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Fertiliser requirements for balanced nutrition of cassava across eight locations in West Africa

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ABSTRACT

Insufficient and unbalanced fertiliser use widens cassava yield gaps. We assessed the spatial variability of optimal fertiliser requirements of cassava for enhanced nutrient use efficiency and increased yield using the balanced nutrition approach of the QUEFTS model. Two datasets comprised of five fertiliser experiments conducted at eight locations across Southern Togo, Southern Ghana and Northern Ghana from 2007 to 2012 were used. The ratio of storage roots dry matter yield over the sum of available N, P and K expressed in crop nutrient equivalent from the soil and nutrient inputs was used as a proxy to estimate nutrient use efficiency. Nutrient use efficiencies of 20.5 and 31.7 kg storage roots dry matter per kilo crop nutrient equivalent were achieved at balanced nutrition at harvest index (HI) values of 0.50 and 0.65, respectively. N, P and K supplies of 16.2, 2.7 and 11.5 kg at an HI of 0.50, and 10.5, 1.9 and 8.4 kg at an HI of 0.65 were required to produce 1000 kg of storage roots dry matter. The corresponding optimal NPK supply ratios are 6.0–1.0–4.2 and 5.3–1.0–4.2. Nutrient use efficiencies decreased above yields of 77–93% of the maximum. Evaluation of the performance of blanket fertiliser rates recommended by national research services for cassava production resulted in average benefit:cost ratios of 2.4 ± 0.9, which will be unattractive to many farmers compared to 3.8 ± 1.1 for the balanced fertiliser rates. The indigenous soil supply of nutrients revealed that, at balanced nutrition, K was the most limiting nutrient to achieve storage roots yields up to 8 Mg dry matter ha^{-1} at most sites, whereas N and P were needed at greater yields. Dry weight of storage roots measured on the control plots in our researcher managed experiment ranged from 5.6 to 12.2 Mg ha^{-1}, and were larger than the average weight in farmers' fields in West Africa of 4 Mg ha^{-1}. Substantial yield increase could be attained in the region with improved crop management and fertiliser requirements formulation on the basis of balanced nutrition.

1. Introduction

Cassava (*Manihot esculenta* Crantz) has long been considered a subsistence crop, but is becoming increasingly commercialised. The world production of fresh cassava storage roots increased tremendously from 176 to 277 million Mg between 2000 and 2013 (FAOSTAT, 2014). West Africa produces 28% of the world's cassava and the rest of Africa a further 26% (FAOSTAT, 2014). The increase in production was achieved through both expansion of the cultivated area and enhanced yields of cassava. Although average yields in West Africa increased between 2000 and 2013 from 9.7 to 13 Mg ha^{-1} of fresh storage roots (FAOSTAT, 2014), a large yield gap remains, given that yields close to 60 Mg ha^{-1} have been attained in researcher-managed fields in the region (Odedina et al., 2009).

Plausible reasons for this yield gap are nutrient limitations due to poor soil fertility. In general, fertiliser use on roots and tuber crops in Sub-Saharan Africa is negligible. However, nutrient removal for cassava production is on average 4.5 kg nitrogen (N), 0.83 kg phosphorus (P) and 6.6 kg potassium (K) per 1000 kg dry matter of storage roots (Howeler, 1991). The insufficient use of external nutrients leads to soil nutrients depletion (Howeler, 2002). Application of external fertilisers is necessary to replenish the soil with nutrients removed through harvested products and exported

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crop residues. The fertiliser recommendations for cassava production found in most countries in West Africa and elsewhere in SSA are usually blanket recommendations, regardless of agro-ecological or soil diversity. The use of blanket fertiliser recommendations for cassava production is likely to generate unbalanced crop nutrition since cassava is cultivated on diverse soils in West Africa, and soils on farmers' fields are highly heterogeneous (Adjei-Nsiah et al., 2007). Unbalanced nutrition may lead to increased nutrient losses (Cassman et al., 2002), which can hamper the productivity and profitability of the farm (Angus et al., 2004), and cause environmental pollution. Appropriate fertiliser recommendations based on balanced nutrition may contribute to reduce cassava yield gaps.

Balanced nutrition of a given nutrient refers to supplying that nutrient to the plant in accordance with the plant's need while maximizing the use efficiency of this nutrient. When more than one nutrient is considered, e.g., N, P and K together, balanced nutrition refers to the optimization of the use efficiency of these nutrients together giving the strongest response to their supply in congruence with plant needs. The term optimising is used given the difficulty of maximising the use efficiency of several nutrients simultaneously. The method developed by Janssen (1998, 2011) can handle several nutrients simultaneously by assuming that balanced nutrition is achieved when the supplies of all nutrients expressed in crop nutrient equivalent (CNE) units are equal. As a unit, 1 kilo CNE (kCNE) or 1000 CNE of a nutrient is defined as the quantity of that nutrient that has the same effect on yield as 1 kg of N under conditions of balanced nutrition. The concept of CNE allows summing up the total supply of N, P and K and quantitatively describing balanced nutrition as the situation where the supplies of each of the three nutrients are equal. Both CNE and balanced nutrition concepts were also applied by Maro et al. (2014) for coffee production in Tanzania using QUEFTS model.

The model for the quantitative evaluation of the fertility of tropical soils (QUEFTS) (Janssen et al., 1990) accounts for the interaction between N, P and K to derive the balanced nutrition, which explains its widespread use in tropical agro-ecologies where these nutrients can seriously hinder crop production. Originally developed for maize (Janssen et al., 1992), QUEFTS has been also adapted to rice (Witt et al., 1999; Xu et al., 2013), wheat (Pathak et al., 2003; Chuan et al., 2013), highland banana (Nyombi et al., 2010) apart from coffee. Literature on the balanced nutrition of cassava is scarce, with only one case study from India (Byju et al., 2012). Site-specific fertiliser requirements for balanced nutrition of cassava in the region and their relative performance compared to existing blanket fertiliser rates have yet to be assessed. In this paper we assess the spatial variability in fertiliser requirements of cassava under balanced nutrition conditions in West Africa in order to increase nutrient use efficiency and yields.

2. Materials and methods

2.1. Field experiments

Two datasets, referred to as Sets 1 and 2, were used in this study. Set 1 was collected in three field experiments at three locations in southern Togo (Davié), southern Ghana (Kumasi) and northern Ghana (Nyankpala, Table 1). The trials were laid out in a randomised complete block design (RCBD) with four blocks at each site containing 10 NPK fertiliser combinations (Table 2). N, P and K rates were defined in Set 1 to assess the indigenous supply of nutrients by the soil (S1, S3 and S5 in Table 2), as well as the response of the crop to different rates of fertilisers (other treatments). N was applied as urea (46% N, Davié and Kumasi) or sulphate of ammonia (21% N, Nyankpala), P as triple super phosphate (TSP: 20% P) and K as muriate of potash (MOP: 50% K). All TSP and one third of the urea and MOP were applied 4 weeks after planting, the remaining urea and MOP at 10 weeks after planting. Set 2 was collected in two other field experiments at five locations across southern Togo (Gbave, Davié Tekpo and Sevekpota) and northern Ghana (Gbanlahi and Savelugu) (Table 3) in agro-ecological zones that are similar to those in Set 1. Set 2 experiments comprised five NPK fertiliser combinations (Table 2). These fertiliser combinations were used to evaluate performance of the QUEFTS model in simulating yields in response to fertiliser applications. At each site, Set 2 experiments were laid out following a RCBD with four blocks in a single field, except for Sevekpota where seven farmers each harboured a single block (replication) of the full set of treatments. Fertilizer was applied in a similar way in both Sets 1 and 2.

2.2. Description, parameterisation and verification of QUEFTS

The original QUEFTS model simulates crop yields in response to nutrient supplies following four steps (Janssen et al., 1990). In Step 1, QUEFTS estimates nutrient supplies from soil and inputs of organic materials or fertilizer. In Step 2, the actual uptake of a nutrient is calculated as a function of the total supply of that nutrient, and of the interaction with the two other macronutrients. In Step 3, two yields are calculated by the model for each nutrient uptake, one corresponding to a situation where the nutrient is maximally diluted in the crop, and another one corresponding to a situation of maximum accumulation of that nutrient. The relation between yield and nutrient uptake is indicated by the physiological nutrient use efficiency (PhE), which varies between *PhEmin* and *PhEmax*. *PhEmax* represents the situation where the nutrient is maximally diluted in the crop; *PhEmin* the situation of maximum nutrient accumulation. In Step 4, the yield is calculated for pairs of nutrients (*Y*12, yield in

Table 1
Characteristics of the sites in the Set 1 experiments.

Site	Davié	Kumasi	Nyankpala
Country, district	Togo, Maritime Region	Ghana, Ashanti Region	Ghana, Northern Region
Geographic coordinates	6.385°N, 1.205°E	6.686°N, 1.622°W	9.396°N, 0.989°W
Altitude (m above sea level)	89	267	170
Soil type	Rhodic ferralsol	Ferric acrisol	Gleyi-ferric lixisol
Agro-ecological zone	Coastal Savannah	Humid Forest	Southern Guinea Savannah
Rainfall distribution	Bi-modal	Bi-modal	Mono-modal
Season[a] 1	May 10–March 17, 2007–2008	June 28–March 22, 2008–2009	June 29–February 25, 2007–2008
Season 2	April 26–February 23, 2008–2009	June 15–March 15, 2009–2010	May 23–December 03, 2008
Rainfall (mm, seasons 1 and 2)	731, 813	986, 938	731, 1017
Cultivar	Gbazekoute[b]	Afisiafi[b]	Afisiafi
Planting density (per stem cutting)[c]	0.8 × 0.8 m	1 × 1 m	1 × 1 m

[a] Season refers to the period from planting to harvest of the crop.
[b] Gbazekoute is TMe-419; Afisiafi is TMe-771.
[c] Planting schemes follow the recommended densities for cassava in the study sites. These correspond to 15.625 and 10.000 plants ha^{-1}, respectively for 0.8 × 0.8 m and 1 × 1 m.