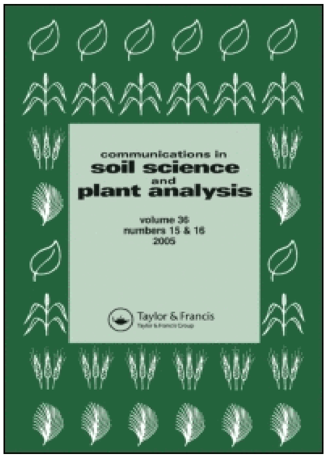

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Use of Farmers' Empirical Knowledge to Delineate Soil Fertility-Management Zones and Improved Nutrient-Management for Lowland Rice

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Use of Farmers' Empirical Knowledge to Delineate Soil Fertility-Management Zones and Improved Nutrient-Management for Lowland Rice

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Abstract: Development of a field-specific nutrient-management program with the use of farmers' empirical knowledge of soil-fertility is important for its adoption and to increase yield in farmers' fields. Using nutrient-management trials conducted in farmers' fields of three districts in Bangladesh, the objectives of this study were to (i) identify farmers' defined fertility-management zones (FMZ) at the village level, (ii) compare the farmers' perception of soil-fertility with the laboratory soil-test results, and (iii) compare an improved nutrient-management (INM) program (based on soil-test results of FMZs and farmers' opinion) with the farmers' practice (FP) of nutrient-management. Farmers of the participatory villages prepared soil-fertility maps for each village (100–200 ha) delineating three management zones—zone I (most fertile soil), zone II (medium fertile soils), and zone III (least fertile soils). Farmers were able to identify difference in soil between management zones through their empirical knowledge, such as soil color, texture, water-holding capacity, depth of plow, or presence of earthworms. Laboratory analyses of soil samples showed that the soil organic carbon (OC), total nitrogen (N) concentration, exchangeable calcium (Ca) and magnesium (Mg), available sulfur (S), and micronutrient concentration were higher in FMZ I and the least in zone III. In each management zone, the INM was compared with the FP. The INM programs, in most cases, consist of 11–71% greater dose of N, 6–100% higher dose of phosphorus (P), and 39–100% higher dose of potassium (K) fertilizers. The application of INM doses increased

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rice yield in all the participatory villages. The magnitude of yield increase with the INM doses varied from 4 to 63% in Aus (April–July), 9–52% in T. Aman (July–November), and 7–56% in Boro (December–May) seasons. The yield ranges of FP and INM were 2.03–3.68 and 2.80–4.56 t/ha in Aus, 2.34–3.80 and 3.21–4.44 t/ha in Aman, and 3.17–5.44 and 3.88–7.76 t/ha in Boro, respectively. The investigation informed the farmers of required fertilizer doses for the parcels of land of the specific management zone to achieve higher rice yield. The INM doses may be disseminated to the neighbor villages of similar topography and soil properties through farmer-to-farmer communications. However, cost of fertilizers and their availability in the villages may stand in the way for farmers to adopt INM.

Keywords: Farmers practice, improved nutrient-management, rice season, rice yield

INTRODUCTION

Integrated plant nutrient-management to provide balanced nutrition to rice plants is one of the important ways to increase rice yield in farmers' fields of Asia. Soil fertility, fertilizer use, and crop response to fertilizer application may vary among rice fields within smaller irrigated and rainfed environments (Cassman et al. 1996; Olk et al. 1999; Adhikari et al. 1999). Dobermann and White (1999) introduced the site-specific nutrient-management (SSNM) concept, which is dynamic, field-specific management of nutrients in a particular cropping season to optimize the supply and demand of nutrients according to their differences in cycling through soil–plant systems. The SSNM, in China, increased rice yield to 6.4 Mg ha^{-1} from the 5.9 Mg ha^{-1} obtained with the farmers' fertilizer practice (Wang et al. 2001). Compared with the farmers' nutrient-management practice, SSNM increased nutrient uptake, agronomic N-use efficiency, N-recovery efficiency, and profit (Wang et al. 2001). Fertilizer recommendation based on SSNM needs an accurate estimate of the indigenous nutrient supply (IS) of the soils. The indigenous supply of nutrients can be estimated from (i) soil-test results (Janssen et al. 1990) and (ii) omission plot technique (Witt et al. 2002; Dobermann et al. 2003a). However, spatial and temporal variation in soil-fertility and thus indigenous supply of nutrients is large within and among the irrigated rice domains (Dobermann et al. 2003b).

The spatial variability of soil-fertility when recommending fertilizer-management may be helped by a soil-fertility-management map (Pierce and Nowak 1999). Ping and Dobermann (2003) demonstrated spatially contiguous yield classes for site-specific management. Soil-fertility-condition maps and fertilizer-management maps can be created from grid data or grid-cell data using combinations of geostatistical tools, mathematical interpolations, and graphical procedures (Wollenhaupt, Mulla, and Crawford 1997). The quality of the maps for site-specific fertility management depends on variability within zones, which can be improved by increasing intensity of sampling (Mueller et al. 2001). Besides grid and grid-cell sampling, a management zone approach has been used for obtaining soil-nutrient spatial information (Fleming, Westfall, and Busch 2000). Dobermann et al. (2003c) classified crop yield variability in irrigated fields of China. Development of management zones should consider both soil-nutrient variability and yield variability. Chang et al. (2003) compared several methods of the management zone delineation approach and determined that a 4-ha grid-cell sampling and detail soil survey map gave the lower within-zone yield variability. Scharf et al. (2005) suggested a management zone of 1 ha or less for nitrogen (N) in corn fertilization. The site-specific management zones accurately characterized variability in N uptake and grain yield response to applied N fertilizer in corn (Inman et al. 2005).

In Asian countries such as Bangladesh, India, Thailand, or Nepal, fertilizer recommendations are given for an agro-ecological region with little differentiation according to field-specific information. However, smaller individual plot sizes and management differences between farmers within a short distance (less than 100 m) limits the application of grid or grid-cell map methods in many Asian countries. Because of limited access to soil-testing services and small land parcels (0.1–0.3 ha), fertilizer recommendations based on soil-test results are not yet practical in the farmers' fields. However, farmers have their own conceptions about soil-fertility, and they change constantly, taking into account the factors that impede or favor crop performance, such as plot age, location, previous fertilizer use, weed infestation, and pest buildup (Sikana 1994).

With trial and error and experience, farmers generally know which area of a field is more productive than other areas and accordingly assess nutrient needs for different parts of a field. Smallholders in Kenya and other East African countries recognized various categories of soil-fertility upon which subsequent management decisions were made (Murage et al. 2000). Understanding farmers' empirical knowledge of soil-fertility, describing them, and disseminating them to other farmers would be a cost-effective soil-fertility-management program, especially for the resource-poor farmers in developing countries where soil-testing services are limited. However, farmers' empirical perception of the effect of spatial variability in soil-fertility on crop production and nutrient-management may be useful in quantifying and managing spatial variability (Fleming, Westfall, and Busch 2000; Khosla et al. 2002; Koch et al. 2004). Recently, Hornung et al. (2006) reported that soil-color-based management zones, which considers farmers' perception of field topography, past crop, and soil-management experience, was better than yield-based management zones for fertilizer recommendation. However, Asian farmers' perceptions of soil-fertility are not well recognized. It was hypothesized by appraising farmers' knowledge about the fertility variation at village levels, that improved nutrient-management programs can be developed for farmers' defined specific management zones and each village can be delineated in the form of village-level soil-fertility maps. The objectives of the present investigation were to (i) assess the ability of farmers to recognize spatial variability in soil-fertility in their rice fields, (ii) compare the farmers' perception of soil-fertility with the laboratory soil-test results, and (iii) identify farmer-defined fertilizer management zones (FMZ) in villages and develop fertilizer recommendations for rice on an FMZ basis.

MATERIALS AND METHODS

Farmers' Management Zone Map

Farmers' experience of soil-fertility evaluation was assessed through participatory rural appraisal (PRA). Twelve villages from the upazilla of (1) Sreemangal and (2) Kamalganj from Moulovibazar district and (3) Chunarughat from Habiganj district were selected randomly based on the intensity of rice farming and easy communication. In each village, 20 farmers were selected randomly from the group who has rice provision for 4 to 8 months per year. Group meetings were held with the participating farmers. The villagers were asked to provide information on village boundaries; rice yield in different types of the fields in the village; rice variety grown in April–July (Aus), July–November (Aman), and December–May (Boro); fertilizer use in different seasons; and variety use.

The participating farmers drew a village map, delineating crop fields and uncultivable area. After the village map was completed, participating farmers drew a field map, and we facilitated the drawing of subfield boundaries. Each of the subfields was composed of several individual plots. Farmers put the local name of each subfields. On the field map, the participating farmers recognized management zones according to the fertility level of all the subfields, although the area of each of the subfield was about 20 to 30 ha and area of the entire field of a village was 100 to 200 ha. Farmers divided the entire field into three classes of fertility zones based on yield history, and they marked the highest fertile soil as I, the next one as II, and the least fertile as III. Eventually, farmers' defined FMZ map was created in 12 villages through the active participation of the farmers.

Soil Analysis

Soil samples (2–3 subsamples from each management zone from 0–15 cm deep) were collected in January 2002 from 12 villages with the active participation of the villagers following the FMZ map prepared by the farmers. Soil samples covered each of the subfields and soil management zone. Soil samples were analyzed for water pH (1:2.0 w:v, soil–water) (McLean 1982); organic carbon (OC) (Nelson and Sommers 1982); Kjehldal N (Keeney and Nelson 1982); available phosphorus (P) (Bray and Kurtz 1945); exchangeable potassium (K), calcium (Ca), and magnesium (Mg) (Chapman 1965); and available sulfur (S), iron (Fe), manganese (Mn), copper (Cu), and zinc (Zn) (PCARR 1978).

Nutrient-Management Programs

Rice crops were grown in Aus (April–July), Aman (July–November), and Boro (December–May) in 2002 and 2003. Aus and Aman seasons are rainy seasons, and Boro is a dry season. Both Aus and Aman crops were grown on the same fields in consecutive seasons, but the Boro crop was grown in separate fields. Two nutrient-management plans were tested in three FMZs of each village. One of the plans was farmers' practice (FP), which was farmers' traditional nutrient-management program; another one was improved nutrient-management plan (INM), nutrient required for rice based on soil-test results and decided with the involvement of farmers so that farmers were aware of the nutrient doses for the specific management zone. The nutrient doses in FP varied from place to place and between FMZs within a site. The main difference in fertilizer rate was observed with N; N rates between FMZs were in the ranges of 4–10 kg N ha^{-1} in Aus (Table 1), 10–21 kg ha^{-1} in Aman (Table 2), and 22–52 kg ha^{-1} in Boro (Table 3). Most of the farmers did not apply P and K fertilizers for rice crop, although the soils were deficient in P and K in general, because they were not aware of the benefit of P and K fertilizers and deficiency symptoms of P and K were not as visible as that of N to the farmers. The variability in N doses in INM between FMZs ranged from 8 to 19 kg ha^{-1} in Aus, 5 to 14 kg ha^{-1} in Aman, and 11 to 49 kg ha^{-1} in Boro season; the variability in P doses was 3–4 kg ha^{-1} and that in K doses was 10–15 kg ha^{-1}.

Crops and Variety

Popular rice (*Oryza sativa* L.) varieties in each site were grown in several farmers' fields, representing three FMZs. In Aus season the varieties were 532, Arai IRRI, and Chandina. In Aman only BR11 and in Boro BRRI Dhan28 and BRRI dhan29 were grown. All the varieties were modern rice, and the same variety was grown in both FP and INM plots of the same farmers; however, varieties varied between farmers. Within each FMZ, a piece of land of 500–700 m^2 area was divided into two equal halves, one for FP and the other for INM. Farmer-grown rice seedlings were transplanted, and the age of seedling was 25–30 days for Aus, 30–35 days for Aman, and 45–50 days for Boro. The participatory farmers conducted all the field operations, and we only provided the required fertilizers for the INM treatment. Farmers were actively involved in the trial, including collecting plant height, tiller and panicle count (data not shown), and yield.

Table 1. Fertilizer use in farmers' practice (FP) and improved nutrient-management (INM) plans in Aus (April–July) rice grown in farmers' fields at four locations at three farmers' defined fertility-management zones

Fertility zone[a]	Cow dung (t/ha)		N^b (kg/ha)		P^b (kg/ha)		K^b (kg/ha)	
	FP	INM	FP	INM	FP	INM	FP	INM
Sreemangal								
Zone I	10	9	27	53	6	14	3	50
Zone II	10	7	38	72	4	17	10	50
Zone III	10	9	37	66	1	18	0	53
Kamalganj								
Zone I	0	0	29	70	6	17	0	50
Zone II	2	0	33	78	4	17	0	58
Zone III	3	0	29	75	3	18	3	60
Chunarughat								
Zone I	7	4	58	65	8	14	3	35
Zone II	8	4	49	69	7	15	3	33
Zone III	11	0	43	58	0	12	0	35
Moulovibazar								
Zone I	12	10	37	67	0	15	0	50
Zone II	14	10	41	62	0	18	0	43
Zone III	10	10	45	71	0	21	0	50

[a]Zone I refers to the most fertile zone, zone II refers to medium fertile zone, and zone III refers to the least fertile zone.
[b]N was applied from urea, P from tripple super phosphate, and K from muriate of potash.

Field Days and Village Workshops

Field days were conducted during the growing seasons where the participatory farmers and their neighbors attended. All the participants observed the differences in crop growth between FP and INM. In most cases, the plants in INM plots produced more tiller and were taller than the FP plots. The participants had interactions with the participatory farmers (owner of the trial plot), and we also took part in the discussion just to facilitate continuing discussions.

Immediately after harvest, workshops were conducted in all the experimental villages. The participants in each of the workshop were 25–30, where 8–10 were participatory farmers who conducted the trials and the rest were non participatory farmers interested to know about the better-looking crops in the INM plots. The participatory farmers presented their results in the workshop with simple economic analysis explaining how much they spent for additional fertilizer and how much they earned through extra harvest.

Table 2. Fertilizer use in farmers' practice (FP) and improved nutrient-management (INM) plans in Aman (July–November) rice grown in farmers' fields at three locations at three farmers' defined fertility zones

Fertility zone[a]	N^b (kg/ha)		P^b (kg/ha)		K^b (kg/ha)	
	FP	INM	FP	INM	FP	INM
Sreemangal						
Zone I	37	80	3	22	5	69
Zone II	35	75	2	21	10	66
Zone III	47	66	5	18	28	47
Kamalganj						
Zone I	62	98	7	23	40	66
Zone II	70	103	15	23	0	67
Zone III	60	101	3	24	13	67
Chunarughat						
Zone I	47	99	6	22	8	67
Zone II	65	100	12	23	23	65
Zone III	68	112	9	24	20	66

[a]Zone I refers to the highest fertile zone, zone II refers to medium fertile zone, and zone III refers to the least fertile zone.

[b]N was applied from urea, P from tripple super phosphate, and K from muriate of potash.

Data Analysis

Statistical analysis was performed using IRRISTAT 4.1 on yield data. Within a location, each farmer's field was considered as one replication. Because the number of replications for each management zone was not same, the grain yield differences between management zones were analyzed using a fixed-effect, two-factor nested design analysis of variance (ANOVA) in which treatments were nested within management zones. The mean separations between treatments and management zones were performed using least square difference (LSD) at ($P < 0.05$), only when ANOVA was found significant ($P < 0.05$).

RESULTS AND DISCUSSION

Farmers' Empirical Knowledge of Soil Properties

Farmers demonstrated indigenous technical knowledge (ITK) to classify soil-fertility (Tables 4–6). Those indigenous diagnostic tools for soil-fertility evaluation includes soil color, organic matter content, soil texture, plow depth, footmark depth, water-holding capacity, presence of earthworms, and

Table 3. Fertilizer use in farmers' practice (FP) and improved nutrient-management (INM) plans in Boro (December–May) rice grown in farmers' fields at five locations at three farmers' defined fertility zones

Fertility zone[a]	N^b (kg/ha) FP	N^b (kg/ha) INM	P^b (kg/ha) FP	P^b (kg/ha) INM	K^b (kg/ha) FP	K^b (kg/ha) INM
Sreemangal						
Zone I	49	70	4	19	7	58
Zone II	32	90	4	16	8	59
Zone III	57	92	5	18	16	62
Kamalganj						
Zone I	74	138	15	18	0	58
Zone II	76	149	14	19	19	61
Chunarughat						
Zone I	135	170	25	15	0	59
Zone II	111	173	14	16	11	61
Zone III	125	161	23	17	8	61
Madhabpur						
Zone I	128	118	9	15	0	60
Zone II	108	151	14	16	11	63
Zone III	106	158	12	17	4	62
Bahubal						
Zone I	72	118	17	18	0	47
Zone II	100	141	27	17	0	46
Zone III	48	167	22	18	0	50

[a]Zone I refers to the highest fertile zone, zone II refers to medium fertile zone, and zone III refers to the least fertile zone.

[b]N was applied from urea, P from tripple super phosphate, and K from muriate of potash.

soil odor. In Sreemangal areas, the rice yield in the wet season in management zones I, II, and III were 4.0–4.5, 3.0–4.0, and 2.5–3.0 t ha^{-1}, respectively. Soils of the three categories had contrasting colors—zone I soils were black to brown when wet, whereas the zone III soils were pale reddish to reddish. Farmers differentiated three soils also by touching wet soil with their fingers. The soil samples from the field of zone I seemed to be smooth, whereas that in zone II field was coarser, and there was sandy feeling in the zone III soils. The farmers evaluated water-holding capacity of the soil through the period by the presence of standing water after rain or application of irrigation water. Water-holding capacity of the soils of management zone I was higher than that in zone II or zone III soils. It certainly due to the lower percolation rate in zone I than others. Effective rooting depth in zone I soil was deeper than in zone II and III soils. In response to the question of subsurface soils and earthworm population, farmers mentioned that there was field-to-field variation in the color of subsurface soils and presence of earthworm

Table 4. Farmers' diagnostic tools to characterize soil of different fertility-management zones in Sreemangal, Moulovibazar, Bangladesh[a]

	Fertility-management zone		
Characteristics	Zone I	Zone II	Zone III
Yield (t ha^{-1})	Highest yield	Medium	Lowest
Color	Black to brown	Grey to grayish black	Reddish or whitish
Texture	Clayey to silty clay	Sandy loam to loam	Sandy
Standing water remains in rice field after irrigation or rain (days)	5–6	3–4	<2
Plow depth (cm)	25–30	15–23	<15
Puddling and transplanting	Puddling is easy and easy to transplant	Puddling and transplanting is easier than in zone III	Laborious to puddle and transplanting
Earthworm population after rice harvest	Many	Less	Few
Mole cricket in dry soil	Not observed	Seldom	Frequent
Subsurface soil	Hard red soil is observed in subsurface soil	Reddish sandy soil with some hard granules is observed	Hard granules are observed under 6–12 inches of soil

[a]Data were collected through farmers' survey.

Table 5. Farmers' diagnostic tools to characterize soil of different fertility-management zones in Kamalganj, Moulovibazar, and Bangladesh[a]

	Fertility-management zone		
Characteristics	Zone I	Zone II	Zone III
Yield (t ha^{-1})	4.00–4.30	3.07–3.60	2.77–3.07
Color	Dark brown	Light brown	Light red
Texture	Clay	Loam	Sandy
Standing water remains in rice field after irrigation or rain (days)	7–10	5–7	4–5
Plow depth (cm)	18–20	13–15	8–10
Puddling and transplanting	Easy	Medium	Difficult
Subsurface soil	Yellowish-red soil	Yellowish-red soil	Yellowish-red soil

[a]Data were collected through farmers' survey.

Table 6. Farmers' diagnostic tools to characterize soil of different fertility-management zones in Chunarughat, Habiganj, Bangladesh[a]

Characteristics	Fertility-management zone		
	Zone I	Zone II	Zone III
Yield (t ha^{-1})	3.0–4.0	2.5–3.0	1.5–2.0
Color	Brownish	Light red	Light red
Texture	75–80% fine grain	60% fine grain	75–80% coarse grain
Standing water remains in rice field after irrigation or rain (days)	10	7	3–4
Plow depth (cm)	18–23	15–20	12–15
Puddling and transplanting	Easy	Medium	Difficult
Subsurface soil	Hard and red	Whitish	Red sand

[a]Data were collected through farmers' survey.

after rice harvest. Some farmers mentioned that the soils of management zone I had a characteristic odor after irrigation.

Farmers of Kamalganj and Chunarughat upazillas indicated that variation in yield, soil color, water-holding capacity, ease of plowing, and hardness of subsoil among three FMZs. In Kamalganj, farmers mentioned that the rice yield in management zone I was 4.00–4.30 t ha^{-1} whereas that in management zone III was 2.77–3.07 t ha^{-1} (Table 5). Color of the surface soil was reported as dark brown, light brown, and light red for management zones I, II, and III, respectively. In Chunarughat, rice yield in management zone I was reported to be 3.0–4.0 t ha^{-1}, whereas that in zone III was 1.5–2.0 t ha^{-1} (Table 6). Management zone I soil was brownish; zones II and III had light red color. Farmers also mentioned that the zone III soil is underlain by red sand, which contributed to easy percolation of rain and irrigation water.

Farmers' experience of soil-fertility variations within a village would have great value in the crop and soil research, especially in the densely populated countries such as Bangladesh. Site-specific management zones have the potential to be an effective alternative to grid soil sampling for quantifying and managing spatial variability for fertilizer recommendation (Fleming, Westfall, and Busch 2000; Khosla et al. 2002). Because of land fragmentation for ownership and efficient water-management, most pieces of land in Asian rice fields are a size of less than 0.1 ha. Differential nutrient-management by the owners and fertility differences due to microtopography among plots made it difficult to prescribe a uniform rate of fertilizer for a wider area without consulting with the farmers. Therefore, farmers experience may be utilized to prepare village-level soil-fertility maps as an aid to decide site-specific nutrient-management in the village.

A national soil map has broad scale of 1:50,000, which is too large to recognize soil-fertility difference within a village of 100–200 ha. Farmers do not apply uniform fertilizers in all the plots of a national map unit because of different productivity, but the farmers expect uniform yield from all the plots. The national soil map cannot recognize this productivity difference with such small area of a village, which can be eliminated in the village-level farmers' management-zone map.

Comparison of Soil-Test Results with the Farmers' Soil-Management Zone

Most of the soil-test results were consistent with the farmers' category of soil-management zone. In Sreemangal, soil pH values in zones I, II, and III soils were 5.88, 5.87, and 5.99, respectively (Table 7). Difference in pHs among three sites was not significant. Soil organic C content and Kjeldahl N content of soil across the FMZ was consistent with the FMZ. In management zone I, organic C and total N were 21.2 and 2.0 g kg^{-1} compared with 16.6 and

Table 7. Soil properties determined by chemical/physical laboratory analyses in different farmers' defined fertility-management zones: Sreemangal, Moulovibazar, Bangladesh

	Fertility-management zone		
Soil properties	Zone I[a]	Zone II[b]	Zone III[c]
pH[d]	5.88 ± 0.07	5.87 ± 0.06	5.90 ± 0.04
Organic C (g kg^{-1})	21.2 ± 1.9	16.6 ± 0.8	14.5 ± 1.0
Kjeldahl N (g kg^{-1})	2.0 ± 0.3	1.3 ± 0.1	1.2 ± 0.1
Avail. P (mg g^{-1})	6 ± 3	6 ± 1	7 ± 2
Exch. K (cmol kg^{-1})	0.06 ± 0.01	0.07 ± 0.01	0.09 ± 0.01
Exch. Ca (cmol kg^{-1})	3.08 ± 0.30	2.34 ± 0.16	1.98 ± 0.18
Exch. Mg (cmol kg^{-1})	0.90 ± 0.18	0.56 ± 0.06	0.44 ± 0.08
Avail. S (mg g^{-1})	27 ± 7	19 ± 2	17 ± 2
Avail. Cu (mg g^{-1})	2.4 ± 0.2	2.9 ± 0.2	2.6 ± 0.3
Avail. Fe (mg g^{-1})	202 ± 21	176 ± 15	163 ± 17
Avail. Mn (mg g^{-1})	32 ± 6	22 ± 3	19 ± 4
Avail. Zn (mg g^{-1})	3.4 ± 0.6	2.8 ± 0.3	2.3 ± 0.3

[a]Each value is mean of 16 observations.

[b]Mean of 40 observations.

[c]Mean of 17 observations, ± standard error (SE) of means.

[d]pH (1:2 w:v soil–water) (McLean 1982); organic carbon (Nelson and Sommers 1982); Kjehldal N (Keeney and Nelson 1982); available P (Bray and Kurtz 1945); exchangeable K, Ca, and Mg (Chapman 1965); and available S, Fe, Mn, Cu, and Zn (PCARR 1978).

1.3 g kg^{-1} in zone II and 14.5 and 1.2 g kg^{-1} in zone III, respectively. Similar consistency of soil organic C and total N with the farmers' defined category of soil-fertility was observed in Kamalganj (Table 8) and Chunarughat (Table 9). However, in each zone, soil organic C and total N in Sreemangal soils were higher than in Kamalganj and Chunarughat. Although soil organic C and total N in management zone I of Kamalganj and Chunarughat soil were greater than those of the zones II and III of respective sites, the difference between them was not as large as was observed in the Sreemangal site.

Exchangeable K content in all the three soils was low (0.06–0.11 cmol kg^{-1}). Critical level of exchangeable K for rice in Bangladesh was established as 0.08 cmol kg^{-1} (Saleque et al. 1990). In the Sreemangal site, exchangeable K values in zones I, II, and III were 0.06, 0.07, and 0.09 cmol kg^{-1}, respectively. In Kamalganj, zone I had 0.10 cmol kg^{-1}, which was slightly lower (0.09 cmol kg^{-1}) in zone II, and zone III showed the lowest exchangeable K (0.08 cmol kg^{-1}). There was no difference in exchangeable K between farmers' defined soil categories in the Kamalganj site, and all three management zone had exchangeable K of 0.11 cmol kg^{-1}.

Soil-test values of Ca, Mg, Cu, Fe, Mn, and Zn showed some degree of agreement with the farmers' category of soil-fertility. Soils in the Sreemangal

Table 8. Soil properties in farmers' defined different fertility-management zones: Kamalganj, Moulovibazar, Bangladesh

	Fertility-management zone		
Soil properties	Zone I[a]	Zone II[b]	Zone III[c]
pH[d]	4.70 ± 0.04	4.77 ± 0.05	4.74 ± 0.07
Organic C (g kg^{-1})	10.9 ± 0.5	10.2 ± 0.6	9.0 ± 0.6
Kjeldahl N (g kg^{-1})	1.1 ± 0.1	1.0 ± 0.1	1.0 ± 0.01
Avail. P (mg g^{-1})	3 ± 0.3	3 ± 0.5	5 ± 1
Exch. K (cmol kg^{-1})	0.10 ± 0.01	0.09 ± 0.01	0.08 ± 0.01
Exch. Ca (cmol kg^{-1})	4.04 ± 0.34	3.24 ± 0.30	2.44 ± 0.22
Exch. Mg (cmol kg^{-1})	3.30 ± 0.26	2.66 ± 0.44	1.62 ± 0.12
Avail. S (mg g^{-1})	20 ± 2	17 ± 2	15 ± 3
Avail. Cu (mg g^{-1})	2.8 ± 0.2	2.2 ± 0.2	1.5 ± 0.2
Avail. Fe (mg g^{-1})	232 ± 22	178 ± 17	144 ± 10
Avail. Mn (mg g^{-1})	51 ± 5	46 ± 6	30 ± 5
Avail. Zn (mg g^{-1})	1.8 ± 0.2	1.2 ± 0.1	1.3 ± 0.1

[a]Each value is mean of 22 observations.

[b]Mean of 17 observations.

[c]Mean of 18 observations, ± SE of means.

[d]pH (1:2 w:v soil–water) (McLean 1982); organic carbon (Nelson and Sommers 1982), Kjehldal N (Keeney and Nelson 1982); available P (Bray and Kurtz 1945); exchangeable K, Ca, and Mg (Chapman 1965); available S, Fe, Mn, Cu, and Zn (PCARR 1978).

Table 9. Soil properties in farmers' defined different fertility-management zones: Chunarughat, Habiganj, Bangladesh

	Fertility-management zone		
Soil properties	Zone I[a]	Zone II[b]	Zone III[c]
pH[d]	5.21 ± 0.04	5.12 ± 0.03	5.20 ± 0.04
Organic C (g kg^{-1})	9.6 ± 0.4	8.1 ± 0.4	7.6 ± 0.03
Kjeldahl N (g kg^{-1})	1.1 ± 0.0	0.9 ± 0.0	0.9 ± 0.0
Avail. P (mg g^{-1})	4 ± 1	3 ± 0.3	3 ± 0.6
Exch. K (cmol kg^{-1})	0.11 ± 0.00	0.11 ± 0.00	0.11 ± 0.00
Exch. Ca (cmol kg^{-1})	6.46 ± 0.10	6.16 ± 0.20	5.96 ± 0.26
Exch. Mg (cmol kg^{-1})	3.10 ± 0.11	2.86 ± 0.12	2.71 ± 0.13
Avail. S (mg g^{-1})	12 ± 0.7	13 ± 0.6	15 ± 0.9
Avail. Cu (mg g^{-1})	3.8 ± 0.1	2.6 ± 0.1	2.6 ± 0.1
Avail. Fe (mg g^{-1})	170 ± 10	162 ± 7	158 ± 10
Avail. Mn (mg g^{-1})	110 ± 5	91 ± 4	79 ± 4
Avail. Zn (mg g^{-1})	2 ± 0.1	2 ± 0.1	2 ± 0.1

[a]Each value is mean of 38 observations.
[b]Mean of 68 observations.
[c]Mean of 42 observations, ± SE of means.
[d]pH (1:2 w:v soil–water) (McLean 1982); organic carbon (Nelson and Sommers 1982); Kjehldal N (Keeney and Nelson 1982); available P (Bray and Kurtz 1945); exchangeable K, Ca, and Mg (Chapman 1965); available S, Fe, Mn, Cu, and Zn (PCARR 1978).

site were deficient in Ca and Mg, but the degree of deficiency was more in zones II and III than in zone I (Table 7). The exchangeable Ca and Mg in zone I were 3.08 and 0.90 cmol kg^{-1}, respectively, but these values in zones II and III were 2.34 and 0.56, and 1.98 and 0.44 cmol kg^{-1}, respectively. Critical levels of Ca and Mg are considered as 4.0 and 1.6 cmol kg^{-1}, respectively. In Kamalganj, Ca concentration in the management zone I was 4.04 cmol kg^{-1}, which is marginally deficient, but in management zones II and III, the exchangeable Ca was lower: 3.12 and 2.44 cmol kg^{-1}, respectively (Table 8). The Ca concentration in Chunarughat soil was not deficient in zones I and II, but in zone III it was very close to the critical level (Table 9). Magnesium concentration in Chunarughat soil was greater than the critical level.

Available S was greater than the critical level in all the three sites. In Sreemangal and Kamalganj, the S was higher in management zone I and the lowest in management zone III, but in Chunarughat, the farmers' category of soil-fertility did not match with the soil S concentration. Micronutrients (Cu, Fe, Mn, and Zn) were not deficient in soils of the three sites; however, their values were higher in management zone I followed by zones II and III. Because of the long experience of farmers in specific villages, they became familiar with the fertility status of soil across the area.

Nutrient-Management and Rice Yield

Aus Rice

In Sreemangal, the mean yields in the FP plots in management zones I, II, and III were 3.47, 2.74, and 2.45 t/ha, respectively. The yield in zone I was significantly higher than that of zones II ($P < 0.05$) and III; however, the difference in yield between zones II and III was not significant (Table 10). The application of INM doses gave significant ($P < 0.05$) yield increase in all three fertility-zone soils, but the yield difference between management zones in the INM treatment was not significant in the Sreemangal site. In management zone I, the yield increase due to INM was about 9% over the FP, and in zones II and III it was 25 and 43%, respectively. The Aus (variety Chandina) yield in Chunarughat ranged from 3.06 to 3.47 t/ha in FP plots and from 3.41 to 4.56 t/ha in INM

Table 10. Effect of improved nutrient-management program (INM) compared to farmers' nutrient-management (FP) on the yield of Aus (April–July) rice in farmers' fields of Piedmont soils

Fertility-management zone[a]	No. of observations	Grain yield (t/ha)[b]		Increase (%)[c]
		FP	INM	
Sreemangal (Var. 532) 2003				
Zone I	6	3.47	3.76	9*
Zone II	11	2.74	3.43	25*
Zone III	15	2.45	3.50	43*
$LSD_{0.05}$		0.39	0.39	
Kamalganj (Var. Arai IRRI)				
Zone I	2	2.66	3.78	42*
Zone II	20	2.55	4.17	63*
Zone III	6	2.03	2.80	38*
$LSD_{0.05}$		0.44	0.44	
Chunarughat (Chandina)				
Zone I	13	3.47	4.56	31*
Zone II	21	3.47	4.10	18*
Zone III	2	3.06	3.41	11*
$LSD_{0.05}$		0.40	0.40	
Moulovibazar (Var. 532)				
Zone I	1	3.68	3.81	4 NS
Zone II	3	3.05	3.80	25*
Zone III	1	2.95	3.18	8 NS
$LSD_{0.05}$		NS	NS	

[a]Zone I is the most fertile, zone II is medium fertile, and zone III is least fertile soils.
[b]FP = farmers' fertilizer dose, INM = improved fertilizer dose.
[c]NS indicates not significant and * indicates significant at 5% level of LSD.

plots (Table 10); the yield difference between management zones was significant in both cases of FP and INM treatment. The mean yield over the management zones in FP plots was 3.47 t/ha, which was increased to 4.56 t/ha with the application of INM doses. This 31% yield increase may be attributed to the application of additional 12 kg N, 6 kg P, and 32 kg K/ha in INM plots than the FP plots. The FP plots received 58 kg N, 8 kg P, and 3 kg K/ha along with 7 t/ha cow dung. The yield increases in management zones II and III were 18% and 11%, respectively. Unlike other Upazilla, at Kamalganj Upazilla the yield increase in Aus season due to INM was not significant except in management zone II (Table 10).

T. Aman Rice

In Sreemangal, the mean yield of T. Aman (var. BR 11) in soil FMZ I plots was 2.50 t/ha with the FP dose, and the yield was increased to 3.81 t/ha with INM doses (Table 11). In management zone II, the yields of FP and INM plots were 2.96 and 3.01 t/ha, respectively. The rice yields in zone III soil were 2.34 and 3.21 t/ha with FP and INM programs, respectively. The yield difference between FP and INM was significant in all the three management zones. There was about 52% greater yield with INM than FP in

Table 11. Effect of improved nutrient-management program (INM) compared to farmers' nutrient-management (FP) on the yield of Aman (July–November) rice in farmers' fields of Piedmont soils

Fertility-management zone[a]	No. of observations	Grain yield (t/ha)[b]		Increase (%)[c]
		FP	INM	
Sreemangal (Variety BR11)				
Zone I	6	2.50	3.81	52*
Zone II	18	2.96	4.01	35*
Zone III	6	2.34	3.21	37*
$LSD_{0.05}$		0.60	0.60	
Kamalganj (Variety BR 11)				
Zone I	11	3.57	4.44	24*
Zone II	9	3.68	4.37	19*
Zone III	7	3.04	4.06	34*
$LSD_{0.05}$		NS	NS	
Chunarughat (variety BR11)				
Zone I	8	3.04	3.58	18*
Zone II	20	3.08	4.23	37*
Zone III	9	3.80	4.15	9 NS
$LSD_{0.05}$		0.71	0.71	

[a]Zone I is the most fertile, zone II is medium fertile, and zone III is least fertile soils.
[b]FP = farmers' fertilizer dose, INM = improved fertilizer dose.
[c]NS indicates not significant and * indicates significant at 5% level of LSD.

management zone I, and magnitudes in management zones II and III were 35 and 37% respectively (Table 11).

The FP plots' yields in management zones I, II, and III in Kamalganj were 3.57, 3.68, and 3.04 t/ha, respectively, and corresponding yields with INM in these three zones were 4.44, 4.37, and 4.06 t/ha (Table 11). The application of INM gave the highest yield benefit of 34% in management zone III and the lowest 19% in management zone II. However, in all the three management zones, the application of INM gave about 1 t/ha greater yield than that obtained with FP doses in Kamalganj (Table 11).

In Chunarughat, the rice yields in management zones I, II, and III with FP were 3.08, 3.04, and 3.80 t/ha, respectively. The application of INM doses gave rice yields in management zones I, II, and III as 3.58, 4.23, and 4.16 t/ha, respectively. The yield increases due to INM in Chunarughat were 18 and 37% in management zones I and II, respectively, but in management zone III, it was only 9%, which was not significant.

Although the INM gave greater yields than FP treatments, the field results of T. Aman rice in three Upazillas demonstrated that the yield difference with the FP among soil-fertility levels was not significant. It may be due to greater doses of fertilizer application in soils with poor fertility, which might have masked the contribution of inherent soil-fertility. For example, in Sreemangal, the mean N dose with FP was 37 and 35 kg/ha in management zones I and II, respectively, whereas it was 47 kg/ha in management zone III. In Chunarughat, too, the N dose in management zone I was 47 kg/ha, but in zones II and III it was 65 and 68 kg/ha. The mean P and K doses were also greater in zones II and III soils than in zone I soil. However, there was no consistency of fertilizer use with the soil-fertility levels in Kamalganj, although there was large variation in fertilizer doses between soil-fertility zones, probably because of ignorance of farmers.

The variable fertilizer doses among the soil-fertility zones and almost similar yields further showed that the farmers have the capability of calculating fertilizer doses according to the soil-fertility zones. However, their decision in fertilizer use may be improved further through some interventions such as group meetings, village-level workshops, farmers' school, and field days. The application of INM gave yield increases in all the management zones, and the yield difference with INM doses among management zones was not significantly different. The application of appropriate fertilizer programs may increase rice yield in all fertility zones of soil to a level of 3.5 to 4.0 t/ha from the present level of 2.5 to 3.5 t/ha. Such increase in T. Aman rice yield is possible with farmers' present level of knowledge and may increase rice provisions of resource-poor farmers.

Boro Rice

The test variety in Boro was mostly BRRI Dhan28; however, only in a few trials BRRI Dhan29 was grown in both FP and INM plots. The effect of INM in Boro season was more pronounced than in Aus and Aman season. In Sreemangal, the

FP plots yielded 4.43, 4.21, and 3.39 t/ha in management zones I, II, and III, respectively; the corresponding yield in the INM plots were 5.96, 5.83, and 4.77 t/ha, respectively (Table 12). In all the three management zones, the yield increase due to INM was statistically significant ($P < 0.05$). The magnitude of yield increase due to INM was the highest in management zone III (41%) and the lowest (35%) in management zone I. The yield difference between management zones neither in FP nor in INM was significant. Unlike Sreemangal, the increase in yield due to INM was not significant in Kamalganj, where the crop suffered from water stress and insect infestation (Table 12).

In Chunarughat, the application of FP doses gave 3.77 t/ha yield in management zone I, 3.57 t/ha in management zone II, and 4.36 t/ha in

Table 12. Boro rice yield with farmers' and improved fertilizer-management practices on soils of different fertility-management zones

Fertility zone[a]	No. of observations	Grain yield (t/ha)[b] FP	INM	Increase (%)[c]
Sreemangal (variety BRRI Dhan 28 and 29)				
Zone I	6	4.43	5.96	35*
Zone II	7	4.21	5.83	38*
Zone III	5	3.39	4.77	41*
$LSD_{0.05}$		NS	NS	
Kamalganj (variety BRRI Dhan 28 and 29)				
Zone I	1	4.15	4.42	7 NS
Zone II	4	3.17	3.88	22 NS
$LSD_{0.05}$		NS	NS	
Chunarughat (variety BRRI Dhan 28 and 29)				
Zone I	1	3.77	5.86	55*
Zone II	4	3.57	5.57	56*
Zone III	6	4.36	5.73	31*
$LSD_{0.05}$		0.61	0.61	
Madhabpur (variety BRRI Dhan 28 and 29)				
Zone I	2	5.44	7.76	43*
Zone II	11	4.36	6.01	38*
Zone III	6	3.70	5.46	48*
$LSD_{0.05}$		1.07	1.07	
Bahubal (Variety BRRI Dhan 28 and 29)				
Zone I	1	4.70	5.91	26*
Zone II	3	4.00	5.28	32*
Zone III	1	4.92	7.23	47*
$LSD_{0.05}$		NS	NS	

[a]Zone I is the best fertile, zone II is medium fertile, and zone III is least fertile soils.
[b]FP = farmers' fertilizer dose, INM = improved fertilizer dose.
[c]NS indicates not significant and * indicates significant at 5% level of LSD.

management zone III, respectively (Table 12). The application of INM doses increased yield by 55%, 56%, and 31% in management zones I, II, and III, respectively. The yield increase in Chunarughat may be attributed to the application of K fertilizer and an increased N doses.

In Madhabpur Upazilla, the rice yield varied from 3.70 t/ha in management zone III to 5.44 t/ha in management zone I when it received only FP doses (Table 12). The application of INM doses increased rice yield over that obtained with FP doses. In management zone I, the mean yield was 7.76 t/ha, which was 43% greater than that of FP plots. Similarly, the yield increases due to INM doses in management zones II and III were 38 and 48%, respectively. The yield increases due to INM in Bahubal Upazilla varied from 26% in management zone I to 47% in management zone III (Table 12).

Applications of improved nutrient-management programs, based on soil-test results, were proven to increase rice grain yield in all soil-fertility zones. The INM for the participatory farmers is useful in the future for the specific FMZ of their village. In the same villages, the farmers yet to participate may also apply the INM dose, as the fertility zone is already delineated. The exclusivity of the INM program is that its extrapolation area covers a particular management zone of a village, and the farmers are quite familiar with the management zone. Comparing the microtopography and soil quality determined by indigenous tools may identify the soil-fertility-zone-specific INM program for the neighboring village. The implication of this participatory research is that the farmers can decide how much fertilizer would be needed for a specific fertility zone. Research and extension activity at the farm level may simultaneously proceed, which can help increase yields to the participatory farmers. Adoption of farmers' participatory fertility-zone-specific improved nutrient-management program may contribute to the national target of a 25% food grain increase in Bangladesh by 2015.

The main difficulty in area soil sampling is the absence of investigator's experience in classifying the study region into areas homogenous with respect to yield or soil-fertility status. This difficulty can be eliminated largely through the participation of the villagers, who are vastly experienced with the fertility delineation of their village. Preparations of soil FMZ map with the active cooperation of the villagers would yield a practical guide for their fertilizer recommendation for different parts of the village.

CONCLUSIONS

This study demonstrated that the farmers were able to delineate spatial variability in soil-fertility within the plots in their village. Soil-test results in the laboratory were in close agreement with farmers' defined soil-fertility category according to management zone. Nutrient-management recommendations based on soil-test results for the FMZs in the villages substantially increased rice yields by an average of 28%.

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