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GIS-aided mapping of DTPA extractable copper in the soils of Punjab-NW India.

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ABSTRACT

Detailed characterization of soils of Punjab was carried out. Data for various soil characteristics are presented agro-eco-subregion wise. The descriptive statistics on soil characteristics indicated that the range of pH, electrical conductivity (EC), calcium carbonate, sand, silt, clay, available K, available P, cation exchange capacity (CEC) and exchangeable sodium percentage (ESP) was 2.53, 4.43(dS m^{-1}), 1.55(%), 9.96(%), 81.77(%), 73.5(%), 39.2(%), 1159.2(kg ha^{-1}), 236.88(kg ha^{-1}), 13.63 (cmol(p^+)kg^{-1}) and 33.1(%) respectively. The DTPA-Cu content ranged from 0.3 to 2.38 mg kg^{-1} with a mean value of 1.03 mg kg^{-1}. GIS-aided thematic maps indicated that Cu deficiency was not a problem in Punjab soils as only a part of Hoshiarpur and Ropar area of Siwalik hills and undulating eco-subregion in Punjab are deficient. Based on critical limit as 0.2 mg kg^{-1}, only 0.36 per cent (181.30 km^2) of the total geographical area of Punjab was affected by Cu deficiency.

Key words: Punjab, DTPA-Cu, GIS and thematic maps

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INTRODUCTION

The continuous use of high analysis nitrogen and phosphatic fertilizers in the intensive cropping system with diminishing use of organic manures has resulted in the depletion of micronutrient cations from the soil reserves. The micronutrient deficiencies which were sparse and sporadic initially [1] are now widespread, especially of Zn and Fe throughout the country. Maps illustrating the geographic distribution of nutrient in the state of Punjab should contribute to the improvement and sustainability of agriculture and livestock production to improvements in diet quality and extent of plant, human and animal deficiencies. In addition maps will be useful in considering the consequences of land application of copper laden solid waste and sewage sludge. Such maps will also be needed to characterize and interpret the geographic distribution of plant available micronutrients, regional patterns of deficiencies in plant, animal and human beings and their relationship with soil parent material, genesis and surface geology.

Micronutrient deficiency frequently occurs in arid and semi-arid regions of the Indo-Gangetic plains of India and is exhibited mainly in upland crops (e.g. sugarcane, sorghum, wheat, chickpea and groundnut) grown on soils with coarse texture, high pH, high calcium carbonate content and poor retention of water and nutrients [2]. The identification copper deficiencies in agriculture crops stimulated early efforts to delineate their geographic distribution. However, even after three decades of intensive research on these elements in Punjab, a simple state level map showing their status is still not available. This is not due to the lack of work but mainly on account of following of unsystematic sampling techniques. In view of the necessity of comprehensive soil resource information for developing sustainable land use plans, there is an urgent need for developing a soil resource map using latest techniques.

In this digital age GIS has many advantages compared with the paper map. The digital data are brought into GIS and then it is stored in a standard format. It is possible to update, share, retrieve, manipulate and analyze quickly. Once a GIS database is created it will be useful for long period and its updating is easy. Integration of available copper status data collected from geographically well-defined mapping units of soil maps using GIS and its interpretation in relation to inherent soil characteristics using principles of soil genesis is required to understand long-term availability of this micronutrient for sustaining intensive agriculture in Punjab. Using Arc info GIS in Patiala district of Punjab Minakshi et al. [3] observed that about 11 % (39,369ha) of total area of district was deficient in Zinc. Only 5, 4 and 5% of the area was deficient in Cu, Mn and Fe respectively. Deficiency of two or three micronutrients in combinations was sparsely distributed in maps. The maps generated through remote sensing help in delineating the homogeneous units to decide the sampling size and thereby saving a lot of time. This also helps to monitor the changes in micronutrient status over a period of time as geo-referenced sampling sites can be revised with the help of GPS. Which is other wise difficult in the random sampling [4].

Accordingly, the present investigation was undertaken to prepare maps showing geospatial distribution of DTPA-extractable copper of the soils of Punjab using Geographic Information System (GIS).

MATERIALS AND METHODS

Description of area: Punjab state lies between $29^{0}30^{/}$ and $32^{0}32^{/}$ N latitude and $73^{0}55^{/}$ and $76^{0}55^{/}$ E longitudes. It is bound by Pakistan in the west, Jammu and Kashmir in the north, Himachal Pradesh in the northeast, Harayana in the south and Rajasthan in the southwest. It covers an area of 5,0362 km^{2}. The state has three major physiographic regions; viz Siwalik hills, piedmont plain and alluvial plain. They have been further sub divided into sub-units: Siwalik hills, piedmont plain, recent alluvial plain, old alluvial plain, alluvial plain with sand dunes, alluvial plain with occasional sand dunes and aeo-fluvial plain. The elevation varies from about 180 to 300 m above m.s.l. in the plains and from 300 to 700 m above m.s.l. in hilly tract of the Siwaliks. The general slope of the state is from northeast to southwest. The Ravi, Beas, Satluj and Ghagger rivers and numerous other streams like chakki, the white Bein and the Black Bein drain the state. Many drainage channels have also been constructed to drain the waterlogged areas in the southern parts of the state. The climate of the state is dominantly sub tropical semi arid and monsoonic type. The mean summer (May to July), mean winter (December to February), mean annual rainfall is 705 mm. The soil moisture regimes are Udic, Ustic and Aridic. The soil temperature regime is mainly hyperthermic. Based on visual interpretations of the Landsat imagery interpretation (IRS-IC for the years 1997-2001), three major physiograpic units. Viz. terraces, sand dunes and palaeochannels were recognized in the study area.

Soil survey techniques and procedures: The soils samples were ground 2mm. Soil pH in 1:2 soil: water suspension, was determined using pH meter. Electrical conductivity was determined in 1:2 soil: water supernatant solutions with the help of conductivity bridge. Organic carbon was determined by Walkley and Black's using diphenylamine indicator [5], Particle size analyses was carried out by following the international pipette method [6], $CaCO_3$ was determined by rapid titration method of Puri [7]. Available potassium was estimated by ammonium acetate extraction method [8] and available Phosphorus was determined by developing blue colour using ascorbic acid method and the intensity of the colour was measured at 760 nm on the spectrophotometer [9]. Cation exchange capacity was determined by the procedure of Belyayeva [10] as modified by Jackson [11]. This method involves removal of soluble salts with 80% methanol. Available copper (Cu) in soil was determined using the procedure of Lindsay and Norvell (1969) The extracting solution consisted of 0.005 M DTPA (diethylene triamine penta-acetic acid), 0.01 M $CaCl_2$ and 0.1 M TEA (Tri ethanol amine) buffer adjusted to pH 7.3. Ten grams of air-dried soil was shaken with 20 ml of extracting solution for 2 hours at 25^0 C and filtered. Concentration of nutrients in the extract was determined by GBC Avanta atomic absorption spectrophotometer.

Representative values (mean and range) of soil physical and chemical parameters were calculated with the help of descriptive statistics. Geographic information system (GIS), which has been used in the present investigation, incorporates both the fundamental soundness of statistical techniques used earlier and spatial integration of data with the base maps. The base maps were scanned and then converted into digital form. The digital thematic maps were geo-rectified and transformed from the computer co-ordinates to the real world co-ordinates, by selecting ground control points (GCPs) for each of the maps and the total root mean square error (RMSE) for high accuracy in rectification. Location of the surface soil sample collected from different soil mapping units with the help of GPS was digitized on the base map of Punjab state using Arc GIS software. This digitized layer was over layered on the other layer of soil mapping units for preparing the thematic maps. A vector-based GIS software package Arc GIS 9.2 was used to map, query, and analyze the data in this study. Maps for copper available was generated using Arc-info GIS software.

RESULTS AND DISCUSSION

Data for various soil characteristics are presented subregion wise. Owing to less number of samples for Siwalik hills eco-subregion, their data are presented along with the undulating eco-subregion.

Physical and chemical properties: One hundred fifty two soil samples collected from 5 agro-ecological sub regions represented most of the mapping units of soil map of Punjab. These were analyzed for pH, EC, organic carbon, calcium carbonate, texture, available P, available K, exchangeable cations, CEC and ESP. The descriptive statistics on soil characteristics indicated (Table 1) that the pH of the soils varied from almost neutral to alkaline (6.77 to 9.3) and EC ranged from 0.14 dS m-1 to 4.57 dS m-1.Organic carbon was irregularly distributed and its content varied from 0.00 to 1.55 per cent This may be attributed to the repeated addition of organic residues to the surface soil. The soils were calcareous with CaCO3 content varying from 0.50 to 10.46 per cent. High CaCO3 in some samples may be due to the contribution from calcareous rich aeolian materials. Sand content in these soils varied from 10 to 92 per cent. Silt and clay contents were in range of nil to 73.5 per cent (mean=28%) and 0.2 to 39.4 per cent (mean=8.95%) respectively.

Table 1: Descriptive statistics of soil properties of Punjab

Statistical measures	pH (1:2)	EC (dS m^{-1})	O.C	$CaCO_3$	Sand	Silt	clay	Av.P	Av.K	Ca^{2+}+Mg^{2+}	Na^+	K^+	CEC	ESP (%)
			← (%) →					←(kg ha^{-1})→		Exchangeable cation ← (cmol (p^+)kg^{-1}) →				
Mean	7.93	0.63	0.57	3.94	62.96	28.30	8.95	42.77	280.57	5.68	0.41	0.41	6.54	6.55
Median	7.92	0.52	0.55	3.77	65.71	26.87	7.8	23.52	280	5.2	0.33	0.26	6.04	5.51
Minimum	6.77	0.14	00	0.5	10.23	0.00	0.2	1.12	33.6	1.2	0.12	0.05	1.87	0.03
Maximum	9.3	4.57	1.55	10.46	92	73.5	39.4	238	1192.8	14	3.06	3.65	15.5	33.13

The clay content increased with depth in the Siwalik hills and undulating eco-subregion but there is no systematic pattern in the southwestern alluvial plain eco-subregion due to more stratified nature of the soils. Available P content of Punjab soils ranged from 1.12 to 238 kg ha^{-1} This may be due to the addition of large amount of phosphatic fertilizers to potato crop in undulating subregion. Available K in Punjab soil ranged from 33.6 to 1192 kg ha^{-1} with a mean value of 280.57 kg ha^{-1}. This is due to higher amount of biotite mineral in the sand function of soils of southwestern alluvial plain eco-subregion than the soils of Siwalik hills and undulating eco-subregion. The CEC and exchangeable cations values varied widely in the soil developed on different eco subregion. NH_4Cl extractable Ca^{2+} and Mg^{2+} varied from 1.2 to 14 cmol(p^+)kg^{-1} with a mean value of 5.68 cmol(p^+)kg^{-1}. Exchangeable Na^+ and K^+ varied from 0.12 to 3.06 cmol(p^+)kg^{-1} (mean=0.4 cmol(p^+)kg^{-1}) and 0.05 to 3.65 cmol(p^+)kg^{-1} (mean=0.41 cmol(p^+)kg^{-1}) respectively. The southwestern eco-subregion has relatively higher biotite content in the coarse fraction than the Siwalik hills and undulating eco-subregion. CEC ranged from 1.87 to 15.5 cmol(p^+)kg^{-1} with a mean value of 6.54 cmol(p^+)kg^{-1} . The ESP ranged from 0.03 to 33.13 percent.

DTPA extractable Cu

Siwalik hills and undulating eco-subregion

The DTPA extractable copper varied from 0.13 to 1.8 mg kg^{-1} (mean = 0.89 mg kg^{-1}) (Table 3). DTPA-Cu content of fifty percent of the samples was more than 0.88 mg kg^{-1}. Considering 0.2 mg kg^{-1} as the critical limit for Cu deficiency, it may be assumed that 91 per cent soils sample were found to be in adequate range and 9 per cent are in deficient range. Thus most of the soils samples were well supplied with DTPA extractable copper. The statistical relationship (Table 2) shows a significant correlation of DTPA extractable Cu with soil pH (r = -0.51), EC (r = 0.47), sand (r = -0.44) and clay (r = 0.57). In general, sand was negatively correlated with micronutrients, which may be the result of quartz in the sand size particles. In multiple stepwise linear regressions equation R^2 (Table 4) improved from 32.7 per cent to 66.2 per cent for DTPA Cu with threshold significance value of 0.05 with clay, pH and EC.

Piedmont and alluvial plain eco-subregion

The DTPA extractable copper varied from 0.2 to 4.02mg kg^{-1} (mean=1.2 mg kg^{-1}) (Table 3). The soils of this subregion were well supplied with DTPA extractable copper. DTPA extractable Cu was positively and significantly correlated (Table 2) with EC (r = 0.61), OC (r = 0.38), silt (r = 0.45), K^+(r = 0.35) and CEC (r = 0.30) and negatively correlated with sand content (r = -0.40). The DTPA Cu was partially correlated with pH (r = 0.45), EC (r = 0.63), OC (r = 0.28), silt (r = 0.53), Ca^{2+}+Mg^{2+} (r = 0.37), Na^+(r = 0.36), K^+ (r = 0.36) and CEC (r = 0.44) and negatively correlated with sand (r = -0.49) and av. P (r = -0.33). According to Hodgson (1963), complexing agents generated by organic matter promote micronutrient availability in soils. In multiple stepwise linear regressions equation 42.7 per cent of variation in DTPA Cu was determined with EC and OC (Table 4).

Central alluvial plain eco-subregion

The content of DTPA extractable Cu ranged from 0.26 to 2.77 mg kg^{-1} (mean=1.0 mg kg^{-1}) (Table 3). The data further showed that Cu deficiency was not a problem in these soils as no samples were found to be below the critical limit. The estimates coefficient of simple correlation (Table 2) indicated that the extractable Cu was positively correlated with OC (r = 0.59), silt (r = 0.48), exchangeable ions i.e. Ca^{2+}+Mg^{2+} (r = 0.58), Na^+ (r = 0.43), K^+ (r = 0.52) and CEC (r = 0.73) and negatively correlated with sand (r = -0.50) and av. P (r = -0.03). The DTPA Cu was partially correlated with silt (r = 0.50), Ca^{2+}+Mg^{2+} (r = 0.41), Na^+ (r = 0.37), K^+ (r = 0.34) and CEC (r = 0.57) and negatively correlated with sand (r = -0.51). Accretion of organic matter in surface horizons by biological process associated with natural vegetation and crop production appears to have resulted in relatively higher extractable values [12]. In multiple stepwise linear regressions equation 53.7 per cent to 75.3 per cent of variation in DTPA Cu was determined with silt, Na^+, K^+, pH and ESP (Table 4) .

Southwestern alluvial plain eco-subregion

The DTPA-Cu content ranged from 0.3 to 2.38 mg kg^{-1} with a mean value of 1.03 mg kg^{-1}(Table 3). Estimates of coefficient of sample correlation indicated that the extractable Cu was positively correlated (Table

2) with available K (r = 0.52), K^+ (r = 0.51) and CEC (r = 0.35) and partially correlated with available K (r = 0.41) and K^+ (r = 0.43). High content of micronutrients in the A horizons of these soils appear to be due to rapid decomposition of organic matter or phytocycling or relatively more weathering of minerals in epipedon. In multiple stepwise linear regressions equation 31.7 per cent to 42.3 per cent of variation in DTPA Cu could be determined with OC and $CaCO_3$ (Table 4).

GIS aided mapping

The soil is the most basic resource for production, and the main manageable source of variability within the field. Geo-referenced digital soil surveys are now available for almost every field and contain a great wealth of information about each soil type in a field. This information can be incorporated into the field's GIS records and used with numerous analytical and decision-aid software tools to help make management decisions. Spatial distribution of DTPA-Cu in soils of Punjab under five different agro ecological sub regions was overlaid on the soil map layer (Figure 1). DTPA Cu varied widely and ranged from 0.13 to 4.02 mg kg^{-1}(Table 5). Based on critical limit, Cu deficiency was not a problem in these soils as only a small part of Hoshiarpur and Roopnagar districts in Siwalik hills and undulating eco-subregion in Punjab are deficient Based on critical limit, only 0.36 per cent (181.30 km^2) of the total geographical area of Punjab was affected by Cu deficiency ranging from 0.13 to 0.20 mg kg^{-1} with a mean value of 0.16 mg $kg^{-1.}$

Only 1.3 per cent samples were found deficient in DTPA-Cu. However, per the per cent area based on GIS-aided statistical analysis, only 0.36 per cent area of the total geographical area of Punjab state is deficient in DTPA-Cu. This indicates that there is misleading relationship between per cent sample deficient and per cent deficient area.

Table 2: Pearson and partial correlation matrix (r) for DTPA-Cu eco-subregions.

	pH	EC	OC	$CaCO_3$	Sand	Silt	Clay	Av. P	Av. K	Ca+Mg	Na	K	CEC	ESP	Cu
Siwalik hills and undulating eco-subregion															
Pearson	-0.51*	0.47*	0.41	0.06	-0.44*	0.23	0.570**	-0.11	-0.33	-0.30	0.19	0.01	-0.29	0.31	1.00
Partial	0.27	.64**	0.21	-0.11	-0.45	0.29	0.59**	-0.14	-0.24	-0.02	0.26	-0.14	-0.02	0.14	1.00
Piedmont and alluvial plain eco-subregion															
Pearson	-.06	0.61**	0.38**	0.20	-0.40**	0.45**	0.06	-0.20	0.02	0.27	0.25	0.35*	0.30*	0.14	1.00
Partial	0.45**	0.63**	0.28*	0.06	-0.49**	0.53**	0.13	-0.33*	0.06	0.37**	0.36*	0.36*	0.44**	0.14	1.00
Central alluvial plain eco- subregion															
Pearson	0.09	0.26	0.59**	0.19	-0.50**	0.48**	-0.02	-0.03*	0.08	0.58**	0.43**	0.52**	0.73**	0.15	1.00
Partial	0.24	0.21	0.27	0.12	-0.51**	0.50**	0.06	-0.23	0.11	0.41**	0.37*	0.34*	0.57**	0.18	1.00
Southwestern alluvial plain eco-subregion															
Pearson	-0.32	0.31	0.56**	0.33	-0.08	0.11	-0.02	-0.07	0.52**	0.18	-0.01	0.51**	0.35*	-0.21	1.00
Partial	-0.19	0.27	0.3	0.35	-0.12	0.24	-0.20	-0.05	0.41*	0.11	-0.17	0.43*	0.25	-0.28	1.00

** Correlation is significant at the 0.01 level (2-tailed)
* Correlation is significant at the 0.05level (2-tailed)

Table 3: Descriptive statistics of DTPA-Cu

DTPA Cu (mg kg^{-1})	Mean	Median	Minimum	Maximum
Siwalik hills and undulating eco-subregion	0.89	0.88	0.13	1.8
PiedmontPiedmont and alluvial plain eco-subregion	1.21	1.13	0.22	4.02
Central alluvial plain eco- subregion	1.04	0.89	0.26	2.77
Southwestern alluvial plain eco-subregion	1.03	0.97	0.3	2.382

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Table 4: Linear stepwise regression equations for DTPA-Cu in agro-eco-subregions

Agro-eco-subregion	Linear stepwise regression equation	R^2
Siwalik hills and undulating plain eco-subregion	4.3 + 0.23E-02 clay-0.534pH+1.16EC	0.662
Piedmont and alluvial eco subregion	5.33E-02 + 1.67EC+0.45OC	0.427
Central alluvial eco subregion	4.87+ 1.84Na^+ +0.41K^+-0.10ESP+0.01silt-0.57pH	0.753
Southwestern alluvial eco-subregion	-0.21 + 1.22OC +0.11$CaCO_3$	0.423

Table 5: Mapping parameters of GIS aided DTPA –Cu map of Punjab

DTPA-Cu (mg kg^{-1})	Number of polygons	Sum of the area of polygon	Mean	SD	Area of Punjab state in km^2	Percent area of Punjab state
0.13-0.20	2	0.02	0.16	0.03	181.30	0.36
0.21-0.50	98	0.81	0.37	0.07	8954.36	17.78
0.51-1.00	230	1.87	0.83	0.14	20774.32	41.25
1.01-1.50	103	0.95	1.25	0.15	10601.20	21.05
1.51-2.00	45	0.44	1.73	0.13	4885.11	9.70
2.01-4.02	41	0.45	3.14	0.81	4965.69	9.86

Micronutrients related constraints to productivity were also diagnosed by Sood et al. [4] in Muktsar, Patiala, Hoshiarpur, Amritsar and Ludhiana districts of Punjab. Linear regression equation showing combined influence of percent deficient sample and percent area deficient in 5 district of Punjab showed an R^2 of 0.66 only, which means only 66 per cent of variation is predictable and remaining 34 per cent still remains unexplained. Thus, number of samples deficient in an area cannot present the real picture about the magnitude of the problem.

Therefore, the maps generated on the basis of only number of sample collected from different site may not be able to quantify the area which is deficient in particular nutrient. Knowledge of exact area deficient in particular nutrients is necessary for planning the fertilizer requirement and its spatial distribution as per demand. Most of the soil-testing laboratory engaged in the macro and micronutrients analysis, indicate the deficiency of the nutrient based on percent of number of sample, which are deficient in particular nutrient, but in reality there estimates are far from the ground truth in terms of magnitude of the deficiency of a nutrient. The nutrient deficiency maps based on soil maps help in delineating the homogeneous units to decide the sampling size and thereby saving a lot of time. This will also help in monitoring the changes in micronutrient status over a period of time as geo referenced sampling sites can be revisited with the help of GPS, which is otherwise difficult in the random sampling.

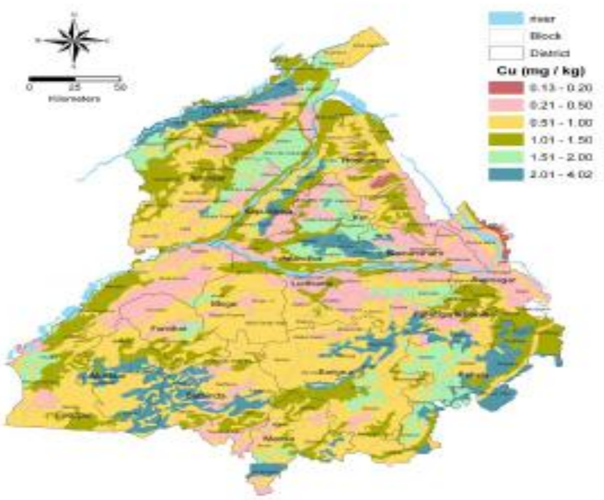

Figure 1: DTPA Extractable Copper

CONCLUSION

The studied soils though, contained adequate amount of DTPA-Cu, however, deficiencies of DTPA-Cu may be expected in some of the soils.The results indicated that clay, pH and EC in Siwalik hills and undulating eco-subregion ,EC and OC in Piedmont and alluvial plain eco-subregion, silt, Na^+, K^+, pH and ESP in Central alluvial plain eco-subregion and OC and $CaCO_3$ in Southwestern alluvial plain eco-subregion as main soil characteristics playing major role in controlling availability of DTPA-Cu in these soils. The maps generated on the basis of only number of sample collected from different site may not be able to quanify the area which is deficient in particular nutrient. Knowledge of exact area deficient in particular nutrients is necessary for planning the fertilizer requirement and its spatial distribution as per demand. Only 0.36 per cent area of the total geographical area of Punjab state is deficient in DTPA-Cu.

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