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Delineation of soil management zones for a rice cultivated area in eastern India using fuzzy clustering

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ABSTRACT

Efficient, cost effective and easy to use tools are needed for site specific management of soils for increasing the crop productivity. Currently nutrient management recommendations for rice in the study are typically uniform without consideration of spatial heterogeneity of nutrient content in soil. This study has emphasized the use of management zones (MZs) as an efficient method for variable application of fertilizers. Rajnagar Block of Kendrapada District in India was selected as the study area for the present study and 225 soil samples were collected on 1.5 kilometer grids. Soil samples were analyzed for pH, electrical conductivity, soil organic carbon, available nitrogen, available phosphorous, available potassium DTPA extractable micronutrients i.e., iron, zinc, copper, and manganese. Spatial variability of these soil properties was analyzed and spatial distribution maps were generated using geostatistics and ordinary kriging technique. Further, principal component analysis and fuzzy c-means clustering algorithm were performed to delineate the management zones based on optimum clusters identified using fuzzy performance index (FPI) and normalized classification entropy (NCE). The results revealed that the optimum number of MZs for this study area was three and there was heterogeneity in soil nutrients in three MZs. The delineated MZs provide a basis of information for site-specific fertilizer management in the rice cultivated fields in the study area.

1. Introduction

There is an increasing demand for tools to assess the soil fertility status for increasing the crop productivity in a cost-effective and environmental friendly manner. Moreover knowledge about the soil fertility status may help to assess the long-term impact of modern, intensive agricultural practices (Dobermann and Oberthur, 1997). Optimum plant growth is achieved when soils have the capacity to supply nutrients. However, the optimum nutrient status alone will not ensure soil productivity (Sumner, 2000). Various field and laboratory diagnostic techniques have been used to quantify the nutrient status of soils to assess the capability of the soil for producing a quantified plant product. Diagnostic techniques include chemical, physical and biological soil tests. At present site specific assessments of soil fertility at a regional scale are done by using new techniques and tools such as remote-sensing and geographic information systems (GIS), geostatistics and kriging.

Soils are characterized by a high degree of spatial variability due to combined effects of soil physical, chemical and biological processes that operate with different intensities and at different spatiotemporal scales and also due to some extrinsic factors such as crop management practices, fertilization and irrigation (Goovaerts, 1998; Jenny, 1941). As a consequence, soils can exhibit marked spatial variability on the macro- and micro-scale, and these factors interact with each other across spatial and temporal scales (Brejda et al., 2000). Therefore uniform management of fields often results in over-application of inputs in areas with high nutrient levels and under-application in areas with low nutrient levels (Ferguson et al., 2002). Various authors (Cahn et al., 1994; Mc kinion et al., 2001) suggested site-specific management of nutrient via variable rate fertilizer application, as one means for addressing this problem. Subsequently, use of zone management technique emerged as the most popular approach to manage spatial variability within fields. In this technique, the field is subdivided into different zones that have relatively homogeneous attributes in landscape and soil conditions, and can be used for direct variable rate fertilizer application (Ferguson et al., 2002). The zone management technique is defined as a method, utilizing the spatial management tools of precision agriculture which is a cost-effective approach to

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improve crop management and reduce detrimental environmental impact (Franzen et al., 2002). Kyaw et al. (2008) reported that site-specific use of iron fertilizers and chlorosis-tolerant cultivars might be more profitable than uniform management whereas Ortega and Santibanez (2007) realized the potential of using management zones (MZs) for the site-specific management of traditional crops and vineyards.

Various methods and techniques such as soil survey and topographical maps (Reyniers et al., 2006), crop yield based management zone technique (Flowers et al., 2005; Hornung et al., 2006), cluster analysis algorithm (Ortega and Santibanez, 2007), fuzzy c-mean (Fridgen et al., 2004; Yan et al., 2007) and soil fertility (Ortega and Santibanez, 2007), have been used for defining management zones. Abdul et al. (2007) found that MZ based on soil N provided useful information for N fertilizer management. Vrindts et al. (2005) compared different methods of defining MZs based on soil and crop information. Other researchers have used yield maps to coarsely identify MZs of low, medium and high productivity potentials (Stafford et al., 1998). In China, MZs based on spatial variability in soil properties have been developed to aid site specific management of fertilizers (Chen and Lu, 2008).

Cluster algorithm is an effective approach for identifying management zones by using different layers of information. Multivariate classification by cluster analysis enables the identification of sub-region in the fields that internally have similar characteristics. Aaron et al. (2004) used yield data whereas fuzzy clustering of combined soil properties was used by Fleming et al. (2000) to divide a field into potential management zones. Similarly, principal component analysis (PCA) is often used to for delineating MZs (Mallarino et al., 1999). Various authors delineated the management zones by the combined usage of principal component analysis and fuzzy cluster algorithm based on soil fertility attributes (Davatgar et al., 2012; Xin-Zhang et al., 2009).

Currently nutrient management for study area which is mostly cultivated with rice is based on uniform recommendations of fertilizers. This may result over-application in areas with high nutrient levels and under-application in areas with low nutrient levels. Therefore, keeping the above discussions in mind, the main objectives of this research were to (1) characterize the spatial variability of the soil properties using geostatistics analysis defining the soil fertility of study area in Rajnagar Block of Kendrapada District of Odisha, India (2) identify the potential management zones based on soil nutrient status using principal component analysis and fuzzy cluster analysis.

2. Material and methods

2.1. Site details

The study area spread around the Bhitarkanika Sanctuary includes nearly two hundred fifty five inhabited villages under the administrative jurisdiction of Rajnagar Block in Kendrapada District of Odisha. The location of study area is depicted in Fig. 1. The study area located between 20°32′ to 20°50′ N and 86°45′ to 87°05′ E is humid with mean annual temperature of 20.5 °C and mean annual precipitation of about 1400 mm mostly during monsoon period (July to September). Bhitarkanika mangrove ecosystem flourishes in the deltaic region, formed by the rich alluvial deposits of Brahmani, Baitarani & the Dhamra Rivers. It is a mangrove area of high tidal range (1–4 m) having strong bidirectional tidal fluxes which forms extensive, low gradient inter-tidal zones available for mangrove colonization (Selvam, 2003).

The residents of the region depend mostly on fishery and coastal agriculture. However, due to lack of irrigational facilities and freshwater resources, mostly a mono-cropping pattern of paddy cultivation is common in the region on the adjoining areas of the mangrove forests. Salt tolerant rice (*Oryza sativa*) varieties are cultivated in rainfed lowland paddy fields of the study area. Land is plowed followed by puddling and harrowing. This makes the soil suitable for transplanting and percolation losses of water are reduced considerably. Most farmers in the vicinity of the mangrove forests do not apply any fertilizer. In general, the farmers apply only nitrogenous fertilizers (60 kg ha^{-1} N) in the form of urea with occasional application of P (40 kg ha^{-1}) in the form of single super phosphate (SSP).

2.2. Soil sampling

Grid wise (1.5 km grids) soil samples were collected from 225 locations. Soil samples were collected from the points on grid intersection except from the mangrove forest area where soils sampling were a very difficult task due to difficult terrain and estuaries and administrative restrictions. As many soil samples from the mangrove forests were collected as were possible keeping the interest and objectives of our study (Fig. 1). Soil samples (0–15 cm) were collected before monsoon using a soil core sampler (8 cm diameter, 15 cm length), litters, organic debris was removed. Soil samples were taken before fertilizing and planting the fields. Soil samples were collected from plow layer (0–15 cm). The location coordinates of each sampling site were recorded using handheld global positioning systems (GPS unit). Samples were air dried in shade and passed through a 2 mm sieve and analyzed for physico-chemical properties.

2.3. Analysis of soil physicochemical properties and DTPA extractable micronutrients

The soil pH was measured both in a soil–water suspension (1:2). The electrical conductivity (EC) was determined from the soil–water suspension (1:2). The soil organic carbon (SOC) and available N of the soil samples were analyzed by standard procedures. Phosphorus (Bray P, NH_4F + HCl) and potassium (NH_4OAc), the methods outlined by Bray and Kurtz (1945) and Black (1965) were adopted, respectively.

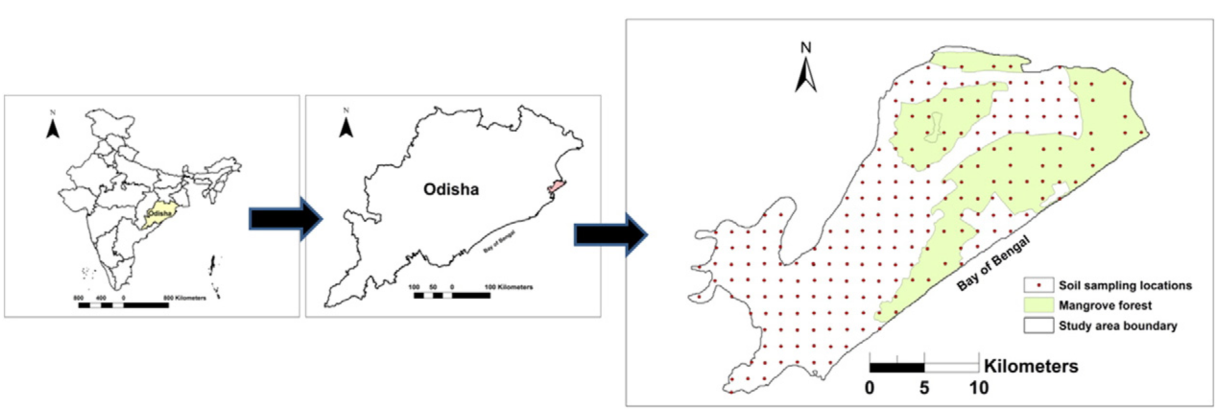

Fig. 1. Study area located in Rajnagar Block of Kendrapada District in coastal Odisha, India and soil-sampling points.