Precision Nutrient Management Strategies using GIS-based Mapping in Western Uttar Pradesh

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Site-specific nutrient management (SSNM) strategies have produced tangible yield gains, along with higher efficiency and improved soil health, but the process is quite intensive and feasible in small domains only. Integration of SSNM with GIS-based spatial variability mapping has the potential to become a useful technique for use in large domains.

Nutrient management and recommendation processes in India are still based on response data averaged over a large geographic area. Agricultural holdings in India are highly fragmented; with each farmer managing small field plots separately. This pattern of farming increases variability between fields due to individual farmer knowledge, fertilisation history, crop sequence, farm management, and resource availability. Generalised nutrient recommendation over large areas of such small-scale farming leads to the possibility of over- or under-use of nutrients with adverse economic and environmental challenges. Such farms would require individual attention in terms of nutrient management to attain optimum yield.

The precision nutrient management concept, modified to suit India's unique farming systems, is expected to provide ways to reverse the productivity and fertility trends in India. Geo-statistical analysis and GIS-based mapping can provide an opportunity to assess variability in the distribution of native nutrients and other yield limiting/improving soil parameters across a large area. This can aid in developing appropriate nutrient management strategies leading to better yield and environmental stewardship. Research has shown a direct correlation between variability and production conditions and improvement in production and profit under different scales of operation by managing variability. However, there is a lack of studies integrating GIS with SSNM (Sen et al., 2007, 2008; Iftikar et al., 2010). We conducted a study to characterise existing nutrient management practices and to assess the spatial variability of physico-chemical properties and native nutrient pools in agricultural soils across different cropping systems of western Uttar Pradesh (WUP) using GIS-based mapping.

During 2011-12, a study was conducted in the districts of Muzaffar Nagar, Saharanpur, Baghpat, Ghaziabad, Buland Shahr, Gautam Buddh Nagar, and Meerut in WUP. From these districts, 210 farmers were surveyed and soil samples were collected from their fields. The "Proportionate Area Method" was used for judicious stratification of samples in different districts of WUP. For this, Fertiliser Statistics (FAI, 2011) data on crops and district-wise area were used to identify the predominant cropping systems. The distribution of samples among different cropping systems in a district was determined using Area Spread Index (ASI) approach:

$$ASIC = (ACS/\ TACS) \times 100$$

where, ASIC is the Area Spread Index for a cropping system, and ACS and TACS represent net area under a particular cropping system in a district and total area of three predominant cropping systems of that district, respectively.

Common abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulphur; Ca = calcium; Mg = magnesium; Fe = iron; Cu = copper; Mn = manganese; Zn = zinc; C = carbon; SSP = single super phosphate; DAP = diammonium phosphate; FYM = farmyard manure; GIS = geographic information system; GPS = global positioning system; SAR = sodium adsorption ratio; DTPA = diethylene triamine pentaacetic acid.

Geo-referenced soil samples collected by Dr. V.K. Singh (on left) and his assistant.

In order to select the agricultural development blocks (ADBs) to be targeted for sampling in a particular cropping system, ASIC for a different cropping system was calculated at the block level to determine the spread of a particular cropping system in comparison to the whole district.

For recording current crop/fertiliser management practices, farmers representing different socio-economic groups were selected. Participatory rural appraisal (PRA) methodologies were used to gather survey information on various aspects influencing, directly or indirectly, the nutrient management practices of the farmers. Detailed information on fertiliser and manure use pattern and the productivity levels were also collected. During the survey, soil samples (0 to 20 cm profile) and plant samples from the fields of pre-dominant cropping systems of each farmer were collected along with GPS coordinates (longitude, latitude, and mean sea level) and analysed using standard methods. Samples of FYM, sulphitation pressmud (SPM), and crop residue were also collected and analysed for total N, P, and K contents. Irrigation water samples collected from different irrigation water sources were analysed for its quality parameters as well as for K and S content (Page et al, 1982).

Surface maps of basic soil properties were prepared using semivariogram parameters through ordinary kriging. Kriged map for each soil property was prepared using ESRI ArcGIS™ 10.1—a geo-statistical analysis tool.

Predominant Cropping Systems and Fertiliser Use Patterns

Farmers' participatory diagnostic surveys reveal that sugarcane-ratoon-wheat is the most predominant cropping system (> 60% acreage) followed by rice-wheat cropping system in WUP. Since dairying is an important enterprise after agriculture in this region, sorghum/pearl millet (fodder)-based systems are also followed. Yields of different crops grown in WUP are fairly high as compared to national and the state averages and fertiliser NPK use varied in accordance with the cropping system, farmers' land holding size, and available resources. On average, small (< 2 ha), medium (2 to 4 ha) and large (> 4 ha) farmers apply 380 to 463 kg N/ha to the sugarcane-ratoon-wheat system, and from 253 to 357 kg N/ha to the rice-wheat system (**Figure 1**). Phosphorus use under different crops grown in the region was sub-optimal, except in the potato-based systems, wherein farmers apply more than double the recommended dose of P (80 kg P_2O_5/ha). Fertiliser K use was restricted to a few crops only such as rice, wheat, sugarcane, mustard, and potato, and a very meagre amount was applied. Highest K use was noticed in the potato-based cropping systems (24 to 75 kg K_2O/ha) followed by the sugarcane-ratoon-wheat system (20 to 30 kg K_2O/ha) and other systems (4 to 32 kg K_2O/ha). Overall, fertiliser use was skewed towards N, whereas nutrients like K, S, and micronutrients were generally neglected. Of the total NPK use, N's share stood at 68 to 71%, indicating that fertiliser management practices of the region are highly imbalanced and may not sustain high productivity in the long run.

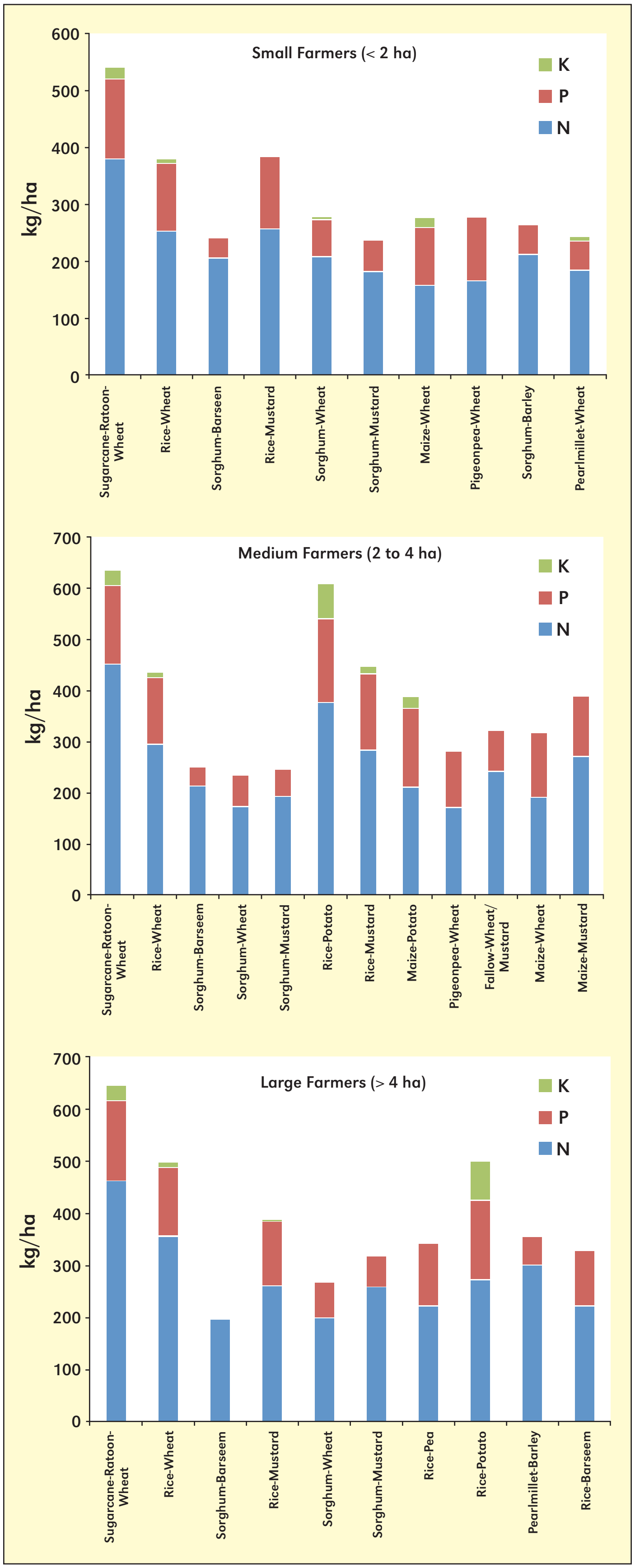

Figure 1. Fertiliser N, P, and K use under different cropping systems of western Uttar Pradesh.

Farmers growing rice, potato, and sugarcane commonly apply Zn as zinc sulphate, while wheat rarely receives direct application of Zn fertiliser. Zinc application allows inadvertent addition of S to the soil, although it is inadequate to meet crop S demand. Direct application of S was rarely noticed. Some medium and large farmers have started preferential use of single superphosphate (SSP 12% S) over DAP in potato and oilseed crops, as they experienced greater benefit with the use of SSP.

Table 1. Use of farmyard manure and its frequency in different crops of western Uttar Pradesh.

	FYM use, t/ha			Frequency, year		Farmers using FYM, %
Crop	Range	Mean	SE±	Range	Mean	
Rice	10-40	27.6	0.0	1-12	3.3	84.8
Wheat	15-35	28.5	0.0	0-10	2.5	24.3
Potato	20-35	25.5	0.2	1-3	1.6	78.6
Sugarcane	10-40	29.9	0.0	1-9	3.4	86.7

Crop Residue Management and Use of Organic Manures

In general, large farmers harvest rice and wheat crops using combine harvesters and burn rice residue in situ, whereas, they remove whole wheat straw after threshing and leave only stubbles (10 to 15% of total residue) in the field. Farmyard manure is the only organic manure used by small farmers, whereas medium and large farmers prefer to use SPM, which they purchase and transport from nearby sugar mills. Farmers apply 25 to 30 t of FYM at 2 to 3 year intervals in crops like rice, wheat, potato, and sugarcane (**Table 1**).

Irrigation Water Quality and Potassium Input through Irrigation

Irrigation water quality was analysed based on samples collected from different sources of irrigation including, tube-

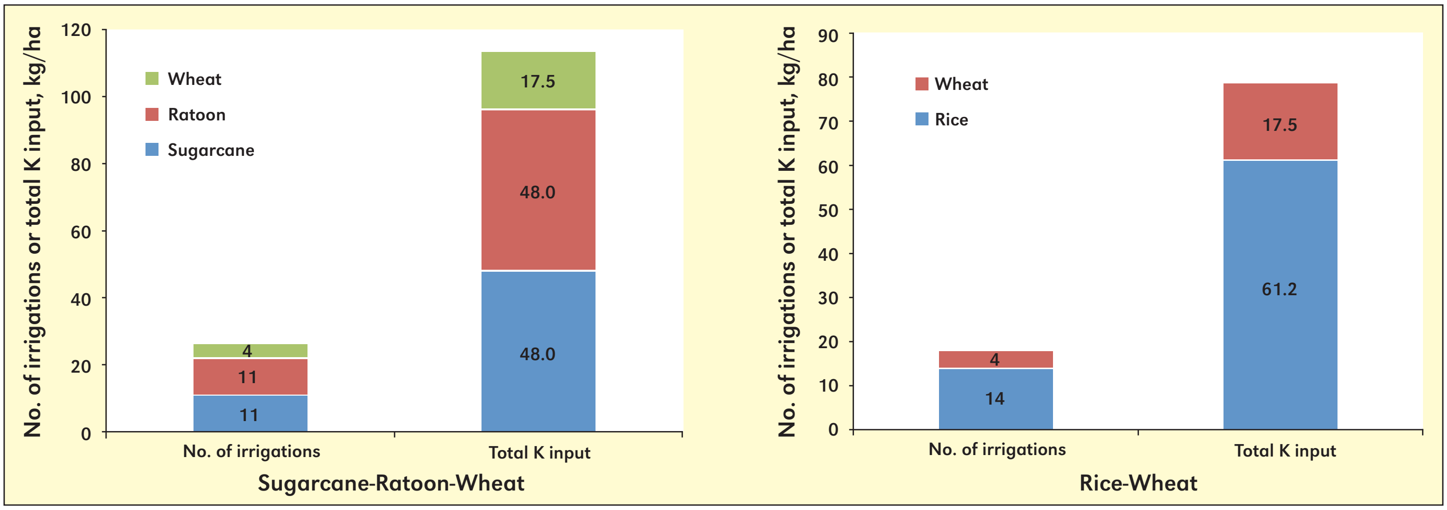

Figure 2. Total number of irrigations and K input through irrigation water under sugarcane-ratoon-wheat and rice-wheat systems in western Uttar Pradesh.

Table 2. Soil organic carbon and NPK status under predominant cropping systems of western Uttar Pradesh.

Cropping system	No. of samples	Min.	Max.	Mean	Samples in range, % Low[b]	Medium[b]	High[b]
			Organic carbon, %				
S-R-W[a]	94	0.32	0.75	0.53	10	90.0	0.0
R-W[a]	83	0.26	0.73	0.48	25	75.0	0.0
S/P/M-Mu/Pt/W[a]	35	0.26	0.67	0.45	0	100	0.0
Over all	212	0.26	0.75	0.49	0	100	0.0
			Available N, kg/ha				
S-R-W	94	77.8	324	168	94.7	5.3	0.0
R-W	83	57.7	309	142	100	0.0	0.0
S/P/M-Mu/Pt/W	35	69.0	332	151	94.3	5.7	0.0
Over all	212	57.7	332	154	96.3	3.7	0.0
			Olsen-P, kg/ha				
S-R-W	94	5.2	35.5	15.0	30.9	63.8	5.3
R-W	83	7.2	30.9	14.8	13.3	75.9	10.8
S/P/M-Mu/Pt/W	35	0.6	29.6	15.8	20.0	77.1	2.9
Over all	212	0.6	35.5	15.2	21.4	72.3	6.3
			Exchangeable K, kg/ha				
S-R-W	94	59.4	728	195	18.1	78.7	3.2
R-W	83	85.1	918	246	8.4	75.9	15.7
S/P/M-Mu/Pt/W	35	54.9	562	240	11.4	74.3	14.3
Over all	212	54.9	918	227	12.6	76.3	11.0
			Available S, mg/kg				
S-R-W	94	4.8	27.0	16.2	19.1	63.8	17.0
R-W	83	7.8	37.2	17.8	22.9	57.8	19.3
S/P/M-Mu/Pt/W	35	8.6	39.3	18.2	22.9	48.6	28.6
Over all	212	4.8	39.3	17.4	21.6	56.7	21.6

[a]S-R-W stands for sugarcane-ratoon-wheat (first predominant cropping system), R-W stands for rice-wheat (second predominant) and S/P/M-Mu/Pt/W stands for sorghum/pearl millet/maize-mustard/potato/wheat (third predominant).
[b]Low, medium, and high ranges for available N ,Olsen P, exchangeable K, and extractable S are < 280 kg, 280 to 560 kg, and > 560 kg N/ha; < 10 kg, 100 to 25 kg, and > 25 kg P/ha; < 130 kg, 130 to 280 kg, and > 280 kg K/ha; < 10 mg/kg, 10 to 20 mg/kg, and > 20 mg/kg S, respectively.

Table 3. Soil micronutrient status under different cropping systems of Western Uttar Pradesh.

Cropping system	No. of samples	Deficient[a]	Sufficient
		DTPA-Zn, %	
S-R-W	93	31	69
R-W	83	39	61
S/P/M-Mu/Pt/W	35	43	57
Over all	211	36	64
		DTPA-Fe, %	
S-R-W	93	16	84
R-W	83	14	86
S/P/M-Mu/Pt/W	35	26	74
Over all	211	17	83
		DTPA-Mn, %	
S-R-W	93	6	94
R-W	83	11	89
S/P/M-Mu/Pt/W	35	17	83
Over all	211	10	90
		DTPA-Cu, %	
S-R-W	93	3	97
R-W	83	10	90
S/P/M-Mu/Pt/W	35	9	91
Over all	211	7	93

[a]Critical limit for Zn, Fe, Mn, and Cu are 0.75 mg/kg, 4.5 mg/kg, 2.0 mg/kg, and 0.2 mg/kg, respectively.

wells, canals, etc. The majority of the samples had neutral reaction and average SAR (1.96) as well as bicarbonate (8.58 me/l), Ca + Mg (7.00 me/l), and K (6.2 ppm) contents. Overall quality of irrigation water in WUP, from a crop production viewpoint, was rated as good. Among the predominant crops grown, rice had maximum K input through irrigation

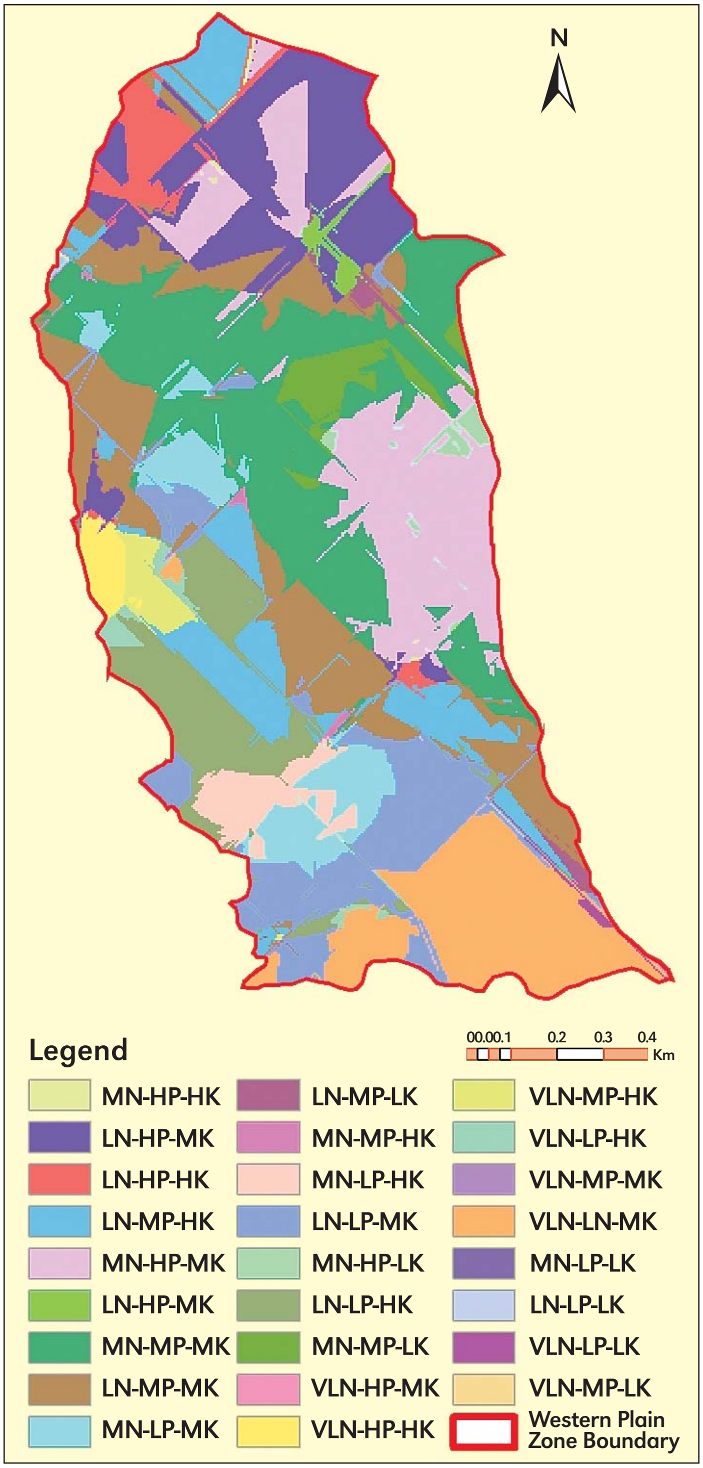

Figure 3. Homogenous Management Zones in western Uttar Pradesh.

water (61 kg K/ha), followed by sugarcane (48 kg K/ha). Potassium input in other crops ranged between 9 to 26 kg/ha only. Highest K recycling through irrigation water was noticed under the sugarcane-ratoon-wheat system (112 kg K/ha) followed by rice-wheat system (79 kg K/ha) (**Figure 2**).

Soil Fertility Status

Different soil fertility parameters, analysed after harvest of crops, varied with the cropping system followed, nutrients used, and agronomic management practices adopted. Soils of WUP fall under low-to-medium category (< 0.75%) of organic C content (**Table 2**). Averaged across the cropping system and locations, 96%, 21%, 13%, and 22% of soils were low and 4%, 72%, 76%, and 57% of soils were under medium category for N (< 280 kg/ha), P (< 10 kg/ha), K (< 130 kg/ha), and S (< 10 mg/kg) contents. In these soils, responses to fertiliser application can be expected.

Analysis of micronutrients (i.e., DTPA extractable-Zn, Fe, Mn, and Cu in the different cropping systems indicated a varying degree of deficiencies (**Table 3**). Using a threshold of 0.6 mg/kg soil Zn, highest Zn deficiency was found in soils under the sorghum/pearl millet/maize-mustard/potato/wheat system, followed by the rice-wheat system, and the sugarcane-ratoon-wheat system. Iron deficiency in different cropping systems across WUP was 17% based on threshold of 4.5 mg/kg DTPA-Fe. The magnitudes of Mn and Cu deficiencies were smaller than Zn and Fe deficiencies.

In order to generate homogenous fertility management zones, different fertility parameters were classified into low, medium, and high categories by user-defined ranges. The ranges used for classification within low, medium, and high classes were (kg/ha): N < 120, 120 to 160 and > 160; P <13, 13 to 16 and > 16; and K <150, 150 to 250 and > 250, respectively. Based on the developed homogenous fertility zones (**Figure 3**), fertiliser recommendations can be developed for these zones.

Summary

Wide variations in the fertiliser use patterns were revealed under predominant cropping systems in the WUP through farmers' participatory surveys on nutrient management practices. Generally, fertiliser use was skewed in favour of N, whereas nutrients like K, S, and micronutrients were neglected. Based on different soil fertility parameters, predicted surface maps were generated and homogenous fertility management zones were developed. BC-SA

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References

FAI, 2011. The Fertiliser Association of India, New Delhi.

Page, A.L., R.H. Millar, and D.R. Keeney. 1982. Methods of soil analysis Part-2. ASA/SSSAm, Madison, WI, USA

Iftikar, W. G.N. Chattopadhayay, K. Majumdar, and G.D. Sulewski. 2010. Better Crops 94(3):12-14.

Sen, P., K. Majumdar, and G.D. Sulewski. 2007. Better Crops 91(2):10-11.

Sen, P., K. Majumdar, and G.D. Sulewski. 2008. Indian J. Fert. 4 (11):43-50.