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Geostatistical mapping of soil fertility constraints for yam based cropping systems of North-central and Southeast Nigeria

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ABSTRACT

An extensive survey covering the area of 92,764 km^2 was conducted in the fields of over 385 yam grower farmers under yam based cropping system of the North-central and Southeast Nigeria. Using geo-statistical mapping tools, we aimed to quantify the degree of spatial variability of selected soil fertility parameters under yam based copping system and to pave the way to develop an appropriate recommendation for a profitable fertilizers management for the small farmer of the region. Spatial analysis of the data showed that the best fit semi-variogram models for nutrients N and K were rational quadratic and hole effect for available P. Relative nugget effect (RNE) and nugget-to-sill ratio ($Co/Co + C$) of the total N concentration in soil were 70% and 45%, respectively for exchangeable K. The available P in soil (Bray-P) showed a weak spatial dependence with RNE of 83% and a range of 1.8 km. The moderate spatial dependence observed for N and exchange K recommends for developing a strategy for site-specific management of N and K nutrients taking into account the structural and random factors dominant in the study areas. The management of P nutrient to improve yam production in north–south and southeast of Nigeria is generalized at regional scale, given the weak spatial dependence observed for this nutrient.

1. Introduction

Yams (*Dioscorea* spp.) are among the very important staple food crops for millions of the tropic including the Caribbean, Oceania and South Asia (Suja et al., 2012; Tchabi et al., 2008). The tuber is of economic importance to many subsistence farmers in West and Central Africa (FAO, 2005). Additional qualities in the crop include their high and rich carbohydrate content, accounting for about 50–80% starch on dry weight basis.

Despite its importance, yam production faces many challenges resulting in very low yield compared to the potential of the crops, mostly attributed to biotic and abiotic constraints including pests and diseases, weed competition, and deteriorating soil fertility problems (Amusa et al., 2003; Bridge et al., 2005; Coyne et al., 2005; Tchabi et al., 2010). Under the subsistence conditions of many smallholders in the crop growing areas, soil fertility in yam production systems is one of the key challenges. Ample evidence of declining soil fertility and nutrient depletion is frequently observed for many crops growing in African soils, including yam due to the shortening duration of fallow, nutrient mining, the highly fragile nature of many of these soils, the accelerated degradation process, and the lack of adapted agricultural practices to restore soil fertility (Stoorvogel et al., 1993; Sanchez, 2002; Schlecht et al., 2006; Frossard et al., 2007).

In the traditional cropping system, yam is generally the first crop planted after the conversion of long-term fallows into agricultural land, mostly because of the crop's high nutrient requirement and demand (Diby et al., 2011; Carsky et al., 2001). Major macronutrients essential for the optimal growth and wellbeing are nitrogen (N), phosphorus (P) and potassium (K). Their bioavailability to roots is of considerable economic importance because they are the major plant nutrients derived from the soil in organic or in inorganic forms (Marschner, 2011). However, with the yam crop, there is a paucity of information governing the plant's nutrient acquisition, and the whole soil fertility problem is still unsolved, with a very limited knowledge of the crop physiology related to uptake efficiency and use (Hgaza et al., 2012). Not at all, adequate or balanced site-specific fertilizer recommendations have so far been developed or proposed for the various areas the crop are being cultivated in Africa.

In another hand, at the farm scale, various research outputs on nutrient recommendations; if exist in certain countries are to treated fields as homogenous areas and develop the fertilizer requirements on a whole field basis. However, large spatial heterogeneity in soil fertility, nutrient resource allocation and distributions in smallholder agricultural land are frequently observed, with high variability within a single farm field (Tittonel et al., 2013). Flowers et al. (2005) and Santra et al.

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(2008) reported that at least 70 sampled fields were not homogeneous and sampling techniques to describe field variability have been recommended in India.

The broad expansion of the geo-statistical tools in the recent years and the introduction of the digital soil mapping by spatial prediction combined with Global Positioning Systems (GPS) data, and Geographic Information Systems (GIS) have accelerated modeling and predictions of landscape study. This has contributed to delineate potential areas of low or high nutrients distribution (Burrough and McDonnell, 1998). Geo-statistical mapping is also used in producing soil fertility maps, to demarcate areas that express low nutrient availability and define threshold values that could be important to measure the recovery of such lands, and also to helping in designing trials with the objective of formulating fertilizer recommendation at a regional or country scale (Goovaerts, 1997; Webster and Oliver, 2001; Nielsen and Wendroth, 2003). These technologies allow point data from field observation to be used accurately to map their distribution and to compute complex spatial relationships between soil fertility factors at the very high and detailed robust resolution scale (Patil et al., 2011). The kriging technique has been used for many decades as a synonym for geo-statistical interpolation and has been proved as sufficiently robust for estimating values at un-sampled locations based on the sampled data (Yost et al., 1982; Trangmar et al., 1987; Miller et al., 1988; Voltz and Webster, 1990; Chien et al., 1997; Lark, 2002). Most geostatistical studies which have been so far being conducted exist in many parts of the world that have led to precise soil reclamation and improve crop yields, however, relative data are available for spatial variability prediction of many African crops including yam crops.

The objectives of the present study were: a) to characterize and quantify the level of spatial variability of important soil fertility parameters under which yam is being cultivated, and b) to allow designing appropriate site-specific recommendations for a generalized profitable fertilizer management at the regional scale for the famers growing yam in the North-central and Southeast Nigeria.

2. Material and methods

2.1. Site description

In both north-central and south locations of the Nigeria yam belt ago-ecologies, two main yam production systems are predominant in the farmer fields. They consist of associating landraces of white yam varieties or water yam with other yam species, intercropped with maize, cowpea, cassava, and vegetables, generally grown on degraded and infertile land under shifting cultivation practices or in rotational with yam species. The fields are largely managed by farmers and the difference between the two production systems resides on plant density and planting period, yam seed weight, the associated plant species and composition, and their growth duration (i.e. maize as short duration 90 days for system one, while cassava, with approximately similar growth duration period (6–8 months) with yam crops).

An initial selection of potential sampling sites was done using Ar-GIS 10.0, this to determine major yam production areas. Sites that encompass low yam yield, high poverty index, poor resource allocation, and low input addition were selected. This was important to relate if all these above listed factors are linked to low soil fertility status, poor

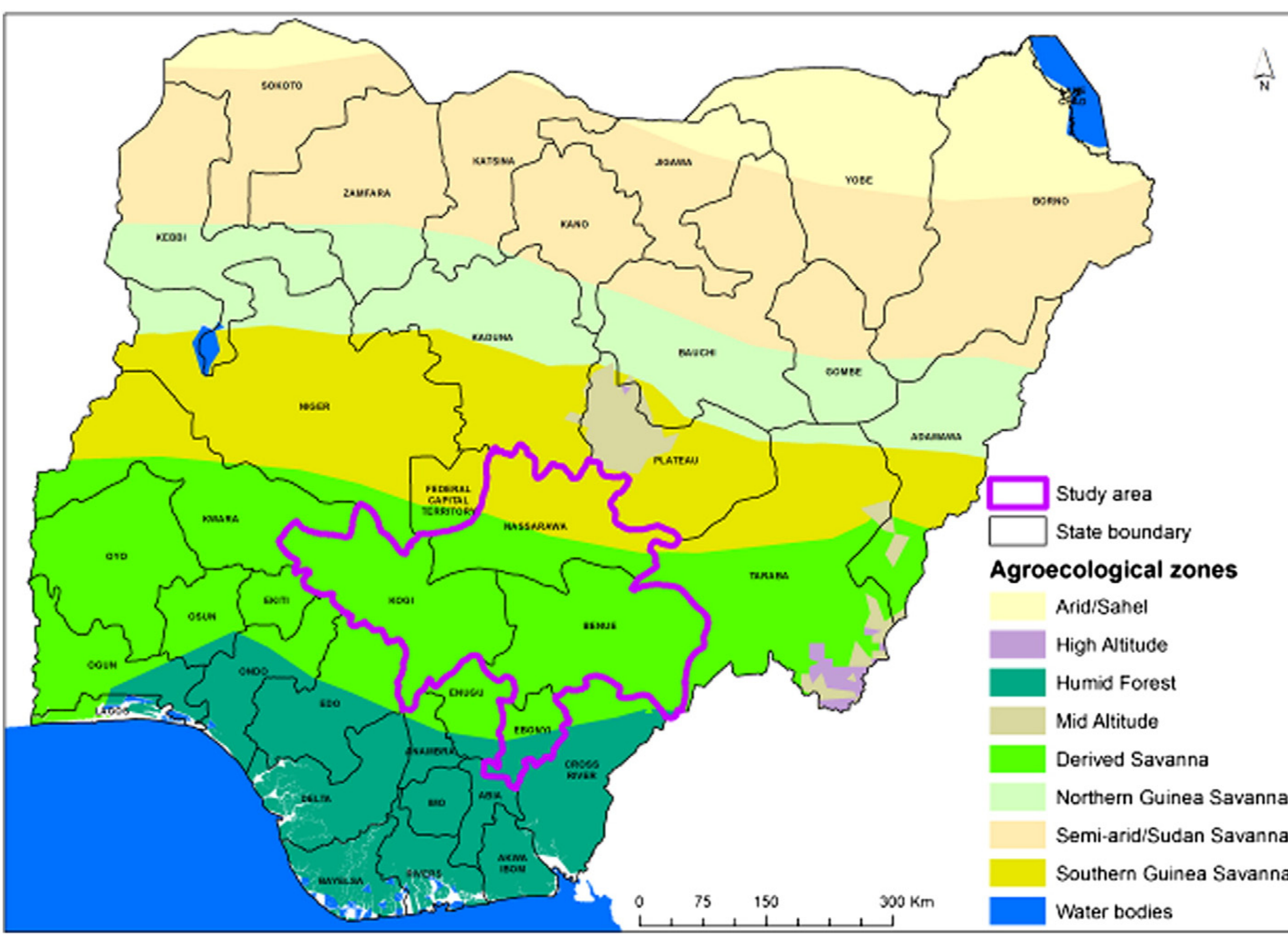

Fig. 1. Boundaries of the Republic of Nigeria showing the areas in the yam belt targeted and sampled for the study.