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On-farm trial assessing combined organic and mineral fertilizer amendments on vegetable yields in central Uganda

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ABSTRACT

Integrated Soil Fertility Management (ISFM) is a soil management approach that emphasizes combined application of organic and mineral fertilizer inputs with the goal of improving yields and fertilizer use efficiency. Combined applications have resulted in a positive interaction between organic inputs and mineral fertilizers on vegetable yields, where yields from combined treatments are greater than yields from sole fertilizer treatments. ISFM studies have been conducted with a diverse range of crops, including grains, legumes, tubers, and bananas, but not vegetable crops. Particularly lacking are ISFM studies conducted under participatory, smallholder farmer management. A researcher-designed, farmer-managed, on-farm study was conducted on highly weathered soils (Ferralsols) in the Lake Victoria Crescent of Uganda to determine the influence of combined organic and mineral fertilizer treatments on yields of a commonly grown indigenous leafy vegetable known as nakati (*Solanum aethiopicum*). Farmer-managed plots allowed for the effect of farmer participation and management to be analyzed in conjunction with fertilizer treatment effects. A gradient of 100% organic (sole manure) to 0% organic (sole mineral) fertilizer treatments were applied at both an upper (200 kg ha^{-1}) and lower (100 kg ha^{-1}) nitrogen (N) rate. N rates were derived from survey results on typical organic application rates used by smallholder farmers in their vegetable plots. Fertilizer treatments resulted in significantly different vegetable yields; however, combined treatments did not necessarily result in higher yields than sole treatments. Differences between organic-mineral ratios were only seen when fertilizers were applied at the higher N rate. The highest yields were obtained when fertilizer was applied at a ratio of 67% organic to 33% mineral fertilizer. Effects of soil properties on yield were also observed; after accounting for the effect of fertilizer treatment, yields significantly increased with increasing soil pH. Farmer participation level had a significant effect on yield. All treatment means were significantly increased by greater participation in the study, and the interactive effects of all treatments became less negative when participation was higher. On-farm studies are needed to demonstrate the applicability of a technology under real world conditions, but trials need to maintain farmers' interest throughout the study period.

1. Introduction

Decline in soil fertility is considered by many to be the most important constraint to crop production across sub-Saharan Africa (Sanchez, 2002). Tropical soils are inherently susceptible to nutrient loss, but poor agricultural management further exacerbates the rate at which nutrients are lost. Nutrient mining occurs as a result of continuous nutrient removal through crop harvest without nutrient replenishment, uncontrolled soil erosion, and burning of crop residues rather than the return of organic resources to the soil. Soil fertility is declining faster in Uganda than in other countries of sub-Saharan Africa, yet smallholder farmers have limited adoption of soil fertility management technologies developed by researchers (Esilaba et al., 2005; Nkonya et al., 2005).

Researchers have long advocated for a soil fertility management approach that combines mineral fertilizer with organic inputs because adequate quantities of either fertilizer source on their own

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are often unavailable or unaffordable to smallholder farmers (Bationo et al., 1998). Manure is frequently of low or imbalanced nutrient content, which means manure sources are less likely to meet crop demands and can lead to temporary nutrient immobilization following application (Mafongoya et al., 2006; Masaka et al., 2013; Vanlauwe et al., 2005). Mineral fertilizers can supplement the nutrient supply of organic inputs and are thought to be necessary to correct nutrient outflows from smallholder fields (Nkonya et al., 2005; Tittonell et al., 2008a). Integrated Soil Fertility Management (ISFM) emphasizes combining both input types with the recognition that adequate quantities of either input on its own are often unavailable or unaffordable for smallholder farmers. A meta-analysis of studies demonstrated that, across sub-Saharan Africa, the combined use of organic inputs and nitrogen fertilizers leads to a greater yield response than either input on its own (Chivenge et al., 2010). Some trials have also reported a positive "interactive effect," or a boost in crop yields beyond what is observed when either amendment is applied alone at a nutrient rate equivalent to the combination (Bekunda et al., 2010). This interactive effect is thought to occur through two mechanisms. First, organic inputs may temporarily immobilize mineral nitrogen (N) from fertilizer and prevent the rapid leaching of N that is often witnessed in tropical systems (Vanlauwe et al., 2002). Second, yield increases may occur indirectly as general soil conditions are improved through the addition of organic inputs (Vanlauwe et al., 2001a). Both mechanisms most likely occur simultaneously and increase use efficiency of mineral fertilizers (Mosier et al., 2004).

Despite research trials demonstrating yield benefits from combined nutrient sources, ISFM adoption in central Uganda is currently low due to the lack of recommendations appropriate for highly weathered soils undergoing rapid nutrient mining. The Lake Victoria Basin is dominated by Ferralsols, which are characterized by low soil pH, low nutrient reserves and availability, and high clay content. Ferralsols are the most dominant (25%) soil type in Uganda, and an additional quarter of Uganda's soil types are also considered highly weathered (Bamutaze, 2015). Rapid population growth in the Lake Victoria Basin is accelerating the rates of soil nutrient mining on these already nutrient-poor soils. Understanding how highly weathered soil types respond to combined fertilizer treatments can potentially increase the adoption of ISFM soil management among smallholder farmers.

It is known that on-station research results often do not accurately reflect yield outcomes when technologies are moved onto surrounding farms (Leeuwis, 2004). Yield responses to mineral fertilizer use are often significantly lower and more variable under typical smallholder conditions than yield responses seen on research stations (Sileshi et al., 2010). Mugwe et al. (2008) found that on-farm yields of combined organic and mineral N treatments were generally >50% lower than the same treatment plots located on-station in western Kenya. Lower yield outcomes on farms are thought to result in part from less consistent crop management by farmers in the form of less timely planting, weeding, and watering. Trials that are designed by researchers, but managed by farmers, can produce reliable biophysical data over a broad range of management approaches (Franzel and Coe, 2002; Selener, 1997). Participatory trials ensure that research results accurately incorporate the effects of farmer management, which could otherwise obscure treatment effects when technologies move onto farms (Mutsaers et al., 1997). Technologies that perform well during on-farm trials are most likely particularly adept at eliciting a yield response under a variety of conditions.

Our objectives were to measure the effect of organic and mineral fertilizers, separately and combined, on indigenous vegetable yields through an on-farm, researcher-designed, farmer-managed trial in the Lake Victoria Crescent of Uganda. We hypothesized that mineral fertilizer would complement the organic resources already used by smallholders farming on highly weathered clay Ferralsols. The use of combined fertilizer treatments was expected to lead to yield gains beyond what either input generates alone, resulting in a positive interactive effect under on-farm conditions.

2. Materials and methods

2.1. Study site

The study plots are located within central Uganda's Lake Victoria Crescent region around the Nkokonjeru town council (0°14′58″ N; 32°54′ 39″ E). The region is sub-humid tropic and has two distinct rainfall periods, allowing for two cropping seasons per year. On average, the region receives approximately 1500 mm of rainfall distributed with bimodal peaks in April and November. Temperature ranges from 17 to 27 °C with a daily mean of 22 °C. This region is characterized by highly weathered, clay texture soils classified as orthic Ferralsols (FAO, 1977). Historically, the region was highland tropical forest, but over the past twenty years has been converted to primarily mixed banana/coffee systems with maize, beans, cassava, and potatoes as other important staple crops. Smallholder farms are typically less than one hectare in area.

2.2. Study crop

The indigenous vegetable *Solanum aethiopicum*, locally referred to as nakati, was chosen as a test crop because of its commercial and nutritional importance in central Uganda (Ssekabembe, 2003). Nakati can be grown as a bushy perennial or annual. Unlike the related *Solanum aethiopicum* 'Gilo group' whose white or cream colored fruits are harvested and referred to as African eggplants, the leaves and stems of *Solanum aethiopicum* 'Shum group' are not hairy and are used as a vegetable (Shackleton et al., 2009). The small red fruits of the 'Shum group' plants are not eaten. Nakati can be present on farms as a weedy species, but it is more often deliberately cultivated for sale or household use. Farmers value nakati for its relatively high and stable market price, as well as the fact that it is capable of surviving and re-growing after prolonged droughts (Ssekabembe, 2003). Nakati is frequently found in Kampala markets. It has a large geographic range across Africa and is also grown in South America and the Caribbean (Schippers, 2000).

2.3. Study design

Trials were conducted during two consecutive growing seasons, the short (April) and long (Aug/Sept) rains of 2013. Experimental trials (31 during the short rainy season and 38 during the long rainy season) were established on-farm in a randomized block design, with one replicate per treatment in each block (farm). Forty-five total farms were included in the study; twenty-four plots repeated the experiment both seasons. Plots offered by farmers were accepted if they were free of shade trees, tree stumps, burned areas and other environmental conditions that could create confounding effects. Plots were located within a 50 km radius between 1150 to 1233 m above sea level. Plot slopes ranged from 0 to 14%.

Treatments consisted of a control and varying levels of composted cow manure and mineral fertilizer (urea) to reach two different levels of N application rates. Nitrogen rates were calculated based on survey results capturing farmers' home garden fertilization practices. Farmers provided their application rates in wheelbarrows, which were then translated to a lower rate of 100 kg N ha^{-1} and an upper rate of 200 kg N ha^{-1} by taking the average dry weight and N content