might also compensate for the extra cost of hybrid seed. The ratooning ability of 57 hybrids and 5 check varieties was evaluated in the 1983 dry season at IRRI; 14 hybrids and IR56 performed consistently well. Hybrid IR19657-34-2-2-3-3A/IR36 showed the highest regeneration and had the most tillers and panicles/m^2. Selecting parents with good ratooning ability is suggested for hybrid rice breeding programs.

Because there is little possibility for bringing more land under cultivation, crop intensification and higher yields seem to be the only research avenues open for scientists to bridge the increasing gap between food production and food demand. The world will need 30% more rice in the next decade; that rice has to be produced on the same amount of land. Higher yields can be obtained by adopting improved production technology — high yielding varieties and efficient use of land, water resources, fertilizers, and pesticides for better crop management.

Hybrid rice has a great potential for increasing rice productivity in certain areas. The success of hybrids in China encouraged the International Rice Research Institute (IRRI) to revive research on hybrid rice in 1979 (1) and to explore its potential and problems outside China. Several national rice improvement programs in India, Indonesia, Thailand, Bangladesh, Pakistan, Philippines, and the Republic of Korea have also shown interest in hybrid rice production technology (4).

The success of hybrid rice and its acceptance by farmers usually depends on the relative cost of the hybrid seed versus the economic gain obtained by cultivating a hybrid instead of a nonhybrid variety (4). Hybrid seed yields are very low (0.45-1.5 t/ha) in China. At IRRI, hybrid seed yields ranged from 0.02 to 0.62 t/ha in the wet season and 0.04 to 1.58 t/ha in the dry season (Table 1) (2).

Seed production depends on environment, management levels, male-sterile lines, and synchronization of A and B lines in the CMS reproduction plot. Such intensive efforts for such low seed yield result in high seed cost, estimated to be 3-4 times higher than seed costs of conventionally bred varieties.

Table 1. Hybrid seed yields obtained at IRRI farm. 1983-84.[a]

Season	Plot (no.)		Seed yield (t/ha)		Seed set (%)	
	A/B	A/R	A/B	A/R	A/B	AIR
1983 dry	6	16	0.06-0.60	0.19-1.58	11-13	19-43
1983 wet	13	17	0.01-0.07	0.07-0.62	5-17	4-23
1984 dry	14	22	0.04-0.84	0.04-1.02	3-35	3-38
1984 wet	16	17	0.01-0.18	0.02-0.23	5-10	3-15

[a]A/B = cms line multiplication plot, A/R = hybrid seed production plot.

About 8.8 million ha of irrigated land in China are planted to F_1 hybrids (5) that yield 20-30% more than the best semidwarf, nonhybrid varieties. IRRI studies have confirmed the superiority of hybrid over nonhybrid varieties. Hybrid rice has been found to have a stronger and more active root system and early seedling vigor and to utilize applied fertilizers more efficiently (3). The strong and deep root system should impart drought tolerance. This means hybrid rice should adapt well in rainfed lowland conditions in the tropics.

A successful ratoon crop from a hybrid rice crop grown in rainfed lowlands would be an additional advantage in production and might help compensate for the extra cost of hybrid seed. Ratooning has two possible uses in hybrid rice — seed production and higher total yield.

Hybrid seed production

The second flowering in the ratoon of the male-sterile (A) and maintainer (B) lines in the CMS reproduction plots can increase the seed yield of male-sterile lines. Ratooning restorer lines (R) and male-sterile lines in hybrid seed production plots would increase seed yield per se, an added advantage at no added cost. However, the potentials and problems of ratooning male-sterile, maintainer, and restorer lines need further study.

Ratooning hybrids

The feasibility of ratooning hybrid rice in the tropics has not been explored. In an experiment at IRRI, 57 rice hybrids and 5 check varieties were evaluated in the dry season (Jan-May) 1983. Three separate experiments studied hybrids of early, medium, and late maturity. The experiments were laid out in a randomized complete block design with 3 replications. Standard agronomic practices were followed on the main crop.

Hybrids and checks were ratooned by cutting the stalks 15 cm above the ground at maturity. Immediately after cutting, 40 kg N/ha was topdressed. The plots were irrigated as needed. Ratooning ability was rated 3 wk after cutting. Regeneration (%), plant height, and viral disease occurrence in the field were recorded.

Ratooning ability varied widely. IR56 and 14 hybrids performed well in 2 or more replications. Mean regeneration of hybrids varied from 62% for IR19657-34-2-2-3-3A/IR13146-45-2-3 to 97% for IR19657-34-2-2-3-3A/IR36 (Table 2). IR56 had 90-100% regeneration except in 1 plot, where regeneration was only 40-50%.

Table 2. Characters of rice hybrids screened for ratooning ability. IRRI, 1983 dry season.[a]

Hybrid, variety	Regeneration (%)	Plant ht (cm)	Total tillers (no./m^2)	Tillers (no./hill)	Total Panicles (no./m^2)	Panicles (no./hill)	Viral disease rating[b]
IR19657-34-2-2-3-3A/IR56	70	65	279	11	180	8	1
IR10154-23-3-3A/IR15795-232-3-3-2	69	51	323	13	149	6	1
IR56 (check)	81	62	284	10	179	6	0
IR19657-34-2-2-3-3A/IR36	97	65	515	15	423	12	1
IR19657-34-2-2-3-3A/IR48	81	60	389	14	145	6	0
IR19657-34-2-2-3-3A/IR19661-364–1-2-3	68	61	329	14	171	8	0
IR19657-34-2-2-3-3A/IR19735-5-2-3-2-1	93	64	485	15	420	13	0
IR19657-342-2-3-3A/IR19729-67-3	83	68	301	10	246	8	0
IR19657-34-2-2-3-3A/IR13146-45-2-3	62	58	325	15	401	18	0
IR19657-34-2-2-3-3A/IR10781-143-2-3	68	–	346	15	–	–	0
IR19799-17-3-1-1A/IR13420-6-3-3-1	a3	55	349	12	231	8	0
IR19799-17-3-1-lA/IR2797-125-3-2-2	81	70	353	12	274	10	1
IR56 (check)	93	60	348	11	294	9	0
MR365A/IR19661-364-1-2-3	68	69	327	14	218	9	0
MR365A/IR19661-131-1-2	64	67	337	15	213	10	0
MR365A/IR48	80	65	378	14	307	9	1
IR56 (check)	93	56	348	11	307	9	0

[a]Average of 3 replications. [b]0 = no incidence, 1 = less than 1% incidence (3).

Ratoon height varied from 51 to 70 cm, about 40-50% of the height of the main crop. Tillers/ m^2 ranged from 279 to 515; panicles/ m^2 varied from 145 to 401, IR19657-34-2-2-3-3A/IR36 had the most tillers and panicles/m^2. Hybrid IR19657-34-2-2-3-3A/ IR13146-45-2-3 showed the maximum panicles/ hill (18), whereas IR19657-34-2-2-3-3A/IR48 had the fewest panicles/hill(6). IR56, although it had very good regeneration, had only 10-11 tillers/ hill and 6-9 panicles/ hill. In some hybrids with relatively poor regeneration, missing hills were compensated for by many tillers and panicles per regenerated hill. Hybrid ratoons were more vigorous than those of IR56. Because the experiment was terminated before maturity. number of tillers and panicles/ m^2 may not reflect yield potential.

Judging from flowering time of the ratoons, it appears that hybrid ratoon growth duration would be 30-50% of main crop growth duration. Hybrids with good ratooning ability were observed in all three maturity groups. Hybrids with IR19657-34-2-2-3-3A in their parentage had high regeneration and vigorous ratoons.

Because the parents of the hybrids were not evaluated in the experiment, it is difficult to project the bases of good ratooning ability. Differential response of some hybrids and IR56 in different replications suggests that, in addition to genetic factors, cultural management factors may influence ratooning ability.

The studies suggest that it is possible to take an additional ratoon crop with little additional cost. It would save time, labor, and money. Although a ratoon crop will grow if only water is added, grain yield would be significantly higher if fertilizer also is added. In rainfed conditions, where yield levels are rather low, hybrid ratoon yields of 1.5-2.0 t/ha could cover the additional cost of hybrid seed. In breeding programs for hybrid rice, emphasis should be given to selecting parents with good ratooning ability.

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Ratooning with rice hybrids

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ABSTRACT

Simultaneous plot experiments and production demonstrations on ratooning with rice hybrids were conducted in Sichuan Province, China, from 1981 to 1985. To prolong land use and obtain high yields, hybrid rice combinations that give high main crop and ratoon crop yields are required, and cultural practices to increase the number of productive panicles and percentage of filled grains must be followed. Cultural practices recommended include 1) early sowing and harvesting of the main crop to insure that the ratoon crop escapes low temperature injury at heading, 2) applying N fertilizer 2 wk before main crop harvest, and 3) cutting the main crop at least 30 cm above ground at harvest. In a 1,350-ha demonstration area, average main crop yields (7.9t/ha) were as high as those of popular single crop hybrids and ratoon crop yields were 1.8 t/ha.

Rice ratooning is practiced in the tropics and subtropics. Rice farmers in the Yangtze River basin conventionally practice ratooning because of the shorter duration of the ratoon crop and lower labor and production costs. Chauhan et al (1) have reviewed the literature on varieties for ratooning and the biological mechanism and cultural factors affecting ratooning. Yang and his coworkers have comprehensively studied rice ratooning in Sichuan Province since 1937 (5-12). Since hybrid rice was developed in China in 1976, some workers have studied ratooning with hybrids (2, 13), but further research is needed.

There are about 800,000 ha of lowland rice below 400 m elevation in southeast Sichuan. Single crop rice is generally planted on more than 60% of the rainfed fields, which are flooded and fallowed in winter. About half are planted to hybrid rice. The field growth duration of hybrids is only 120 d, from mid-April to mid-August. During the rest of the year, the fields lie fallow in submergence, which is an inefficient use of natural resources.

This paper discusses the effect of hybrid rice ratooning on prolonging utilization of ricefields and increasing production, and the cultural factors that affect ratooning in southeast Sichuan.

VARIETIES AND CULTURAL PRACTICES

Coordinated trials of rice ratooning were conducted from 1981 to 1985 in southeast Sichuan. Through varietal screening and multilocation yield tests, the hybrids Zaishengyou, Aiyou I, Aiyou 2, and Shanyou 63 were identified as having good ratooning ability. Ratoon crop growth and development, yield, planting time, N fertilizer application, and cutting height were studied at five sites; production demonstrations with hybrid rice ratooning were conducted using test results.

Varieties

Multilocation ratooning yield trials were conducted in 1981-85. Some hybrid rices are not only high grain yielding but also have high ratooning ability (Table 1).

Zaishengyou (Chaoyang IA/ Taiguodaoxuan) was the best among the entries. Its main crop yield was comparable to that of the popular hybrid Shanyou 2, and it matured 4 d earlier. Yield components of the ratoon crop were 300 panicles/m^2, 60 spikelets/panicle, and about 80% filled grain. Its ratoon yield was higher and more stable than the others.

Aiyou 1 had wide adaptability, relatively high main crop yield, and rather strong ratooning ability. It has been adopted by many farmers.

Aiyou 2 ranked third in ratoon yield, but the main crop yield was low because of its low tolerance for high temperature at flowering. It seems unsuitable for ratoon cropping.

Shanyou 63, a hybrid rice resistant to blast disease, showed rather high ratooning ability. It yielded 7.6 t/ha in the main crop and 2.5 t/ha in the ratoon crop. It is extensively grown and we are promoting its use for rice ratooning.

Yield components

In 1981, Ren (3) analyzed ratoon grain yield of the hybrid Aiyou 2 in relation to the yield components: number of mature panicles, spikelets per panicle, filled spikelet percentage, and 1,000-grain weight. Mature panicles and percentage of filled spikelets were the principal factors affecting ratoon crop output. The correlation coefficients were 0.93** for number of panicles and 0.71** for percentage of filled

Table 1. Grain yields of main and ratoon crops of some rice varieties in Jiangjin, Sichuan, 1983.

Type	Variety	Grain yield (t/ha)[a]		
		Main crop	Ratoon crop	Total
Hybrid	Zaishengyou	8.0 a	3.0 a	11.0 a
Hybrid	Aiyou 1	6.8 b	1.7 bc	8.5 bc
Hybrid	Aiyou 2	6.7 b	2.6 ab	9.3 b
Hybrid	Shanyou 63	7.6 a	2.5	10.1
Hybrid	Shanyou 2	7.6 a	1.3 c	8.9 bc
Conventional	Zaishengai	5.2 c	2.7 ab	7.9 c
Conventional	Luke 3	6.3 b	2.0 bc	8.3 bc

[a]Av of 3 replications. Means in a column followed by the same letter are not significantly different at the 5% level.

grains. There were no significant correlations between the other components and ratoon grain yield. Early sprouting, formation of many good tillers, and early flowering favor ratoon cropping.

Rice ratoons emerge from dormant buds on the 2d, 3d, and 4th nodes from the top of mother culms. Some hybrids have a higher percentage of viable buds at ripening of the main crop. The viability of buds on each node varies. Normally, most buds on the 2d, 3d, and 4th nodes are viable, but on the 5th node, viability is about 70%.

Ratoon panicles from lower nodes produced more grains per panicle than those from upper nodes, but filled spikelet percentage decreased. Therefore, even if panicles from the 2d nodes produce fewer grains, their higher fertility means that a comparable number of filled grains are produced.

The contribution of different buds to ratoon yield varied considerably (Table 2). The contribution of 2d node tillers to total yield varied from 20 to 45% depending on the variety or conditions. The total contribution of the 2d and 3d node tillers was about 70%. To obtain high and stable ratoon yield, most ratoon panicles should be formed from buds of the 2d, 3d, and 4th nodes.

The yield components of the main crop and ratoon crop of Zaishengyou, which yielded 12.4 t/ha on a farmer's field in 1983, are shown in Table 3. Because recommended practices were carefully followed, there were 38% more ratoon panicles than in the main crop and fertility was nearly equal.

Ratoon panicle development and heading

Upper buds develop earlier and more uniformly than lower buds. Buds differentiated at each node of Zaishengyou and Aiyou 1 in the main crop at ripening. About 80% of the panicle primordia on the 2d to 4th nodes had developed. The young panicle development stage was from the first-bract primordium differentiation stage to the

Table 2. Contribution of different buds to ratoon yield, cutting height 40 cm.

Variety	Site	Yield (t/ha)	Yield contribution (%) of each bud (top to bottom)				
			2	3	4	5	6
Zaishengyou	Jiangjin	4.1	18	50	30	2	
Zaishengyou	Yongchuan	3.3	43	37	18	2	
Aiyou 1	Yongchuan	2.3	35	35	38	2	
Shanyou 63	Jiangjin	2.5	44	37	11	6	2

Table 3. Yield components of main and ratoon crops of Zaishengyou in 1983.

Crop	Spacing (cm)	Tillers/ m^2	Panicles/ m^2	Spikelets/ panicle	Filled spikelets (%)	1,000-grain wt (g)	Yield (t/ha)
Main[a]	30X 14	405	279	160	88	25	8.3
Ratoon		517	384	62	86	22	4.1

[a]Cut on 11 Aug at 43 cm above ground.

spikelet primordium differentiation stage; 6.9% of the buds on the 5th node of Aiyou 1 had developed at the first-bract primordium differentiation stage, but the bud on the 5th node of Zaishengyou had not. These results are consistent with those of Yang et a1 (8) who conducted similar studies on the conventional variety Shuibaitiao.

The duration from main crop harvest to heading of each ratoon tiller was in order of panicle development. The higher the bud position, the earlier the ratoon panicle matured (Table 4). When the main crop is cut high, most ratoon tillers grow from the 2d and 3d nodes of the main crop; the period from main crop harvest to ratoon crop heading is 30 d and to ripening 60 d.

Ratoons head in September when the air temperature begins to decline sharply. There was significant and positive correlation between decline in temperature from 25 to 20 °C and decline in percentage of fertility. It is believed that optimum daily mean temperature for good seed set in ratoons is 23 °C or more at flowering. In southeast Sichuan, the critical period in which mean temperature for 10 d is 23 °C ends around 10 Sep.

To ensure that the ratoon crop heads before the risk of cold damage, we recommend sowing the main crop in early March (I 5 d earlier than normal) and raising rice seedlings under polyethylene film. The main crop should have a growth duration of about 155 d to mature in early August; the ratoon crop should head in early September and mature in early October. Total growth duration of the main and ratoon crops should be 210-220 d.

Nitrogen fertilization of ratoon crop

In general, the ratoon crop was fertilized immediately after main crop harvest. Applying mineral N fertilizer before main crop harvest increased ratoon grain yield, but suppressed main crop yield (7, 11). We conducted N fertilizer trials on conventional and hybrid rices to determine the effect of N application before main crop harvest on main crop and ratoon crop yields.

Nitrogen was topdressed 14 d before main crop harvest at 0, 27, 54, and 81 kg N/ ha. Nitrogen fertilizer did not significantly affect the main crop yield or maturity, although it increased N metabolism at later growth stages, delayed leaf senescence, and promoted germination of dormant buds. Nitrogen content of the main crop stubble increased with increased N application at the main crop ripening stage

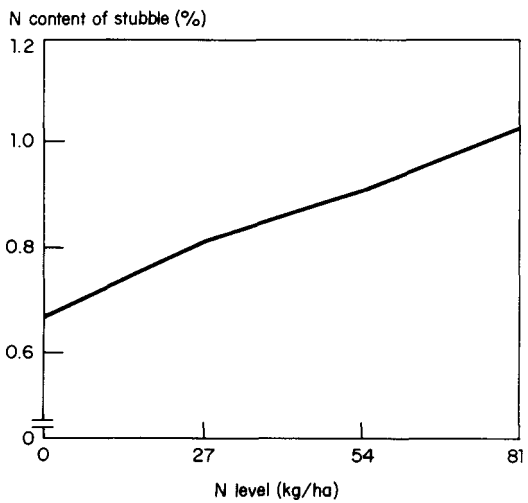
Table 4. Heading duration of each tiller grown from different buds of Zaishengyou in 1983.

Bud position (top to bottom)	Date of heading		Time (d) from main cut[a] to ratoon head	
	AV	Range	Av	Range
2	8 Sep	4-19 Sep	25	20-35
3	12 Sep	3-20 Sep	28	19-36
4	14 Sep	8-20 Sep	30	24-36
5	18 Sep	13-24 Sep	34	29-40

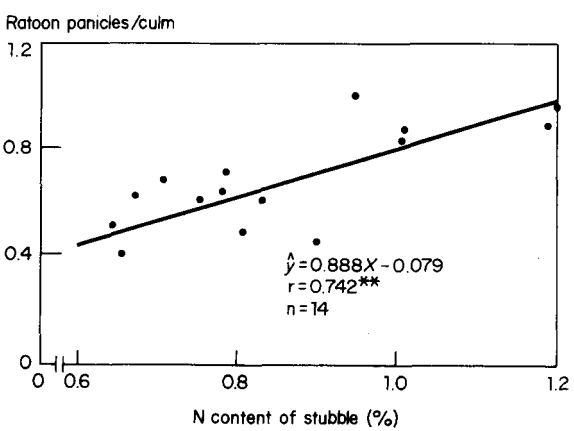
[a]Cut on 15 Aug at 40 cm above ground.

(Fig. l), soluble sugars decreased, and starch content increased slightly. Average bud length increased with N rate. Bud length was 2.3 cm with zero N, 3.9 cm with 27 kg N/ha, 6.3 cm with 54 kg N/ ha, and 6.6 cm with 81 kg N/ha. The relation between N content of main crop stubble and the number of ratoon panicles per culm is shown in Figure 2.

Sun et a1 (4) studied the effect of N level and time of application on the main and ratoon crops of variety Aiyou 2. N applied at 75 and 187.5 kg N/ ha increased main crop yield but had little effect on the ratoon crop. N applied before the main crop harvest (34.5 and 69 kg N/ha) did not affect main crop yield (Table 5), but produced significantly more ratoon tillers and panicles, resulting in higher ratoon crop yield. The yield difference between the two N levels, however, was not statistically significant. N application time for ratooning was 21 d (T1), 14 d (T2), and 7 d (T3) before main crop harvest. Ratoon tillers at T2 grew significantly more



1. Relation between N fertilizer applied to main crop 14 d before harvest and N content of main crop stubble.



2. Relation between N content of main crop stubble and effective panicles of ratoon crop.

Table 5. Effect of N level before main crop harvest on tillers, panicles, and ratoon crop yield of Aiyou 2, cut 40 cm above ground, 1981.

N level (kg/ha)	Tillers (no./m^2)	Panicles (no./m^2)	Yield (t/ha)[a]
69.0	435 a	306 a	2.9 a
34.5	360 b	277 a	2.7 a
0	230 c	192 b	1.9 b

[a]Av of 3 replications. Means in a column followed by the same letter are not significantly different at 5% level.

Table 6. Effect of cutting height on plant characters of ratoon crops of varieties Aiyou 2 (1981) and Zaishengyou (1983).

Character	Aiyou 2				Zaishengyou		
	26 cm	33 cm	40cm	43cm	23cm	33cm	43cm
Percent of 2d node cut					63	4	0
Heading date	26 Aug	21 Aug	19 Aug	19 Aug	10 Sep	6 Sep	2 Sep
Panicles/m^2	244	274	304	301	283	391	483
Spikelets/panicle	54	54	51	50	65	56	58
Filled spikelets (%)	79	76	80	87	85	86	87
1000-grain wt (g)	22	23	23	22	21	21	21
Yield (t/ha)	2.4	2.6	2.9	3.0	2.9	3.2	4.1
(%)	100	108	119	126	100	114	148

than those at T1 and T3. The yield of T2 was 4.4% higher than T1 and 5.2% higher than T3, but yield did not differ significantly.

In production trials, N rate and application time varied with soil fertility and main crop status. Generally, quick-acting N fertilizer at 35-70 kg N/ha was topdressed 2 wk before main crop harvest. No additional N fertilizer was necessary.

Cutting height

Cutting height determines the origin of the ratoon tiller and the growth duration of the ratoon crop. Most ratoon tillers of hybrid rice sprouted from the 2d, 3d, and 4th nodes of the main crop stubble and headed before low temperature in autumn.

When cutting height of the main crop ranged from 23 to 43 cm, the ratoon crop formed more panicles, matured earlier, had a higher percentage of filled grains, and higher yield (Table 6). The maximum yield increase from a 23 cm cutting height to 43 cm was 48%.

Height of the 2d node of variety Zaishengyou was 18-34 cm above ground; average height was 24.9 ± 3.9 cm. Furthermore, most of the 2d node remained by cutting above 33 cm (Table 6), which means that the optimum cutting height ranges from 30 to 40 cm.

PRODUCTION DEMONSTRATIONS

From 1983 to 1985, ratoon crops were obtained with hybrid rice on 1,346 ha, in Jiangjin, Yongchuan county, Sichuan. The average main crop yield was 7.9 t/ha

and the ratoon crop yield was 1.8 t/ha (9.7 t/ha total), 25.9% higher than a single crop of hybrid rice. Zaishengyou was planted on 216 ha. The main crop yield was 8.2 t/ha, the ratoon yield was 2.0 t/ha. Aiyou 1 was grown on 1,130 ha. The main crop yield was 7.9 t/ha, the ratoon yield was 1.7 t/ha.

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Agronomic principles and practices of rice ratooning

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ABSTRACT

Ratooning offers the possibility of economically increasing rice yields where opportunities to profitably grow a second rice crop or an upland crop do not exist. Although rice ratooning has been practiced in many countries, it has not been widely adopted because of low grain yields and other problems associated with its culture. Screening trials identified varieties with good ratoon yield potentials. Thorough and deep tillage in the main crop enhanced ratoon tillering. More dense main crop planting led to higher ratoon tiller populations. Higher cutting height (about 15 cm) increased tillering, shortened crop growth duration, and generally increased yield. Relatively low levels of N fertilizer application improved ratoon plant growth and grain yield. Delayed flooding (about 10 d after main crop cutting) considerably decreased proportion of missing hills, especially where stubble was cut at ground level. Weeds in the main and ratoon crop can be controlled by integrating cultural practices with herbicides. Insects and diseases common to the main and ratooned crops also can be controlled by using resistant varieties and appropriate insecticides. Effects of temperature and plant growth regulators were not consistent; further studies should examine growth regulators. Varieties with desirable ratooning ability and resistance to insect pests and diseases should be bred. Ratooning should be considered in the context of its economic viability in cropping systems.

Rice ratooning offers an opportunity to increase cropping intensity per unit of cultivated area because a ratoon crop has a shorter growth duration than a main crop (41, 43). In addition, a ratoon crop can be grown with 50-60% less labor. No land preparation nor planting is needed and the crop uses 60% less water than the main crop (10).

Rice ratooning has been practiced to some extent since 1927 (22) in the USA (12,16), India (5,18,40), Japan (30), Colombia (42), Swaziland (47), Thailand, and the Philippines (37). However, ratooning is practiced only in limited areas (4).

Although high yields have been recorded in some instances, ratoon crop yields are considerably lower than main crop yields (22, 41) or second transplanted or direct-seeded crop yields (4). Other constraints to adoption are lack of cultivars with good ratooning ability, lack of appropriate cultural practices, high insect and disease pressures, and lack of good investment returns because of low grain yield (41).

EFFECT OF ENVIRONMENT

Among the environmental factors affecting plant growth, temperature and light have been found to greatly influence ratooning performance, particularly tiller production.

Temperature

Among other plant traits, Ichii (26) studied differences in ratoon height and percentage of ratoon tillers/cut plant exposed to high (30 °C) or low (20 °C) temperatures (Fig. 1). He noted that the higher the temperature, the greater the ratoon plant height and percentage of tillers at early stages of development (5, 10, and 20 d after cutting). Maximum tillering was before 10 d at 30 °C and before 20 d at 20 °C.

However, temperature had a different effect on plant characters in later growth stages. Plants exposed to low temperature (20/20 °C) at booting formed 3 times more basal ratoon tillers than those exposed to high (35/27 °C) temperature and 2 times more than those exposed to normal (29/21 °C) temperature (41) (Table 1). Total and productive tillers were significantly higher under low than under normal temperature. However, grain yield at 20/20 °C was significantly lower than yields at high and normal temperatures because of high spikelet sterility, Temperature also affected ratoon growth duration. Crop maturity lengthened from 56 d at high temperature to 96 d at low temperature.

Light intensity

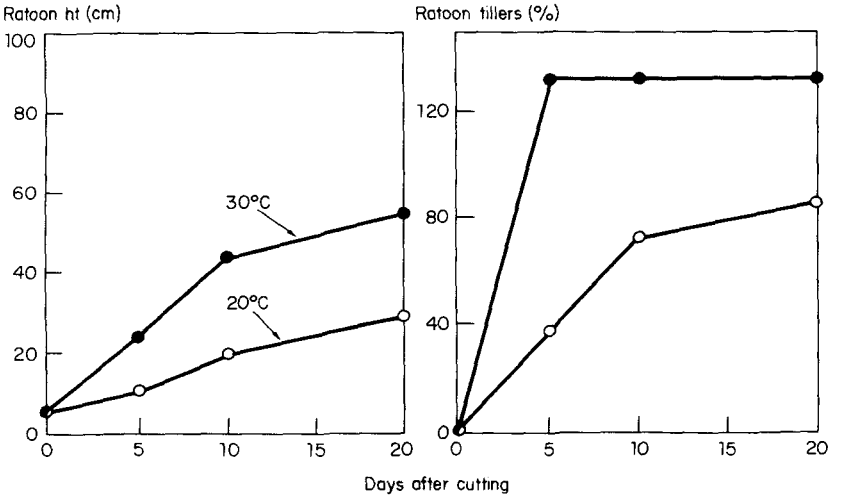
Shading the main crop affected ratoon tillers, height, weight, and grain yield (28, 39). For example, ratoon height and percentage of tillers of plants grown under different light intensities (full sunlight, 50% shading, and 75% shading) for 2 wk before cutting significantly decreased with increased shading (28) (Fig. 2). Maximum ratoon height differed with light intensity, tillering did not. Maximum height was attained in 30 d at full sunlight, 25 d at 50% shading, and 20 d at 75% shading. Tillering stopped altogether at about 15 d, regardless of light intensity. Ratoon weight and percentage of tillers/cut plant were also lower in dark than in light environments (26). However, ratoons were taller in dark than in light environments.

Shade duration also influenced ratoon growth (39). Shading from flowering of the main crop to 7 d after harvest (28 d) resulted in significantly lower ratoon yields

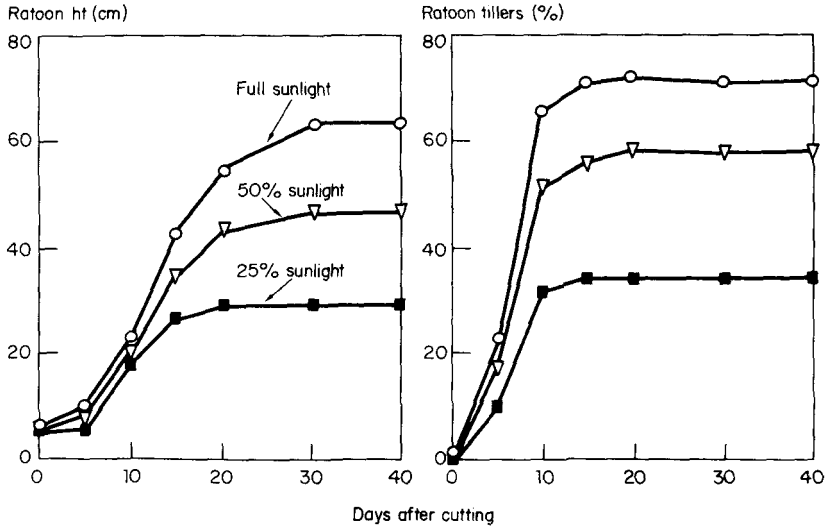
Table 1. Plant characters of rice ratoon as influenced by temperature regime (4).

Temperature regime (°C)		Plant character [a]				
		Tillers (no./hill)			Maturity (days)	Grain yield (g/hill)
Day	Night	Basal	Total	Productive		
20	20	33 a	47 a	41 a	96 c	1.9 b
29	21	16 b	27 b	26 b	61 b	5.7 a
35	27	11 b	36 ab	33 ab	56 a	5.8 a

[a]Av of 4 replications and 2 (IR22 and IR36) rices. In a column, means followed by a common letter are not significantly different et the 5% level.



1. Ratoon height and tiller percentage as affected by temperature (26).



2. Ratoon height and tiller percentage as affected by light intensity (28).

than shading from late milk stage to 7 d after harvest (24 d) or shading from harvest for 7 d. Regardless of shade duration, shading produced a higher proportion of hills without ratoon tillers.

VARIETAL REQUIREMENTS

Plucknett et al (36) stated that, of the genetic factors affecting ratoon performance of grasses, tillering is probably the most important. Because there are high and low

Table 2. Tiller number and grain yield of the first ratoon crop of 3 outstanding direct-seeded rainfed bunded rice cultivars under 2 soil moisture levels[a] (33).

Cultivar	Abundant water supply[b]		Moderate water supply[c]	
	Tiller no.[d] (/m^2)	Grain yield (t/ha)	Tiller no.[d] (/m^2)	Grain yield (t/ha)
IR2058-78-1-3-2-3	522	3.3	520	2.6
IR2863-38-1-2	745	3.1	643	2.4
IR4722-36-1	582	3.0	506	2.2

[a]Av of 2 replications [b]Fully or heavily flooded. [c]Saturated to slightly flooded. [d]Total of basal end above-base tillers.

Table 3. Grain yields of main and ratoon crops of some rice cultivars in Sichuan Province, China, 1983 (45).

Type	Cultivar	Grain yield[a] (t/ha)		
		Main crop	Ratoon crop	Total
Hybrid rice	Zaishengyou	8.0 a	3.0 a	11.0 a
Hybrid rice	Aiyou 2	6.7 b	2.6 ab	9.3 b
Hybrid rice	Aiyou 1	6.8 b	1.7 b	8.5 bc
Conventional rice	Luke 3	6.3 b	2.0 b	8.3 bc
Conventional rice	Zalshengai	5.2 c	2.7 ab	7.9 c

[a]AV of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level.

tillering rices, ratoon cropping depends to a large extent on the inherent tillering capacity of a cultivar. Ratooning ability has been found to be a varietal character (3, 5, 18, 19, 23, 33, 35). Nadal and Carangal (33) identified three rice selections with outstanding tillering capacities and high ratoon yields under varying soil moisture regimes (Table 2). Haque (19) found that IR2061-423, IR2145-20-4, and IR1924-36-22 possess high ratooning ability. In India, C3810, Ratna, CR20-66, and CR156-5021-207 were superior in ratooning and in yield ability (8). In China, some hybrid rices produced high grain yields, and had high ratooning ability (45). The hybrid Zaishengyou produced the highest main and ratoon crop yields, resulting in a significantly higher total yield (Table 3). Despite the lower ratoon yield of Aiyou 1, Sun et a1 (45) considered it more suitable for ratooning than Aiyou 2. They observed that Aiyou 1 had wide adaptability and strong ratooning ability, while Aiyou 2 was susceptible to high temperature at flowering.

Because of increasing cropping intensity, another genetic factor important to ratooning is crop maturity. Some researchers recommend early-maturing cultivars for ratooning (15, 35). Others observed that late-maturing cultivars possess stronger ratooning abilities (23). The ratoon crops of cultivars with medium to late maturity (≥125 d) produce higher yields than those with early maturity (³ 115 d). For example, late-maturing IR42 gave significantly higher ratoon yield than early-maturing IR36 or medium-maturing IR38 (44, 47).

However, the cultivars used in those trials were not specifically bred for ratooning. There is an urgent need to breed for early-maturing cultivars with strong ratooning ability among their traits if ratoon cropping is to become attractive.

CULTURAL PRACTICES

Several cultural operations that affect plant growth in general also affect ratoon crop growth. However, some specific cultural practices largely determine the success of a ratoon crop.

Land preparation

The ratoon crop has been observed to be dependent on the land preparation for the main crop (35). Deeper plowing for the main crop increased culm elongation and number of panicles per plant. Plowing 25 cm deep gave higher grain yields than shallower tillage (24). However, plowing deeper than 25 cm tended to decrease ratoon viability.

In a trial at IRRI, ratoon crop performance was significantly influenced by tillage method (4) (Table 4). Ratoon plants of a main crop grown under regular land preparation (plowing followed by harrowing) gave higher grain yield and panicle number and lower spikelet sterility than ratoon plants of a main crop grown under zero tillage. Plots that received regular land preparation in the main crop also tended to produce more tillers in the ratoon crop.

These results suggest that a successful ratoon crop will depend to some extent on the degree of land preparation.

Crop establishment

Transplanting and direct seeding (wet or dry) are the two main methods of rice crop establishment. Although the effect of transplanting and direct seeding on ratooning performance has not been extensively examined, indications of good ratoon yields from drilled crops have been reported (14, 15). At IRRI, under adequate moisture conditions in a rainfed rice regime, a high ratoon yield (3.3 t/ha) was obtained in a direct-seeded bunded field (33) (Table 2). In Indonesia, dry-seeded IR30 grew a successful ratoon crop (34). One of the advantages of direct seeding over transplanting for ratoon cropping is that, with the large number of plants per unit area, only a few ratoon tillers are needed to produce a high number of tillers.

In transplanted rice, plant population in the main crop can also be increased by planting at closer spacing, increasing potential ratoon tillers. Planting at 10 × 10 cm yielded significantly higher than planting at 20 × 20 cm and wider (1).

Table 4. Effect of tillage method on plant characters of the main and ratoon crops of IR28[a] (4).

Tillage method[b]	Tiller (no./m^2)		Panicle (no./m^2)		Spikelet sterility (%)		Grain yield (t/ha)	
	Main Crop	Ratoon crop	Main crop	Ratoon crop	Main crop	Ratoon Crop	Main Crop	Ratoon Crop
Zero	344 a	298 ab	334 a	244 b	17 c	50 a	2.2 b	0.3 d
Paraquat fb harrowing	429 a	281 b	423 a	226 b	15 b	49 a	3.3 e	0.7 c
Harrowing	393 a	336 a	383 a	277 a	15 b	47 a	3.4 a	0.8 b
Plowing fb harrowing	381 a	326 a	375 a	271 a	12 a	38 a	3.7 a	1.1 a

[a] Av of 4 replications, In a column, means followed by the same letter are not significantly different at the 5% level. [b] fb = followed by.

Table 5. Effect of main-crop cutting height on percentage of missing hills and grain yield of IR28 ratoon (4).

Cutting height (cm)	Missing hills (%)	Grain yield (t/ha)
5	37 b	0.9 b
15	12 a	1.3 a
20	5 a	1.5 a

[a]AV of 4 replications. In a column, means followed by a common letter are not significantly different et the 5% level.

However, irrespective of stand establishment method, with increased tiller number per unit area, the crop is more prone to lodge. Greater lodging resistance should be incorporated into cultivars to minimize yield and quality losses.

Cutting height

Among the ratoon plant characters greatly affected by cutting height are grain yield, tillering, and growth duration. However, the response of grain yield to cutting height has been inconsistent.

In Colombia, plants cut at 15 cm gave higher yields than plants cut at ground level (42). At IRRI, cutting at 15 cm also encouraged tillering, significantly reducing missing hills and increasing grain yield over cutting at 5 cm (4) (Table 5). In India, cutting close to the ground produced the lowest yield; the best cutting height was 35 cm (43). In Ethiopia, ratoon yield was significantly higher when the main crop was cut at ground level, although tillering percentage increased as cutting height increased from ground level to 12 cm high (38). In the Philippines, ground-level cutting was suggested to prevent growth of unproductive tillers (35). In Japan, ratoon stand varied with cutting height but grain yield did not (30).

The effect of cutting height on ratooning and growth duration was consistent. Higher cutting height always resulted in improved tillering (4, 30, 38) and shorter growth duration (4, 14, 21, 41). The ideal cutting height appears to be about 15 cm above ground level.

Fertilizer management

Fertilizer is another input that greatly influences growth and yield of rice ratoons. But requirements vary widely. Some studies indicate that growth of the ratoon is dependent on composition and rate of fertilizer used (12, 17); others, that fertilizer mixtures are needed not only on the main crop, but also on-the ratoon crop (46). But in other studies, only N fertilizer had a significant effect on ratoon performance. In Taiwan, P and K did not affect ratoon grain yield (25). In Texas, P and K application on the ratoon crop was not necessary if the main crop received adequate amounts of those elements (15). Sufficient amounts of P and K applied to the main crop were still available to the ratoon crop (13).

Nitrogen has been observed to improve tillering and increase grain yield of the ratoon crop. However, responses of ratoon to N rate were not consistent. In some instances, N level did not affect tiller and panicle number, 100-grain weight, grain-straw ratio, and missing hills (3). In other cases, tiller number gradually increased with increasing N level, although ratoon weight was not significantly affected (5). At

Table 6. Effect of nitrogen level on grain yield of IR28 ratoon[a] (4).

N level (kg/ha)	Grain yield (t/ha)
0	1.0 b
20	1.0 b
40	1.1 b
60	1.5 a
80	1.5 a

[a]Av of 4 replications. Means followed by a common letter are not significantly different at the 5% level.

Table 7. Ratoon grain yield and yield components of Aiyou 2 rice as affected by different levels of nitrogen applied 2 wk before main crop harvest in Sichuan Province, China, 1981[a] (45).

Nitrogen level (kg/ha)	Tiller (no./m^2)	Panicle (no./m^2)	Grain yield (t/ha)
69	435 a	306 a	2.9 a
34	360 b	277 a	2.7 a
0	230 c	192 b	1.9 b

[a]Av of 3 replications. In a column, means followed by the same letter are not significantly different at the 5% level.

Table 8. Grain yield and other plant characters of ratooned rices as affected by method of nitrogen application to the main crop[a] (44).

Application method	Plant height[b] (cm)		Tiller[b] (no./m^2)		Panicle (no./m^2)		Grain yield (t/ha)	
	IR36	IR42	IR36	IR42	IR36	IR42	IR36	IR42
Split	60 b	67 a	226 a	345 b	190 a	277 a	0.9 b	1.4 b
Placement	64 a	66 e	254 a	403 a	210 a	325 a	1.2 a	1.6 a

[a]Av of 4 replications and 4 seedling ages. In a column, means followed by a common letter are not significantly different at the 5% level. [b]At harvest.

IRRI, grain yield significantly increased as N rate increased; N level was optimal at 60 kg/ha (4) (Table 6). In China, as N increased from 0 to 69 kg/ha, ratoon tiller numbers of Aiyou 2 rice increased significantly (45) (Table 7). However, N level for panicle number and grain yield was optimal at 34 kg/ha. In Colombia, CICA-4 rice ratoon yielded 3.8 t/ha with the application of 25-50 kg N/ha (42). In Texas, only 50 or 70 kg additional N/ha (approximately 3/4 of the recommended N for the main crop) [14,21] was required for the ratoon crop (2). Although excessive N application increased sprouting rate (25), it weakened the plant and resulted in a marked decrease in ratoon crop viability (23). High N application also delayed ratoon crop maturity (6).

Method of N application in the main crop also affected the ratoon crop (41, 44). Deep placement of N in the main crop significantly increased height of IR36 ratoons, tiller number of IR42 ratoons, and yield of ratoons of both cultivars (44) (Table 8). Deep placement produced 15% higher ratoon yield and higher panicle density than split application. Split N application in the main crop resulted in delayed maturity and lower leaf area index of the ratoon crop. Samson (41) also

noted that deep N placement in the ratoon crop produced more panicles per plant, more spikelets per panicle, and more vigorous ratoon plants, resulting in a significantly higher yield than did an equal amount of broadcast N.

Water management

Although only about 60% of the water normally required for the main crop is needed (10), water is very essential to a successful ratoon crop. In India and Taiwan, irrigated ratoon crops yielded higher than nonirrigated ratoons (18, 23). Dry-seeded rices produced more ratoon tillers and higher yields when water was abundant than when it was only moderate (33) (Table 2).

However, availability of water, per se, does not assure rice ratooning success. Time of flooding the field is equally critical. Some researchers have suggested that the field be kept drained but moist for 2 wk (31) or at least 10 d (4, 25) after harvest of the main crop to promote sprouting. Others suggest that flooding be withheld until ratoon tillers are 10-15 cm high (2). Irrigating the field immediately after harvest may cause rotting of stubble, preventing ratooning (20). Hsieh and Young (25) reported that fewer hills produced shoots in flooded than in nonflooded ratoon plots.

A significant interaction existed between flooding time and cutting height. When stubble was cut lower, delaying irrigation 4-6 d was better than flooding 1 d after cutting (4, 21, 36, 38). However, many hills died when the crop was cut at ground level and flooded 5 cm deep (27). Bahar and De Datta (4) reported that plants cut at ground level and immediately flooded gave significantly lower yields than plants cut at 15 cm with the same water regime (Table 9). Percentage of missing hills increased as time between flooding and cutting height shortened, significantly so in the ground-level cutting. Differences between ground-level and 15-cm cutting were significant from 0 to 12 d flooding after harvest.

Plant growth regulators

Plant growth regulators (PGR) have been reported to affect plant growth and development (32). Although studies on using PGR to improve the performance of rice ratoons are very limited, preliminary trials indicate that PGR enhanced growth and increased grain yield of ratoon crops.

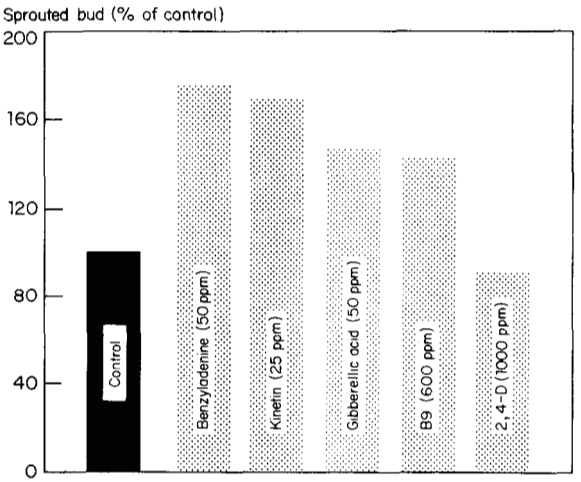
Hou (22) observed that benzyladenine (BA), kinetin, gibberellic acid (GA_3), and B9 at certain concentrations increased percentage of sprouted buds over untreated ratoons (Fig. 3). BA and kinetin produced the most sprouted buds. Bud sprouting response to PGR treatment was generally highest at the milk stage.

There were also indications of changes in panicle number, spikelet sterility, and yield (22) (Table 10). Again, BA and kinetin gave the most panicles. BA increased panicle number when applied at 25 or at 40 d after transplanting (DT) and kinetin did so when applied 25 DT, followed by 40 DT, regardless of PGR rate. Spikelet sterility increased with increased concentrations of GA_3, irrespective of application time. However, BA generally produced more sterile spikelets than GA_3. Kinetin (50 ppm) applied at the milk stage and B9 (600 ppm) applied 40 DT gave the highest yields. Except for B9, all PGR gave higher grain yields when applied at the milk stage than at other stages.

Table 9. The effect of cutting height and flooding time on missing hills and grain yield of IR2061-632-3-1 ratoon[a] (4).

Flooding time (d after harvest)	Cutting height					
	Missing hills (%)			Grain yield (t/ha)		
	Ground level	15 cm	Difference	Ground level	15 cm	Difference
0	79 c	3 a	76**	0.0 c	2.5 a	–2.5**
4	3.3 b	2 a	31**	1.7 b	2.4 a	–0.7 ns
8	25 ab	2 a	23*	1.9 ab	2.4 a	–0.5 ns
12	18 ab	1 a	17*	2.4 a	2.3 a	0.1 ns
16	16 a	1 a	15 ns	2.3 a	2.6 a	–0.3 ns

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. *, **Significant at the 5 and 1% levels, respectively.



3. Percentage of sprouted bud of IR42 as affected by plant growth regulator (22).

Quddus (39) reported that GA_3, indole acetic acid (IAA), naphthalic acetic acid (NAA), and 2,4-D also increased panicle number but had no pronounced effect on grain yield and other yield components.

The use of PGR in improving ratoon crops is a relatively new research topic. Preliminary results have not clearly defined their effects on yield, much less on total performance of the ratoon crop. More studies on this aspect are needed to arrive at definite conclusions.

PESTS OF RATOON CROPS

Insects and diseases

One of the many risks associated with rice ratooning is the buildup of insects hosting on cut stubble left on unplowed ground (11). Insects that are likely to heavily infest rice ratoons are stem borers and leaf beetles.

Table 10. Panicle number, spikelet sterility, and grain yield of IR42 ratoon as affected by plant growth regulators applied at different growth stages of the main crop[a] (22).

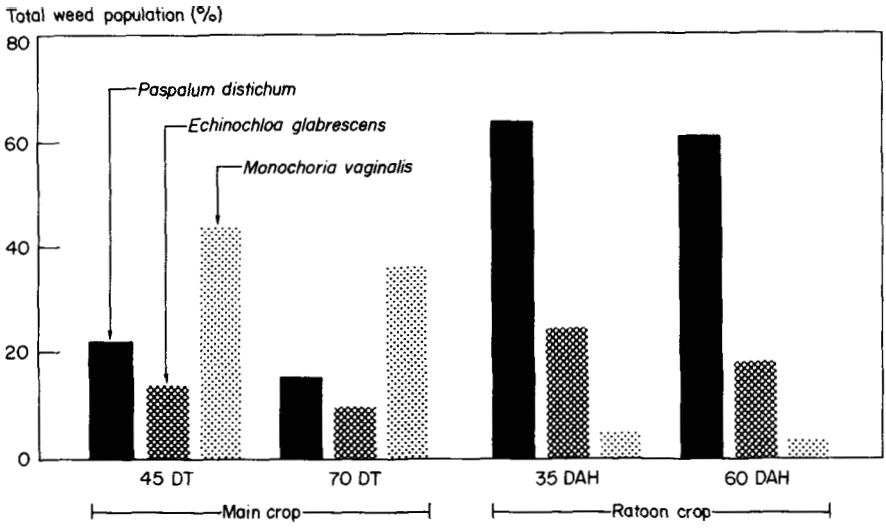
Plant growth regulator	Concentration (ppm)	Time of application[b]											
		25 DT			40 DT			Milk stage			25 fb 40 DT		
		Panicle (no./plant)	Sterility (%)	Grain yield (g/plant)	Panicle (no./plant)	Sterility (%)	Grain yield (g/plant)	Panicle (no./plant)	Sterility (%)	Grain yield (g/plant)	Panicle (no./plant)	Sterility (%)	Grain yield (g/plant)
GA_3	50	9	15	21	9	17	18	13	15	21	10	19	16
GA_3	100	8	22	13	9	21	18	13	16	21	10	25	17
BA	50	12	18	20	12	23	21	9	21	19	10	19	15
BA	100	13	17	21	14	18	22	10	15	23	11	17	15
Kinetin	26	10	16	18	9	21	20	13	22	21	15	14	20
Kinetin	60	12	16	20	11	13	19	14	18	23	14	20	21
B9	600	13	19	20	12	15	24	12	14	17	9	19	16
B9	6000	12	22	21	13	23	16	14	17	19	10	19	14
2,4-D	1000	11	30	16	9	18	17	14	18	18	9	17	15
Control	–	10	24	18	9	19	18	11	21	19	9	25	17

[a]AV of 4 replications. [b]DT = days after transplanting, fb = followed by.

Table 11. Disease infections in the ratoon crop of IR32 (41).

Treatment	Stem rot (%)	Sheath blight rating[a]
Puddled		
Standing water	8.2	0.4
Midseason drainage	5.7	0.4
Unpuddled		
Standing water	8.1	0.1
Midseason drainage	5.5	0.2

[a]Scale: 1 = lesions limited to lower 1/4 of leaf sheaths; 5 = lesions present on more than 1/2 of leaf sheaths, slight Infection on lower (3d or 4th leaves); 9 = lesions reaching top of tiller, severe infection on all leaves.



4. Shift in weed composition from the main crop to the ratoon crop (22). DT = days after transplanting, DAH = days after harvest.

Rice ratoons are also prone to infection with certain diseases. Grassy stunt virus, stem rot, and sheath blight have been observed infecting the crop (4, 41). Bahar and De Datta (4) reported that all the rices used in their study were infected with varying degrees of grassy stunt virus, which may partly explain why ratooning is not widely accepted in the tropics. Samson (41) noted stem rot and sheath blight on ratoon crops (Table 11). Stem rot appeared to be influenced by water regime and cutting height. Plots with standing water had a higher incidence of stem rot than plots with midseason drainage. Longer stubbles (25 cm) also had higher stem rot infection, producing less vigorous ratoons than shorter stubble (15 or 3 cm).

Insect and disease problems could be minimized by breeding resistant rices and applying appropriate pesticides.

Weeds

A change in either the cropping system or weeding treatment can cause a significant change in the weed flora of the subsequent seasons (9). In reduced tillage, weeds

Table 12. Weed biomass of selected species in transplanted IR42 as affected by weed control method[a] (22).

Treatment	Rate (kg al/ha)	Biomass[b] (g/m^2)		
		Paspalum distichurn	*Echinochloa glabrescens*	*Monochoria vaginalis*
2,4-D	0.8	70 ab	2 a	1 e
Bentaron	2.0	10 ab	8 a	3 a
Butachlor	1.5	2 a	0 a	1 a
Thiobencarb/2,4-D	1.0/0.5	10 ab	1 a	5 a
Hand weeding	–	3 a	2 a	6 a
No weeding	–	33 b	30 b	30 b

[a]Av of 4 replications. In a column, means followed by a common letter are not significantly different at the 5% level. [b]Sampled at 70 d after transplanting.

shifted from annuals to perennials (29). For example, a change from conventional to zero tillage in lowland rice shifted weed species from the annuals *Echinochloa* sp. and *Monochoria vaginalis* to the perennials *Paspalum distichum* and *Scirpus maritimus* (7). Because rice ratooning is a no-till culture, the same weed shift could also occur.

Hou (22) reported that of the 10 weed species present in the main crop, *M. vaginalis* comprised 37%, *P. distichum* 21%, and *Echinochloa glabrescens* 7%. In the ratoon crop, however, *M. vaginalis* decreased to 3%, *P. distichum* increased to 63%, *E. glabrescens* to 18% (Fig. 4). The weed shift could be partly due to the weed control measures used (Table 12). *E. glabrescens* and *M. vaginalis,* but not *P. distichum,* were significantly reduced by all herbicides. The tolerance of *P. distichum* for the herbicides used and the absence of tillage contributed to its increase in the ratoon crop.

These data suggest that weed control, particularly of perennial weeds, which are tolerant of herbicides, should be done on the main crop to minimize their proliferation in the ratoon crop. Annual weeds in the ratoon crop can easily be controlled with supplemental manual or mechanical weeding or with chemical treatment.

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Rice ratooning: breeding, agronomic practices, and seed production potentials

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ABSTRACT

Except in the Dominican Republic and Texas, USA, no special efforts have been made to develop varieties suitable for a rice ratoon cropping system. Varieties observed to possess good ratooning ability were selected incidentally from material screened for other characteristics. Systematic study of the genetics of ratooning ability and related characters has not been done. Disease resistance is important. Available information on selection criteria in breeding for ratoon rice is discussed. Agronomic practices, such as managing the main crop in a way suitable for the whole system, stubble height at main crop harvest, water management under different planting and soil conditions, and fertilizer management, have not been developed for particular situations. A few articles report contradictory results on ratoon grain and seed quality. Possibilities of producing quality seed, maintaining CMS lines, synchronizing female and male parents, and reducing the cost of hybrid seed production using ratoon crops are discussed. Needed location-specific research on potentials of this system in breeding, agronomic practices, and seed production are indicated.

The importance of ratoon cropping as a way to enhance yield without increasing land area and at less per unit production cost has been emphasized (10, 22). Ratooning forage crops, sorghum, sugarcane, and forest trees is successfully practiced in many countries. In many agriculturally important countries (India, China, Australia, Israel, Philippines, and Brazil) ratooning different crop species is being developed for use under modem intensive farming methods (4, 22).

Although ratoon rice cropping is an old system, it has been established only in the USA (Texas) and Colombia and is starting to be established in Ecuador and Swaziland. In many other countries, reports of successful ratoon crops are published periodically, but the practice has not been widely adopted. Very recently, it has been established in a small way in Karnataka, India (10, 22).

The lack of acceptance of rice ratooning by commercial farmers has been attributed to low yields, lack of good ratooning varieties, uneven maturity, disease and insect problems, lack of location-specific cultural practices, inferior grain quality, and lack of assured return from investment (4). It is important to discuss breeding, agronomic practices, and seed production potentials of this system so that the priority research programs can be initiated.

BREEDING POTENTIALS

Ratooning ability and related characters

Several reports of varietal differences in ratooning ability have been exhaustively reviewed (4). Samson (27) suggested a rating scale for ratoon vigor. Different varieties produce ratoon tillers of different kinds (30). Genotypes differ in proportion of basal and nodal tillers (1, 6, 32); high basal tillers were found desirable. Late leaf senescence of the main crop is considered favorable for the ratoon crop (4). Main crop root vigor and stem thickness (9) generate better regrowth.

Therefore more basal tillers with uniform flowering and late leaf senescence and stem and root characters can be considered as important breeding objectives.

Reports of successful ratoon crops from early-maturing (3), medium-duration (35), and late-maturing (11, 24, 25) varieties suggest that breeding for ratooning ability should emphasize the length of maturity needed for specific growing conditions. Breeding lines of less than 100 d growth duration have been reported to possess high ratooning ability (4), but other reports contradict this.

Mahadevappa observed about 700 genotypes at IRRI and many more at Karnataka experimental stations. He found an apparent correlation between ratoon growth period and ratoon yield (10). Ratooning ability, as a genetically controlled character, can be incorporated into any maturity group. Biometrical studies of a range of material could confirm and elaborate this observation.

Studies on the genetics of ratooning ability are limited and contradictory (2, 5, 29). The total inability of some genotypes to initiate regrowth, even under the most favorable conditions; the ability of certain other genotypes to ratoon vigorously, despite adverse environments; and the existence of moderate ratooning types indicate that ratooning ability is influenced by a number of genes. Hybrids in general seem to have higher ratooning ability than the parents, revealing the heterotic nature of the genes governing ratooning ability inheritance.

Resistance to biotic and abiotic stresses

One reason for the nonadoption of rice ratoon cropping systems, despite many attempts, is the lack of recognition of the importance of resistance, especially to the systemic diseases (viruses, microplasma-like organisms) and their vectors found in most rice growing countries. Ratoon rice is more likely to be damaged by virus and MLOs since a main crop infection is also manifested in the ratoon crop. Many of the good ratooning genotypes selected in the International Rice Cold Tolerance Nursery at Karnataka and in other locally constituted trials at Bangalore had to be rejected because of their susceptibility to viruses. Of 338 genotypes, only 86 were unaffected, including B2983-b-853-2-4, IR15579-135-3, IR18476-55-2, IR19743-25-2-2, IR9202-25-1-3, and NR10073-167-2-1-1. These are under further evaluation. The varieties Intan, being adapted for ratooning in the hill region of Karnataka, and Mingolo, now under prerelease farm trial, have been showing high resistance to viruses and MLOs. Breeding even more good ratooning and disease-resistant genotypes is necessary. It is risky to depend on only one or two varieties which may break resistance, as happened for blast resistance in Intan in the same region.

Field and laboratory screening for virus and MLO epidemiology have been reported (14, 15, 16, 17). The need is for further standardization of simple and efficient screening techniques.

Until now, ratoon crop experiments were based on cultivars not bred specifically for ratoon cropping. Little work has been done to select genotypes especially adapted to high ratoon yields. Many wide crosses are needed to understand the nature of ratooning ability inheritance and characters attributing to ratoon yield.

AGRONOMIC MANAGEMENT

Main crop planting time

The planting time of the main crop cannot be fixed in many rice growing environments, especially in tank and rainfed rice areas where the start of rains is erratic. This results in varying harvest times for the main crop. Delayed or very early harvests may lead to subsequent problems in the ratoon crops, such as flowering coinciding with low temperatures, harvest coinciding with heavy rains, and delayed harvest overlapping planting time for a subsequent crop (3, 11). Bird pests also cause heavy damage to ratoon crops at the grain ripening stage if the ratoon plots are in different growth stages.

To solve these problems, it is important to identify varieties with good ratooning ability for different main crop planting dates. In Karnataka, if the season is late for Intan, early-maturing Mingolo has been found to come to timely harvest in both the main and the ratoon crops. However, if Mingolo is planted early, its ratoon flowers in severe winter and fails to set any seed (23).

Selecting the main crop plot for ratooning

A good uniform plant stand with a vigorous root system in the main crop is a prerequisite to a successful ratoon crop (4, 10). The growing period available for the ratoon crop and the weather conditions (temperature and rainfall) that prevail during ratoon growth also determine whether a particular plot is worth selecting for ratooning. A main crop plot that lodged because of rain, wind, and other factors or an overmature plot may not be fit for ratooning. A plot located near the day roosts of birds during the active growth season may pose problems. Specific varieties, locations, and seasons need to be identified for a main crop-ratoon crop system.

Stage and height of cutting main crop

Early results suggest that the best time to cut the main crop is when it is fully ripe, but before the green disappears. However, because senescence is a varietal character, the stage has to be fixed in reference to the variety recommended for the specific situation. The effect of cutting height on ratoon crop performance has been profusely studied (4, 10, 21). Varieties differ markedly in their ratoon tiller production. Some are unaffected by the cutting height (30). Stubble height also is reported to influence ratoon growth duration. Variety by location-specific study is important. The relationship between cutting height and disease needs to be

established; the information now available is scanty. Cutting the growing stubble more than once also appears to offer scope for manipulating ratoon duration and yield components (8).

Fertilizer management

Although research results on the timing and dosage of fertilizer applied to the ratoon crop are inconsistent, plots fertilized with N and other nutrients have always yielded more (25, 26, 33). Soil fertility status, ratoon crop growth duration, topography of ratoon crop plots (mid- and lowlands in areas where P deficiency and Fe and A1 toxicity are common) vary enormously. Experiments on these aspects are needed to determine optimum doses of nutrients for each growing condition. P and Ca may have a definite bearing on ratoon crop yields in acid soils.

Water management

Water management immediately before and after main crop harvest influences ratoon stand and tiller production. Most studies in the past conclude that withdrawal of water some days before harvest, leaving only moist soil, and irrigating as ratoon growth progressed encouraged ratoon crop production. Since significant interaction is reported between cutting height and water management in ratoon growth, as well as flooding and weed control, this is an important aspect to study in areas with ratoon crop potential. Water management and nitrogen fertilization were reflected in increased yield and milling recovery with Labelle ratoon rice (12, 13).

SEED PRODUCTION

Seed grain quality of the ratoon crop is one of the eight points Plucknett et a1 (21) listed as needing study. Main and ratoon crop yields as grain and as seed have been compared. Except for seed viability, all other yield component characters (plant height, panicle length, spikelet size, number of productive tillers, and grain setting) are less pronounced in the ratoon crop than in the main crop. Viability and productivity of ratoon crop seeds have been found to be as good as those of the main crop seeds (26, 28). Webb et a1 (31) reported ratoon crop grain of some varieties to be relatively less uniform. Protein content, although varying greatly, tended to be considerably higher in ratoon crop grain than in main crop grain. Gelatinization temperature and viscosity values were consistently lower for ratoon crop samples. Gay (7) reported that the quality of the ratoon crop grain harvested from Gulfrose variety graded No. 1. Nadal and Carangal (18) observed that the grains produced by the second ratoon were superior to those produced by the first ratoon. Nagaraja and Mahadevappa (19) noted that the seed quality of main and ratoon crops varied with variety and that the viability of ratoon crop seeds deteriorated faster than main crop seeds. However, the field performance of a variety remained unchanged, regardless of whether the crop was raised from seed obtained from the main crop or from seed obtained from the ratoon crop (Table 1, 2).

The ability of some genotypes, reported to have ratoon crop grain and seed quality as good as main crop seed quality (19), needs to be exploited by selecting such genotypes for a ratoon cropping system. Nutritional and other factors affecting

Table 1. Comparison of main crop (M) and ratoon crop (R) seeds for 1000-seed weight, electrical conductivity of seed leachate, root length, shoot length, and dry weight of seedlings.

Treatment		1000-seed weight (g)	Electrical conductivity of seed leachate (mmhos/cm)	Seedling character		
				Root length (cm)	Shoot length (cm)	Dry wt (mg/10 seedlings)
T_1 cv. Mangala	M	20.84	0.37	14.97	11.29	112.0
T_2	R	19.81	0.30	10.65	8.20	106.3
T_3 cv. Cold Adakkan 27	M	21.03	0.62	13.67	14.68	124.0
T_4	R	22.02	0.42	11.03	11.62	131.3
T_5 cv. Mulliam Puncha	M	22.94	0.38	7.08	2.68	202.7
T_6	R	20.49	0.28	5.52	1.84	146.3
T_7 cv. Cold Adakkan 74	M	26.75	0.34	12.83	13.29	169.7
T_8	R	23.12	0.53	9.87	11.87	148.0
T_9 cv. CH2	M	22.82	0.38	13.61	14.07	145.7
T_{10}	R	22.38	0.41	9.11	9.85	71.0
T_{11} cv. Cold Adakkan	M	22.21	0.50	14.44	14.42	110.3
T_{12}	R	22.83	0.45	9.80	11.26	85.3
T_{13} cv. Mingolo	M	24.97	0.28	15.12	12.87	165.3
T_{14}	R	23.17	0.23	16.29	13.19	141.0
	Mean	22.53	0.39	11.66	10.80	132.8
F test		**	**	**	**	**
SEM ±		0.126	0.015	0.955	0.805	6.23
CD (0.01)		0.492	0.058	3.730	3.144	24.34
CV (%)		0.972	6.767	14.187	12.907	8.13

**Significant at the 1% level.

Table 2. Germination capacity, germination speed, field emergence, and vigor index of seeds from main crops (M) and ratoon crops (R) of seven rice cultivars.

Treatment		Germination capacity (%)[a]	Germination speed	Field emergence	Vigor index
T_1 cv. Mangala	M	80.27 (97.00)	19.05	53.42 (64.00)	2483
T_2	R	31.62 (27.67)	3.72	27.62 (21.67)	517
T_3 cv. Cold Adakkan 27	M	81.94 (96.33)	17.92	61.37 (77.00)	2738
T_4	R	39.22 (40.00)	4.77	39.81 (41.00)	904
T_5 cv. Mulliam Puncha	M	58.59 (72.67)	9.89	57.89 (71.67)	712
T_6	R	24.29 (17.00)	1.19	28.65 (23.00)	127
T_7 cv. Cold Adakkan 74	M	71.92 (90.33)	17.38	69.16 (87.33)	2358
T_8	R	47.64 (54.33)	7.02	53.93 (65.33)	1176
T_9 cv. CH2	M	77.63 (94.67)	18.76	67.21 (85.00)	2635
T_{10}	R	28.51 (23.00)	2.51	20.23 (12.00)	439
T_{11} cv. Cold Adakkan	M	80.91 (97.33)	19.32	69.75 (80.00)	2810
T_{12}	R	50.38 (59.33)	8.10	43.66 (47.67)	1245
T_{13} cv. Mingolo	M	76.73 (94.67)	17.26	71.58 (90.00)	2649
T_{14}	R	67.94 (85.00)	15.89	70.94 (89.33)	2504
	Mean	58.40 (67.81)	11.63	52.51 (61.50)	1664
F test		**	**	**	**
SEM ±		2.761	0.439	2.449	146.0
CD (0.01)		10.787	1.716	9.568	570.3
CV (%)		8.189	6.549	8.079	15.2

**Significant at the 1% level. [a]Figures are transformed values of angles corresponding to percentage. Figures in parentheses are original percentage values. Vigor index = mean seedling length x germination %.

ratoon crop seed quality of certain genotypes need to be investigated so that the quality of ratoon crop seed can be improved through specific management practices. Seed vigor and storability also need to be studied concurrently.

Table 3. Pattern of seed setting on A and B lines of Pankhari 203 stubble planted during kharif 1984.

Observation	A	B
Mean seed setting (%)	9.3	73.0
Range (%)	2.6-27.2	51.7-89.9
Mode (%)	10	77.5
Seed yield per plant (g)	3.1	15.9
Seed yield per hectare (kg)	508	2656

Maintenance of CMS lines

Vegetative propagation techniques, through stubble planting or ratooning, are important in the production of foundation and certified hybrid seed. Maintenance of CMS lines itself is challenging, because of the very poor seed setting performance of the parents. The stubble of the previous crop can be used to multiply CMS plants, provided the genotypes have a regeneration capacity (34). In some CMS lines, like Pankhari A and B, and MS 577 A and B, the stubble grew as well as the main crop. The seed yields from those were comparable to those of the main crop (Table 3).

Because on stubble planting each plant can produce 6-10 plants, it is worth selecting or developing CMS lines that have good regeneration potential. Also, when the CMS plants of the main crop fail to set seeds because of non-synchronization of flowering of A and B or of A and R plants or for some other reasons, stubble planting is useful for maintaining and multiplying the CMS plants. The system is also useful when the initial seed stock is limited.

Synchronization of flowering

One detrimental factor in maintaining CMS lines and in F_1 seed production is asynchronization in the flowering of female and male plants. Staggered planting and adjusting the planting times are among the techniques to get better nicking in flowering of female and male plants. Stubble planting may become an accepted technique to accomplish synchronization of flowering, since the stubble-planted CMS and male plants tend to produce panicles with relatively less time difference (34). We can induce pollen production and distribution for a long period by cutting a few tillers of the pollen parent at the vegetative stage (20).

In Bangalore, clones of vegetatively propagated KMS 1 varied in the flowering time of tillers produced in the same hill; some tillers flower early. To adjust the flowering of the female parent (KMS 1), the early-flowering tillers were cut above ground level 2 times within 1 wk in summer and 3 times within 10 d in the wet season. This accounted for a higher seed set on KMS 1 (20).

Reduced cost of hybrid seed production

Stubble planting is one way to minimize the cost of parent and hybrid seed production, since buying new seeds for every planting can be avoided. The cost of seed, nursery preparation, labor-intensive transplanting, and, to some extent, the cost of fertilizers and irrigation will be reduced. If we can incorporate ratooning ability into the hybrid crop itself, through A or R, it will be a great advantage.

Hybrid vigor has been observed in crop establishment and in ratoon crop performance (K.P. Vishwanatha, R.A. Krishnamurthy, and M. Mahadevappa, pers. comm.).

The overall advantage of use of a ratoon crop system for grain and seed production can be summarized as:

1. The lag time for plant establishment is avoided in the ratoon crop because of the absence of the seedling stage,
2. The crop cycle is reduced,
3. The growing season is better utilized, and
4. In a given period of time, yield per unit is higher.

Seed production in winter

Seeds produced in the ratoon crop season have better luster and quality because of the absence of rains, at least toward the second half of the cropping season. Also, in high- and medium-elevation areas, flowering coinciding with low temperature leads to crop failure. This could be overcome by ratooning the main crop at the appropriate vegetative stage in late season plantings. This practice is common in tank-dependent tracts in Southern Karnataka. The cutting provides green fodder to cattle; in fact, the system prevailed with S. 1092 even before the advent of semidwarf rices.

Induction of flowering in photoperiod-sensitive varieties

Photoperiod-sensitive varieties planted in the dry season do not flower under the long days in Bangalore. But a main crop of photoperiod-sensitive Intan, planted in July and ratooned by cutting the main crop during December-January, will flower normally during April. This is an indirect advantage of ratoon cropping. The quality of seeds harvested in dry season should be superior; this needs to be studied.

CONCLUSION

Rice ratoon cropping shows potential for increasing rice production at low cost without increasing land area and without sacrificing high productivity growing conditions. Superior resistant varieties bred especially for particular growing conditions (taking into consideration ratooning ability, growth duration, and grain or seed quality) and scientific management practice applicable to the growing situations should establish rice ratooning as a viable rice-based farming system practice, at least in favorable agroclimates. In fact, continuous ratooning (twice) seemed feasible, based on the performance of two early-maturing varieties where the second crop ratoon had much higher yields and better grain characteristics than the first ratoon (18). With the hybrid varieties being developed in rice, using ratooning in foundation seed multiplication and certified seed production opens up new lines of research. Using ratooning to produce lustrous and good quality seeds, even from photoperiod-sensitive varieties under long day conditions, is worthwhile. More detailed ratoon cropping research on all aspects is needed, simultaneously with the search for resistant genetic material.

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N fertilizer management for maximum ratoon crop yields

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ABSTRACT

Main crop rice in Texas sometimes appears to be N deficient during grain filling, which may restrict ratoon crop yields. A 2-yr experiment was designed to determine if N applied near main crop heading would increase ratoon crop yields. Field plots of two cultivars received common N rates before the reproductive stage plus one of the five following treatments during the reproductive stage: N applied at panicle differentiation, one-half at panicle differentiation and one-half at heading, at heading, 2 wk after initial heading, or no N applied during main crop reproductive stage. In addition, a main crop postharvest N application of 0, 56, or 112 kg/ha was applied to each of the 5 main crop N treatments. N applied at or near main crop heading rather than at panicle differentiation tended to increase ratoon crop yields but decreased main crop yields, resulting in little effect on total (main crop + ratoon crop) yields. However, since ratoon crop yields were not affected by main crop yield or main crop N applied before heading, it seems probable that a N application at panicle differentiation plus an application near heading will increase total yields. Applying N at heading, 2 wk after initial heading, or one-half at panicle differentiation and one-half at heading rather than at panicle differentiation resulted in quicker tiller regeneration and ratoon crops that matured 7-10 d earlier. Postharvest N application to main crop consistently increased ratoon crop yields.

An annual frost-free growing season exceeding 250 d in the U.S. Gulf Coast region is favorable for producing a 120-d main crop of rice and an 80-d ratoon crop. Rice ratoon crops require minimal inputs (mainly N fertilizer and water) and may yield up to one-third that of the main crop. Usually, the ratoon crop is more economical than the main crop. Increasing ratoon crop yields should increase annual profits from rice production (9).

Nitrogen fertilizer rate and application frequency are critical management factors in ratoon cropping worldwide. In the southern U.S., ratoon crop N is generally applied after main crop harvest; yield responses to 60 kg N/ha or more have been demonstrated (1, 4, 7). Ratoon yield responses to applied N and other inputs depend upon early main crop harvest, so that the ratoon crop can develop before days become shorter and cooler in fall (10). Although ratoon tiller development is determined by genotype and a number of management and environmental factors, Chauhan et al (2), Hsieh et al (5), and Ichii (6) showed that N

was the most effective element promoting development and growth of ratoon tillers. Ichii (6) observed a significant decrease in ratoon tillering percentage and ratoon tiller weight as a result of subjecting rice plants to N, P, or K deficiency for 10 d after removing main crop tillers just after they began to flower. Percentage of ratoon tillering suppression and ratoon shoot weight due to N, P, or K deficiency were greatest with N as the deficient element. P and K had less effect than N on ratoon tiller development. N availability just after removing main crop plant tops is important in utilizing reserve carbohydrates accumulated in stem bases, and eventually in the growth of the ratoon plant. N effects on mobilization of carbohydrate reserves of the rice plant are also known from studies relating to main crop yield (3, 8, 12).

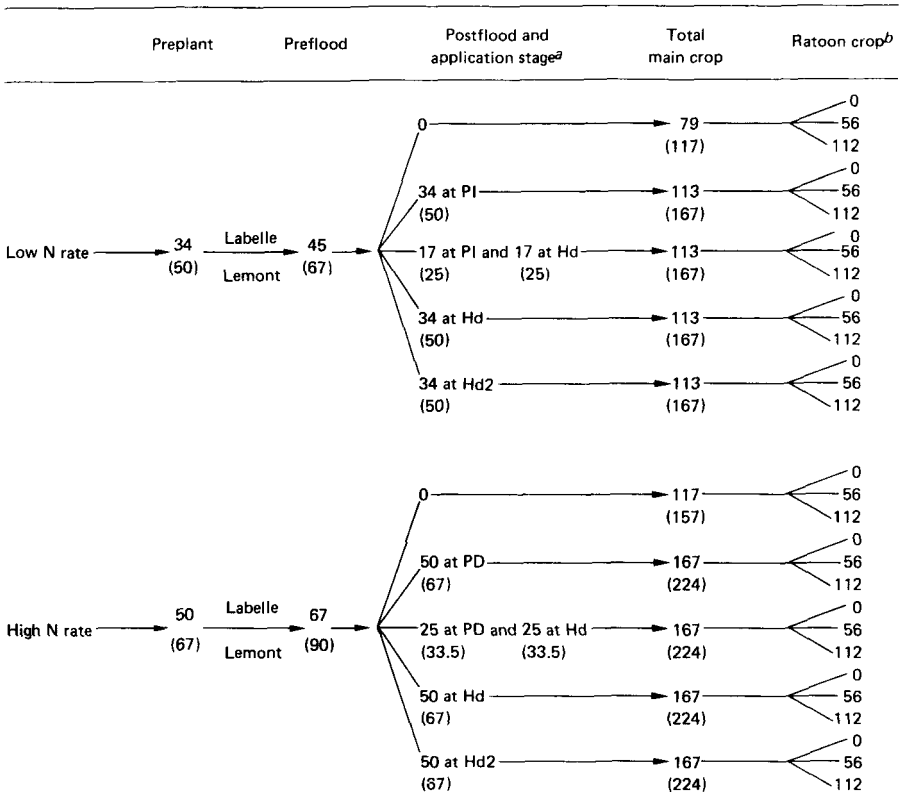
In the southern U.S., N fertilizer management for maximizing main crop yield frequently results in N deficiency near main crop maturity, and consequently insufficient ratoon tillering for high ratoon yields. Conversely, in some fields, main crop plants may remain green and viable near maturity because certain soils apparently supply sufficient N for good ratoon tillering. In the southern U.S., greatest N use efficiency and main crop yields are usually obtained when the last supplemental N application occurs near panicle differentiation (PD) (11). After PD of main crop, plants may become N deficient for ratoon crop development. Timing of N application, dosage, and kind of fertilizer best suited for ratoon cropping require further study (2).

MATERIALS AND METHODS

Labelle and Lemont cultivars were used for this experiment. Labelle, a commonly grown, low maincrop tillering (1-2 tillers/plant in field populations), early-maturing (115-120 d from seeding) cultivar about 106 cm tall, is susceptible to lodging but has good ratooning ability. Lemont, a semidwarf plant type, is replacing Labelle in area planted. Lemont matures in 125- 135 d, has 2-4 tillers/plant in normal plant populations of 160-320 plants/m^2, averages about 80 cm in height, is lodging resistant, and appears to have good ratoon yield potential.

Labelle and Lemont were drill-seeded at 112 kg/ ha on 5 Apr 1984 and 4 Apr 1985 on a Beaumont clay soil (Entic Pelludert) at the Texas A&M University Agricultural Research and Extension Center near Beaumont, Texas. In 1985 Lemont was also grown on an Edna very fine sandy loam soil (Vertic Albaqualfs) at Ganado, Texas. Plots consisted of 6 rows, 6 m long with 15 cm row spacing. Generally, in the southern U.S., rice is not flooded until about 35 d after emergence. N fertilizer was applied to the main crop as preplant, preflood, and postharvest treatments (Fig. 1).

The timing of postflood N applications, the critical treatments of the experiment, included no postflood N (control) or N applications at PD, at initial heading, one-half at PD and one-half at heading, or 2 wk after initial heading. The PD stage is defined as the plant growth stage when 3 of 10 main culms have panicles at least 2 mm long. The 10 N treatments were replicated 12 times, so that each of the



[a]PD = panicle differentiation, PI = panicle initiation, Hd = heading, Hd2 = 2 wk after initial heading. [b]Numbers in parentheses are N rates for Lemont, numbers above parentheses are N rates for Labelle. Both cultivars received same ratoon crop N rates.

1. N fertilizer rates (kg/ha) and application times for main and ratoon crops of varieties Lemont and Labelle in 1984 and 1985 at Beaumont and Ganado. Texas.

treatments could have 4 replications of the 3 postharvest or ratoon crop N rates (0, 56, or 112 kg N/ha).

Preflood main crop N rates were 79 or 117 kg/ha for Labelle and 117 or 157 kg N/ha for Lemont (Fig. 1). The lower main crop preflood N rate was chosen to help ensure response to postflood N application, and the higher rate to establish the N response potential. All N was applied as urea at stages shown in Figure 1. P was applied preplant at 20 kg P/ha.

Hand harvesting resulted in a uniform stubble height of about 45 cm for Labelle and about 50 cm for Lemont, from which the ratoon crop could develop.

After main crop harvest, N applied on dry soil at 56 or 112 kg/ha promoted ratoon crop development. Plots were then reflooded to an initial depth of 5 cm, and the flood increased to 10 cm within 14 d. Floodwater was drained about 10 d before ratoon crop harvest each year.

RESULTS

Main crop N rate and timing effect on main crop yield

Labelle main crop yields without N fertilizer are about 2.0 t/ha on Beaumont clay or 3.5 t/ha on Edna very fine sandy loam at Ganado. Without N, main crop yields of Lemont are usually 3.0 t/ha on Beaumont and 4.0 t/ha on Ganado soil. The time of applying main crop postflood N (N applied after flooding and during the reproductive stage) influenced main crop yield. Applying N at PD stage of Labelle and Lemont always produced highest yields, and represents a common fertilizer practice for commercial rice production in the southern U.S. Applying N at initial heading or at 2 wk after initial heading rather than at PD tended to reduce main crop yields by 0.1 to 1.0t/ha, especially at lower N rates, probably because the main crop became N deficient during PD (Tables 1, 2, and 3).

As the total N applied by the PD stage increased from 79 to 167 kg N/ha, the main crop yield of Labelle increased from 4.9 to 6.6 t/ha (Table 1). Yields of main crop Lemont at Beaumont increased from 7.5 to 8.6 t/ha as N applied up to the PD stage increased from 117 to 224 kg N/ha (Table 2). However, Lemont yield increases at Ganado (Table 3) were only from 8.2 to 8.6 t/ha for the same N rates.

Main crop N rate and timing effect on ratoon crop yield

Even though the main crop yields increased with total N applied at the main crop PD growth stage, ratoon crop yields of either cultivar were not related to main crop N rate or main crop yield. As total N increased from 79 to 167 kg N/ha for Labelle, ratoon crop yield stayed between 1.6 and 1.8 t/ha (Table 1). Lemont ratoon crop yield at Beaumont varied from 1.9 to 1.8 t/ha as N rate increased from 117 to 224 kg N/ha. At the Ganado site (Table 3) the change in Lemont ratoon crop yield as N increased was greater (1.9 to 2.4 t/ha) than at the Beaumont site, but ratoon crop yield did not always increase with main crop N rate.

Table 1. Effect of N management on ratoon and main crop yields of Labelle grown at Beaumont, Texas, in 1984 and 1985 (all N applied by the PD stage).

Treatment (no.)	N fertilizer rate and application time[a]					Total N (kg/ha)	Yield (t/ha)		
	PP	PF	PD	Hd	Hd2		Main crop	Ratoon crop[b]	Total
113 kg N/ha									
1	34	45	0	0	0	79	4.9	1.8	6.7
2	34	45	34	0	0	113	5.7	1.7	7.4
3	34	45	17	17	0	113	5.6	1.7	7.3
4	34	45	0	34	0	113	4.7	1.8	6.5
5	34	45	0	0	34	113	5.0	1.8	6.6
167 kg N/ha									
1	50	67	0	0	0	117	5.7	1.7	7.4
2	50	57	50	0	0	167	6.6	1.6	8.2
3	50	67	25	25	0	167	6.5	1.7	8.2
4	50	67	0	50	0	167	5.9	1.8	7.7
5	50	67	0	0	50	167	5.9	2.0	7.9
						LSD (.05)	= 0.3	n.s.	0.3

[a]PP = preplant, PF = permanent flood, PD = panicle differentiation, Hd = heading, Hd2 = 2 wk after initial heading. [b]Ratoon crop yield when no N was applied at main crop harvest.

Applying main crop N at heading or 2 wk after initial heading rather than at PD tended to increase ratoon crop yields of Labelle by 0.1-0.4 t/ha and ratoon crop yields of Lemont by 0.3-0.7 t/ha at Beaumont and by 0.3-0.6 t/ha at Ganado.

Along with the increase in ratoon crop yields where N was applied at or near heading, there was a decrease in main crop yield, apparently because no N was applied at PD. N application at heading did not significantly increase total rice yields. However, since ratoon crop yields seem independent of main crop N rate and main crop yield, it is reasonable to assume that a N application at PD followed by an application at or near heading would have increased ratoon crop and total rice yields.

Table 2. N management effects on main and ratoon crop yields of Lemont grown at Beaumont, Texas, in 1984 and 1985.

Treatment (no.)	N fertilizer rate and application time[a]					Total N (kg/ha)	Yield (t/ha)		
	PP	PF	PD	Hd	Hd2		Main crop	Ratoon crop[b]	Total
167 kg N/ha									
1	50	67	0	0	0	117	7.5	1.9	9.4
2	50	67	50	0	0	167	8.5	1.7	10.2
3	50	67	25	25	0	167	8.4	2.0	10.4
4	50	67	0	50	0	167	8.0	2.2	10.2
5	50	67	0	0	50	167	8.1	2.4	10.5
224 kg N/ha									
1	67	90	0	0	0	157	8.1	1.7	9.8
2	67	90	67	0	0	224	8.6	1.8	10.4
3	67	90	33.5	33.5	0	224	8.6	2.2	10.8
4	67	90	0	67	0	224	8.2	2.1	10.3
5	67	90	0	0	67	224	8.6	2.2	10.8
						LSD (.05)	= 0.5	0.25	0.5

[a]PP = preplant, PF = permanent flood, PD = panicle differentiation, Hd = heading, Hd2 = 2 wk after Initial heading. [b]Ratoon crop yield when no N was applied at main crop harvest.

Table 3. N management effects on main and ratoon crop yields of Lemont grown at Ganado, Texas, in 1985.

Treatment (no.)	N fertilizer rate and application time[a]					Total N (kg/ha)	Yield (t/ha)		
	PP	PF	PD	Hd	Hd2		Main crop	Ratoon crop[b]	Total
167 kg N/ha									
1	50	67	0	0	0	117	8.2	2.2	10.4
2	50	67	50	0	0	167	8.6	2.4	11.0
3	50	67	25	25	0	167	8.2	2.3	10.5
4	50	67	0	50	0	167	8.0	2.8	10.8
5	50	67	0	0	50	167	8.0	2.7	10.7
224 kg N/ha									
1	67	90	0	0	0	157	8.3	1.9	10.2
2	67	90	67	0	0	224	8.6	2.4	11.0
3	67	90	33.5	33.5	0	224	8.4	2.8	11.2
4	67	90	0	67	0	224	8.2	2.8	11.0
5	67	90	0	0	67	224	8.2	3.0	11.2
						LSD (.05)	= 0.5	0.3	0.5

[a]PP = preplant, PF = permanent flood, PD = panicle differentiation, Hd = heading, Hd2 = 2 wk after Initial heading. [b]Ratoon crop yield when no N was applied at main crop harvest.

Ratoon tiller regeneration occurred sooner and the ratoon crop matured 7-10 d earlier when the postflood N was applied one-half at heading, all at heading, or all 2 wk after heading, compared with when the postflood N was applied at PD. Earlier ratoon crop maturity should improve chances for a better growing climate and reduce risk (10).

Effect of N applied after main crop harvest on ratoon yield

Tables 4 and 5 show the ratoon crop yield potential of both cultivars when the main crop stubble is in good condition for ratoon crop production and N application rates after main crop harvest are 0, 56, and 112 kg N/ha. As N rate increased to 56 kg N/ ha, the ratoon crop yield increased from 0.3 to 0.9 t/ ha. Maximum yield increase to 112 kg N/ha for both cultivars was 1.1-1.2 t/ha. Good ratoon crop yields (2.6t/ha for Labelle and 2.8 t/ ha for Lemont) can be obtained when main crop yields are relatively low (Fig. 1, Table 1), N is applied only at preplant and just before flooding, and 112 kg N/ ha is applied after main crop harvest.

CONCLUSIONS

The amount of N applied to main crop at the PD stage did not influence ratoon crop yields. Good ratoon yields (2.6 and 2.8 t/ha) can be obtained under Texas climate when main crop yields are relatively low (4.9 t/ha for Labelle and 7.5 t/ha for Lemont), provided main crop stubble is healthy.

Applying N at or near main crop heading rather than at PD increased ratoon crop yields but decreased main crop yields, resulting in only a slight increase in total

Table 4. Labelle ratoon crop yield as influenced by N applied immediately after main crop harvest at Beaumont, Texas.

Main crop postflood N timing[a]	N applied after main crop harvest (kg/ha)	Average ratoon crop yield (t/ha), 1984 and 1985	
		Low main crop N	High main crop N
No application	0	1.8	1.1
	56	2.3	2.3
	112	2.6	2.8
PD	0	1.7	1.6
	56	2.4	2.4
	112	2.8	2.7
PD and Hd	0	1.7	1.7
	56	2.6	2.5
	112	2.9	2.9
Hd	0	1.8	1.8
	56	2.5	2.5
	112	2.7	2.7
Hd2	0	1.8	2.0
	56	2.3	2.6
	112	2.7	2.8
		LSD (.05) = 0.2	

[a]PD = panicle differentiation, Hd = heading, Hd2 = 2 wk after initial heading.

Table 5. Lemont ratoon crop yield as influenced by N applied immediately after main crop harvest at Beaumont, Texas.

Main crop postflood N timing[a]	N applied after main crop harvest (kg/ha)	Average ratoon crop yield (t/ha), 1984 and 1985	
		Low main crop N	High main crop N
No application	0	1.9	1.7
	56	2.6	2.3
	112	2.8	2.9
PD	0	1.7	1.8
	56	2.5	2.2
	112	2.7	2.6
PD and Hd	0	2.0	2.2
	56	2.5	2.5
	112	3.1	3.2
Hd	0	2.2	2.1
	56	2.9	2.8
	112	3.5	2.9
Hd2	0	2.4	2.2
	56	2.9	2.7
	112	3.3	3.1
		LSD (.05) = 0.25	

[a]PD = panicle differentiation. Hd = heading, Hd2 = 2 wk after initial heading.

rice yields. Data suggest that N application at main crop PD followed by N applications near main crop heading would increase total yields of certain varieties. However, additional experiments will be required to verify this.

Applying one-half or all of the postflood N at heading or 2 wk after heading rather than at PD provided earlier ratoon crop tillering and 7-10 d earlier ratoon crop maturity.

Nitrogen fertilizer applied immediately after main crop harvest has a more evident and positive influence on ratoon crop yields than N applied before main crop harvest.

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Insect pests and their natural enemies in ratoon rice

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ABSTRACT

A ratoon crop is potentially at risk from insect pests because it extends the time rice is available as a host. With its shortened vegetative stage, a ratoon crop is unsuitable to early season insects — whorl maggot *Hydrellia philippina* and caseworm *Nymphula depunctalis.* Stem borer numbers are severely reduced at main crop harvest, but some survive to attack the ratoon crop. Leaffolder infestation is higher at the vegetative stage on a ratoon crop than on a sown main crop. The lack of land preparation in establishing a ratoon crop allows a high carryover of natural rice pest enemies, particularly of the predators which prevent significant buildups of brown planthopper, whitebacked planthopper, and green leafhopper. Virus diseases on the main crop pose the most serious insect-related problem in ratoon rice.

As with any system that intensifies production, double rice cropping involving a ratoon crop may create a higher risk of pest buildup. Intensified cropping that extends the time rice is available allows more insect generations per year. Insect populations increase exponentially with time. In theory, ratoon rice should sustain higher insect populations than a single or a double rice crop separated by a fallow or rotation with a nonrice crop (20).

During a rice-free period, specializing pests must either subsist on suboptimal hosts, on which their rate of increase is low or negative; enter a quiescent or dormant stage, during which they are often subject to severe mortality; or undertake highly risky, long distance dispersal. The potential increase of a pest population over the annual cycle depends on the length of time rice is available.

Loevinsohn et al (21) indicate that increasing the cropping intensity within a contiguous area greater than 1 km^2 (314 ha) can encourage insects that are rice specialists. Brown planthopper (BPH) is an exception, it has a dispersal range of 2 km. Using a composite index of spatio-temporal intensity/number of "hectare days," Loevinsohn et al showed exponential increases in populations of five rice insect pests.

The effect of a ratoon crop on pest populations could be positive, negative, or neutral. Insect groups that prefer the vegetative stage should decrease, because the vegetative stage is radically shorter in a ratoon crop. Insect groups that have no particular preference for a crop growth stage or that prefer the reproductive or ripening stages should stay the same, or increase.

Except for rice whorl maggot (KWM) *Hydrellia philippina* (12), ratoon crops have been reported to harbor rice insect pests that primarily attack late vegetative and reproductive stage crops. Examples are gall midge (GM) *Orseoli oryzae* (10, 18, 28, 35), tarsonemid mite *Steneotarsonemus spinki* (11), stem borers (SB) *Scirpophaga incertulas* and *Chilo suppressalis* (6, 8, 14, 17), and leaffolder (LF) *Cnaphalocrocis medinalis* (5). Vectors and the related virus diseases also show up: BPH *Nilaparvata lugens* and grassy stunt (15, 23, 26), whitebacked planthopper (WBPH) *Sogatella furcifera* (22) and green leafhopper (GLH) *Nephotettix virescens* and tungro virus (24, 29, 33). Yellow dwarf virus vectored by *Nephotettix* spp. and *Recilia dorsalis* is known as the ratooning disease, because it most often shows up on a ratoon crop (19).

Work at CRRI (3) compared the suitability of ratoon and direct-seeded crops as hosts to pink stem borer (PSB), striped stem borers (SSB), and GM but found no differences.

The stability of GLH and BPH resistence in a ratoon was studied by Wilde and Apostol (34). They found a slightly lower level of resistance in an older ratoon crop than in a direct-seeded crop.

On the other hand, a ratoon crop may also be a favorable environment for natural enemies of rice pests. Agronomic preparation does not involve habitat-disturbing land preparation, Higher rates of GM parasitization were observed in a ratoon crop because parasite numbers increase toward the end of the wet season (18).

In areas where irrigation and drainage are well developed and where labor costs are high, farmers increasingly are direct seeding pregerminated rice (wet-seeding) rather than transplanting. It is not known whether crop establishment method alters insect pest or natural enemy populations in the succeeding ratoon crop.

Standing water in a rice paddy attracts aquatic insect pests such as RWM and caseworm (CW) as well as aquatic natural enemies such as the ripple bug. Ratoon crops may or may not get standing water.

We designed a study to

1. compare the population buildup of insect pests and their natural enemies in a ratoon crop and a seeded second crop;
2. determine if water management and crop establishment method affect arthropod abundance; and,
3. assess the suitability of a ratoon crop as host to rice insect pests.

MATERIALS AND METHODS

In the 1983 wet season, a field trial at IRRI compared the population buildup of insect pests and natural enemies in a ratoon and in a seeded second crop and examined the effects of crop establishment methods and water regimes on arthropod populations. In the same year, the suitability of a ratoon crop as host to nine rice insect pests was studied in the greenhouse.

Field trial

Transplanted and wet-seeded main crops of IR1917 (susceptible to insects but resistant to tungro) were grown side by side. To ensure the same maturity date, the wet-seeded crop was sown at 120 kg seed/ha 2 wk ahead of transplanting. No pesticides were used. Nitrogen was applied at 100 kg N/ha in 3 equal splits: basal, maximum tillering, and panicle initiation. P_2O_5 and K_2O at 30 kg/ha were basally applied.

The field was kept weed free and ponded 3-5 cm deep throughout the growing period. Prior to harvest, the field was divided into 24 bunded plots (9 × 12 m) for a randomized complete block design. Twelve plots were thoroughly plowed and puddled and half wet-seeded, half transplanted for second crops. Mature plants were ratooned in the other 12 plots by cutting stalks at 15 cm. Canals gave independent irrigation to each plot. Water was supplied continuously (flooded 3 times a week) or intermittently (flooded once a week for 1 d).

Fertilizer (60 kg N/ha) was broadcast in the ratoon 1 d after harvest of the main crop and basally applied in the transplanted and wet-seeded second crop.

Main crops were sampled weekly for leafhoppers and planthoppers and their natural enemies with a FARMCOP suction machine (2). Sampling on the ratoons and second crops was twice a week. FARMCOP samples of 1 m^2 were taken from 3 sites selected at random in each plot in a stratified grid on each sampling date.

A similar sampling area was used to determine RWM, LF, and SB numbers.

Greenhouse trial

Ratoon and transplanted check plants were studied for their suitability as hosts to insects that prefer to feed on rice at the vegetative stage (RWM, CW, green semilooper [GS], and green hairy caterpillar [GHC]) and to insects that can attack rice from the vegetative to ripening stages (BPH, GLH, WBPH, YSB, and LF).

To grow the ratoon, we transplanted IR1917 seedlings in earthen pots 30 cm in diameter and 25 cm high. When the plants matured, they were cut 15 cm above the soil surface. The check was grown by transplanting 30-d-old seedlings in pots of the same size filled with puddled soil. Both ratoon and transplanted rice were grown with and without 60 kg N/ha.

When ratoon and transplanted rice were 3 wk old, they were covered with cylindrical mylar film cages (10 × 75 cm) with nylon mesh windows on 1 side and on top. These gave access to measure insect survivorship, development period, and weight, the criteria for assessing host suitability. Each treatment was replicated six times in a randomized complete block design.

Survivorship, weight, and developmental period were determined separately for all species except whorl maggot. Ten first-instar larvae or nymphs were introduced into the cages over the potted plants, using an aspirator or a fine camel hair brush. Plants were hand-infested with greenhouse-collected mature RWM eggs (dark color) by inserting a leaf section containing the eggs into a slit made on an unfurled leaf or between the youngest leaf and leaf sheath (10 per plant).

Insect survivorship was calculated as the percentage of individuals surviving to adulthood. Developmental period was considered the number of days from first instar to adulthood. Insects were allowed to develop for 10 d, then weighed together using a Mettler ME balance (5 µg sensitivity).

The oviposition preference of the same nine insect species was studied as another basis for evaluating the suitability of ratoon as an insect-host crop. Potted 3-wk-old ratoon and transplanted plants with and without 60 kg N/ha were randomly arranged inside a nylon mesh cage (100 × 15 × 75 cm). Each setup of four treatments was replicated six times in a randomized complete block design.

Ten pairs of adults less than 3 d old were introduced into each cage and allowed to oviposit for 7 d. Egg production was determined in the greenhouse, except for hoppers. Those eggs were counted by dissecting tillers and leaf sheaths under a stereomicroscope.

RESULTS AND DISCUSSION

Insect pest population dynamics

The ratoon crop was less attractive to RWM (fewer eggs and damaged leaves were recorded) than was the seeded second crop (Table 1), probably because ratoon plants covered more of the paddy water during early crop growth period than did plants of the seeded second crop. More sunlight reflecting on the water surface of the

Table 1. Effect of crop establishment methods and flooding regimes of the second crop on insect pests and their predators.[a] IRRI, Aug 1983-Feb 1984.

Arthropod	Crop establishment method[b]			Seeding method[c]			Flooding regime[d]		
	Ratoon	Seeded	Δ	TPR	WSR	Δ	Intermittent	Continuous	Δ
Whorl maggot[e] (nœggs/m^2)	0.6	1.4	**	1.4	2.8	**	2.0	2.2	ns
Whorl maggot[f] 30 DT (%damaged leaves)	0.8	2.4	**	11.3	14.8	**	2.9	2.9	ns
Leaffolder[g] (%damaged leaves)	0.6	0	**	0.3	0.4	ns	0.4	0.3	ns
Green leafhopper[h] (no./m^2)	0.6	1.4	**	1.1	1.9	**	1.7	2.2	··
Whitebacked planthopper[h] (no./m^2)	1.1	1.8	**	0.9	0.9	ns	0.9	1.0	ns
Brown planthopper[h] (no./m^2)	0.9	0.7	ns	0.8	0.7	ns	0.6	0.9	ns
Spiders[h] (no./m^2)	9.5	3.9	**	7.2	6.2	ns	4.1	9.3	··
Ripple bug[h] (no./m^2)	15.4	11.9	ns	11.3	14.4	ns	7.9	9.4	··
Mirid bug[h] (no./m^2),	0.3	1.1	**	0.4	0.9	**	0.6	0.8	ns
Stem borers[i] (% Infested tillers)	0.4	0.1	**	0.3	0.1	**	0.1	0.2	ns

[a]Av of 3 replications. ns = not significant at P = 0.05; ** = significant at P = 0.01, [b]Av over seeding methods and flooding regimes. [c]Av over crop establishment methods and flooding regimes. [d]Av over crop establishment and seeding methods. [e] 1 m^2 sampled weekly 3-7 WT. [f]1 m^2 sampled at 30. DT. [g] 1 m^2 sampled 40 DT.[h] 1 m^2 sampled twice a week (18 times) with FARMCOP sampler. [i]1 m^2 sampled unit In 3 locations per date over 7 sampling date.

seeded second crop could have attracted more ovipositing adults. It is also possible that the ratoon was less attractive to RWM because it has an abbreviated vegetative stage. RWM prefer young, actively tillering plants.

Although RWM are attracted to flooded fields, we found no difference in infestation levels between continuous and intermittently flooded fields. This does not agree with Karim's findings (16). He reported that maintaining a flooded field attracted more ovipositing RWM.

Transplanted rice plots provided less plant cover over the paddy water, resulting in fewer eggs and damaged leaves than the more rapid canopy development in wet-seeded rice. This again does not agree with findings elsewhere, indicating that the ovipositional preference of RWM for a less dense crop was superseded or modified by other factors in this experiment.

We posit two reasons why a wet-seeded crop, whether ratooned or seeded, appeared more attractive to RWM. First, the ratoon from a wet-seeded main crop developed more basal tillers than the ratoon from a transplanted main crop. Tillers that emerged from the base of the stubble were considered physiologically younger than the nodal tillers that appear immediately in the cut stubble after harvest. It is likely that ovipositing whorl maggots were more attracted to the basal than to the nodal tillers. Second, the wet-seeded second crop, established 2 wk earlier than the transplanted rice second crop, could have been exposed to higher RWM populations.

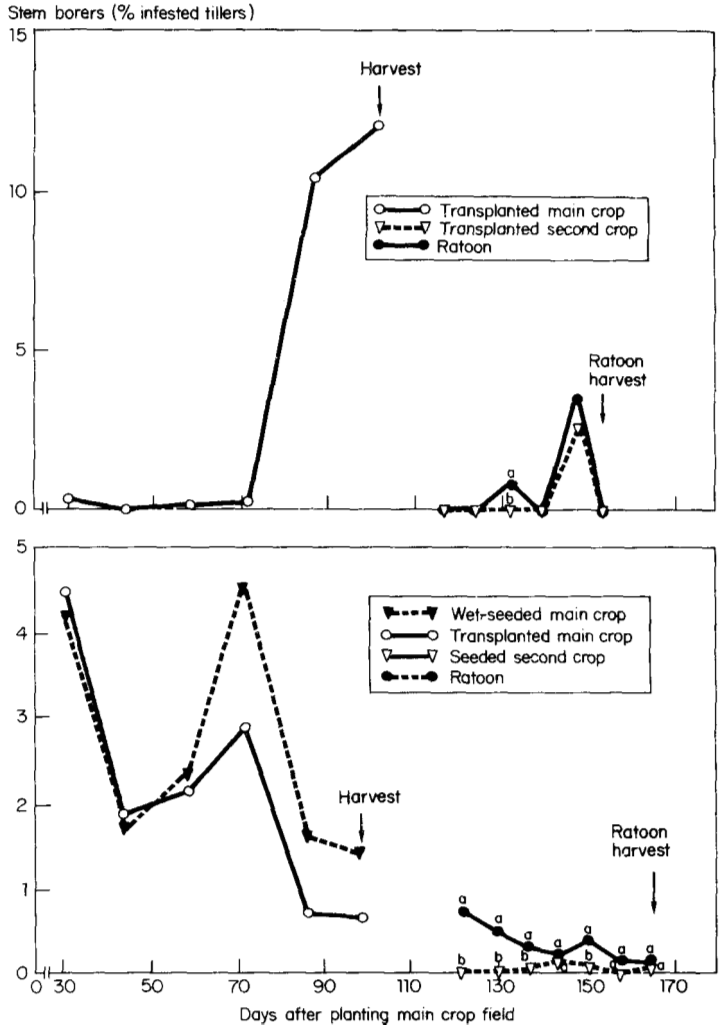
LF numbers which did not represent a carryover from the main crop were low overall (less than 1% damaged leaves), but significantly more occurred on the ratoon crop than on the seeded second crop (Table 1). It is unlikely that the reproductive-stage ratoon, which has larger leaves, was more attractive to ovipositing LF than the vegetative-stage seeded second crop. Neither water regime nor seeding method affected LF, again indicating that LF prefers older rice.

SB infestation (deadhearts or whiteheads) was much less on the ratoon crop and seeded second crop than on the main crops (Fig. 1), but a significantly higher infestation occurred on the ratoon than on the seeded second crop (Table 1 and Fig. 1). Larvae were carried over to the ratoon and recolonization of ovipositing moths was greater. Duport (7) found a ratoon crop attractive to ovipositing YSB.

However, the initially high SB populations on the ratoon declined progressively with crop age, indicating a lack of new colonization. Harvesting the main crop further removed a substantial proportion of stem borer larvae and pupae, reducing their potential to increase in the ratoon.

SSB *Chilo suppressalis* and dark-headed stem borers (DHSB) *C. polychrysur* were equally prevalent on the main crop; populations of YSB *Scirpophaga incertulas* and PSB *Sesamia inferens* were low (Table 2). Young larvae of SSB and DHSB predominated on the young ratoon, suggesting that these insects would readily oviposit on a ratoon crop. The seeded second crop had no older larvae or pupae, indicating that infestation occurred late.

The transplanted rice plots had higher SB populations than the wet-seeded rice plots, which may be a reflection of the lower tiller numbers in transplanted rice (Table 1).



1. Stem borer occurrence on main rice crop, ratoon crop, and seeded second crop (P= 0.05). IRRI. Aug 1982-Jan 1983 (top) and Aug 1983-Feb 1984 (bottom).

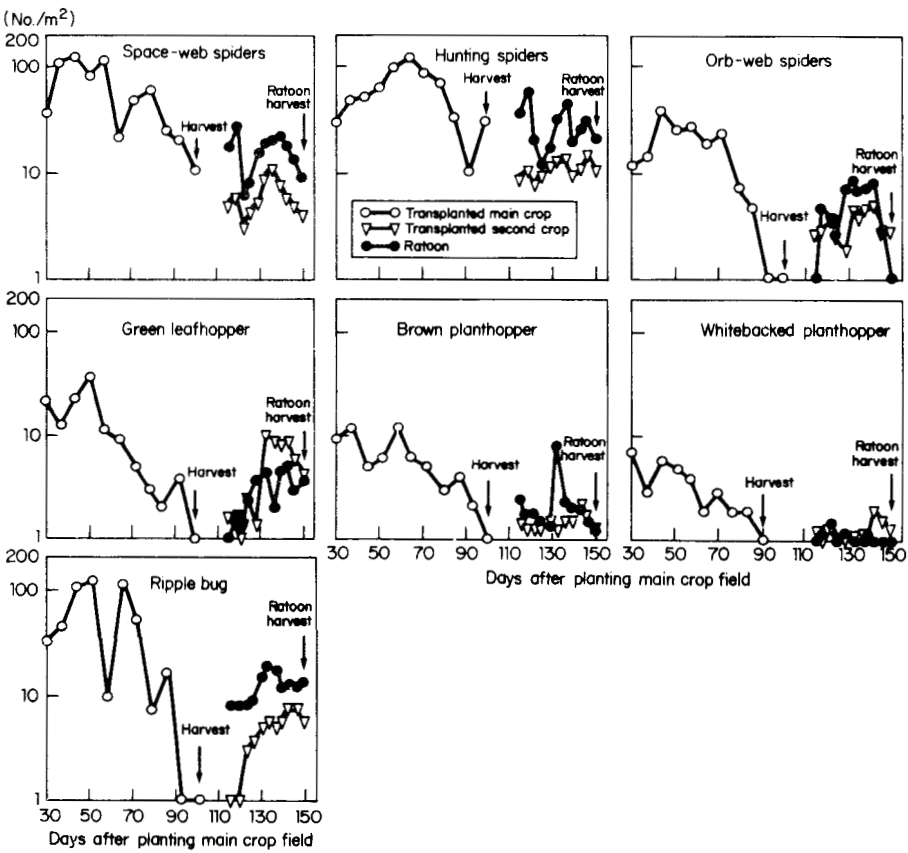
GLH numbers peaked during the late vegetative stage of the main crops but declined at the reproductive stage (Fig. 2, 3). Numbers on both ratoon and seeded second crops were so low that generation peaks could not be discerned, but significantly fewer occurred on the ratoon than on the seeded second crop.

Significantly more GLH were found in the wet-seeded than in the transplanted plots, indicating that closer plant spacing encouraged multiplication of this insect (Table 1). Perhaps fewer GLH parasitized in the wet-seeded plots because the plants had more tillers and a dense canopy, which could have affected the host-searching capacity of the parasites. For example, fewer SB egg masses are found in wet-seeded than in transplanted rice (13).

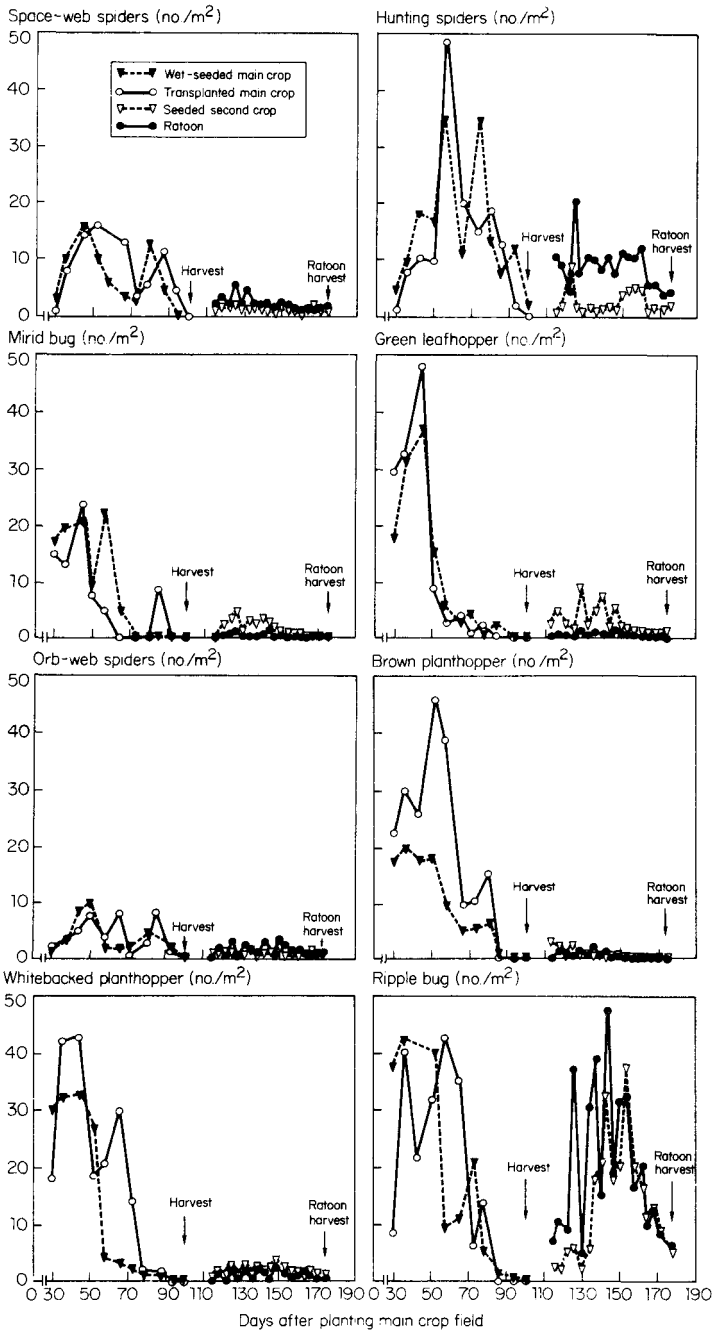
Table 2. Abundance of four SB species on a ratoon and seeded second crop.[a] IRRI. Nov 1983-Feb 1984.

Stem borer species	Main crop[b]			Ratoon[c]			Seededsecond crop[c]	
	Larvae + pupae (no./m^2)		Species composition (%)	No./m^2		Species composition (%)	Larvae + pupae[d] (no./m^2)	Species composition (%)
	Stubble	Straw		L1-L3	L4-pupa			
Chilo suppressalis	11	3	40	21	6	49	4	33
C. polychrysus	10	2	34	11	1	22	4	33
Scirpophaga incertulas	2	3	15	5	6	20	3	25
Sesamia inferens	1	3	11	5	0	9	1	9
Total	24	11		42	13		12	

[a]AV of 3 replications. AV Of TPR and WSR treatments, [b] Sampled at harvest. [c] Sampled weekly from 15 d after ratooning or planting until date of ratoon harvest, L = larval instar. [d] All larvae younger than L3.



2. Population dynamics of hoppers and their predators on the transplanted main rice crop, ratoon crop, and transplanted second crop. IRRI, Aug 1982-Jan 1983.



3. Population dynamics of hoppers and their predators on the main rice crop, ratoon crop, and seeded second crop. IRRI, Aug 1983-Feb 1984.

The increase of GLH on the wet-seeded plots could be attributed to density dependence. In wet-seeded plots, there was more plant surface to exploit, offering less crowded conditions than in transplanted plots. Continuous flooding also significantly affected GLH numbers. More GLH were attracted to an aquatic environment. Ghose et al (9) noted more GLH in ill-drained habitats.

Like the GLH, WBPH numbers peaked at the late vegetative stage, then declined rapidly, regardless of planting method (Fig. 2, 3). Even though low levels of WBPH occurred on the second crop, significantly fewer occurred on the ratoon than on the seeded crop (Table 1). Seeding method or water regime had no effect on WBPH numbers.

The transplanted main crop developed higher BPH numbers than the wet-seeded main crop, but populations markedly declined with plant age in both seeding methods (Fig. 2, 3). BPH numbers in ratoon and seeded second crops were extremely low, which may explain why no significant differences were found (Table 1).

Natural enemy population dynamics

Spider numbers closely tracked GLH and planthopper numbers in the main crop. Hopper numbers rose slowly on vegetative rice, but second generations showed a rapid increase. Spiders increased in number during the reproductive stage (Fig. 2, 3). Hunting spiders were twice as abundant on the main crop as were space-web spiders and five times more prevalent than orb-web spiders. The rank order of spider abundance on the main crop carried over to the ratoon, where spiders were more abundant than on the seeded second crop. The ratoon, being undisturbed after harvest of the main crop, was a refuge for spiders. It is also highly probable that the spiders foraged from the ratooned plots to the seeded second crop plots in response to the presence of more prey, explaining why hopper numbers in general were low on all second crops (30).

The hunting spiders were dominated by *Lycosa pseudoannulata,* which maintained an even population level throughout the ratoon crop. Space-web spider *Atypena* (=*Callifrichia*) *formosana* numbers declined slightly as the ratoon matured. Because it makes its webs at the base of tillers, *A. formosana* and the highly mobile hunting spiders can readily colonize a new crop or remain unaffected during harvest and growth of a ratoon.

Orb-web *Tetragnatha* spp. and *Dyschiriognatha* sp. spider numbers were lowest on the ratoon. They were more devastated during harvest of the main crop than the other groups because they need a tall crop from which to suspend their webs. These spiders normally become abundant during later growth stages. They declined in numbers at harvest of the main crop, when hoppers had dispersed to colonize younger crops.

Spider numbers did not significantly differ in transplanted and wet-seeded crops. Significantly more spiders occurred on continuously flooded than intermittently flooded plots (Table 1), probably reflecting the higher GLH numbers on the flooded plots.

Microvelia ripple bug and *Cyrtorhinus* mirid bug declined with crop age on the main crop but were capable of rapid colonization of newly planted fields (Fig.

2, 3). *Microvelia* was highly abundant on the main crop and regained a high level on both the ratoon and seeded second crops after an initial population buildup.

As would be expected of an aquatic species, significantly more *Microvelia* occurred on continuously flooded plots.

The *Cyrtorhinus* population was severely reduced by the main crop harvest, probably because their eggs were removed in the straw. Numbers built up slowly on the seeded second crop, then rapidly declined as the crop matured. Populations were continuously low on the ratoon crop, perhaps in response to GLH numbers. The difference in *Cyrtorhinus* numbers between the seeded second crop and the ratoon crop was significant. The higher numbers of GLH on the wet-seeded plots may also explain why *Cyrtorhinus* was significantly more abundant on wet-seeded plots than on transplanted plots.

Significantly fewer GLH occurred on the ratoon, apparently because of high numbers of *Lycosa* hunting spiders. Sasaba and Kawahara (31) underline the importance of *Lycosa* in regulating GLH population. They observed that this spider climbed rice plants at night. Because GLH usually inhabit the upper canopy, it is likely that *Lycosa* encountered more GLH than other hopper species.

Orb-web spiders spin their webs in the rice canopy where GLH live; they also could have selectively preyed on more GLH.

On the other hand, high numbers of *Atypena* space-web spider on the ratoon crop explained the significantly low numbers of WBPH. This small spider could have exerted considerable control of WRPH because of its habit of constructing webs between rice tillers at the base of the rice plants, where WBPH also live.

The equal abundance of ripple bugs on both the ratoon crop and the wet-seeded second crops probably explained the lack of difference in BPH numbers on both ratoon and seeded second crops. Because the ripple bug prefers small hopper nymphs (25), its impact on the pest population should be greatest right after egg hatch. This was confirmed in a preliminary cage experiment with BPH in which the pest population was reduced by ripple bug after hatch. Under normal field conditions, BPH frequently fall off plants to be attacked by *Microvelia*.

Suitability of ratoon as insect host

Results show ratoon rice as a poor host for RWM, CW, and GSL; survival and body weight of these insects were low (Table 3). The GHC, LF, and GLH reared on ratoon rice also showed body weight reductions, indicating that ratoon rice is less nutritious than transplanted rice. However, developmental periods of insects tested on ratoon and transplanted rice did not differ significantly.

Perhaps leaf toughness of the ratoon plant was responsible for the weight differences and lower survival rates of some insect pest species studied. Tough mature leaves and stems make feeding difficult for larvae, nymphs, or maggots, decreasing the rate at which they can ingest leaf material and minimizing any potential for increased feeding rates that could compensate for the low nutrient content of the leaves. Toughness of the leaves or stems of the host plants has been shown to inhibit feeding by several other species of phytophagous insects (1, 27, 32). These studies suggest that leaf toughness by itself may often function as a defense mechanism against phytophagous insects. It is also possible that toxic secondary

Table 3. Comparison of the host quality of ratoon and transplanted rice for nine rice pests.[a] IRRI Greenhouse. 1983.

Pest species	Crop establishment method[b]	Survivorship[c] (%)	Weigh[d] (mg/insect)	Developmental period[e] (days)	No. of eggs/ egg mass laid 10 ♀♂
Whorl maggot	Ratoon	8	0.2	24.5	29.2
	Transplanted	53	0.8	23.7	10.5
	D	**	**	ns	*
Caseworm	Ratoon	29	7.8	29.7	0.0
	Transplanted	49	11.4	29.3	107.1
	D	*	**	ns	**
Green hairy caterpillar	Ratoon	89	9.2	17.8	13.5
	Transplanted	85	15.6	17.9	40.2
	D	ns	**	ns	ns
Green semilooper	Ratoon	25	13.2	15.3	26.7
	Transplanted	37	20.5	14.9	15.1
	D	**	*	ns	ns
Leaffolder	Ratoon	55	13.6	26.1	10.5
	Transplanted	63	20.1	26.5	7.0
	D	ns	**	ns	*
Yellow stem borer	Ratoon	48	6.0	30.9	2.7
	Transplanted	22	8.9	31.8	3.5
	D	**	ns	ns	ns
Brown planthopper	Ratoon	87	0.9	14.9	51.0
	Transplanted	75	1.1	14.9	93.4
	D	ns	ns	ns	ns
Whitebacked planthopper	Ratoon	81	0.6	13.5	48.9
	Transplanted	78	0.7	13.8	15.8
	D	ns	ns	ns	**
Green leafhopper	Ratoon	52	0.7	18.4	28.1
	Transplanted	47	1.1	18.6	29.5
	D	ns	*	ns	ns

[a]AV of 6 replications. ns = not significant P = 0.05; * = significant at P = 0.05; ** = significant at P = 0.01. Analysis were based on values transformed to log (X) or square root (X + 0.5). [b]Av over 2 nitrogen rates. [c]Except whorl maggot, where matured eggs were used, 10 instar I placed on 3-week-old plants and allowed to develop into adults. [d]Except whorl maggot, where matured eggs were used, 10 instar I placed on 3-week-old plants and allowed to develop for 10 days. [e]Except whorl maggot, where matured eggs were used, 10 instar I placed on 3-week-old plants and allowed to develop into adults. [f]Ten mated pairs of recently emerged adults except whorl maggot and yellow stem borers were adults directly collected from the field allowed to oviposit for 7 days.

plant chemicals are produced in older rice plants, limiting population buildups of these pests.

Significantly more YSB survived in the ratoon crop than in the transplanted crop. That higher survival was attributed to the better niche (large diameter stem) provided by the ratoon crop than by a young seeded crop.

Attempts to determine the ovipositional preference of the nine test insects were not completely successful. Results were highly variable for certain species. In contrast to the results of the field trial, RWM laid significantly more eggs on ratoon than on transplanted rice (Table 3). This is difficult to explain on the basis of the crop growth stage preferred. It is probable the RWM confined in a cage cannot fly high enough to see water reflection, so it lays its eggs on the tallest plants.

CW laid significantly more eggs on transplanted rice than on ratoon; that ovipositing moth prefers to lay eggs on leaves that droop into the water (4). Caseworm was deprived of oviposition sites on ratoon because its leaves do not touch water.

Leaffolder and whitebacked planthopper laid significantly more eggs on ratoon than transplanted rice, perhaps these insects prefer reproductive- to vegetative-stage rice, if given a choice (Table 3). No significant differences were observed in the number of eggs/egg masses by the other test insects.

Virus diseases

Insect-vectored virus diseases pose a continual threat to ratoon crops. During the 1984 dry season field trial, 14% of the ratoon hills were infected with yellow dwarf and 4% with tungro virus; none were infected on the transplanted second crop. IR1917, although resistant to tungro, still contracted the virus in the ratoon. The fact that the transplanted crop was virus free meant that the viruses were transmitted in the later growth stages of the main crop, when the fully grown plants showed no symptoms. Becauses the viruses are systemic, there is no way to directly protect a ratoon crop from the disease carryover. It also is not feasible to prevent virus infection during the later growth stages of the main crop.

CONCLUSIONS

This study demonstrates that:

- The ratoon is a poor host for RWM and CW and will not encourage buildup of these insects. It has an abbreviated vegetative stage not suitable for their growth and development. These insects prefer young and actively tillering rice plants.
- Leafhoppers and planthoppers leave a senescing crop, but the highly mobile insects readily colonize ratoon fields. However, they are less serious on the ratoon because their initial population will be controlled by natural enemies carried over from the main crop.
- About 1/3 of SB numbers can be carried over from the main crop stubble to the ratoon. Stem borers will also oviposit and build up on a ratoon, but because a ratoon is harvested early, they are not expected to be serious.

- The ratoon is attractive to LF because that insect prefers reproductive-stage rice plants. LF probably is more attracted to larger leaves.
- The ratoon is a favorable habitat for natural enemies, particularly predators, because of the lack of land preparation. Spiders and ripple bugs, major hopper predators, tend to accumulate on the rice stubble after harvest and are better able to respond to initial hopper influx. Ratoon cropping may enhance early biocontrol.
- Flooding a field continuously is an insect pest predator conservation cultural practice.
- Varieties highly resistant to virus diseases are necessary for ratoon stability.

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Diseases and disease management in rice ratoon crops

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Little has been reported on diseases and disease management in relation to ratoon rice. Two aspects of disease management are important considerations in ratoon rice crop production.

First, the speculation is that ratoon rice will manifest a disease problem because the inoculum is likely to be perpetuated from main crop to ratoon crop; available host tissues for continuous infection are also prolonged. Few data and reliable information have been reported in the literature. The general belief among plant pathologists is that, like volunteer rices or stubble left in fields, a ratoon crop will provide ample reservoir for diseases to continue to cause damage and for the inoculum to perpetuate, ready to cause secondary and tertiary infection.

Second, with the development of genetic resistance to diseases in many rice cultivars, it is assumed that the ratoon crop will possess the same degree of resistance.

This paper examines these issues. The sources of information are predominantly our own observations over the past several years of monitoring disease development in main crops and ratoon crops on IRRI farms. Experiments on the effects of disease management in main crops on ratooning and on disease development in ratoon crop are also reported.

DISEASES OF MAIN AND RATOON CROPS

The diseases commonly observed in main rice crops can also be found in ratoon tillers. Also, the diseases to which a rice cultivar is known to be resistant are absent in the ratoon rice. Yellow dwarf, caused by a mycoplasma-like organism which has a 1-3 mo latent period in rice plants, depending on the temperature (4), is often observed in ratoon rice (Fig. 1, Table 1). Yellow dwarf is transmitted by *Nephotettix cincticeps, N. virescens,* and *N. nigropictus.* In addition to the long latent period in the plants, the incubation period in the vector insect body is usually 25-30 d. Yellow dwarf was observed on ratoon crops of susceptible cultivar IR32.

Rice ragged stunt is a new virus disease, found in South and Southeast Asia 1977-79. The spherical virus is transmitted only by nymphs and adults of *Nilaparvata lugens* (Stål). Symptoms of the systemic disease are also manifested in ratoon rice (2). In a survey of ratoon rice on 9,000 ha of ricefields in Malaysia after the main crop had been harvested, Ooi (3) reported finding a low level of rice ragged stunt. He attributed the low incidence on ratoon rice to the absence of disease on off-season rice, when the vector was prevalent.

1. Yellow dwarf commonly observed on ratoon crop developed from rice cultivar IR32.

Table 1. Diseases of IR32 and IR50 on main crop and ratoon tillers. IRRI, 1980.

Disease	IR32		IR50	
	Main crop	Ratoon tillers	Main crop	Ratoon tillers
Yellow dwarf	–	+	–	+
Sheath blight	+	+	+	+
Stern rot	+	+	+	+

+ = Incidence, – = no incidence.

Bacterial stripe caused by *Pseudomonas setariae,* which often occurs in nurseries, was also observed on ratoon tillers (Fig. 2). The seedborne bacterial pathogen causes seedling blight. Its occurrence on ratoon tillers indicates that, although signs of infection are not evident on mature plants, yet the bacteria are present, most likely as epiphytes on plant surfaces.

Sheath blight, caused by *Rhizoctonia solani (Thanatephorus cucumeris),* and stem rot *(Sclerotium oryzae)* are often observed on main rice crops on the IRRI farm and on farmers' fields elsewhere in the Philippines. The relationship of the two diseases in main and ratoon crops was monitored at IRRI Farm.

In a field planted to selected rice cultivars and breeding lines being screened for sheath blight resistance, most of the rices exhibited a moderate level of resistance, but that resistance was not reflected in the ratoon crop (Table 2).

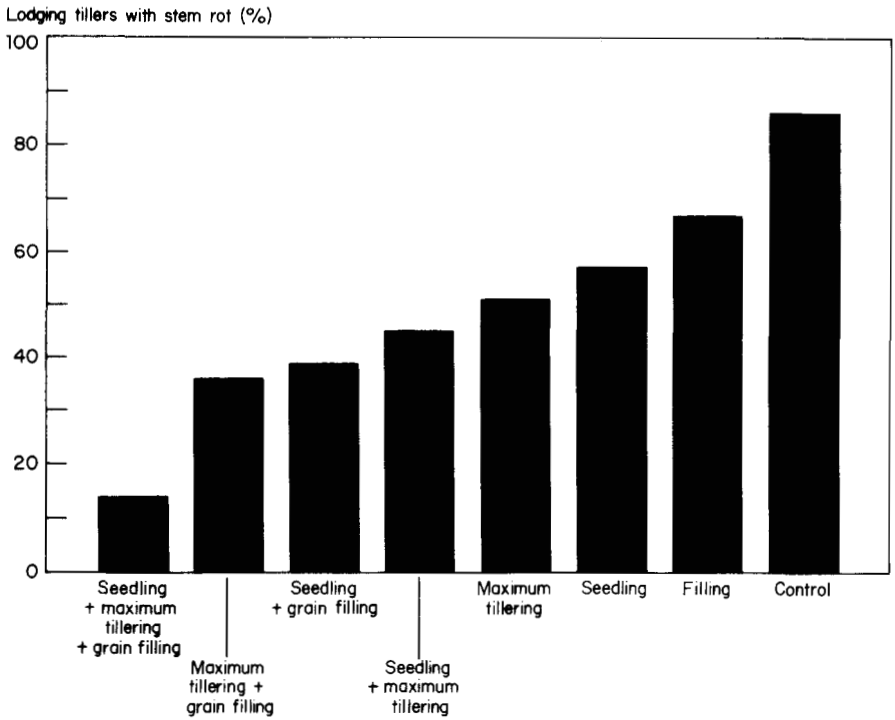
Stem rot incidence on these rice cultivars or breeding lines was high, but no correlation could be drawn between incidences on main and ratoon crops. Those

2. Bacterial stripe, a seedling disease caused by *Pseudomonas setariae,* occasionally occurs on ratoon tillers.

Table 2. Sheath blight severity and stem rot incidence on selected rim varieties and lines, 1979.

Variety/line	Sheath blight rating[a]		Stem rot[b]	Ratoon rating	
	Main crop	Ratoon crop	(%)	Tillers produced (%)[c]	Leaf color[d]
Bahagla	4.6	0	41.2	3	1
BR2-29-2-1-3	5.0	0	13.0	1	1
IR1544-340-6-1	4.7	0	13.2	2	1
IET4699	5.3	0	26.6	1	1
BR4	5.3	0.4	24.9	2	1
IR2070-423-2-5-6	5.0	0	0	1	1
IR2058-85-3-3	5.2	0	0	1	1
IR2793-97-3-2	5.0	0	16.9	1	1
Pankaj	5.0	0	17.8	1	1
IR2328-198-1-1-1	5.0	0	36.4	1	1
IR2071-588-4-4	5.0	0	40.4	1	1
IR2843-26-3-2	4.5	0	18.8	1	1
IR1910sel	5.0	0	37.9	1	1
IR2071-588-5-1-1	5.0	0	40.7	1	1
IR4531-10057-5-1-1	5.0	0	32.5	1	1
Tadukan	5.0	0	25.0	2	1
IR20	5.0	0	25.8	4	1
Suduwee	5.0	0	20.7	4	1
IR4422-98-3-6	5.3	0	48.7	4	1
Ta-poo-cho-z	5.0	0	60.6	2	1
Laka	5.0	0	0	2	1
IR36	4.8	0	29.6	2	1
IR1317	6.7	0	36.1	4	1
IR42	4.9	0	28.6	3	1

[a]Based on *Standard evaluation system for rice* 1); data taken from 12 inoculated hills/variety, only main crop inoculated. [b]taken from hills that did not produce ratoon. [c]1 = 75-100%, 2 = 50-75, 3 = 2j-50, 4 = 0-25. [d]1 = green, 2 = yellow.



3. The effect of fungicide application at different growth stages of the main crop on lodging of ratoon tillers with stem rot infection.

hills that did not produce ratoon tillers were shown to have a high incidence of stem rot (Table 2). Ratoon tillers with stem rot infection often lodged at later stages, which was not the case in the main crop (Fig. 3). When stubble of the main crop has severe stem rot infection, ratoon tillers regenerated from the stubble may be killed by the disease (Fig. 4). This shows the inoculum of infected stubble might be carried over to infect the ratoon tillers. The potential infectivity of such inoculum is probably influenced by field conditions at the time of ratooning.

The incidence of diseases of the main crop in the ratoon crop bears a close relationship to the kind of disease. During several years of studies, ratooning resulted in severe systemic infections of tungro, grassy stunt, and ragged stunt. If the infection started late in the main crop, disease in the ratoon crop was common and ratoon yields were minimal. But with diseases such as sheath blight and stem rot, unless the basal and auxillary buds of the stubble are killed, there is no positive correlation with their incidence on the ratoon crop.

The same phenomenon may be shown with bacterial blight caused by *Xanthomonas campestris* pv. *oryzae.* The bacterium invades the vascular system of the plants. In a screenhouse experiment, incidence and intensity of the disease varied in IR56 infected with different strains of the bacterial pathogen (Table 3). On hills in which infection resulted in kresek, no ratoon tillers were produced. If the plants were not killed, ratoon tillers regenerated and bacterial blight developed on those tillers.

4. Diseased ratoon tillers regenerated from stubbles with stem rot.

Table 3. Bacterial blight incidence and intensity on main crop and ratoon crop of IR56 in the screenhouse, IRRI, 1985 dry season.

Strain	Main crop[a]		Ratoon crop[b] Incidence (%)
	Incidence (%)	Severity (%)	
IRN 724	67.0	27.5	8.7
IRN 741	64.2	26.3	11.3
IRN 729	56.1	26.4	11.3
IRN 731	54.5	22.4	8.7
IRN 699	54.0	21.9	4.7
IRN 700	53.7	19.7	16.0
IRN 720	49.0	27.6	20.7
IRN 717	48.5	17.1	12.0
IRN 734	43.7	18.6	2.0
IRN 705	41.4	19.1	3.0
PXO 61	37.9	13.9	7.3
IRN 736	35.5	17.3	10.7
IRN 733	33.5	17.4	13.3
PXO 86	33.3	17.9	12.0
IRN 730	24.1	10.8	10.0

[a]Mean of 9 scores at 3 replications/strain taken at weekly Intervals from 11-49 d after Inoculation. Mean of 3 replications/strain taken about 1 mo after harvest.

Although the intensity was not high enough to kill the ratoon tillers, grain yield was reduced. The data also provide evidence that inoculum of the bacterial pathogen may be generated from ratoon tillers and stubble to infect a subsequent crop.

MAIN CROP DISEASE CONTROL AND RATOONING

Initial field observation has shown that diseases in the main rice crop usually affect ratooning and the kinds of diseases that occur on the ratoon crop. The effects of diseases caused by *Rhizoctonia solani* and *Sclerotium oryzae* were not always clear.

In the 1980 wet season, the effect of main crop disease management on ratooning of IR32 was studied. This cultivar is known to be resistant to some of the major rice diseases of the Philippines: blast, tungro, grassy stunt, ragged stunt, and bacterial blight. A fungicide mixture of benomyl-thiram was applied at different stages of rice growth (Table 4, 5). At harvest, rice stubble was cut about 15 cm high. Ratoon rating was at 35 d after ratooning.

Table 4. Chemical control of main crop and ratoon rice disease development on ratoon crop of IR32, IRRI, 1980.

Time of fungicide application[a]	Diseaseincidence[b] (%)					
	Main crop			Ratoon crop		
	SH	SR	YD	SH	SR	YD
Seedling	11.7	84	0	44.1	74	22.6
Maximum tillering	35.0	86	0	52.1	76	19.4
Filling	18.3	83	0	38.3	71	21.2
Seedling + maximum tillering	26.7	80	0	38.5	72	17.0
Seedling + filling	26.7	59	0	43.5	73	13.0
Maximum tiliering + filling	8.3	61	0	17.6	72	20.8
All three stages	8.3	60	0	19.7	66	18.0
Check	12.3	85	0	43.1	74	24.4

[a]Benomyl-thiram (20% ai.i.) at 1 g/liter H_2O. [b]SH = sheath blight, SR = stem rot, YD = yellow dwarf.

Table 5. Effect of fungicide application on stem rot infection of main rice crop and ratoon crop development.

Time of fungicide application[a]	Main crop		Ratoon crop				
	Stem rot (%)	Yield (t/ha)	Tillers/hill (no.)			Ratoon[b] rating	Yield (t/ha)
			Basal	Nodal	Total		
Seedling	84	8.1 a	10.1 a	8.1 abc	18.2	0.80 bc	1.3 ab
Maximum tiliering	86	7.8 a	12.0 a	6.4 bc	18.4	0.77 c	1.4 ab
Filling	83	7.7 a	10.5 a	6.2 bc	16.7	0.74 c	1.3 ab
Seedling + maximum tillering	80	6.7 a	11.5 a	5.6 c	17.1	0.77 c	1.5 ab
Seedling + filling	59	7.4 a	12.2 a	8.8 ab	21.0	0.85 bc	1.6 ab
Maximum tillering + filling	61	7.5 a	12.0 a	8.5 abc	20.5	1.00 ab	1.6 ab
All three strages	60	8.3 b	11.4 a	10.0 a	21.4	1.07 a	1.8 a
Check	85	7.3 a	10.2 e	7.0 bc	17.2	0.72 c	1.2 b

[a]Benomyl-thiram. [b]Ratoon rating = $1 - \frac{MH}{T_h} \times \frac{T_t}{16} \times (1 - 0.1 \times V)$, where 16 = av no. of tillers /hill, MH = missing hills, T_h = total no. of hills, T_t = total number of tillers (nodal + basal), V = vigor rating: 1 = extra vigorous, 5 = intermediate, 9 = weak.

The diseases common in this experiment were sheath blight, stem rot, and yellow dwarf. Sheath blight incidence in both the main and ratoon crops was not effectively controlled by fungicide. Differences among the treatments which could not be attributed to the fungicide were evident. Stem rot occurrence showed a similar pattern. Yellow dwarf was observed only on the ratoon crop, with 13-24.4% incidence (Table 4).

The ratooning ability was significantly improved with fungicide application (Table 5). The percentage of both basal and nodal tillers produced from plants receiving fungicide treatment was generally higher than from untreated plants. Obviously, the best ratoon ratings were from plants that received fungicide applications at all three stages: as seed dressing, at maximum tillering, and at grain filling.

Grain yields both from the main and the ratoon crops also increased despite the differences in yield, ratoon ratings, and percentage of ratoon tillers. Disease incidence was erratic. This seems to indicate that after main crop harvest, ratooning ability decreased rapidly, perhaps because ratoon development was hindered by these diseases on the main crop. Infection by the fungal pathogens may cause slow decomposition of basal and auxillary buds of the stubble or roots.

WATER MANAGEMENT AFTER MAIN CROP

An initial observation of ratoon development in puddled and unpuddled fields with either standing water or midseason drainage showed a relationship between ratooning and stem rot incidence (Table 6). Ratooning improved with midseason drainage and stem rot was higher on ratoon tillers developed with standing water.

The effects on ratooning of water management practices and fungicide disease control were studied. Cultivar IR32 was planted as a lowland irrigated rice crop with 120 kg N/ha as urea. The main crop received insecticide and herbicide, but not fungicide, to keep down insects and weeds. The main crop was cut at 15 cm above the water level. The ratoon crop was then divided into 2-factorial treatments, with and without fungicide (benomyl-thiram) spray, in combination with water maintained at saturation level and at 5-10 cm. Ratooning was rated at 35 d.

In the main crop, stem rot incidence was relatively high, but of low severity (Table 7). Fungicide applied to the ratoon crop lowered the disease incidence but did not improve the ratooning ability. More ratoon tillers developed from stubble that had a higher incidence of stem rot in the field with standing water. Water management and disease control at this stage had no significant effect on ratoon tiller development and ratoon crop yield.

In these experiments, the ratoon crop was also infected with yellow dwarf. Incidence seemed lower in the plots where water was drained.

Cutting height of the main crop affected stem rot development. The shorter the stubble (3 cm), the less stem rot developed (Table 8). Ratoon rating also improved. Land preparation after harvest of the main crop together with water management did not show significant effects. However, the number of rotten tillers which could not produce any ratoon tillers was higher in plots with standing water than in those drained.

Table 6. Sheath blight and stem rot incidence on main and ratoon crops of IR32 under various methods of crop establishment. IRRI, 1979 dry season.

Treatment	Sheath blight[a]		Stem rot[b]		Ratoon rating[c]
	Main crop	Ratoon crop	Main crop	Stubble (%)	
Puddled					
Standing water	0.36	0	trace	8.4	1.6
Midseason drainage	0.41	0	trace	5.7	1.6
Unpuddled					
Standing water	0.13	0	trace	8.0	1.3
Midseason drainage	0.20	0	trace	5.5	1.0

[a]Based on the *Standard evaluation system for rice* (1).

[b]% stem rot = $\frac{\text{No. of infected tillers}}{\text{Total no. of tillers observed}} \times \frac{\text{No. of infected hills}}{\text{Total no. of hills observed}}$

[c]% hills producing ratoon: 0 = 0%, 1 = 1-25%. 2 = 26-50%, 3 = 51-75%, 4 = 76-100%.

Table 7. Effect of water management after harvest and main crop disease on ratooning and ratoon yield.

Water treatment[a]	Stem rot (%)	Ratoon tillers/hill (no.)			Ratoon[b] rating	Ratoon yield (t/ha)
		Nodal	Basal	Total		
Field saturated						
Yes	53.0 a	10.4 a	7.6 a	18.0	0.52 a	2.2 a
No	66.9 ab	6.1 b	11.2 ab	17.3	0.51 a	2.4 a
Mean	58.8	8.2	9.4	17.6	0.51	2.3
Field irrigated						
Yes	64.7 ab	7.5 b	9.1 ab	16.6	0.50 a	2.5 a
No	72.2 b	7.0 b	12.2 b	19.2	0.56 a	2.4 a
Mean	68.4	7.2	10.6	17.8	0.53	2.4

[a]Drained plots are maintained at saturation level while irrigated plots were maintained at 5-10 cm water level. Stubbles were cut at 15 cm length. Benomyl-thiram at 1 g FP/liter was applied after harvesting.

[b]Ratoon rating: R. R. = $1 - \frac{MH}{T_h} \times \frac{MH}{T_h} \times \frac{T_t}{16} \times (1 - 0.1\ V)$, where MH = missing hills, T_h = total no. of hills, T_t = total number of tillers (nodal + basal), 16 = av no. of tillers/hill, and V = vigor rating. SES scale: 1 = extra vigorous, 5 = intermediate, 9 = weak. In a column, values with the same letter are not significantly different at the 5% level.

Table 8. Effect of stubble height, land preparation, and water management after harvesting main crop on stem rot incidence of IR32 ratoon crop.

Stubble height (cm)	Stem rot (%)[a]		Ratoon rating[b]	
	Puddled	Unpuddled	Puddled	Unpuddled
Field with standing water				
3[c]	30.8	33.6	1	2
15	46.7	59.7	2	4
25	52.5	59.2	3	5
Field with midseason drainage				
3	35.4	30.6	1	1
15	46.5	59.6	2	5
25	56.6	59.5	3	4

[a]scored 30 d after harvesting main crop. [b]According to Standard evaluation system for rice (1): 1 = extra vigorous, 5 = intermediate or normal, 9 = very weak and small. [c]Many tillers rotted and did not produce ratoon.

SUMMARY

1. If rice cultivars possessed resistance to certain rice diseases, the level or degree of resistance also showed in the ratoon crop.
2. If the main crop has systemic disease infection, the stubble was unlikely to produce any ratoon tillers; if the infection was late, with diseases such as tungro, ratoon tillers may develop but subsequently succumb to the disease.
3. Yellow dwarf, a disease caused by a mycoplasma-like organism, was often observed in ratoon crops, probably because of its long latency in rice plants.
4. Diseases such as sheath blight and stem rot were observed not only on the main crop, but also on the ratoon crop. Their effect on ratooning was erratic.
5. It appears to be more effective for ratoon production to manage diseases like sheath blight and stem rot in the main crop rather than in the ratoon crop.
6. Individual ratoon tillers may be prone to lodge or die as a result of diseases such as sheath blight and stem rot in the main crop.

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Yellow dwarf disease in ratoon rice

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ABSTRACT

Yellow dwarf disease was observed in up to 27% of main crop (var. MR249) and in up to 82% of ratoon crop (Selection CR-126-6) in Karnataka, India. Plants were infected at all growth stages. Yellow dwarf disease was transmitted by leafhoppers *Nephotettix virescens, N. nigropictus, N. cincticeps, N. malayanus,* and *N. parvus. N. virescens* transmitted the disease to 14 species of plants. Mycoplasma-like organism was observed in the phloem sieve tubes of yellow dwarf-infected rice plants. In transplanted crops, disease incidence was high from September to December, but low from January to April. The occurrence of disease in the field was decreased to some extent by the application of insecticides against leafhoppers. The varieties or breeding lines MR363, Gamasolu, HY256, CT43, CT57, CT1351-1, CT1351-2, Doddabyra, Gandsali, HR35, Intan Mahsuri, IET5975, and KMP104 showed field tolerance to the disease.

Yellow dwarf has been reported in Japan, India, China, Taiwan, Malaysia, Philippines, Bangladesh, and Sri Lanka, and in almost all rice growing areas in India (22, 28, 35, 39, 44).

INCIDENCE AND LOSSES

The area severely damaged by yellow dwarf in Japan was about 20,000 ha; the yield loss amounted to 10,000 t (9). Abeygunawardena (1) recorded 13.8-20.7% infection in the ratoon crop at Peradeniya, Sri Lanka, and 0.08-2.20% infection at Batalagoda. In Karnataka, India, yellow dwarf incidence was up to 27% on the main crop (var. 249) and up to 82% in the ratoon crop (Selection CR 126-6).

Incidence was lower in the dry-season crop than in the wet-season crop. High incidence was observed in rabi (35). Rice yellow dwarf was more severe in the ratoon crop than in the main crop (3, 5, 16, 35).

SYMPTOMS

Plant leaves are pale green at the onset of the disease and become uniformly yellow as the disease progresses. Later-formed leaves become short, narrow, and soft.

Infected young plants are severely stunted and exhibit uniform yellowing on all tillers. In older plants, symptoms are seen on newly emerging tillers. Numerous tillers are produced at all stages of infection. A week to 10 d after harvest, new sprouts show yellowing in all infected plants. Infected plants produce excessive tillers and fail to produce any grain (2, 19, 30, 32, 42, 43, 49).

TRANSMISSION

Yellow dwarf is transmitted by *Nephotettix cincticeps* (10); *N. nigropictus* (41); *N. malayanus* (12, 13); *N. parvus* (11), and *N. virescens* (47). *N. nigropictus* and *N. virescens* are known to transmit the disease in India (37, 44). A blue race of *N. virescens* is more efficient in transmitting yellow dwarf than the usual green form (38).

HOST RANGE

Yellow dwarf has been transmitted by *N. virescens* to *Alopecurus aequalis, Glyceria acutiflora, Oryza cubensis* (48, 49); *O. barathi, O. glaberrima, O. longistaminata, O. minuta, O. nivara, O. perennis, O. punctata, O. rupifogon, O. rupifogon* × *O. nivara, O. sativa* f. *spontanea, and Heteropogon contortus* (33, 36).

VARIETAL RESISTANCE

Kurosawa (18) first observed varietal reaction to yellow dwarf in the field in Taiwan in 1932. He noted that almost all the Japanese varieties examined after harvest were severely infected with yellow dwarf when their tillers grew from the stubble. In field tests, Hashioka (4) found considerable differences in resistance or susceptibility among 331 varieties tested in Taiwan. Among the varieties tested, 151 varieties showed 0-6% infection, 43 showed 7-10% infection, 50 showed 11-20% infection, 32 showed 21-30% infection, and 34 showed 41-60% infection. Komori and Takano (17) found that Kaladumai, Loktjan, PeBiHun, Saitama Mochi No. 10, and Tetep were highly resistant in the field in Japan. Of 70 varieties tested, only Taipei-131, Taipei-3 10, and No-Lin-49 remained disease free (6).

Several cultivars derived from crosses of T(N) 1 × (T 65 X S 705), T 65 × S 705, and Wanar 1 × T 65 showed no infection in the main crop and low infection in the ratoon crop in the field (36). Of 80 varieties/selections tested in the field, 58 showed symptoms in the main crop and 77 in the ratoon crop. Twenty-two varieties showed no symptoms in the main crop and 3 (MR363, Gamasolu, and HY256) showed no symptoms either in the main crop or in the ratoon crop (Table 1) (33).

We screened 106 varieties and breeding lines (including hybrids) for yellow dwarf in the 1984-86 ratoon crop (Table 2, 3). Sixteen lines showed no symptoms in ratoon growth. Twenty lines showed less than 2% infection. The lines CT43, CT57, CT1351-1, CT1351-2, Doddabyra, Gangasali, HR35, Intan Mahsuri, lET5975, and KMP104, which did not show infection in the ratoon crop, can be tested in the

Table 1. Yellow dwarf disease incidence in main and ratoon rice crops, 1979 (33).

Variety/selection	% incidence	
	Main crop	Ratoon crop
MR363	0.00	0.00
Gamasolu	0.00	0.00
HY256	0.00	0.00
MR359	0.00	0.71
IET1785	0.00	1.07
RP 974-5-7-6-2	0.00	1.07
HY258	0.00	1.42
MR161	0.00	2.14
IET3280	0.00	2.87
HY25-10	0.00	3.21
Y4	0.00	3.93
MR343	0.71	5.71
MR292	1.07	6.42
A200	1.07	7.86
IET1444	2.86	8.57
MR367	0.36	10.35
IET2700	2.14	12.50
MR18	1.42	13.21
MR362	1.07	14.28
MA261	0.71	14.64
MR360	11.50	25.00
ADT 32	8.00	30.00
IET4702	1.07	35.00
IET3626	15.00	45.00
IET2295	10.00	62.00
I Sona	2.50	71.50

laboratory by leafhopper inoculation. Lines that resisted infection can be used in breeding for disease resistance.

RESISTANCE TO VECTORS

Of several varieties tested, MTU 17 was most tolerant of infestation by *N. virescens* followed by IR8 and Pankhari 203; Pikutokumoto showed least tolerance (25). *N. cincticeps* showed nonpreference for the highly resistant rice varieties Firoz-1, Kalbara, and C4-63A (4).

EPIDEMIOLOGY

In India the leafhopper (*N. virescens* and *N. nigropictus*) population in the field was high from July to September in Delhi (24), April to September in Bihar (15), and May to June and October to November in Karnataka (35). Disease incidence was low in the crops transplanted from January to April. Disease incidence was correlated with the vector population. Field collection of leafhoppers in the ratoon crop showed that 4% of them carried the disease. Wherever there is continuous cropping, these active transmitters carry the disease from one season to the other. There was steady increase in the incidence throughout the growth of the first ratoon, peaking in the second ratoon (35). Ninety percent of leafhoppers in epidemic fields in Faizabad (Uttar Pradesh, India) were viruliferous (24).

Table 2. Yellow dwarf incidence in ratoon rice crop, 1984-85.

Variety/Selection	% incidence
CT43	0.00
CT57	0.00
CT1351-1	0.00
CT1351-2	0.00
Doddabyra	0.00
Gandsali	0.00
HR35	0.00
Intan Mahsuri	0.00
IET5975	0.00
KMP104	0.00
China 5	1.00
CT36	1.09
Intan Mutant	1.04
HP3 (Neela)	1.04
ACM 7	1.83
HP2 (Nag)	2.00
CR263-506	2.06
KBCP-1 (Hema)	2.50
S 317 (Halubbalu)	3.33
Fu Meln Huang	3.33
Fu Men Huan	3.35
HP8	3.50
Chun-Chen-2	3.50
HP5 (Sharavathi)	3.63
Mangala	4.50
ACM 5	5.00
CT97	5.00
Jeerigesanna	5.00
Pankhari 203	5.00
Phalguna	5.00
IR50	5.00
Pragathi	5.00
VL-8	5.00
Che-Eu-Hung	6.32
Tainung Sen Yu	7.10
HP1 (Nandhi)	7.50
2-Yah-Tsan	8.22
CH2	10.00
Cold AMBT-2	10.00
CT67	10.00
ADT14185	10.00
MR365	10.00
Madhu	10.00
Rasi	10.64
China 1039	10.78
IR9202-25-1-3	12.87
HP12	13.50
ACM 6	15.00
KMP106	15.00
IET1522	20.00
Mandya Vani	20.00

CAUSAL AGENT

A mycoplasma-like organism was found in the phloem sieve tubes of yellow dwarf-infected rice plants (21, 40). Remission of symptoms was achieved by treating infected plants with oxytetracycline hydrochloride and chlortetracycline at 100-500 ppm by wick feeding and 250-1500 ppm by spraying (34).

Tabla 3. Yellow dwarf incidence in ratoon hybrid rices, 1985-86.

Variety/selection	% incidence
P203A/Intan Mutant	
IR29723-243-3-2-1	0.00
Wei-You 64	0.16
IR46830A/13292-5-2	0.16
MS 577A/Intan Mahsuri	0.17
P203A/Intan Mahsuri	0.30
IR21845-90-3A/IR54	0.31
97A/Milyang 54	0.46
Iri 356A/Milyang	0.47
IR46828A/Milyang 54	0.63
577A/Intan Mutant 1	0.79
IR46831A/IR 54	1.09

CONTROL

The occurrence of yellow dwarf in the field was decreased to some extent by applying carbaryl (1-naphthyl N-methylcarbamate) or vamidothion (N-methyl O,Odimethyl-triolophosphoryl-5-thio-3-methyl-2-valeramide) twice during the rice nursery period (29). Malathion, carbaryl dust, and other chemicals were used, usually soon after transplanting, to kill overwintering insects (7, 27).

Carbaryl (1-naphthyl N-methylcarbamate) when applied to soil at 3 kg ai/ ha controlled *Nephotettix* spp. effectively (14). Seed treatment with carbofuran or methomyl or phorate or propoxur protected rice seedlings from the leafhoppers (26, 45).

Leafhopper mortality was higher in plots treated with phosphamidon (0.03%), carbofuran (0.04%), dimethoate (0.0125%), and demeton-S-methyl (0.025%) and yellow dwarf incidence was reduced from 5.80 to 0.94% (31).

CONCLUSIONS

In recent years ratoon cropping of rice has been practiced in parts of Karnataka (20, 23, 46). There is a great potential for adopting rice ratoon cropping in parts of the country. Yellow dwarf might become a limiting factor for raising a ratoon rice crop because the disease is predominant in the ratoon crop. Only tolerant varieties should be recommended wherever ratooning is practiced. Also, resistant varieties should invariably be used in future breeding programs to evolve resistant types suitable for ratoon cropping.

After the main crop is harvested, leafhoppers persist on the stubble. Because the initial inoculum is available, the disease spreads much faster in the ratoon crop. A week or 10 d after main crop harvest, it is important to spray the ratoon crop with insecticides to kill leafhoppers to prevent further spread of the disease.

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Rice ratooning and ratoon-based system in Kerala

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ABSTRACT

Eleven major cropping situations, making up the total 740,000 ha under rice in Kerala, and an estimated possible area of 120,000 ha for rice ratooning are presented. The 3-yr data from ratooning studies presented suggest that varieties of 140-160 d duration are better than short-duration ones for good ratoon yields. Reduction in size and weight of grains has been indicated in the produce from ratoon crop. Suggestions for future work on rice ratooning in Kerala also are presented.

Although there is no typical rice ratooning being practiced in Kerala, one special system of rice cultivation locally known as *koottumundakan* resembles ratooning in some aspects. In this system, a mixture of a photoperiod-sensitive, long-duration rabi (postrainy season) variety is sown in kharif (rainy) season to take two harvests, one in kharif and the other in rabi. Although after the spread of the high-yielding semidwarf rice varieties remarkable regrowth and biomass production from harvested stubble have been observed, only one study actually evaluating rice varieties for their ratoon yields has so far been reported from Kerala (1). Results of further studies in this line are presented and the possibility and potential of rice ratooning in Kerala are discussed.

ESTIMATES OF AREA

Rice is cultivated in Kerala on about 740,000 ha. Rainfall pattern, topography, and soil conditions have given rise to some very special systems of cultivation in about 28% of this area. Analysis of the 11 major cropping situations in the state shows that about 120,000 ha could be brought under rice ratooning (Table 1).

Palliyal lands

At least two-thirds of the area under this category is severely affected by drought, not allowing a second crop. This area could be brought under ratooning, contributing an additional area of 20,000 ha.

Table 1. Estimate of possible areas for rice ratooning in Kerala, India.

Cropping situation with main characteristics	Area (thousand ha)	Possiblearea for ratooning (thousand ha)
Modan lands – rainfed uplands	20	–
Palliyal lands – terraced uplands		
Where two crops are possible by irrigation	10	–
Where only one crop is possible for want of irrigation	20	20
Typical double-cropped wetlands of midland region		
With assured water supply for both seasons	367	–
Without assured water supply at posttiliering stage of rabi crop	160	80
Koottumundakan lands – varietal mixture with two harvests	15	10
Kuttanad – lake area below sea level, southern districts	54	–
Kole – lake area below sea level, Central Kerala	10	–
Pokkali – saline areas	27	–
Waterlogged low flooded areas	2	1
Poonthal padam – structureless soils	2	1
Onattukara – coastal sandy areas	30	–
High-altitude areas	23	8
Total	740	120

Typical double-cropped wetlands

About 160,000 ha are estimated to be seriously affected by drought at the post-tillering stage of the rabi crop. This risky rabi crop can be replaced by a ratoon crop, which can be harvested before the drought sets in. The irrigation water saved by such a duration reduction can be used for stabilizing the major portion of the rabi crop.

***Koottumundakan* lands**

In about one-third of the 15,000 ha in this system, a practice similar to ratooning is used to obtain heavy straw yields. In the remaining area, the system is practiced either to drastically reduce cultivation cost or to avoid machinery power when harvest of the first crop and planting of the second crop overlap. This area of about 10,000 ha can be conveniently brought under ratooning.

Waterlogged low flooded areas

These lands are at present planted to tall, lodging-prone varieties with low yields. In identifying varieties of semidwarf stature with tolerance for ill-drained low flooded situation, we have found a few promising cultivars. These cultivars have also been found suitable for ratooning. Thus, at least 1,000 ha in these areas can be brought under ratooning.

Poonthal padam

About 2,000 ha of rice in this situation also require a change from the tall varieties to the semidwarfs, to avoid losses from lodging. A changeover to such varieties, if combined with ratooning, will allow the land a longer dry period, considered beneficial for such structureless soils. Sulfide injury to seedlings after rabi planting is a usual problem in these lands, and reduced tillage is considered useful in minimizing

such injury. From this angle also, ratooning can be a useful alternative cropping system. Ratooning possibility in this situation is estimated at 1,000 ha.

High-altitude areas

Long duration of the first crop varieties due to cold weather makes irrigation water scarce for a fresh crop over one-third of the hectarage at high altitudes. Ratooning is considered a possible way to bring an additional area of 8,000 ha in this region under rice with the limited water available.

VARIETAL CHOICE

Ratoon yields of some rice varieties were evaluated in three trials (Table 2, 3, 4). The results, although scanty, indicate that

- for better ratoon yields, varieties of moderately long duration (140-160 d) are to be preferred.
- the ratoon crop can be harvested in about 55-60 d after the main crop harvest, irrespective of the duration of the variety.
- the grains from the ratoon crop are not as heavy and plump as those from the main crop.
- per day productivity of the ratoon crop is comparable to, and even better than, that of the main crop.

POTENTIALS AND PROBLEMS

In Kerala, where there has been a reduction of area under rice from 874,000 ha in 1972-73 to 740,000 ha in 1982-83, bringing more new areas under rice is considered very difficult for socioeconomic reasons. The need is also to reduce cultivation costs by various technological adjustments. Ratooning, if well established with good ratooning varieties and appropriate ratoon management technologies, can be rightly considered a new strategy with proportionately less pressure on its limited irrigation potential.

Table 2. Ratoon performance of seven short-duration rice varieties, Pattambi, India, 1981.

Variety	Main crop[a]			Ratoon crop[b]		
	Duration (d)	Grain yield (t/ha)	Per day yield (g/m^2)	Duration (d)	Grain yield (t/ha)	Per day yield (g/m^2)
Chianung Sen yu – 13	113	3.6	3.2	51	0.4	0.7
IR9209-48-3-2	104	4.9	4.7	60	0.3	0.5
IR9761-19-1	103	4.9	4.7	61	0.3	0.5
IR13427-40-2-3-3	113	4.6	4.1	51	0.5	0.9
IR13429-109-2-2-1	108	4.6	4.3	56	0.4	0.8
IR13429-287-3	113	4.8	4.2	51	0.3	0.6
Taichung Sen yu 285	113	3.6	3.2	51	0.4	0.7
Mean	110	4.4	4.1	54	0.4	0.7

[a]Fertilizer was applied to supply 40 kg N, 20 kg P, and 20 kg K/ha. [b]No fertilizer was applied.

Table 3. Ratoon performance of six longduration rice varieties, Pattambi, India, 1983.

Variety	Main crop[a]					Ratoon crop[b]				
	Duration (d)	Grain yield (t/ha)	Par day yield (g/m^2)	Volume weight (kg/ha)	1,000-grain weight (g)	Duration (d)	Grain yield (t/ha)	Per day yield (g/m^2)	Volume weight (kg/ha)	1,000-grain weight (g)
BR51-315-4	154	2.9	1.9	55.9	23.6	55	1.6	3.0	53.9	21.0
BR52-96-3	147	2.6	1.8	57.5	25.7	55	1.4	2.5	56.1	23.1
BR10	142	1.5	1.1	57.1	23.2	55	1.3	2.3	55.6	19.7
BR2489 BKN 1-76-8	148	1.9	1.3	54.1	28.4	50	1.0	2.0	54.1	23.6
B3063 BTK-72-2	151	1.6	1.1	56.2	25.9	63	1.3	2.0	53.8	23.0
CR 1002	154	1.9	1.2	58.5	27.3	55	1.0	1.9	56.8	22.2
Mean	149	2.1	1.4	56.5	25.7	55	1.3	2.3	55.0	22.1

[a]Fertilizer was applied to supply 40 kg N, 20 kg P, and 20 kg K/ha. [b]Fertilizer was applied to supply 10 kg N/ha only.

Table 4. Ratoon performance of two long-duration rice varieties, Pattambi, India, 1985.

Variety	Main crop[a]				Ratoon crop[b]			
	Duration (d)	Grain yield (t/ha)	Per day yield (g/m^2)	1,000-grain weight (g)	Duration (d)	Grain yield (t/ha)	Per day yield (g/m^2)	1,000-grain weight (g)
BR51-315-4	144	2.4	1.6	22.4	53	0.9	1.7	17.4
BR52-96-3	151	2.9	1.9	24.0	52	0.6	1.2	18.6
Mean	147	2.6	1.7	23.2	52	0.7	1.4	18.0

[a]Fertilizer was applied to supply 40 kg N, 20 kg P, and 20 kg K/ha. [b]Fertilizer was applied to supply 1.0 kg N/ha only.

Of the 120,000 ha estimated to be brought under ratooning, from only 28,000 ha is additional production as a direct result of ratooning expected. In the remaining area, indirect benefits of reduced water requirement for the ratoon crop and savings in water, contributing to stabilization of other areas, may be expected.

Before this technology can be translated into an actual action plan, however, there are several prerequisites:

- Elaborate varietal evaluation should be made for ratoon performance and identification of good varieties, preferably with red kernel and bold seeds.
- Appropriate cultural and management practices must be developed to achieve maximum yield within the short ratoon crop period.
- The potential danger of insect pests and diseases being directly carried over from the main crop must be studied in detail to evolve a viable plant protection strategy for the ratoon crop.
- Special cultural and manurial practices for the main crop to assure better ratoon performance need to be studied.
- Quality aspects of the ratoon produce, both as grain and seed, need to be studied in detail.
- Possibilities of relay cropping of ratoon rice with other crops to take full advantage of residual moisture need to be investigated.

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Disease and insect pests and their control in rice ratooning systems

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ABSTRACT

Diseases and insect pests on ratoon rice and transplanted main crop in season are reviewed. Brown leaf spot, stem rot, udbatta, and diseases caused by viruses and mycoplasma-like organisms (MLOs) damage the ratoon crop. The survival mode of nematodes indicates their possible occurrence on the ratoon crop. Important insect pests of the crop are leaf and planthoppers, stem borers, and leaf rollers. Application of fungicides and insecticides, once after main crop harvest and again at the flag leaf stage of the ratoon crop, may reduce the incidence of disease, insect vectors, and insect pests. The importance of mechanical roguing of virus-infected plants, sanitation around the ratoon field, and proper cutting height of the stubble are discussed. Further study on the importance of diseases and insect pests and their control is suggested. The need for varieties with good ratooning ability and resistance to diseases, especially to those caused by viruses and MLOs, is stressed.

Some research has been carried out on plant protection in rice ratooning systems in different countries (7, 16). Although the ratoon crop generally yields 60% of the main crop, it has outyielded the main crop (20). With adequate moisture, the highest ratoon yield at International Rice Research Institute was 3.3 t/ha with IR2058-78-1-3-2-3 (19). Two or three consecutive harvests have been obtained by ratooning (9). In India, ratoon cropping is becoming popular in hilly regions of Karnataka.

Little information is available, however, on the importance of diseases and insects in ratoon cropping systems. Systematic work is lacking except for some observations on the effect of cutting height on incidence of grassy stunt virus and stem rot disease (2, 21). Grassy stunt incidence was higher on the ratoon crop than on transplanted main crop seedlings, which were virus free (3). Stem rot infection reduced the number of ratoon tillers (21). Heavy insect pest infestations have been reported on ratoon crops (11). Insect damage can reduce or prevent ratooning (22). The ratoon crop may be heavily infected with stem borers, leading to total crop loss (8). We review here observations of disease and insect pest occurrence on a ratoon crop and on a transplanted seedling crop, and possible control measures.

DISEASES

Rice is prone to several diseases caused by bacteria, fungi, nematodes, viruses, and mycoplasma-like organisms (MLOs). Although many diseases are widespread, and a few can cause heavy damage to the main crop, only some are noticed on the ratoon crop. Damage also is limited by climatic conditions prevailing during the ratoon crop period. However, diseases caused by viruses and MLOs are a severe problem in ratoon crop production.

Diseases caused by bacteria

Bacterial leaf blight (caused by *Xanthomonas campestris* pv. *oryzae*) and bacterial leaf streak *(X. campestris* pv. *oryzicola)* are widespread and cause considerable damage in main crops (13), but are not of much importance on ratoon crops. They do not appear in a severe form because of climatic conditions prevailing during the ratoon crop season.

Diseases caused by fungi

Although blast (caused by *Pyricularia oryzae*) is a widespread and destructive disease of rice in almost every area, its damage is negligible Dec-May on both transplanted main crops and ratoon crops because of the unfavorable climatic conditions during the season. In fact, local experience is that a main crop of S-1092 heavily infected with leaf blast can put out regrowth and give a normal yield without being reinfected at the leaf or neck stages. This means blast may not be a problem on ratoon crops in the Karnataka hill valley, but it could be a problem in other areas. Studies for forecasting and for developing preventive measures are needed.

Brown leaf spot caused by *Cochliobolus miyabeanus (Drechslera oryzae)* disease is an important fungal disease on the transplanted main crop and ratoon crop. It causes leaf spot symptoms during the vegetative stage (seedling to flag leaf) and “ear blighting” symptoms similar to neck blast, with brown discoloration of the uppermost internode, which leads to partial or complete chaffiness of the panicle. The fungus also attacks glumes, producing dark-brown or black oval spots. The surface of the grain may be blackened and the seeds shrivelled and discolored. In India, a crop grown with well-balanced nutrients usually will not be severely attacked by brown leaf spot (5). Fungi surviving on the stubble and debris left after cutting are the main source of infection. Secondary spread is through airborne conidia.

Spraying the cut stubble (field) with zineb, mancozeb, carbendazim, or any other suitable fungicide immediately after the main crop harvest may reduce the primary source of inoculum. Two more sprayings of the ratoon crop, once 20-25 d after cutting and again at the flag leaf stage, may reduce leaf spot incidence and ear blighting and glume discoloration. It is worth experimenting on these lines to develop a suitable plant protection schedule applicable to local situations.

Stem rot (*Sclerotium oryzae*), although not serious on the main crop, may damage the ratoon crop because of the weakening of the host plant at the time of cutting. Samson (21) observed that longer stubbles expressed more stem rot

incidence in the ratoon. The infected plant shows brown or black necrotic area on the outermost leaf sheath, leading to withering and breaking up of main culm, and death. Abnormal tillers produced at the plant base after infection produce nothing; if any ears are produced, they have a high proportion of light grains. Spraying edifenphos benomyl, or blasticidin-S might control the disease, although fungicides are not widely used to control this disease (5). Proper management, such as optimum cutting height, may also reduce its incidence.

Udbatta caused by *Ephelis oryzae,* a systemic infection that is increasing in hilly areas of Karnataka, is important in ratoon cropping. Infected main crop stubble cause 100% loss in ratooned plants. Infected plants produce dirty colored, hard cylindrical spikes instead of normal ears. Careful roguing to uproot udbatta-infected plants in the main crop before cutting is a prerequisite to ratooning.

Other minor diseases of rice (sheath rot, caused by *Rhizoctonia solani;* false smut, by *Ustilaginoidea virens;* kernel smut, by *Neovossia barclayana;* foot rot or bakanae, by *Fusarium moniliforme;* etc.) are of little importance on ratoon crops during the cropping season in Karnataka.

Diseases caused by nematodes

Nematode diseases have not been reported on ratoon crops. Burning rice stubble has been recommended, because rice leaf nematode caused by *Aphelenchoides besseyi* survives on them. Survival of rice stem nematode caused by *Ditylenchus angustus* on self-sown rice plants, stubble, and ratoons left in the main field after harvest has been reported (5). This indicates their possible occurrence on the ratoon crop in endemic areas, although such reports are not available. Root-knot nematode caused by *Meloidogyne* spp., rice cyst nematode caused by *Heterodera oryzae,* rice root or burrowing nematodes caused by *Hirschmanniella* spp., rice stunt nematode caused by *Tylenchorhynchus martini,* and rice nematode caused by *Macroposthonia onoensis* are other nematodes reported. Their importance, if any, on ratoon crops in potentially infected areas and studies of control methods may be worthwhile.

Diseases caused by viruses and mycoplasma-like organisms

Seventeen diseases have been reported to be caused by viruses and two diseases by MLOs have been reported on rice (15). Six of them: tungro, grassy stunt, ragged stunt, chlorotic streak, necrosis, and yellow dwarf, are occurring in India. All of the viruses and MLOs pose a threat to ratoon rice cultivation. They are normally unnoticed or found only in late stages of the main crop, when little sign of disease or latent infection is noticed. But regrowth from such stubble will show typical symptoms, causing total failure of the ratoon crop.

Yellow dwarf appeared in an epidemic form in Japan, infecting 70-80% of the hills and causing 50% yield reduction (12). In India, yellow dwarf was observed up to 27.3% on the main crop (var. MR249) (18). Distinct chlorotic symptoms appear on ratoon growth, which produces numerous, yellow, stunted tillers from the basal nodes. They normally do not flower. Yellow dwarf is transmitted by *Nephotettix* species (green leafhoppers). *N. virescens, N. cincticeps,* and N. *nigropictus* are the more efficient vectors of the disease.

Grassy stunt virus-infected plants are severely stunted with excessive tillers showing a grassy or rosette appearance with narrow, short, stiff, pale-green to green leaves. It is transmitted by brown planthopper *Nilaparvata lugens.* The incidence of this virus is higher on a ratoon crop; the main crop may be virus free (3). Bahar (2) reported that higher cutting heights increased the incidence of grassy stunt.

Other virus diseases, although not reported so far on a ratoon crop, may pose problems when they are prevalent on the main crop. Rice tungro virus is very serious in many parts of India, causing substantial yield losses in main crops (1). The symptoms include stunting, with reduced number of tillers. It is transmitted by green leafhoppers *Nephotettix virescens* and *N. nigropictus* and a zigzag leafhopper *Recilia dorsalis,*

Ragged stunt virus symptoms are stunting, ragged leaves, twisting at the leaf tip, vein swelling, nodal tillers, delayed flowering, incomplete emergence of panicle, and unfilled grains. It is transmitted by brown planthopper *Nilaparvata lugens.*

Chlorotic streak virus symptoms include stunting, chlorotic streaking on leaf and leaf sheath, striping or mottling of newly emerged leaves, and difficult emergence of leaves. It is transmitted by rice mealybug *Heterococcus rehi.*

Necrosis mosaic virus produced pale-yellow streaks on young leaves, turning into chlorotic streaks parallel to the veins with interveinal chlorosis. Tiller number and spreading growth also were limited. The disease is transmitted by sap inoculation and through the soil.

With varieties susceptible to viruses, no ratoon crop is possible. At Bangalore, only 15 of 260 genotypes tested were unaffected by yellow dwarf/ grassy stunt in the ratoon growth; the rest had to be plowed and incorporated even though some of them possessed ratooning ability (4). In a rice cold tolerance nursery, of 232 genotypes tested in the 1984-85 winter season, 86 were unaffected by yellow dwarf disease in their ratoon growth. But incidence was 5-20%, even though there was no infection in the main crop. Breeding should aim at developing varieties that have both ratooning ability and resistance to virus and MLO-caused diseases. The varieties currently under test at Karnataka are Intan, Mingolo (prerelease), and Intan Mutant. They possess resistance to these diseases.

Cultural practices, such as optimum cutting height, play a primary role in ratooning ability while minimizing virus diseases (2). Bahar says that higher cutting heights favor higher infection by grassy stunt virus. Constant monitoring for symptoms of these viruses and MLOs is necessary; infected plants must be destroyed as soon as they are noticed, both in the main crop before ratooning and in the ratoon growth. Mechanical removal and deep burial of infected plants as soon as they are noticed is a regular practice we have adopted to maintain CMS lines. We are getting good control.

The spread of the disease is mainly through leafhopper vectors. More leafhoppers died in phosphamidon-, carbofuran-, and dimethoate-treated plots, reducing yellow dwarf incidence from 5.8% to 0.94% (17). Sevin, applied at 3 kg a.i./ ha, controlled *Nephotettix* spp. effectively (14). Effective control can probably be achieved by applying suitable insecticides immediately after the main crop is cut. Applying granular insecticides, such as carbofuran, phorate, or sevin, or spraying

suitable systemic insecticides, such as dimethoate or phosphamidon, immediately after the main crop harvest may take care of the insect vectors at the initial stages of ratoon growth and reduce the incidence of these diseases. All these aspects need to be studied.

INSECT PESTS

Insect pests on the ratoon crop have been studied in relation to the main crop at Mudigere, Karnataka (6). On Intan paddy, higher incidences of orange leafhopper *Thaia subrufa,* green leafhoppers *Nephotettix* spp., and brown planthopper *Nilaparvata lugens* are observed on the ratoon crop than on the main crop. Other insects present on both main and ratoon crops are whorl maggot *Hydrellia griseola,* paddy gall midge *Orseolia oryzae,* leaffolder *Cnaphalocrocis medinalis,* thrips *Baliothrips biformis,* and stem borers *Tryporyza incertulas* and *T. innotata.*

The leafhoppers do not cause much damage in the regular season, but hopperburn damage is enormous November-March. The orange-headed leafhopper seems to be specific to the hilly region of Karnataka, with severe damage November-May (10). This pest has not been observed around Bangalore, perhaps because of seasonal conditions in that region. Stem borers produce deadheart symptoms during early growth and white ears during flowering, causing considerable damage to the rice crop. Leaf roller-infested plants appear scorched and sickly; high infestation leads to severe yield losses.

Because pest populations start building up in a ratoon crop, without plant protection they could migrate to the transplanted summer crop and cause severe damage. Population in the initial stage of buildup on the ratoon crop must be effectively controlled. Applying suitable granular insecticides, such as carbofuran, phorate, and sevin (granular), or spraying systemic insecticides, such as dimethoate or phosphamidon, immediately after the main crop is cut may be sufficient to eliminate all insect pests as well as disease vectors in early stages of the ratoon crop. One more spraying of dimethoate or phosphamidon at the flag leaf stage may be sufficient to reduce insect pests at later stages of the ratoon crop, especially stem borers and leaf rollers. Cultural practices such as removing all the debris around the ratoon crop may help in controlling not only insect pests and vectors, but also diseases by reducing the primary sources of inoculum.

However, research on important diseases and insect pests occurring mainly on the ratoon crop and economic control measures is needed. Breeding work also must be intensified to develop good-ratooning varieties with resistance to the diseases caused by viruses and MLOs.

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Inheritance of ratooning ability in Chinese rice varieties [*O. sativa* subsp. *xian* (or indica)]

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ABSTRACT

To study the inheritance of ratooning ability in rice varieties, short-duration Shu-Fong No. 1(11), a high ratooning variety, and Ai-Nan-Zao, a nonratooning variety, were used as tester parents, mated reciprocally with Hon-Mei-Zao, short duration, and Tai-Guao-Dao-Xuan and Shong-Zao-Xian No. 26, medium duration. These varieties are characterized by different ratooning abilities. All F_1, F_2, BC_1, BC_2, and reciprocals were raised. All F_1 crosses showed relatively large variation in hybrid vigor, ranging from negative to positive. The F_1 from crosses with Ai-Nan-Zao generally showed lower heterosis than those from crosses with Shu-Fong No. 1(11). Cytoplasmic effects and nucleo-cytoplasmic interaction were observed in Shong-Zao-Xian No. 26. No such significant effect or interaction was found in Hon-Mei-Zao. Estimates of narrow-sense heritability on ratooning ability varied greatly with the hereditary background of the parents. These results indicate the possibility of breeding new variety or hybrids with strong ratooning ability, provided the right parents and mating scheme are selected.

The first record of ratoon rice cultivation in China dates from more than 1,500 yr ago (1). In the 1950s, it was common practice for the peasants living in the lowlands by the lakes, along the valley of the Yangtse River, and in the region of paddy fields to raise ratoon rice. This practice also has been adopted in the rice-based cropping system in Texas, USA.

Ratooning offers many advantages: it makes better use of light and heat in the paddy field in autumn and saves labor and seed to reduce production cost. However, in the past, ratoon yields were low and unstable and the practice disappeared gradually as rice production developed and yields increased in China. But ratoon rice again aroused the interest of some Chinese rice scientists when the Ethiopian Academy of Agricultural Science reported that when varieties IR8 and IR5 were ratooned, record yields were obtained — 8.7 t/ha and 8.3 t/ha, more than the main crop yield.

Studying ratoon rice, Kai Chiu Yang (5), professor in Sichuan Agricultural University, expected to enhance the yield level of ratoon rice by improving cultivation techniques. He systematically studied its morphological and ecological characters in the early 1940s (5). Since the 1970s, reports on ratoon rice in the world have focused on rice morphology, ecology, and physiology, and it has been suggested that strong ratooning ability is the most fundamental factor in enhancing

the yield of the ratoon rice. Accordingly, some breeding programs started to screen for higher ratooning ability among current commercial varieties, as a prelude to planned breeding for a new variety with better ratooning ability and other elite synthetic traits.

It is urged that the inheritance of ratooning ability of rice be explored to help produce a new variety with higher ratooning ability. This paper reports on research in this field from 1980 to 1984 in China.

MATERIALS AND METHODS

From short-duration Xian varieties, Ai-Nan-Zao, a short-duration variety without ratooning ability, and Shu-Fong No. 1 (11), a medium-duration one with higher ratooning ability, were used as the testers.

Tai-Guao-Dao-Xuan, medium-Xian medium-duration variety, was tested in 1980-1981; Shong-Zao-Xian No. 26, medium-Xian early-duration, in 1983; and Hon-Mei-Zao, early Xian medium-duration, in 1984.

Because ratooning ability appears to be a quantitative trait, a crossing design based on genetic analysis of the generation means was made (2, 3). The six generations consist of parents, F_1, F_2, BC_1, and BC_2 in normal or reciprocal crosses. Each tester variety (P_1) was crossed with each testing variety (P_2)′ $P_1/P_2 = F_1$, $(P_1/P_2)'$ F_1 (x = F_2, $(P_1 \times P_2)$ $F_1 \times P_1 = BC_1$, and $(P_1 \times P_2)$ $F_1 \times P_2 = BC_2$. Reciprocal crosses were also made: $P_2 \times P_1 = F_1'$, $(P_2 \times P_1)$ $F_1' = F_2'$, $(P_2 \times P_1)$ $F_1' \times P_1 = BC_1'$, $(P_2 \times P_1)$ $F_1' \times P_2 = BC_2'$ (Table 1).

The experiments were made at the Sichuan Agricultural University; the crop seeded in April was transplanted in May, 23.1 × 16.5 cm equidistant, 14 or 9 hills/row. The plants were investigated, measured, and recorded individually, leaving 4 border plants in each row. The fields were managed according to normal ratoon rice production.

A randomized complete block design with two replications with Ai-Nan-Zao group and Shu-Fong No. 1 (11) was adopted. The arrangement follows the order of generation in the group. Unequal plots were used for different generations. In each replication, data were taken from 24-30 plants of the generations P_1, P_2, and F_1 and F_1', 150 plants of F_2', F_2', and 80 plants of BC_1', BC_2, and BC_1', BC_2'.

Table 1. Rice varieties tested for inheritance of ratooning ability.

Parents \ Year	1980,1981 Tal-Guao-Dao Xuan (P_2) Normal	1983 Shong-Zao-Xian No. 26 (P_2) Normal	1984 Hon-Mei-Zao (P_2) Normal
Ai-Nan-Zao (P_1)	F_1, F_2, BC_1, BC_2 reciprocal F_1', F_2', BC_1', BC_2' normal	F_1, F_2, BC_1, BC_2 reciprocal F_1', F_2', BC_1', BC_2' normal	F_1, F_2, BC_1, BC_2 reciprocal F_1', F_2', BC_1', BC_2' normal
Shu-Fong No. 1 (11)	F_1, F_2, B_1, B_2 reciprocal F_1', F_2', BC_1', BC_2'	F_1, F_2, BC_1, BC_2 reciprocal F_1', F_2', BC_1', BC_2'	F_1, F_2, BC_1, BC_2 reciprocal F_1', F_2', BC_1', BC_2'

Ratooning ability was defined as the number of ratoon tillers derived from the stubble at 10 d (or maximum ratooning) after the main crop harvest.

The bud of the third node from the top was kept and most of the buds of the second nodes were kept by leaving the stubble of the main crop up to 16.5 cm above the ground.

RESULTS AND ANALYSIS

Hybrid vigor for ratooning ability

The hybrid vigor of the F_1 varied from -72.29% to 233.62% among the different parent combinations (Table 2). The ratooning ability of F_1 in crosses with Ai-Nan-Zao is generally lower than that of crosses with Shu-Fong No. 1 (11), the former even had crosses with negative hybrid vigor. The hybrid vigor differed distinctly among the F_1s from crosses with Tai-Guao-Dao-Xuan, Shong-Zao-Xian No. 26, and Hon-Mei-Zao, respectively. For example, the heterosis of (Ai-Nan-Zao/Tai-Guao-Dao-Xuan) F_1 is strongly negative, -72.29% or -66.8%, whereas that of its reciprocal F_1 is positive, 56.68%; that of Shu-Fong No. 1 (11)/Tai-Guao-Dao-Xuan) F_1 is positive, 93.38% (or 71.57%), and its reversal F_1 is up to 233.62%.

There is a significant difference between the normal and reciprocal crosses, which suggests the existence of significant cytoplasmic effects. The heterosis of the crosses with Shong-Zao-Xian No. 26 did not differ significantly between the reciprocal crosses. The heterosis of the crosses with Hon-Mei-Zao (Ai-Nan-Zao/Hon-Mei-Zao) F is 16.74%, and that of its reciprocal F_1 is 49.12%. There is a highly significant difference between the reciprocals, and this shows significant cytoplasmic effect. But thecytoplasm of Hon-Mei-Zao,when incorporated with the nucleus of the pollen cell of Ai-Nan-Zao, shows a weakly minus value for its heterosis. However, it shows a highly positive value when incorporated with the nuclear of the pollen cell of Shu-Fong No. 1 (11). This indicates that the difference between reciprocals results from the incorporation of different nucleus genes, rather than from the cytoplasm.

Narrow-sense heritability of ratooning ability

The narrow-sense heritability (h_N^2) in the tiller regeneration ability of the reciprocals and its significant F value were estimated (Table 3). 1) The h_N^2 of the reciprocal crosses with Tai-Guao-Dao-Xuan in ratooning ability is not significant by the F test, except for Ai-Nan-Zao/Tai-Guao-Dao-Xuan; 2) the h_N^2 among the reciprocal crosses with Shong-Zao-Xian is distinctly different. In a normal cross, e.g., Shu-Fong No. 1 (11)/Shong-Zao-Xian No. 26, h_N^2 = 65.56% + 14.70%, with highly significant F value, but in its reciprocal, h_N^2 = 23.01% + 19.01%, with nonsignificant F value; 3) in Shu-Fong No. 1 (11)/Hon-Mei-Zao, h_N^2 = 70.15% + 14.07%, larger than its reciprocal h_N^2 = 41.82% + 17.00%, and they are all highly significant.

In Ai-Nan-Zaol Hon-Mei-Zao, h_N^2 = 38.52% + 20.69% which is significant only at the 10% level. But the h_N^2 of its reciprocal cross = 57.03% + 16.49%, which is highly significant.

Table 2. Heterosis of F_1's from different crosses.

Parents	Av ratoons (no.) per plant F_1[a]	Mean of parents (MP)	Heterosis (%[b]) (F_1-MP)/MPX100
	1980		
Ai-Nan-Zao	0.52 ± 0.2		
(Ai-Nan-Zao/Tai-Guao-Dao-Xuan) F_1	1.65 ± 0.56	5.96	–72.29
(Tal-Guao-Dao-Xuan/Ai-Nan-Zao)F_1	9.33 ± 2.37	5.39	56.68
Tai-Guao-Dao-Xuan	10.26 ± 1.33		
(Shu-Fong No. 1(11)/Tal-Guao-Dao Xuan)F_1	20.83 ± 1.03	10.50	98.38
(Tai-Guao-Dao-Xuan/Shu-FOng No. 1 (11) F_1	35.03 ± 1.97	10.50	233.62
Shu-Fong No. 1 (11)	10.74 ± 1.22		
	1981		
Ai-Nan-Zao	1.85 ± 0.32		
(AI-Nan-Zao/Tai-Guao-Dao-Xuan)F_1	2.52 ± 0.40	7.43	–66.06
Tai-Guao-Dao-Xuan	13.00 ± 0.74		
Tal-Guao-Dao-Xuan	5.73 ± 0.45		
(Shu-Fong No. 1 (11)/Tal-Guao-Dao-Xuan)F_1	14.18 ± 0.89	8.27	71.57
Shu-Fong No. 1 (11)	10.80 ± 0.54		
	1983		
Ai-Nan[c] - Zao	0.13 ± 0.13		
(Ai-Nan-Zao/Shonu-Zao-Xian No. 26)F_1	1.89 ± 0.29	1.28	46.24
(Shong-Zao-Xian No. 26/Ai-Nan-Zao)F_1	1.44 ± 0.21	1.28	12.94
Shong-Zao-Xian No. 26	2.42 ± 0.45		
(Shu-Fong No. 1 (11)/Shong-Zao-Xian No. 26 F_1	15.66 ± 0.70	6.10	156.51
(Shong-Zao-Xian No. 26/Shu-Fong No. 1 (11) F_1	14.80 ± 0.77	6.10	142.42
Shu-Fong No. 1 (11)	11.96 ± 0.17		
	1984		
Ai-Nan-Zao	1.15 ± 0.03		
(Ai-Nan-Zeo/Hon-Mei-Zao)F_1	5.44 ± 0.41	4.66	16.75
(Hon-Mei-Zao/Ai-Nan Zao) F_1	4.40 ± 0.23	4.66	–3.06
Hon-Mei-Zao	8.17 ± 0.59		
Hon-Mei-Zao	7.67 ± 0.33		
(Shu-Fong No. 1 (11) /Hon-Mei-Zao)F_1	10.40 ± 0.32	9.25	26.06
(Hon-Mei-Zao/Shu-Fong No. 1(11) F_1	12.22 ± 0.43	8.25	48.12
Shu-Fong No. 1 (11)	8.83 ± 0.73		

[a]Most ratoons in 1980-81. [b]% = (F_1 . . . MP/MPX 100). [c]Number of ratoons 10 d after the main cropping harvest in 1983-84.

Analyses of genic effect in ratooning ability

The inheritance of ratooning ability in rice varieties appears to have cytoplasmic effects in varying degrees. But with the current analytical modes of quantitative genetics mostly based on nucleus inheritance, it is necessary to use the difference of reciprocal crosses to detect both cytoplasmic effects and nucleocytoplasmic

Table 3. The comparison of h_N^2 in ratooning ability of the recriprocals of different parents.

h_N^2 Taster parent	Parent to be tested	Ratooning ability (%)		
		Tai-Guao-Dao Xuan	Shong-Zao-Xian No. 26	Hon-Mei-Zao
Shu-Fong No. 1 (11)	Normal	–64.54 ± 30.92 F = 0.76	65.56 ± 14.74 F = 1.49**	70.75 ± 14.07 F = 1.55**
	Reciprocal	12.21 ± 25.94 F = 1.06	23.01 ± 19.10 F = 1.134	41.82 ± 17.00 F = 1.264**
Ai-Nan-Zao	Normal	76.41 ± 14.07 F = 1.618**	1.55 ± 21.93 F = 1.347	38.52 ± 20.69 F = 1.239.
	Reciprocal	13.01 ± 21.52 F = 1.070		57.03 ± 16.049 F = 1.399**

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

interaction. Using Mather and Jinks' (4) procedures, six generations of each cross combination and its reciprocals were used to estimate the genetic parameters and comparisons were made between corresponding estimates of these parameters obtained from reciprocal crosses. Various components of genic effects in the reciprocal crosses have been estimated as in Table 4. This indicates that

1) the additive [d] in crosses with Ai-Nan-Zao are all negative and highly significant, which shows that Ai-Nan-Zao will decrease ratooning ability;
2) Shu-Fong No. 1 (11) mated with Tai-Guao-Dao-Xuan. Shong-Zao-Xian No. 26 or Hon-Mei-Zao shows additive effects [d] which are extremely significant except in Shu-Fong No. 1 (11)/ Hon-Mei-Zao;
3) the crosses produced by parents possessing a certain degree of ratooning ability show different genic effects [m], [h], [i], [j], and [l], among filial generations from different parents of and between the reciprocals of the same parents.

Cytoplasmic effects and nucleocytoplasmic interaction in ratooning ability

To understand further how the cytoplasm affects the various components of genic effect in ratooning ability, the difference between the reciprocals in the various components of heredity is estimated from the data in Table 4 by the formula of 1/2 [reciprocal 2 minus normal (l)], and listed in Table 5.

In the column of component of heredity in Table 5,1/2 (m_2-m_1) is equal to the mean of differences between the reciprocals in average genic effects, that is, the cytoplasmic effects. 1/2($[d]_2$-$[d]_l$) equals the mean of difference, which subtracts normal additive $[d]_l$ from the reciprocal one $[d]_2$. As 1/2($[d]_2$ - $[d]_1$) is equal to zero, there seems to be no additive-cytoplasm interaction in the crosses under investigation. 1/2($[h_N^2$ - $[h]_1$) equals the interaction of dominance with the cytoplasm. l/2($[i]_2$ -$[i]_1$, 1/2($[j]_2$ - $[j]_l$, 1/2($[1]_2$ - $[1]_1$) are the interactions of additive/additive, additive/ dominance, and dominance/ dominance with the cytoplasm, respectively. Results are obtained by T testing. Tai-Guao-Dao-Xuan's cytoplasmic effect appears to be positive for Shu-Fong No. 1 (11) and negative for Ai-Nan-Zao, and they are all highly significant. Shong-Zao-Xian No. 26 shows extremely significant negative effect for Shu-Fong No. l(11), while Hon-Mei-Zao shows no significant cytoplasmic effect for Shu-Fong No. 1(11) but some cytoplasmic effects for Ai-Nan-Zao.

Table 4. The genic effects of ratooning ability in rice varieties.

Heredity component Genic effect Parent	[m]	[d]	[h]	[i]	[j]	[l]
Shu-Fong No. 1 (11)/Tal-Guao-Dao-Xuan	0.27±3.16	2.54±0.35	22.79±8.40	8.00±2.82	−11.91±2.50	-8.87±5.53
Tai-Guao-Dao-Xuan Shu-Fong No. 1 (11)	11.21±4.56**	2.54±0.35**	−	−2.94±4.54	−12.97±3.13	−
Ai-Nan-Zao/Tai-Guao-Dao-Xuan	9.0 ± 1.9**	-5.58±0.40**	−0.22±4.88	−1.58±1.94	3.05±1.43*	1.73±3.046
Tai-Guao-Dao-Xuan/Ai-Nan-Zao	3.80±2.11**	-5.60±0.40**	−	3.70±2.07	3.80±1.64*	−
Shu-Fong No, 1 (11)/Shong Zao-Xian No. 26	15.30±2.50*	5.90±0.60**	−27.24±6.15**	-9.18±2.14**	−2.30±1.85	27.61±3.91
Shong-Zao-Xian No. 26/Shu-Fong No. 1(11)	7.83±2.35**	5.86±0.59**	−10.04±5.91	−1.72±7.28	−7.47±1.87	17.01±3.902
Ai-Nan-Zao/ Shong-Zao-Xian NO.26	6.10 ± 1.36*	-1.15±0.24**	−7.22±5.16	-4.82±1.84.	0.19±1.65	3.01±3.38
Shong-Zao-Xian No. 26/Ai-Nan-Zao	−	1.15±0.24**	−	−	−	−
Shu-Fong No. 1 (11)/Hen-MeCZao	10.43±1.95*	0.58±0.40	−1.05±4.69	−2.18±1.91	−2.98±1.35	1.02±2.88
Hon-Mei-Zao/ Shu-Fong No, 1 (11)	8.73±1.85**	0.58±0.40	0.11±4.52	−0.48±1.80	1.16±1.34	3.38±2.84
Ai-Nan-Zao/ Hon-Mei-Zao	5.14±2.07*	-3.51±0.30**	1.26±5.35	-0.48±2.20	−0.34±1.60	−0.96±3.43
Hon-Mei-Zao/ Ai-Nan-Zao	7.94±1.80**	-3.51±0.30**	−6.70±4.40	−3.28±1.78	−0.26±1.33	3.24±2.72

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

Table 5. Difference between reciprocals in genic ratooning effects.

Heredity component Difference Parent	1/2 (m_2 - m_1)	1/2 ($[d]_2$-[d] 1)	1/2 ($[h]_2$-[h] 1)	1/2 ($[i]_2$-[i] 1)	1/2 ($[j]_2$-[i] 1)	1/2 ($[l]_2$-[l] 1)
Shu-Fong NO. 1 (11) /Tai-Guao-Dao-Xuan	5.47±1.39**	0	−	-5.47±1.37**	−0.53±1.00	−
Ai-Nan-Zao/Tai-Guao-Dao-Xuan	−2.62±0.72**	0	−	2.62±0.71**	0.36±0.54	−
Shu-Fong No. 1 (11)/Shong-Zao-Xian No. 26	−3.73±0.86**	0	8.60±2.13**	3.73±0.83**	−2.59±0.66**	−5.30±1.58**
Ai-Nan-Zao/Shong-Zao-Xian No, 26	−	0	−	−	−	−
Shu-Fong NO. 1 (11)/ Hon-Mei-Zao	0.85±0.67	0	0.58±1.63	0.85±0.66	2.67±0.47**	1.18±1.01
Ai-Nan-Zao/ Hon-Mei-Zao	1.40±0.69*	0	±1.73*	-1.40±0.71	0.04±0.51	2.10±1.09

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

The interaction of nucleocytoplasm is clear in Table 5. For the crosses with Tai-Guao-Dao-Xuan, the difference between reciprocals in [h] [I] cannot be estimated because there was no reciprocal hybrid F_1' in 1981. But the interaction of [i] with the cytoplasm appears to be extremely significant. For Shu-Fong No. l(11)/Shong-Zao-Xian No. 26, the interaction of [h] and [i] with the cytoplasm appears to be significantly positive and that of [j] and [l] significantly negative. For

Shu-Fong No. 1(11)/Hon-Mei-Zao, the interactions of [h], [i], and [l] are all nonsignificant except [j]. For Ai-Nan-Zao/Hon-Mei-Zao, the interactions of [h] and [i] with the cytoplasm show either significant or nearly significant negative effect.

DISCUSSION

The inheritance mechanism of ratooning ability in rice varieties is complex. Heterosis, heritability, and various components of genic effect in ratooning ability appear liable to variation. This implies that selecting for ratooning ability is possible in rice germplasm.

While the comparison is made by the combined estimated results of h_N^2 with the genic effects (see Table 5), the heritability of ratooning ability seems related to the cytoplasmic effect. In these experiments, although Tai-Guao-Dao-Xuan shows strong ratooning ability and significant cytoplasmic effects for Shu-Fong No. 1(11), its heritability is nonsignificant. On the other hand, although Hon-Mei-Zao does not display apparent cytoplasmic effects for Shu-Fong No. 1(11) and analysis of genic effects shows that [d] and [i] are all nonsignificant, the heritability of tiller regeneration ability is extremely significant. This indicates that Hon-Mei-Zao is a better parent in enhancing the ratooning ability for new varieties in breeding practice. Of course, because of the limited number of the varieties under study, the relationship between cytoplasmic effect and heritability needs to be explored further with more varietal types.

There is a great possibility of breeding a new variety (or hybrid rice) with high tiller regeneration ability; it is important to select optimal parents and the manner of combination between parents.

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Varietal improvement for rice ratooning: traits, procedures, collaboration

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ABSTRACT

Ratooning ability has not received consistent attention in breeding programs. Its genetics still are unclear. Ratooning ability may be more appropriately considered a composite trait. The challenge for breeders and plant physiologists is to create a common base of germplasm suitable for ratooning and to design consistent testing methods that are less influenced by the vagaries of weather. Collaboration with virologists could add germplasm to improve virus resistance. In the long run, wild rices may contribute both ratooning ability and disease resistance.

Ratooning utilizes the vegetative regrowth after harvest of the first crop (main crop) to obtain a second harvest (ratoon crop) from the same field. Ratooning is practiced in some areas of all rice-growing continents except Europe (9). Research under way is aimed at introducing ratooning where it has not been practiced before (1, 3).

Ratooning is a well-established agronomic practice, but for many plant breeders, ratooning ability as a selected trait of rice is new. To facilitate collaboration in varietal improvement with respect to ratooning ability, agronomic and economic aspects of the ratooning phenomenon, the nature of ratooning and the parameters for measuring trait components, and breeding techniques and strategies need attention.

AGROECONOMIC ASPECTS OF RATOONING

Reasons for using ratooning in a rice cropping system can be classified into one or more categories.

Timing

Practical examples of ratooning deal with a rice season long enough for more than one, but less than two, full rice crops. Because ratoon crops take only about half the time to mature as the main crop (12), this is where they are most often fitted in: the traditional main season crop is maintained, with a ratoon crop added as a continuation after the main season.

Should the season be long enough for two successive main crops, then ratooning becomes considerably less attractive. Usually the yield per day per area of a ratoon crop is far less than that of a main crop (2).

Saving on inputs

Ratooning often means getting something for nothing. Another crop is possible without additional inputs (land preparation, fertilizer, etc), an important consideration in almost all situations. Ratooning has been considered for use with hybrid rice (10) to gain more benefits from the extra inputs associated with its seed production.

Avoiding natural hazards

Natural hazards, such as drought or flood, can make ratooning attractive. Older plants often tolerate such stresses better than young plants. One approach to weather-related stress is to redesign the cropping calendar, moving the conventional rice crop up to before the main season, and ratooning during the main season. This procedure has been proposed for deep water rice (5). Other examples are cold spell avoidance in Swaziland (14) and India (6).

In this type of main crop/ratoon crop pattern, the calendar is radically changed.

Other uses

Ratooning is used by rice scientists for other purposes, many of which are not related to cropping. Ratooning is used as a breeding method for conventional rice, in growing F_1 generations in more than one successive season (27), in collecting rice germplasm from farmers' fields as stem cuttings while the crop is still vegetative (24 and current author), and in using ratooning ability as an indicator of lodging resistance and spikelet fertility (1 8, 20).

CHARACTERIZATION OF RATOONING ABILITY

For agronomists and breeders, characterization of the ratooning phenomenon is very important. Breeders are especially interested in ratooning aspects that are amenable to selection.

COMPONENTS OF RATOONING ABILITY

Ratooning is a complex phenomenon. It is possible to distinguish six groups of factors that contribute to a successful ratoon crop.

Vegetative buds

Genotypic. Varietal differences in tendency to produce basal or upper nodal axial tillers (23, 31).

Environmental. Water management before and after cutting, cutting height of the stubble (31).

Nutrient reserves

Genotypic. Ratooning ability of Mingolo variety has been related to high carbohydrate concentration (11). Other varieties were found to differ in timing of deposit and in final quantity of reserves in the stems (21).

Environmental. In studies where nutrient (carbohydrate) supply in the stems was manipulated, ratoon growth was seen as an indicator of the physiological situation of the crop (20, 29). Percentage of ratoon tillers, ratoon height, and ratoon weight depend on total available carbohydrate and weight of the stem base. In source-sink manipulations, subsequent ratooning was stimulated by prior removal of competitive sink and hampered by leaf pruning (29).

Agronomic practices, such as delay in cutting, cutting height, etc, have been related to ratooning ability (21). Conservation, or proper translocation, of nutrients results in better ratooning ability. Main crop sterility encouraged earlier ratoon crop development because it removed competitive sink. The post-grainfill accumulation of carbohydrates is in the lower 20% of stems; successful ratooning from a low cutting height depends on late cutting, to give time for reserves to move down.

Main-crop photosynthetic tissue and roots

Genotypic. Slow senescence has been mentioned as a varietal trait that facilitates vigorous ratoon growth because the new growth uses the remaining main-crop photosynthetic surface (11).

Environmental. Early ratoon growth (up to 2 wk after main crop harvest) was found to depend chiefly on the main-crop root system (8). Lower cutting heights slow early ratoon growth and lengthen ratoon crop duration (26).

Total maturity duration

Genotypic. This crucial factor in the success of ratooning technology is strongly genotypically controlled. Many authors have investigated the need for medium- to short-duration main crop varieties. In one study, panicles emerged from stem cuttings of variety PTB10 1 mo after transplanting; in variety PH37, this took 2.5 mo (23). Early-maturing varieties Dhairal and CH-4-10 were suitable for ratooning; late-maturing Charmock was not (30). Earliness was also favored for ratooning ability (15). A photoperiod-sensitive Mahsuri mutant, CRM 10-3628, useful as a ratoon crop, enabled the first ratoon crop to start in mid-October (1). The ratoon crop outyielded the main crop (3.3 t/ha vs 2.7 t/ha). Lateness in ratooned rices was associated with lateness in the main crop (25). Early flowering of the ratoon was related to high carbohydrate concentration in the stems. But late-flowering F_2 segregants were disproportionally good ratooners (11).

Environmental. Maturity took longer with taller cuts (25). But a lower 5-cm cutting height delayed maturity 9 d beyond a l5-cm cutting height (26). Cutting at 5-25 cm high gave ratoon crops 2-3 wk later than cutting at 45 cm high (15). Long growth duration induced by long photoperiods correlated with low ability to regenerate ratoon tillers, probably because of low N content in the late-flowering plants (16).

Yield and yield-components

Genotypic. Yielding ability, traced through a sufficient number of tillers per unit area, is partly a varietal trait. Several authors report ratoon yields correlated strongly with percentage of ratooning ability (17, 19). IR22 ratoon had more panicles than IR8 ratoon, and yielded higher (25). Ratoon crop yields also were related to ratoon crop durations (31).

Environmental. Important management factors are plant population, fertilization, harvest time (as early as possible) (31), and cutting height (15-20 cm). A cutting height of 15 cm and a spacing of 15 cm were best (2). Phosphate fertilizer on the main crop gave a very significant increase in ratoon crop yield, adding phosphate fertilizer to the stubble gave less yield (15).

In direct seeding, ratoon crops sometimes had more tillers than the main crop (2,3). The importance of nutrient status for the ratoon and the main crop has been well-documented (15,16). Ratoon yield from unshaded main crop plants was 34.2% higher than from 2/3 shaded plants (16).

Insect and disease resistance

Genotypic. The most important diseases are viruses; they affect ratoon crops more severely than main crops (31). Grassy stunt virus infection has been mentioned (2).

Environmental. In nutritional value to insects, the ratoon crop was inferior to the main crop. Population densities of most insects did not increase; in fact, populations in the ratoon crop most often decreased (13).

GENETICS OF RATOONING

Ratooning ability is seen as a complex trait, dependent on many heritable and environmental factors. Table 1 gives selected data from a study evaluating ratooning ability as a gauge of main crop physiologic traits (19).

The correlation coefficients, estimated from phenotypic and error variance and covariance components, indicate a very strong codetermination of ratooning ability and main crop traits, especially when cuttings are made before harvest (forfeiting the main crop). However, genotypic correlation estimates are still high 30 and 40 d after heading.

In the genetic study cited earlier (11), the F_3-on-F_2 regression coefficients for ratooning percentage were low and insignificant. On the other hand, within-year variance components indicated significant varietal effects, with estimates of a 0.26:0.43 ratio of genotypic variance to phenotypic variance. It has also been

Table 1. Genotypic correlation coefficients between percentage of ratoon tillers and agronomic characters of the mother plant (19).

Cutting time (d after heading)	Culm length (%)	Fertility (%)	Grain yield (%)
10	–0.63	0.94	0.55
20	–0.26	0.76	0.29
30	–0.34	0.38	0.11
40	–0.23	0.26	0.22

mentioned that ratooning ability appears to be associated with lateness of the F_2 segregants. The question is how much of the genotypic variance for ratooning percentage was caused by variance for flowering date. In a study of deepwater rice ratooning (5), ratooning ability was postulated to be simply inherited (5). The distribution pattern of an F_2 population fit a 1:3 ratio of ratooning:no ratooning segregates. However, ratooning ability was also strongly correlated with (late) flowering, leading to speculation that the ratooning gene is actually a flowering duration gene.

Is ratooning ability a genetic trait in its own right, or a trait derived from an interaction of genotypic and environmental factors? The data and experience appear to support the conclusion that it is a composite trait.

Consequently, in genetics studies of ratooning ability, it would be advisable to identify the trait being measured specifically as one of many traits contributing to ratooning success and to measure all conceivably related traits at the same time.

BREEDING

Before a breeder can focus on ratooning ability, he must have some concept of the physiology of the trait and be confident that it is at least partly genotypically determined. A testing method for the trait must be selected. The desired expression of the trait should not be linked to unfavorable expressions of other important traits. And sufficient breeding materials must be available.

SELECTION CRITERIA

These important heritable supporting traits can be distinguished:

Location of ratoons

Some varieties have a tendency to basal ratoons, others to axial upper-nodal ratoons (31). Because not much work has been done beyond this basic finding, it may be best to express this trait as the average location of ratoons in cm or nodes from the ground. Care should be taken after harvest to allow time for photosynthates to translocate to the lower part of the stems of the main crop.

Nutrient reserves

The choice is between several parameters: number of ratoon tillers per hill or per area, weight of ratoon tillers, height of ratoon tillers, etc. Number of ratoon tillers as a percentage of main crop tillers is a reliable parameter to use (11, 17). Other traits used could be the most heritable (19) or the ones best correlated with carbohydrate reserves (20). Another is the proposed ratoon rating formula (29):

$$(\text{average number ratoon tillers per hill}) \times \{1-(.01 \text{ ratoon vigor})\}$$

The degree of source or sink limitation, as a varietal trait contributing to ratooning ability, could be measured as the response of main crop yield and yield components to source-sink manipulations.

Main-crop photosynthetic tissue

Breeders and physiologists recognize varietal differences in speed of senescence. I have found several breeding lines for this trait. Chlorophyll assessments, visual or by instrument, could be made on rice varieties at maturity to assess senescence speed.

Maturity duration

Techniques for measuring maturity duration in ratoon crops are not different from those used in main crop research. Ratoon crop duration can never be seen in isolation from + main crop ratoon. Given the interaction of ratoon crop duration with such traits as stubble length, care should be taken to control stubble length at the locally desired level.

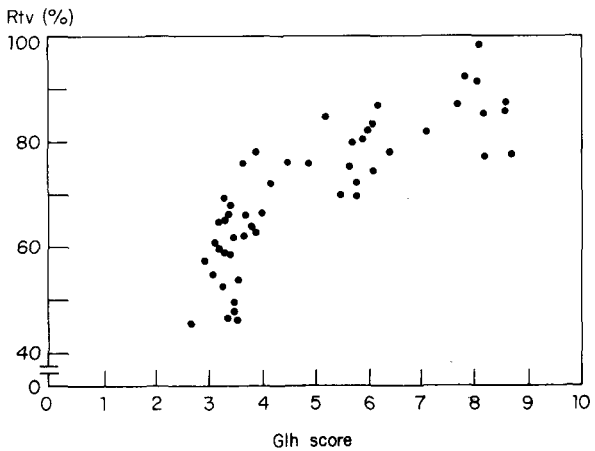
Yield

Much the same can be said for yield as for duration: ratoon yield should not be judged in isolation from main crop yield.

Diseases

Virus diseases deserve strong emphasis. The three assessing methods are: 1) resistance to the vector, 2) within vector resistance class, % virus infestation, and 3) resistance to the virus after artificial inoculation. The first method is already well-developed at several centers, including IRRI. Care should be taken to also consider resistance to the viruses themselves; evaluation should not be confined to resistance to the vector. Figure 1 illustrates the potential importance of assessing resistance to rice tungro virus (RTV) in relation to green leafhoppers (GLH). While there seems to be a strong association between resistance to GLH and low RTV infection, there are large differences within the group of lines resistant to GLH (score 3-4) in their RTV infection.

Table 2 illustrates work in progress at IRRI aimed at developing rices resistant to rice ragged stunt virus (RSV), independent of resistance to brown planthoppers.



1. The relation of average resistance score to green leafhoppers and average % tungro virus intection. glh scores from at least 5 tests—rtv % from at least 10 tests, using the Standard Evaluation System (SES).

Table 2. Seed set of plants in F_3 populations and varieties with different resistance to rice ragged stunt virus (RRSV).

Population	Fertility (%)				
	0	0-25	25-50	50-75	75-100
Susceptible check					
IR20	96.9	1.2	1.3	0.5	0.1
IR82340T-9-2	95.0	0.5	1.7	1.0	1.8
Resistant check					
SITOPAS	35.6	0.7	2.5	12.0	49.2
Segregating populations					
IR46630 IR20/SITOPAS//BR118-3B-17	85.0	2.4	5.0	4.5	3.1
IR46641 SITOPAS/I R26702-52-3//IR8234-0T-9-2	77.8	1.7	5.2	9.4	5.9

Table 3. Outstanding ratooning ricer cited in the literature.[a]

Belle Patna (9); Blue Bonnet (9); Century Patna 2 (9);
Century Patna 231 (9); CRM10-3628 (9); Gulfrose (9); IET3273 (26);
IET3305 (26); IET3629 (26); IET4555 (26); Intan (9, 23, 30);
IR5-47-2=IR5 (9); IR8-288-3= IR8 (9); IR1561-228-3 (2);
IR1924-30-2-2 (17); IR2058-78-1-3-2-3= 146 (9, 31)
IR2061-214-3-8-2=1R48 (2); IR2061-423-1 (17); IR2061-464-2 (2);
IR2061-632-3-1 (2, 17); IR2070-747-6-3-2 =IR32 (31);
IR2145-13-3 (17); IR2145-20-4 (17); IR2797-105-2-2-3 (31);
IR2863-38-1-2 =IR44 (9); IR4722-36-1 (9); IR8608-183-2-3-3 (31);
IR978452-2-3-2 (31); IR9802-50-1-2-2 (31); IR9852-19.2 (31);
IR13429-109-2-2-1 =IR56 (10); IR13471-57-3 (31); IR15315-26-3-2 (31);
IR19657-34-2-2-3-3A (10); Milbuen 5 (9); Swazi 2 (9)

[a] References in parentheses.

The resistance donor is the Indonesian variety Sitopas. It is clear that Sitopas has a significantly higher proportion of normal-yielding but virus-infected plants than the check varieties. Among the F_3 progenies from crosses involving Sitopas, a significant number of plants are similar to Sitopas in resistance.

SOURCES OF VARIABILITY

Historically, ratooning is an afterthought. The sources of variability reflect this; breeders have used leading local varieties and introductions for ratooning trials.

Table 3 lists varieties and lines reported outstanding in ratooning trials. Few have been reported more than once. A common base with rices of superior ratooning ability is lacking.

BREEDING STRATEGY

A realistic breeding objective should be to develop a profitable main crop-ratoon crop combination. But main crop performance should come first.

Short-term

Given the complicated nature of ratooning and its contributing traits, rigorous screening in early generations will be impractical. But no delay is necessary in addressing the two most important component traits: maturity duration and resistance to viruses or their vectors. In later generations, detailed assessments of ratooning ability can be made on the remaining lines. In fact, this is the procedure described for selecting deepwater rices for dry-season to wet-season ratooning cycles (4, 7).

Substantial international collaboration will be helpful in broadening the germplasm base. As a first measure, the existing reservoir of good medium- and early-maturity rices now being distributed and tested through the International Rice Testing Program (IRTP) should be accessed. Instead of starting a new ratooning nursery, interested breeders can test IRTP's early- and very early-maturity yield nurseries for ratooning ability. Results may indicate the consistency of ratooning performance across environments.

Long-term

The challenges are:

Crop physiology. Development of the relationship between ratooning ability and varietal characterization for source or sink limitation is needed.

Testing methods. Testing for ratooning ability is easy if it can be added to normal yield testing. In practice, this is difficult because of the lack of land, the interaction of ratooning ability with uncontrollable weather factors (temperature), and the different maturity ranges of entries in such trials. Methods for analyzing basal stem cuttings for carbohydrates and regeneration ability of crops at maturity may provide more flexibility and precision.

Resistance to virus diseases. Concerted attention is needed. Screening methods that include assessment of the ratoon crop after main crop virus inoculation should be tried. Resources at IRRI, including breeding materials, data bases, and the germplasm bank, can be shared.

New sources of variability. In the long run, wild rices may contribute both apparent resistance to diseases, including viruses, and strong tillering and regeneration ability. Work is in progress at several centers, including CRRI in India. At IRRI, *O. longistaminata* and *O. perennis* accessions are being used in crosses with modern varieties and deepwater rices. Progenies from such crosses may be exchanged at early development stages.

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Commercial ratoon rice production in Texas, USA

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ABSTRACT

Rice ratoon cropping on a widespread commercial scale in the Southern United States dates back to the early 1960s, when the first very early-maturing cultivar Belle Patna became available. About 50% of the rice hectarage in Texas and South Louisiana is ratooned annually, depending somewhat on weather conditions during main crop harvest. Cultural practices used in ratoon cropping have remained relatively consistent. Principal factors affecting ratoon yields are date of main crop harvest, weather conditions at main crop harvest (diseases and lodging in the main crop), mechanical damage field, fertilizer and water management for the ratoon crop, and temperatures during reproduction stages of the ratoon crop. Milling quality, grain uniformity, and grain appearance of the ratoon crop are generally lower than those of the main crop. A successful ratoon crop significantly reduces the unit cost of producing the total crop. Because of the greatly increased rice production costs in the United States during the past 3 or 4 yr, interest in and research on ratooning is receiving more attention. Breeding very early-maturing cultivars with increased seedling vigor and cold tolerance, developing improved cultural practices, and applying higher levels of management are expected to significantly raise average yields and quality of ratoon crop rice.

Rice ratooning in the United States was first practiced on a limited scale in Texas in the late 1950s (8). Cultivars available at that time were of moderately early to medium maturity, in general short-seasoned enough for consistent, reliable ratoon crop production. The release in 1961 of very early-maturing cultivar Belle Patna, with its superior ratooning ability, led to the rapid adoption of ratoon cropping as a commercially important enterprise (1). In the U.S., the growing season is too short to grow two successive rice crops from seed. A ratoon crop can be produced in only 2/3 to 3/4 of the time required for the main crop.

Approximately 40-50% of the Texas main rice crop is now ratooned annually, adding millions of dollars to farmers' incomes. Ratooning is also practiced widely in Louisiana and on about 75% of the limited rice hectarage in Florida. Since the establishment of ratooning on a commercial scale, the principal cultivars used for ratoon cropping have been Belle Patna, Bluebelle, Labelle, and Lebonnet (2, 3, 6).

Research on rice ratooning in the U.S. has been very limited and has been concerned primarily with cultural practices and and with evaluating selections in breeding programs for improved ratooning ability. U.S. literature on ratooning was included by Chauhan et al in their recent comprehensive review of rice ratooning (7).

Since widespread commercial ratooning was established in the Gulf Coast region of the U. S. more than two decades ago, ratoon crop cultural practices have changed very little. The proportion of Texas rice hectarage that is ratooned annually has remained relatively constant; weather is the principal factor in year-to-year hectarage fluctuations. Now, depressed economic conditions resulting from markedly increased production costs during the past 34 yr are causing researchers, producers, and industry personnel to review all aspects of rice production in an effort to optimize profitability. Economic analyses indicate that ratoon cropping can reduce per unit cost of production dramatically. As a result, research on breeding, cultural practices, and economics of ratooning is increasing.

AREA AND CLIMATE

The approximately 200,000 ha planted to rice in Texas during peak production years lies between 94 and 97 west longitude and between 28 and 30 north latitude, along the Texas-Louisiana Gulf Coast. Altitude varies from near sea level to 30 m above. Mean annual rainfall is 1,374 mm on the east edge, 889 mm on the west edge. Monthly rainfall (86-137 mm) is fairly evenly distributed through the year; October and March have the lowest rainfall and May-September the highest. Soils, alluvial clay and sandy loams, remain wet through much of December-February when rainfall/evaporation ratios range from 1.6 to 2.5. The ratio drops to about 1 during the summer.

Because of less favorable light and temperature (below 10 °C) as winter approaches and because hurricanes occur most frequently during August-September, rice producers obtain their best yields when they harvest the main crop before mid-August. When the main crop is not harvested by the end of August, ratoon cropping may not be economical because the ratoon crop is likely to be exposed during flowering to temperatures low enough to cause sterility. The average date of first frost is 28 Nov, the average date of last frost is 26 Feb. The normal growing season for rice is about 210 d.

The growing season in other parts of the U. S. rice belt (Arkansas, California, and Mississippi) is too short for commercial ratoon crop production.

PRODUCTION PRACTICES

Cultivar selection

Early or very early maturity (100-130 d from seeding) is necessary for any cultivar to produce consistent, satisfactory ratoon crop yields in the Southern U.S. For the past decade, Labelle has been the primary cultivar used for ratoon cropping. With the release of Lemont and Skybonnet in 1983, hectarage planted to Labelle has decreased markedly.

Table 1. Planting date effect on yields of main crop (MC) and ratoon crop (RC) of Labelle and Lemont cultivars, Eagle Lake, Texas, 1985.[a]

Planting date		Harvest date		Days to maturity		Yield (t/ha)	
		Labelle	Lemont	Labelle	Lemont	Labelle	Lemont
13 Mar	MC	24 Jul	24 Jul	133	133	5.8	9.4
	RC	18 Sep	18 Oct	56	86	2.4	3.2
	Total	—	—	189	219	8.2	12.6
28 Mar	MC	24 Jul	31 Jul	118	125	6.0	9.5
	RC	5 Oct	18 Oct	73	79	1.7	3.5
	Total	—	—	191	204	7.8	13.0
19 Apr	MC	14 Aug	14 Aug	117	117	5.8	8.6
	RC	18 Oct	8 Nov	65	86	1.4	2.2
	Total	—	—	182	203	7.3	10.9
1 May	MC	23 Aug	26 Aug	114	117	6.1	8.1
	RC	18 Nov	19 Nov	87	85	1.3	1.5
	Total	—	—	201	202	7.5	9.7
13 May	MC	4 Sep	6 Sep	114	116	5.2	7.7
	RC	18 Nov	5 Dec	75	90	0.6	0.5
	Total	—	—	189	206	5.8	8.2

[a]M. O. Way, Texas Agricultural Experiment Station, Beaumont, Texas, unpublished data.

Skybonnet is superior to Labelle in main crop yielding ability and appears to be equal or superior in ratooning ability. When grown under a high level of management, Lemont has a main crop yield potential significantly higher than that of any other Texas and Louisiana cultivar. When seeded early, Lemont also has superior ratooning ability (Table 1). Lemont is expected to be the most widely planted cultivar in Texas and Louisiana in 1986.

Planting date

Planting dates that result in the main crop maturing after the end of August lead to inferior or inconsistent ratoon crops. Planting late-maturing cultivars (140 plus d) before the recommended planting date (15 Mar-15 Apr) does not increase the chances of harvesting the main crop before the end of August; the cooler temperatures before mid-March only lengthen the time to maturity. Planting recommended cultivars 15-31 Mar may sometimes produce lower main crop yields than 1-15 Apr plantings due to cool spring temperatures, but planting at earlier dates increases the chances of harvesting in time to optimize the ratoon crop.

A recommended cultivar harvested by 15 Aug usually will produce a ratoon crop in 2/3 to 3/4 of the time needed for the main crop. The ratoon crop yield can reach 1/3 of the main crop yield. The effect of planting date on main crop and ratoon crop yields of Labelle and Lemont cultivars are shown in Table 1. Even though Lemont matures 10-14 d later than Labelle, it consistently produces higher main crop and ratoon crop yields. Planting on 30 Apr or later results in lower ratoon crop yields.

Main crop harvesting

Field experience has shown that cutting lower than the height necessary to remove the main crop grain has no advantage. Normal cutting height is 45-60 cm. Cutting

lower puts more straw through the combine, which slows harvest and increases the amount of grain left in the field. Mowing or rolling after harvest improves the uniformity of ratoon crop maturity and in some cases may improve grain milling. However, mowing or rolling delays the ratoon crop, which may result in a limited growing season and yield loss.

One concern at main crop harvest is that the soil is dry so that harvest equipment does not rut the field and destroy stubble. Damaged stubble does not recover, or recovers but is delayed, resulting in poor ratoon crop grain milling.

Fertilizer

Phosphorus and potassium are applied if needed to the first crop; only N is applied to the ratoon crop. The current practice is to apply N immediately after main crop harvest. The N is applied onto dry soil and the field is flooded immediately. N rate varies from 0 to 100 kg N/ha, depending on the ratoon crop yield potential (i.e, main crop harvest date, weeds, ruts in fields, etc.).

We found that N applied about 2 wk after initial main crop heading usually will accelerate ratoon tillering and result in 7-10 d earlier maturity in the ratoon harvest. Additional experiments are under way to evaluate yields when 1/2 of the ratoon crop N is applied about 2 wk after initial heading of main crop and 1/2 immediately after main crop harvest.

Water management

During main crop harvest, the field should be dry enough to support heavy machinery. However, if the field is drained earlier than about 3 wk after initial heading (harvest 30-35 d after initial heading), the soil may dry so much that ratoon tillering is suppressed.

As soon as the main crop is harvested and fertilizer applied, the field should be flooded 8-10 cm deep (9). If floodwater is not maintained, main crop grain that falls to the ground during mechanical harvest will germinate and compete with the ratoon crop for light and nutrients.

MILLING AND COOKING QUALITY

Whole grain yield of the ratoon crop is generally lower than that of the main crop (10). Ratoon crop kernels are generally smaller, lighter weight, and less uniform than those of the main crop. Depending on cultural practices, weather conditions, and harvest date, the ratoon crop tends to have a higher proportion of discolored hulls, deformed grains, and immature grains. Cooking quality of ratoon crop rice is equal or superior to that of the main crop. Surveys of commercial fields indicate that the higher the ratoon crop yield, the better the milling yield (1985 unpublished data).

ECONOMICS

The marked increase in rice production costs in the Southern U.S. during the past several years, primarily the result of increased energy costs, has led to an increased

Table 2. Estimated average annual yield (t/ha) and cost of production ($/t) in Texas, 1983-85.

Year	Yield[a] (t/ha)	Cost[b] ($/t)	Hectarage in new cultivars (%)
1983	4.8	295.40	1
1984	5.5	273.10	35
1985	6.3	239.00	80

[a]Source Crop Reporting Service. [b]Based on Gerlow's production cost estimates.

Table 3. Main, ratoon, and total yields (t/ha) and estimated production cost ($/t) for Lemont, Skybonnet, and Labelle cultivars. Texas, 1985.[a]

Cultivar	Fields (no.)	Main crop			Ratoon crop					Total crop			
		Area (ha)	Yield (t/ha)	Cost ($/t)	Area (ha)	Yield (t/ha)	% of main crop yield	Cost ($/t)	% of main crop cost	Area (ha)	Yield (t/ha)	Cost ($/t)	%of main crop cost
Lemont	21	1,375	6.6	233	844	2.3	34	63	27	844	9.6	176	75
Skybonnet	14	690	5.8	263	372	2.0	34	66	25	372	8.0	205	78
Labelle	3	351	5.5	275	284	1.6	30	73	27	284	7.2	227	83

[a]Survey by J. W. Stansel.

interest in ratooning as a way to reduce per unit production costs. Newly released cultivars Lemont and Skybonnet have higher main crop yield ability than Labelle, the principal cultivar in Texas and the South for almost a decade (4, 5). With high levels of management, they also appear to have higher ratoon crop potential. With the increase in Texas rice hectarage planted to the new cultivars, from 1% in 1983 to 80% in 1985, average yields increased from 4.3 to 6.3/ha (Tab1e 2). At the same time, estimated costs of production declined from $295 to $239/t.

Stansel (unpublished data) compared yields of the main and ratoon crops of Lemont, Skybonnet, and Labelle in 1985 and estimated the unit cost of production (Table 3). He also analyzed the costs of production among producers who obtained very high yields with Lemont and Skybonnet (Table 4). Unit cost of production was inversely related to yield of both the main and the ratoon crops. There was a distinct cost advantage in growing a ratoon crop. For both the main and ratoon crop, the unit cost of production was lowest for Lemont. Fields that produced very high yields required the lowest costs and provided the greatest economic benefits.

ADVANTAGES AND DISADVANTAGES OF RATOONING

Because the ratoon crop requires little additional input over the main crop, the principal advantage of ratooning rice in the U.S. is the lower unit cost of production. A successful ratoon crop can add significantly to overall rice farming profitability. But, despite the potential profit ratooning may provide, only about 50% of the producers in those areas of the Southern U.S. where ratooning is possible actually grow a ratoon crop. A 1982 informal survey of the rice-producing counties in Texas showed a wide variation in the proportion of the crop that was ratooned (from below

Table 4. Cost of production ($/t) by yield level, Lemont and Skybonnet cultivars.[a]

Number of producers		Yield level	Estimated cost ($/t)
Lemont	Skybonnet		
20	3	7.8 t/ha Main crop	200
12	3	10.0 t/ha Main crop + Ratoon crop	169
3	–	11.2 t/ha Main crop + Ratoon crop	152

[a] Survey by J. W. Stansel.

30% to above 95%). The eastern side of the Texas rice belt had the least ratoon cropping and the western end the most.

There are a number of reasons for the variation in the amount of ratooning practiced in Texas. The eastern edge of the rice area receives on average 475 mm more rainfall a year than the western edge. The higher rainfall tends to delay land preparation and seeding in the spring, which has a negative impact on ratoon crop yield. Higher rainfall also may interfere with main crop harvest and with ratoon crop cultural practices. Harvesting the main crop when the soil is wet may rut the field so badly that the opportunity for a successful ratoon crop is eliminated, or at least the ratoon crop yield potential is reduced. Because drier soils tend to warm up earlier in spring, seeding in the west begins 1-2 wk earlier than in the east. On the whole, higher rainfall tends to be associated with greater weed control problems as well as with higher disease incidence, both of which can have a negative impact on ratoon cropping.

Although climatic factors are the major influence on the amount of ratooning practiced in Texas, other factors affect the practice. Ratooning on land infested with red rice tends to increase the severity of infestation in the following crops. Heavy soils dry out more slowly than light, sandy soils and are more likely to have problems with rutting during main crop harvest. On the local level, heavy populations of black birds can totally consume a ratoon crop in the vicinity of their roosts.

Social or socioeconomic factors also influence the amount of ratooning practiced. In some cases, landlord-tenant agreements do not encourage ratooning. Some farmers who failed at early attempts to ratoon, through poor management or inappropriate weather at critical times, have not made another attempt. Some farmers do not plan to ratoon, but depend on chance rainfall and main crop fertilization to produce a ratoon crop. With essentially no investment in the ratoon crop, they harvest it only if there appears to be sufficient production to cover harvesting costs and to provide a small profit. In some instances, the lack of water or its prohibitive cost discourages ratooning.

For progressive farmers who recognize the potentials offered by ratooning, and plan to ratoon from the beginning of the main crop season, and apply a high level of management for both the main and the ratoon crops, the success rate is very high. The cost/price squeeze on U.S. rice producers now is a greatly increased economic incentive to grow a ratoon crop. With the accelerated research programs now under way in the Southern U.S., we expect ratoon cropping to reach its full potential and contribute significantly to the economic well-being of the rice farmer.

We have discussed ratoon cropping in a rice production system that is highly mechanized, direct seeded, with controlled irrigation. The primary constraints that have a strong impact on ratooning in the U.S. are declining daylength and decreasing temperatures in the autumn. Other regions of the rice-growing world may benefit from ratoon cropping, but differences in climatic conditions, cultural practices, and disease incidence are so different, our experiences and practices with ratooning may have only limited application.

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Screening rice genotypes for ratooning ability in the Tungabhadra River Project of Karnataka

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In the Tungabhadra River Project, farmers prefer rice cultivars with good grain quality (good grain appearance, short and slender grains, and high milling recovery), responsiveness to high rates of chemical fertilizers, and resistance to insect pests and diseases. Many recommended and unrecommended rice cultivars are cultivated. The major portion of the area in autumn is occupied by Sona Mahsuri, a late-maturing (150-160 d) genotype. In summer, farmers prefer Tellahamsa, a medium-maturing (135-140 d) variety with long, slender grains. Both are, however, susceptible to brown planthopper, so we are trying to replace them with tolerant genotypes of comparable grain quality.

EVALUATING GENOTYPES FOR RATOONING ABILITY

Many genotypic differences in ratooning ability have been reported and were summarized by Chauhan et al (1). However, we felt a need to evaluate genotypes for their main crop performance and ratooning ability in the Tungabhadra project area.

Main crop

Twenty-two promising rice genotypes belonging to medium- and late-maturity groups were planted in demonstration plots in autumn, 1985. Spacing was 20 cm between rows and 15 cm between plants. Fertilizer was applied to the main crop at the rate of 100 kg N, 22 kg P, and 42 kg K/ ha. Days to flowering varied from 98 to 135 d. Autumn yields among genotypes varied greatly, but were comparatively lower than summer yields because of brown planthopper incidence and bacterial leaf blight.

Ratoon crop

The main crop was cut 15 cm above ground. Nitrogen at 50 kg/ ha and P at 18 kg/ ha were applied. The number of regenerated tillers was highest in cultivars that had high main crop yields. Genotypes ratooned irrespective of their main crop flowering duration.

Table 1. Observations of main and ratoon crops of 23 rice genotypes, Tungabhadra River Project, Karnataka.

Genotype	Main crop			Ratoon crop[a]												
	Tillers/ plant	Days to 50% flowering	Yield (t/ha)	Regene-rated tillers (no.)	Ratoon vigor[b]	Stem girth (cm)	Shoot wt (g) 1 MAR	Root wt (g) 1 MAR	Shoot wt (g) 2 MAR	Root wt (g) 2 MAR	Days to flowering	Ratoon ht(cm)	Yield (t/ha)	1000-grain wt(g)	% germination	HI
IR50	9.6	99	2.02	13.4	5	0.32	4.98	1.38	7.30	0.90	46(46.5)	58.2	0.29(14.36)	17.1	58	0.18
IR30864	9.6	99	3.83	17.80	5	0.32	3.26	0.34	8.30	1.40	51(51.5)	66.0	0.54(14.09)	18.1	32	0.20
PUSHPA	11.2	99	3.15	16.20	9	0.40	2.20	0.32	8.15	1.60	50(50.5)	66.0	0.10(3.17)	17.5	53	0.49
IET7575	11.0	118	2.52	14.40	5	0.43	8.04	2.08	10.45	1.40	51(42.2)	69.8	0.32(12.70)	19.4	65	0.25
KNS5914	18.2	135	3.38	14.20	1	0.40	5.04	1.86	8.90	1.50	49(36.3)	72.4	0.47(13.90)	13.0	48	0.16
PUSA-150	11.6	102	3.23	16.00	9	0.38	6.84	3.04	6.90	2.55	51(50.0)	72.4	0.70(21.67)	17.2	18	0.27
BPT-2685	13.0	120	2.26	16.2	1	0.38	10.04	8.70	16.05	8.30	53(44.2)	61.2	1.61 (71.24)	17.2	79	0.39
IET-8110	15.2	121	2.94	17.6	1	0.40	11.30	4.20	9.00	4.90	52(43.0)	70.2	1.50(52.04)	19.5	49	0.35
IET-8101	10.4	117	2.94	19.8	5	0.40	15.15	9.35	17.75	12.25	51(43.6)	54.2	1.23(41.83)	20.5	38	0.33
IET-8114	11.0	102	4.73	24.2	1	0.33	7.40	5.50	13.75	6.90	53(53.0)	68.6	0.94(19.87)	21.4	48	0.25
IET-7431	11.0	123	3.55	23.2	1	0.36	8.36	3.65	12.25	3.15	54(43.9)	74.2	1.81(50.99)	22.4	25	0.35
IET-6463	14.4	119	2.85	24.4	5	0.40	12.80	6.35	17.75	8.10	50(42.0)	66.2	1.53(53.68)	20.0	37	0.46
IET-6211	14.0	125	3.39	20.0	5	0.45	11.35	3.05	14.50	3.25	51(40.8)	49.8	1.07(31.56)	24.3	86	0.25
IET-7297	11.6	125	2.66	26.4	1	0.44	13.65	14.10	19.50	12.95	48(38.4)	71.2	1.37(51.50)	20.4	85	0.26
ET-7300	16.0	124	3.23	27.0	1	0.43	10.70	6.00	17.50	7.20	51(41.1)	69.6	0.65(20.12)	20.8	47	0.29
ET-7999	10.2	116	2.65	25.0	1	0.42	17.15	4.50	18.5	5.75	47(40.5)	63.4	1.48(55.84)	20.0	17	0.25
IET-8004	10.6	114	4.62	28.6	1	0.41	17.40	6.60	21.05	3.60	45(39.5)	70.0	0.75(16.23)	16.0	32	0.37
IR54	16.5	99	4.03	23.2	5	0.47	6.10	2.95	7.95	3.50	51(51.5)	65.0	0.52(12.90)	13.6	87	0.17
ET-8614	17.6	114	3.06	26.0	1	0.42	11.75	6.80	12.55	7.10	45(39.5)	49.0	0.80(29.41)	13.6	75	0.40
BPT-5204	21.2	120	3.83	17.3	1	0.44	7.40	1.05	7.57	2.25	51(42.5)	65.5	1.01(26.37)	15.6	56	0.30
S-9271	22.4	112	4.54	18.8	1	0.44	16.10	5.75	15.85	2.00	51(45.5)	62.4	0.89(19.60)	24.0	67	0.20
RNR-52147	19.6	113	3.94	18.4	1	0.44	10.75	3.10	12.65	2.15	52(43.7)	65.6	1.13(28.68)	17.6	87	0.25
BPT-2226	20.4	114	3.51	30.2	1	0.42	11.75	6.00	13.30	4.40	45(38.5)	57.6	1.56(45.67)	15.0	89	0.43

[a]MAR = months after ratooning, HI = harvest index. Figures in parentheses are % of main crop. [b]1 = Very good, 5 = medium, 9 = low.

Table 2. Correlation coefficients among main crop characteristics with ratoon yield.

	Tillers/plant	Days to 50% flowering	Main crop yield (ha)	Ratoon crop yield (ha)
Tillers/plant	1.00	0.11	0.35.	0.30
Days to 50% flowering		1.00	0.34	0.46*
Main crop yield			1.00	0.58**
Ratoon crop yield				1.00

r = main crop flowering duration/ratoon flowering duration = 0.14.

Table 3. Correlation coefficients among ratoon characters with ratoon yield.

	Days to 50% flowering	Regenerated tillers	Ratoon ht	Panicles/ Plant	1000-wt	Ratoon yield
Days to 50% flowering		0.46*	0.33	0.05	0.31	0.38*
Regenerated tillers			0.23	0.34	0.01	0.88**
Ratoon height				0.06	0.24	0.38*
Panicles/plant					-0.55**	0.29
1000-grain weight						0.35*

The ratoon crop stand was impressive in cultivar BPT-2685, which had dark green leaves, probably due to high N content. We did not observe any significant association between days to flowering in the main crop and in the ratoon crop. Most dry matter in the ratoon crop accumulated in shoots, but ratooning ability was dependent upon higher root weight and volume. This supports the conclusion of Chauhan et al (1) that IR44 ratoon tillers are dependent on the main crop root system until at least 21 d after harvest.

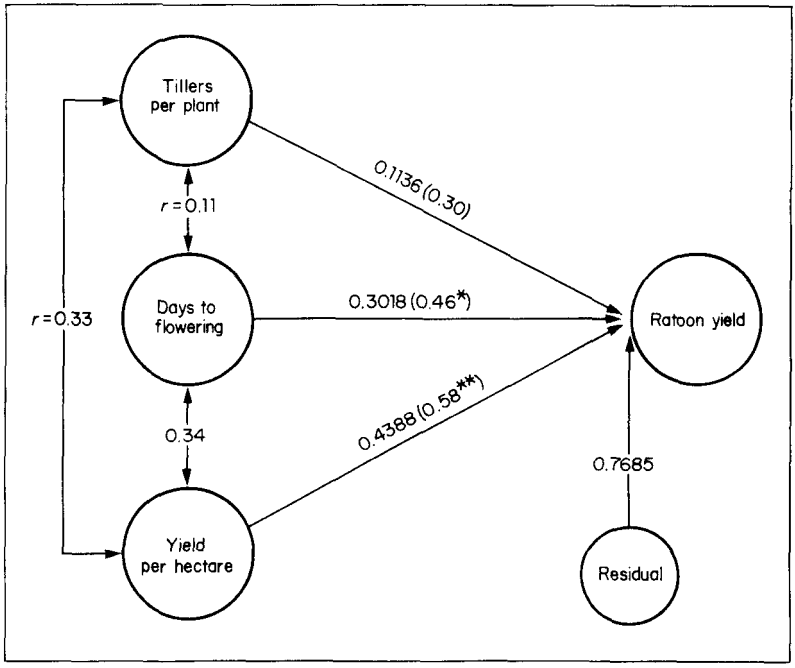
Grain filling was excellent in many cultivars and ratoon stands of many genotypes were as good as the main crop stand. Genotypes such as BPT-2226, BPT-2685, IET-7431, and KMS-5914 had superior ratoon crop stands. Many of them are late maturing and can be exploited for ratooning.

In the main crop, a large variability was observed in tillers/plant, days to flowering, and yield. In the ratoon crop, variability was observed in number of regenerated tillers, root and shoot weights, days to flowering, yield, 1000-grain weight, and germination percentage,

There was 40-50% reduction in days to 50% flowering of the ratoon crop compared to the main crop. Similarly, ratoon crop yields ranged from 3.17 to 71.24% of the main crop yields. The harvest index ranged from 0.16 to 0.49 in the ratoon crop, which is indicative of biomass production along with its compartmentalization between grain and straw (Table 1).

Correlation coefficients between grain yields of main and ratoon crops were highly significant (Table 2) (r=0.58). However, the main crop flowering duration did not affect ratoon flowering duration. Among the ratoon characters, number of regenerated tillers had the highest association with ratoon yield (r=0.88) (Table 3).

The path analyses revealed that main crop yield and number of regenerated tillers had higher direct effect on ratoon crop yields (Fig. 1, 2).



1. Path analysis showing influence of some main-crop characters on ratoon yield.

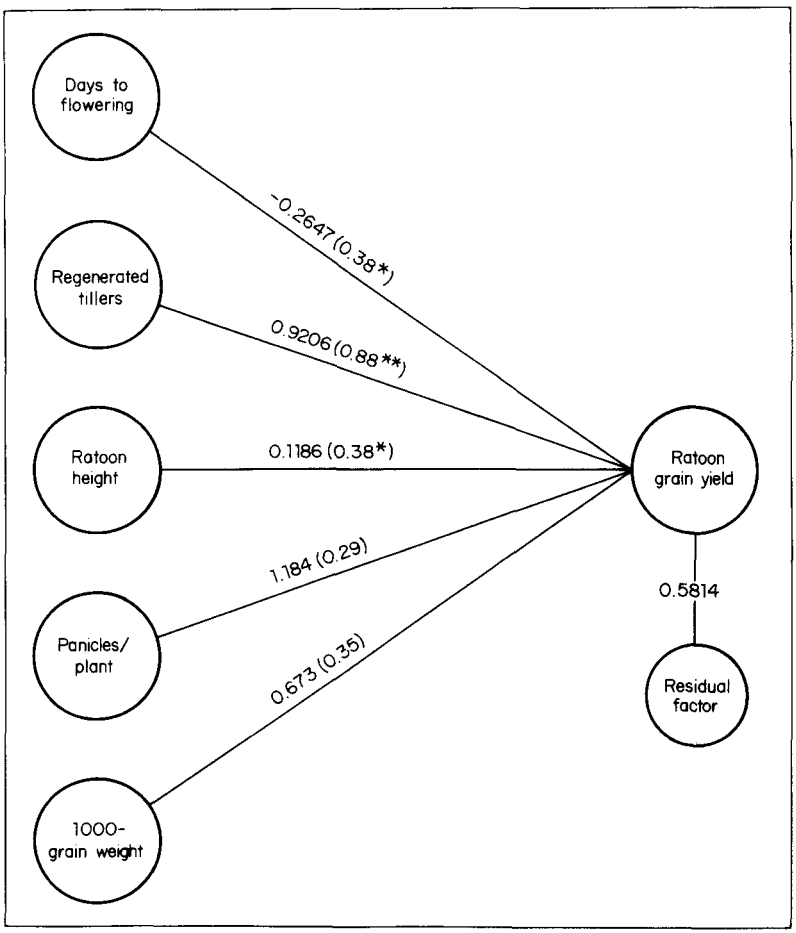
FUTURE RESEARCH NEEDS

We have compared the grain quality of the ratoon crop with that of the main crop. We have also compared the quality of the ratooning genotypes. Percentage of broken rice was higher in the ratoon crop grains. The cooking quality of the ratoon rice was on par with that of the main crop. If ratooning is to be accepted in the Tungabhadra River Project, the ratoon crop must have comparable grain yields and quality to the present cultivars.

We have only limited genetic stock for ratoon evaluation, but we hope to include more genotypes in the future. Breeding programs to evolve genotypes for this agroecological zone should also include evaluation for ratooning ability. Genetic divergence studies utilizing ratooning-related parameters have been initiated to identify genotypes with diverse backgrounds, and many crosses between these genotypes will be evaluated.

CONCLUSIONS

Because of the dwindling reservoir capacity to sustain a second rice crop during summer months, great potential exists for rice ratooning in the Tungabhadra River Project. Genotypes with economic ratoon yields must be identified if ratooning is to



2. Path analysis showing influence of ratoon characters on rice grain yield.

be accepted by rice growers. The results of the preliminary evaluation for genetic variability are encouraging and have opened possibilities for further genotypic evaluation and breeding for ratooning ability.

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Recommendations

Varietal Improvement and Agronomic Practices

1. *Collect all cultivars with proven ratooning ability.*
   a. Make the germplasm with ratooning ability at IRRI available to other scientists and identify cultivars suitable for different agroecological zones.
   b. Make available a screening set of varieties with high ratooning ability classified according to desirable ratooning characters such as plant height, growth duration, etc.
2. *Screen all existing high yielding varieties for ratooning ability.*
   a. Screen farmers' varieties for ratooning ability under farmers' inputs.
   b. Identify IRTP nursery entries with good ratooning ability at stations receiving IRYN early, medium, and late nurseries and share data with other scientists.
3. *Determine methods for screening a good ratoon crop based on site-specific standards.*

   There is no single criterion by which to measure a good ratoon crop. Standards for different sites vary depending on need, cropping pattern, crop management, water availability, environment, and sociological factors. Main crop and ratoon crop yields are the ultimate measures. The following characters, however, may be used as indicators depending on need:
   a. growth duration of the ratoon crop,
   b. disease and insect resistance,
   c. slow senescence,
   d. lodging resistance,
   e. ratooning ability,
   f. bud length of a good crop at harvest, and
   g. drought, submergence, and cold tolerance.
4. *Taking a long-term view, make crosses using exotic material such as* O. longistaminata, *which has high regeneration ability.*
5. *Identify potential sites for ratooning in different rice-growing areas.*
6. *Group-test the best performing ratoon rices identified by various programs and provide seed samples to IRRI so that other scientists can test them.*
7. *Use November plantings of IRTP deepwater rice, floating rice, and rainfed rice nurseries to explore possibilities for ratoon rice in Eastern India and Bangladesh.*
8. *Concentrate on evaluating ratoon crops in farmers 'field.*
9. *Devise methods to test ratooning ability without compromising main crop yield.*

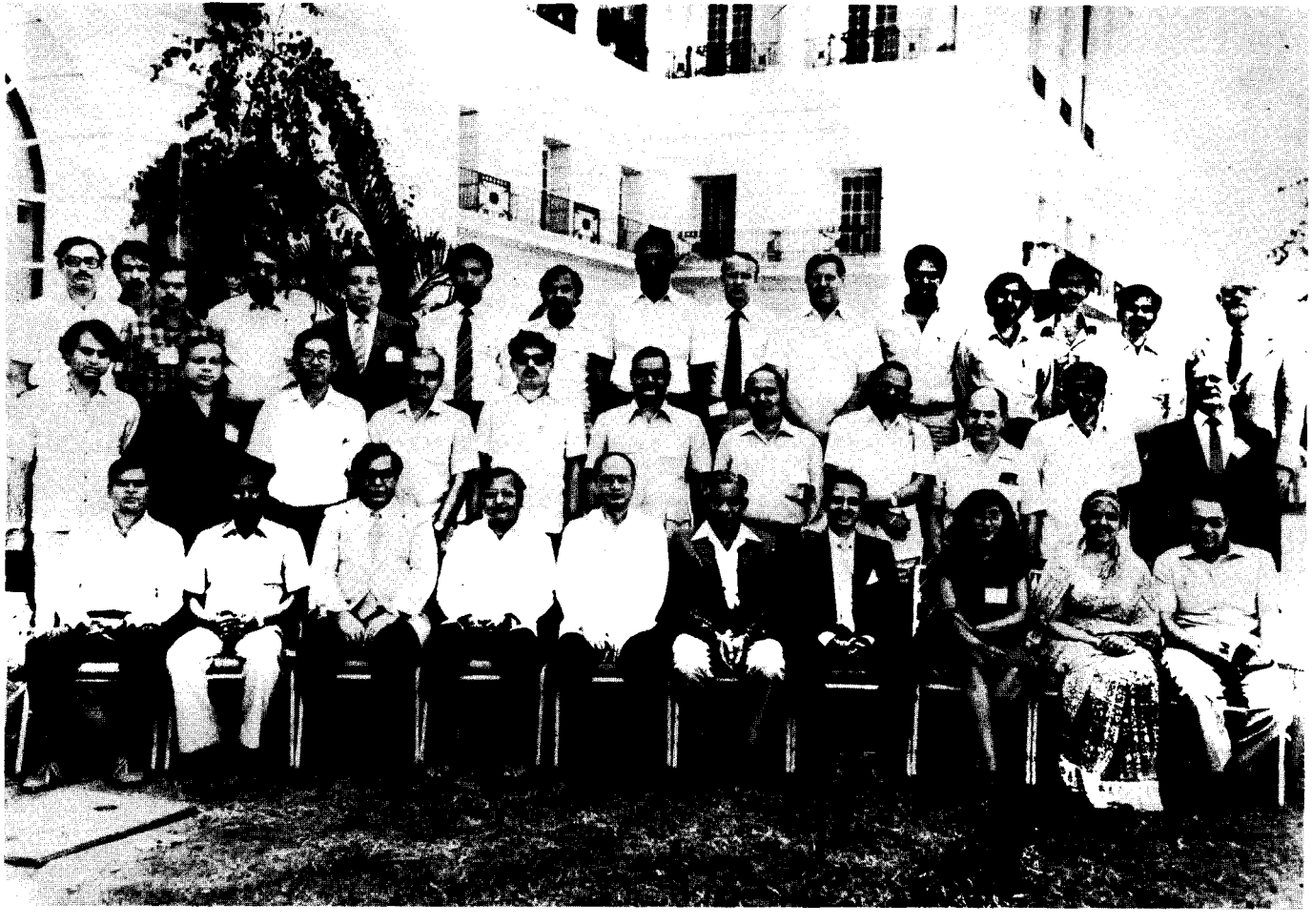
10. *Consider consumer quality and seed quality of the ratoon crop when introducing ratooning as a cropping option.*
11. *Study ratooning ability, not in isolation but in concert with other agronomic traits that potentially influence the ratoon crop.*
12. *Give priority in pest management to the prevalent main crop insect pests and diseases with particular attention to yellow dwarf disease.*
13. *Conduct yield loss trials in ratoon crops to develop economic thresholds for insect pests.*

Cultural Management

1. *Initiate research on rice ratooning in broadcast seeded rice; determine management practices for the main crop and ratoon crop.*
2. *Study optimum plant spacing, including within-row spacing, to obtain best results with the ratoon crop in transplanted rice.*
3. *Combine fertilizer management studies with water management studies in the ratoon crop.*
4. *Study integrated weed control methods for the main crop that will not adversely affect the ratoon crop.*
5. *Study cultural practices that will enhance ratooning ability.*
6. *Give sufficient attention to the efficiency and profitability of main crop disease management in relation to ratoon crop management.*
7. *Study the potentialfor increasing biomass production in the ratoon crop for use as fodder.*
8. *Study the possibility of intercropping a green manure crop with the ratoon rice crop.*

Physiology

1. *Determine the possibility of using stem cuttings in screening entries for ratooning ability.*
2. *Compare the physiological difference between a ratooning cultivar and a nonratooning cultivar through growth analysis.*
3. *Study the effect of salinity on tiller regeneration andperformance of the ratoon crop.*
4. *Study the control of tillering in the main crop stubble.*



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Varietal index

A200, **221**
Achra 108/1, **6, 71, 76, 136-140**
ACM5, **222**
ACM6, **222**
ACM7, **222**
ACM8, **113, 116**
ACM9, **113**
ACM10, **113**
AD54-1, **113**
AD2774, **113**
ADT27, **71, 114-116**
ADT29, **113, 116**
ADT30, **113, 116**
ADT31, **113, 116**
ADT32, **221**
ADT14185, **222**
Ai-Nan-Tsao, **239-245**
Ai-Nan-Zao, see Ai-Nan-Two
Ai-You 1, **81, 83, 84, 156-158, 166**
Ai-You 2, **156, 159, 160, 166, 169**
Ai-You 4, **81**
Aluvbatta, **74**
Andramota, **133**
AP30, **121**
B29816–SR-85-3-2-4, **187**
B2983-b-853-24, **173**
83063 BTK-72-2, **230**
Bahagia, **211**
Bansmoti man **136, 138**
Baspati, **146, 147**
Basumathi, **70, 72**
Belle Patna, **6, 47, 52, 253, 257**
Bengiza, **133**
Bhasamanik, **136, 131**
Bhavani, **76, 111-117**
Bluebelle, **6, 257**
Bluebonnet, **253**
BM2060, **121**
Botohavana, **133**
BPI 76, **37, 112**
BPT 2226, **266, 267**
BPT 2685, **266, 267**
BPT 5204, **98, 266**
BRI, **145, 147, 148**
BR2-29-2-1-3, **211**
BR3, **145-147**
BR4, **145, 211**
BR8, **127**
BR9, **145**
BR10, **145, 230**
BR11, **145, 147, 148**
BR51-3154, **230, 231**
BR52-96-3, **230, 231**
BR118-3B-17, **253**
BR2489 BKN 1-76–8, **230**
C4-63A, **221**
C23-3–1, **93**
C3810, **5-7, 70, 72, 76, 122, 166**
C8585, **124, 125**
Carreon, **92**
Century Patna, **253**
CH2, **11, 106, 111, 222**
CH4-10, **249**
CH10, **125, 126**
CH45, **11, 74, 106**
CH988, **121**
CH1039, **121**
Chaoymg IA, **156**
Churmock, **249**
Cbe-Eu-Hung, **222**
Chianung-Sen-Yu 13, **229**
Chianung 8, **139, 133**
China 5, **222**
China 1039, **222**
Choayang IA, **83**
Chun-Chen 2, **222**
CICA 4, **134, 169**
CI9857, **51**
Co 32, **71, 76, 113, 115, 116**
Co 42, **113-115**
Co 43, **113**
Co44, **113**
Cold Adakkan 27, **74, 181**
Cold AMBT-2, **222**
CR20-66, **166**
CR44–35, **124, 127**
CR126-33-11, **11**
CR142-3-8, **121**
CR146-224, **113, 116**
CRI56–50021-207, **72, 133, 166**
CR157-22-IB00, **7**
CR2Md6, **7**
CR238-3–2-99, **121**
CR263-506, **222**
CR1001, **113**
CR1002, **230**
CR1014, **149, 141**
CRM10-3628, **6, 78, 75, 249, 253**
CT19, **107**
CT36, **222**
CT43, **219, 220, 222**
CTSI, **107**
CT57, **219, 220, 222**
CT67. **222**
CT97 **222**
CT1351, **73, 74, 106, 107**
CT1351-1, **219, 220, 222**
CT1351-2, **219, 226, 222**
D52-37, **5**
De Abril, **9, 56-59**
Dhairal, **249**
Doddabyra, **219, 220, 222**

Double Dwarf, **92**
Elang, **121**
Firoz 1, **221**
FR13A, **6,71,76,136-140**
Fu Mein Huang, **222**
Fu Men Huan, **222**
Gamadu, **219-221**
Gandsali, **219,222**
Gangasali, **220**
GMR13, **113**
Guangerai, **81**
Gulfmont, **47,49,52**
Gulfrose, **93,106,180, 253**
Halubbalu, **73,107,222**
Hon-Mei-Zao, **239-245**
HP1, **222**
HP2, **222**
HP3, **222**
HP5, **222**
HP8, **222**
HP12, **222**
HR35, **219,220,222**
HY25-10, **221**
HY256, **219-221**
HY258, **221**
I Sona, **221**
IET405, **92**
IET1444, **124,142,221**
1ET1522, **222**
IET1785, **221**
IET2295, **221**
IET2683, **142**
IET2700, **221**
IET2885, **113**
IET3127, **92**
IET3273, **253**
IET3280, **221**
IET3305, **253**
IET3600, **133**
IET3626, **221**
IET3629, **6, 71, 253**
IET4094, **92**
IET4555, **71,253**
IET4699, **211**
IET4702, **221**
IET5975, **219, 220, 222**
IET6211, **266**
IET6463, **266**
1ET7191, **5,10,106**
IETl297, **266**
IET7300, **266**
IETl431, **266, 267**
IET7575, **98, 266**
IET7999, **266**
IET8004, **266**
IET8101, **266**
IET8110, **266**
IET8l14, **266**
IET8614, **266**
IET9667, **5, 11, 107**
IET9668, **5, 11, 107**
IET9670, **5,11,107**
Immo, **121**
Impoare, **121**
Intan, **2, 5-7, 9, 11-13, 69, 72-76, 88-91, 97, 105-107, 134, 178, 179, 183, 236, 237, 253**
Intan (IRRI), **73, 91, 94**
Intan (UAS), **73, 91, 94**
Intan Mahsuri, **219, 220, 222, 223**
Intan Mutant, **105-107, 222, 223, 236**
Intan Mutant 1, **106, 223**
Intangouri, **106**
1R5, **239,253**
IR547-2, see IR5
IR8, **5, 7, 71, 76, 113-116, 121, 221, 239, 250, 253**
IR8-288-3, see IR8
IR20, **113-117, 211, 253**
IR22, **122, 164, 250**
IR24, **81, 121**
IR28, **5, 6, 12, 167-169**
IR29, **81, 167**
IR32, **173, 209, 210, 214-216, 253**
IR36, **6, 76, 94, 121, 136, 138, 140-142, 151-153, 164, 166, 169, 211**
IR38, **166**
IR42, **5, 6, 141, 142, 166, 169, 171, 172, 174, 211**
IR44, **31-33, 133, 166, 253, 267**
IR46, **57, 134, 146, 166, 233, 253**
IR48, **153, 253**
IR50, **136, 138, 140, 141, 143, 147-149, 210, 222, 265**
IR54, **223, 265, 266**
IR56, **151-153, 212, 213, 253**
IR58, **94**
1Rl27-80-3-10, **11**
IR238-3-249, **121**
1R356-1-46B-4-6-18 **133**
IR579, **142**
IR661, **81**
IR747B2-6, **12**
IR841, **55,57,59**
IR841-63-5, **9,55-58**
IR889-55-6-4-6, **9**
IR975-303-3-1-3-2-3, **92**
IR1317, **211**
IR1529-680-3. **113**
IR1544-340-6-1, **211**
IRl561-228-3, **12, 253**
IR1910 sel, **211**
IR1917, **197, 206**
IR1924-30-2-2, **253**
IR1924-36-22, **166**
IR205542-3-2, **92**
IR2058-78-1-3-2-3, see IR46
IR2058-85-3-3, **211**
IR2061-214-3-8-2, see IR48
IR2061423, **166**
IR2061-423-1, **253**
IR2061.462-2, **134**
IR2061-464-2, **12,253**

IR2061465-1, **12**
IR12061-632-3-1, **6, 12, 134, 171, 253**
IR2070-423-2-5-6, **211**
lR2070-747-6-3-2, see IR32
IR2071-588-44, **211**
IR2071-588-5-1-1, **211**
IR2145-13-3, **253**
IR2145-204, **166, 253**
IR2328-198-1-1-1, **211**
IR2793-97-3-2, **211**
IR2797-105-2-2-3, **253**
IR2797-125-3-2-2, **153**
IR2843-26-3-2, **211**
IR2863-28-1-2, **6,7**
IR2863-38-1-2,see IR44
IR4422-98-36, **211**
IR4531-10057-5-1-1, **211**
IR4722-36-1, **6, 134, 166, 253**
IR58574lE-6, **93**
IR7682-135-3-2-2-2, **93**
IR8234-0T-9-2, **253**
IR8460-180-2-1-3, **93**
IR8608-75-3-1-3, **94**
IR8608-76-3-2, **94**
IR8608-183-2-3-3, **253**
IR9129-209-2-2-2-3, **94**
IR9129-393-2-6-2-2, **94**
IR9129-417-1-3, **92**
IR9129-457-2-2-1-2, **94**
IR9201-101-2-2-7, **92**
IR9202-25-1-3, **178, 222**
IR920948-3-2, **92, 94, 229**
IR9209-49-1-2-1-2, **92**
IR9209-81-2-3-2-2, **92**
IR9209-217-1-2-2, **94**
IR9224-23-2-2-2-3, **94**
IR9224-223-2-2-1, **94**
IR9224-223-2-2-2-1, **94**
IR9698-16-3-3-2, **94**
IR9752-71-3-2, see IR58
IR9758-150-3, **94**
IR9761-19-1, **229**
IR976140-3-2, **94**
IR39782-111-2-1-2, **94**
IR9784-52-2-3-2, **253**
IR9802-50-1-2-2, **253**
IR9814-14-3, **94**
IR9828-41-2-1, **92**
IR9846-23-2, **94**
IR9846-256-34, **92**
IR9852-19-2, **94, 253**
IR9940-11-2-3, **92, 93**
IR10154-23-3-3A, **153**
IR10167-87-3-3, **93**
IR10167-129-3-4, **93**
IR10198-21-1-3, **93**
IR10781-143-2-3, **153**
IRI1248-8-242-3-1-1, **92**
IRI1248-227-1-2-2, **92**
IR13047-76-1, **93**
IR1314645-2-3, **152, 153**
IR13214-99-2-2-3, **92**
IR13240-15-3-3-2, **92**
IR133684-3, **92**
IR13371-86-1, **92**
IR13420-6-3-3-1, **153**
IR13423-71-2-2, **94**
IR1342740-2-3-3, **229**
IR13429-109-2-2-1, see IR56
IRl3429-287-3, **229**
IRI3429-305-3, **92**
IR13471-57-3, **253**
IR136414, - **92**
IR13641-20, **92**
IRI5315-26-3-2, **253**
IR15324-117-2-2-3, **94**
IR15579-135-3, **178**
IR15599-135-3, **107**
IR15675-74-1-3, **92**
IR15795-232-3-3-2, **153**
IR17525-8-12-3-3-2, **94**
IRl8476-55-2, **107,178**
IR19362-62, **93**
IR1%57-34-2-2-3-3A, **151-153, 253**
IR19661-131-1-2, **153**
IR19661-364-1-2-3, **153**
IR19729-67-3, **153**
IR19735-5-2-3-2-1, **153**
IR19743-25-2-2. **178**
IR19794-2-2-2, **92**
IR19796–14-2-2, **92**
IR19799-17-3-1, **92**
IR19799-17-3-I-IA, **153**
IR21845-90-3A, **223**
IR23057-247-2-2-3, **94**
IR26702-52-3, **253**
IR129723-243-3-2-1, **223**
IR30864, **266**
IR46630, **253**
IR46641, **253**
IR46828A, **223**
IR46830A, **223**
IR46831A, **223**
Iri 356A, **223**
ISA21, **65**
ISA 40, **65**
Jatri, **120**
Jaya, **121**
Jeeragasamba, **113-116**
Jeerige sanna, **70, 72, 222**
JS, **71, 76**
Kakirekkalu, **70, 72**
Kaladumai, **220**
Kalbara, **221**
Kalila, **133**
Kameji, **130**
Kaoshung 21, **130, 133**
Karekagga 78, **93**
KBCPI (Hema), **222**
KBCPI, **107**
Khonorullu, **121**
KMP104, **219, 220, 222**

KMP106, **222**
KMSI, **76,106,182**
KMS4, **76**
KMS5, **76**
KMS5914, **266,267**
Kurnargore, **136,138,140,141**
L 5738, **57-59**
Labelle, **5, 6, 9, 47, 49, 51, 52, 134, 180, 188-192, 257-259, 261**
Laka, **211**
Latisail, **138**
Lebonnet, **49, 257**
Lemont, **47-49, 52, 188-193, 258, 259, 261, 262**
Loktjan, **220**
Luke 3, **84, 156, 166**
Madhu. **222**
Mahsuri, **5, 75, 106**
Makalioka, **130**
Mampana, **129, 130, 133**
Mandya Vani, **222**
Mangakely, **133**
Mangala, **73, 74, 106, 107, 181, 222**
Manila, **122**
MDU2, **113,116**
Metica 1, **57-59**
MG209, **57-59**
Milbuen 5, **6, 134, 253**
Milbumum, **93**
Milyang 54, **223**
Mingolo, **37,65,73-75,91,94,105-107, 178, 179, 181, 236, 249**
MR18, **221**
MR161, **221**
MR249, **219, 235**
MR261, **221**
MR278, **11**
MR292, **221**
MR343, **221**
MR359, **221**
MR360, **221**
MR362, **221**
MR363, **219, 220, 221**
MR365, **222**
MR365A, **153**
MR367, **221**
MR1-IR22, **58**
MS577A, **182, 223**
MS577B, **182**
MTU17, **221**
Mulliam Puncha, **181**
N22, **106, 124**
N136, **124**
Nag, see HP2
Nagra 41-14, **136, 137**
Nahda-11, **133**
Nandi, see HP1
Nan-You 2, **81**
NC365, **136-138**
NC1263, **138**
NC1626, **124,125**
Neela, see HP3
Newrex, **49, 51**
Ngoba, **121**
No-Lin 49, **220**
No. 27. **76**
No. 34, see Makalioka
No. 40-1, **79, 82, 83**
No. 97A, **223**
No. 1300. **130,133**
No. 13292-5-2, **223**
NP97, **70,72,76**
NP125, **70, 72**
NR10073-167-2-1-1, **178**
NR10073-167-3-1-1, **187**
OR100-25, **7**
P101, **59**
P102, **59**
P203A, **223**
P899, **55-59**
P899-55-6-4-6-1B, **56-58**
Pajarn. **144, 145, 147**
Pajam 11, **143, 146, 149**
Pankaj, **106, 211**
Pankhari 203, **182, 221, 222**
PankhariA, **182**
PankhariB, **182**
Patna, **76**
Pawnbuh, **120, 121**
Pe-Bi-Hun, **220**
PESAGRO 101, **57,58**
PESAGRO 102, **58**
PESAGRO 103, **58**
Peta, **112**
PH37, **249**
Phalguna, **222**
Phulbuh, **121**
Pijurn, **121**
Pikutokumoto, **221**
Ponni, **113-117**
Popy, **120**
Pragathi, **222**
PTB10, **106, 249**
Puduvai Ponni, **113**
Pusa 33, **121, 124, 127**
Pusa 150, **98, 266**
Pusa 221, **124**
Pushpa, **266**
Pyat Pyapu, **121**
Ram Tulasi (Thulasi), **92**
Rasi, **121, 222**
Ratna, **7, 70, 76, 166**
Rexmont, **49**
RNR-52147, **266**
Rojofotsy, **133**
RP974-5-7-6-2, **221**
RP1045-5-6-2. **113**
RP1045-10-6-2-1. **113**
RPKN 2, **93**
RPS 32, **106**
RU7401011, **51**

RU7502006, **49,51**
RU7601007, **51**
RU7602015, **49**
RU7603009, **49, 51**
RU7701001, **51**
RU7701004, **51**
RU7701014, **49, 51**
RU7701021, **51**
RU7702003, **51**
RU7702010, **51**
RU7702016, **49, 51**
RU7703005, **49**
RU7703008, **49, 51**
RU7703012, **49, 51**
RU7801001, **49**
RU7801004, **49**
RU7801007, **49**
RU7801011, **49**
RU7802003, **49**
RU7802010, **49**
RU7802013, **49**
S317, see Halubbalu
S684, **2, 4, 72,73**
S705, **74, 106, 220**
S1092, **183, 234**
S9271, **266**
Saitama Mochi No. 10, **220**
Sattari, **121**
Sel, CR-l26-6, **219**
Shan-You 2, **81, 84, 156**
Shan-You 63, **83, 156, 157**
Sharavath, see HP5
Sheng-Li-Xian, **80**
Shinei, **130, 133**
Shintsu, **130**
Shong-Zao-Xian 26, **239-244**
Shu Feng 1, **81**
Shu Fong 1(11), **239-245**
Shuibaitiao, **158**
SITOPAS, **253**
Skybonnet, **49, 51, 258, 259, 261, 262**
SL 016, **124**
Soiki, **120**
Sona Mahsuri, **99-103, 265**
SR26B, **6, 71, 76, 136-140**
Subhadra, **121**
Suduwee, **211**
Sugadas, **70, 72**
Swazi 2, **253**
T65, **220**
T(N)1, **124,220**
T21, **124**
Ta-poo-cho-z, **211**
Tadukan, **211**
Tai-Guao-l>ao-Xuan, **239-245**
Taichung 150, **130**
Taichung Native-I, see T(N)1
Taichung Sen Yu 285, **229**
Taichung-150, **133**
Taiguodao Xuan, **83, 1-56**
Tainung Sen Yu, **222**
Taipei 131, **220**
Taipei 310, **220**
Tellahamsa, **100, 101, 103, 265**
Telep, **220**
Thilalek Chanian, **92**
Tilakkachari (Tillakkachari), **6, 71, 76, 136, 138-140**
TKM8, **113, 116**
TNAU13613, **7, 133**
Tomoe Masari, **130**
Toyokekari, **130**
Tsimatahotrosa, **133**
Tsipala, **133**
TTB2, **I21**
Vaigai, **76, 113-116**
VL 8, **222**
Wan-Li-Xian, **80**
Wanar I, **220**
Wei-You 64, **223**
Xiao-Jia-Huo, **81**
Y4, **221**
Yabar, **120**
Yang-Xian 203, **81**
Z-Yah-Tsan, **222**
Zai-Sheng-Ai, **156, 166**
Zai-Sheng-You, **79, 83, 84, 156-158, 160, 161, 166**
Zai-Sheig-Ai, **84**
Zhrn-Zhu-Ai, **81**