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Title
USE OF VILLAGE LEVEL SOIL FERTILITY MAPS AS A FERTILIZER DECISION SUPPORT TOOL IN THE RED AND LATERITIC SOIL ZONE OF INDIA

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Introduction

Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have high degree of spatial variability resulting from the combined effects of physical, chemical or biological processes (Goovaerts, 1998). However, major constraints impede wide scale adoption of soil testing in most developing countries. In India, these include the prevalence of small holding systems of farming as well as lack of infrastructural facilities for extensive soil testing (Sen *et al*, 2008). Under this context, Geographic Information System (GIS)-based soil fertility mapping has appeared as a promising alternative. Use of such maps as a decision support tool for nutrient management will not only be helpful for adopting a rational approach compared to farmer's practices or blanket use of state recommended fertilization but will also reduce the necessity for elaborate plot-by-plot soil testing activities. However, information pertaining to such use of GIS-based fertility maps are meager in India (Sen and Majumdar, 2006; Sen *et al*., 2008).

The current study was initiated to assess the relative efficiency of GIS map-based soil fertility evaluation with regard to traditional soil testing in the red and lateritic soil zone of West Bengal.

Materials and Methods

Location

The study was carried out in two locations within West Bengal, India. The study locations fall under the semi-arid subtropical zone, 60 m above mean sea level, with average year round temperatures between 6-41°C and a relative humidity range between 45-96%. Average annual rainfall is about 87 mm, mainly concentrated between June to September. Soils from this area are generally Hyperthermic Typic Haplustalfs with sandy loam texture, moderate water holding capacity, acidic pH, and low fertility status.

Developing fertility maps

Geo-referenced soil samples were collected at a 50 m grid and were analyzed for common soil productivity attributes including pH, organic C, available N, P_2O_5 and K_2O by standard methods (Jackson, 1973). The spatial variability for each attribute was assessed using spatial descriptive statistics (Iqbal *et al*., 2005). This data was then integrated into a GIS platform (ESRI, 2001). An inverse distance weighted method of interpolation created continuous surface maps for each parameter allowing estimation of soil properties for un-sampled points within the study area (Sen *et al.*, 2008). Random soil sampling was carried out and comparisons were then made between actual soil test values and their corresponding GIS map-based predicted values.

To assess the efficacy of GIS-based soil fertility mapping, nine on-farm trials were conducted in three locations during 2007-2008. Four treatments evaluated (T1) farmers' practice, (T2) State recommended fertilization, (T3) soil test-based fertilization, and (T4) GIS-based fertilization within a monsoon rice-potato-sesame cropping system (**Table 1**).

Table 1. Nutrient rates (kg N-P_2O_5-K_2O/ha) used in each treatment and crop.

Treatments	Rice	Potato	Sesame
T1: Farm practice	60:30:30	300:200:200	Residual
T2: State rec.	80:40:40	200:150:150	80:40:40
T3: Soil test-based	Variable	Variable	Variable
T4: GIS-based	Variable	Variable	Variable

Another study was simultaneously carried out to assess the effect of grid size on map development and the predictability of soil fertility status. Three separate GIS maps of the study area were prepared using samples collected at three grid sizes including 50 m, 100 m and 250 m. A farmer's plot was selected from the study area and soil samples were analyzed for pH, organic C, available P_2O_5 and available K_2O. Latitude/longitude values were used to predict the same using each grid size and its respective GIS maps. Predicted soil fertility levels were classified into low, medium or high categories according to existing norms (Ali, 2005). Trials on a rice-potato-sesame cropping system were carried out using fertilizer recommendations based on parameters predicted from these different grids.

Results and Discussion

The comparative assessment of soil pH and nutrient content from farm fields, sampled and predicted from the GIS, found only minor variations in available N content and practically no variation in available P content under the two methods of evaluation (**Table 2**). However, larger difference was observed in the case of available K, which was attributed to less variation in available N and P in these red and lateritic soils. While available N and P status were generally low, soil K was well distributed between low, medium and high fertility groups, which were not well predicted through the GIS maps.

Table 2. Percent samples of the study area falling under low, medium and high categories for available nutrient content and soil acidity under the two systems of assessment.

Parameters	Low/Acidic		Medium/Neutral		High/Alkaline	
	Soil test	GIS	Soil test	GIS	Soil test	GIS
Available N	89	78	11	22	0	0
Available P	100	100	0	0	0	0
Available K	44	33	33	67	22	0
pH	56	67	44	33	0	0

Average yields for the initial rice crop were significantly higher under soil test and GIS-based soil fertilizer application over farmers' practice and State recommended fertilization – indicating better agronomic efficiency (**Table 3**). Yield levels under soil test-based and GIS map-based fertilization were statistically at par indicating feasibility for using GIS-based fertility maps for nutrient management.

Potato was cultivated as the second crop, and across treatments, average yields and yield attributes were statistically on par (**Table 4**), which may be attributed to the general trend of using relatively high doses of fertilizers in potato.

In sesame, yields were generally low due to a scarcity of irrigation water during the season. However, the yield attributes and yields of sesame did follow a similar trend to that observed in rice (**Table 5**). Thus, soil test-based and GIS map-based fertilization produced significantly higher yields than farmers' practice while no significant differences in yield were noted between soil test-based and GIS map-based fertilizer application.

Table 3. Yield and yield attributes of monsoon rice under different treatments.

	Plant height (cm)	No. of	Dry weight (g/hill)	Yield (t/ha)

Treatment	45 DAT	90 DAT	tillers /hill	45 DAT		90 DAT			Grain	Straw
				Leaf	Stem	Leaf	Stem	Panicle		
Farmers' practice	70.1	101.8	23.2	7.2	11.3	8.0	25.3	20.6	4.2	4.6
State rec.	72.1	103.6	23.3	7.7	11.9	8.0	25.6	21.0	4.4	5.0
Soil test-based	77.6	108.4	24.1	9.2	13.7	11.4	33.8	28.3	4.7	6.0
GIS-based	77.3	107.7	23.9	9.1	13.4	10.7	33.2	26.6	4.7	6.0
CD at 5%	4.7	6.1	3.14	0.7	3.0	1.8	3.4	3.2	0.26	0.32

Table 4. Yields and yield attributes of potato under different treatments.

Treatment	Plant height (cm) 45 DAS	Dry weight (g/m^2) 45 DAS			Yield (t/ha)
		Tuber	Leaf	Stem	
Farmers' practice	45.7	10.5	13.8	3.4	28.7
State rec.	41.3	8.8	12.3	3.1	22.5
Soil test-based	44.6	9.5	13.5	3.5	28.3
GIS-based	43.2	9.5	13.5	3.4	27.6
CD at 5%	5.8	2.3	3.9	1.5	6.4

Table 5. Yields and yield attributes of sesame under different treatments.

Treatment	Plant height (cm)		Dry weight (g/m^2) At maturity	No. of capsule/ plant	No. of seeds/ capsule	Test weight	Seed yield (t/ha)	Stick yield (t/ha)
	45 DAS	At maturity						
Farmers' practice	41.9	76.3	75.8	18.7	40	2.8	0.8	3.0
State rec.	48.8	85.2	110.3	27.3	48	3.1	1.2	3.9
Soil test-based	52.1	87.9	112.8	30.3	52	3.2	1.4	4.2
GIS-based	51.2	88.6	110.6	29.4	50	3.2	1.4	4.1
CD at 5%	5.6	5.5	12.4	4.5	4.6	0.3	0.3	0.4

The above studies concur that fertilizer recommendations generated from GIS maps were as effective as those generated from soil testing. It is likely that small variations in the absolute concentrations of nutrient availability under these two systems were minimized when the values were categorized and recommendations were generated. To substantiate this, a comparison was made between the mean fertilizer (NPK) doses under the soil test and GIS-based treatments for each crop. Results found the N and P application rates to be identical, but K rates varied slightly (data not shown), which again was attributed to comparatively higher variations in the availability of soil K.

A substantial amount of research has tried to assess the appropriate sampling density needed to characterize the central tendency of soil properties with a specified degree of accuracy (McBratney and Webster, 1983; Webster and Oliver, 1990). A larger number of samples can produce more accurate maps (Mueller *et al*., 2001; Wollenhaupt *et al*., 1994). However, the cost of sample collection and analysis can be prohibitive to implementing site-specific management. Previous research suggests that soil sampling on 60 m grids (Hammond, 1992) or even 30 m grids (Franzen and Peck, 1993) might be needed, but most commercial soil sampling is done on a 1 ha grid basis. To arrive at a cost effective grid size of sampling, we compared actual soil analysis values of pH, organic C and available P_2O_5 and K_2O contents of random samples from the study area with the predicted values from maps using 50, 100 and 250 m grid sampling. Variation existed for soil parameters values under the three grid sizes, but the deviations from the actual soil test values were insignificant and made no difference when the values were classified into high, medium and low categories (data not shown).

An additional study was carried out on a rice-potato-sesame sequence to further examine the predictions from GIS maps generated from the different grid sizes against soil test-based recommendations. Use of either GIS or soil test-based fertilization resulted in comparatively higher rice yields over farmers' practice and the State recommendation (**Table 6**). The comparison between soil test and GIS-based fertilizer application showed only a marginal advantage for the former with regard to both grain and straw yields. No significant difference in rice yield was found among the three grid-based recommendations suggesting a 250 m grid to be adequate for this fertilizer recommendation process.

Table 6. Yields and yield attributes of rice under different treatments.

Treatment	Plant height (cm)		Dry weight (g/hill)					No. of tillers /hill	Yield (t/ha)	
	45 DAS	90 DAS	45 DAS		90 DAS				Grain	Straw
			Leaf	Stem	Leaf	Stem	Panicle			
Farmers' practice	72.2	99.6	7.1	11.1	8.4	26.4	20.6	22.6	4.0	4.2
State rec.	74.3	104.5	7.6	11.7	9.1	27.8	21.8	23.6	4.3	4.8
50 m grid	78.2	108.0	9.0	13.4	11.6	34.1	27.3	23.9	4.5	5.8
100 m grid	77.7	106.9	9.1	13.2	11.1	33.9	27.3	23.5	4.4	5.6
250 m grid	75.1	104.7	7.7	13.0	10.4	32.0	26.8	23.5	4.3	5.3
Soil test-based	78.5	108.3	9.2	13.3	12.3	35.2	28.1	23.9	4.6	5.9
CD at 5%	1.6	1.2	0.8	0.9	1.0	1.7	1.1	0.5	0.2	0.3

For potato, farmers' practice resulted in comparatively higher yield than all other treatments while State recommended fertilization provided the lowest yield (**Table 7**). The 50 and 100 m grid-based maps showed comparatively better results than the 250 m map. Fertilization based on smaller grid-based maps exhibited yield levels of potato that were comparable to soil test-based fertilization.

Table 7. Yields and yield attributes of potato under different treatments

Treatments	Plant height (cm) 45 DAS	Dry weight (g/m^2) 45 DAS			Yield (t/ha)
		Tuber	Leaf	Stem	
Farmers' practice	44.3	10.1	13.1	3.2	27.7
State rec.	40.5	8.6	12.1	3.1	21.9

50 m grid	43.0	9.5	13.3	3.4	27.2
100 m grid	43.0	9.5	13.4	3.4	27.1
250 m grid	42.2	9.3	13.0	3.3	25.5
Soil test-based	43.8	9.6	13.3	3.5	27.3
CD at 5%	1.1	0.6	0.7	0.2	0.6

In sesame, farmers' practice resulted in the lowest yield among all the treatments (**Table 8**). Farmers hardly use any nutrient inputs for sesame cultivation and rely on residual fertility after potato. Use of State recommended fertilization increased the seed and stick yields of sesame over the farmers' practice. However, considerably higher yields were obtained under the soil test-based and the various grid-based recommendations. No significant differences in yield were observed between soil test and GIS-based fertilization as well as between the three grid sizes, which further corroborates the suitability of the 250 m grid size.

Table 8. Yields and yield attributes of sesame under different treatment.

Treatment	**Plant height (cm)**		**Dry weight (g/m^2) At maturity**	**No. of capsule/ plant**	**No. of seeds/ capsule**	**Test weight**	**Seed yield (t/ha)**	**Stick yield (t/ha)**
	45 DAS	**At maturity**						
Farmers' practice	40.7	75.8	74.6	18.5	40	2.8	0.8	2.7
State rec.	46.3	84.3	110.4	26.7	45	3.1	1.2	3.9
50 m grid	53.9	88.3	112.4	30.3	52	3.3	1.4	4.1
100 m grid	53.2	87.9	112.5	30.5	51	3.2	1.4	4.1
250 m grid	45.9	84.1	109.7	28.7	47	3.1	1.4	3.9
Soil test-based	53.8	88.6	112.8	30.8	52	3.3	1.4	4.2
CD of 5%	0.9	0.8	1.7	1.8	3.1	0.2	0.1	0.3

Conclusion

In contrast to developing countries, where precision nutrient management addresses in-field nutrient variability in large-scale individual operations, this study's approach addresses spatial variability of soil parameters between fields at the village scale. Geo-statistical analysis and GIS-based mapping provided an opportunity to assess variability in the distribution of native nutrients and other yield limiting/building soil parameters across a large area. This has helped in strategizing appropriate management of nutrients in a rice-potato-sesame cropping sequence leading to better yield. This method can help to do away with the expensive plot-to-plot soil testing leading to better ease and economics of implementing SSNM with associated increase in production and productivity.

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