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Methodology to map spatial variability of available nutrients in area of intensively growing potato (*Solanum tuberosum*) using remote sensing and GIS

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ABSTRACT

A methodology is developed for mapping spatial variability of available nutrients of soils of a pocket growing potato (*Solanum tuberosum* L.) crop using GIS. For this purpose potato growing pockets of the Jalandhar district were demarcated based on the available information, ground truth and classification of the IRS P6 AWiFS image. The classified potato area in the image was taken as background to generate the sampling site map and representative soil samples of potato fields from these sites were collected along with geographical coordinates using GPS receiver (E-TREX-VISTA, Garmin). Values of different parameters (like pH, OC, available P and K and micronutrients) were tagged with corresponding points and interpolation maps for each individual parameters were prepared using suitable semivariogram and kriging in remote sensing GIS software. These prepared maps were further classified giving suitable ranges of different soil parameters.

Key words: Geographic information system (GIS), Global positioning system (GPS), Major nutrient, Micronutrient, Multi-nutrient deficiencies, Spatial distribution

Fertilizer and nutrient recommendations for different crops are mostly region specific and very general in nature which results into a blanket application of fertilizer leading to its poor efficacy and wastage of costly resources as well as of environmental pollution. In addition, this has caused severe imbalance of nutrients in soil. The spatial variability of available nutrients properly mapped along with other relevant parameters will help to develop site specific nutrient management practices with increased productivity and profitability apart from checking nutrient imbalance and environmental pollution. The proper understanding of spatial nutrient variability, if integrated with fertilizer recommendation for the cropping system, can ensure the fertilizer use in adequate and balanced manner (Sen *et al.* 2008). Since, the rate of nutrient application will match with local available nutrient status, there will be improvement in efficiency and productivity with minimum damage to the environment.

Punjab being an important potato (*Solanum tuberosum* L.) growing state of India and contributes about 5% to national acreage and production. In Punjab, Jalandhar is the number one district with about 25% of potato acreage and production shares. In Jalandhar district there are few pockets where majority of farmers follow potato based cropping systems and during the main season a very large contiguous area of potato crop can be seen. Potato being the most important and responsive crop in the system receives maximum share of fertilizers. In addition the potato cultivation as well as other agricultural practices are highly mechanized and farmers generally have very small and meager amount of farm or animal based organic waste to recycle to the fields. Besides, farmers in rice-potato system don't allow rice crop residue to decompose and it is a general practice to burn the residue to facilitate early or timely planting of potato. These compulsive situations have led to severe deficiency and imbalances of nutrients in these potato growing pockets. Imbalances of available nutrients particularly build up of P and deficiency of K at many locations has been reported (Sharma 2004, Trehan *et al.* 2008). These high intensity cropping, poor recycling of organic residue and use of heavy doses of micronutrient free high analysis fertilizers has given rise to wide spread deficiency of even micronutrients in different districts of Punjab (Bansal *et al.* 1986, Singh *et al.* 1988). There seems urgent need to spatially map the emerging nutrient imbalances and deficiencies to suggest pocket specific management practices for these nutrients. Use of GPS in identifying exact location of sampling and further using GIS software for development of spatial distribution map can be very important in recommending the site specific nutrient management. Therefore, the present study was undertaken to assess the major (N, P and K) and micro (Fe,

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Cu, Zn and Mn) nutrient status of soils of potato growing areas in Jalandhar district of Punjab and to map their spatial variability using GPS and GIS to refine fertilizer recommendations and promote site specific nutrient management.

MATERIALS AND METHODS

The potato growing pockets of Jalandhar district were demarcated based on the available information, ground truth and classification of the IRS P6 AWiFS image (Dua *et al.* 2007). Approximate sampling points were marked in the classified image by counting number of pixels under potato crop to have atleast one sample point in every one to two square kilometers of potato area. Actual sampling was done while transacting the area through different roads and attempting to reach very close to the geographical coordinates of approximate sampling points mark in the image with the help of GPS. Representative soil samples of potato fields from 0 to 0.15 m depth were collected during October 2009 at every one to two kilometer distance using GPS receiver (E-TREX-VISTA, Garmin) to record geographical coordinates. To account for greater variability, depending upon visual observation, more number of samples were collected wherever needed. Sampling intensity was kept more in pockets having larger proportion of potato crop. Collected soil samples were processed and analysed for their chemical properties using standard techniques. Soil pH was determined in 1: 2 soil: water suspension, and organic carbon by wet acid oxidation of organic matter (Walkley and Black 1947). Available P and K were determined by Olsen *et al* (1954) and neutral ammonium acetate methods (Jackson 1971), respectively. Diethylenetriamine pentaacetic acid extractable Zn, Fe, Mn and Cu contents in the soils were determined by using "Hitachi" make atomic absorption spectrophotometer (Lindsay and Norwell 1978). After analyzing the samples for various macro and micronutrients, they were grouped into different categories (Low, medium, high and very high for P and K and deficient and sufficient for micronutrients).

The actual soil sample points marked using GPS were fed into the GIS environment in already digitized boundary of Jalandhar district. The classified potato area in IRS P6 AWiFS image was also taken as background to generate the sampling site map. Values of different parameters (like pH, OC, available P and K and micronutrients) were tagged with corresponding points and interpolation maps for each individual parameters were prepared using suitable semivariogram and kriging in remote sensing GIS software "Geomatica". Further, the maps generated for pH, OC, P, K and micronutrients (Zn, Cu, Mn and Fe) were classified taking the ranges for different parameters suitable for potato cultivation. The integration of classified maps of P and K and that of four micronutrients were generated to find out specific locale of single or multinutrients deficiency. GIS software was also used to estimate the area falling under different class of available nutrients.

RESULTS AND DISCUSSION

Sampling points: Out of 205 approximate sampling points marked in the image 35 points were sampled with less than 20 m of accuracy based on GPS navigation, 72 points were sampled with 20 to 50 m accuracy and 88 points were sampled with 50 to 100m accuracy. Remaining 10 points could not be sampled as we could not reach within 100m of approximate points marked in image due to some obstruction or absence of approach road.

Soil reaction and organic carbon: The reaction of the soil samples was near normal, pH value ranging from 6.14 to 8.74 with a mean value of 7.49 (Table 1). About 55% soil samples were having pH more than 7.5. The organic carbon content (OC) in these soils was low, ranging from 0.09 to 0.51 with a mean of 0.30%. Only 2.6% of soil samples falling in medium category indicated very precarious situation of soil health in these pockets. Due to very intensive and exhaustive cropping systems followed in the region, almost no recycling of crop residue and negligible availability of FYM has resulted into severe deterioration of soil organic carbon. In the majority of area following rice-potato-wheat cropping system in the district rice straw are never incorporated in soil and are burned after harvest

Table 1 Per cent soil samples from potato fields and potato growing area falling in different ranges of pH, organic carbon (%), available P and K.

pH		OC (%)		Available P (ppm)		Available K (ppm)	
Range	% samples	Range	% samples	Range	% samples	Range	% samples
6.0-6.5	5.1	= 0.2	19.8	<10	0.6	<105	87.9
6.5-7.0	15.3	0.2-0.3	28.0	10-20	30.6	105-150	10.2
7.0-7.5	24.2	0.3-0.4	31.2	20-30	58.0	150-200	0.6
7.5-8.0	33.8	0.4-0.5	18.5	>30	10.8	>200	1.3
>8.0	21.7	>0.5	2.6				
Range	*% area*	*Range*	*% area*	*Range*	*% area*	*Range*	*% area*
6.0-6.5	0.7	<0.2	8.6	<20	10.1	<50	13.8
6.5-7.0	15.5	0.2-0.3	44.0	20-30	79.9	50-105	75.3
7.0-7.5	36.2	0.3-0.4	37.9	30-40	8.9	105-150	10.7
7.5-8.0	29.0	0.4-0.5	9.3	>40	1.1	150-200	0.2
>8	18.8	>0.5	0.3				

to make field quickly available for subsequent potato crop. These facts might have resulted in decrease of organic matter in soils over a period of time.

Available phosphorus and potassium: More than 68% samples with available P more than 20 ppm indicated it's buildup in these soils (Table 1). In fact less than 1% of samples were deficient suggesting very conservative use of P fertilizers. Potato crop recovers only 10-15% of applied P during the growing season (Trehan *et al.* 2008) and the rest resides in the soil as less soluble products. The continuous application of phosphatic fertilizers to each crop in the potato based cropping systems generally results in the positive balance of this nutrient in soil as efficiency of applied P is very low and it comes in available form very slowly (Sharma *et al.* 2008). Therefore, it is needed to go cautiously on application of phosphorus depending on the soil test values.

Less than 2% samples were found to be high (150 – 200 ppm) in available K, whereas, 88% samples were low (<105 ppm) and remaining 10.2% samples tested medium (105–150 ppm) in available K status (Table 1). Potato crop being high feeder of K, many times its uptake exceeds even that of N. In fact, most of the potato based cropping systems have negative balance of K. In addition, different crops in the system do not show response to applied K as much as that of N resulting into its' lower application rate. Sharma *et al.* (2008) also reported deficiency of K has started appearing in all pockets of the Jalandhar district which is a matter of concern.

DTPA extractable micronutrient: The DTPA extractable Zn in these soil samples varied from 0.11 to 5.95 ppm with a mean value of 1.45 ppm. Considering 0.75 ppm as the critical limit for potato (Trehan *et al.* 2008), 29.3% of samples were found to be deficient (Table 2). Reasons for deficiency of Zn in these soils are intensive cropping system followed, poor organic residue recycling, low organic carbon and relatively higher pH. Sood *et al.* (2009) reported widespread deficiency of Zn in the soils due to increase in pH and decrease in organic carbon. The available (DTPA-extractable) Fe content of the soils varied from 2.11 to 47.47 ppm with a mean value of 14.85 ppm. Considering 6.6 ppm as the critical limit for potato cultivation (Trehan *et al.* 2008), the percentage of samples deficient in Fe was 23.6%. Sood *et al.* (2009) reported that the available Fe content was correlated positively to organic carbon and negatively with soil pH of the soil.

Table 2 Per cent soil samples from potato fields and potato growing area in deficient and sufficient in available micronutrients.

Micro-nutrient	Zn	Cu	Mn	Fe	Zn	Cu	Mn	Fe
Critical limit (ppm)	0.75	0.32	3.00	6.60	0.75	0.32	3.00	6.60
	Per cent samples				*Per cent area*			
Deficient	29.3	15.9	13.4	23.6	13.7	11.4	11.1	14.3
Sufficient	70.7	84.1	86.6	76.4	86.3	88.6	88.9	85.7

The DTPA extractable Cu varied from 0.06 to 9.00 ppm with the mean value of 0.63 ppm. There were about 15.9% samples deficient taking critical limit of 0.32 ppm and likely to respond to Cu application (Table 2). The content of DTPA extractable (available) Mn in the studied soil samples varied from 0.70 to15.00 with mean value 5.54 ppm and based on the threshold limit (3.0 ppm) there were about 13.4% of the soil samples deficient and likely to respond to external application of Mn.

Spatial distribution of available major and micronutrients

Spatial variability maps were prepared after kriging of point values of different parameters in 'Geomatica' environment. Classification results clearly showed the specific locales of the pockets where attention is required with respect to management of major and micronutrients.

Soil pH and organic carbon: After kriging for soil pH and classification in the five classes in the range of 6.0 to 6.5, 6.5 to 7.0 and 7.0 to 7.5, 7.5 to 8.0 and more than 8.0 potato area falling under these categories were 0.7, 15.5, 36.2, 29.0 and 18.8%, respectively (Table 1 and Fig 1). The 47% area plunged in last two categories with pH value more than 7.5 may be considered a situation not very suitable for potato cultivation. This figure is somewhat smaller when compared with number of samples (55%) above pH 7.5. The neutral to slightly alkaline pH may be attributed to application of higher amount of inorganic fertilizer material in the soil for potato crop, which resulted in the retention of basic cations on the exchangeable complex of the soil and low level of organic carbon which resulted in poor buffering capacity (Sharma *et al*. 2008). Similarly, area under organic carbon in range <0.2, 0.2 to 0.3, 0.3 to 0.4, 0.4 to 0.5 and >0.5%, were 8.6, 44.0, 37.9, 9.3 and 0.3%, respectively (Table 1 and Fig 1). In fact, this situation of higher pH value (near 8) with low organic carbon cannot be treated as most suitable situation for potato cultivation. The area having organic carbon in medium range was much smaller (not even 0.5%) as compared to number of samples (2.6%). This happened because while kriging value at any point depended on weight given to value of different nearby samples. There were more points with lower value, so proportionally more area came under lower organic carbon.

Available phosphorus and potassium: Area under medium (10-20 ppm), high (20-30 ppm) and very high (>30 ppm) available P was 10.1, 79.9, and 10%, respectively (Table 1, Fig 1). More area under higher value of available P as compared to number of samples was for similar reason as in case of organic carbon. This further indicated that in potato based system due to poor efficiency of P in potato crop and regular application to all crops of the system has resulted into it's high build up in the soil. Many earlier works has also reported positive balance of P in the potato based systems.

More than 89% of area under potato growing pockets were low in available K (<105 ppm) for potato crop as compared to 88% of soil samples (Table 1, Fig 1) which

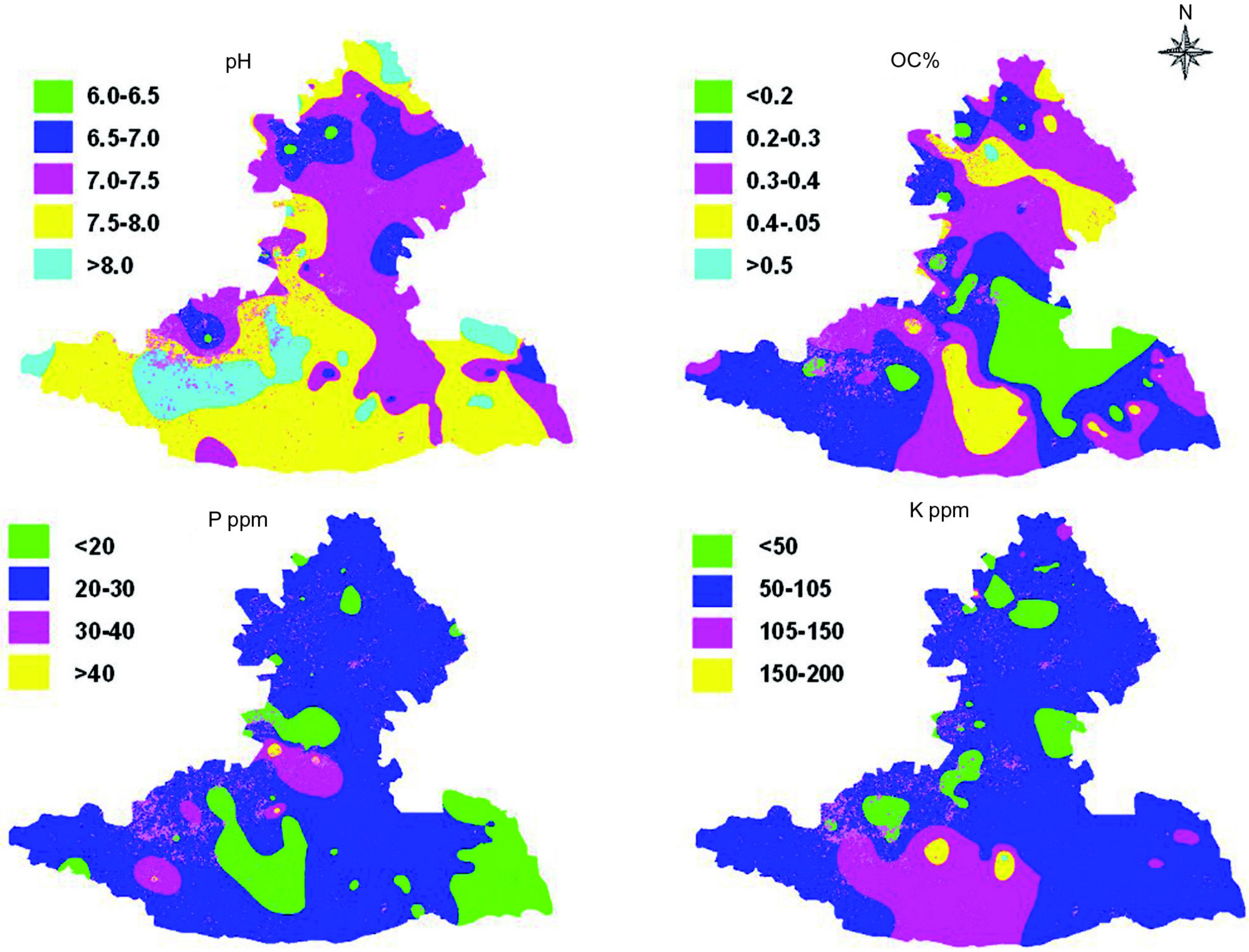

Fig 1 Spatial distribution of soil pH, organic carbon (OC%), available P and available K in potato growing pockets of Jalandhar district of Punjab. (pink pixels represent potato area)

was the result of very intensive cultivation, along with sandy loam texture and poor cation holding capacity of soils in these pockets. Potato crop is one of the most exhaustive crop to soil potassium and potato based cropping system mostly have negative balance for this nutrient. In these pockets there appears very severe pressure on soil K reserve and to maintain the reserve there is need to apply as much K as to replenish the amount removed by the crops of the system.

Integration of P and K map by overlaying showed that about 8.5% area was high in P and medium in K, whereas, about 81.5% area was high to very high in P but low in available K. Similarly, about 2.5% area was medium in available K but low in available P and 7.6% area was low in both available P and K. Therefore, while recommending fertilizer for these areas one must take care of soil status. Not all fields having high requirement of K need high application of P and low requirement of K need less application of P.

Micronutrients: In general percent area under micronutrients deficiency was less than the percent of samples, and percent deficient area under individual micronutrient varied from 11.1% for Mn to 14.3% for Fe (Table 2). It is important to note that not even a single field was deficient in all micronutrients, therefore, there is a need to apply these nutrients on soil test basis. Multi-micronutrients map obtained from integration of four maps of individual micronutrients made it clear that less than 1% area was deficient in all four micronutrients, about 1.78% area was deficient any of three elements (Zn, Cu, Mn; Zn, Cu, Fe; Cu, Mn, Fe or Zn, Mn Fe), 8.03% area were deficient in at least two elements and 26.69% area was deficient in only one of these four elements (Table 3). However, majority of potato area (62.92%) had sufficient levels of all four micronutrients, hence does not require immediate attention for application of micronutrients. It was clear that out of 37% area deficient in one or more nutrients majority of area (26.69%) was deficient in only one nutrient element. This becomes important management point of view as it will require selective use of different micronutrients at different location in the pockets. From these spatial distribution maps it was also evident that deficiency zones of Cu and Mn was in the area where potato fields were more concentrated, whereas, deficiency of Zn was more in the area where potato fields were not so dense. It infers that percent areas of the district deficient in

Table 3 Area under various multi-micronutrient deficiency categories of potato growing region in the Jalandhar district in Punjab

Fe	Cu	Mn	Zn	Area (%)
D	D	D	D	0.68
D	D	D	S	0.90
D	D	S	D	0.33
D	D	S	S	1.79
D	S	D	D	0.01
D	S	D	S	0.40
D	S	S	D	4.48
D	S	S	S	5.68
S	D	D	D	0.45
S	D	D	S	0.27
S	D	S	D	0.27
S	D	S	S	6.72
S	S	D	D	0.82
S	S	D	S	7.61
S	S	S	D	6.68
S	S	S	S	62.92
				100.00

S, Sufficient, D, deficient

Zn are likely to be much more than what indicated for potato pockets, while that may not be true for Cu and Mn.

The spatial classified maps generated under the study will be useful for identifying specific locale of potato growing pockets with different nutrient management problems. While large area came under high P, requiring low or less application of this nutrient, this study also highlighted almost whole area low in OC indicating severe N deficiency and identified locales with low available K. With the identification of locales with one or more macro/ micronutrients deficiency it is possible to suggest very site specific recommendations and management. These maps can further be overlaid on the digitized boundaries of village/block/tehsil to prioritize the villages which need immediate attention of the district officials, scientists, and individual farmer in respect of application/management of required amount and kind of macro and micronutrient elements. Further, with the use of prescription equations yield target specific recommendation may also be given for all fertilizer nutrients. It is also possible to monitor the changes taking place at different locations over a period of time due to different cropping systems and management practices with respect to nutrient status and other soil properties. In addition such studies may be extended to map spatial variability of available nutrients of large number of pockets in order to progress towards precision farming.

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