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Optimal soil-sampling design for rubber tree management based on fuzzy clustering

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ABSTRACT

Farming management practices related to nutrient recommendation for rubber tree plantations have been a challenge for scientists, farm managers and local producers. Specific caves and building contour ledges to prevent nutrient losses through soil erosion often cause spatial variation of topsoil nutrients in such plantations of rubber trees (*Hevea brasiliensis*). The design of soil-sampling schemes to test chemical properties of the soil is critical for successful nutrient recommendation for rubber trees. Our objectives were to characterize the spatia variability of soil pH, macronutrient NPK and organic matter in rubber plantations and to evaluate the rationality of soil sampling schemes in rubber plantations for tree nutrient management. The study was conducted in an area of 84 m^2 consistent of nine rubber trees and soil samples (0–0.2 m depth) were taken from 168 grid points with a dimension of 1 m $\times$ 0.5 m. Concentrations of total nitrogen, organic matter, available phosphorus, available potassium and pH levels were determined for each soil sample. Based on their spatial variability patterns, the analyzed variables were divided into several homogeneous zones through fuzzy cluster algorithm. The number of subzones was determined using fuzzy performance index and normalized classification entropy to optimize the classification algorithm. The classification results showed that there were three optimal sampling zones for the soil chemical properties. The analysis of variance indicated that chemical properties were significantly different between the delineated zones. The delineated management zones could be used as a reference for making soil-sampling scheme in the rubber plantation. The results of this study have the implication in optimization of soil sampling planning for soil testing for nutrient recommendation. Fuzzy cluster algorithms could classify soil chemical properties into three practical zones by reducing intrazone variability, which would provide with useful information for making effective soil-sampling schemes in rubber tree plantations.

1. Introduction

Rubber tree (*Hevea brasiliensis*) is the main source of natural rubber that is cultivated in the tropical regions and natural rubber is an important economic product for many tropical countries in Asia, South America and Africa (Rao et al., 1998). The global total production of natural rubber was 10.01 million metric tons during 2009–2010 (IRSG, 2010). China was the sixth largest producer of natural rubbers (0.65 million metric tons) and the largest consumer of natural rubber. In 2009, rubber plantation covered approximately 980×10^3 ha as 0.1% of total land in China and approximately 47% of the total plantation areas were located in Hainan Island, southern China (Mo, 2010). Rubber tree plantations had become the largest artificial ecosystem in the island (Chen et al., 2012).

Rubber trees are perennial plants for latex extraction and the trees have an economic life-span of 15–30 years or even longer (Michels et al., 2012). Nutrient degradation under intensive rubber plantation is a problem due to the long term extraction of latex to export many soil nutrient elements. In addition to other nature process such as soil leaching and surface run-off erosion can be a problem (Cheng et al., 2007; Zhang et al., 2007). To maintain sustainable tree growth and high yield of rubber production, it is

Abbreviations: AK, available K; AP, available phosphorus; CV, coefficient of variation; FPI, fuzzy performance index; NCE, normalized classification entropy; OK, ordinary Kriging; OM, soil organic matter; PCA, principal component analysis; PCs, principal components; SD, standard deviation; TN, total nitrogen.

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absolutely necessary to add chemical fertilizers during rubber production (He et al., 1992).

At present, the best recommended fertilization models are considering soil nutrient status in rubber tree plantations (Chen et al., 2011). The rational soil management requires knowledge about how soil properties vary across the region. Spatial variability of soil chemical properties is influenced by both intrinsic factors (soil formation factors such as soil parent materials and topography) and extrinsic factors (agricultural management practices such as fertilization locations and application rates) (Sun et al., 2003). In rubber tree plantations, management practices such as fertilization in specific cave areas and building contour ledges for preventing nutrient and water loss from soil erosion often cause a high spatial variability of nutrients in the micro-regional topsoil around the individual rubber trees (Lin et al., 2012). In such circumstances, where and how to obtain representative soil in the highly variable topsoil are important to conduct soil testing and nutrient recommendation. This problem is not only existing in rubber tree plantation but also in other long-term cash trees (such as mango orchards and citrus orchards) in Hainan Island (Lin et al., 2013). Therefore, analyzing spatial variability of soil chemical properties and then putting forward feasible soil-sampling schemes to obtain a reliable representative sample is the critical step of successful fertilizer recommendation for rubber trees and other cash trees.

The most applicable approach to manage spatial variability within fields is the application of zone management technique (Ferguson et al., 2002). Many approaches to delineate management zones have been proposed and evaluated (Miao et al., 2006). An effective approach for identifying the zones with different soil chemical properties is cluster algorithm (Davatgar et al., 2012). Multivariate classification by cluster analysis enables the identification of sub-zones with similar characteristics (Fu et al., 2010). However, a few of these strategies deal with the optimization of sampling design for multiple soil variables (Vašát et al., 2010).

To make an effective nutrient recommendation, the collected soil samples must give a reliable representation of the area. At present, the conventional soil sampling sites in rubber plantation are in the shrub and ruderal zones, where are no-tillage zones and at the specific free land between the adjacent rubber planting strips with natural vegetation growth (He and Huang, 1987). Whether it could reliably represent the nutrient levels in rubber plantations were unknown. The objectives of this study were: (1) to characterize spatial variability of soil chemical properties (pH, total N, available P, available K and organic matter) in rubber plantation areas, (2) to identify the sampling zones of the soil chemical properties through fuzzy cluster analysis, and (3) to evaluate the rationality of soil sampling from shrub and ruderal zones in the plantations for rubber tree nutrient management.

2. Materials and methods

2.1. Site description, soil sampling and measurements

This study was conducted on a rubber tree plantation zone of 84 m^2 at Yangjiang State Farm (19°18′47.8″N and 109°45′52.0″E), located in Qiongzhong, Hainan Island, China (Fig. 1). In the local, the climate was a tropical monsoon with a mean precipitation of 2000 mm per year and a mean annual temperature of 23.5 °C. The soil was mainly derived from granites, classified as a Udic Ferralosol in Chinese Soil Taxonomy (Gong, 1999) and also in the World Reference Base for Soil Resources (FAO, 1998).

The selected study area was 14 m × 6 m, with a mean slope of 4°and 0.5 m higher in elevation in the east than in the west. Nine rubber trees were included within the experimental plots (Fig. 2). Rubber trees were planted 7 m apart between rows and 3 m on the row spacing. Conventional fertilization caves dug for fertilizer applications were located between two rows with a vertical distance of 1.5 m from the rhizome neck (the stump place of rubber trees). Subsoils dug from the fertilization caves were used to preserve the outer edge of the contour ledge (a contour barrier built with subsoil to prevent soil erosion). The shrub and ruderal zones were in the middle of the same row, where was a free land between the adjacent rubber-planting strips with natural vegetation growth approximately 3 m in width.

The existing fertilization model was recommended to annual amount of 2.0 kg mixing chemical fertilizers for each tree, which was corresponding to 600 kg/ha as usual in the region. The fertilizer compounds were composed of 0.7 kg $CO(NH_2)_2$, 1.0 kg $Ca(H_2PO_4)_2$ and 0.3 kg KCl. Three applications were scheduled in the middle of March, June and September each year. Half of the total fertilizers were applied in March and the rest was split equally in other two applications. North–south contour ledges were built within the plot. In Hainan, the management practices such as the sites of fertilizer caves and contour ledge, amounts and types of fertilizers for rubber trees were relatively constant and rubber plantations were usually located in the hilly areas (Dong et al., 2012). Therefore, the small plot around nine rubber trees studied in this paper could be considered as a mirror of rubber plantation in Hainan.

Soil samples were collected before the third fertilization time on August 28, 2011. The plot was divided into 168 grid-points with equivalent rectangles. The dimension of each rectangle grid for sampling was 1 m × 0.5 m. Each rectangle sample was consisted of 5 individual cores. Soil samples at the rectangles with opposite angles were collected using a 8-cm-diameter auger at 0.2 m soil depth. The soil samples were air-dried and ground to pass through a 2 mm sieve. Soil chemical properties were analyzed using the standard test methods (Bao, 2000). Soil organic matter (OM) was determined using potassium dichromate-wet combustion procedure simultaneously. Total nitrogen (TN) was determined by Kjeldahl distillation method. Available phosphorus (AP) was extracted using NH_4F–HCl solution. Soil available K (AK) was extracted using 1.0 mol/L CH_3COONH_4 and then measured by an atomic absorption spectrometer. Soil pH was measured using glass electrode in a 1:2.5 soil/water suspension.

The soil TN, OM, AP and AK levels related to rubber tree latex yield were determined using the classifications defined by Lu (1983) as follows: when TN, OM, AP and AK concentrations in the topsoil (0–20 cm) were lower than 0.8 g/kg, 20 g/kg, 5 mg/kg and 40 mg/kg, respectively, low yield latex will be attained and the effects of corresponding fertilizers were significant. If the TN, OM, AP and AK levels were within 0.8–1.4 g/kg, 20–25 g/kg, 5–8 mg/kg, and 40–60 mg/kg, respectively, median yield latex would attain and a small amount of fertilizers was needed. If TN, OM, AP, and AK levels were greater than the high yield latex critical values of 1.4 g/kg, 25 g/kg, 8 mg/kg, and 60 mg/kg, respectively, it was not necessary to apply any fertilizers.

2.2. Descriptive statistics and geostatistical analysis

The descriptive statistics including mean value, standard deviation (SD), minimum value, maximum value, coefficient of variation (CV), skewness and kurtosis values were calculated for each of the soil chemical properties. Normal distribution of these variables was tested using the Kolmogorov–Smirnov statistics. The probability value of Kolmogorov–Smironov greater than 0.05 indicates that the variable is normally distributed. Although the semivariogram analysis did not request that the data sets must be normal distribution, yet the statistically abnormal distribution of variables can be an adverse impact on semivariogram analysis and further interpolation of data sets (Cressie, 1993).