Effect of organic farming on management of rice brown planthopper

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In southern India, brown planthopper (BPH) *Nilaparvata lugens* takes a heavy toll on rice production. It directly causes damage and acts as a vector of many diseases. An experiment involving a cultural method of control was conducted using synthetic fertilizers and biofertilizers. Biofertilizers are becoming popular as a cheap and safe alternative to conventional chemical fertilizers (Sharma 2001).

The experiment was laid out in a completely randomized block design in the insectary. Test variety ADT36 was planted in pots with wetland soil collected from the field. There were nine treatments (1: 100-50-50 kg NPK ha^{-1}, 2: 120-50-50 kg NPK ha^{-1}, 3: 2 kg azospirillum ha^{-1}, 4: 500 kg azolla ha^{-1}, 5: 100-50-50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}, 6: 100-50-50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}, 7: 120-50-50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}, 8: 120-50-50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}, 9: untreated check [12.5 t farmyard manure ha^{-1}]) and each treatment was replicated thrice. Five hills were maintained per plot. Inorganic and organic fertilizers at the computed doses were applied in the respective treatments and the soil was thoroughly mixed.

Ten second-instar nymphs were released at 15 d after treatment (DAT) in each treatment and the population recorded for two generations. Five hills were selected in each treatment. The total number of tillers and productive tillers was observed. Plant height was measured from the ground level to the tip of the longest leaf and expressed in cm at the time of last observation. Grain yield was recorded.

The combination of inorganic fertilizer (120-50-50 kg NPK ha^{-1}) and azospirillum resulted in the lowest population of BPH (26.66 hill^{-1}) when compared with 120-50-50 kg NPK ha^{-1} alone (62 hill^{-1}), followed by the combination of 120-50-50 kg NPK ha^{-1} and azolla (33 hill^{-1}) in the first generation (Table 1). A similar trend was evident in the second generation.

When azospirillum and azolla were applied alone, the BPH population was 43 hill^{-1} and 47 hill^{-1}, respectively, in the first generation. When synthetic fertilizer was applied alone, the populations were bigger in both generations.

Application of 120-50-50 kg NPK ha^{-1} + azolla and 120-50-50 kg NPK ha^{-1} + azospirillum resulted in the highest tiller production, 1,000-grain weight, and grain yield (Table 2). With higher doses of azolla, productive tillers were 11 hill^{-1}, plant height was 71.96 cm, 1,000-grain weight was 21.38 g, and yield was 4,091.33 kg ha^{-1}. The corresponding numbers for azospirillum were 10.33 hill^{-1}, 66.80 cm, 22.56 g, and 4,113.66 kg ha^{-1}. The lowest yield was obtained from plots treated with inorganic fertilizer alone.

Organic farming is a recent approach that aims to conserve natural resources and protect the environment. BPH populations were low in plots treated with organic amendments along with synthetic fertilizers. This supports the findings of Kajimura et al (1995) who noted low densities of BPH and whitebacked planthop-

Table 1. BPH populations on rice variety ADT36 in response to application of organic and inorganic fertilizers.[a]

Treatment	Generation	
	First	Second
100-50-50 kg NPK ha^{-1}	52.66 (7.25) d	73.34 (8.56) d
120-50-50 kg NPK ha^{-1}	62.00 (7.86) d	88.34 (9.39) d
2 kg azospirillum ha^{-1}	43.0 (6.55) cd	58.33 (7.63) c
500 kg azolla ha^{-1}	47.0 (6.84) cd	62.67 (7.91) cd
100-50-50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}	38.3 (6.18) bc	48.33 (6.94) b
100:50:50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}	39.0 (6.23) bc	48.66 (6.97) b
120:50:50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}	26.66 (5.15) a	39.00 (6.24) a
120:50:50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}	33.00 (5.74) b	45.33 (6.73) b
12.5 t farmyard manure ha^{-1}	49.66 (7.04) cd	67.66 (8.22) cd

[a]Mean of three replications. Numbers in parentheses are square root-transformed values. In a column, means followed by the same letter(s) are not significantly different at P = 0.05 by Duncan's multiple range test.

Table 2. Growth and yield characteristics of rice variety ADT36 as affected by application of organic and inorganic fertilizers and biofertilizers.[a]

Treatment	Total tillers hill^{-1}(no.)	Productive tillers hill^{-1}(no.)	Plant height (cm)	1,000-grain weight(g)	Grain yield (t ha^{-1})
100-50-50 kg NPK ha^{-1}	10.66 c	7.33 c	52.46 c	18.5 bc	3.4 d
120-50-50 kg NPK ha^{-1}	12.33 b	9.66 ab	56.46 bc	19.66 abc	3.6 c
2 kg azospirillum ha^{-1}	12.66 b	9.00 b	53.43 c	19.66 abc	3.5 cd
500 kg azolla ha^{-1}	13.00 b	9.33 b	59.50 bcd	19.1 abc	3.4 d
100-50-50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}	12.66 b	9.66 ab	66.93 abc	21.73 a	3.9 b
100:50:50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}	12.33 b	9.66 ab	67.63 ab	21.23 a	3.9 b
120:50:50 kg NPK ha^{-1} + 2 kg azospirillum ha^{-1}	14.33 a	10.33 ab	66.80 abc	22.56 a	4.1 a
120:50:50 kg NPK ha^{-1} + 500 kg azolla ha^{-1}	14.66 a	11.00 a	71.96 a	21.38 a	4.1 a
12.5 t farmyard manure ha^{-1}	12.33 b	9.33 b	64.13 abc	20.66 ab	3.6 c

[a]Mean of three replications. In a column, means followed by the same letter(s) are not significantly different at $P = 0.05$ by Duncan's multiple range test.

per in organically farmed fields and those with low N content. Chino et al (1987) reported that asparagine content of plant phloem sap was significantly lower under organic cultivation, thereby adversely affecting the feeding activity of BPH. Plots treated with 120-50-50 kg NPK ha^{-1} had significantly higher levels of BPH (Table 1). But BPH levels in azolla plots were not significantly different from those in control plots (with farmyard manure).

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The effect of nitrogen on rice grain iron

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Previous studies have shown that iron (Fe) content of rice grain may vary widely among rice genotypes (Senadhira et al 1998, Prom-u-thai and Rerkasem 2001). In addition, grain Fe may also be affected by environmental and management conditions. This experiment measured grain Fe concentration in five rice genotypes (KDML 105, IR68144, Ubon 2, Basmati 370, and RD6) grown under three levels of N (0, 60, and 120 kg N ha^{-1}). The field experiment was in a split-plot design with three replications. Basal fertilizer consisted of 6.6 kg P and 12.4 kg K ha^{-1}. The basal fertilizer and half of the N were applied at transplanting and the other half of N was applied after 4 wk. Fe concentration was determined in mature grain, as unhusked (whole grain with palea and lemma intact) and brown rice (palea and lemma removed), husk (palea and lemma), and polished grain (30 s) by dry-ashing and atomic absorption spectrometry (Emmanuel et al 1984).

In all five genotypes, grain yield increased slightly with the application of 60 kg N ha^{-1}, but there was no further effect of increasing N to 120 kg ha^{-1} (P<0.05) (Table 1). Nitrogen fertilizer generally increased N content of the rice grain (Table 2). On the other hand, grain Fe concentrations in the five genotypes were affected differently by N rates (Table 3). The Fe concentration in unhusked KDML 105, IR68144, Ubon 2, Basmasti 370, and RD6 increased

Table 1. Grain yield (t ha^{-1}) of five genotypes grown at three levels of nitrogen (0, 60, 120 kg N ha^{-1}).

Genotype	Grain yield (t ha^{-1}) 0 kg N	60 kg N	120 kg N
KDML 105	3.6	4.0	3.8
IR68144	2.7	4.7	3.9
Ubon 2	4.1	4.0	3.7
RD6	3.1	3.4	3.3
Basmati 370	3.7	3.3	3.4
	3.2 a	3.8 b	3.6 b
Analysis of variance			
P (genotypes [G])	ns		
P (N)	<0.05		
P (G × N)	ns		
LSD (N, 0.05)	0.4		

Table 2. The N concentration (% N) in unhusked rice of five genotypes grown under three levels of N (0, 60, and 120 kg ha^{-1}).

Genotype	Grain N concentration[a] (%)		
	0 kg N	60 kg N	120 kg N
KDML 105	1.3 aA	1.6 aB	1.8 bB
IR68144	1.5 aA	1.6 aA	1.9 bcB
Ubon 2	1.5 aA	1.6 aA	2.0 cB
RD6	1.3 aA	1.6 aB	1.8 bB
Basmati 370	1.3 aA	1.5 aA	1.5 aA
Analysis of variance			
P (Genotype [G])	<0.01		
P (N)	<0.01		
P (G × N)	<0.01		
LSD (N, 0.05)	0.30		
LSD (G, 0.05)	0.20		

[a]Lower case for comparison of genotype effect, upper case for comparison of N effect.

Table 3. The Fe concentration (mg kg^{-1}) in unhusked, brown rice, husk, and polished grain (white grain) at 30 and 60 s of five genotypes grown under three levels of N (0, 60, and 120 kg ha^{-1}).[a]

Genotype	N (kg ha^{-1})	Fe concentration (mg Fe kg^{-1})			
		Unhusked	Brown rice	White rice[b]	Husk
KDML 105	0	13.0	7.8 a	7.9 a	36.0 a
	60	14.6 ab	8.2 a	7.2 a	32.6 a
	120	16.1 b	8.8 a	7.3 a	37.4 a
IR68144	0	15.8 a	13.5 a	12.3 b	37.9 a
	60	17.2 a	13.0 a	13.6 b	38.3 a
	120	21.1 b	13.1 a	10.0 a	48.6 a
Ubon 2	0	13.8 a	9.3 a	4.6 a	42.7 a
	60	13.6 a	8.1 a	8.8 b	44.8 a
	120	13.5 a	8.3 a	6.5 ab	48.5 a
RD6	0	15.2 a	8.2 a	5.1 a	39.8 a
	60	15.8 b	8.3 a	10.3 b	51.3 a
	120	18.3 b	9.0 a	8.2 b	44.2 a
Basmati 370	0	15.6 a	10.8 a	7.6 a	35.8 a
	60	16.3 a	12.1 ab	6.5 a	37.5 a
	120	18.3 b	12.4 b	10.2 b	47.3 b
Analysis of variance					
P (G)		<0.01	<0.01	<0.01	<0.01
P (N)		<0.01	ns	<0.05	<0.05
P (G × N)		<0.05	<0.05	<0.01	<0.05
LSD (0.05)		2.6	1.5	2.3	11.5

[a]LSD used to compare differences in the same genotypes at different treatments. [b]Polished for 30 s.

with the application of 120 kg N ha^{-1}. Nitrogen had no effect on Fe in unhusked grain of Ubon 2. Much higher concentrations of Fe were found in the rice husk compared with the rest of the grain. Nitrogen levels had no effect on Fe concentration in brown rice and husk. However, in the brown rice of Basmati 370, it was increased with 120 kg N ha^{-1}. To produce white rice, the mill normally polishes brown rice for about 30 s. In this study, we found that grain Fe concentration generally declined after polishing, indicating that a high proportion of Fe is contained in the bran. For Ubon 2 and RD6, grain Fe in white rice from 60 kg N and 120 kg N applications was twice as much as with 0 N. There was a similar, although slightly less, effect of N in Basmati 370. In IR68144, the grain Fe in white rice with 120 kg N was slightly less than with 0 N and 60 kg N, but in KDML 105, the grain Fe in white rice showed no response to N. However, the grain Fe in unhusked, brown, and white rice was not correlated with the grain N in rice grain and grain yield at three levels of N application.

Different parts of the rice grain—the husk, the bran, and the endosperm—appeared to contain Fe at different concentrations and their Fe contents responded differently to N fertilizer. The effect of N fertilizer on grain Fe appeared to be mostly in the husk. The Fe concentration in unhusked rice was only weakly correlated with that in brown rice (r = 0.66) and white rice (r = 0.42).

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Influence of irrigation, nutrient management, and seed priming on yield and attributes of upland rice

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The productivity of upland rice is very low because of a host of problems, among which soil moisture stress, poor native soil fertility, and high weed infestation are the most important ones. Under upland situations, moisture stress is likely to occur during any of the growth stages of the crop, which may adversely affect growth and yield. Presowing treatment improves germination, promotes plant and root growth, and increases crop survival under water-stress conditions. A field experiment was conducted at the Instructional Farm in Vellayani of Kerala Agricultural University, India, during the late first crop season of 1999 to examine the response of upland rice to different levels of irrigation, nutrient management, and seed priming.

Soil characteristics at the trial site were a sandy clay loam texture, organic C 1.7% (Walkley and Black's rapid titration method, Jackson 1973), pH 4.8 (pH meter with glass electrode, Jackson 1973), and available N, P_2O_5, and K_2O of 238 (alkaline potassium permanganate method, Subbiah and Asija 1956), 32.8 (Bray 1 method, Jackson 1973), and 160 kg ha^{-1} (ammonium acetate method, Jackson 1973), respectively. Treatments consisted of three irrigation levels (irrigation water [IW]/cumulative pan evaporation [CPE] ratio of 1.5 [I_1], 0.1 [I_2], and rainfed [I_3]; three nutrition levels (20-10-15 [F_1], 40-20-30 [F_2], and 60-30-45 [F_3] kg NPK ha^{-1}); and two seed priming methods (1% [S_1] and 2.5% (KCl) [S_2]. The experimental layout was a split-split-plot design with three replications: irrigation levels in main plots, nutrient management in subplots, and seed priming in sub-subplots. Irrigation was given to a depth of 50 mm. Upland rice variety Matta Triveni (PTB45) was dibbled at a spacing of 20 × 10 cm. This variety was released from RARS, Pattambi, Kerala. It has a duration of 95–105 d. The grains are red, long, and bold.

Irrigation was scheduled 1 wk after sowing, according to the treatment. N was applied in three equal splits—i.e., basal, at tillering, and at panicle initiation. The rice seeds were immersed in 1.0% and 2.5% KCl solution for 15 h and dried before pregermination. The total quantity of water received by irrigation treatments I_1, I_2, and I_3 during the cropping period was 544, 456, and 214 mm, respectively. The area of the experimental site has a humid tropical climate. The mean rainfall received during the cropping period was 422 mm. The mean annual maximum and minimum temperatures were 32.2 and 23.1 °C, respectively. The mean relative humidity was 82%.

The number of productive tillers hill^{-1} and the number of spikelets hill^{-1} were influenced by irrigation and nutrient treatment only. Treatment levels I_1 and F_3 recorded the highest values for both these attributes (Table 1). Panicles produced by plants subjected to a rainfed situation often failed to emerge and had a high percentage of sterile spikelets.

The data showed that both irrigation and nutrient levels had a significant influence on the

Table 1. Response of upland rice to different levels of irrigation, nutrient management, and seed priming at the Instructional Farm, Vellayani, Kerala, India.

Treatment[a]	Productive tillers hill^{-1} (no.)	Spikelets panicle^{-1} (no.)	Filled grains panicle^{-1} (no.)	Chaff percentage	1,000-grain weight (g)	Grain yield (kg ha^{-1})
Irrigation						
I_1	11	119	101	14	22.44	2676
I_2	9	116	101	13	21.58	2145
I_3	6	91	426	31	7.07	371
F (2, 4)	15.297*	6.771*	43.8**	511.67**	990.5**	2,163.2**
CD	2.715	22.82	20.69	4.97	0.351	101.8
Nutrients						
F_1	8	91	71	26	19.76	1299
F_2	8	115	87	30	20.65	1798
F_3	10	120	89	34	20.68	2094
F (2, 16)	6.426**	14.923**	7.649**	10.764**	83.5**	53.1
CD	1.61	12.12	10.23	4.03	0.154	165.1
Seed priming						
S_1	8	109	79	32	20.29	1736
S_2	9	109	85	28	20.30	1724
F (1, 34)	0.954	0.001	1.539	5.421*	0.194	0.036
CD	ns	ns	ns	3.584	ns	ns

[a]Irrigation levels: I_1 = irrigating the crop at an IW/CPE ratio of 1.5, I_2 = irrigating the crop at an IW/CPE ratio of 1.0, I_3 = rainfed; nutrition levels: F_1 = 20-10-15 kg NPK ha^{-1}, F_2 = 40-20-30 kg NPK ha^{-1}, F_3 = 60-30-45 kg NPK ha^{-1}; seed priming: S_1 = 1.0% KCl for 15 h, S_2 = 2.5% KCl for 15 h. * = significant at 5% level, ** = significant at 1% level.

number of filled grains panicle^{-1}. Irrigation treatments I_1 and I_2 were on a par with each other and were significantly superior to I_3. Similarly, F_2 and F_3 were on a par with each other and were significantly superior to F_1. The interaction I × F was significant and the treatment combination I_2 F_2 recorded the highest number of filled grains panicle^{-1} (Table 2).

Both the irrigation treatments I_1 and I_2 registered less chaff percentage compared with the rainfed treatment (Table 1). The nutrient level F_3 produced significantly higher values of chaff percentage than F_1 and F_2. A higher fertilizer dose increased vegetative growth, resulting in higher leaf area index, and this might have resulted in mutual shading, which affected photosynthesis and thus gave a high chaff percentage. The seed priming treatment S_2 recorded lower values of chaff. Lowest chaff percentage values were found in combinations I_1 F_1 and I_1 F_1 S_1.

Irrigation at the I_1 level recorded significantly higher 1,000-grain weight over I_2 and I_3. Similarly, the highest level of NPK (F_3) produced a higher 1,000-grain weight than F_2 and F_1. The interaction effect of I × F indicated that the highest level tested in the trial (I_1 F_3) gave the highest test weight and was on a par with I_1 F_2. Among I × F × S combinations, I_1 F_2 S_1 recorded the highest test weight and was on a par with I_1 F_2 S_2.

Data indicated that the factors irrigation and nutrition and the interaction I × F had a significant influence on grain yield. I_1 gave the highest grain yield (2,676 kg ha^{-1}), which was significantly superior to I_2 (2,145 kg ha^{-1}) and I_3 (371 kg ha^{-1}). I_1 recorded a yield increase of 24.8% in grain yield over I_2 (IW/CPE = 1.0). This increase in yield was due to the concomitant increase of the yield attributes at higher levels of irrigation. The drastic reduction in yield under moisture stress was mainly due to the increased number of unfilled grains panicle^{-1} rather than a reduction in panicle per unit area. Among the nutrient levels tested, F_3 recorded the highest grain yield of 2,094 kg ha^{-1}, which was significantly superior to the other two levels. Among I × F combinations, I_1 F_3 registered the highest grain yield of 3,223 kg ha^{-1}. This value indicates that good water availability and better nutrition result in higher yields and that seed priming has no influence. It is evident from the study that the crop responds to an irrigation level with an IW/CPC ratio of 1.5 and that an NPK level of 60-30-45 kg ha^{-1} helps attain maximum yield.

Table 2. Interaction effects of irrigation, nutrients, and seed priming on number of spikelets panicle^{-1}, number of filled grains panicle^{-1}, chaff percentage, 1,000-grain weight (g), and grain yield (kg ha^{-1}).[a]

Treatment	Spikelets panicle^{-1}(no.)	Filled grains panicle^{-1}(no.)	Chaff percentage	1,000-grain weight (g)	Grain yield (kg ha^{-1})
I_1 F_1	110	101	9.83	21.11	2,155
I_1 F_2	112	96	13.83	23.14	2,650
I_1 F_3	136	113	17.33	23.45	3,223
I_2 F_1	91	79	13	21.73	1,431
I_2 F_2	139	121	14.67	21.20	2,386
I_2 F_3	118	104	12.83	21.80	2,617
I_3 F_1	72	34	53.83	16.43	313
I_3 F_2	95	43	75.17	17.60	358
I_3 F_3	107	49	60.17	17.20	441
F(4, 16)	14.9**	4.37*	6.997**	53.616**	11.106**
CD	12.121	17.721	6.9	0.367	286.05
$I_1F_1S_1$	107	97	8.33	21.63	2,029
$I_1F_1S_2$	113	105	11.33	20.60	2,279
$I_1F_2S_1$	113	102	9.67	23.25	2,599
$I_1F_2S_2$	110	90	18	23.00	2,701
$I_1F_3S_1$	142	115	19	22.40	3,276
$I_1F_2S_2$	129	110	15.67	22.50	3,169
$I_2F_1S_1$	93	80	13.33	22.47	1,355
$I_2F_1S_2$	89	78	12.67	21.00	1,506
$I_2F_2S_1$	110	94	17.67	21.40	2,742
$I_2F_2S_2$	167	148	10.67	21.00	2,030
$I_2F_3S_1$	128	116	10.67	22.20	2,828
$I_2F_3S_2$	107	92	15	21.40	2,406
$I_3F_1S_1$	73	33	56	15.47	177
$I_3F_1S_2$	70	34	51.67	17.40	449
$I_3F_2S_1$	99	36	91.33	17.00	261
$I_3F_2S_2$	91	50	59	18.20	456
$I_3F_3S_1$	113	42	62.67	16.77	358
$I_3F_3S_2$	101	57	57.67	17.60	523
F(4, 34)	2.649	3.696*	4.173**	20.7**	1.461
CD	–	27.45	10.17	0.888	–

[a]* = significant at 5%, ** = significant at 1%.

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Effect of organic and inorganic P fertilizers on sustainability of soil fertility and grain yield in a rice-pulse system

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The use of indigenous rock phosphate (RP) as fertilizer is becoming increasingly important in India. The RP deposit in India was estimated to be about 260 t (Narayanasamy and Biswas 1998). Khasawnch and Doll (1986) reported that RP is as effective as water-soluble P fertilizer under suitable environments. As the availability of RP increases slowly and continuously when in contact with the soil, its effectiveness was two to three times more than that of triple superphosphate (Chien and Hammond 1988).

The application of RP with organic manure enhances the dissolution of RP in the soil and thus increases the plant availability of P. The organic acids produced during the decomposition of organic manure supply protons (W) for RP dissolution (Bagavathiammal and Mahimairaja 1999). In association with phosphate-solubilizing microorganisms and organic manure, RP could be used as a P source in many crops. The mechanism behind the solubilization of P from RP by microorganisms is related to the production of organic acids and chelating substances (Datta et al 1982). The residual effect of RP is more pronounced in the presence of organic manure in a rice-rice cropping system (Panda 1989). Roy et al (1997) found that in Udic Ustochrepts, rice yield and soil enrichment could be improved by using Mussoorie RP (MRP) incorporated with legume straw and phosphobacteria (PB) *(Bacillus polymyxa* and *Pseudomonas striata)* in neutral to slightly alkaline soils. Because not much work on the effectiveness of Rajphos (Udaipur RP, a product of Rajasthan Mines and Minerals Ltd., Udaipur, India) as a source of P was done, we evaluated its agronomic effectiveness along with other sources of P. The study aimed to determine the effect of organic manure and biofertilizer on the effectiveness of Rajphos and to examine the residual effect of Rajphos application in rice soil. Different inorganic P fertilizers were used with organic manures (e.g., green leaf manure, [GLM] was pungam leaf *Pongamia glabra)* and biofertilizer-phosphobacteria. The yields of rice and blackgram and soil fertility changes were noted.

The field experiments were conducted in 1996-97 at the TNAU Soil Science Department in Coimbatore. Soil is a clay loam alluvial with pH 7.86, EC 0.48 dS m^{-1}, 0.42% organic C, 183 kg $KMnO_4$-N ha^{-1}, 17.8 kg Olsen P ha^{-1}, and 543 kg NH_4OAcK ha^{-1}. The average total P (dry weight basis) was 7.2%, 8.3%, 20.1%, and 0.17% in Udaipur RP (Rajphos), MRP, diammonium phosphate (DAP), and GLM, respectively. The treatments were replicated three times in a randomized block design. Short-duration rice variety ADT36 (110 d) was planted in the first week of December every year using 15 ¥ l0-cm spacing. Freshly collected leaves of *P. glabra* were incorporated at 6.25 t ha^{-1} (equivalent to 1.875 t ha^{-1} on a dry weight basis) into the field 1 wk before transplanting. Phosphobacteria as biofertilizer were applied at 2 kg ha^{-1}. The phosphobacterial inoculant was prepared with lignite as a carrier. Rock phosphates and other fertilizers were applied as basal 3 d before transplanting. Recommended doses of N (120 kg ha^{-1}) as urea and K (41.5 kg ha^{-1}) as muriate of potash were applied in four equal splits at initial, tillering, panicle initiation, and flowering stages. Plots were irrigated and 25-d-old rice seedlings were transplanted in the puddled field. Other cultivation practices such as weeding (four times) and plant protection measures (two times) were carried out. The crop was harvested at maturity and its yield recorded. Postharvest soil samples after rice were analyzed for Olsen P with 0.5 M $NaHCO_3$ (pH 8.5) as extractant. Representative soil samples were collected at 0-15-cm depths, air-dried, sieved through a 2-mm sieve, and analyzed.

At first, the highest grain yield of rice was obtained with DA, followed by the RPs (Table 1). Though MRP contains relatively higher total P content (8.3%) than Rajphos (7.2%), the latter appeared to perform relatively better in rice soil than the former. However, MRP and Rajphos were on a par at the 5% level. This may be due to the differences in chemical composition and varying dissolution patterns of P from these two RPs. Rajphos, up to 32.73 kg P ha^{-1}, performed as well as DAP, but it gave a higher rice yield than MRP at all levels. The addition of GLM at 6.25 t ha^{-1} and PB at 2 kg ha^{-1}, along with different sources of P, considerably increased yield, mainly by improving the dissolution and availability of P from the RPs. The combination of Rajphos at 21.82/32.73 kg P ha^{-1}, GLM, and PB resulted in higher grain yields, a value comparable with the sole application of DAP (21.82 kg P ha^{-1}) in the cropping sequence.

The application of Rajphos (32.73 kg P ha^{-1}) along with GLM + PB recorded the highest benefit-cost ratio of 2.7 (Table 2), which was followed by DAP (32.73 kg P ha^{-1} + GLM + PB; 2.5). The P buildup in the soil was significantly increased with the application of phosphatic sources in combination with GLM/PB (Table 3). The application of organic fertilizers, along with Rajphos, enhanced the solubility of Rajphos by producing organic acids, which, in turn, improved P availability at the later stages of crop growth and thus increased grain yield. The lower yield obtained by Rajphos alone might be ascribed to the slow release of P (and in less amount) from Rajphos in the available form (Rabindra et al 1986).

To examine the residual effect of Rajphos, a rice fallow summer crop of black gram (variety Co 5, 75-d duration) was sown on the same plots without further application of nutrients. The application of Rajphos at 32.73 kg P ha^{-1}, along with GLM applied to rice, recorded the highest residual black gram yield of 480 kg ha^{-1}, which was followed by Rajphos + GLM + PB (Table 4).

These results suggest that the combined application of Rajphos (up to 32.73 kg P ha^{-1}, GLM (6.25 t ha^{-1}), and PB (2 kg ha^{-1}) could be a substitute for inorganic phosphate fertilizers (particularly DAP) in a rice-pulse cropping system.

Table 1. Effect of different sources and levels of P on yield (kg ha^{-1}) of rice variety ADT36 (av of 2 y).[a]

Level (L) (kg P ha^{-1})	Sources (P)				
	RP	MRP	DAP	L mean	O mean
P alone					
10.91	4,051 c	3,955 c	4,241 c	4,082 C	
21.82	4,502 b	4,457 b	4,661 b	4,540 B	
32.73	4,952 a	4,757 ab	5,006 ab	4,905 A	
43.64	4,627 ab	4,907 a	5,302 a	4,945 A	
P mean	4,533 B	4,519 B	4,803 A		4,618 C
P + GLM (0)					
10.91	4,727 c	4,613 b	4,902 c	4,747 C	
21.82	5,066 bc	4,989 b	5,222 bc	5,092 B	
32.73	5,490 a	5,384 a	5,524 ab	5,466 A	
43.64	5,163 ab	5,569 a	5,799 a	5,510 A	
P + GLM (0) mean	5,122 B	5,139 B	5,362 A		5,204 A
P + GLM +PB (0)					
10.91	4,455 c	4,327 b	4,611 b	4,464 C	
21.82	4,817 bc	4,660 b	4,956 b	4,811 B	
32.73	5,277 a	5,060 a	5,377 a	5,238 A	
43.64	4,952 ab	5,192 a	5,514 a	5,219 A	
P + GLM +PB (0) mean	4,875 b	4,810 b	5,115 a		4,933 B

	SE	LSD (5%)
P	56	113
O	56	113
L	65	130
P × L	113	225
O × P	98	195
P × L × O	195	389

[a]Means followed by small letters are compared within the column. Means followed by capital letters are compared within the column (L & O) and across the row (P). RP = Rajphos, MRP = Mussoorie rock phosphate, DAP = diammonium phosphate, P = sources of P, L = levels of P, O = organic fertilizers such as GLM/phosphobacteria (PB).

Table 2. Effect of different sources and levels of P on benefit-cost ratio (BCR).

Treatment	BCR		
	P source	P source GLM	P source + GLM + PB
Control	2.0	2.1	2.2
RP at 10.91 kg ha^{-1}	2.3	2.4	2.4
RP at 21.82 kg ha^{-1}	2.4	2.4	2.5
RP at 32.73 kg ha^{-1}	2.5	2.5	2.7
RP at 43.64 kg ha^{-1}	2.2	2.3	2.3
MRP at 10.91 kg ha^{-1}	2.2	2.4	2.4
MRP at 21.82 kg ha^{-1}	2.3	2.4	2.4
MRP at 32.73 kg ha^{-1}	2.3	2.4	2.4
MRP at 43.64 kg ha^{-1}	2.2	2.4	2.3
DAP at 10.91 kg ha^{-1}	2.3	2.5	2.5
DAP at 21.82 kg ha^{-1}	2.4	2.5	2.5
DAP at 32.73 kg ha^{-1}	2.4	2.5	2.6
DAP at 43.64 kg ha^{-1}	2.4	2.5	2.5

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Table 3. Effect of different sources and levels of P on soil P (Olsen P) (kg ha⁻¹).[a]

Level (L) (P kg ha⁻¹)	Sources (P)				
	RP	MRP	DAP	L mean	O mean
P alone					
10.91	8.98 b	8.82 ab	9.25 b	9.02 CD	
21.82	9.30 ab	9.12 ab	10.34 ab	9.59 BC	
32.73	10.43 a	9.64 a	11.26 a	10.44 A	
43.64	10.47 a	8.03 b	10.91 a	9.80 AB	
P mean	9.80 A	8.9 B	10.44 A		9.71 AB
P + GLM (0)					
10.91	9.30 b	9.78 a	9.72 bc	9.60 C	
21.82	9.82 ab	9.99 a	9.16 c	9.66 C	
32.73	10.95 a	10.60 a	10.91 ab	10.82 AB	
43.64	10.82 a	10.91 a	11.56 a	11.10 A	
P + GLM (0) mean	10.22 A	10.32 A	10.34 A		
P + GLM + PB (0)					
10.91	8.64 b	8.42 b	9.56 ab	8.87 B	
21.82	9.30 ab	8.73 b	8.68 b	8.90 B	
32.73	10.47 a	10.56 a	9.03 b	10.02 A	
43.64	10.56 a	8.86 b	10.65 a	10.02 A	
P + GLM + PB (0) mean	9.74 A	9.14 A	9.48 A		9.46 BC

	SE	LSD (5%)
P	0.19	0.38
O	0.19	0.38
L	0.22	0.44
P × L	0.38	0.76
O × P	0.33	0.66
P × L × O	0.66	1.31

[a]Means followed by small letters are compared within the column. Means followed by capital letters are compared within the column (L & O) and across the row (P). RP = Rajphos, MRP = Mussoorie rock phosphate, DAP = diammonium phosphate, P = sources of P, L = levels of P, O = organic fertilizers such as GLM/phosphobacteria (PB).

Table 4. Residual effect of different sources and levels of P on grain yield of Black gram variety Co 5 (av of 2 y).[a]

Level (L) (P kg ha⁻¹)	Sources (P)				
	RP	MRP	DAP	L mean	O mean
P alone					
10.91	240 c	290 a	275 a	286 C	
21.82	323 b	215 b	170 c	236 D	
32.73	320 b	310 a	230 b	287 B	
43.64	385 a	297 a	280 a	321 A	
P mean	317 A	278 B	239 C		278 C
P + GLM (0)					
10.91	260 c	260 b	220 c	240	
21.82	360 c	270 b	320 b	317	
32.73	480 a	330 a	360 a	390	
43.64	365 b	310 a	320 b	332	
P + GLM (0) mean	366 ns	293 ns	305 ns		321 A
P + GLM + PB (0)					
10.91	230 c	270 b	280 c	260	
21.82	315 b	270 b	290 b	288	
32.73	390 a	360 a	310 b	353	
43.64	325 b	275 b	355 a	318	
P + GLM + PB (0) mean	315 ns	294 ns	309 ns		306 B

	SE	LSD (5%)
P	0.47	0.94
O	0.47	0.94
L	0.54	1.09
P × L	ns	
O × P	ns	
P × L × O	11	22

[a]Means followed by small letters are compared within the column. Means followed by capital letters are compared within the column (L & O) and across the row (P). RP = Rajphos, MRP = Mussoorie rock phosphate, DAP = diammonium phosphate, P = sources of P, L = levels of P, O = organic fertilizers such as GLM/phosphobacteria (PB), ns = nonsignificant.

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Participatory research on the effect of on-farm water management practices

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Irrigation facilities have been built for considerable areas of cropped land, but the desired level of output by way of increased irrigated area and agricultural production has not been achieved. This is mainly attributed to the wastage of water at certain reaches. As rice is a major consumer of irrigation water, much has to be done to improve water-use efficiency in rice fields and this is possible only through farmers' participation. Farmers generally have the impression that field-to-field flowing water is best for rice growth. They are reluctant to follow scientific recommendations in water management. (Scientific water management relates to maintaining the standing water at 1-2 cm from transplanting to tillering and 1-5 cm from tillering to 10 d before harvest.) Rice yield can be influenced by different water management practices such as continuous submergence (Mandal and Chatterjee 1984), varying levels of submergence at different growth stages (Thorat et al 1987), and shallow submergence (5 ± 2 cm) during the crop's entire growth cycle (Jha and Sahoo 1988). Our study aimed to evaluate the effect of scientific water management along with farmers' practices on rice cultivation and to demonstrate how farmer participation in the research program can enhance water management.

This study was conducted in the Ichannur subdistributory command of the Kuttiyadi Irrigation Project in Kerala, India, in the 1999-2000 summer seasons (Jan-May). The *field boothies* (canals below the subdistributory and above the outlet of the command area) were lined with concrete and the field and drainage channels laid out with the participation of the members of the Beneficiary Farmers' Association. These interventions ensured reliable water delivery in the command area. Even with this, farmers practiced only field-to-field flowing irrigation, which resulted in enormous wastage of water. To optimize water use, an experiment was set up in outlets 7 and 12 of the Ichannur subdistributory, where farmers' associations were active and initiated the experiment.

Rice variety Triveni (PTB38) was used in the study and a common nursery was raised. Nursery raising, transplanting, manure and fertilizer application, aftercare, and harvest were done following the recommendations of the Kerala Agricultural University. The treatments consisted of scientific water management (T_1) and the farmers' practice of water management (T_2). Scientific water management relates to maintaining standing water at 1-2 cm from transplanting to tillering and 1-5 cm from tillering to 10 d before harvest. It also involves complete drainage 1 d prior to N topdressing and irrigation 12 h after topdressing. Water is let into the field from the field irrigation channel, either through a siphon or small regulatory slots made for the purpose. The farmers' practice is letting water into the fields to maintain standing water of a convenient height (as decided by them) and adopting field-to-field irrigation.

In both outlets, two adjacent plots (about 10,000 m^2 each) were selected. There were thus two major plots for each treatment. Soil at the experimental site was clay loam with medium fertility and pH 5.3. Treatments were imposed accordingly and water depth was maintained using marking pegs distributed randomly to various portions in the field. Evaporation from the field was recorded using can evaporimeters. The quantity of water diverted to each plot was also recorded. Observation sites in each plot were fixed randomly at 10 different spots, each having an area of 1 m^2. From this area, 10 plants were selected for observation. Grain and straw yields were taken from the harvested produce. At harvest, plant height, number of tillers, and number of panicles were recorded. Grain yield and straw yield were recorded after drying to 14% moisture content. Water-use efficiency was calculated as the ratio of grain yield to total quantity of water used (expressed as kg ha^{-1} cm^{-1}). Statistical analysis was done using methods specified by Panse and Sukhatme (1978). The results on growth, yield, and yield attributes are presented in the table.

Plant height did not vary significantly in both years, indicating that this growth attribute is not influenced by differences in conditions under both flowing and standing water in the field.

Growth and yield attributes, grain yield, and water use of rice as influenced by water management treatments.

Attribute	1999			2000		
	T_1	T_2	CD (0.05)	T_1	T_2	CD (0.05)
Plant height (cm)	79.00	78.40	ns	76.80	78.70	ns
Tillers hill^{-1} (no.)	8.48	9.33	ns	9.46	8.44	ns
Panicles hill^{-1} (no.)	4.01	4.52	ns	4.53	4.37	ns
Grain yield (t ha^{-1})	2.33	2.42	ns	2.40	2.60	ns
Straw yield (t ha^{-1})	2.83	2.60	ns	3.01	2.90	ns
Water used (cm)	111.30	198.40	–	129.90	217.70	–
Water-use efficiency (kg ha^{-1} cm^{-1})	20.89	12.19	–	18.46	11.94	–

The number of tillers per hill (at harvest) likewise did not vary significantly. Similar results were noted for number of panicles. Grain yield showed a slightly increasing trend because of flowing water in both years, but there was no statistical difference between the two years. Straw yields under both water management treatments were on a par. There was a considerable difference in the total quantity of water used in the two water management practices during the 70-d growth period of the crop in the main field. During the first and second year of the study, the water used with scientific management was only 56% and 60% of that used with farmer management, and, since no yield increase was observed, this additional input of water was simply wasted. The farmers realized that they could have used this precious irrigation water to bring about a considerable area under cultivation. Water-use efficiency in both years was also considerably lower under the farmers' practice: 12 and 12 vs 21 and 18 kg ha cm^{-1}.

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