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The effect of mineral and organic nutrient input on yields and nitrogen balances in western Kenya

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ABSTRACT

Soil fertility declines constrain crop productivity on smallholder farms in sub-Saharan Africa. Government and non-government organizations promote the use of mineral fertilizer and improved seed varieties to redress nutrient depletion and increase crop yields. Similarly, rotational cropping with nitrogen (N)-fixing legume cover crops or trees is promoted to improve soil fertility and crop yields. We examined maize grain yields and partial N balances on 24 smallholder maize farms in western Kenya, where interventions have increased access to agricultural inputs and rotational legume technologies. On these farms, mineral fertilizer inputs ranged from 0 to 161 kg N ha^{-1} (mean = 48 kg N ha^{-1}), and maize grain yields ranged from 1 to 7 t ha^{-1} (mean = 3.4 t ha^{-1}). Partial N balances ranged from large losses (−112 kg N ha^{-1}) to large gains (93 kg N ha^{-1}) with a mean of −3 kg N ha^{-1}. Maize grain yields increased significantly with N inputs (from fertilizer and legumes) in 2012 but not in 2013 when rainfall was lower. Nitrogen inputs of 40 kg N ha^{-1} were required to produce 3 t of maize per hectare. N balances varied both among farms and between years, highlighting the importance of tracking inputs and outputs on multiple farms over multiple years before drawing conclusions about nutrient management, soil fertility outcomes and food security. The addition of N from legume rotations was a strong predictor of grain yields and positive N balances in lower-yielding farms in both years. This suggested that legume rotations may be particularly important for buffering yields from climate variability and maintaining N balances in low rainfall years.

1. Introduction

Continuous, low-input agriculture in sub-Saharan Africa (SSA) has removed nutrients from the soil without replenishing nutrient stocks (Moebius-Clune et al., 2011). As such, while most other regions in the tropics have seen increases in food production over the past fifty years, per capita yields in SSA have remained the same or even declined (Hazell and Wood, 2008). The “African Green Revolution” (AGR; Annan, 2004) is an effort to increase use of nutrients, high-yielding seed varieties and extension services to increase low crop yields in SSA (Denning et al., 2009; Sanchez et al., 2009). Numerous national government agencies, non-government and international organizations support programs that provide these inputs at subsidized rates or through rural credit. Recent studies show that local cereal yields may double or even triple where adoption rates of both improved seeds and fertilizers are high (Denning et al., 2009; Nziguheba et al., 2005; Sanchez et al., 2007; Sanchez, 2015; Snapp et al., 2010).

The inclusion of legume cover rotations (often called “improved fallows”) on farms has been promoted as a strategy for soil fertility improvement in SSA for many years (Buresh and Tian, 1998; Kiptot et al., 2007; Scherr, 1995; Sileshi et al., 2008). Fast-growing tree, shrub, and herbaceous legumes are grown for six months to two years after which they are cut and the fields planted in a cereal crop. By fixing atmospheric N_2, these legumes increase N inputs to a farm field. Their N contribution may partially replace or complement mineral fertilizer application while simultaneously increasing soil carbon (C) stocks (Sanchez, 2002). However, the

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amount of N_2 fixed by rotational legumes can vary from 24 to 142 kg N ha^{-1} depending on the species present and their plant density (Giller, 2001). Such technologies are often rapidly tested by farmers when introduced but widespread, continued adoption remains limited (Gathumbi et al., 2002b; Kiptot et al., 2007). Negative nutrient balances remain common at the farm and even country-level in SSA (Cobo et al., 2010; de Graaff et al., 2011; Nandwa and Bekunda, 1998; Van den Bosch et al., 1998).

Intensification of agriculture with higher fertilizer rates typically leads to imbalances between inputs and outputs (Heathwaite et al., 1993; Liu et al., 2010; Oenema et al., 2003; Vitousek et al., 2009). Resulting nutrient surpluses can cause declines in soil biodiversity (Wood et al., 2015a) and nutrient loading of terrestrial, aquatic, and atmospheric systems (Forster et al., 2007; Carpenter et al., 1998; Vitousek et al., 2009). These consequences occur widely in parts of the US, China, and Europe and have the potential to occur in locations such as SSA where nutrient inputs to farms may begin to increase substantially.

Because nutrient balances summarize the nutrient inputs and outputs of a farming system (Oenema et al., 2003), they are useful tools for farmers, extension agents, and policy makers when assessing the sustainability of the system. Nevertheless, these assessments must be considered in terms of the overall soil fertility status, the length of time that nutrient depletion has occurred, as well as other factors.

The aim of this study was to investigate the effects of farm management practices (e.g., fertilizer and legume rotations) on grain yields and nitrogen balances in smallholder maize farms in East Africa. We wanted to (i) test if higher N inputs lead to higher maize grain yields and less negative N balances, (ii) quantify the amount of N contributed through rotational legumes and determine their effect on yields and N balances, and (iii) determine the importance of soil chemical and physical properties on maize yields and N balances. We hypothesized that farms with the highest fertilizer application rates would have the highest grain yields and more positive N balances (more surplus N) across all farms regardless of site-specific soil properties. We expected farms receiving no or little fertilizer to have the lowest grain yields and negative N balances (N deficits). Finally, we hypothesized that farms cultivating rotational legumes would have intermediate maize grain yields and N balances. We expected maize grain yields to be positively correlated to N input and soil N concentrations and we expected that soils with legume rotations would have highest soil C content across all farms.

To test these hypotheses, we surveyed farmers participating in the Sauri Millennium Village Project, where agroforestry and rotational legume technology and trainings have been promoted since the early 1990s and where fertilizer subsidy programs were promoted from 2005 to 2008.

2. Methods

2.1. Study sites

This study was conducted on 24 maize farms in the Sauri village cluster of the Millennium Village Project (MVP) in Yala Division, Siaya District, Nyanza Province, Kenya (Fig. 1). The area has a mean annual temperature of 24 °C and an average monthly range from

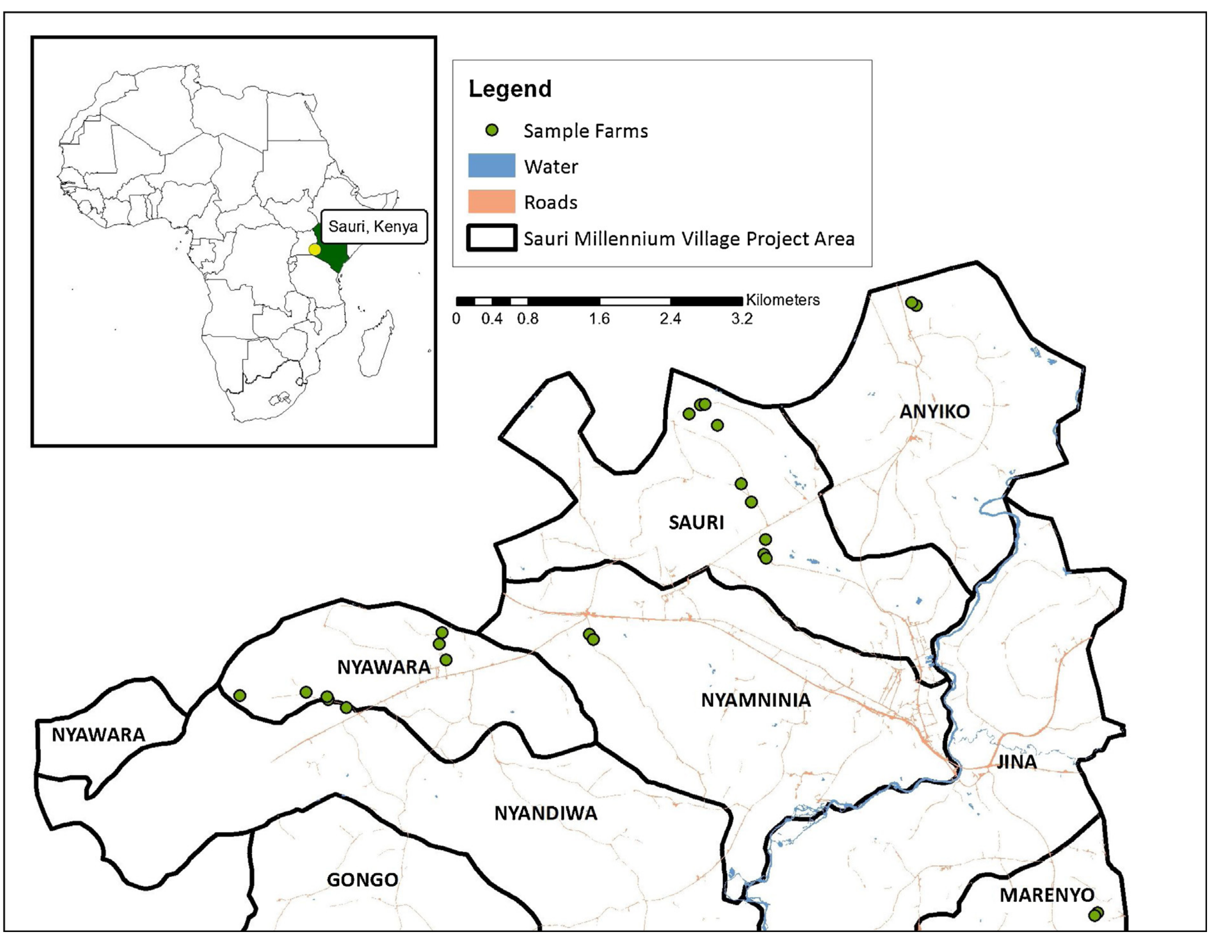

Fig. 1. Site map of village and farm sets within the study area.