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ENHANCING WATER AND FERTILIZER SAVING WITHOUT COMPROMISING RICE YIELD THROUGH INTEGRATED CROP MANAGEMENT

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ABSTRACT

Water and fertilizer scarcity amid the increasing need of rice production challenges today's agriculture. Integrated crop management (ICM) is a combination of water, crop, and nutrient management that optimizes the synergistic interaction of these components aiming at improving resource use efficiency, i.e. high productivity of water, land, and labor. The objectives of the study were to investigate the effects of crop establishment method, organic matter amendment, NPK management, and water management on yield of lowland rice. Five series of experiments were conducted at Sukamandi and Kuningan Experimental Stations, West Java. The first experiment was focused on crop establishment method, i.e. plant spacing and number of seedlings per hill. The second, third, and fourth experiments were directed to study the effect of NPK and organic matter applications on rice yield. The fifth experiments was designed to evaluate the effect of water management on rice yield. Results showed that 20 cm x 20 cm plant spacing resulted in the highest grain yield for the new plant type rice varieties. Organic matter and P fertilizer application did not significantly affect grain yield, but the yield response to P fertilization tended to be stronger with organic matter amendment. Split P application did not significantly increase grain yield. The use of a scale 4 leaf color chart reading resulted in a considerable N fertilizer saving without compromising rice yield. Intermittent irrigation technique saved water up to 55% without affecting yields, resulting in a 2-3 times higher water productivity.

[***Keywords***: Rice, integrated nutrient management, fertilizer application, water requirements]

INTRODUCTION

Major problems in rice farming in Java include declining yields, reducing soil fertility, and excessive use of agrochemicals. Yield decline at an annual rate of 0.5% was reported in the less favorable climatic season. Prolonged submergence, insufficient soil drying during fallow periods, and soil P depletion were diagnosed as possible causes for the yield decline (Dawe *et al*. 2000).

Approximately 15% of the lowland rice soils in Java are deficient in available P due to soil acidity (Setyorini 2004). A major constraint of these acid soils is their high P-fixing capacity, caused by high Fe and/or Al levels. P accumulation mainly occurred where P fertilizers have been applied continuously for a prolonged period (Rochayati *et al*. 1990).

A decline in indigenous soil N supply, associated with a decrease in soil organic matter content has been as one of the causes of yield decline. The decrease in soil organic matter appeared to be positively correlated with increased frequency of cropping, associated with long anaerobic periods (Olk *et al*. 1999). In efforts to increase rice yields, farmers in Java tended to increase the rates of fertilizer up to 500 kg ha^{-1} per season, appreciably higher than the current recommendation that ranges from 250 to 300 kg ha^{-1} of urea or equal to 115-138 kg N ha^{-1} (Departemen Pertanian 2006). This excessive use of N fertilizer has resulted in rice crops highly susceptible to pests and diseases and to lodging, and with high fractions of unfilled grains (Aldrich 1980). Moreover, excessive N fertilizer application leads to environmental pollution (Tilman *et al*. 2002).

Application of the system of rice intensification (SRI) resulted in significantly higher yields that were ascribed to the synergistic effects of seedling age and culture technique (Sattar and Roy 1991; Uphoff 2001). SRI culture technique consists of transplanting single seedlings of less than 15-day old, plant spacing of more than 25 cm x 25 cm, in combination with organic matter application, intermittent irrigation, and frequent weeding. SRI originated in Madagascar (Stoop *et al*. 2002), reportedly increased rice yield from 2 to 6 t ha^{-1}. SRI inspired the Indonesian Agency for Agricultural Research and Development (IAARD) in developing an integrated crop management (ICM) system for rice. ICM is a combination of water, crop, and nutrient management that aims at exploiting the synergistic interaction of these components to improve resource use efficiency, i.e. higher productivity of water, land, and labor (Kartaatmadja and Fagi 2000).

Taking an integral approach, a complete set of management practices was compiled into the ICM approach, some of which were adopted by farmers. Intermittent irrigation, adapted to the local irrigation facilities, was combined with planting of 1-3 seedlings younger than 21 days, at a plant spacing of 20 cm x 20 cm. The combined use of herbicides, hand weeding, and mechanical weeder was promoted, along with the application of straw combined with manure. Mineral fertilizers were compulsory applied. P and K fertilizer rates were based on soil P and K status at the onset of growing season, and rate and timing of N fertilizer application were based on the leaf color chart (LCC) readings. Biocides were applied based on pest and disease incidences (Las *et al*. 2002).

The research was conducted to evaluate the effects of crop establishment method, i.e. plant spacing and number of seedlings per hill, timing and rates of NPK fertilizer application, type of organic matter, and water management on rice yield. Water, nutrient, and land productivity are used as indicators to assess the performance of ICM relative to the current practices.

MATERIALS AND METHODS

Experiment 1
Effect of Crop Establishment Method on Yield

Experiment 1 was focused on the effect of crop establishment method on rice yield. It was located at Sukamandi Experimental Station in the wet season (WS) of 2002/03, dry season (DS) 2003, and WS 2003/04. Three new plant type rice varieties, i.e. Fatmawati (V_1) and Ciapus (V_2) and Gilirang (V_3), and a widely adopted high yielding variety IR64 (V_4) were used in these studies. The crop establishment methods applied were transplanting at 20 cm x 20 cm spacing (E_1), transplanting at 20 cm x 10 cm spacing (E_2), and direct seeding at 20 cm x 5 cm spacing (E_3). Two different numbers of seedlings per hill, i.e. one seedling (S_1) and three seedlings (S_2) were included. The experiment was arranged in split-split plot design with varieties as the main plot, crop establishment method as subplot, and number of seedlings per hill as sub-subplot. Three replications were performed and the area of each plot was 8 m x 6 m.

Seedlings were transplanted at 15 days after seeding (DAS). Dry composted straw of 3 t ha-1 was applied land preparation 2 weeks before transplanting. Chemical fertilizers were applied at rates of 112 kg N, 36 kg P_2O_5, and 60 kg K_2O ha^{-1} in the forms of urea, SP36, and KCl, respectively. N fertilizer application was based on leaf color chart (LCC) readings and P and K were as basal dressing. Intermittent irrigation was applied during the vegetative stage until panicle initiation followed by continuous flooding with a water head of 2-5 cm during the reproductive stage until 2 weeks before harvest, when the field was drained. Weeding was done by hand combined with a mechanical weeder, one day before urea application. An insecticide (carbofuran 3G) at the rate of 10 kg ha^{-1} was applied 14 days after transplanting (DAT) mixed with urea. Fipronil 50 SC was sprayed following urea application to reduce stemborer populations.

Experiment 2
Effect of P Management and Organic Matter Application on Yield

The second experiment was directed to evaluate rice yield performance in relation with the application of organic matter and P management. This experiment was conducted in DS 2001 and WS 2001/02 at both Sukamandi and Kuningan Experimental Stations, using a split-plot design with three replications. Individual plot size was 6 m x 8 m. Organic matter treatment was selected as the main plot. Three types of organic matter were tested, i.e. no organic matter addition (O_1), 2 t ha-1 composted straw (O_2), 2 t ha^{-1} cattle manure (O_3), and 2 t ha-1 mixture of composted straw and manure in equal weight (O_4). Technique of P application was selected as subplot, consisted of without P (P_0), 36 kg P_2O_5 ha^{-1} as basal application (P_1), 36 kg P_2O_5 ha^{-1} applied in two equal splits (P_2) at 14 and 28 DAT, and 36 kg P_2O_5 ha^{-1} applied in three equal splits (P_3) at 14, 28 and 49 DAT. Organic matter was applied after land preparation, one day before transplanting. Split P application was tested to verify the findings of previous research on site-specific nutrient management that recommended a P dose of 19 kg ha^{-1} (Dobermann *et al*. 1996). Fifteen-day old seedlings of Way Apo Buru variety were transplanted at one seedling per hill at 25 cm x 25 cm spacing. Based on LCC readings, 113 kg N ha^{-1} was applied in both seasons during the growing period, 34 kg each at 14 and 28 DAT, and 45 kg at 49 DAT. K fertilizer at 60 kg K_2O ha^{-1} was applied at 14 DAT. The lands plants were irrigated during the vegetative stage after the first soil surface cracks appeared, i.e. every 7-10 days under no rain. During the reproductive stage, they were flooded at 2-5 cm depth, until 2 weeks before harvest, when they were drained. Weeding was done by hand, one day before urea application, while rat control included fumigation, baits, traps, mechanical control, and plastic fences. Insecticides were applied at booting and grain filling stages to prevent damage by stemborers and stink bugs, respectively.

Experiment 3
Effect of Organic Matter and N Application on Yield

The third experiment was conducted to study the effect of organic matter application and N management on rice yield. The experiment was carried out in DS 2002 at Sukamandi Experimental Station, using a split-split plot design with four replications. Plot size was 10.0 m x 4.5 m. Organic matter treatment was selected as main plot and it consisted of no organic matter (O_1) and 10 t ha^{-1} as a mixture of compost and manure in equal weight (O_2). N fertilizer was applied as subplot, consisted of without N (N_0), 30 (N_1), 60 (N_2), 90 (N_3), and 120 (N_4) kg N ha^{-1}. Seedling age was selected as sub-subplot, i.e 10- and 20-day old seedlings. Single seedlings of Way Apo Buru were planted at 25 cm x 25 cm. N fertilizer was applied in three equal splits at 14, 28, and 52 DAT, respectively. P fertilizer (SP36) was applied as basal dressing at 36 kg P_2O_5 ha^{-1} and K_2O was applied at 60 kg ha-1 in two equal splits as basal application and at panicle initiation. Composted straw and manure were applied 2 weeks before transplanting. The plots were irrigated to 2-5 cm water head during the vegetative stage after the first soil surface cracks appeared, i.e. every 7-10 days and during the reproductive stage until 2 weeks before harvest, when the field was drained. Weeding was done by hand at 21 and 42 DAT. At harvest, yield was determined from 10 m2 harvested area in each plot.

Experiment 4
Effect of NPK Management and Rice Varieties on Yield

The fourth experiment was carried out to investigate the interactive effects of NPK management and rice varieties on yield. The experiment was conducted in DS 2003 and WS 2003/04 at Sukamandi Experimental Station. Two-factor strip plot design with three replications was performed with plot size of 5 m x 8 m. Four rice varieties were used as the first factor, i.e. Fatmawati (V_1), Ciapus (V_2), Gilirang (V_3), and IR64 (V_4). The following levels of NPK were tested as the second factor:

F_1: 115 kg N + 36 kg P_2O_5 + 30 kg K_2O ha^{-1}, with splits of N: 1/3-1/3-1/3
F_2: 172.5 kg N + 54 kg P_2O_5 + 45 kg K_2O ha^{-1}, with splits of N: 1/3-1/3-1/3
F_3: 172.5 kg N + 54 kg P_2O_5 + 45 kg K_2O ha^{-1}, with splits of N: 1/2-1/4-1/4
F_4: N applied based on scale 4 LCC reading + 36 kg P_2O_5 + 30 kg K_2O ha^{-1}
F_5: N applied based on scale 5 LCC reading + 36 kg P_2O_5 + 30 kg K_2O ha^{-1}.

Seedlings were planted at 20 cm x 20 cm spacing with single seedling per hill. N fertilizer (urea) was applied at 14, 28, and 52 DAT for treatments F_1, F_2 and F_3. For treatments F_4 and F_5, N application was based on the LCC readings which was read every week. P fertilizer (SP36) was applied as basal dressing and K fertilizer (KCl) was applied in two equal splits as basal dressing and at panicle initiation. Composted straw and manure in equal proportions at 2 t ha^{-1} were applied 2 weeks before transplanting. The plot was irrigated to 2-5 cm water head during the vegetative stage after the first soil surface cracks appeared, i.e. every 7-10 days and during the reproductive stage it was flooded at 2-5 cm depth until 2 weeks before harvest, when the field was drained. Weeding was done by hand at 21 and 42 DAT.

Experiment 5
Effect of Intermitten Irrigation on Yield and Water Use Efficiency

The fifth experiment was designed to study the effect of intermittent irrigation and composted rice straw on yield and water use efficiency. The experiment was conducted in DS 2002 at Sukamandi Experimental Station by using a split-split plot design. Soil-water management as the main factor included continuous flooding with 5-10 cm standing water layer (W_1); intermittent irrigation after the first soil surface cracks appeared, i.e. every 7-10 days (W_2); irrigation with the water table kept 5-10 cm below soil surface (W_3), and a raised-bed technique with a drainage system and water kept at 5-10 cm below soil surface of the bed (W_4). The water table of 5-10 cm was monitored using a piezometer in each plot. The irrigation treatments were applied from 10 DAT until the onset of grain filling stage. The plots were drained 2 weeks before harvest. The organic matter amendment as subfactor included without amendment (C_0) and with 5 t ha-1 composted rice straw (C_1). The P fertilizer was selected as sub-subfactor and it consisted of two levels: 0 kg P_2O_5 ha-1 (P_0) and 50 kg P_2O_5 ha^{-1} (P1).

Each treatment was replicated three times. Fifteen-day old seedlings of Ciherang rice variety were transplanted at one seedling per hill at 25 cm x 25 cm plant spacing. Individual plot size was 10 m x 10 m. Organic matter was incorporated during land preparation. In W_4, 10.0 m x 1.5 m raised beds were prepared with 15-cm deep furrows between the beds. Nitrogen (125 kg N ha-1) and potassium (45 kg K_2O ha^{-1}) fertilizers were applied in equal splits at 14 and 42 DAT. Hand weeding was performed at 15, 30, and 45 DAT.

Analysis of Soil Characteristics

Soil characteristics were analyzed at laboratory of the Indonesian Center for Rice Research (ICRR). The following characteristics were analyzed: clay, silt, sand, pH, total N, organic C, available and total P, CEC, exchangeable Ca, Mg, K and Na, minerals (Fe, Zn, Cu and Mn) with methods as described in Table 1.

Measurement of Yield and Yield Component

At harvest, yield was derived from 10 m^2 harvested area in each plot and it was expressed as t ha^{-1}. Yield components were determined by measuring the number of panicles per hill, grains per panicle and 1000-grain weight. They were derived from 12 randomly selected hills in each plot.

Measurement of Field Water Status (FWS)

FWS was measured by using 60 cm long piezometers. Water table depth was monitored at 5-day intervals from 10 to 85 DAT.

Water consumption referred to water input and it was calculated from the sum of effective rainfall and irrigation application from transplanting to harvest (Bouman and Tuong 2001). Water productivity (WP) was calculated by dividing grain yield with unit volume of total water input (kg m^{-3}).

Statistical Analysis

The analysis of variance of the data was according to the Gomez and Gomez (1984) and mean values were compared by Duncan's multiple range test (DMRT).

RESULTS AND DISCUSSION

Climate and Soil Nutrient

Average annual rainfalls at Sukamandi and Kuningan in 2001 and 2004 were 1394 and 2124 mm, respectively. Wet season rainfalls in Sukamandi and Kuningan were 1117 and 1543 mm, and dry season rainfalls were 276 and 581 mm, respectively. Annual radiation in Sukamandi was 616.5 GJ m^{-2} and in Kuningan 597.9 GJ

Table 1. Soil characteristics at Sukamandi and Kuningan Experimental Stations, 2001.

Soil analysis	Sukamandi	Kuningan	Method
Clasification	Ultisols	Inceptisols	USDA
Clay (%)	65.0	33.0	Pipette
Silt (%)	25.0	36.0	Pipette
Sand (%)	10.0	31.0	Pipette
pH H_2O (1:2.5)	5.5	5.3	Glass electrode
Total N (%)	0.1	0.2	Kjeldahl
Organic C (%)	1.4	2.5	Walkley and Black
Available P (ppm)	1.7	1.2	Bray 1
Total P (ppm)	250.0	697.0	HCl 25%
Cation exchange capacity (CEC) (me 100 g^{-1})	14.0	12.6	1 *N* NH_4OAc pH 7
Exchangeable Ca (me 100 g^{-1})	7.0	9.9	1 *N* NH_4OAc pH 7
Exchangeable Mg (me 100 g^{-1})	1.8	5.9	1 *N* NH_4OAc pH 7
Exchangeable K (me 100 g^{-1})	0.7	0.4	1 *N* NH_4OAc pH 7
Exchangeable Na (me 100 g^{-1})	0.2	0.4	1 *N* NH_4OAc pH 7
Fe (ppm)	160.0	12.0	DTPA
Zn (ppm)	4.5	12.5	DTPA
Cu (ppm)	2.9	11.8	DTPA
Mn (ppm)	140.0	60.6	DTPA

m^{-2}. Soil characteristics at Sukamandi were completely different from those at Kuningan (Table 1).

Acid soil was observed at Sukamandi and Kuningan. As a consequence, P may be immobilized in Al- or Fe-phosphates, resulting in low P availability for the crop. A long-term P fertilization might have been practiced in the past at both experimental sites, as shown by the high total P level and low available P.

Effect of Crop Establishment Method on Yield

New plant type (NPT) rice varieties were characterized by lower tiller numbers per hill, but longer panicles, compared with conventional high yielding varieties, and are assumed therefore to perform better under closer plant spacing. It was found that the NPT varieties were not consistently superior. In the wet season, the yield of Fatmawati variety was higher than those of other varieties. However, in the dry season the higher yield was shown by IR64. Directseeded rice yielded significantly less than transplanted rice in all three seasons, while the closer spacing (20 cm x10 cm) yielded less than the wider (20 cm x 20 cm) spacing, but the difference was significant only in the WS 2002/03. The result was in agreement with the study reported by Baloch *et al*. (2002). Rice plants grown at wider spacing can exploit a larger soil volume for nutrients and absorb more solar radiation, and hence perform better as individual plants. Table 2 presents the effect of crop establishment method on yield. The interaction among varieties, plant spacing, and number of seedlings per hill did not significantly affect the yield.

Table 2. Effect of rice variety, plant spacing and number of seedlings per hill on rice yield, Sukamandi Experimental Station, WS 2002/03, DS 2003, and WS 2003/04.

Treatment	Yield (t ha^{-1})		
	WS 2002/03	DS 2003	WS 2003/04
Variety			
V_1: Fatmawati	7.84a	7.50ab	7.29a
V_2: Ciapus	7.35b	7.41ab	6.92b
V_3: Gilirang	7.31b	7.18b	7.21a
V_4: IR64	7.52b	7.75a	6.88b
Plant spacing			
E_1: 20 cm x 20 cm	7.81a	7.77a	7.29a
E_2: 20 cm x 10 cm	7.55b	7.72a	7.13a
E_3: 20 cm x 5 cm	7.15c	6.65b	6.66b
Number of seedlings per hill			
S_1: one	7.68a	7.61a	7.21a
S_2: three	7.33a	7.25a	6.98a

Values in a column followed by the same letter are not significantly different at 5% DMRT.

In all seasons, yields were not significantly different for young single seedling and three seedling per hill. Transplanting of single young seedlings gave a slight yield advantage over three young seedlings. Smaller plant number per hill resulted in vigorous plant growth due to better root system and lower intra-specific competition (Uphoff and Gani 2004). Based on these results, with a slight tendency for higher yield with single seedling, wider plant spacing was recommended for inclusion in the ICM package for promoting dissemination of the NPT varieties to reduce seed requirements without compromising rice yield.

Effect of NPK Management and Organic Matter Application on Yield

Soil productivity is closely linked with soil organic matter status. Organic amendments play an important role in the improvement of soil structure and soil organic matter content. A decrease in soil organic matter content associated with a decline in indigenous soil fertility (Ponnamperuma 1984).

Table 3 shows the rice yield due to P fertilizer and organic matter application. The yield obtained from Kuningan Experimental Station was consistently higher than those from Sukamandi Experimental Station.

Application of organic matter at 2 t ha^{-1} did not significantly affect rice grain yield, neither in Sukamandi nor in Kuningan. This phenomenon was also applicable to the interaction effect. There was no interaction effect between the two factors of location and season. The interaction between organic matter and P fertilizer application did not significantly affect the yield. This could be the result of incomplete decomposition of the organic matter applied one day before transplanting. Organic matter should be applied earlier, for example following the first land preparation, so that nutrients are timely available for plant growth.

Phosphorous accumulation has been reported for sites where P fertilizer has been continuously applied for a prolonged period such as in Java (Rochayati *et al*. 1990). P can be adsorbed by Al and Fe and thus is not available for rice crop. Split P fertilizer application might be applied for soil having relatively high P adsorption capacity to give P better chance of gradually absorbed by rice crop. However, splitting the P fertilizer rate did not significantly affect grain yield.

The effect of NPK management on rice yield grain in wet and dry seasons is shown in Table 4. Our study revealed that average yield was some-what higher in the dry season than that in the wet season. The data also indicatet that the effect of NPK management on yield varied within varieties.

At the same rates of P and K, application of 102 kg N ha^{-1} according to the scale 4 LCC reading in the dry season gave a higher average yield (7.04 t ha^{-1}) than 115 and 143 kg N ha^{-1} in preset splits. In the wet season, the highest yield was recorded at 143kg N ha^{-1}.

Among the NPT tested, Gilirang had the lowest yield (4.50-6.52 t ha^{-1}) in both dry and wet seasons, followed by Ciapus (5.27-7.03 t ha^{-1}) and Fatmawati (5.09-7.05 t ha^{-1}), while IR64 yielded intermediate (5.42-6.64 t ha^{-1}). N applied based on scale 4 LCC reading resulted in urea application of 222 kg ha^{-1}. However, if scale 5 was used, 311 kg urea ha^{-1} was applied. In this study, the fertilizer dosage was kept the same for all varieties and seasons, but the time of application was different.

In the DS 2003, the increase in urea application had different effects on each variety. Rice yield under F4 was higher than that of F1 for Fatmawati and IR64, but this phenomenon was not applicable for Ciapus and Gilirang. The same result was only obtained for Gilirang in WS 2003/04. For other varieties, higher urea application resulted in insignificant yield increases.

Table 3. Effect of organic matter and P application on rice grain yield, Kuningan and Sukamandi Experimental Stations, DS 2001 and WS 2001/02.

Treatment	Yield (t ha^{-1})			
	Kuningan		Sukamandi	
	DS 2001	WS 2001/02	DS 2001	WS 2001/02
Organic matter				
O_1: without compost and manure	7.86a	6.54a	5.3a	5.4a
O_2: composted straw 2 t ha^{-1}	8.62a	6.69a	5.5a	5.6a
O_3: manure 2 t ha^{-1}	8.65a	6.82a	5.6a	5.7a
O_4: composted straw 1 t ha^{-1} + manure 1 t ha^{-1}	8.45a	6.72a	5.6a	5.6a
P fertilizer				
P_0: without P	8.39a	6.57a	5.4a	5.5a
P_1: P_2O_5 36 kg ha^{-1} (1 split)	8.41a	6.61a	5.6a	5.8a
P_2: P_2O_5 36 kg ha^{-1} (2 splits)	8.46a	6.88a	5.6a	5.5a
P_3: P_2O_5 36 kg ha^{-1} (3 splits)	8.32a	6.70a	5.5a	5.6a

Values in a column followed by the same letter are not significantly different at 5% DMRT.

Table 4. Effect of varieties and NPK application on rice yield, Sukamandi Experimental Station, DS 2003 and WS 2003/04.

Treatment/season	Yield (t ha^{-1})				
	Fatmawati	Ciapus	Gilirang	IR64	Mean
NPK-fertilizers: (N-P_2O_5-K_2O)					
DS 2003					
F_1: 115-36-30[1]	6.18b	6.97bc	6.34b	6.45bc	6.49
F_2: 172.5-54-45[1]	7.35a	7.44a	6.90ab	6.85ab	7.14
F_3: 172.5-54-45[2]	7.25a	6.77bc	7.01a	6.53bc	6.89
F_4: 102-36-30[3]	7.14a	7.30ab	6.61ab	7.11a	7.04
F_5: 143-36-30[4]	7.34a	6.67c	5.72c	6.24c	6.49
Mean	7.05	7.03	6.52	6.64	6.81
WS 2003/04					
F_1: 115-36-30[1]	5.10a	4.86a	3.84c	5.19a	4.75
F_2: 172.5-54-45[1]	5.22a	5.69a	4.40bc	5.68a	5.25
F_3: 172.5-54-45[2]	5.23a	5.19a	4.32bc	5.43a	5.04
F_4: 102-36-30[3]	4.65a	5.00a	5.23a	5.35a	5.06
F_5: 143-36-30[4]	5.26a	5.63a	4.71b	5.46a	5.27
Mean	5.09	5.27	4.50	5.42	5.07

Values in a column within treatment followed by the same letter are not significantly different at 5% DMRT.
N splits: [1]1/3-1/3-1/3, [2]1/2-1/4-1/4, [3]based on 4 scale LCC reading, [4]based on 5 scale LCC reading.

Effect of Intermittent Irrigation on Yield and Water Use Efficiency

Yield and yield components resulted from the tested treatments in terms of water management and incorporation of organic matter and P fertilizer are shown in Table 5. Even though yield in the flooded treatment (W_1) was the lowest, yields under the other irrigation treatments were not significantly different. However, on the raised bed (W_4), the plant population was 136,000 hills ha^{-1}, compared to 160,000 hills ha^{-1} in the other treatments. Neither 5 t ha^{-1} straw incorporated into the soil nor P fertilization at a rate of 50 kg ha^{-1} P_2O_5 increased yield. The number of panicles per hill (22) was highest on the raised beds, significantly higher than that in flooded and intermittent irrigation treatments (Table 5). The number of filled grains per panicle was significantly affected by P fertilization.

Water management did not result in significant differences in the yield, however it saved water consumption and consequently increased water productivity (Table 6). In this study, we assumed that water consumption in subplot and sub-subplot was similar since water was not measured in each plot. Total water consumption consisted of water consumed during land soaking, early flooding, harrowing, transplanting, and the first 10 days after transplanting before the irrigation treatments were applied, in addition to irrigation and total rainfall during the cropping period. In the flooded treatment, water used was 21,213 m^3 ha^{-1}, and in the other three treatments (W_2, W_3 and W_4), the water uses were 46%, 38%, and 35% of that amount, respectively.

Intermittent irrigation saved up to 54% water, compared to conventional flood irrigation, without a significant effect on grain yield. Similar findings were reported by Thiyagarajan *et al*. (2002) in Coimbatore (India), with water savings of 56%, Cao *et al*. (2002) with savings up to 36% in Nanjing (China), and Bindraban *et al*. (2006) with water savings up to 50% for a range of experimental conditions, while Shi *et al.* (2002), also in China, reported similar water savings and a slightly positive effect on yields. Water-saving irrigation from transplanting to flowering, followed by maintenance of a thin layer of standing water during the post-flowering stage did not lead to reduced grain yields.

Water productivity varied between 0.29 kg m-3 under flooded irrigation and 0.65-0.85 kg m-3 under water-saving irrigation management. These values are of the same order of magnitude as reported by Thiyagarajan *et al*. (2002), i.e. 0.40 kg and 0.73 kg m-3 for conventional and alternate wet and dry irrigation, respectively. Lu *et al*. (2002) reported water productivity in hybrid, inbred and aerobic rice varieties ranging

Table 6. Water consumption, rice yield and water productivity for different irrigation methods, Sukamandi Experimental Station, DS 2002.

Irrigation method	Total water consumption[1]		Yield (%)	Water productivity (kg m^{-3})
	kg ha^{-1}	m^3 ha^{-1}		
W_1: flooded	21,213	100.00	6,088	0.29
W_2: intermittent	9,750	45.96	6,315	0.65
W_3: below soil surface	8,116	36.26	6,595	0.81
W_4: raised bed	7,383	34.80	6,275	0.85

[1]Total water consumption includes total rainfall during the crop season.
[2]Water consumption for subplot and sub-subplot was not measured.

Table 5. Rice yield and yield components under different irrigation methods, Sukamandi Experimental Station, DS 2002.

Treatment	Yield (t ha^{-1})	Yield component		
		Panicles per hill	Grains per panicle	1000-grain weight (g)
Water management				
W_1: flooded	6.1a	17.9b	105.4a	26.2a
W_2: intermittent	6.3a	18.0b	105.6a	26.0a
W_3: below soil surface	6.6a	19.9ab	102.6a	25.9a
W_4: raised bed	6.3a	22.0a	105.3a	26.2a
Organic matter				
C_0: without compost	6.3a	19.4a	105.1a	26.1a
C_1: compost 5 t ha^{-1}	6.4a	19.5a	104.3a	26.1a
P fertilizer				
P_0: without P_2O_5	6.3a	19.2a	102.9b	26.0a
P_1: P_2O_5 50 kg ha^{-1}	6.4a	19.7a	106.5a	26.2a

Values in a column followed by the same letter are not significantly different at 5% DMRT.

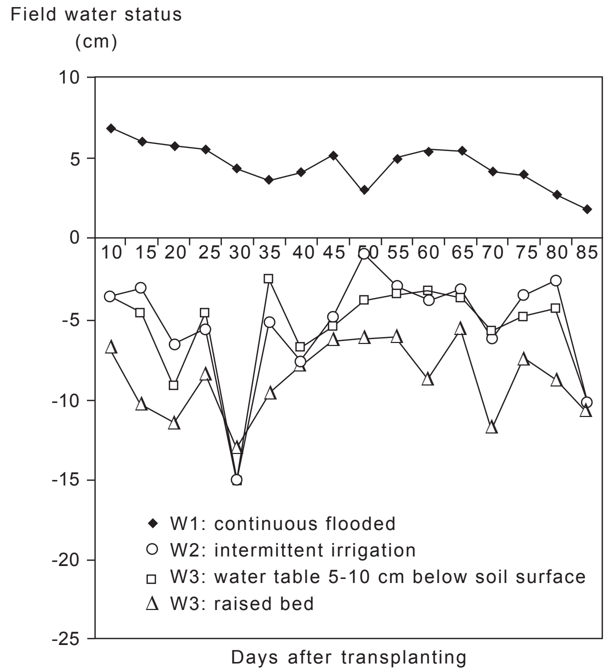

Fig. 1. Field water status at different irrigation treatments from 10 to 85 days after transplanting (DAT), Sukamandi Experimental Station, DS 2002.

between 0.87 and 1.45 kg m-3. Belder *et al*. (2002) showed in experiments carried out in Tualin (China) and at Philrice (Philippines) that average water productivity under intermittent irrigation exceeded 1 kg m^{-3}, while under conventional irrigation, the values were below 1 kg m^{-3}.

Although the raised bed technique resulted in water savings of 65% compared to flood irrigation, it is not yet practiced in farmers' fields. Farmers are reluctant to adopt this irrigation technique because of the high labor demands and the low price of water, while it does not lead to significantly higher rice yields. Hence, as long as farmers have little incentive to reduce water input, raised beds will most likely not be adopted in practice.

Field water status, expressed as positive or negative hydraulic head, is shown in Figure 1. Only in the flooded treatment was field water status above the soil surface, ranging from 1.8 to 6.9 cm. In the water-saving irrigation treatments (W_2, W_3 and W_4), field water status was below the soil surface, with the lowest values in W_2 and W_3.

CONCLUSION

The transplanting method combined with currently recommended plant spacing (20 cm x 20 cm) for the new plant type of Fatmawati rice variety resulted in significantly higher grain yields than the narrower plant spacing combined with direct seeding. The grain yield of crops starting from single young seedlings was not significantly different from that of three seedlings. Therefore, single seedling establishment is recommended to reduce the costs for seed.

The combination of chemical N fertilizer with organic compost gave inconsistently higher yields. However, by using LCC readings, N fertilizer rate can be reduced compared to the current recommendation without compromising yield, so that N use efficiency can be increased. Split P application did not significantly increase grain yield.

Intermittent irrigation resulted in higher water use efficiency and water productivity than flooding, as similar yields were attained with less water. Hence, regionally we can grow 'more crop per drop' to maintain rice self-sufficiency.

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