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Spatial variability of soil properties and delineation of soil management zones of oil palm plantations grown in a hot and humid tropical region of southern India

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ABSTRACT

Sustainable soil nutrient management with proper understanding of spatial variability of soil properties helps in enhancement of crop productivity and avoiding soil degradation. It has more importance in oil palm plantations, since the area under oil palm cultivation is on rise globally. Moreover, the crop is a nutrient-requiring one and effective nutrient management contributes about 50% of fresh fruit bunch (FFB) production. Therefore, the present study was carried out to assess spatial distribution of soil properties and to delineate soil management zones (MZs) in oil palm plantations of a hot and humid tropical region of India for efficient soil nutrient management. A total of 180 geo-referenced representative soil samples (from 0 to 0.20 m depth) were collected from oil palm plantations of Pedavegi and Denduluru *mandals* of west Godavari district of Andhra Pradesh, India. Collected soil samples were processed and analysed for soil properties like pH, electrical conductivity (EC), soil organic carbon (SOC), available phosphorus (P), available potassium (K), exchangeable calcium (Ca), exchangeable magnesium (Mg), available sulphur (S) and available boron (B). The values of soil properties varied widely with low (7.7%) to moderate (29.0 to 77.4%) coefficient of variations. Semivariogram analysis and ordinary kriging revealed varied spatial distribution pattern with moderate to strong spatial dependence for most of the soil properties. Development of the MZs was carried out by principal component (PC) analysis and fuzzy *c*-means clustering. Three PCs with eigen values > 1 and accounting 60.31% of total variance were used for further analysis. On the basis of fuzzy performance index and normalized classification entropy, three MZs were identified. The MZs differed significantly with respect to studied soil properties. Thus, the study emphasized that the methodology for delineating MZs could be effectively used for site-specific soil nutrient management in oil palm plantations and other crops for maximizing crop production in the study area.

1. Introduction

Soil is a heterogeneous body and key to ecosystem processes which govern nutrient cycling (Fitter et al., 2005). Sustainable soil management with proper understanding of soil properties helps in maintaining or improving the level of soil fertility and avoiding soil degradation, which is a global problem of importance (Thapa and Yila, 2012; Zhao et al., 2013). Soil properties vary spatially due to combined impact of physical, chemical and biological processes operating in soil along with human/animal activities (Goovaerts, 1998). Proper understanding of the spatial distribution of soil properties and their mapping is the key to site-specific soil management for sustainable crop production by variable-rate application of nutrients (Behera and Shukla, 2015; Brevik et al., 2016; Shukla et al., 2017; Bogunovic et al., 2017a). Assessment of spatial distribution of soil properties can be carried out by geostatistical methods (Mueller et al., 2003). According to Saito et al. (2005), prediction of values at un-sampled locations can be done by geostatistical estimation by considering spatial correlation between estimated and sampled points and reducing estimation error and involved costs. Addressing soil heterogeneity by delineation of management zone (MZ) of soil is a technique, in which an area is divided into different zones having homogenous characters (Ortega and Santibanez, 2007; Xin-Zhang et al., 2009; Peralta et al., 2015). Several researchers have delineated soil MZs in different agro-ecosystems including different crops for site-specific soil management using geostatistics, principal component analysis (PCA) and fuzzy *c*-means classification (Davatgar et al., 2012; Tripathi et al., 2015; Shukla et al., 2017; Nawar et al., 2017).

Oil palm is the highest oil producing crop of the world, having

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yielding potential of 18.8 t oil ha^{-1} $year^{-1}$ (Hoffmann et al., 2014). To fulfil the demand of vegetable oil requirement, it is being cultivated in 28 developing countries of the world having significant level of palm oil production (Anonymous, 2017). In India, it presently occupies 0.3-million-hectare area in 14 states of the country as small holders' plantation crop. However, an area of 19.3 million ha covering 19 states is having potential for oil palm cultivation in India (Rethinam et al., 2012). The Government of India is making efforts to enhance the area under oil palm cultivation in the country by planting this crop in fallow land and/or replacing less remunerative crops. Out of the 0.3 million ha of cultivated area, the west Godavari district of Andhra Pradesh lying in hot and humid tropical climate is having 70, 000 ha area under oil palm cultivation.

Among the several factors influencing oil palm yield, nutrients play a key role as it contributes about 50% towards fresh fruit bunch (FFB) yield of oil palm (Woittiez et al., 2017). The nutrient requirement of oil palm is relatively higher and it requires a large amounts of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and boron (B). According to Mengel and Kirkby (1987), oil palm requires 162 kg of N, 30 kg of P, 217 kg of K, 38 kg of Mg and 36 kg of calcium (Ca) to produce 2.5 t oil ha^{-1} $year^{-1}$ (equivalent to 10 t FFB ha^{-1} $year^{-1}$, considering oil to bunch ratio of 1:4). The nutrient-limited yield is site-specific and it is predominately owing to the influence of soil properties on availability of nutrients. Nutrient disorders like N/K imbalance, K, Mg and B deficiencies in oil palm plantations adversely affect oil palm production in India (Rao et al., 2014). Out of several soil properties, soil pH and soil organic carbon (SOC) content mostly affect the nutrient availability by influencing chemical environment of soil (Tisdale et al., 1985). Soil pH affects nutrient availability, whereas SOC modifies physical and biological environment and chemical reactions in soil. Fertilizer requirement in oil palm is effectively assessed by carrying out soil and leaf analysis (Goh et al., 2003) as soil is the source of nutrients for oil palm and the leaf nutrient concentration and palm productivity is directly correlated. It is therefore essential to assess soil properties of oil palm plantations for nutrient management in a sustainable manner.

The spatial variability of soil properties in oil palm plantations of India is expected to be high mainly owing to adoption of different land management practices and varied amount of fertilizer application (Prasad et al., 2013). The information regarding spatial variability of soil properties and soil management zones in oil palm plantations of India is limited. Keeping above facts in view, the present study was carried out (i) to assess spatial distribution of the soil properties by using the geostatistics and (ii) to delineate MZs in the oil palm plantations of a hot and humid tropical region of west Godavari district of Andhra Pradesh, India.

2. Materials and methods

2.1. Study area

The study was carried out in Pedavegi and Denduluru *mandals* of west Godavari district of Andhra Pradesh, India situated at 16°07′N and 81°01′E (Fig. 1). The area experiences hot and humid tropical climate receiving average rainfall of 950 mm. A significant portion of rainfall is received during June to September. The mean highest (39 °C) and the mean lowest (23 °C) temperature prevails in the month of May and December respectively. The mean highest (90%) and the mean lowest (60%) relative humidity is obtained in the month of July–August and February respectively. The area is having igneous, metamorphic and sedimentary geological formations. Soils of the study area belong to orders Entisols, Alfisols and Vertisols (Soil Survey Staff, 2014) with sandy clay loam to loamy sand in texture. Oil palm was grown as irrigated crop and planted at 9 m × 9 m × 9 m distance viz. equilateral triangular planting. Fertilizers were applied in 3 m radius weeded palm basins for four times a year.

2.2. Collection of soil samples, processing and analysis

Altogether 180 surface (0 to 0.20 m depth) soil samples were collected from oil palm plantations situated at an interval of 1 to 2 km within the study area. Soil samples were collected using hand auger from 3 m radius weeded palm basins. Five sub-samples were collected and mixed to obtain representative sample from each sampling location. Using hand-held Global Positioning System (GPS), the geographical coordinates viz. latitude and longitude of each sampling point were noted. The collected soil samples were air-dried. Stones and debris present in samples were removed. Grinding of soil samples was carried out by using wooden pestle and mortar and then passed through a 2 mm sieve. The processed soil samples were stored in polyethene bottles for estimation of different properties. Soil pH and electrical conductivity (EC) was estimated in 1:2.5 (w/v) soil and water suspensions (Jackson, 1973). Soil organic carbon content is an important and manageable soil property and it influences many other soil properties. Available N status in soil can be predicted from SOC content value (Murphy, 2015; Palmer et al., 2017). The content of SOC was estimated by Walkley and Black method (Walkley and Black, 1934). Available P (Olsen et al., 1954), available K (Hanway and Heidel, 1952), exchangeable Ca (Jones Jr., 1998), exchangeable Mg (Jones Jr., 1998), available S (Williams and Steinbergs, 1969) and available B (Gupta, 1967) concentration in soil samples were estimated by respective methods.

2.3. Statistical, geostatistical, principal component and fuzzy cluster algorithm analysis

Using SAS 9.2 software pack (SAS, 2011), the descriptive statistics revealing minimum, maximum, mean, standard deviation (SD) and coefficient of variation (CV) of studied soil properties was obtained. The test of normality for soil properties was also performed using the Kolmogorov-Smirnov test (K-S test) and all the soil properties passed the test. Pearson's correlation coefficient values demonstrating relationship among the soil properties were obtained. For assessment of spatial distribution pattern of soil properties, ArcGIS 10.4.1 software was used and semivariogram for each soil property was calculated using Eq. (1) as given below.

$$\gamma(\mathbf{h}) = \frac{1}{2N(\mathbf{h})}\sum_{\alpha=1}^{N(\mathbf{h})}[Z(\mathbf{X}_\alpha + \mathbf{h})]^2 \tag{1}$$

where γ(h), N (h), $z(\mathbf{x}_\alpha)$ and $z(\mathbf{x}_\alpha + h)$ represent semivariance for the lag distance h, number of sample pairs separated by the lag distance h, measured value at αth sample location and measured value at point α + hth sample location, respectively. Semivariogram models like circular, spherical, K-Bessel, exponential, stable and Gaussian were evaluated to determine the best-fit one for each soil property. The semivariogram models were chosen by using the cross validation technique, i.e. by comparing the actual values with the values estimated by kriging using the semivariogram model. Prediction accuracy of semivariogram models was evaluated by mean square error (MSE).

$$MSE = \frac{\sum_{i=1}^{n}[z(x_i,y_i) - z*(x_i,y_i)]^2}{n} \tag{2}$$

where, n is the number of observation for each case, $z(x_i, y_i)$ is the observed soil parameter, $z*(x_i, y_i)$ is the estimated soil property, and (x_i, y_i) are sampling coordinates.

Interpolation mapping to estimate the values of soil properties at un-sampled locations was done using ordinary kriging (OK) procedure (Goovaerts, 1998). Ordinary kriging was used because it is more reliable than other methods based on MSE (Meul and Van Meirvenne, 2003). Furthermore, OK is the best unbiased predictor for the random process as specific unsampled locations in case of sparse and randomly selected soil sampling. It has also an additional benefit of reducing influence of outliers (Triantafilis et al., 2001). Goodness-of-prediction