Long-term Nutrient Management for Sustaining Rice and Wheat Yields in Rice-Wheat Systems

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Abstract

An experiment was initiated in November 1991 at Dinajpur, Bangladesh with organic and inorganic fertilization integrated over a sequence of three crops per year. The experiment is being conducted to determine the relationship of nutrient import and export through three crop sequence, to estimate soil nutrient balances over time in different rice-wheat systems and to determine management strategies of organic and inorganic fertilizers for long-term productivity of rice-wheat systems. The experiment included transplanted *aus* (spring) rice (BR 21), transplanted *aman* (summer) rice (BR 11), wheat (Kanchan), and jute (Falguni Tosa) varieties for long-term yield trends.

During the last 4 cycles, the yields of *aus* and *aman* rice showed increase of 20% yr^{-1}, whereas yields of wheat for the last 4 seasons were variable (excluding the first crop). Overall grain production for different fertilizer treatments increased by 3–24% for the 3 cycles. The highest yield increase was under the treatment one, where all nutrient elements were applied at recommended rate. Considering the nutrient import and export, all treatments had negative balances for nitrogen (assuming 35% use efficiency) and potash (except treatment T1 and T2). Phosphate balances were positive considering no loss of applied phosphate. This was also reflected in soil analysis data after two complete cropping cycles.

Introduction

Rice (*Oryza sativa* L.), a major staple food, covers almost 80% of the total cultivated area. The second staple food is wheat (*Triticum aestivum* L.) and it follows rice in rotation. Rice-wheat crop sequence has become the major cropping system in Bangladesh. To meet an increasing demand of food for the ever increasing population of the country, the sustainability of the system productivity of these two staples has become inevitable. The long-term rice-wheat system research would determine nutritional requirements of both rice and wheat and soil fertility issues for sustainability of the system productivity over time.

Expanding irrigation facilities have increased the cropping intensity. Increased cropping intensity demands an increased use of fertilizer inputs. However, survey data of farmers' fields (Ahmed and Elias 1986; Badaruddin 1989; Saunders 1990) indicated that amounts of applied nutrients [especially nitrogen (N), phosphorus (P), and potassium (K)] were lower than those of the requirement. Since fuel and fodder are becoming more costly, crop residues are collected from the fields, leaving little behind for incorporation into the soil. As a result, deficiency symptoms have become progressively

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Badaruddin, M., Razzaque, M.A., Meisner, C.A. and **Razu, R.A.** 2000. Long-term Nutrient Management for Sustaining Rice and Wheat Yields in Rice-Wheat Systems. Page 56–62 *in* Long-term Soil Fertility Experiments in Rice-Wheat Cropping Systems (Abrol, I.P., Bronson, K. F., Duxbury, J. M. and Gupta, R. K. eds.). Rice-Wheat Consortium Paper Series 6. New Delhi, India: Rice-Wheat Consortium for the Indo-Gangetic Plains.

prominent in crops for both major and micronutrients in rice-wheat areas.

Abedin and Mukhopadhyay (1990) reported that system productivity in a wheat-rice-rice system did not decline when recommended doses of N, P, K, sulfur (S), and zinc (Zn) were applied to wheat and when P and K rates were reduced to half for subsequent rice crops in Ishurdi and Jamalpur areas of Bangladesh. In a wheat-mung bean [*Vigna riadiata* (L.) Wilczek]- T. (transplanted) *aman* (summer) rice system, Abedin and Mukhopadhyay (1990) reported that the total wheat and rice yields were similar during 3 years when grown after a well-fertilized wheat (recommended N, P, K, S, and Zn) and T. aman rice and mung bean were grown with 50% rate of P and K. The soil nutrient balance after 3 cycles showed negative balance for N and K and positive balance for P when application exceeded 110 kg P_2O_5 ha^{-1} (Abedin and Mukhopadhyay 1990).

Based on the results reviewed in literature, an experiment was initiated at the Wheat Research Centre in Nashipur, Bangladesh to determine how long the recommended fertilizers could maintain the potential high yields of the crops grown in different sequences, estimate soil nutrient balance over time in different systems, and determine management strategies of organic and inorganic fertilizers for long-term sustainability of rice-wheat productivity.

Materials and Methods

An organic and inorganic fertilization study integrated over a sequence of three crops per year planned for a 10-year duration was initiated during November 1991 with a wheat crop at Dinajpur, Bangladesh. The land was prepared with disc harrowing three times after the harvest of previous *aman* rice. *Aman* rice stubble (about 10–15 cm height) was incorporated into the soil during harrowing. Six crop sequences were included in this trial. The treatments were laid out in the field in 6 × 6 Latin square design. The unit plot size was 13 m × 16 m. The plots were made permanently for all crops included in the sequences. From the wheat season 1995/96 this design was changed to a randomized complete block keeping the same 6 fertilizer treatments in each block (previously treated as column) for each crop. So for three crops per year, 6 cropping sequences and fertilizer treatments remained same in each block (Table 1).

Table 1. Crop sequence and fertilizer treatments for long-term cropping system at Dinajpur, Bangladesh.

Treatment	Crop sequence	Fertilizer treatment	Farmyard manure ($t\ ha^{-1}$)
T1	*Aus* rice-*aman* rice-wheat	As soil test recommendation, for each crop	0
T2	*Aus* rice-*aman* rice-wheat	As T1, except N and K at 150% of the recommendation	0
T3	*Aus* rice-*aman* rice-wheat	As T1	10
T4	*Aus* rice-*aman* rice-wheat	As T3, except N at 150% of the recommendation	10
T5	Jute-*aman* rice–wheat	As in T1	10
T6	Green manure (*Sesbania*)–*aman* rice-wheat	As in T1	0

Fertilizer rates were adjusted for low soil test value and high yield (> 4 t ha^{-1}) (BARC 1988). Therefore, the rates of fertilizers were different for different crops. The rates of all the fertilizers were not changed during the last 4 cycles. The rates will remain same until the soil test value for each fertilizer will change from low to medium or high value. Nitrogen, P, K, S, Zn, and boron (B) were applied from urea, triple superphosphate, muriate of potash, gypsum, zinc sulfate, and borax respectively. Two-third (for wheat) or one-third [for rice or jute (*Corchorus capsularis* L.)] of urea and full amount of other fertilizers were broadcast and incorporated before seeding or transplanting. The remaining one-third of urea was top dressed after the first irrigation at crown-root initiation for wheat. For rice and jute the remaining two-third of urea was top dressed at 20 days and 35 days after planting, respectively.

Wheat was planted with a Wintersteiger plot seeder in rows. The seeder was adjusted to use 120–130 kg seed ha^{-1}. Prior to seeding, the seed was treated with Vitavax-200®. For both *aus* (spring) rice (April to June) and *aman* rice (July/August to November) about 1-month-old seedlings were transplanted by hand. Two to three seedlings were used per hill. Jute and *Sesbania aculeata* Poir. were planted in rows 25–30 cm apart by hand. The varieties used for the sequences were Kanchan (wheat), BR 26 (*aus* rice), Falguni Tosa (jute), and BR 11 (*aman* rice). *Sesbania* was used as green manure.

All fields were weeded once between 25 days and 30 days after planting. However, *aman* rice, jute, and *Sesbania* fields were weeded twice between 25 and 30 days and 40 and 45 days after planting by hand. Wheat crop was harvested using a Wintersteiger plot combine harvesting one section (6 rows) in the middle of each plot. In case of *aus* rice, *aman* rice, jute, and *Sesbania*, the middle 5 rows were harvested by hand. After harvest the grain was cleaned, dried, and yields were adjusted to 12% moisture level. For jute and *Sesbania*, only biomass yields were taken. Biomass yields were taken at 35 days and 70 days after planting or transplanting and at harvest for all crops and were sampled for chemical analysis. Biomass subsamples were ground and 250 g sample was saved. Soil samples were taken from 0–15, 15–30, 30–45, and 45–60 cm depth. Initial soil samples and samples after the second wheat crop were analyzed using standard analysis method. The nutrient balance was calculated using a standard value for wheat or *aman* rice yield of >3.5 t ha^{-1} and for *aus* rice of about 2 t ha^{-1} (BARC 1988). The soil analysis data are presented in Tables 2, 3, and 4.

Results and Discussion

Analyses of variance showed that grain yield of wheat did not vary significantly amongst treatments in any of the 4 cropping cycles. Mean

Table 2. Soil physical properties at the experimental site at Dinajpur, Bangladesh.

Soil depth (cm)	Bulk density (g cm^{-1})	Clay content (%)	Silt (%)	Sand (%)
0–15	1.66	23	53	24
15–30	1.66	28	48	24
30–45	1.58	30	48	22
45–60	1.62	28	46	26

Table 3. Soil chemical properties at the experimental site at Dinajpur, Bangladesh.

Soil depth (cm)	pH	Organic matter (%)	Ca	Mg	K	N	P	S	B	Cu	Fe	Mn	Zn
			(meq 100g^{-1})			(mg g^{-1})							
0–15	4.9	0.8	2.5	1.2	0.25	14	56	36	0.3	2	235	15	1
15–30	5.6	0.5	3.6	1.3	0.26	10	46	33	0.2	3	234	11	1
Critical level		2.0	2.0	0.8	0.20	75	14	14	0.2	1	10	5	2

Table 4. Soil chemical properties after a wheat crop in rice-wheat cropping systems at Dinajpur, Bangladesh during 1993.

Treatment[1]	Depth (cm)	pH	OM[2] (%)	Ca	K	NH_4-N	P	S	B	Cu	Zn
				(meq 100g^{-1})			(mg g^{-1})				
T1	0–15	5.8	1.2	3.6	0.58	41.7	40.0	24.0	0.20	4.5	Tr[3]
	15–30	5.9	1.0	3.0	0.48	49.3	27.0	23.8	0.16	4.0	Tr
T2	0–15	5.6	1.2	3.4	1.13	41.2	42.0	24.5	0.20	4.5	Tr
	15–30	5.8	1.1	3.9	0.40	46.8	27.7	23.5	0.22	3.8	Tr
T3	0–15	5.7	1.1	4.7	0.69	48.5	38.2	23.3	0.20	4.2	Tr
	15–30	6.0	1.1	3.1	0.44	52.2	30.0	21.0	0.15	3.8	Tr
T4	0–15	5.8	1.2	4.2	0.72	43.0	48.3	27.7	0.23	4.2	Tr
	15–30	5.9	1.1	2.9	0.50	51.2	20.3	24.8	0.22	3.3	Tr
T5	0–15	6.0	1.1	3.0	0.51	36.1	42.5	27.2	0.23	4.3	Tr
	15–30	5.9	1.1	2.8	0.42	50.3	30.0	22.5	0.15	3.3	Tr
T6	0–15	5.9	1.2	5.2	0.60	43.2	37.0	21.0	0.14	4.5	Tr
	15–30	5.9	1.1	3.0	0.54	49.5	31.2	28.3	0.12	2.8	Tr

1. Different fertilizer treatments and cropping sequences were tested (see Table 1).
2. OM=Organic matter.
3. Tr=Traces.

grain yield across fertilizer treatments varied from 3.99 t ha^{-1} in 1992 to 2.68 t ha^{-1} in 1996. The wheat crop in 1992 was the first crop in the sequence and was not subjected to intensive rice-wheat cropping sequence. Before setting up this experiment, normally one wheat crop per year was grown there. Thus, yield in that year may be ignored in developing wheat yield trend. The variation in yield in subsequent years might be due to variation in weather conditions.

Mean effect of fertilizer treatments over the years, although not significant, indicated that treatments T3, T4, and T5 [with 10 t ha^{-1} farmyard manure (FYM)] and T2 (high doses of N and K) appeared to have maintained high yields over the whole period. The results indicate that in an intensive cropping sequence, organic manure with recommended inorganic fertilizers and/or higher than recommended amounts of inorganic fertilizers are necessary to sustain high productivity of wheat in rice-wheat system.

Four transplanted *aus* (T. *aus*) rice crops were harvested during 1992–95. Grain yields of *aus* rice were similar each year by fertilizer treatments. However, mean grain yields increased by 23% per year on an average. Means of fertilizer treatments over the years were greater where 10 t ha^{-1} FYM was applied to wheat and/or where higher amount of N and K were applied. This again indicates that 10 t ha^{-1} FYM besides recommended N, P, K, and S maintained the increased yield trend of *aus* rice in the rice-wheat system.

Aman rice in 1995 was affected by flood; thus, it was not harvested. During 1992–94 fertilizer treatments did not have any significant influence of *aman* yields in any of the 3 cycles. However, mean yields across fertilizer treatments were about 23% more than the initial yield of rice *aman* in 1992. Although not significant, the positive effect of green manure was greater on *aman* than on *aus* rice or wheat in the system. Unlike wheat and *aus* rice, there was minimal or no benefit from FYM and/or high N for *aman* rice in the system.

All the fertilizer treatments increased total cereal grain production (rice + wheat) by 12–24% during the last 3 crop cycles except where jute and green manure crops were included in rotations (Table 5). Treatments T3, T4, and T2 showed high grain production in 1992. These treatments included 150% recommended N and/or recommended fertilizers with 10 t ha^{-1} FYM. These 3 treatments maintained high grain production during the 3-cycle period. This indicates that there may be a need of higher rates of nutrients than the present recommendation rates of nutrients for sustaining high yields in the rice-wheat system. There was no increase in grain production where jute and green manure were included in the sequence. Grain production was always higher where there were 3 crops in the rotation (rice + rice + wheat) compared with two grain crops in the rotation (rice + wheat + green manure/jute). These results corroborate those of Yang et al. (1989) and Soni and Sikarwar (1991). Yang et al. (1989) indicated that yields of 3 crops in a sequence were always greater than those of 2 crops in the sequence with higher rates of N fertilizer.

Total biomass yield at harvest during each crop cycle for fertilizer treatments was lower in 1992 than that in 1993 and 1994 (Table 6). Biomass yields were higher for treatments T2 and T4 than those of other treatments. These two treatments having high biomass production in the subsequent two years might be due to the application of higher N rate (150% of recommended N). Treatment T5 had the highest

Table 5. Total grain yield of rice and wheat in different treatments at Dinjapur, Bangladesh during 1992–94.

Treatment[1]	Grain yield (t ha^{-1})				
	1992	1993	1994	Mean	Increase (%)
T1	7.45	8.20	9.21	8.29	24
T2	8.46	8.57	9.44	8.82	12
T3	8.72	8.60	9.76	9.03	12
T4	8.56	8.87	9.72	9.05	14
T5	6.55	7.50	6.96	7.00	–
T6	7.44	6.92	7.33	7.23	–

1. See Table 1 for crop sequence and fertilizer treatment.

Table 6. Total biomass yields of crops in different sequences for fertilizer treatments at Dinajpur, Bangladesh during 1991–94.

Crop sequence[1]	Fertilizer treatment[2]	Biomass yield (t ha^{-1}) 1992	1993	1994
Aus rice-*aman* rice-wheat	T1	16.77	24.35	24.33
Aus rice-*aman* rice-wheat	T2	19.77	25.01	25.23
Aus rice-*aman* rice-wheat	T3	17.99	24.77	26.63
Aus rice-*aman* rice-wheat	T4	18.68	26.31	26.65
Jute-*aman* rice-wheat	T5	16.06	29.68	24.34
Green manure-*aman* rice-wheat	T6	16.64	22.67	24.37

1. *Sesbania* is used as green manure.
2. See Table 1 for treatment with inorganic fertilizers and farmyard manure.

biomass production in 1993, owing to unusually high biomass production of jute that year. Thus the highest biomass production that year was not associated with the effect of fertilizer treatments.

A nutrient balance sheet was calculated based on the total nutrient application and theoretical uptake by grain and straw for the cereal crops only (Table 7). No statistical analyses were made on this data. Nutrient loss through leaching, volatilization, fixation, and runoff was not included in this table. Nutrient balance data indicated that there would have been enough reserve of soil N and P by application of recommended rates of these elements. This also has been reflected in the soil analyses data after the second wheat crop (Table 4). The K balance was minimum or negative in the soil.

The trend of wheat, *aus* rice, and *aman* rice yields is still immature to draw any conclusion. The nutrient uptake by different crops and changes of soil parameters need more analysis for

Table 7. Total nitrogen (N), phosphorus (P), and potassium (K) balance in rice-wheat systems at Dinajpur, Bangladesh during 1991–94.

Treatment[1]	Nutrient (kg ha^{-1}) Applied N	Applied P_2O_5	Applied K_2O	Uptake[2] N	Uptake[2] P_2O_5	Uptake[2] K_2O	Balance N	Balance P_2O_5	Balance K_2O
T1	900	720	720	515	152	679	385	568	41
T2	1350	720	760	545	161	722	805	559	58
T3	900	720	720	563	166	740	337	554	–20
T4	1350	720	720	565	166	742	785	554	–22
T5	630	480	480	466	135	586	164	345	–106
T6	630	480	480	466	135	587	164	345	–107

1. See Table 1 for fertilizer treatment and crop sequence.
2. Theoretical calculation on above ground materials.

final assessment. Therefore the experiment needs to be continued for several more years.

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