A simplified soil nutrient information system: study from the North East Region of India

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Soil fertility has direct implications on the agricultural production scenarios of a region. Surface soil samples at 1 km grid were collected to assess the fertility status of Lakhimpur district (Assam) in North East India. Fertility parameters like soil organic carbon, available nitrogen, phosphorus, potassium, iron, manganese, zinc and copper were determined using standard analytical procedure. Spatial distribution maps of the soil parameters were generated using regularized spline method in ArcGIS 10.0. The average soil organic carbon content was 1.05% and the maximum area was under high availability status (78%). In the case of nitrogen, 57% of the area was under low availability status. In the case of available potassium and phosphorus, the areas under low availability status were 48% and 49% respectively. But for micronutrients, in general, the availability status was high except for zinc, which indicated that 40% of the area was under low availability. A methodology was developed to integrate the individual nutrient layers using a set of decision rules to identify the multinutrient deficient zones. The integrated map showed that 24% of the area had multiple nutrient deficiencies and fell under high priority zone that warrant immediate nutrient management interventions to mitigate the situation.

Keywords: Decision rules, multinutrient deficiency, soil fertility, spatial variability, spline interpolation, soil information system.

SOIL fertility plays an important role in soil productivity. Information on spatial variation of fertility parameters of soil is an essential input in precision agriculture and other soil management decisions. Soil fertility information helps to relate the nutrient input rates with the crop demand and thus conserve the resources. The use of fertilizers without considering the soil fertility status and crop requirement may adversely affect both soil and the crops[1]. Presently, Indian agriculture is going through a 'net negative nutrient balance' and in a prevailing regime of widespread negative nutrient balance, soil cannot support a good crop[2,3]. Moreover, such a situation is likely to have negative impact on the sustainability of the agricultural production systems. Thus, it is evident that information on the soil nutrient status is essential for sustainable management of agricultural production systems.

There have been several attempts to study and map the spatial variability of either single or multiple soil fertility parameters[4–10]. However, these studies lacked integrated thematic information with respect to different soil fertility parameters. Such information would help users to have a comprehensive idea about the soil nutrient status of an area from a single map and also avoid aberrations in making management decisions.

Lakhimpur district lacks in a comprehensive[9,10] information about fertility status of soil. It is envisaged that a systematic study to assess the fertility status of Lakhimpur district through geographic information system (GIS) can help in making nutrient management decisions. An attempt has been made here to assess, map and integrate the spatial variability of soil fertility parameters namely soil organic carbon (SOC), nitrogen (N), phosphorus (P_2O_5), potassium (K_2O), iron (Fe), manganese (Mn), zinc (Zn) and copper (Cu). This was achieved through spatial interpolation and by developing a unique methodology to identify multinutrient deficient zones using GIS tool.

Methodology

Study area

Lakhimpur district is situated in the northeast corner of Assam in the North Eastern Region of India between the Himalayan foothills of Arunachal Pradesh in the north and the Brahmaputra River in the south. It is located between 26°48′N–27°42′N and 93°42′E–94°35′E and covers an area of 235,024 ha. The district falls in the upper Brahmaputra valley region and the general gradient of the valley is from north to south. In the northern

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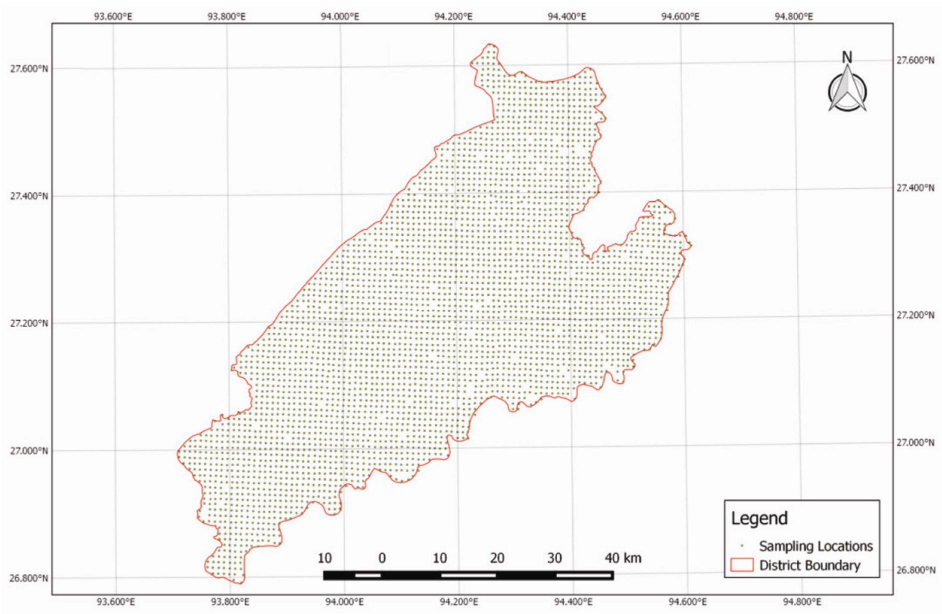

Figure 1. Soil sampling locations, Lakhimpur district, Assam.

parts of the district, the physiography is dominated by piedmonts at the foothills of Himalaya. The area is predominantly covered by Quaternary surficial deposits with frequent exposure of the upper tertiary sediments along the foothills[11].

The district is characterized by humid sub-tropical climate[9]. The mean annual rainfall is 3600 mm and the mean annual maximum and minimum temperatures are 32.4°C and 20.1°C respectively[11].

The soils of the district are classified as *Dystric Eutrudepts* (devoid of bases due to high rainfall) and *Typic Udipsamments* (presence of river channels, channel bars, etc.)[12]. The former type of soils developed on piedmont plain are deep, well drained, silty loam to loam in texture. The latter developed on very gently sloping alluvial plain are very deep, well-drained, sandy loam to loamy sand in texture[11].

Base map preparation, soil sample collection and analysis

The base map was prepared from Survey of India (SoI) toposheets at 1 : 50,000 scale and was demarcated with grid points at 1 km interval using ArcGIS 10.0. A total of 3610 surface soil samples (0–25 cm) were collected from the study area at an interval of 1 km excluding the inaccessible areas (Figure 1). Soil samples were processed, passed through 2 mm sieve and stored for laboratory analysis. SOC content was determined by wet digestion method[13], potassium (K) was determined by extraction with neutral normal ammonium acetate solution[14], available nitrogen (N) was measured by alkaline permanganate method[15] and available phosphorus (P) by Bray's P-1 method[16]. Micronutrients namely Zn, Fe, Cu and Mn were determined using the diethylene triamine penta acetic acid (DTPA) extraction method[17] and were measured using an atomic absorption spectrophotometer (Simadzu model No. AA-6300).

Generation of nutrient maps

Spatial interpolation methods are used for creation of continuous surface from geo-referenced point observations. There are quite a lot of spatial interpolation methods and they fall into any of the three categories namely: (i) non-geostatistical methods, (ii) geostatistical methods and (iii) combined methods. Triangular irregular network (TIN), inverse distance weighting (IDW) and spline methods fall under the first category. Simple kriging, ordinary kriging, block kriging, cokriging, indicator kriging, probability kriging, etc. are some of the spatial interpolation methods that come under the second category. The third category is represented by stratified IDW, stratified ordinary kriging, stratified thin plate spline, etc.[18,19]. Various methods have been used by different authors for prediction of spatial variation of soil properties and have given differing inferences about the best performing interpolation method[20–24]. For the spatial prediction of soil organic matter, salinity, pH and available phosphorus, spline method performed well compared to other methods[20,24]. A surface created by spline interpolation passes through the data points used for creating the surface, but the surface created by IDW or kriging will not pass through the data points used for creating the surface. Spline method is suitable for gently varying surfaces. Moreover, it performs better when the samples

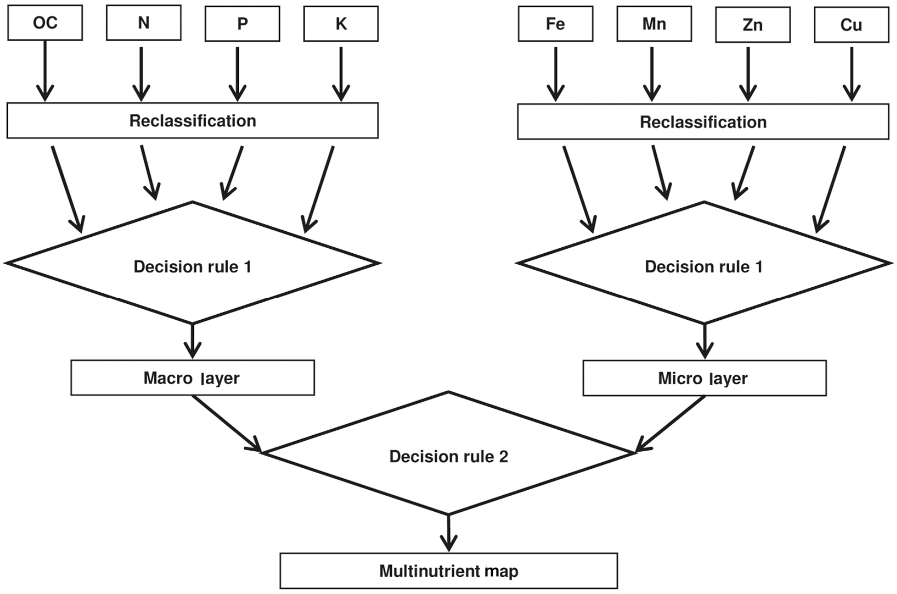

Figure 2. Flow chart of the methodology followed to integrate various nutrient layers using GIS.

are regularly spaced and dense[18,19,25–27]. The soil samples for the present study were collected in a regular grid fashion and a total of 3610 samples were used for interpolation. As the aim of the study was not to assess the performance of interpolation methods and as the sampling strategy qualifies the best performing conditions for spline interpolator, regularized spline method was used to create surfaces of soil nutrient parameters under consideration, using ArcGIS 10.0 software.

Integration of nutrient layers

In order to identify the multinutrient deficient zones, the layers of soil parameters were integrated through raster overlay operation in GIS. While generating an interpolated surface, the software creates a 32-bit floating point raster dataset and the interpolated values are assigned to the respective cells. In the present study, there were 235,024 cells in the interpolated surface and virtually each cell would have a unique value for the parameter considered. If we overlay the eight interpolated surfaces, i.e. SOC, available N, P_2O_5, K_2O, Fe, Mn, Zn and Cu, it would generate a huge number of combinations that would be difficult to comprehend and handle. Hence an improvised methodology (Figure 2) was adopted which would integrate the information from all the layers into a single multinutrient layer in an efficient and meaningful way.

At first, surfaces created for different soil parameters were categorized[28] into low, medium and high according to the nutrient availability status (Table 1). Using reclassification tool, the low, medium and high categories were given values of 1, 2 and 3 respectively.

Table 1. Categorization for the soils parameters studied

	Categories		
Parameter	Low	Medium	High
OC (%)	<0.4	0.4–0.75	>0.75
N (kg ha^{-1})	<280	280–560	>560
P (kg ha^{-1})	<34	34–68	>68
K (kg ha^{-1})	<135	135–335	>335
Fe (mg kg^{-1})	<4.5	4.5–9.0	>9.0
Mn (mg kg^{-1})	<3.5	3.5–7.0	>7.0
Zn (mg kg^{-1})	<0.6	0.6–1.2	>1.2
Cu (mg kg^{-1})	<0.2	0.2–0.4	>0.4

The multinutrient map was generated by integrating each of the reclassified soil parameter layers using a set of decision rules in a raster environment (Tables 2 and 3). Decision rule 1 was used to combine four layers, viz. OC, available N, P and K into a single layer say macro layer. Likewise Fe, Mn, Zn and Cu were also combined into a single layer say micro layer using decision rule 1.

This operation resulted in two layers namely macro layer and micro layer. These two layers were again combined into a single multinutrient map (macro + micro layer) using another set of decision rules namely decision rule 2 (Table 3).

Results and discussions

Soil fertility status

The mean soil organic carbon content was 1.05% (Table 4), whereas the mean available nitrogen content was 270 kg ha^{-1} and the values varied between 38 and

Table 2. Decision rule 1 used for generating macro and micro layers

IF	All the layers have value 1	High priority area
ELSE IF	Three layers have value 1 and one layer has value 2	High priority area
ELSE IF	Three layers have value 1 and one layer has value 3	High priority area
ELSE IF	Two layers have value 1 and other two layers have value 2	High priority area
ELSE IF	All the layers have value 2	Medium priority area
ELSE IF	Three layers have value 2 and one layer has value 1	Medium priority area
ELSE IF	Three layers have value 2 and one layer has value 3	Medium priority area
ELSE IF	Two layers have value 2, third layer has value 1 and fourth layer has value 3	Medium priority area
ELSE IF	One layer has value 2 and two layers have value 1 and fourth layer has value 3	Medium priority area
ELSE IF	Two layers have value 1 and other two layers have value 3	Medium priority area
ELSE IF	All the layers have value 3	Low priority area
ELSE IF	Three layers have value 3 and one layer has value 1	Low priority area
ELSE IF	Three layers have value 3 and one layer has value 2	Low priority area
ELSE IF	Two layers have value 3 and other two layers have value 2	Low priority area

Table 3. Decision rule 2 used for integrating macro and micro layers

IF	Both macro and micro layers have high priority	High priority area
ELSE IF	Macro layer has high priority and micro layer has medium priority	High priority area
ELSE IF	Macro layer has high priority and micro layer has low priority	High priority area
ELSE IF	Macro layer has medium priority and micro layer has high priority	High priority area
ELSE IF	Macro layer has medium priority and micro layer has medium priority	Medium priority area
ELSE IF	Macro layer has medium priority and micro layer has low priority	Medium priority area
ELSE IF	Macro layer has low priority and micro layer has high priority	Medium priority area
ELSE IF	Macro layer has low priority and micro layer has medium priority	Low priority area
ELSE IF	Both the layers have low priority	Low priority area

Table 4. Fertility status of soils in Lakhimpur district

Parameter	Mean	Range	SD
OC (%)	1.05	0.11–4.5	0.48
N (kg ha^{-1})	270	38–472	58.13
P_2O_5 (kg ha^{-1})	38	5–129	19.17
K_2O (kg ha^{-1})	151	28–645	82.37
Fe (mg kg^{-1})	84	12–196	29.38
Mn (mg kg^{-1})	17	2.6–83	11.07
Zn (mg kg^{-1})	0.64	0.12–1.97	0.20
Cu (mg kg^{-1})	1.20	0.13–10.3	0.60

472 kg ha^{-1}. The mean available P_2O_5 content was 38 kg ha^{-1}. The available K_2O content varied widely between 28 and 645 kg ha^{-1} with a mean value of 151 kg ha^{-1}. These values are comparatively lower than those reported earlier[9,10]. The mean available Fe, Cu, Zn and Mn contents were 84, 1.20, 0.64 and 17 mg kg^{-1} respectively, which were comparable to the previous reports[9]. The Brahmaputra alluvium in general is reported to have adequate micronutrients due to nutrient rich parent material and relatively lesser cropping intensity in the region[29].

Spatial distribution of fertility parameters

Spatial distribution map (Figures 3 and 4) of soil parameters indicated the areas under low, medium and high categories (Table 5). The data showed that the area under low and medium nitrogen status were 57% and 43% respectively (Figure 3, Table 5). A similar trend was also observed in the case of soil available P and K. However, SOC content showed that 78% of the area was covered under high category. All micronutrients showed dominance of high status except Zn which indicated that 40% and 60% of the areas were under low and medium categories respectively. This may be due to improper use of soil nutrient management techniques followed by farmers of that area.

Multinutrient maps (macro layer, micro layer and macro + micro layer) were generated by evaluating the status of the soil nutrient parameters considered in the study for a particular cell based on the decision rules (Tables 2 and 3). In case of macro layer (layer consisting of SOC, available N, P and K), it can be observed that nutrient deficiency is more concentrated on the northern part of the district and it constitutes (Figures 3 and 5 and Table 6) 24% of the geographical area (high priority area). On perusal of the individual nutrient maps (Figure 3), one can see that these are the areas with low availability of component nutrients for this layer. This zone requires immediate nutrient management interventions to restore the nutrient balance as the soil is already depleted of their fertility capacity as the result of intensive cropping or due to leaching loss[30]. This should be followed by medium priority area (Table 6) which accounts for 74% of the geographical area wherein the interventions should be such that to prevent further deterioration of the soil fertility

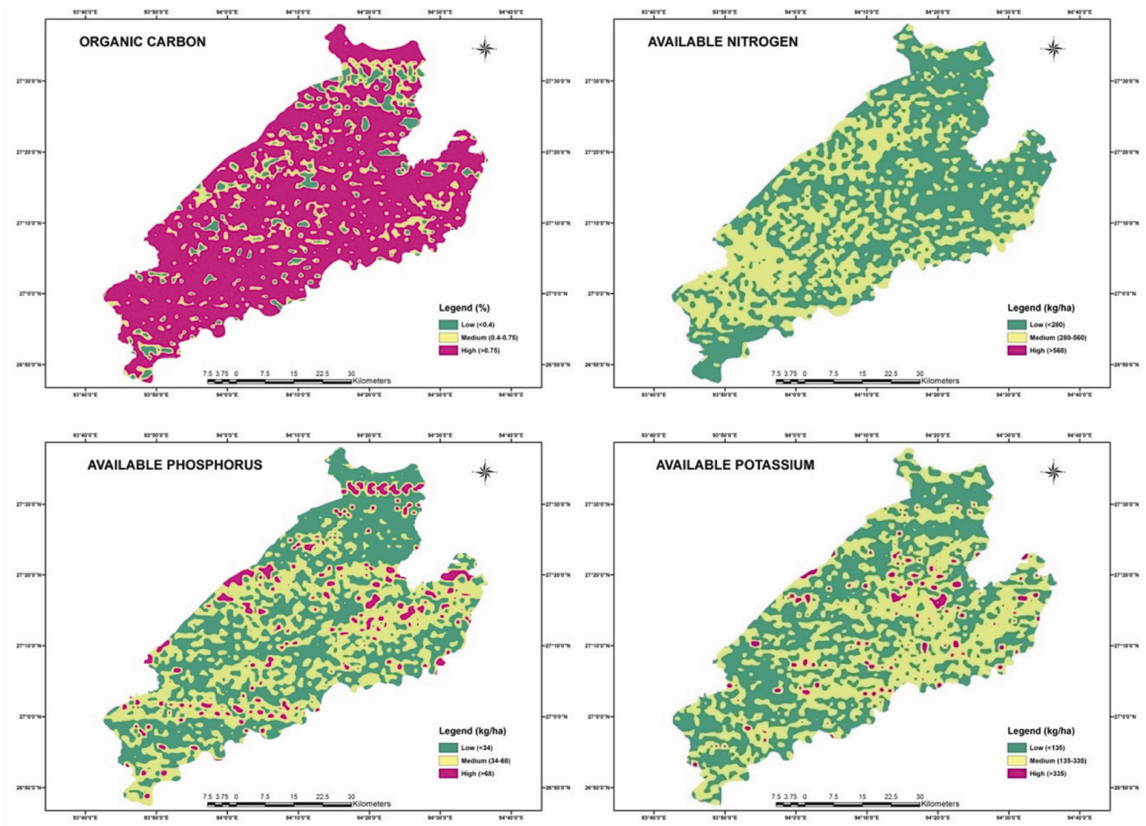

Figure 3. Spatial distribution of SOC, available N, P and K in Lakhimpur district.

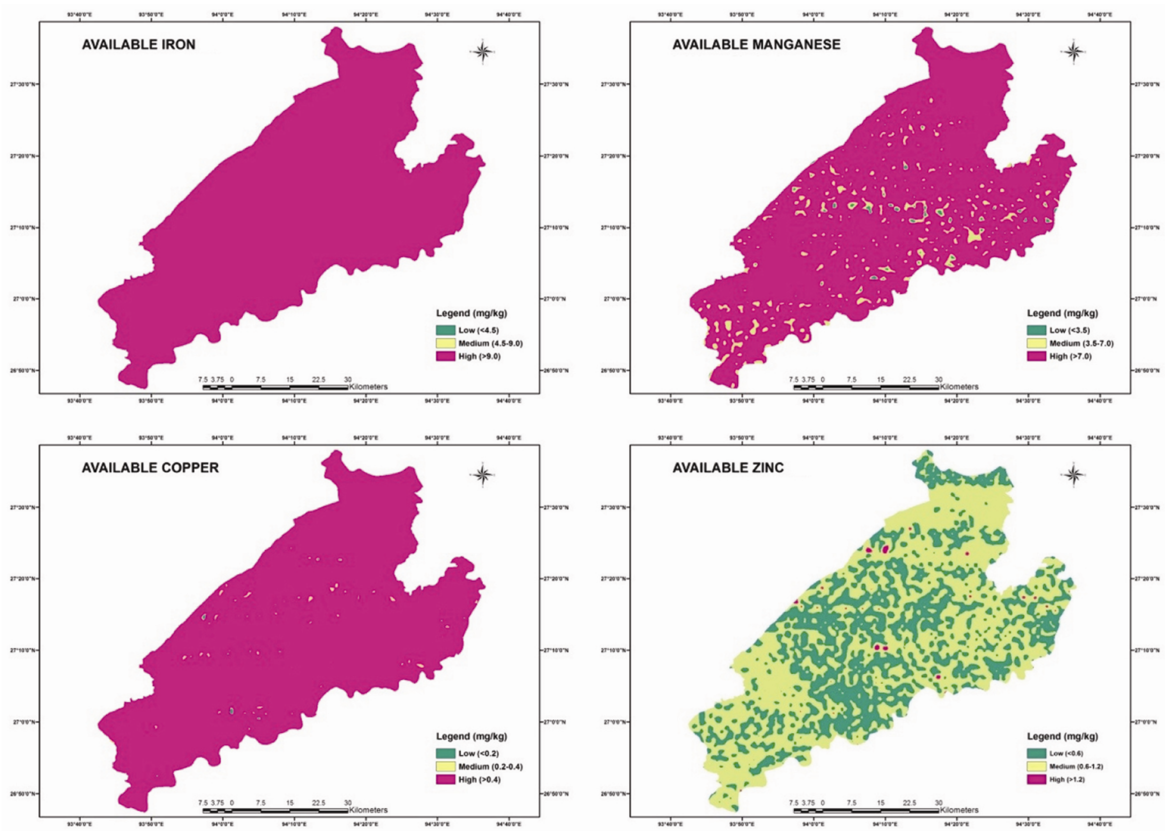

Figure 4. Spatial distribution of available Fe, Mn, Cu and Zn in Lakhimpur district, Assam.

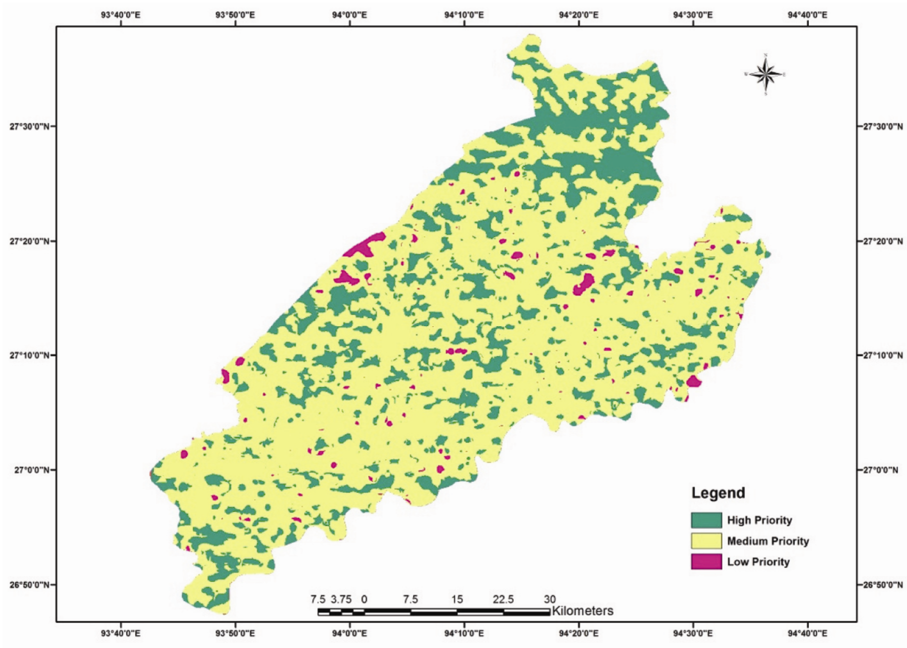

Figure 5. Multinutrient map (macro layer), Lakhimpur district, Assam.

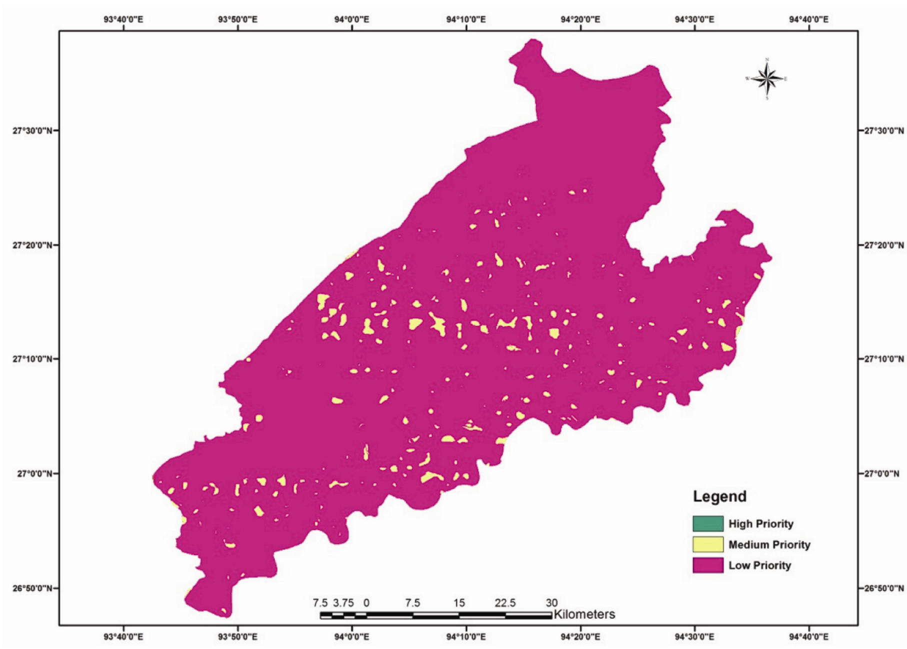

Figure 6. Multinutrient map (micro layer), Lakhimpur district, Assam.

through suitable management practices. In the low priority areas (2% of geographical area), care should be taken to avoid excess application of fertilizers as over-application of fertilizers may not entail significant benefit to the agricultural production system and may result in wastage of resources[31].

In case of micro layer (layer consisting of available Fe, Mn, Zn and Cu), 97% of the total geographical area was under low priority (Figure 6 and Table 6). Barring available Zn, nutrient availability status was dominantly high for micronutrients (Figure 4 and Table 5). On evaluation of the individual spatial distribution maps for available Fe, Mn, Zn and Cu, one can observe that the availability status of Fe is high for 100% of the area and the areas of low availability of Mn and Cu are negligible. This resulted in almost all the area falling under low priority zones in the multinutrient map for micro nutrients (micro layer).

But, when we combine the macro and micro layers using decision rule 2 (Table 3), no significant change was

Table 5. Distribution of area under different nutrient categories in Lakhimpur district

	Low category area (ha)	Medium category area (ha)	High category area (ha)
N	134,154 (57%)*	100,870 (43%)	0 (0%)
P	115,176 (49%)	106,574 (45%)	13,274 (6%)
K	114,009 (48%)	115,369 (49%)	5646 (3%)
OC	12,351 (5%)	40,165 (17%)	182,507 (78%)
Fe	0 (0%)	0 (0%)	235,024 (100%)
Mn	861 (~0%)	138,76 (5%)	220,287 (95%)
Cu	108 (~0%)	1061 (~0%)	233,855 (100%)
Zn	93,457 (40%)	140,805 (60%)	762 (~0%)

*Values in parenthesis indicate the percentage of geographical area.

Table 6. Spatial distribution of multinutrient priority zones in Lakhimpur district

Category	Macro layer	Micro layer	Macro + micro layer
High priority area (ha)	56394 (24%)*	0 (0%)	56394 (24%)
Medium priority area (ha)	174482 (74%)	7517 (3%)	174482 (74%)
Low priority area (ha)	4148 (2%)	227507 (97%)	4148 (2%)
Total	235024 (100%)	235024 (100%)	235024 (100%)

*Values in parenthesis indicate the percentage of geographical area.

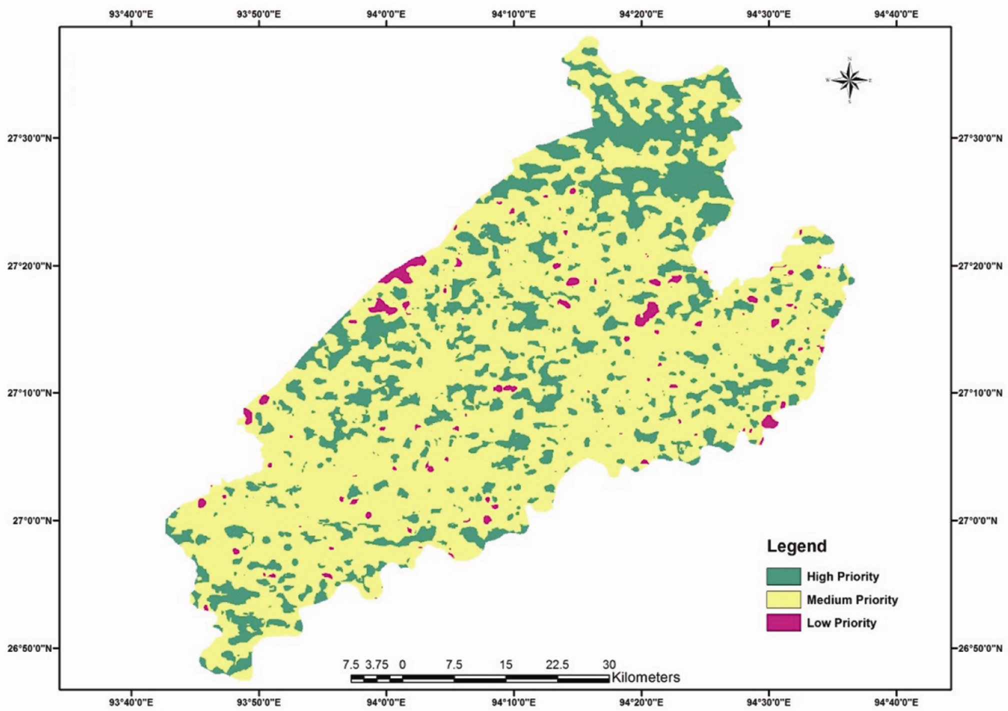

Figure 7. Multinutrient map (macro + micro layers), Lakhimpur district, Assam.

observed in the resultant map (micro + macro layer), i.e. either in the extent or the spatial pattern of nutrient zones (Figures 5 and 7 and Table 6) when compared to that of the macro layer. This is due to the fact that while integrating macro and micro layers (decision rule 2), macro layer was given more preference in the logical statements. For example, if the macro layer has high priority and micro layer has low priority, the corresponding area in the integrated layer will be classified as high priority area. Likewise, if the macro layer has medium priority and micro layer has low priority, the corresponding area in the combined macro + micro layer will be classified as medium priority area (Table 7). Moreover, the spatial pattern of the micro layer was such that medium priority zones overlapped with high or medium priority area of macro layer. In addition, there was no high priority area

Table 7. Values of thematic maps extracted for thirty random locations

Thematic layers											
Macro + Micro layer	Macro layer	Micro layer	Cu	Zn	Mn	Fe	N	P	K	OC
MP	MP	LP	H	L	H	H	M	L	M	H
HP	HP	LP	H	M	H	H	L	L	L	M
MP	MP	LP	H	M	H	H	L	L	M	H
HP	HP	LP	H	L	H	H	L	L	L	M
HP	HP	LP	H	L	H	H	L	L	L	M
LP	LP	LP	H	M	M	H	M	M	H	H
HP	HP	LP	H	L	H	H	M	L	L	L
MP	MP	LP	H	M	H	H	L	H	M	H
MP	MP	LP	H	L	H	H	M	L	L	H
HP	HP	LP	H	L	H	H	L	L	L	H
LP	LP	LP	H	M	H	H	M	H	M	H
MP	MP	MP	H	L	L	H	L	L	M	H
HP	HP	LP	H	M	H	H	L	L	L	L
LP	LP	LP	H	M	H	H	L	H	H	H
MP	MP	MP	H	L	M	H	M	M	M	H
MP	MP	MP	H	L	L	H	M	L	M	H
HP	HP	MP	H	L	L	H	L	M	L	M
MP	MP	MP	H	L	L	H	M	L	L	H
HP	HP	LP	H	M	H	H	L	L	L	H
MP	MP	MP	H	L	M	H	L	M	L	H
HP	HP	LP	H	M	H	H	L	L	L	H
HP	HP	LP	H	M	H	H	M	L	L	L
MP	MP	MP	H	L	L	H	M	M	M	H
MP	MP	LP	H	M	H	H	M	M	M	H
HP	HP	LP	H	L	H	H	L	L	L	L
HP	HP	LP	H	M	H	H	L	L	L	M
HP	HP	LP	H	L	H	H	L	L	L	H
MP	MP	LP	H	L	H	H	M	L	M	H
HP	HP	LP	H	M	H	H	L	L	L	M
MP	MP	LP	H	M	H	H	L	M	M	H

HP, High priority; MP, Medium priority; LP, Low priority; H, High nutrient status; M, Medium nutrient status; L, Low nutrient status.

in the micro layer which would have influenced the spatial pattern of the map while generating the macro + micro layer.

The benefit of such multinutrient deficiency zone delineation is that it can identify the location of both the deficiency of each of the nutrients and a combination of nutrients. Multinutrient map can locate areas that warrant immediate attention by planners and resource managers. The macro layer and micro layer can help planners to concentrate their efforts on the high priority locations, and this becomes more convenient when the resources are limited. A single map can give a comprehensive picture about the fertility status of the area which would be handy for the planners. Moreover, the methodology presented here is very simple and flexible. It involved less generalization and retained the essence of spatial variability information contained in individual layers[32]. One can easily modify the criteria or decision rules for integrating the nutrient layers so that it can perfectly fit to the site-specific conditions.

Conclusion

The spatial distribution map of various soil fertility parameters like SOC, available N, P, K, Fe, Mn, Zn and Cu were generated from point observations for Lakhimpur district. It can be said that spline interpolation is an effective method to create the spatial distribution maps of soil fertility parameters from geocoded point observations. From the spatial distribution map of these fertility parameters, multinutrient deficiency zones can be identified for prioritization of management zones using a set of decision rules. The methodology adopted in this study resulted in maps which are comprehensive and can be used in making nutrient management decisions. Decision rules used in the present study are flexible and can be easily modified to suit specific requirements and situations. The present study indicates that the alluvial soil of upper Brahmaputra valley is under nutrient stress and 24% of the study area requires immediate interventions to restore its productive potential.

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