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Spatial variability of soil micronutrients in the intensively cultivated Trans-Gangetic Plains of India

Arvind K. Shukla[a,*], Sanjib K. Behera[b], Narendra K. Lenka[a], Pankaj K. Tiwari[a], Chandra Prakash[a], R.S. Malik[c], Nishant K. Sinha[a], V.K. Singh[d], Ashok K. Patra[a], S.K. Chaudhary[e]

[a] ICAR-Indian Institute of Soil Science, Nabibagh, Berasia Road, Bhopal, Madhya Pradesh, 462038, India
[b] ICAR-Indian Institute of Oil Palm Research, Pedavegi, West Godavari, Andhra Pradesh, 534450, India
[c] ChaudharyCharan Singh Haryana Agricultural University, Hisar, Haryana, 125004, India
[d] ICAR-Indian Institute of Farming System Research, Modipuram, Meerut, UP, 250110, India
[e] Indian Council of Agricultural Research, New Delhi, 110012, India

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ABSTRACT

Soil micronutrient deficiency adversely affects crop production in intensive agriculture. However, information on the spatial variability of key micronutrients in intensively cultivated regions of India is limited. Thus, the present study was carried out in the Trans-Gangetic Plains (TGP) region of India with the hypothesis that spatial variability of micronutrient availability is high due to small farms and varied management. The major objectives of the study were (i) to assess the spatial variability of plant available micronutrients, *viz.* extractable zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) at a regional scale through geostatistical methods, (ii) to develop distribution maps for soil micronutrients using ordinary kriging and (iii) to assess the relationships of micronutrient availability with several soil properties. A total of 5638 soil samples, representative of the surface (0–15 cm) horizon were collected (covering Inceptisols, Entisols, Alfisols and Aridisols) during April to June between 2011 and 2014 from farms in 21 districts of the TGP. For each micronutrient, semivariograms were calculated and their main parameters (nugget effect, sill and range) were obtained. Moderate spatial dependence for extractable Zn, Cu and Fe and strong spatial dependence for extractable Mn were recorded. The nugget/sill ratio values were 0.60, 0.37, 0.34 and 0.19 for extractable Zn, Fe, Cu and Mn, respectively. Available Fe, Zn, Mn and Cu deficiencies (including acute deficiencies) were observed in 28, 15, 14 and 13% of soil samples, respectively. Soil pH showed significant and negative correlations with the concentrations of extractable Zn, Cu, Mn and Fe; whereas the correlation was significant and positive with soil organic carbon (SOC) concentration. The distribution maps generated could be used as a guide for precise and site-specific micronutrient management in the study region.

1. Introduction

The Indo-Gangetic Plain (IGP) region of India, covering about 15% of the total area of the country, is one of the most intensively cultivated regions of the world (Yadav, 1998; Singh et al., 2015). The Indian IGP consists of four sub-regions, namely (1) Trans-Gangetic Plains (TGP) covering the states of Punjab and Haryana, (2) Upper Gangetic Plains covering the states of Uttarakhand and Uttar Pradesh, (3) Middle and Lower Gangetic Plains covering the states of Bihar and West Bengal (Singh et al., 2007). Rice (*Oryzasativa*) –Wheat (*Triticumaestivum*) cropping sequence is the dominant system in the Trans- and Upper-Gangetic Plains whereas rice based cropping sequences are common in the middle and lower Gangetic Plains. The role and contribution of the IGP region over the last four decades to the food and nutrition security of India is well documented (Yadav, 1998; Kumar et al., 2002). However, declining groundwater table and soil degradation are the two critical constraints for sustainable food production in the region (Kumar et al., 2002; Singh et al., 2007), particularly in TGP.

Unsustainable intensification accompanied by imbalanced soil nutrient management is one of the major causes of declining

* Corresponding author.
E-mail address: arvindshukla2k3@yahoo.co.in (A.K. Shukla).

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productivity and land degradation in the region (Singh et al., 2007). Though a balanced soil nutrient management includes appropriate mix of organics, and addition of macro- as well as micro- nutrients through chemical fertilizers, very often the mined nutrients are not optimally replenished. Such distortions in the soil nutrient management are highly probable in intensively cultivated regions such as IGP (Singh et al., 2007, 2015) primarily due to high cropping intensity, low or non-availability of organics and over-dependence on chemical fertilizers leading to deficiency of several micro-nutrients.

Large scale deficiency of cationic micronutrients like zinc (Zn), copper (Cu), manganese (Mn) and iron (Fe) in different soils has been reported world-wide (Sillanpaa 1990; Shukla et al., 2014). Recent Indian studies report extensive deficiency of micro-nutrients in farms due to regular withdrawal of these nutrients through crop uptake (Shukla et al., 2014; Shukla et al., 2015). The distribution of micronutrients may vary in space and time across management units. In Indian soils, spatial variability in micronutrient availability is presumed to be high due to small farms and varied management.

Geostatistical tools are useful to estimate spatial variability of soil properties and soil nutrients at field, catchment as well as regional scales (Tesfahunegn et al., 2011; Tripathi et al., 2015). Geostatistical estimation helps in predicting values at unsampled locations by taking into account the spatial correlation between sampled points (Webster and Oliver, 1990; Cambardella et al., 1994). At the catchment scale, Tesfahunegn et al. (2011) reported strong (8%) to moderate (63%) degrees of spatial dependence for the soil properties like soil pH, soil organic carbon (SOC), total nitrogen, available phosphorus, cation exchange capacity and available Fe and indicated that soil properties mapped on the basis of kriging interpolation were more accurate than the catchment average values. Information on the spatial variability of micro-nutrients in Indian soils is limited. Thus, the present study in cultivated soils of the TGP of India (one of the most intensively cultivated regions of the country)was undertaken with the following objectives, (i) to estimate the spatial variability of extractable Zn, Cu, Mn and Fe at a regional scale through semivariogram analysis, (ii) to assess the relationship of micronutrient availability with key soil properties, and (iii) to develop spatial maps for soil micronutrients using the parameters of the best-fitted semivariogram model and interpolation by ordinary kriging.

2. Materials and methods

2.1. Study area

The study region is one of the two most intensively cultivated states of the country and comprises all of the districts of Haryana state in the TGP of India. For the study, surface (0–15 cm) soil samples were collected from farms in twenty-one districts of Haryana state (27°50′ to 30° N latitude, 76° 50′ to 77° 30′ E longitude and 200–1200 metres altitude) (Fig. 1) spreading over 44212 km^2. Most part of the study area experiences arid to semi-arid climate except in the north-east where the climate is relatively humid. The average annual rainfall ranges between 300 mm (south-west) to 1300 mm (north) with a state average of 617 mm. The weather is hot (highest mean temperature 40 °C and relative humidity 35%) in summer and cold (lowest mean temperature 7.5 °C and relative humidity 55%) in winter. Soils are alluvial in nature with sandy to sandy loam texture and belong to the Inceptisols, Entisols, Alfisols and Aridisols classes (Bhattacharyya et al., 2013).

2.2. Soil sampling and processing

A total of 5638 geo-referenced soil samples, representative of the surface (0–15 cm) horizon were collected during April to June between 2011 and 2014 from farms in 21 districts of the TGP region of India, following a multistage stratified random sampling method (Cochran, 1977; Gelfand and Schliep, 2016) and using stainless steel soil augers. The soil was sampled under the aegis of the All India Coordinated Research Project of Micro- and Secondary Nutrients and Pollutant Elements in Soils and Plants (AICRP-MSN), after harvest of wheat crop. Samples were collected covering

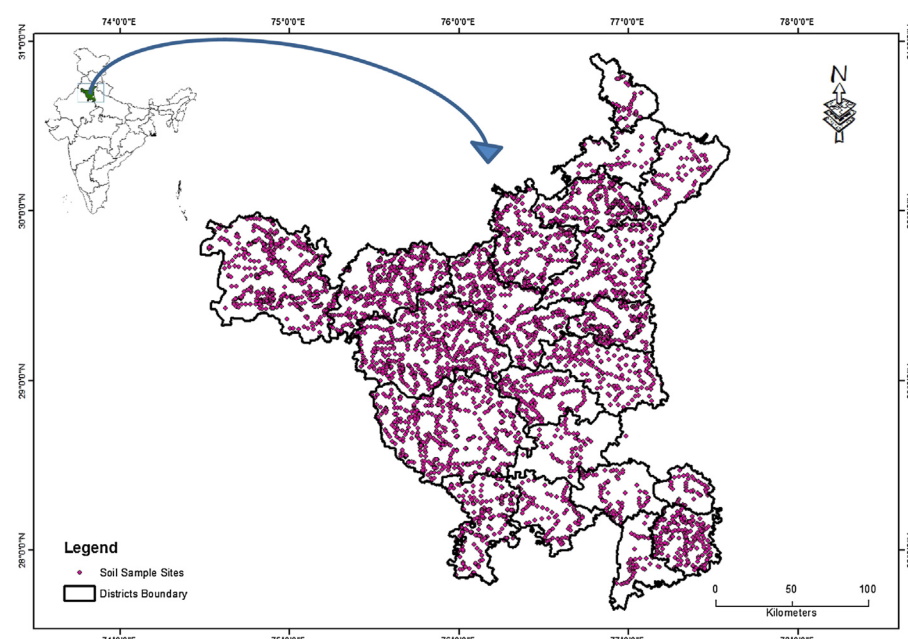

Fig. 1. Location of the sampling sites within the Trans-Gangetic Plains in India.