Mapping of Chemical Characteristics and Fertility Status of Intensively Cultivated Soils of Punjab, India

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Abstract:	Cultivation of high yielding crop varieties and intensive cropping has depleted the soil fertility resulting in appearance of multi-nutrient deficiencies in different crops and cropping systems.. In the present investigation, geo-referenced soil samples were analyzed to map fertility status using geographical information system. Soil texture varied from sand to clay loam with majority (47.3 %) of the polygons were sandy loam. The pH varied from 6.5-9.3. Soil pH 6.5-8.7 and electrical conductivity <0.8 dS m-1 represent about 95 per cent of the total area of the state. Calcium carbonate with <5 % values represents 97 % area of the state. The GIS based mapping indicated that irrespective of the agroclimatic variations, more than 90% of the soils were low to medium in soil organic carbon and 50 % low to medium (<22.4 kg P ha-1) in available Phosphorus (P) with a marginal (7%) deficiency of Potassium (K) . The dominance of low to medium status of available P in these soils could be due to mining of soil P by the rice-wheat cropping system practiced in the region. The intensively cultivated soils of Punjab showed 11% of soil samples were low in Zn, 15% low in Mn, 2% low in copper, and 12 % low in Fe. Availability of micronutrients increased with increase in organic carbon content and decreased with increase in sand content, pH, and calcium carbonate. GIS-based maps are effective in identifying hot spots which need immediate attention and call for strategic planning for sustainable management
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Mapping fertility status of soils using geographical information system in Punjab, India

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Abstract Cultivation of high yielding crop varieties and intensive cropping has depleted the soil fertility resulting in appearance of multi-nutrient deficiencies in different crops and cropping systems in Indian Punjab. In the present investigation, geo-referenced soil samples were analyzed to map fertility status using geographical information system (GIS). Soil texture which affects soil hydraulic properties and soil strength varied from sand to clay loam with majority (47.3 %) of the polygons were sandy loam. The pH varied from 6.5-9.3. Soil pH 6.5–8.7 and electrical conductivity <0.8 dS m^{-1} represent about 95 per cent of the total area of the state. Calcium carbonate with <5 % values represents 97 % area of the state. The GIS based mapping indicated that irrespective of the agroclimatic variations, more than 90% of the soils were low to medium in soil organic carbon and 50 % low to medium (<22.4 kg P ha^{-1}) in available Phosphorus (P) with a marginal (7%) deficiency of Potassium (K) . The dominance of low to medium status of available P in these soils could be due to mining of soil P by the rice–wheat cropping system practiced in the region. The intensively cultivated soils of Punjab showed 11% of soil samples were low in Zn, 15% low in Mn, 2% low in copper, and 12 % low in Fe. Availability of micronutrients increased with increase in organic carbon content and decreased with increase in sand content, pH, and calcium carbonate. GIS-based maps are effective in identifying hot spots which need immediate attention and call for strategic planning for sustainable management.

Key words Geographical information system**,** fertility status, mapping units, macro-micro nutrients and rice-wheat

Introduction

Rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.) and maize (*Zea mays* L.) are important food crops in Indo-Gangetic Plains (IGP) of India and contribute more than 75 per cent of the total food grains produced in the country. About 90 per cent of the area (10 m ha) under rice-wheat system (RWS) is covered by 119 districts of the IGP (Sidhu and Sharma 2010). This area is often called the “Green Revolution Belt” of the country. Rice-wheat and cotton-wheat are the major cropping systems in Indian Punjab. Rice, cotton and wheat crops occupy 67, 11.5 and 84% of the total cultivable area in the state. Highly productive RW belt of North West (NW) India has started suffering from production fatigue. Also, the yield potential of different crops and cropping systems is not uniform across different zones. The evidences of declining partial or total factor productivity are now available from these zones (Hobbs and Morris 1996). The possible causes for this decline include changes in biochemical and physical

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composition of soil organic matter and a gradual decline in the supply of soil nutrients causing macro and micronutrient imbalances due to inappropriate use of fertilizers (Ladha et al. 2000).

Both rice and wheat are exhaustive feeders and the RWS is heavily depleting the soils of their nutrients. A RWS that yields 7 t ha^{-1} of rice and 5 t ha^{-1} of wheat removes more than 250 kg N, 50 kg P and 280 kg ha^{-1} of K from the soil (Kanwar and Mudahar 1986). Similarly, on an average 200 g Zn, 50 g Cu, 1500 g Fe and 400 g Mn ha^{-1} are removed by this cropping system. Even with the recommended rates of fertilizers in this system (straw taken out of the fields), a negative balance of the primary nutrients still exists, particularly for N and K (Tandon and Sekhon 1988; Meelu et al. 1995; Yadvinder-Singh et al. 2003).

Apart from deficiencies of primary and secondary nutrients, occurrences of micronutrient deficiencies like Zn, Fe and Mn are steadily increasing since the first report came in the late 1960s' following the introduction of high yielding varieties of rice, wheat, maize and cotton. Intensive cultivation has been associated with greater dependence on chemical fertilizers with lower emphasis on the use of organics. The soils of Punjab usually are low in organic matter content because of the prevailing arid and semi-arid climatic conditions resulting in limited contribution of soil organic matter to available pools of Zn. The low availability of micronutrients coupled with their fast depletion by the crops has resulted in the emergence of their deficiencies particularly of Zn, Mn and Fe in the soils of IGP. In Punjab, severe deficiency of Mn appeared in wheat during 1980, in areas where wheat was followed by rice cultivation due to excessive leaching of Mn beyond the root zone during rice crop season (Takkar and Nayyar 1981; Sharma et al. 2000; Katyal and Sharma, 1991).

Geographical Information System (GIS) is rapidly developing as primary technology for the investigation of large-scale patterns and processes. The maps generated through Global Poisoning System (GPS) and GIS help in delineating the homogeneous units to decide on the sampling size and thereby saving a lot of time. These can also help to monitor the changes in nutrient 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 (Sood et al. 2004) approach. White et al. (1997) prepared GIS-aided soil zinc map of entire USA based on 1,245 samples of United States Geological Survey and 1,643 samples of United States Department of Agriculture. (USDA).Recently, DTPA extractable zinc and soil characteristics maps of the Punjab using GIS technology have been prepared by Bali et al. (2010).

Fertility of soil being a major input in the present day intensive agriculture, there is an urgent need to prepare spatially integrated inventory of the quality parameters to sustain agricultural productivity in Punjab, India. This is far more important as the quality of soil significantly affects the health of plant–animal–human continuum. Thus, the present investigation was carried out with the main objective of preparing soil fertility maps using GIS so as to guide the farmers to decide on the spatial application of fertilizers for improving their economic returns and identifying hot spots l, which needs immediate attention and is vital for strategic planning by the decision makers. This study included collection of geo-referenced soil samples, their analysis for organic carbon, available P, K and DTPA-extractable Zn, Cu, Fe and Mn content, so as to guide the farmers to decide on the spatial application of fertilizers amount for optimum or economic returns.

Material and methods

Study Area

Punjab is situated in the North-west of India. It is bordered by Pakistan on the west, the Indian states of Jammu and Kashmir on the north, Himachal Pradesh on its north-east and Haryana and Rajasthan to its south. The latitudinal and longitudinal extends of the Punjab are from 29^{o} 32' 31.563" to 32^{o} 34' 39.658" N and 73^{o} 53' 13.453" to 76^{o} 56' 40.597" E (Raj-Kumar et al. 2008). It covers an area of 5.036 Mha. The state has three major physiographic regions; viz Siwalik Hills, piedmont plain and alluvial plain. They have been further sub-divided into subunits: Siwalik hills, piedmont plain, recent alluvial Plain, old alluvial plain, alluvial plain with sand dunes, alluvial plain with occasional sand dunes and aeofluvial plain. The elevation varies from about 180 to 300 m above mean sea level in the plains and from 300 to 700 m in hilly tract of the Siwaliks.

The climate of Punjab is mainly sub-tropical semi-arid and monsoon type. The annual average maximum and minimum temperature ranges from 29 to 32^{0}C in summer months and 15–17^{0}C during winter months. The mean maximum temperature is 25^{0}C in rabi and 38^{0}C in *Kharif* season. Temperature rises to a maximum of 44^{0}C during summer months of May and June in south-western parts of the state. The mean minimum temperature is 8^{0}C in *Rabi* (November to April) and 23^{0}C in *Kharif* (June to October) season. It drops to as low as 1^{0}C in winter months of December and January in northern parts of the state. The mean annual rainfall of the state ranges from 400 to 1,300 mm. More than 75 % of this rainfall is received during the monsoon season of 4 months i.e. June through September. Most of the rainfall is under the influence of south-west monsoon. The rest 20–25 % of rainfall is received during remaining 8 months under the influence of western disturbances. An important characteristic of the rainfall in the state is its extremely high variability in space and time. The variability of annual rainfall is 25–35 % while the monthly variability ranges between 35 and 230 %. The variability is lowest during the months of July–August and highest during November.

Collection of soil samples

Soils of the State belong to four orders of Soil Taxonomy: Inceptisols, Entisols, Aridisols, Alfisols and their associations. Inceptisols are the major soils constituting about 45 % of total geographic area of the state. These are identified by the presence of one or more pedogenic horizons of alteration or little accumulation of translocated materials. Entisols cover 16 % of total geographic area of the state. Such soils can be easily recognized by the absence of diagnostic horizons and mineral nature of the soils. Aridisols are dominant in the South-west parts of the State and cover 9 % of total geographic area of the State. Alfisols are recognized by the presence of markers of processes of clay translocation indicating good internal drainage in the soil. These cover 11% of area of Punjab in association with Inceptisols. Besides these, associations of Entisols-Inceptisols and Entisols-Aridisols cover 15 per cent and 4 per cent of total geographical area of Punjab respectively (Raj Kumar et al. 2008; 2010).

The state of Punjab has been divided into 520 polygons (Sidhu et al. 1995). These polygons have been delineated based on the topographical data from the Survey of India toposheets, interpretation of the satellite imageries and the aerial photographs of the Punjab state. Each delineated polygon is uniform with respect to rainfall, temperature, vegetation, potential evapo-transpiration, soil moisture storage, soil type, topography and parent material. Five hundred sixty two surface soil samples (0-15 cm) were collected from 520 polygons to represent all the agro-ecological-sub regions of the state. Soil samples were collected with the help of global positioning system (GPS) for further spatial integration with the GIS-based digitized maps. 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. This digitized layer was integrated with the table of attributes. A vector-based GIS software package ArcGIS 9.2 was used to map, and analyze the data in this study.

Analytical techniques

Soil samples (<2-mm) were processed and analyzed for pH (1:2 soil : water suspension), electrical conductivity (1:2 soil : water supernatant), organic carbon (Walkley and Black 1934), 0.5M $NaHCO_3^-$, extractable P (Olsen et al. 1954) and 1N ammonium acetate (NH_4OAc)-extractable K (Merwin and Peech 1950). Organic carbon was categorized as low (< 0.40 %), medium (0.40 – 0.75 %) and high (>0.75 %) classes. The available–P was categorized as low (< 12.4 kg ha^{-1}), medium (12.4 – 22.4 kg ha^{-1}) and high (>22.4 kg ha^{-1}) classes. The available–K was categorized as low (< 113 kg ha^{-1}), medium (113-280 kg ha^{-1}) and high (>280 kg ha^{-1}) classes (Muhr et al.1965).

The DTPA extractable micronutrients (Zn, Cu, Mn and Fe) were determined by following the procedure of Lindsay and Norvell (1978). The DTPA extractable Zn was categorized as deficient (<0.6 mg kg^{-1} soil) and sufficient (>0.6 mg kg^{-1} soil) classes. DTPA extractable Mn was categorized as deficient (<3.5 mg kg^{-1} soil) and sufficient (>3.5 mg kg^{-1} soil) classes. DTPA extractable Cu was categorized as deficient (<0.2 mg kg^{-1} soil) and sufficient (>0.2 mg kg^{-1} soil) classes. DTPA extractable Fe was categorized as deficient (<4.5 mg kg^{-1} soil) and sufficient (>4.5 mg kg^{-1} soil) classes.

Results and discussion

The soils of Punjab are alluvial in nature, the soil physical and chemical characteristics which control the nutrients dynamics in the soils vary widely. Both geogenic and pedogenic processes are responsible for the differentiation in the textural composition in the soils. Soils from the old floodplain are relatively finer in texture because of the contribution of parent material, which is mainly from shale rocks. The influence of textural composition is very well reflected in the physicochemical properties and mineralogical composition of the soils. The range, mean and standard deviation represent important measures of central tendency and the descriptive statistics pertaining to these measures are presented in Table 1. The soluble salt content and pH of the soils in sub humid area are relatively lower than in soils of the southwards Punjab due to the prevailing udic moisture condition. The soils have an acidic to slightly alkaline reaction, with pH values ranging from 5.7 to 7.9. Relatively better drained soils tend towards the acidic pH range. All of the soils in the sequence are no saline because EC varies from 0.14 to 1.86 dS m^{-1}. Organic carbon content varied from 0.05-1.37 % (mean value of 0.42 %) and is higher in the subhumid zone followed by semi arid and arid soils. The occurrence of carbonates in the Punjab soil is controlled by rainfall (Sehgal 2005), however, other factors such as parent material and drainage are also important in the study area. Soils from the subhumid are free of calcium carbonate because of the noncalcareous parent rocks and well-drained conditions, respectively, whereas soils from the semi arid and arid soils contain calcium carbonate which varied from 0.2-10.46 %. The Olsen P varied from 1.12-238 kg ha^{-1} with mean values of 40.3 kg ha^{-1}, where as NH_4OAc-extractable K varied from 2.51-533 kg ha^{-1} with mean values of 108 kg ha^{-1}. High standard deviation in available P and K values indicates large spatial variability in the collected samples. In case of micronutrients, Zn concentration varied from 0.13-4.02 mg kg^{-1} with mean values of 1.09 mg kg^{-1}; Cu varied from 0.0.7-3.06 mg kg^{-1} with mean values of 1.11 mg kg^{-1}; Mn varied from 0.68-51.7 mg kg^{-1} with mean values of 6.78 mg kg^{-1} and Fe varied from 1.32-38.9 mg kg^{-1} with mean values of 8.14 mg kg^{-1}.

GIS based digitized maps

All the data were prepared in excel worksheets, which were integrated with the attribute table of GIS-based digitized maps of the Punjab state.

Soil pH

The pH of soils is divided into three categories. The first category is designated as normal with a pH range of 6.5–8.7. It consists of 487 polygons with an average pH value of 7.99 (Table 1 ; Fig. 2). These polygons represent 95 per cent of the total area of the state. Soils in pH range of 6.5–8.7 are considered as the most suitable for most of the crops (Havlin et al. 2004). In the rice wheat system, when an aerobic soil is submerged for growing paddy, its pH decreases during the first few days, subsequently reaches a minimum, and then increases asymptotically to a fairly stable value of 6.7–7.2 a few weeks later (Ponnamperuma 1972). The decrease in pH has implications for the availability of Pand micronutrients. Phosphorus availability is greatest in the pH range 6.5–7.5 and the availability of micronutrients such as Zn, Cu, Fe and Mn increases with decrease in pH. Continuous cropping of maize-wheat-cowpea fodder sequence, for 32 years, exhibited decreased pH of the plough layer in all the treatments (Singh et al. 2007). Benbi and Brar (2009) reported decline in soil pH by 0.8 pH units from 8.5 in 1981-82 to 7.7 in 2005-06 in maize-wheat system.

The second category is designated as alkaline having pH value of soil in the range of 8.8-9.3. It occupies 30 polygons with an average pH value of 8.91 and representing 5 per cent of the total geographical area of the state. Soils having pH between 8.7-9.3 needs special attention by way of regular use of organic manures or green manuring to bring down the pH for normal crop growth.

Soils with pH value > 9.3 lie in third category of alkali soils. There are only 3 polygons in this category that represent only 0.2 per cent of the total area of state. The average pH value in this category is 9.5. Reclamation of these soils with gypsum along with keeping the soil flooded with water through cultivation of rice helps in significant improvement in the productivity. Gypsum amendment and submergence of alkali soils help to leach the soluble salts to deeper layers along with significant decrease in pH.

Electrical conductivity

Dissolved salts in soils create hindrance in normal nutrient uptake process by imbalance of ions, antagonistic and osmotic effects. The primary effect of high electrical conductivity (EC) on crop productivity is the inability of plant to compete with ions in the soil solution for water leading to physiological drought (Ahmed et al. 2002). The higher the EC, the lesser the water available to plants, even though the soil may appear wet. The EC of soil is divided into two categories. Four hundred and ninety three polygons, with an EC of < 0.8 dSm^{-1} and an average value of 0.31 dSm^{-1} fall in the first category. These polygons represent 94 per cent of the total geographical area of the state (Table 2; Fig. 3). These soils are very safe with respect to salt concentration and are suitable for crop production. The reason for high percentage of area in low EC may be due to leaching of salts under intensive irrigated agriculture and increased area under submerged paddy cultivation (Bhalla et al. 1990). The remaining 27 polygons fall in the second category, which have an EC values of > 0.8 dSm^{-1} with an average value of 0.98 dSm^{-1} representing 6 per cent of total area. Regular leaching of such soils with good quality water may ultimately lead to decrease in salt content.

Soil texture

Soil texture is a qualitative classification tool used in both the field and laboratory to determine classes for agricultural soils based on their physical texture. The textural class is then used to determine crop suitability and to approximate the soils responses to environmental and management conditions. Texture of Punjab soils was classified into eight different categories depending upon the varying content of sand, silt and clay (Table 3 ; Fig. 4). The first category of texture (sand) covered only two polygons and represented 0.2 per cent area of the state. Similarly, loamy sand and sandy loam soils covered 52 and 267 polygons representing 12 and 47 per cent area of the state, respectively. Loam and clay loam soils represented 16 and 0.1 per cent area in the state, respectively. Whereas, silt, silt loam and silty clay loam soils occupied 5, 106 and 6 polygons, representing 1.4, 22 and 0.5 per cent area of the state, respectively. Thus, sandy loam is the dominant texture of the state followed by silty loam and loamy sand.

Organic Carbon

The soil organic matter acts as a reservoir of plant nutrients that are essential for plant growth. It also helps in the improvement of soil physical conditions and therefore, considered as the vital and essential for maintaining soil productivity and health (Benbi and Brar 2009; Sharma et al. 2012). The status of organic matter in the soil depends upon the quantity that is periodically added, the soil temperature, and the rate of its decomposition. Decomposition of organic matter is affected by climate, moisture, soil pH, soil texture and drainage (Burke et al. 1989). Most of the N and to some extent P and S are present in their organic forms which are released in mineral form during mineralization of organic matter.

Three categories were formed for organic carbon (OC) content in soils (Table 4; Fig. 5). The first category contains soils with OC content of < 0.4%, which occupies 154 polygons. These polygons represent 32 per cent area of the state, with an average OC content of 0.32%. The second category of 0.4-0.75% OC constitutes 331 polygons with an average OC content of 0.55%. These polygons represent 57% of the total area of state. Thirty five polygons represent third category of organic carbon (> 0.75%) content in soils with an average content of 0.82% OC representing 12 per cent of the total geographical area of the state.

The increased contributions from the root biomass under intensive irrigated agriculture may have resulted in increased organic carbon status of coarse-textured soils. Continuous cropping of maize-wheat-cowpea fodder sequence for thirty two years exhibited increased organic carbon status from 0.26 to 0.30 % (Singh et al. 2005, 2007). Analysis of 25 years (1981-82 to 2005-06) of data on soil organic carbon collected from Punjab (India), Benbi and Brar (2009) demonstrated that intensive agriculture has improved soil organic carbon status. Furthermore, soils under rice remain flooded for 3–4 months decreasing the rate of soil organic matter decomposition, apparently due to excessively reduced conditions (Watanabe 1984).

Available phosphorus

Phosphorus is an important plant nutrient as it has a direct effect on root growth and the reproductive stage of the plant's life cycle and thus regarded as a key nutrient in crop production. Available P (Olsen-P) content in soils of the state was divided into four categories as shown in Table 5 & Fig. 6. The first category includes soils with available P content of <12 kg ha^{-1}. This category covers 178 polygons with an average available P content of 5.1 kg P ha^{-1}. These polygons represent 36 per cent area of the state. Soils with Olsen P content of 12–22 kg P ha^{-1} are included in second category, covering 86 polygons. These polygons having average available P of 16.5 kg P ha^{-1} represent 18 per cent area of state. The third category contains soils with av. P content of 22-50 kg P ha^{-1} which have 121 polygons on the map. With an average available P value of 32.6 kg P ha^{-1}, it represents 19.6 per cent of the total geographical area of the state. Soils with Olsen P content of more than 50 kg P ha^{-1} (mean of 109 kg P ha^{-1}) constitutes fourth category. There are 135 polygons in this category that represent 26 per cent area of Punjab. The large variation in P content in soils has been attributed to differences in pH, $CaCO_3$, organic carbon and soil texture etc. These results have clearly suggested that application of P in 54 percent of the soils is must to sustain productivity.

Results of long-term experiments on RW and maize-wheat systems from this region have shown that with continuous application of P-containing fertilizers for 12 to 22 years the initial low status of available P in soil was raised to high and very high commensurate with P application (Benbi and Biswas 1999; Rekhi et al. 2000). Another long-term study showed considerable build up in Olsen-P with continuous application of P fertilizers in the soils of Punjab state (Singh et al 2007). Due to the buildup of residual P in Punjab soils, farmers are advised not to apply any phosphatic fertilizer to rice crop when recommended dose of fertilizer P has been added to preceding wheat crop in the rice wheat system (Gill and Meelu 1983).

Available potassium

Punjab soils are usually well supplied in this nutrient due to the presence of K bearing minerals. However, intensive cultivation with complete removal of crop residues has resulted in the deficiency of K in coarse textured soils (Dhaliwal et al. 2006). The variation in available K status is controlled by soil texture, mineralogical make up, release dynamics and CEC of the soils.

Available K (NH_4OAc-extractable K) content of the soils was classified in two categories. The first category included soils with available K content of <113 kg K ha^{-1}. It occupies 36 polygons, which represents 8% of the total geographical area of the state (Table 6; Fig. 7). The average content of available K for this area is 81.9 kg K ha^{-1}. The soils in this category fall mainly in the sub humid region of the state (Sharma and Jassal 2012).

Second category of available K (>113) with an average value of 636 kg K ha^{-1} constitutes 484 polygons. It represents 92 per cent area of state. The generally unaltered available K status of soils may be ascribed to the addition of substantial amounts of potassium through irrigation water in the RWS and the state of K-bearing minerals in soils. The K content of groundwater in the state averages 9.2 mg L^{-1} and it is estimated that around 138 kg K ha^{-1} is added annually through 20 irrigations of 7.5 cm each applied to the rice-wheat system (Hundal et al. 2009). Muscovite and biotite are the dominant K containing minerals in sand and silt fractions and illite is the most dominant mineral in the clay fraction in the soils of Punjab. Among all the K-minerals, illite is the least weatherable in different agro-climatic regions and biotite is relatively less stable. Higher solubility of biotite may largely be due to its formation at higher temperature and pressure than illite, which is a secondary mineral (Raj-Kumar and Hundal 2002). The dominance of K-bearing minerals in soils and addition of large amounts of K through irrigation water result in low crop responses to applied K in Punjab, except in the sub-humid region where concentration of K in irrigation water is low and clay mineralogy differs from that of the soils from other regions (Dhaliwal et al. 2006).

DTPA- extractable zinc

The deficiency of Zn is reported to be widespread in Punjab particularly in coarse-textured soils. It has now become the limiting factor in crop production. Availability of Zn to plants is sensitive to changes in pH, presence of free lime, clay and organic matter content of the soils (Katyal and Sharma, 1991). DTPA- Zn was divided into two categories. With an average value of 0.41 mg Zn kg^{-1} soil, first category of Zn (< 0.6 mg Zn kg^{-1} soil), constitutes 58 polygons, representing about 10 per cent area of the state (Table 7 ; Fig. 8). Four hundred and sixty two polygons lie in sufficiency range with an average value of 1.72 mg Zn kg^{-1} soil, representing 90 per cent of the states area.

The contents of DTPA Zn in soils showed large variation across different transects of Punjab. Since soil characteristics and the management practices have a considerable bearing on the micronutrient availability, the magnitude of the deficiency of different micronutrients varied widely from one place to the other not only among states but also within the districts of the same state. The deficiency of Zn is mainly associated with soils having coarse texture, high pH, low organic carbon and high calcium carbonate (Sharma et al. 2004; Katyal and Sharma 1991; Sharma et al.1992 and Sidhu and Sharma 2010). A random sampling of some of the areas in Siwalik revealed an increase in the deficiency of Fe and Mn, particularly in highly permeable coarse-textured soils (Sharma et al.1999).

Our study showed that deficiency of Zn is more widespread in arid zone where the soils are low in organic carbon and high in pH followed by central zone where the soils are relatively low in pH and high in organic carbon content. Also, in the middle plain where greater crop removal of micronutrients with the extensive adoption of intensive rice wheat system with bumper harvests has further accentuated the problem of micronutrient deficiencies over the last more than three decades. However, with the increased use of zinc fertilizers by the farmers in the recent years has resulted in an increase of DTPA Zn contents in soils in many areas. The extent of Zn deficiency will thus depend upon the rate and frequency of Zn application. The regular monitoring of available Zn content of soils is essential to make suitable adjustments in fertilizer use.

DTPA extractable copper

DTPA copper (Cu) was divided into two categories. With an average value of 0.14 mg Cu kg^{-1} soil, first category of Cu (< 0.2 mg Cu kg^{-1} soil), representing 0.5 per cent area of the state (Table 8 ; Fig. 9). Five hundred nine polygons lie in sufficiency range with an average value of 1.13 mg Cu kg^{-1} soil. These represent for 99.5 per cent of the states area. Our study shows that Cu deficiency is not a serious problem at present in the state (Sharma et al. 2014). However, continuous monitoring of DTPA in soils of the state is essential to make suitable fertilizer recommendations to ameliorate the deficiency in different crops in the region. Available Cu content of soil was found to increase with increase in clay and organic matter content (Karim et al. 1976), particularly in soils initially low in organic matter.

DTPA extractable iron

Iron is a main constraint for sustainable rice production in coarse textured soils, low in organic matter content, high calcium carbonate content and with high pH. A wide spread deficiency of Fe in wetland rice was reported in the NW India in early 1980's when farmers adopted rice wheat system on the coarse-textured soils low in organic matter (Sharma et al. 2004). These workers showed that the DTPA Fe can be predicted qualitatively from a few physical and chemical properties especially organic matter content of the soils. DTPA Fe content of the soils was classified in two categories. The first category includes soils with Fe content of < 4.5 mg Fe kg^{-1} soil. It occupies 62 polygons, which represents 6.6 per cent of the total geographical area of the state (Table 9 ; Fig. 10). The average content of Fe for this area is 2.88 mg Fe kg^{-1} soil. Second category of Fe (> 4.5 mg Fe kg^{-1} soil) with an average value of 17.34 mg Fe kg^{-1} soil constitutes 458 polygons, representing 93.4 per cent area of the state.

DTPA extractable manganese

The DTPA Mn has two categories (Table 10 ; Fig. 10). The first category having Mn value of < 3.5 mg Mn kg^{-1} soil has 79 polygons on the map, with a mean value of 2.34 mg Mn kg^{-1} soil and it represents about 8 per cent of the geographical area of the state. The second category represents soils that have Mn content > 3.5 mg Mn kg^{-1} soil. These soils have sufficient Mn content for crop production. These constitute 441 polygons representing 92 per cent area of the state. Its mean value in this region is 6.87 mg Mn kg^{-1} soil. Deficiency of Mn in wheat was first identified in Ferozepur district in Punjab in 1980 (Takkar and Nayyar 1981) and the deficiency has now spread in many other parts of the state. The Mn deficiency has turned out to be a serious problem in the highly permeable coarse-textured soils brought under rice cultivation. Available Mn contents in soils have been reported to decrease with increase in pH and decrease in clay and organic matter content (Sharma et al. 2002).

Factor influencing micronutrient status

In this study organic carbon markedly controlled the distribution of available forms of all the micronutrients (Table 11). A highly significant coefficient of correlation between DTPA-Zn, Cu, Mn and Fe and organic matter content of soils confirms the findings of Follet and Lindsay (1970). According to Hodgson (1963) the complexing agents generated by organic matter promote micronutrient availability in soils. DTPA-Zn was positively correlated with DTPA-Cu, Mn and Fe. Interdependence of micronutrient cations suggested that variation in their distribution depends upon common soil factors (Sharma et al. 2002).

Data presented in Table 5 revealed significant correlation coefficient between clay fraction and DTPA-extractable Cu ($r = 0.38$) and negative coefficient of correlation with sand ($r = -0.38$) fraction . This finding validates the widespread incidence of Cu deficiency in sandy soils (Arora and Sekhon 1980). DTPA-extractable Zn decreased with increased clay content of the soils, which is in line with earlier reports that clay content predominantly controls its availability (Katyal and Sharma 1991; Sharma et al. 1992). The results from the present investigation demonstrate that $CaCO_3$ has negative effect on available forms of all the four micronutrients. A critical review of previous work also suggested that $CaCO_3$ has negative effect on the available forms of Zn, Cu, Mn and Fe micronutrients in soils (Katyal and Sharma 1979, Katyal and

Sharma 1991; Sharma et al. 2002). A significant and negative correlation was observed between soil pH and available content of Mn and Fe. These observations are consistent with earlier reports that pH is the key factor influencing the availability of Fe and Mn (Lins and Cox 1988; Lindsay and Cox 1985) in soils.

Conclusions

Following conclusions can be drawn from our study:

a. A wide variation exists in the pH, electrical conductivity, calcium carbonate, organic carbon and texture of the soils which have direct influence on the fertility of the soils.
b. The large variation in P content in soils has been attributed to differences in pH, $CaCO_3$, organic carbon and soil texture etc. these results have clearly suggested that application of P to 54 percent of the soils is must for sustained crop productivity.
c. Punjab soils are usually well supplied in K content due to presence of K bearing minerals and presence of K in irrigation water. However, intensive cultivation with complete removal of crop residues which likely leads to deficiency of K, particularly in coarse textured soil.
d. The contents of available micronutrients in soils showed large variation across different transects of the state. Because soil characteristics and management practices have considerable bearing on micronutrient availability, the magnitude of the deficiency of different micronutrients varied widely from one place to the other. Available micronutrients increased with increase in organic C content and decreased with increase in sand content, pH, and calcium carbonate.
e. The increased use of Zn fertilizer by the farmers in recent years has increased available Zn contents in soils in many areas.Thus, the extent of Zn deficiency has decreased in these areas, depending upon the rate and frequency of Zn application.The Mn deficiency is likely become a serious problem in the highly permeable, coarse-textured soils under rice-cultivation. The deficiency of Cu in most area in Punjab is presently not a serious problem.

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Figure

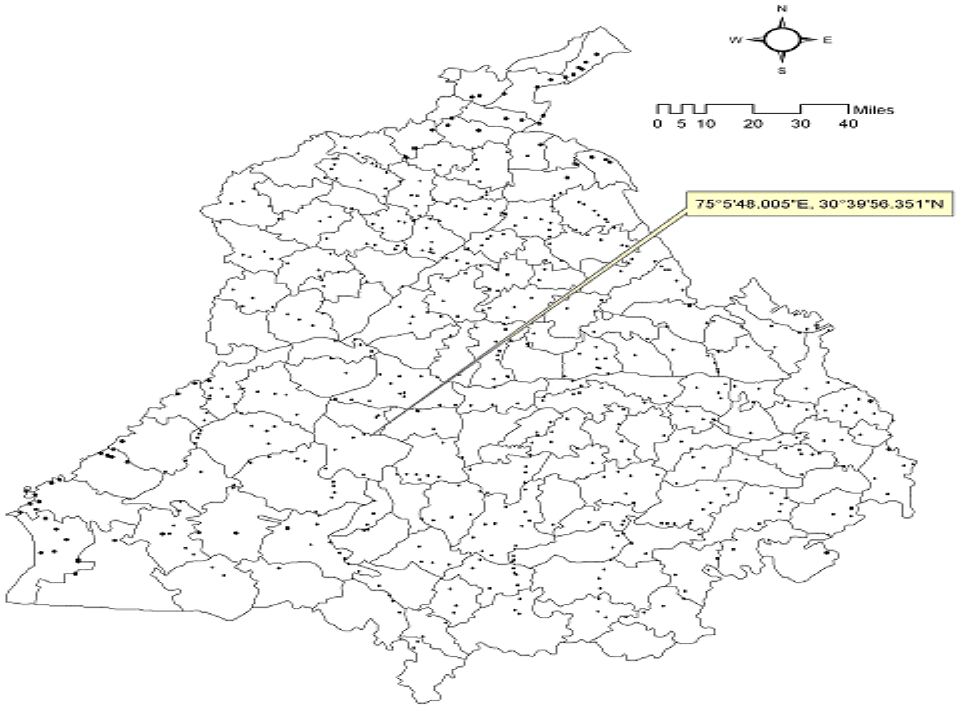

Fig. 1 Location of soil samples

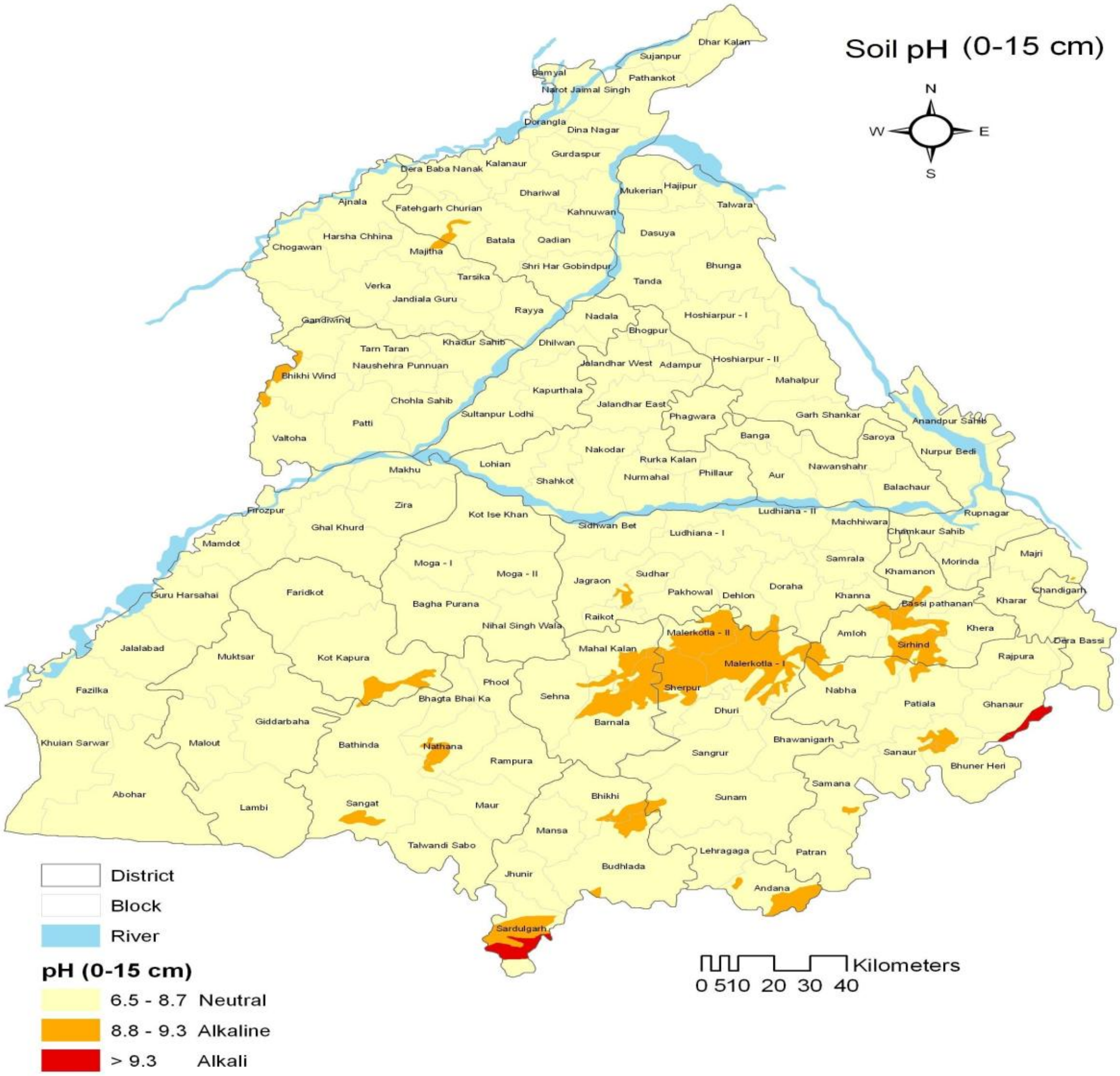

Fig 2. Thematic map of pH status of Punjab soils

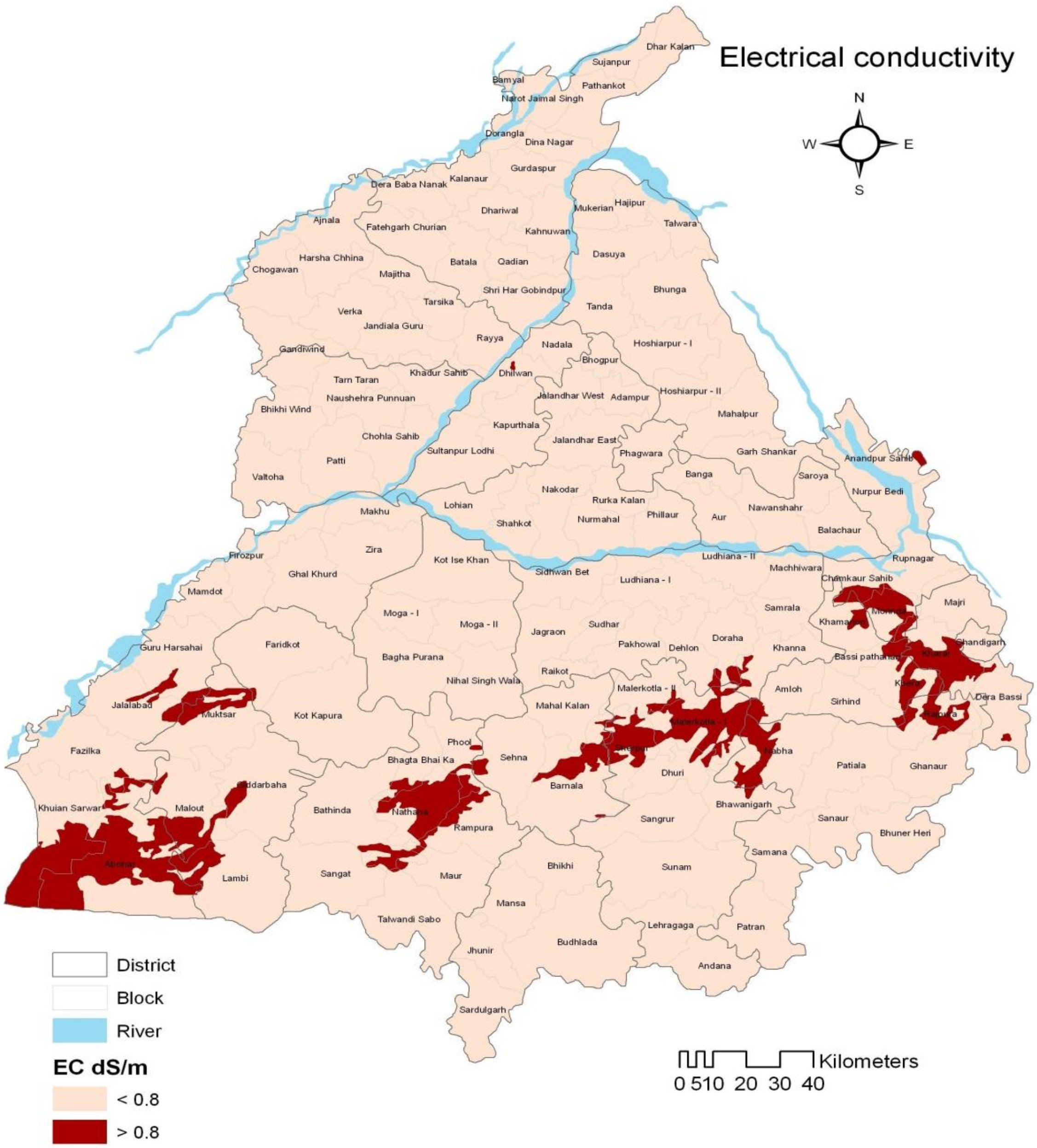

Fig. 3. Thematic map of EC status of Punjab soils

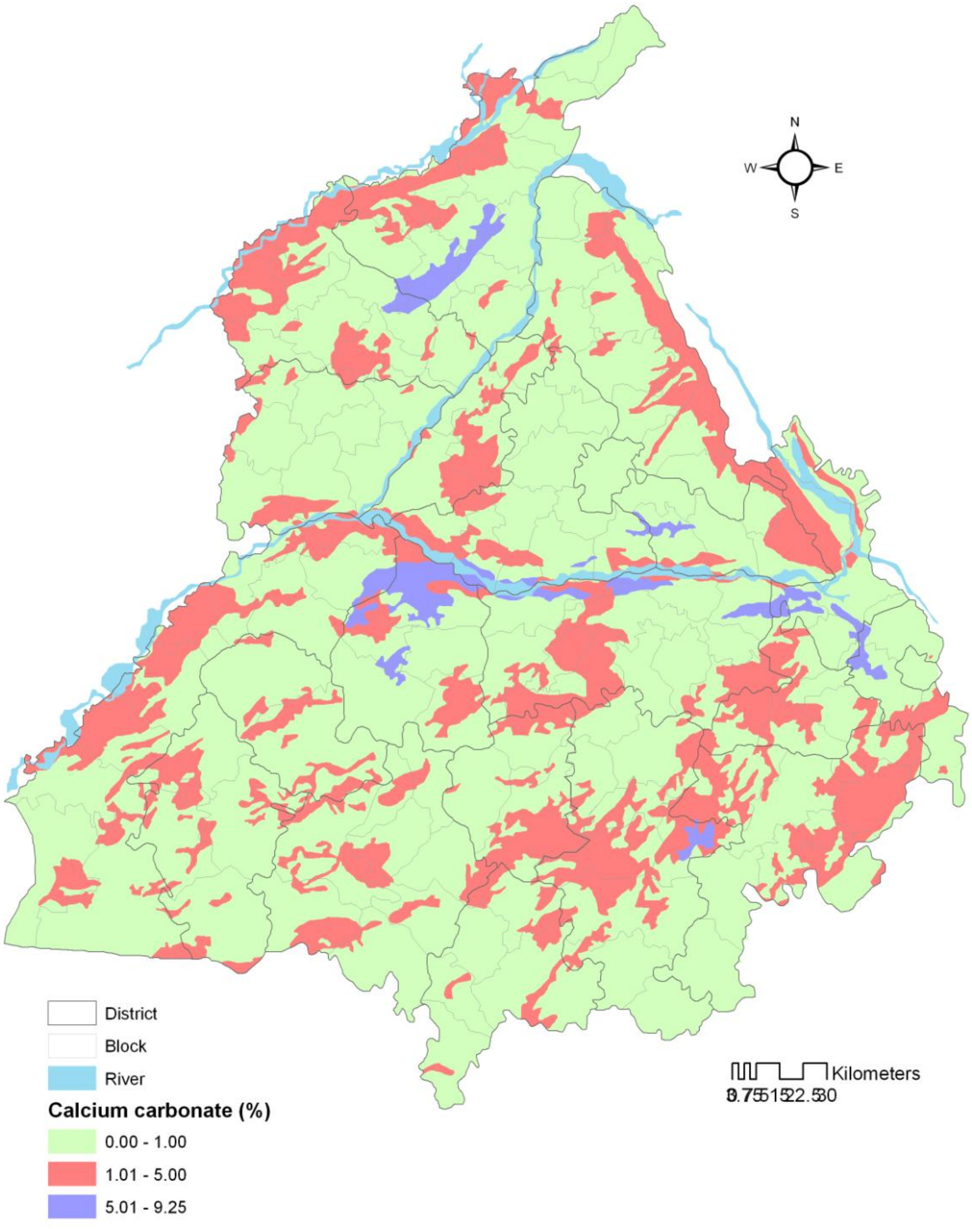

Fig. 4 Calcium carbonate content of Punjab soils

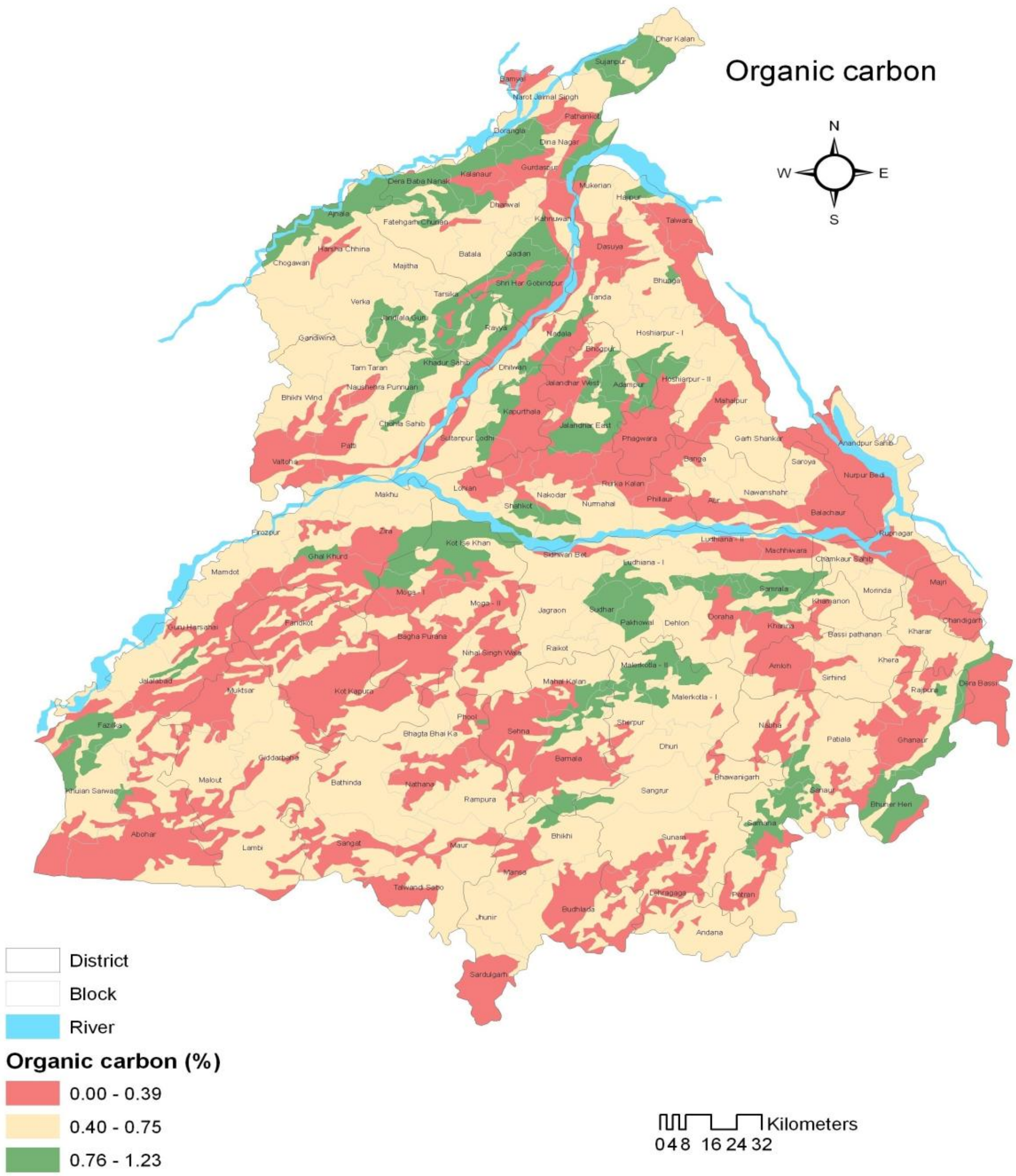

Fig. 5 Thematic map of organic carbon status of Punjab soils

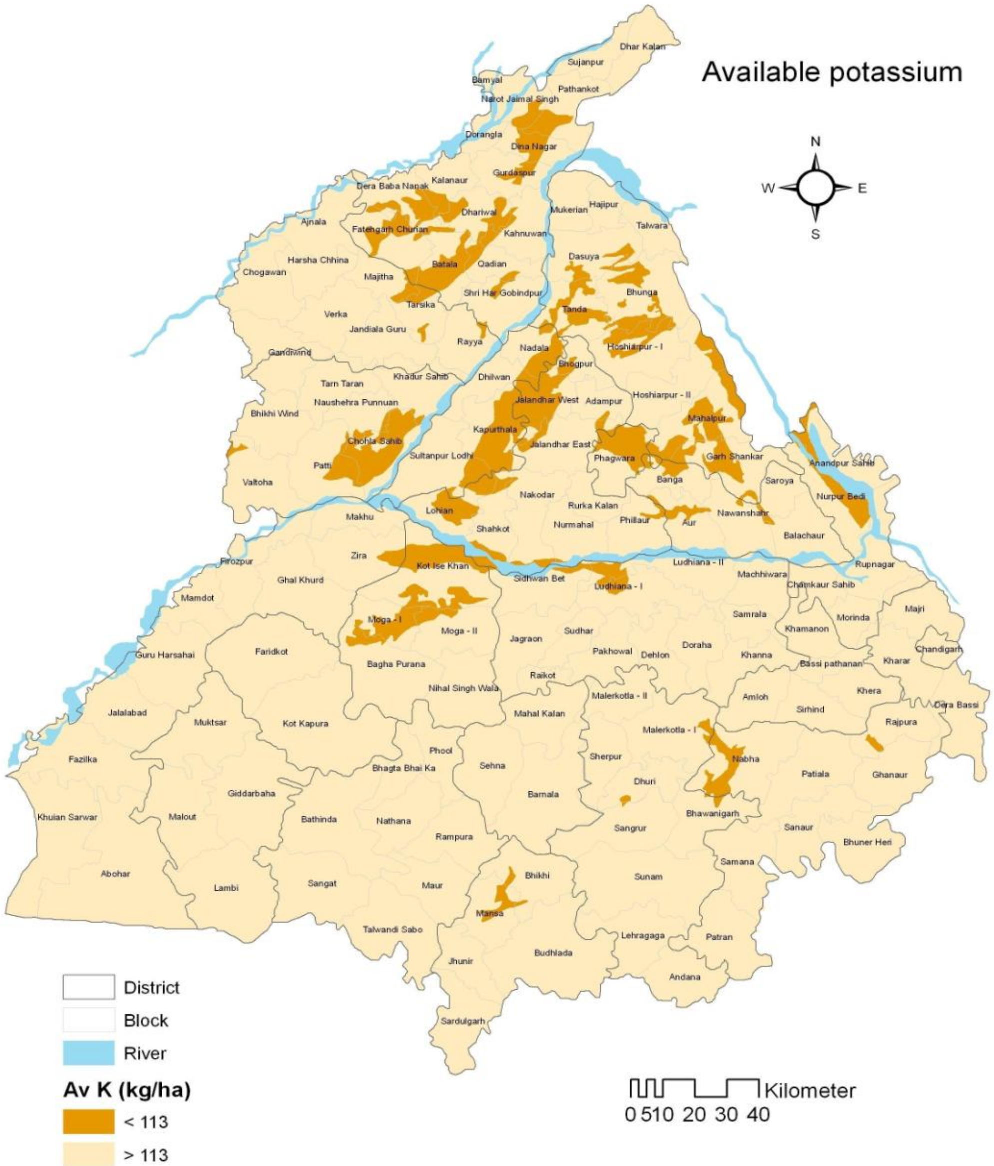

Fig. 6 Thematic map of available Potassium status of Punjab soils

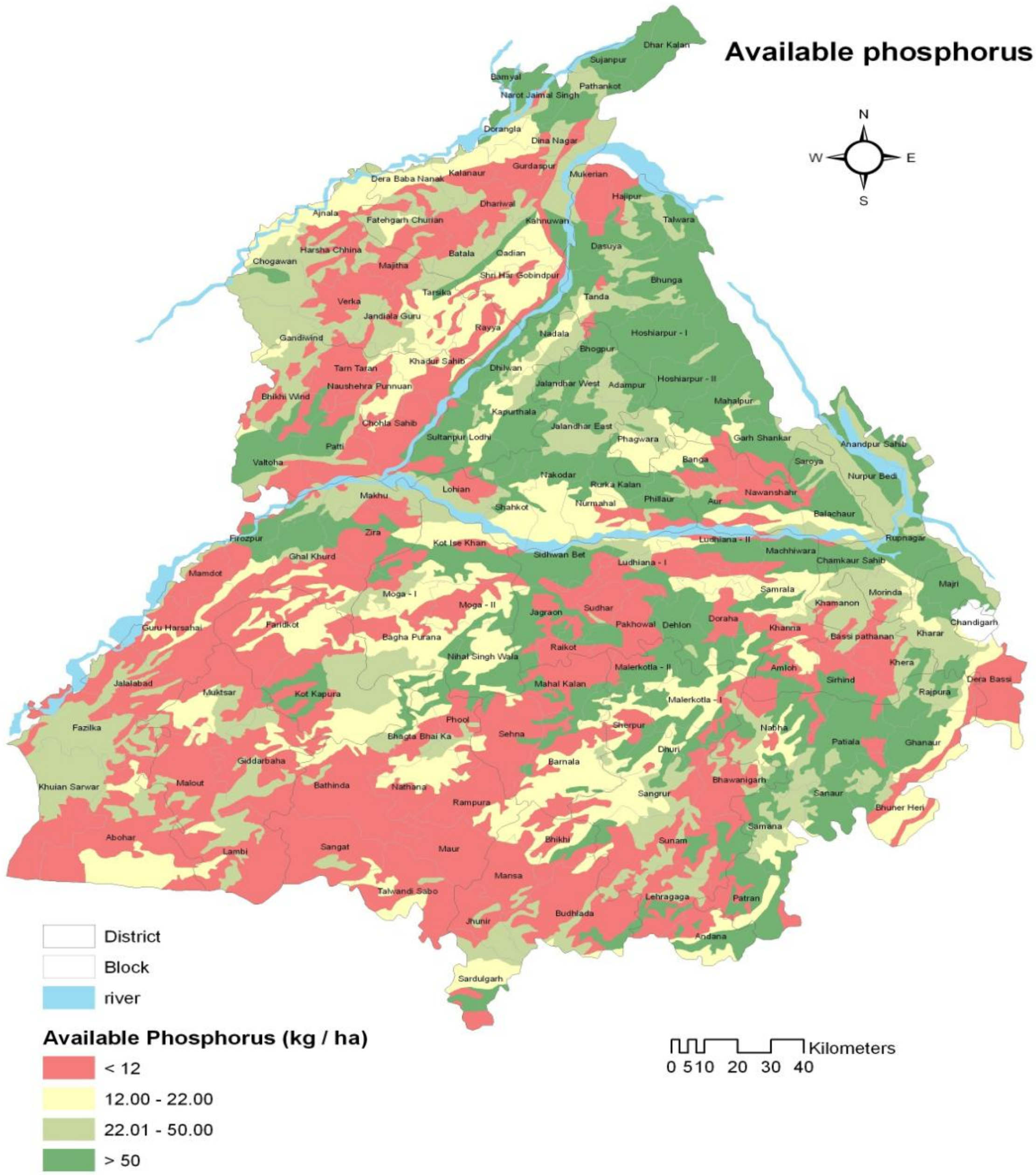

Fig. 7 Thematic map of available phosphorous status of Punjab soils

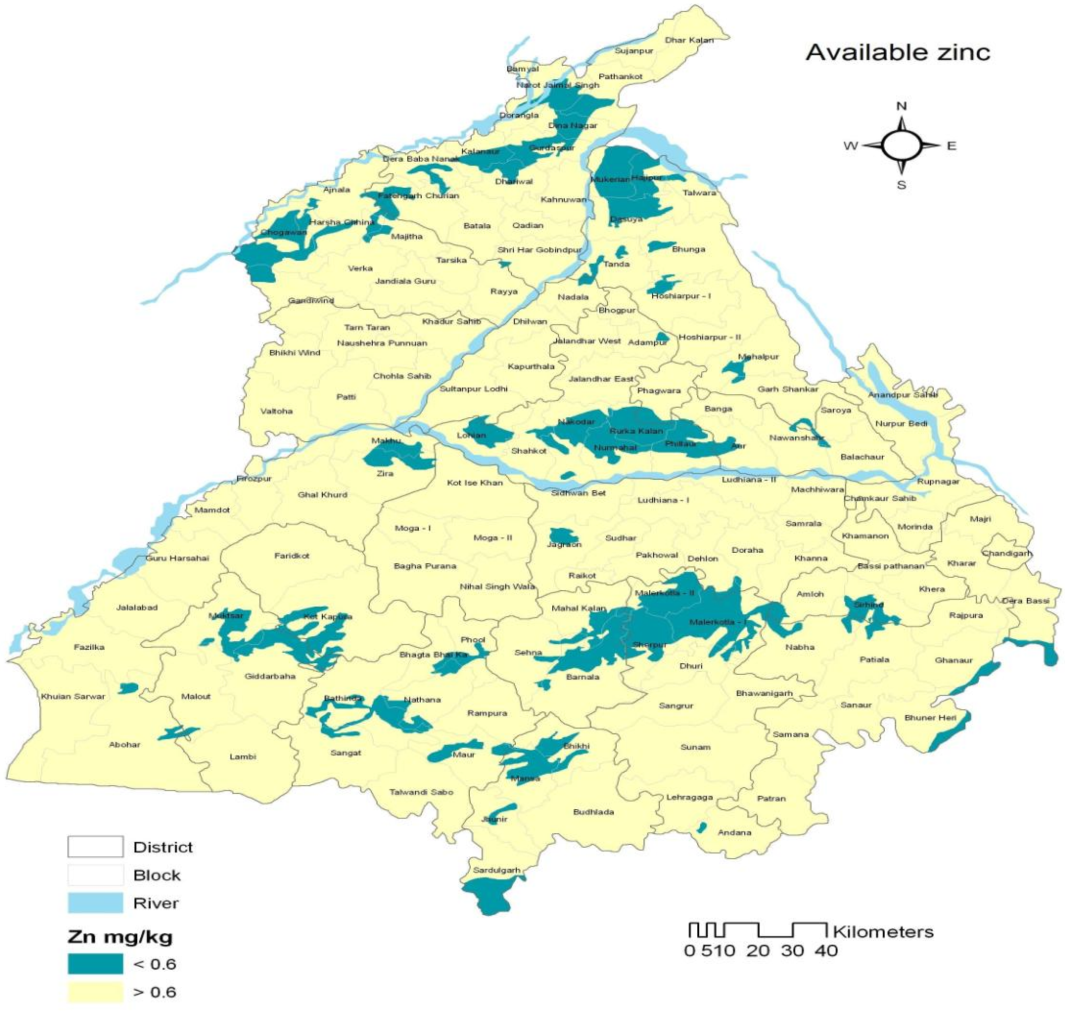

Fig. 8 Thematic map of available zinc status of Punjab soils

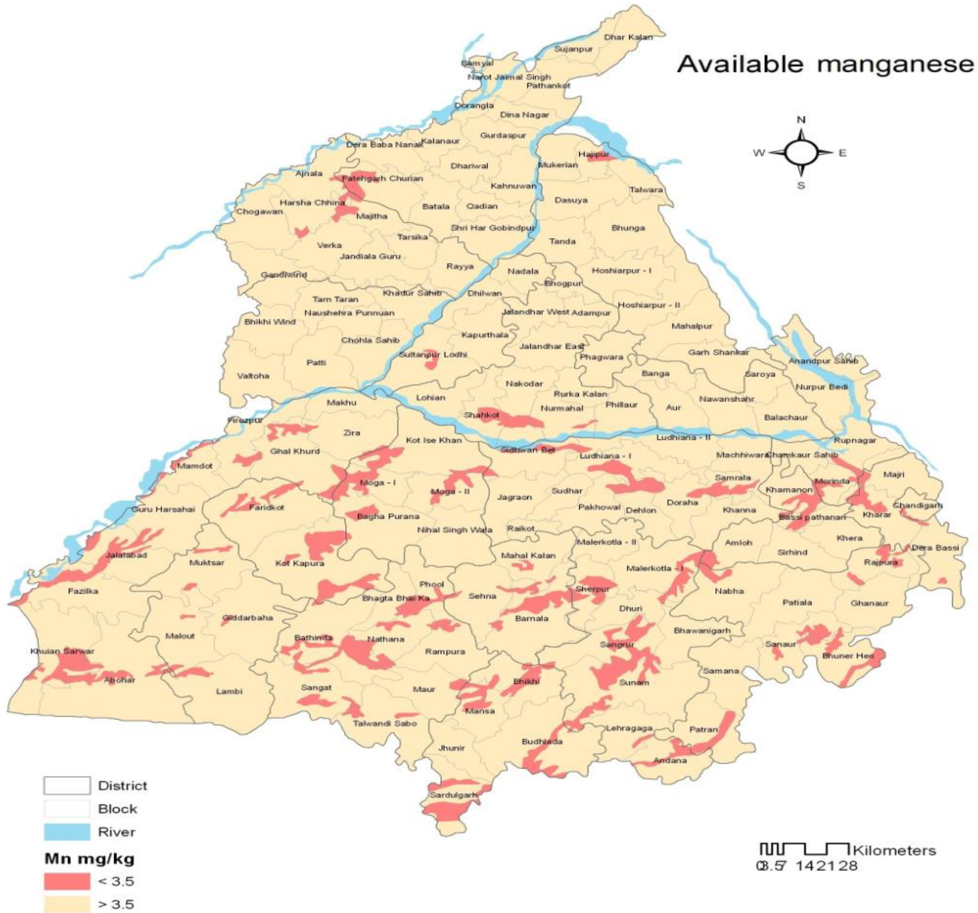

Fig.9 Thematic map of available manganese status of Punjab soils

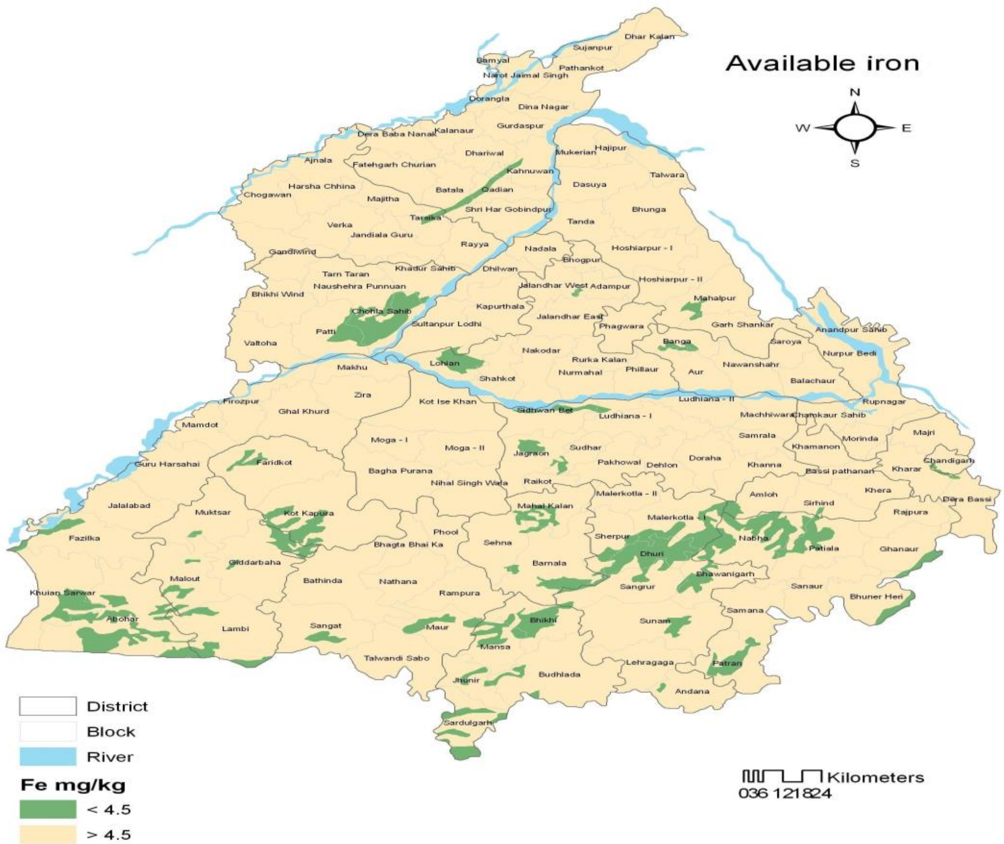

Fig. 10 Thematic map of available iron status of Punjab soils

Table

Table 1: Descriptive statistical parameters of physical and chemical characteristics and fertility indicators of study area

Statistical parameters	pH (1:2)	EC dSm^{-1}	OC (%)	$CaCO_3$ (%)	Sand (%)	Silt (%)	Clay (%)	P Kg/ha	K Kg/ha	Cu mg/kg	Fe mg/kg	Mn mg/kg	Fe mg/kg
Min	6.77	0.14	0.05	0.2	10.2	68.6	21.2	1.12	2.51	0.13	0.07	0.68	1.32
Max	9.25	1.86	1.37	10.46	91.00	73.50	35.00	238.00	533.12	4.02	3.06	51.74	38.86
Avg.	6.23	0.48	0.42	3.25	60.36	27.67	11.60	40.32	73.34	1.09	1.11	6.78	8.14
SD	3.36	0.39	0.32	1.75	18.91	14.93	7.56	49.33	108.34	0.76	0.52	4.97	4.68

Table 2. The pH (1:2) soils of Punjab

Categories pH range	Mean pH values	No. of polygons	Per cent area of state
Normal 6.5-8.7	7.99	487	94.8
Alkaline 8.8-9.3	8.91	30	5.0
Alkali> 9.3	9.51	3	0.2

Table 3. The electrical conductivity (dS m^{-1}) of soils of Punjab

EC Categories with ranges	Mean (dS m^{-1})	No. of polygons	Per cent area of state
Normal< 0.8	0.31	493	93.6
Saline> 0.8	0.98	27	6.4

Table 4. Soil texture of Punjab soils

Soil texture	No. of polygons	Per cent area of state
Sand	2	0.2
Loamy sand	52	12.2
Sandy loam	267	47.3
Loam	81	16.0
Clay loam	1	0.1
Silt	5	1.4
Silt loam	106	22.3
Silty clay loam	6	0.5

Table 5. Organic carbon content (OC %) in soils of Punjab

OC categories with ranges	Mean OC values	No. of polygons	Per cent area of state
Low < 0.40	0.32	154	31.6
Medium 0.40 - 0.75	0.55	331	56.6
High > 0.75	0.82	35	11.8

Table 6. Available potassium content (kg ha^{-1}) in soils of Punjab

K categories with range	Mean available K	No. of polygons	Per cent area of state
Low < 113	81.9	36	7.7
High > 113	636.3	484	92.3

Table 7. Available phosphorus content (kg P ha^{-1}) in soils of Punjab

P categories with range	Mean available P	No. of polygons	Per cent area of state
Low < 12	5.11	178	36.4
Medium12 - 22	16.47	86	17.8
High 22 - 50	32.58	121	19.6
Very high> 50	108.89	135	26.2

Table 8. DTPA extractable zinc content (mg Zn kg^{-1} soil) in soils of Punjab

Zn categories with range	Mean DTPA-Zn values	No. of polygons	Per cent area of state
Deficient < 0.6	0.41	58	9.7
Sufficient > 0.6	1.72	462	90.3

Table 9. DTPA extractable manganese content (mg Mn kg^{-1} soil) in soils of Punjab

Mn categories with range	Mean DTPA-Mn values	No. of polygons	Per cent area of state
Deficient < 3.5	2.34	79	7.6
Sufficient > 3.5	6.87	441	92.4

Table 10. DTPA extractable copper content (mg Cu kg^{-1} soil) in soils of Punjab

Cu categories with range	Mean DTPA-Cu values	No. of polygons	Per cent area of state
Deficient < 0.2	0.14	11	0.5
Sufficient > 0.2	1.13	509	99.5

Table 11. DTPA extractable iron content (mg Fe kg^{-1} soil)
in soils of Punjab

Fe categories with range	Mean DTPA-Fe values	No. of polygons	Per cent area of state
Deficient < 4.5	2.88	62	6.6
Sufficient > 4.5	17.34	458	93.4

Table 12. Correlation coefficient of DTPA- extractable micronutrients with physical and chemical properties

	Zn	Cu	Mn	Fe
OC	0.35*	0.52*	0.34*	0.49*
pH	-0.20	0.10	-0.67*	-0.48*
CaCO3	-0.23	-0.30*	-0.43*	-0.35
Sand	-0.36*	-0.38*	0.24	0.15
Silt	-0.18	0.14	0.20	-0.27*
Clay	0.32*	0.38*	-0.18	0.16
CEC	0.29*	0.32*	-0.15	0.20
Zn	-	0.45	0.20	0.38

* Significant : r >0.26 for p,0.05