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Improving management of rice in semi-arid eastern Indonesia: responses to irrigation, plant type and nitrogen

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Summary. A number of field experiments were undertaken in eastern Indonesia with the aim of improving rice production in this semi-arid region. The objectives of these studies were to examine the effects of irrigation method (raised beds under saturated soil culture *v*. flooded system), irrigation frequency (daily *v*. twice weekly) and genotype (traditional *v*. improved) on rice yield and components of yield, and to examine the response of rice growth on raised beds to sowing time and nitrogen fertilisation.

Recent studies in northern Australia have demonstrated that rice can successfully be grown under saturated soil culture. In the Australian studies, grain yield and quality were maintained, yet saturated soil culture used 32% less water than the flooded control in both wet and dry seasons. Higher efficiencies of water use for rice production with saturated soil culture in semi-arid tropical Australia suggest that similar benefits may be realised with this method of irrigation in West Timor.

The experiments in West Timor were undertaken within a low-external-input system, and all experiments were affected by drought. The central issue is one of aligning crop growth with water availability to ensure adequate quantity and quality of grain production at the end of the season. On this basis, a number of practical strategies for improving rice production under water-limited conditions in West Timor are suggested. First, time of sowing in the wet season is important, with early-sown crops escaping end-of-season drought. Significantly, the improved genotype (cv. Lemont) was only able to fill its grain adequately if sown early in the wet season, thereby avoiding drought during grain filling.

Second, providing soils are sufficiently deep, rice can successfully be grown under saturated soil culture in West Timor. Importantly, preparation of raised beds before the wet season enables rice crops to be sown early, maximising the use of rainfall for crop production. Twice weekly irrigation of rice on beds was found to be more efficient than irrigating daily or flooding the bays.

Third, no differences in grain yield were found between the improved short-statured genotype (cv. Lemont) and the taller traditional genotype under the low-external-input system, although differences in components of yield were observed in the wet and dry seasons. There is some evidence that the traditional genotype filled grain better when water was limiting during grain growth by restricting vegetative production and enabling the crop to finish.

Introduction

Rice production in the semi-arid tropics of West Timor is restricted by water supply. The region is characterised by a monsoonal rainfall pattern with hot, humid wet seasons from November to April and cooler, drier seasons from May to October. Most of the agriculture is undertaken during the wet season, which can be as short as 4 months. Limited irrigation water is available during the dry season in restricted areas. Even so, rice yields under this partially irrigated system remain low (<1.5 t/ha). Cropping systems have evolved in West Timor which minimise the risk of total crop failure due to drought or flooding (Pellokila *et al.* 1991). Increasing the efficiency of water use would improve the stability of food supply for subsistence farmers in this region.

The semi-arid tropical environment of eastern Indonesia is vastly different to the wet tropical environment of western Indonesia. Therefore different methods of improving crop production are required in Timor compared with Java. Barlow and Gondowarsito (1991) claim that both genetic and agronomic solutions must be sought to improve crop production in eastern Indonesia. The variable and sparse environment in Timor requires new agricultural varieties and techniques, since many of the agricultural packages developed for the high

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production regions of western Indonesia are not suitable (Barlow and Gondowarsito 1991). In particular, inefficient use of available water resources needs to be addressed (Duggan 1991). Harvesting and storage of surplus wet season water through collection of rainfall, retention of run-off, and more efficient use of flood plains and aquifers require further attention.

The environment of northern Australia is similar to eastern Indonesia, suggesting that common methods of crop improvement could be used in both regions. Recent studies in northern Australia have found that it is not necessary to flood rice to obtain high grain yield and quality. Saturated soil culture (SSC) is a technique developed for soybeans (Troedson *et al.* 1989; Garside *et al*. 1992*a*) and rice (Borrell *et al*. 1991, 1997) in northern Australia—plants are grown on raised beds of height 0.2 m and width 1.2 m, with water maintained in the furrows (0.3 m wide) some 0.1 m below the bed surface. Compared with flooded production, water savings of about 32% were attained in the wet and dry seasons when rice was grown under SSC (Borrell *et al.* 1997). The use of raised beds in SSC also enables rice to be rotated with other crops in a system (Garside *et al.* 1992*b*). Improved efficiencies of water use for rice production with SSC in semi-arid tropical Australia suggested that similar benefits may be realised with this method of irrigation in West Timor. It is likely that permanent raised beds would also reduce the likelihood of soil erosion in cropping systems by providing ground cover all year. Soil erosion is the most important environmental problem facing Timor, since it reduces the productivity of the land and reduces water quality (Duggan 1991).

Timor's shallow soils cannot sustain the present rate of erosion and continue to feed a growing population (Duggan 1991). This dilemma is exacerbated by the prevalence of slash-and-burn farming systems (Ormeling 1955); recent population pressure has forced the premature return to fallowed ground, limiting the buildup of soil fertility. The decline in crop production through both erosion and nutrient removal is supported by anecdotal evidence from local subsistence farmers (OeNai pers. comm.). Therefore production from the land must be sustainable for a given level of technology. For Timor, this means an agricultural production system without large inorganic fertiliser inputs or sophisticated mechanisation for the foreseeable future. Hence the need to develop low-external-input sustainable cropping systems for eastern Indonesia. Duggan (1991), in a review of land and environment in eastern Indonesia, concluded that efficient management of water resources should be an important focus and that research into sustainable farming systems is urgently required.

The experience of developing a rice-based cropping system in northern Australia suggested that an examination of rice growth on raised beds in West Timor was warranted. The key issue is one of matching crop growth to water supply, ensuring sufficient quantity and quality of grain at the end of the season. The objectives of experiments outlined in this paper were to examine the effects of irrigation method (SSC *v*. flooded system), irrigation frequency (daily *v*. twice weekly) and genotype (traditional *v*. improved) on rice yield and components of yield, and to examine the response of rice growth on raised beds to sowing time and nitrogen fertilisation.

Materials and methods

Location and soil details

Three experiments were conducted at Batu Plat, Kupang, West Timor (10.2ºS, 123.9ºE): experiment 1, 1993 dry season; experiment 2, 1994–95 wet season; and experiment 3, 1995 dry season. The site originally supported a suite of native and introduced pasture grass and leguminous tree (e.g. *Acacia farnesiana*) species before its burning and clearing for the initial experiment. The soil, described as a smectitic clay or Vertosol (Isbell 1996) with pH (1 : 5 soil : H_2O) >8.0, is, according to Pellokila *et al.* (1991), derived from a parent material of marine origin and the profile is consequently dominated by calcium carbonate.

Design and treatments

Experiment 1. A randomised split split-plot design with 3 replications was used in which irrigation method (SSC *v*. flooded system) was split for irrigation frequency (daily *v*. twice weekly applications) which was split for genotype (traditional upland *v*. improved lowland). Each plot contained 3 adjoining beds of length 4 m and width 1.5 m, such that plot size was 18 m^2. In the flooded treatment, 2 irrigations or flushes were followed by a permanent flood of depth 0.1 m at the 3-leaf stage, 21 days after sowing (DAS). In SSC, plants were grown on raised beds of height 0.2 m with a plot width of 1.5 m (1.2-m wide bed plus 0.3-m wide furrow); these plots were flushed until the 3-leaf stage (21 DAS) after which time water was maintained constantly in the furrows some 0.1 m below the bed surface. The traditional upland genotype was obtained from the village of Padang Alang in Alor, an island to the north of Timor. Lemont (Bollich *et al.* 1985), a cultivar used in raised bed studies in northern Australia (Borrell *et al.* 1997), was chosen to represent improved lowland genotypes.

Experiment 2. A randomised block design with 4 replications was used in which rice (cv. Lemont) was sown early (15 December 1994) and late (15 January 1995). Each plot contained 3 adjoining raised beds of length 3 m and width 1.5 m, such that total plot area was 13.5 m^2.

Experiment 3. A randomised split split-plot design with 4 replications was used in which rate of nitrogen (N) fertiliser (0, 40 and 80 kg/ha) was split for time of application (all at sowing, half at sowing and half at panicle initiation, all at panicle initiation) which was split for genotype (traditional upland *v*. improved lowland). Three adjoining raised beds of length 2.7 m and width 1.5 m were contained within each plot, such that plot size was 12.2 m^2.

All N was applied as urea. For the application at sowing, urea was placed at a depth of 0.1 m below the surface of the beds. Recent studies on rice growth under SSC in northern Australia found that N losses were minimised by placement of urea below the watertable (Borrell 1993). Treatments varying in the time of N application were based on earlier work on flooded rice in northern Australia which found that applying half of the N to the soil surface immediately before permanent flood and the remaining half into floodwater around panicle initiation resulted in the highest grain yields (Maltby and Barnes 1986). Timing of panicle initiation was estimated by randomly selecting 10 plants of each genotype from all plots 3 times a week after the emergence of 6 leaves in Lemont. The mainstems were sliced in half and the commencement of stem elongation, an indicator of the onset of initiation, was noted. Earlier research in northern Australia found that initiation in rice (cv. Lemont) coincided with a stem internode length of about 2 mm (Borrell *et al*. 1998*a*).

Agronomy

Experiment 1. For the SSC treatment, raised beds were constructed by hand before the 1993–94 wet season. Rice was hand sown during the 1st week of April 1993. Three seeds were sown into 10-mm deep holes at 0.05-m intervals along 9 rows, of which 7 rows were 0.17 m apart on top of the bed, and 2 rows were 0.2 m apart in the furrow, giving a population of 120 plants/m^2. This array was considered optimal for plant survival should the beds partially collapse during the course of the experiment. Dry poultry manure carried in sawdust was applied to all plots about 2 weeks before sowing at a rate of 7 kg/m^2 and incorporated into the surface 0.1 m. It was not possible to determine the effective contribution of N from poultry manure to crop growth. Irrigation water sourced from a nearby watercourse was siphoned onto plots. To ensure field correlation, the experiment was conducted within constraints typical of a traditional low-input cropping system in West Timor; no mechanical cultivation or inorganic fertilisers or pesticides were used.

Experiment 2. Raised beds of width 1.2 m and height 0.2 m, separated by 0.3-m wide furrows, were constructed by hand before the 1994–95 wet season. All plots were fertilised with urea immediately before sowing (23 kg N/ha) and at 28 DAS (23 kg N/ha). At both sowing times (December and January), rice was planted by hand into beds (6 rows) and furrows (2 rows) to a depth of 10–20 mm at 0.06-m intervals along rows which were 0.19 m apart, giving a population of 90 plants/m^2. No irrigation water was applied.

Experiment 3. Before the 1995 dry season, raised beds of width 1.2 m and height 0.2 m, separated by furrows of width 0.3 m, were constructed by hand. Rice was hand-sown between 8 and 13 February 1995 into beds (6 rows) and furrows (2 rows) to a depth of 10–20 mm at 0.06-m intervals along rows spaced 0.19 m apart, giving a population of 90 plants/m^2. This experiment was not irrigated. Apart from the N treatments, no fertiliser (organic or inorganic) was applied.

Harvests

Experiment 1. Dry matter harvests were taken after physiological maturity in the week commencing 10 July 1993. Physiological maturity was estimated by the yellowing of 90% of the florets. Dry matter was determined from 3 quadrats (5 rows of 1 m, 0.75 m^2) cut at ground level in each plot and dried at 80°C for 48 h. Plant and panicle numbers per quadrat were determined at the time of harvest. Panicles were threshed and grain yields per quadrat were measured. The numbers of filled and unfilled florets on 20 panicles per plot were counted to estimate floret fertility. The 500 grain weight of 3 samples per plot was also determined.

Experiment 2. All plots were harvested after physiological maturity on 23 March 1995 (sowing 1) and 3 May 1995 (sowing 2). Dry matter was determined from 3 quadrats (8 rows of 1 m, 1.5 m^2) cut at ground level in each plot, and each row was harvested separately. Plant and panicle numbers per row were determined at the time of harvest. Within rows, samples were separated into panicle and non-panicle components then dried at 80°C for 48 h. Panicles were threshed and grain yields per row were measured. The 500 grain weight of 3 samples per plot was also measured.

Experiment 3. Dry matter samples were taken from all plots after physiological maturity on 26 July 1995. Dry matter was determined from 3 quadrats (8 rows of 1 m, 1.5 m^2) cut at ground level in each plot. Plant and panicle numbers per quadrat were determined at the time of harvest. The height of 20 plants in each plot was measured. Samples were separated into panicle and non-panicle components then dried at 80°C for 48 h. Panicles were threshed and grain yields per quadrat were measured. The 500 grain weight of 3 samples per plot was also determined.

Statistical analyses

A standard analysis of variance was used with pairwise comparisons of means performed using the protected l.s.d. procedure at $P = 0.05$. Harvest index was

Table 1. Total monthly rainfall, mean daily pan evaporation, mean monthly maximum and minimum temperatures and mean daily solar radiation recorded at Mapoli Station, Kupang, during the experimental periods

Month	Total rainfall (mm)	Mean daily pan evaporation (mm)	Mean maximum temperature (°C)	Mean minimum temperature (°C)	Mean daily solar radiation (MJ/m^2.day)
			Experiment 1 (1993 dry season)		
April	0	6.1	31.4	22.9	n.r.
May	14.0	5.8	28.3	25.3	n.r.
June	5.5	5.2	27.8	22.9	9.7
July	0.2	5.6	27.4	21.3	18.5
			Experiment 2 (1994–95 wet season)		
December	82.2	5.2	31.9	23.4	23.5
January	426.8	2.8	28.8	23.8	18.0
February	566.6	3.9	28.5	23.8	19.8
March	460.0	3.9	29.8	23.3	19.1
April	140.8	4.4	30.1	22.6	19.8
May	59.0	5.4	31.0	22.7	12.2
			Experiment 3 (1995 dry season)		
February	566.6	3.9	28.5	23.8	19.8
March	460.0	3.9	29.8	23.3	19.1
April	140.8	4.4	30.1	22.6	19.8
May	59.0	5.4	31.0	22.7	12.2
June	2.5	5.3	29.9	22.0	20.4
July	0	6.0	30.0	21.1	21.0

n.r., not recorded.

derived by dividing grain yield by above-ground dry mass. Grain number per m^2 was determined from the product of panicle number per m^2 and grain number per panicle. Panicle number per plant was calculated by dividing panicle number per m^2 by plant number per m^2. Correlations were calculated between grain yield and both panicle number per m^2 and plant number per m^2. A single linear regression was fitted to the data of the traditional and improved genotypes for the relationship between panicle number per m^2 and grain yield, since there was no difference (P>0.05) in the slopes or intercepts of these lines. However, separate linear regressions were fitted to the data of the traditional and improved genotypes for the relationship between plant number per m^2 and grain yield, since intercepts differed at the P = 0.05 level, although slopes were not different (P>0.05).

Table 2. Experiment 1. Grain yield, above-ground dry mass, harvest index, grain number per m^2, mass per grain, panicle number per m^2, grain number per panicle, plant number per m^2 and panicle number per plant for two irrigation methods, two irrigation frequencies and two rice genotypes

Treatment	Grain yield (g/m^2)	Above-ground dry mass (g/m^2)	Harvest index	Grain number per m^2	Mass per grain (mg)	Panicle number per m^2	Grain number per panicle	Plant number per m^2	Panicle number per plant
				Irrigation method					
Raised beds	150	487	0.28	6374	21.8	228	29	119	2.3
Flooded	154	353	0.44	6180	24.9	210	32	84	2.0
l.s.d. (P = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
				Irrigation frequency					
Daily	163	465	0.36	6696	24.1	224	32	104	2.2
Twice weekly	140	375	0.35	5858	22.6	214	29	98	2.1
l.s.d. (P = 0.05)	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
				Genotype					
Traditional	127	371	0.34	5546	21.9	163	35	102	1.6
Improved	176	469	0.37	7008	24.8	275	26	101	2.8
l.s.d. (P = 0.05)	n.s.	n.s.	n.s.	n.s.	1.5	50	n.s.	n.s.	0.2

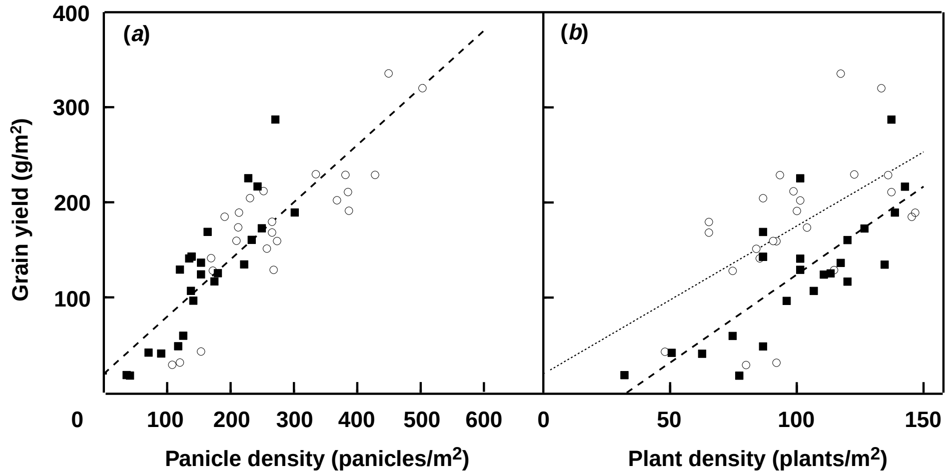

Figure 1. Relationship between (*a*) panicle number per m^2 and grain yield (r^2 = 0.73, *P*<0.01) in traditional (■ and improved (○) rice genotypes, and (*b*) plant number per m^2 and grain yield in a traditional (dasl r^2 = 0.60, *P*<0.01) and improved (dotted line, r^2 = 0.31, *P*<0.01) rice genotype in the dry season. Linear regressions were fitted to the data.

Results

Meteorology

Only 20 mm of rain fell during experiment 1 (Table 1). Mean monthly maximum temperatures decreased from 31.4°C in April to 27.4°C in July. In experiment 2 almost 1500 mm of rain fell between January and March and, consequently, mean monthly maximum temperatures were lower in these months (about 29°C) compared with the remaining months (31°C). Mean daily solar radiation was high in December (23.5 MJ/m^2.day), intermediate between January and April (about 19 MJ/m^2.day), and low in May (12.2 MJ/m^2.day). In experiment 3 the vegetative period was very wet (over 1000 mm of rain was recorded in February and March) and the grain-filling period was very dry (3 mm of rain fell in June and July). Mean monthly maximum and minimum temperatures were about 30 and 23°C respectively. Mean daily solar radiation was relatively constant at 20 MJ/m^2.day for all months except May (12.2 MJ/m^2.day).

Experiment 1

Water management. Grain yield was similar (*P*>0.05) between the raised bed and flooded systems (150 *v.* 154 g/m^2 respectively), suggesting that yield can be maintained in an unflooded system based on SSC (Table 2). There was a trend for increased dry matter production on the beds (487 g/m^2) compared with the paddy (353 g/m^2), however, this was offset by a trend for decreased harvest index on the beds (0.28) compared with the paddy (0.44). There was no difference (*P*>0.05) in grain yield between treatments that were irrigated daily (163 g/m^2) and twice weekly (140 g/m^2).

Traditional versus improved genotype. There was no difference (*P*>0.05) in grain yield between the traditional and improved genotypes, although differences in components of yield were found (Table 2). More panicles per plant (*P*<0.05) in Lemont (2.8) than in the traditional genotype (1.6) resulted in more (*P*<0.05) panicles per m^2 in Lemont. Mass per grain was also higher (*P*<0.05) in Lemont than in the traditional

Table 3. Experiment 2. Grain yield, above-ground dry mass, harvest index, grain number per m^2, mass per grain, panicle number per m^2, grain number per panicle, plant number per m^2 and panicle number per plant for two sowing times in a wet season

Sowing time	Grain yield (g/m^2)	Above-ground dry mass (g/m^2)	Harvest index	Grain number per m^2	Mass per grain (mg)	Panicle number per m^2	Grain number per panicle	Plant number per m^2	Panicle number per plant
December	243	823	0.29	16158	15.0	334	50	107	3.1
January	209	668	0.31	18408	11.5	255	73	112	2.3
l.s.d. (*P* = 0.05)	n.s.	75	n.s.	n.s.	1.3	45	13	n.s.	0.4

Table 4. Experiment 2. Grain yield, above-ground dry mass, harvest index, grain number per row, mass per grain, panicle number per row, grain number per panicle, plant number per row and panicle number per plant for eight rows across a bed and furrow

Rows 1 and 8 are in the furrows and rows 2–7 are on the raised bed

Row number	Grain yield (g/m^2)	Above-ground dry mass (g/m^2)	Harvest index	Grain number per m^2	Mass per grain (mg)	Panicle number per m^2	Grain number per panicle	Plant number per m^2	Panicle number per plant
1	24.1	82	0.30	1797	13.7	32	64	13.7	2.3
2	30.9	98	0.31	2500	12.9	38	81	13.8	2.7
3	32.1	101	0.32	2267	14.5	40	65	14.2	2.8
4	29.4	95	0.31	2319	12.9	39	66	13.7	2.9
5	30.8	105	0.29	2229	14.0	42	58	13.6	3.2
6	27.7	93	0.30	2287	14.0	39	70	14.3	2.7
7	27.2	91	0.30	2022	12.4	34	65	14.0	2.5
8	24.0	82	0.29	2048	13.5	30	73	12.0	2.6
l.s.d. ($P = 0.05$)	5.5	13	n.s.	419	n.s.	7	n.s.	n.s.	0.5

genotype (24.8 *v.* 21.9 mg). A linear correlation was found between panicle number per m^2 and grain yield for the traditional and improved genotypes ($y = 19.6 + 0.60x$; $r^2 = 0.73$, $P<0.01$) (Fig. 1*a*). Linear correlations were also observed between plant number per m^2 and grain yield for the traditional ($y = -61 + 1.85x$; $r^2 = 0.60$, $P<0.01$) and improved ($y = 19.6 + 1.56x$; $r^2 = 0.31$, $P<0.01$) genotypes (Fig. 1*b*).

Experiment 2

Time of sowing. Above-ground dry mass of rice (cv. Lemont) was higher ($P<0.05$) for crops sown in December (823 g/m^2) compared with those sown in January (668 g/m^2) (Table 3). There was no difference ($P>0.05$) in harvest index between sowing times (0.29 *v.* 0.31), resulting in a trend ($P>0.05$) for higher grain yield in the early-sown crop compared with late-sown crop (243 *v.* 209 g/m^2).

Plant number per m^2 was the same for early- and late-sown crops (about 110), although panicle number per plant was higher ($P<0.05$) in the early- than late-sown crop (3.1 *v.* 2.3), resulting in more ($P<0.05$) panicles per m^2 following a December than January sowing (334 *v.* 225). This was offset by fewer grains per panicle

Table 5. Experiment 3. Grain yield, above-ground dry mass, harvest index, grain number per m^2, mass per grain, panicle number per m^2, grain number per panicle, plant number per m^2 and panicle number per plant for two genotypes, three nitrogen rates and three times of nitrogen application

Treatment	Grain yield (g/m^2)	Above-ground dry mass (g/m^2)	Harvest index	Grain number per m^2	Mass per grain (mg)	Panicle number per m^2	Grain number per panicle	Plant number per m^2	Panicle number per plant
				Genotype					
Traditional	164	752	0.22	8315	19.9	221	40	77	3.0
Improved	159	720	0.21	17 325	9.4	376	50	92	4.2
l.s.d. ($P = 0.05$)	n.s.	n.s.	n.s.	4969	4.5	41	n.s.	n.s.	n.s.
				Rate of nitrogen (kg/ha)					
0	164	710	0.23	12 182	14.8	308	42	87	3.7
40	141	692	0.20	11 392	14.5	275	46	81	3.3
80	179	806	0.22	14 885	14.6	313	47	85	3.8
l.s.d. ($P = 0.05$)	n.s.	66	n.s.	2571	n.s.	n.s.	n.s.	n.s.	n.s.
				Time of nitrogen application					
Sowing[A]	159	738	0.21	12 541	15.0	285	48	82	3.5
Sowing/PI[B]	161	728	0.22	12 969	14.2	302	44	87	3.6
Panicle initiation[C]	165	741	0.22	12 949	14.7	309	43	84	3.7
l.s.d. ($P = 0.05$)	n.s.	n.s.	n.s.	n.s.	n.s.	17	n.s.	n.s.	n.s.

[A] All nitrogen applied at sowing. [B] Half of the nitrogen applied at sowing and half at panicle initiation (PI).
[C] All nitrogen applied at panicle initiation. n.s., not significant.

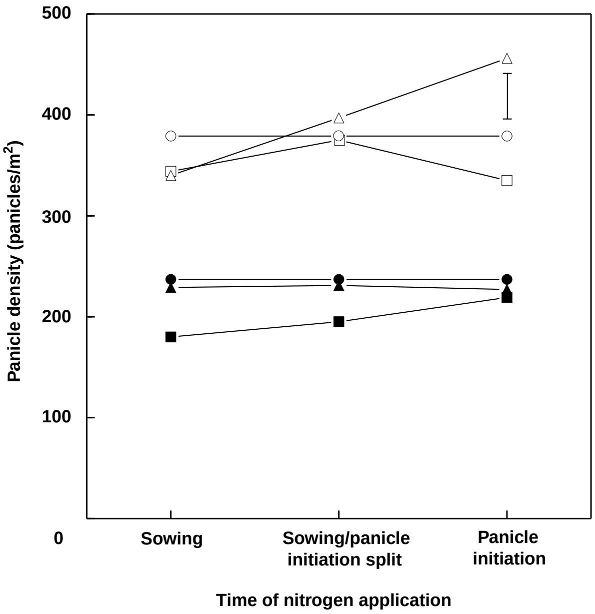

Figure 2. Relationship between time of nitrogen application (sowing, a 50 : 50 split between sowing and panicle initiation, panicle initiation) and panicle number per m^2 in rice for the traditional genotype (solid symbols) and for the improved genotype (open symbols) at 3 rates of N application (● ○, 0 kg N/ha; ■ □ Vertical bar indicates l.s.d. at $P = 0.05$.

(P<0.05) in the early- than late-sown crop (50 *v*. 73). Overall, time of sowing did not affect (P>0.05) grain number per m^2, and the trend for increased yield with a December sowing was primarily due to a higher (P<0.05) mass per grain in the early- than late-sown crop (15.0 *v*. 11.5 mg).

Effect of row position on rice growth. Grain yield of plants grown in furrows (24 g/row) was significantly (P<0.05) less than for those grown on raised beds (30 g/row) (Table 4). Differences in yield were due to differences in dry matter production rather than harvest index, and to differences in grain number per row rather than mass per grain. Higher (P<0.05) grain number per row in bed compared with furrow plants (2271 *v*. 1923) was due to more (P<0.05) panicles per row in bed than furrow plants (39 *v*. 31). Panicle number per plant was higher (P<0.05) in the 2 centre rows of the bed (3.1) compared with the furrows (2.5). There were no differences (P>0.05) in plant number per row.

Experiment 3

Traditional versus improved genotype. There was no difference in grain yield between the traditional and improved genotypes (164 *v*. 159 g/m^2) although significant differences in components of yield were observed (Table 5). Grain number per m^2, an indicator of sink capacity, was considerably higher (P<0.05) in the improved (17 325) than traditional (8315) genotype. Higher grain number per m^2 in the improved genotype was due to more (P<0.05) panicles per m^2. However, mass per grain, an indicator of source capacity, was higher (P<0.05) in the traditional than improved genotype (19.9 *v*. 9.4 mg). The traditional genotype was taller (P<0.01) than the improved genotype (76 *v*. 38 cm).

Table 6. Total monthly rainfall (mm) from November to May recorded at Kupang, West Timor, between 1981 and 1995

Year	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
1981	271	328	579	405	66	55	17
1982	82	172	524	300	278	12	12
1983	126	188	430	441	298	279	0
1984	129	509	549	435	279	27	0
1985	101	57	203	163	196	49	0
1986	47	1075	640	299	129	45	5
1987	250	375	1075	416	52	0	0
1988	378	321	544	112	243	12	0
1989	26	114	272	202	264	0	9
1990	113	252	187	386	337	54	29
1991	180	95	554	456	50	274	0
1992	42	58	314	395	200	154	0
1993	30	150	453	250	189	0	14
1994	7	82	265	319	237	66	0
1995	179	266	426	569	460	141	59

Rate and timing of nitrogen application. Dry matter production and grain number per m^2 responded to 80 but not 40 kg N/ha (Table 5). Panicle number per m^2 was the only component which responded to timing of N application. Panicle numbers were higher (P<0.05) if all N was applied at panicle initiation (309/m^2) compared with all at sowing (285/m^2). A significant genotype x N rate x time of N application interaction (P<0.01) was observed for panicle number per m^2 (Fig. 2). The traditional genotype did not respond to N fertilisation at any of the times of application. In contrast, the improved genotype responded to N fertilisation, but only when all fertiliser was applied at panicle initiation and only for the highest rate of N (80 kg/ha). A genotype x N rate interaction (P<0.05) was observed for seed size such that mass per grain decreased with N rate in the improved type but not in the traditional type.

Discussion

Time of sowing

Crops sown at the beginning of the wet season (i.e. early December) have the potential to better utilise water compared with later-sown crops by escaping drought during the grain-filling period. The underlying issue is the need to match crop growth to available water resources, ensuring adequate quantity and quality of grain. While the wet season generally extends to the end of March, rainfall is often less in April and May

Table 7. Experiment 2. Daily rainfall in Kupang, West Timor, from December 1994 to May 1995

Date	Dec.	Jan.	Feb.	Mar.	Apr.	May
1	4.2	0	0	83.6	0	0
2	1.4	1.0	2.6	38.8	0	0
3	18.0	2.0	18.6	96.6	1.2	0
4	0	25.0	5.8	80.8	25.0	0
5	0	0	83.6	40.6	48.8	0
6	0	13.4	62.0	28.4	1.2	0
7	0	8.0	0	20.8	15.0	0
8	13.0	17.4	0	32.8	14.4	0
9	0	6.0	0	5.0	12.6	0
10	0	12.8	0	4.0	0	0
11	0	19.4	1.0	0	0	0
12	0	14.0	31.6	0	11.2	0
13	13.0	6.6	6.0	0	0	0
14	3.4	6.8	60.4	0	0	0
15	0	50	15.6	0	0.2	0
16	13.0	5.0	25.2	0	11.2	0
17	1.0	19.4	3.8	0	0	0
18	5.0	0	8.6	0	0	0
19	0	8.4	45.2	6.0	0	50.0
20	0	23.2	12.0	1.8	0	9.0
21	0	39.0	1.7	7.4	0	0
22	0	8.6	1.3	2.6	0	0
23	0	32.0	0	0	0	0
24	0	6.0	5.8	0	0	0
25	0	18.4	0	0	0	0
26	0	8.0	0	0	0	0
27	0	16.6	78.6	3.0	0	0
28	0	22.6	99.0	5.0	0	0
29	7.2	11.8	—	1.0	0	0
30	3.0	25.4	—	1.8	0	0
31	0	0	—	0	—	0
Total	82.2	426.8	566.6	460	140.8	59.0

(Table 6). Indeed, no rain fell in Kupang during the month of May for 8 of the 15 years between 1981 and 1995. In experiment 2, Lemont crops sown in mid December and mid January were harvested in late March and early May respectively. Drought affected the late-sown crop more than the early-sown crop, although grain filling was limited by water deficit in both crops. For example in the second half of the grain-filling period, no rain fell on the late-sown crop compared with 27 mm on the early-sown crop (Table 7), resulting in greater water deficit during grain filling for the late-sown crop.

Dry matter production was significantly higher for Lemont sown in mid December than in mid January and, as little variation in harvest index existed, there was a trend for higher grain yield following the earlier sowing. More panicles per m^2 were attained from a December than a January sowing, although this was offset by more grains per panicle from the January sowing. Grain size was reduced by drought in both sowings. Compared with a grain size of 24.8 mg for Lemont in experiment 1, grain size in experiment 2 represents a 40% reduction for the early-sown treatment and a 54% reduction for the late-sown treatment. Crop growth was better aligned with the available water resources in the early sowing, since yield potential (indicated by grains/m^2) was similar for both sowings, yet more water was available to complete grain filling in the early sowing, resulting in higher grain quality (indicated by grain size) for this sowing time.

Pellokila *et al.* (1991) reported that in eastern Indonesia, all crops in a particular area may fail because of a sudden end to the wet season, highlighting the need to sow at the beginning of this season. According to McWilliam (1986), total crop failure may be as high as 1 year in 5. Although the heavy clay soil in parts of eastern Indonesia is well suited to rice production, it is difficult to cultivate and farmers have to wait until the soil is sufficiently wet, forcing them to plant their crops in the mid-wet season (Pellokila *et al.* 1991). Permanent raised beds, such as those used in SSC, provide a mechanism for sowing crops immediately after the onset of wet season rains, thereby minimising the risk of drought late in the grain-filling period. Hence SSC provides a means of better matching crop growth to water supply by enabling farmers to sow at the optimum time.

Water management

There was no difference in grain yield between rice grown on raised beds or in flooded bays (experiment 1), suggesting that yield can be maintained in an unflooded system using SSC. Interestingly, grain yield of plants grown on the raised beds was higher than that of plants grown in the flooded furrows and this was primarily due to differences in panicle number per plant, suggesting that tillering was reduced in the furrow plants. The reason for this is not clear. Irrigation frequency did not impact grain yield, highlighting the advantage of irrigating twice weekly rather than irrigating daily or flooding. Water deficit during the grain-filling period limited grain size in Lemont to only 9 mg in the 1995 dry season compared with 25 mg in the 1993 dry season when the crop was irrigated twice weekly. This indicates that if water had not been limiting during the grain-filling period in the 1995 dry season (i.e. via application of twice weekly irrigation) then grain yield could have exceeded 500 g/m^2, providing other yield-determining factors such as N were not limiting yield.

Although water use was not monitored in these studies, reductions under SSC compared with traditional flooded production may have occurred, as was reported recently in northern Australia (Borrell *et al.* 1997). In the Australian studies, water savings of about 32% were achieved in SSC compared with flooded production in wet and dry seasons; furthermore they concluded that alternative irrigation strategies such as SSC comprising lower depths of ponded water are likely to be most beneficial in relatively porous, non-swelling soils where flooding provides a greater hydraulic head for increased percolation. Therefore SSC will reduce water use most in high percolation areas of Timor.

Other benefits of raised beds are enhanced drainage, particularly in the wet season. Although drought is the main limitation to crop yield in eastern Indonesia, excess rainfall is common between January and February when the north-west monsoons peak. Poor drainage can result in waterlogging, and crops can be waterlogged for a number of weeks following cyclonic activity. Pellokila *et al.* (1991) define the ideal cropping area as one that has sufficient drainage to prevent waterlogging but is capable of storing adequate moisture to minimise water stress during drought. Ideal cropping areas are rare, however, such areas can be created by constructing fields of permanent raised beds which provide excellent drainage during periods of intense rainfall in the wet season, yet capture and store water during periods of low rainfall. A major advantage of permanent raised beds over traditional cropping in northern Australia was the improved timeliness of operations due to enhanced drainage (McPhee *et al*. 1995).

The growth of rice on raised beds also opens the way for other crops to be grown in rotation with rice. Field crops such as maize and soybean are not suited to the flooded soil conditions used for rice production, but these crops do grow well on raised beds in rotation with rice (Garside *et al.* 1992*b*). The development of a rice-based cropping system on permanent raised beds would enable farmers to produce food and cash crops, thereby meeting the dual criteria of food security and income generation highlighted by Pellokila *et al.* (1991).

Traditional versus improved genotype

The performance of an improved short-statured genotype (cv. Lemont) was compared with that of a taller traditional rice from the neighbouring island of Alor in a dry (experiment 1) and wet (experiment 3) season. No differences in grain yield were found between these plant types in either season, although differences in components of yield were observed in both seasons. Low grain yields for Lemont in these studies (about 2 t/ha) compared with earlier Australian studies (about 8 t/ha, Borrell *et al.* 1997, 1998*a*) indicates that conditions were suboptimal for the growth of the improved genotype in Timor. This reflects the low-external-input system used in the current study.

In the dry season (experiment 1), a trend for higher ($P>0.05$) yield in the improved type was due to significantly higher masses per grain, panicles per plant and panicles per m^2. The linear correlation found between panicle number per m^2 and grain yield ($r^2 = 0.73$, $P<0.01$) suggests that yield can be further increased by increasing panicle number (Fig. 1*a*). Increasing sowing rate, and hence panicle number per unit area, could overcome the yield limitation caused by the low number of panicles per plant (associated with asynchronous tillering) in the traditional type. For example, the linear correlation between plant number per m^2 and grain yield in the traditional genotype ($r^2 = 0.60$, $P<0.01$, Fig. 1*b*) indicates that increasing plant number from 100 plants per m^2 (the mean population in experiment 1) to 150 plants per m^2 could raise the yield from about 120 to 220 g/m^2, providing adequate resources were available to attain the additional yield. Asynchronous tillering in the traditional genotype allows farmers to hand pick ripe panicles at a number of different times before the plants finally senesce. This is another strategy of yield stabilisation, since early panicles may fail due to water stress, pests and diseases, or birds, yet farmers still have the opportunity to harvest late-maturing tillers.

The traditional genotype appeared to have an advantage over the improved genotype when growth was limited by water during the grain-filling period. A severe water stress after anthesis in experiment 3 appears to have limited the amount of assimilate available for grain filling. Maintenance of grain size in the traditional type under water-limiting (20 mg, experiment 3) compared with non-water-limiting (22 mg, experiment 1) conditions was probably associated with a smaller sink capacity, as evidenced by less grains per m^2, and retention of some green leaf area (visual observation). Green leaf area retention has also been found to improve the yield of grain sorghum during drought in northern Australia (Borrell and Douglas 1996, 1997). In contrast, the improved genotype senesced more rapidly under drought (visual observation), perhaps in response to its much larger sink size, attaining an average mass per grain of only 9 mg in experiment 3 (water-limiting) compared with 25 mg in experiment 1 (non-water-limiting). Although yields were equivalent for the traditional and improved types under these dry conditions (about 160 g/m^2), the economic value of the Lemont grain was much reduced after threshing due to its small seed size. It should also be noted that the Timorese people prefer to eat the traditional rices compared with improved rices. This could be due, in part, to the fact that small grain size of drought-affected improved genotypes renders the product of much less value. Khush and Juliano (1985) have observed that many types of traditional tropical rice varieties have excellent cooking and eating qualities but low grain yields.

The key issue is one of balancing crop growth and water use requirements, and perhaps this is why the traditional genotype produced a similar grain yield (160 g/m^2) to the improved genotype from a much lower potential yield (8300 *v.* 17300 grains/m^2) in experiment 3.

The plant height of the traditional genotype (76 cm) was twice that of the improved genotype (38 cm). More carbon may have accumulated in the stems of the taller traditional genotype compared with the shorter improved genotype, and the subsequent utilisation of these reserves may have enabled the traditional genotype to continue filling grain under water-limited conditions. Furthermore, the traditional genotype had equivalent biomass to the improved genotype, yet it had 40% fewer tillers/m^2. This illustrates the adaptive advantage of restricted vegetative growth in conserving water resources and enabling the crop to finish.

The choice of traditional versus improved genotypes, and their associated 'input' packages, should be carefully considered. While experience from other parts of Indonesia has shown that rice production can be significantly increased with improved resources, the cost is high and the appropriateness of these high-input systems needs to be fully examined (Pellokila *et al.* 1991). Barlow and Gondowarsito (1991) emphasised the need to better examine the world genetic stocks of crops and forages that are well suited to eastern Indonesia. Early maturing rice varieties that are resistant to disease, adapted to the environment, and will flower during the wet season to thus avoid a potential end-of-season drought are currently being identified (Pellokila *et al.* 1991).

Nitrogen management

The variable response of traditional and improved genotypes to N fertilisation was the key outcome for N management in these studies. The traditional type did not respond to N fertilisation at any rate or time of application in experiment 3. However, panicle number per m^2 responded to N fertilisation in the improved genotype (cv. Lemont), but only when all fertiliser was applied at panicle initiation and only for the highest rate of N (80 kg/ha). It is likely the underlying soil fertility produced acceptable early growth in Lemont, yet a late application of N fertiliser enabled the retention of more tillers and hence panicles at maturity. It is not clear why the traditional genotype did not respond similarly. The responsiveness of Lemont to N fertilisation was highlighted in the northern Australian studies, where Lemont attained 90% of its maximum yield with an N uptake of about 190 kg/ha when grown under flooded conditions on a grey clay soil (Borrell *et al.* 1998*b*).

Conclusions

Overall, the key issue is one of matching crop growth to water supply in a semi-arid tropical environment to ensure adequate quantity and quality of grain production at the end of the season. A number of practical strategies for improving rice production in West Timor arise from these studies, and each strategy is based on better aligning crop growth with the available water resources.

First, time of sowing in the wet season is critical, with early-sown crops escaping end-of-season drought. Crops that mature by the end of March will generally experience considerably less water stress during grain filling compared with crops that mature in early May. To complete grain filling by the end of March, early-maturing genotypes such as Lemont need to be sown by mid December.

Second, within the constraints of a low-external-input cropping system, rice can successfully be grown on raised beds under SSC in West Timor, providing soils are sufficiently deep to construct beds and the labour is available for construction. The water saving advantage of SSC will primarily depend on the magnitude of percolation losses from a range of soils in Timor. Permanent raised beds, such as those used in SSC, provide a mechanism for sowing crops immediately after the onset of wet season rains, thereby minimising the risk of drought late in the grain-filling period. These studies also indicate that irrigation of rice on beds twice weekly is more efficient than irrigating daily or flooding the bays.

Third, no differences in grain yield were found between the improved short-statured genotype (cv. Lemont) and the taller traditional rice under a low-external-input system, although differences in components of yield were found in both seasons. For example, panicle number per m^2 was higher in the improved than traditional genotype, and was more responsive to N fertilisation in the improved genotype. There is some evidence the traditional genotype produced larger grain when water was limiting during the grain-filling period by restricting vegetative growth and enabling the crop to finish.

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