Use of Village-Level Soil Fertility Maps as a Fertiliser Decision Support Tool in the Red and Lateritic Soil Zone of India

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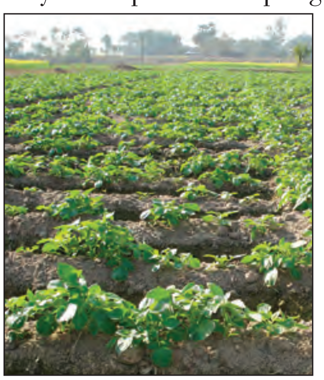
The combined influences of poor infrastructure, high implementation costs, and a diverse mosaic of small holders have limited the effectiveness of soil test-based fertilisation programs in South and Southeast Asian countries. Geographic information system (GIS)-based fertility maps represent an alternative decision support tool and this village-scale field study outlines a cost effective option of implementing improved nutrient management in large tracts of small-scale farming systems in Asia.

Soil test-based fertility management is an effective tool for increasing productivity of agricultural soils that have a high degree of spatial variability. 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, 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 practices or blanket use of state recommended fertilisation, 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 has been 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.



GIS-based fertilizer recommendations focused farmers on nutrient management for their entire rice-potato-sesame crop rotation.

This on-farm study was conducted during 2007/08 at Meherpur Village of Birbhum District in the lateritic soil zone of West Bengal. The village represents 543 land holdings within a 76-ha area. The area falls under the hot, dry sub-humid zone, 60 m above mean sea level, with year round temperatures between 6.6 to 41.4 °C and a relative humidity range between 47.7 to 96%. Average annual rainfall is about 1,192 mm, mainly concentrated between June and September. Soils from this area are generally mixed Hyperthermic Typic Haplustalfs with sandy loam texture, moderate water holding capacity, acidic pH, and low fertility status. The crop system under study was a monsoon rice-potato-sesame cropping system.

Geo-referenced soil samples were collected on a 50-m grid and were analysed for common soil productivity attributes including pH, organic C, available N, P, and K by standard methods (Jackson, 1973). The data were 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 unsampled points within the study area (Sen et al., 2008). See **Figure 1**. The spatial variability for each attribute was assessed using spatial descriptive statistics (Iqbal et al., 2005). A comparative assessment of soil pH and nutrient content values obtained from random sampling (10 samples from an area of about 20 ha) versus those predicted from the GIS found only minor variations in available N content. There was practically no variation in available P content under the two methods of evaluation **(Table 1)**. A larger difference was observed in the case of available K. Red and lateritic soils typically have low available N and P status, but soil K was well distributed between low, medium, and high fertility groups and was not well predicted through the GIS interpolation.

The relative effectiveness of recommendations generated through the grid-based, village-level GIS was evaluated against results obtained from common farmer practice, blanket fertiliser recommendations generated from the State, and field-specific, soil test-based recommendations within a monsoon rice-potato-sesame cropping system **(Table 2)**. Average yields for the initial rice crop were significantly higher under soil test and GIS-based soil fertiliser application over farmer practice

Table 1. Comparison of samples (%) that fall under low, medium, and high nutrient availability and pH categories under two systems of assessment.

	Low/Acidic		Medium/Neutral		High/Alkaline	
Parameter	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

Table 2. Nutrient rates (kg N-P_2O_5-K_2O/ha) used in each treatment and crop.

Treatments	Rice	Potato	Sesame
Farm	60-30-30	300-200-200	Residual
State	80-40-40	200-150-150	80-40-40
Soil test	Variable	Variable	Variable
GIS	Variable	Variable	Variable

Abbreviations: C = carbon; N = nitrogen; P = phosphorus; K = potassium; CD = critical difference, equivalent to Least Significant Difference; INR = Indian rupee (USD 1 is equal to approximately INR 46).

Table 3. Yield of rice, potato, and sesame under different crop fertilisation strategies.

	Rice				Potato			Sesame			
	Yield, t/ha		Economics[1], INR		Yield, t/ha	Economics, INR		Yield, t/ha		Economics, INR	
Treatment	Grain	Straw	Net return	Return per INR invested	Tuber	Net return	Return per INR invested	Seed	Stick	Net return	Return per INR invested
Farm	4.2	4.6	20,592	1.90	28.7	38,210	1.50	0.8	3.0	3,928	1.22
State	4.4	5.0	21,544	1.91	22.5	20,962	1.30	1.2	3.9	8,278	1.51
Soil test	4.7	6.0	25,614	2.05	28.3	41,556	1.58	1.4	4.2	11,267	1.66
GIS (100-m grid)	4.7	6.0	24,760	2.02	27.6	39,128	1.55	1.4	4.1	11,457	1.68
CD at 5%	0.26	0.32	-	-	6.4	-	-	0.3	0.4	-	-

[1]Economic comparisons considered all fixed and variable costs including fertilisers (urea = INR 6/kg, SSP = INR 6/kg, KCl = INR 6/kg) and revenues from rice grain (INR 9/kg) and straw (INR 1.2/kg), potato tubers (INR 4/kg), and sesame seed (INR 20/kg) and sticks (INR 100/t).

and State recommended fertilisation **(Table 3)**. Yield levels under soil test-based and GIS map-based fertilisation were statistically at par, indicating feasibility for using GIS-based fertility maps for nutrient management. The following potato crop had equivalent tuber yields across treatments, which can be attributed to the tendency for farmers to use relatively high rates of fertiliser in potato. In sesame, yields were generally low due to a scarcity of irrigation water during the season. However, yields of sesame did follow a similar trend to that observed in rice. Thus, fertiliser recommendations generated from GIS maps were agronomically as effective as those generated from soil testing. Comparatively, the GIS and soil test-based fertiliser application was higher than State recommendation and farmer practice in rice and sesame. However, potato farmers applied higher amounts of nutrient than State recommendation as well as soil test or GIS-based fertiliser application. A complete economic assessment suggests net returns were maximised under field-specific recommendations in rice and potato, followed by GIS interpolation. In sesame, the GIS-based recommendations were marginally better than those obtained by field sampling. An additional consideration involves the cost of implementing new sampling strategies at the village-scale. Successful adoption of such technologies could rest on proposing a lowest cost solution which, in this setting, is advantageous to grid sampling through its lower sampling density **(Table 4)**.

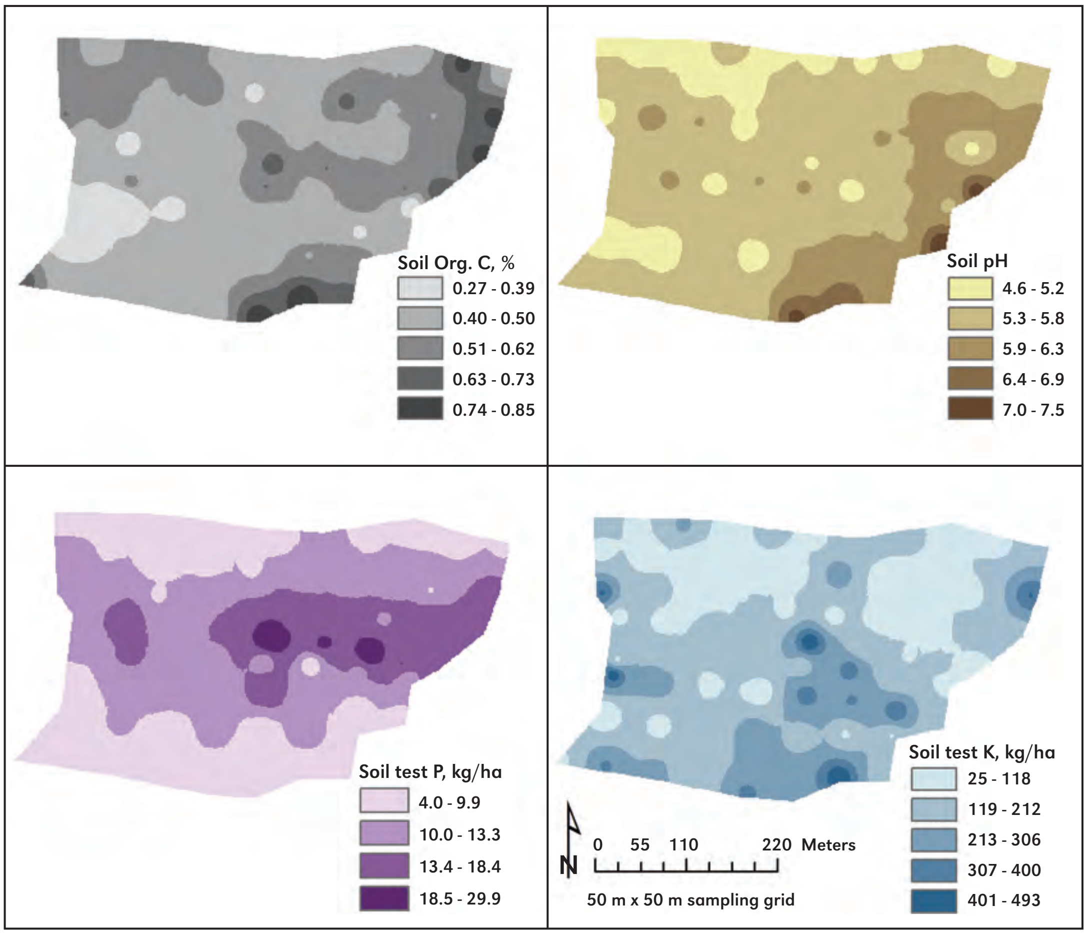


Figure 1. Maps show soil organic C, soil pH, soil test P, and soil test K for study at Meherpur Village.

It is likely that variation between estimates of nutrient availability under the two preferred systems was minimised when values were categorised and recommendations were generated. To substantiate this, a comparison was made between the mean fertiliser (NPK) doses under the soil test and GIS-based treatments for each crop. Results found the N and P application rates to be equal, but K rates varied slightly (data not shown), which again was attributed to comparatively higher variation in the availability of soil K.

Researchers also conducted another study simultaneously to assess the effect of grid size on map development and the predictability of soil fertility status. A substantial amount of research has tried to assess the appropriate sampling density needed to characterise 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. Previous research suggests

Table 4. Outline of implementation cost associated with improved village-scale sampling strategies.

Total number of land holdings		543
Total cultivated area of the village in hectares		76 ha
Actual cost of field-based soil testing (NPK analysis, commercial lab)		543 x INR 50 = INR 27,150
Actual cost of soil testing for GIS	50-m x 50-m sampling	304 x INR 50 = INR 15,200
	100-m x 100-m sampling	76 x INR 50 = INR 3,800
	250-m x 250-m sampling	19 x INR 50 = INR 950

Table 5. Yields (t/ha) of rice, potato, and sesame under different crop fertilisation strategies and grid sizes.

	---- Rice ----		- Potato -	--- Sesame ---	
Treatment	Grain	Straw	Tuber	Seed	Stick
Farm	4.0	4.2	27.7	0.8	2.7
State	4.3	4.8	21.9	1.2	3.9
GIS (50-m grid)	4.5	5.8	27.2	1.4	4.1
GIS (100-m grid)	4.4	5.6	27.1	1.4	4.1
GIS (250-m grid)	4.3	5.3	25.5	1.4	3.9
Soil test	4.6	5.9	27.3	1.4	4.2
CD at 5%	0.3	0.5	1.6	0.2	0.3

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 100-m grid basis.

To arrive at a cost effective grid size of sampling, researchers compared actual soil analysis values of pH, organic C and available P and K contents of random samples from the study area with values predicted from GIS maps using 50, 100, and 250-m grids. Predicted soil fertility levels were classified into low, medium, or high categories according to existing norms (Ali, 2005). 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).

Collecting soil samples within the fragmented landscape of the village of Meherpur, West Bengal.

Trials on the rice-potato-sesame cropping system were carried out using fertiliser recommendations predicted from these different grids, which were also evaluated against farmer practice, State recommendations, and field-specific, soil test-based recommendations. Higher rice grain and straw yields were obtained with either GIS or soil test-based fertilisation compared to farmer practice **(Table 5)**. However, unlike the three GIS sampling grids, field-specific soil testing did generate superior rice grain yields over the State's blanket recommendation. No significant difference in rice yield was found among the three grid-based recommendations, although yields gradually declined with increasing grid size, to the point where yields obtained under the 250-m grid were significantly less than those obtained with soil test-based fertilisation. For potato, farmer practice was once again a relatively high yielding treatment while the State recommendation provided the lowest yield overall. The 50-m and 100-m grid-based maps also provided comparatively better results than the 250-m map, such that these grid sizes generated tuber yields that were comparable to soil test-based fertilisation. In sesame, farmer practice resulted in the lowest yield among all the treatments. Traditional practice in sesame largely relies on residual soil fertility after potato. The blanket State recommendation had higher seed and stick yields over farmer practice. However, considerably higher yields were obtained under the soil test-based and three grid-based recommendations. No significant differences in sesame seed yield were observed between soil test- and GIS-based fertilisation as well as between the three grid sizes.

In contrast to developed 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. Geostatistical 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 to increase awareness at the village scale, while helping farmers strategise for appropriate management of nutrients and strive for better productivity throughout their entire crop sequence. BC-SA

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References

Ali, S.J. 2005. Fertiliser recommendation for principal crops and cropping sequences of West Bengal. Kolkata. SP Press.
ESRI. 2001. ArcView Software version 8.0.
Franzen, D.W. and T.R. Peck. 1993. *In* R.G. Hoeft, ed. Proc. Illinois Fert. Conf., Univ. of Illinois, Urbana-Champaign, IL. pp 81-91.
Hammond, M.W. 1992. *In* Robert, P.C. et al., ed. Proc. of Soil Specific Crop Management Workshop, Minneapolis, MN. ASA, CSSA, and SSSA, Madison, WI. 213-228.
Iqbal, J.J., A. Thomasson, J.N Jenkins, P.R. Owens, and F.D. Whisler. 2005. Soil Sci. Soc. Am. J. 69:1338-1350.
Jackson, M.L. 1973. Soil Chemical Analysis. New Delhi: Oxford & IBH Publications.
McBratney, A.B. and R. Webster. 1983. Soil Sci. 135: 177-183.
Mueller, T.G., F.J. Pierce, O. Schabenberger, and D.D. Warncke. 2001. Soil Sci. Soc. Am. J. 65: 1547-1558.
Sen, P. and K. Majumdar. 2006. *In* Proceedings of the Fifth International Conference of the Asian Federation for Information Technology in Agriculture, Macmillan (India), Bangalore, India: 653-660.
Sen, P., K. Majumdar, and G.D. Sulewski. 2008. Indian J. Fert. 4 (11): 43-50.
Webster, R. and M.A. Oliver. 1990. Statistical Methods in Soil and Land Resource Survey. New York, NY. Oxford University Press.
Wollenhaupt, N.C., R.P. Wolkowski, and M.K. Clayton. 1994. J. Prod. Agric. 7:441-448.