



# Digital soil mapping of PAU-Regional Research Station, Kapurthala, Punjab, India

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## Abstract

Digital soil mapping is an invention that uses modern technologies to express geographical soil information. Across the country, there has been a transition of digital soil mapping from the research phase to the operational phase, but no comprehensive research has been conducted at the Regional Research Station in Kapurthala. Instead of dealing with the whole field as a single unit, dealing with small units per spatial soil properties is the first step towards sustainable agriculture. However, all soil's spatial variations could not be corrected with one blanket recommendation. Considering this in mind, the current investigation carried out the research station with 84.4 ha of agricultural land comprising eight blocks, with an objective of delineating the spatial variation in soil properties viz. soil organic carbon (%), electrical conductivity, pH, available Phosphorus, potash, zinc, iron, manganese, and copper ( $\text{mg kg}^{-1}$ ), respectively on to the soil maps prepared using geo-statistics. Finally, digital soil mapping (DSM) was prepared for dealing with such spatial soil variation after preparing the base maps using GPS-60 (GARMIN). For this purpose, 40 representative spatial soil samples were collected from all the blocks. DSM delineated that most spots are low in SOC at the farm while available P, K, and Cu are sufficiently available. Further, the micronutrients DTPA-Zn, Fe, and Mn, were reported with spatial deficiencies in different blocks. Therefore, these recommendations help in the more sustainable and judicious use of the fertilizers on one side while also helping in controlling micronutrient deficiencies before their symptoms appear. Henceforth, DSM must be prepared and is a prerequisite to achieving sustainability in any soil–plant interphase despite any agro-climatic zone and soil textural class to improve soil health and practice sustainable agriculture at the farm.

**Keywords** Digital soil mapping · Kapurthala · Micro-nutrients · Macro-nutrients

## Introduction

Soils are widely acknowledged as significant contributors to ecosystem services like climate regulation and food production. (Palm et al. 2007; MEA 2005), and demand for current and pertinent information about soil is skyrocketing. However, presenting information about soil to different audiences remains challenging due to the inconsistent usage of technical jargon and antiquated, inaccurate approaches.

Furthermore, soil maps with the high spatial resolution are scarce, so they cannot be used in actual land management. The branches of earth sciences such as geology and climatology have become more quantitative, and also, the digital revolution has benefitted them. However, the traditional method of soil mapping still uses qualitative criteria to delineate space, and maps are created using a sequence of polygons that limit the resolution. These soil maps are unable to express the soil complexity that understandably exists across the terrain. The first soil map using the vocabulary of standard soil classification was released in 1981 by the United Nations (UN), Food and Agriculture Organization (FAO), and United Nations Educational, Scientific and Cultural Organization (UNESCO) (FAO-UNESCO 1998). These maps have been used for several global studies, including land degradation, climate change, and food production, but, owing to the low resolution of the 1:5 million scale, it was not adequate for decisions regarding the management of

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land at watershed scale or field scale. The degradation map of soil has a poor resolution of 1:50 million scales. Also, it lacks quantitative information about the soil parameters that indicate the degree of soil degradation. (Oldeman et al. 1999). The conventional soils with a 1:1 million or finer scale are currently available in 109 countries. Still, only 31% of the land surface, free of ice, is covered, leaving the rest of the nations to depend upon the FAO-UNESCO map. (Nachtergaele 2003). In order to remedy several flaws, it has become imperative for soil scientists to produce a three-dimensional grid with a satisfactory resolution to represent the functional qualities relevant to the users. A digital soil map that is freely accessible can help land users, scientists, and policymakers to obtain good geo-referenced soil quickly. The GlobalSoilMap.net (GSM) initiative is laying the groundwork for such an undertaking. The groundwork for such an undertaking was already initiated by GlobalSoilMap.net (GSM) in 2006. (Hartemink and McBratney 2008) as a response to the dissatisfaction of policymakers and to answer several questions related to quantitative information such as the amount of carbon stored or emitted in the soil from a particular region, the effect on biomass production and human health, etc. There are three major components: digital soil mapping, soil management advice, and serving end-users undertaken by GSM and supported by its strong cyber infrastructure. Digital soil mapping is the prediction of soil properties from point data using a statistical algorithm which further helps in managing the soils in a more sustainable way (Panday et al. 2018; Itichaa and Takeleb 2019; Biswajit and Divya 2020).

Variations in soil properties spatially in a particular field or a region might be due to the inherent and extrinsic factor which also involves the anthropogenic activities, viz. fertilization, tillage practices, etc. (Cambardella and Karlen 1999; Gessler et al. 1995; McBratney et al. 2003; Grunwald et al. 2016). These variations finally resulted in variable soil fertility levels within a field or a region. Site-specific fertilizer management is challenging (Bhatt and Singh 2021; Bhatt et al. 2021a, b). Un-judicious use of fertilizers over here resulted in lesser use efficiencies (Russenes et al. 2019; Bhatt et al. 2021a, b, c) and finally declined overall land productivities (Fowler et al. 2013; More et al. 1988). Therefore, fertilizer applications per crop need and inherent soil fertility are a must-adopted approach for sustainable agriculture (Gupta et al. 1999; Vavoulidou et al. 2009). The survey of the field and classification of the field into soil mapping units for proper need-based management are often the best solutions for soils with significant spatial variations in their attributes (Inman et al. 2005; Barman et al. 2013; Cullum et al. 2017).

Intensive rice–wheat cropping sequence of PAU-RRS, Kapurthala, Punjab, India resulted in several sustainability issues at the station, viz. deprivation of soil health, declining of the water table below ground, intensification in

insect-pest and diseases attacks coupled with the dearth of micro-nutrients (Bhatt et al. 2021a,b) which stood as a significant challenge in front of sustainable agriculture (FAO, 1994; Dharumarajan et al. 2018a). Nitrogen use efficiency reduced from 71% in the 1960s to 44% from 2010–to 2016 due to unscientific approaches (Elrys et al. 2019). Hence, using DSM, sustainably dealing with spatial soil fertility is very important for sustainable land management (Lagacherie 2008; McBratney et al. 2003) and modeling calculations (Hartemink and McBratney 2008), and no such maps of our station are available up to now. Therefore, DSM could be the best move toward soil spatial fertility mapping, bringing overall sustainability to farms (McBratney et al. 2003; Arrouays et al. 2014; Lagacherie and McBratney 2006; Lagacherie 2008).

## Material and methods

### Location

Regional Research Station (RRS), Kapurthala (established in 1973), with an area of 84.4 ha, is an important seed farm and research station of Punjab Agricultural University, Ludhiana (Fig. 1), which is located at 31° 23.414' N longitude and 75° 21.586' E latitude at the height of 225 m above sea level (Bhatt and Singh 2020). Station represents the country's sub-tropical conditions and has 8 blocks viz. A (11.2 ha), B (8.4 ha), C (3.2 ha), D (9.4 ha), E (15.4 ha), F (1.6 ha), G (11.6 ha), and H blocks (7.2 ha) are there at the RRS, Kapurthala. Further, the mandi area (2.8 ha) and JJ farm (13.2 ha) are also part of the station. Hot summers are there (41.8° to 47.0 °C), followed by quite cold conditions (0.8° to 1.0 °C) during the winter. Rainfall is limited to the months of July and September, with an average of 650 mm (Anonymous 2018). The soil textural class predominately pertains to the sandy loam class at the station. The scale of all the maps used in the illustrated in the paper is 1:250.

### Samples collection

For preparing DSM, 40 representative surface soils were collected from all over the farm, including different blocks viz. A, B, C, D, E, F, G, and H blocks using a standard procedure (Andreas and Berndt 2005; Bhatt and Sharma 2014) with GPS-60 (GARMIN) during 2018. Large roots, litter, and stones from collected samples were meticulously removed throughout the sampling depths. Soil samples were spread out on a clean sheet of paper on the ground to dry for 48 h in the shade. Once the drying operation was completed, the wooden hammer was

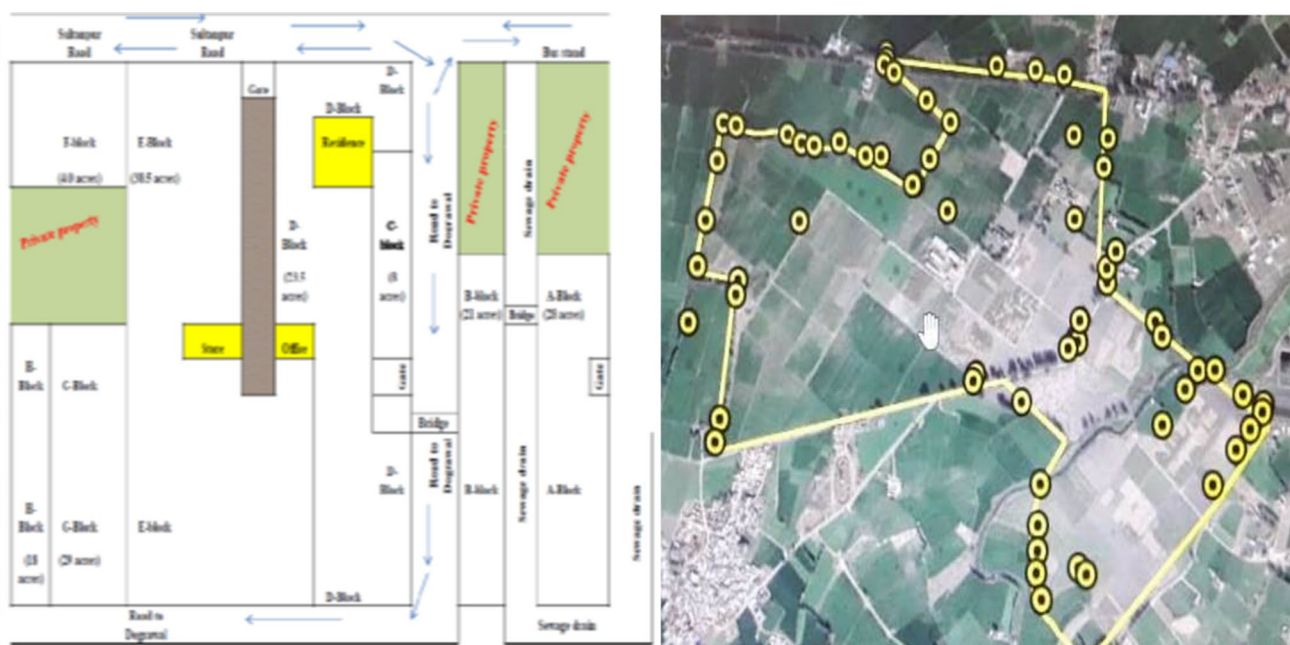


Fig. 1 Location map of Regional Research Station, Kapurthala, Punjab ( Source Google Earth, Alphabet Company)

used to shatter the dirt clods and then passed through a 2 mm sieve. After that, a clean polythene bag was used for placing the materials, and they were properly labeled for physical and chemical property assessments. The feel method was used to estimate the texture of the soil. Jackson's conventional protocols for estimating soil pH and EC in a 1:2 soil: water solution were used (1967). The wet digestion and quick titration method of Walkley and Black were used to assess soil organic carbon (Walkley and Black 1934). 0.5 M NaHCO<sub>3</sub> extract (Olsen et al. 1954) and 1N ammonium acetate (pH 7) extract were used to assess available Phosphorus and potassium, respectively (Jackson 1967). The available zinc, manganese, iron, and copper in soil were quantified by the diethylene triamine penta-acetic acid (DTPA) method (Lindsay and Norvell 1978). Then they were examined using an atomic absorption spectrophotometer (AAS). DSM delineates the different uncertainties, providing dynamic soil properties information based on time-series data. However, here purpose is to develop the digital soil maps pertaining to the various nutrients viz. macro and micro-nutrients, for the site-specific and judicious use of fertilizers so that site-specific nutrient deficiencies should be handled well in time. Therefore, above facts in mind, the present study planned to prepare the DSMs of RRS, Kapurthala pertaining to spatial variations in different soil physico-chemical viz. soil pH, EC, organic carbon (%), macro-nutrients viz. P and K, and micro-nutrients viz. Zn, Mn, Fe, and Cu for the sustainable use of fertilizers as per plant requirements and inherent fertility of soils.

### Digital soil mapping (DSM)

The beginning of these maps was initiated by (Webster et al. 1979), which up to the 1980s entered in their advanced stages due to the evolution of remote-sensing technologies, modeling and computing, and global positioning systems (GPS). Under proper agreements, these technologies undergo experimentation, which is further used in natural resource management and preparation of C-sequestration patterns in a more sustainable way (Minasny et al. 2008; ; McKenzie et al. 2008; Grimm et al. 2008). All three steps involved in the DSM preparation as (i) Soil sampling using GPS, entering of data inputs, and preparation of base maps, (ii) Analyzing the so collected samples for their physico-chemical properties, macro, and micro nutrients, and finally (iii) spatially inferred soil properties at maps for making sustainable recommendations. Further, DSM was very useful for dealing with degraded and eroded lands. Therefore, essential for formulating the land reclamation programs (Symeonakis and Drake, 2004; Dharumarajan et al. 2018b; Hengl et al. 2017; Reynolds et al. 2000). Recently, soil health cards were distributed by the government of India for the farmers (<https://soilhealth.dac.gov.in/>), and this is only possible because of the available DSM. DSM is entirely different from the conventional maps as earlier maps also estimate an idea regarding spatial variation in soil fertility of the points that are not even sampled.

Further, conventional soil maps provide limited access to spatial detail (Zhu 1997) and are expensive, time-consuming, and not reproducible. However, DSM covers all the



limitations of conventional maps (Carré et al. 2007a, b; Behrens et al. 2010). The only limitation is that the wrong data entry might be human error or typing errors. Further, many un-sampled points (Arrouays et al. 2014) and wrong analysis of entered data (Nussbaum et al. 2018) also reduce the quality of DSMs. Further, due to difficulty collecting many soil samples from all sites and lack of funds to meet analysis costs, there is difficulty in fertilizer management at all spots.

The cost associated with field collection and laboratory analysis will reduce if the study region adequately represents the study region (Johnson et al. 2012). In QGIS, a geo-statistical tool known as Kriging has been utilized to interpolate the observed values of soil nutrients. Several digital map layers were created based on each soil nutrient. Kriging has proved robust for estimating values at locations that are not sampled based on the available sample data and provide the best linear unbiased estimates and information about the distribution of estimation error. (Wang et al. 2009). The field measurements were taken at various sites along the surface. The intermediate values were calculated using an interpolation approach, a popular GIS technique for generating a continuous surface from discrete points. The weighted sums of the nearby sampled concentrations were used to produce the kriging estimations. The kriging approach estimates the spatial distribution structure of soil characteristics using semi-variance (Zandi et al. 2011; Wang and Shao 2013). Yao et al. 2013, explore the formula used in the kriging approach in depth. These maps would allow soil experts to assess existing farm soils and assist farmers in making efficient management decisions to ensure long-term production sustainability. Thus, digital maps of soil nutrients were created using the kriging approach, and the findings were grouped into distinct classes based on the range representing their magnitude in the soil.

## Results and discussions

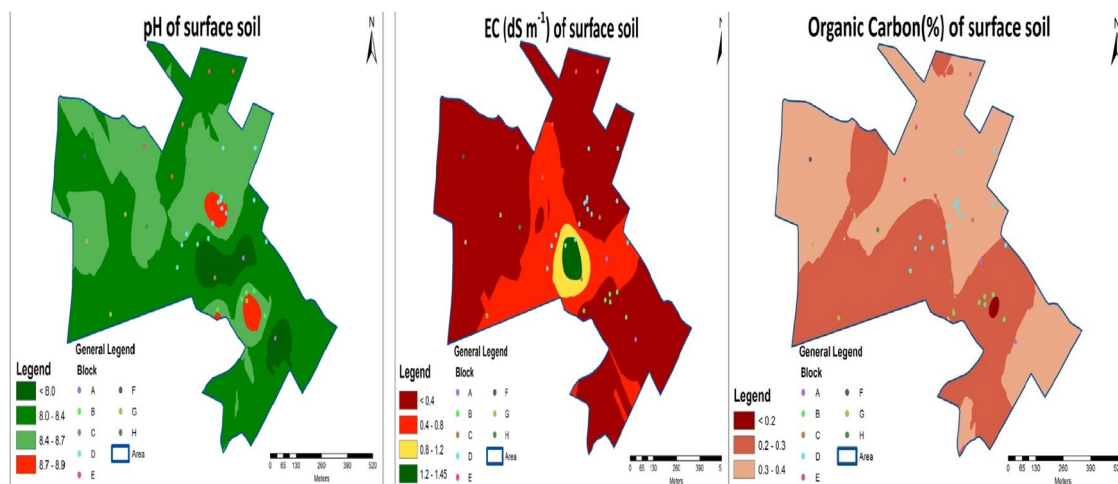
### Physico-chemical properties

#### pH

Among physico-chemical properties of the station, it revealed that blocks E, F, G, and H blocks had a relatively spotic higher range of pH, which needs to correct either through the green manuring or through gypsum application. Soil pH ranged from 7.73 to 8.91, with mean values of 8.03, 8.64, 8.13, 8.48, 8.37, 8.39, and 8.53 for blocks A through H, with an overall mean of 8.38. The higher range might be due to soluble and exchangeable sodium ions and bicarbonate ions in the field, which might precipitate after evaporation in parts of the fields (Deshmukh 2012). Furthermore, 82.5% of the soil samples tested were in the normal pH range, whereas 17.5% had a pH of 8.7 to 9.3. DSM revealed that other blocks are normal for growing the different crops while the pH of E, F, G, and H blocks needs to be brought down, resulting in the sustainable improvement in sound quality seed grains (Fig. 2).

#### EC

The EC of the farm ranged from 0.17 to 0.70 m mhos  $\text{cm}^{-1}$ , with mean values of 0.30, 0.23, 0.70, 0.47, 0.37, 0.30, 0.33, and 0.34 m mhos  $\text{cm}^{-1}$  in blocks A to H, respectively, and an average value of 0.38 m mhos  $\text{cm}^{-1}$ . A large percentage of soil samples (92.5%) were within acceptable bounds (6.5–8.7). Coming over to the EC, only D and C blocks were reported with somewhat higher EC spot values, which needs to be addressed/reclaimed for favorable soil health as the higher the salts lesser will be the availability of the soil



**Fig. 2** DSMs of pH, EC, and OC of regional Research Station, Kapurthala, Punjab, India



moisture to the plants (Bhatt et al. 2021a, b, c). Considering this, 275, 324, and 424 qt of gypsum were already applied in D, E, G, and H blocks to reclaim these salt-affected sites for better quality yields of different field crops during May–June 2018, 2019, and 2020, respectively.

### Soil organic carbon

Soil organic carbon (SOC) reflects soil organic matter, further responsible for higher input, viz. fertilizers use efficiency in various physicochemical qualities and superior response to applied N fertilizer (Johnston 1986). The farm's SOC status ranged from 0.14 to 0.46%, with mean values of 0.41, 0.22, 0.29, 0.31, 0.31, 0.36, 0.29, and 0.34% for blocks A to H, respectively, and a mean of 0.32% for the entire farm. DSM revealed that all the blocks had a lower value of the SOC (%), which made applying 25% higher dose than the recommendations except for A, D, and E blocks, where some spots showed higher SOC and practiced green manuring might be a reason for this.

### Macronutrients

#### Available phosphorus

Phosphorus is the second most essential plant nutrient, and its availability in soils depends on several factors (Singh et al. 2021). In the soils of the RRS station in Kapurthala, available P content (averaged value) was 32.4, 18.5, 12.0, 9.3, 12.3, 8.3, 13.9, and 13.2 mg kg<sup>-1</sup> in blocks from A to H, respectively with an overall average of 14.9 mg kg<sup>-1</sup>. Available P content (mg kg<sup>-1</sup>) was reported to be higher throughout the farm due to excessive use of P fertilizers during the earlier years except for D block, which showed spotic deficiency of inherent P status, thereby needs to apply

P fertilizers over there for having improved land as well as water productivity in this block (Fig. 3).

#### Available potassium

The average accessible K concentrations in blocks A to H were 104, 197.3, 55, 95.3, 72.8, 38.0, 65.8, and 36.0 mg kg<sup>-1</sup>, with an average value of 83.0 mg kg<sup>-1</sup>. Further, available K status (mg kg<sup>-1</sup>) is generally assumed to be higher in illite rich soils of Punjab, but these facts are not true due to practiced intensive cropping sequences with no use of K fertilizers and more K- samples reported to be deficient in the district (Bhatt and Sharma 2011; Bhatt et al. 2021a, b, c). DSM revealed that inherent K status except for B, C, D, E, F blocks has spotic deficiencies where values reported to be lesser than 137.5 kg ha<sup>-1</sup>, and this needs to be addressed with proper application of K fertilizers viz. murate of potash alone or with polyhalites (Bhatt et al. 2021a, b, c).

### Micronutrients

Instead of being required in small amounts, micronutrients are essential for the plants to complete their life cycle and be involved in different physiological and metabolic activities (Tripathi et al. 2015). Therefore, the micronutrient status of the farm varied differentially as per other blocks depending on several factors.

#### Available iron

The accessible Fe concentration in the station's soils averaged 8.21, 6.13, 5.57, 11.6, 7.90, 9.80, 13.8, and 10.1 mg kg<sup>-1</sup> in blocks A to H (overall mean 9.15 mg kg<sup>-1</sup>) accordingly (Fig. 4). Soil analysis revealed that 87.5% of

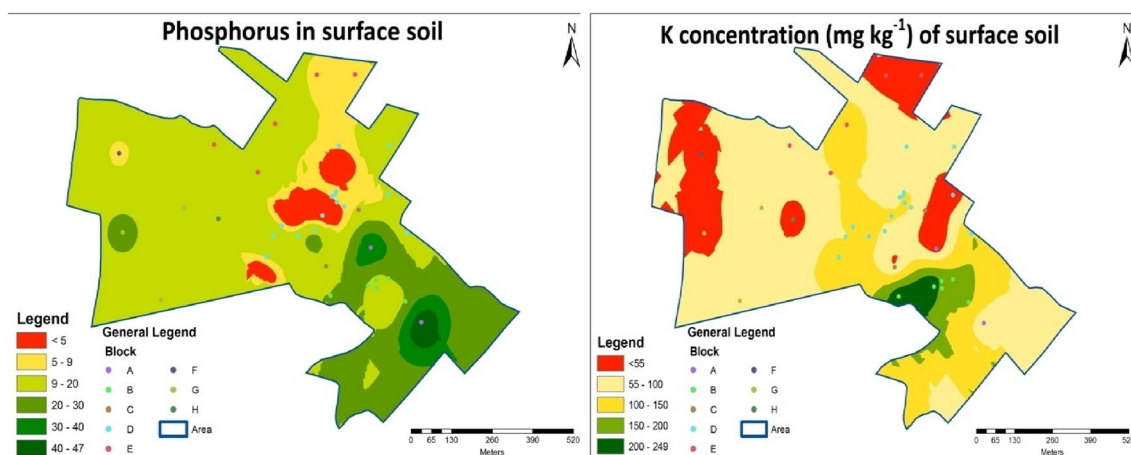
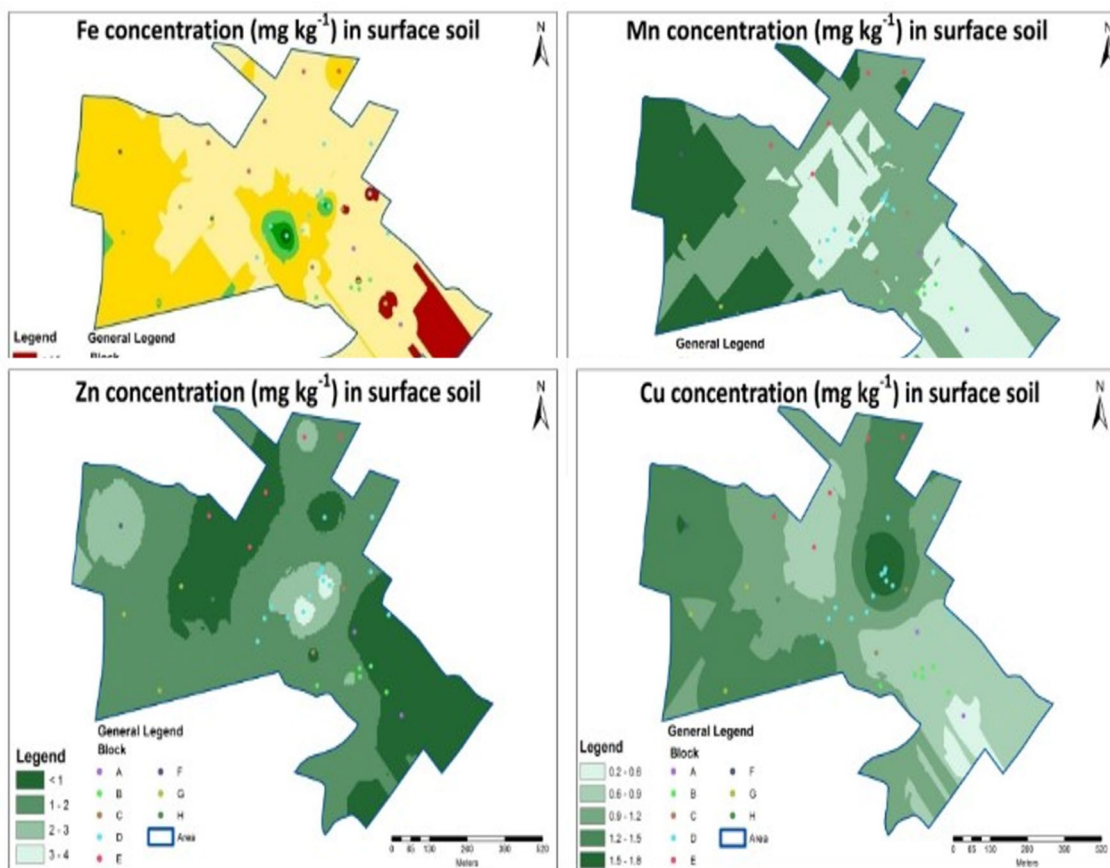


Fig. 3 DSMs of P and K of regional Research Station, Kapurthala, Punjab, India





**Fig. 4** DSMs of micronutrients at Regional Research Station, Kapurthala, Punjab, India

samples fell into the high category, while 12.5% fell into the low category, using  $4.50 \text{ mg kg}^{-1}$  as the threshold limit for accessible Fe concentration. To reduce Fe deficiency in crops like sugarcane and maize,  $\text{FeSO}_4$  sprays may be required. DSMs revealed that A and D blocks reported some deficient samples, which might be due to the lesser irrigation facilities as only a single tube well there for irrigation of all the field crops.

#### Available manganese

The accessible Mn concentrations in the station's soils varied significantly between blocks, with mean values of 5.77, 4.58, 6.17, 5.50, 5.19, 3.80, 9.08, 4.92  $\text{mg kg}^{-1}$  in blocks A to H, respectively, with 5.63  $\text{mg kg}^{-1}$  observed as overall mean (Fig. 4). Using  $3.50 \text{ mg kg}^{-1}$  as the critical limit of Mn deficiency, 80% of soil samples were within the acceptable range, while 20% had insufficient Mn. However, available Mn is reported to be in a lesser range in the A, C, D, and E blocks and particularly needs to be applied to the wheat crop as it affects crop performance significantly if ignored.

#### Available zinc

In blocks A to H, the available Zn status of the soils at the station had mean values of 1.21, 1.39, 1.15, 2.01, 1.08, 2.90, 1.39, and 0.92  $\text{mg kg}^{-1}$ , with 1.51  $\text{mg kg}^{-1}$  as overall mean. DSM of available Zn status ( $\text{mg kg}^{-1}$ ) revealed spotty deficiency at A, B, D, E, and G blocks at some sites which must be applied with a recommended dose of Zn either through broadcasting or afterward through sprays, particularly in rice though same blocks also reported with samples showing acceptable range (Fig. 4).

#### Available copper

The mean accessible Cu content in RRS Kapurthala soils varied from 0.68 to 1.38  $\text{mg kg}^{-1}$  in different blocks, with values of 0.79, 0.84, 0.68, 1.38, 0.96, 1.80, 1.13, and 0.86  $\text{mg kg}^{-1}$  in A to H blocks, respectively, with 1.06  $\text{mg kg}^{-1}$  as an overall mean value (Fig. 4). Because all soil samples had  $> 0.50 \text{ mg kg}^{-1}$  (far beyond the threshold level), no soil sample lacked accessible Cu throughout the farm at all the blocks. Therefore, DSMs of this nutrient also

revealed that there is no need to apply Cu in any station block.

## Conclusion

Finally, it could be summarized that DSMs of the station revealed that 82.5% of soil samples had an average pH (6.5–8.7), while 17.5% were alkaline, which needs to be reclaimed for better input use efficiency of the applied inputs. Coming over to EC, only 7.5% of samples reported with higher range, viz.  $>0.8 \text{ m mho cm}^{-1}$ . Only 12.5% of samples reported medium-range viz. 0.4–0.75%), while 5 and 30% of samples were classified as low and medium, respectively. With a few exceptions, available P, K, and Cu were higher across the farm with some spotty deficiencies. Among available micro-nutrients viz. Zn, Fe, and Mn reported around 15, 12.5 and 20% deficient samples where these must be applied as per recommendations. Finally, DSMs recommend using the recommended dose of urea in the A block while a 25% higher dose in rest blocks, followed by a 25% higher dose of Phosphorus in the F block. Similarly, only B, C, H, and F blocks need potash application for better root development and facing stressed conditions. Therefore, RRS, Kapurthala soils are neutral in pH, normal in EC, low to medium in OC, and higher in P and K while sufficiently rich in zinc, iron, manganese, and copper status except for spotty deficiencies. This method must be taught to a new generation of soil scientists. The new maps and management recommendations that result will assist solve some of our time's most pressing issues, including food security, climate change, environmental degradation, water scarcity, and threatened biodiversity.

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