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Soil nutrient build-up, input interaction effects and plot level N and P balances under long-term addition of compost and NP fertilizer

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ABSTRACT

Decline in farmland soil fertility due to nutrient depletion is a concern for smallholder farmers in the highlands of Ethiopia. In this study we tested if long-term addition of compost, either alone or in combination with nitrogen (N) and phosphorous (P) fertilizer, affected available soil nutrient status, grain/tuber harvests, agronomic N use efficiency, and plot level N and P nutrient balances. The on-farm experiments were conducted on four farm fields for up to 6 years in Beseku, Ethiopia. A randomized complete block design was used, with four treatments: full dose of compost applied alone at 2.4 t ha^{-1} DW organic matter (C); full dose of fertilizer (F); half compost and half fertilizer (CF); and, unfertilized control. In the upper 10 cm of the surface soil, several Mehlich-3 extractable nutrients (B, Ca, K, Mg, P, S, and Zn) had significantly higher concentrations in the C treatment ($P < 0.01$), and some in the CF treatment ($P < 0.05$) than in the control. Phosphorus was the only nutrient with a higher concentration in the F treatment than the control. Maize and faba bean showed added benefits (synergy) in terms of yield increase in the CF treatment and a better agronomic efficiency for added N. Plot level N balances were negative for all treatments except C, with strong depletion in the control (−76 kg N ha^{-1} yr^{-1}) and F (−65 kg N ha^{-1} yr^{-1}) treatments. When the N balance was compared to measured change in soil N, the F and control treatments were significantly ($P < 0.05$) lower than zero. N in the CF and C treatments was close to steady-state, i.e., the input of N in organic matter compensated for the loss of N through mineralization. The control treatment had a negative P balance of 11 kg P ha^{-1} yr^{-1}, with moderately negative balance of 4 kg P ha^{-1} yr^{-1} in the C treatment. The CF and F treatments had positive P balances. Thus, the addition of compost, both alone or in combination with mineral fertilizer, can prevent N and reduce P mining and improve the nutrient status of the soil. When only NP fertilizer was used, the crop utilized all N that was mineralized indicating that the crop was N limited.

1. Introduction

Nutrient depletion of agricultural soils is a major concern to smallholder farmers in the highlands of Ethiopia (Yirga and Hassan, 2010) and large parts of sub-Saharan Africa (van der Pol and Traore, 1993). This depletion is related to nutrient outflow through crop harvest and crop residue removal (Haileslassie et al., 2005) and losses through erosion (Shiferaw and Holden, 1999) and leaching (van der Pol and Traore, 1993). The decline in soil fertility is partly compensated by increasing arable land at the expense of forests, bush land and grazing land. However, in highly populated areas in Ethiopia this alternative is not viable as land suitable for conversion to cropland is becoming scarce (Lemenih et al., 2008). Similarly, long fallow periods are no longer an alternative due to small and continuously decreasing farm sizes associated with population growth (Shiferaw and Holden, 1999; Abegaz and van Keulen, 2009). As a result, smallholder farmers tend to continuously cultivate their cropland (Lemenih et al., 2005a), and the soils no longer have time to recuperate fertility. This in turn leads to nutrient depletion (Haileslassie et al., 2005; Abegaz and van Keulen, 2007) and reduction in per capita food production (Haileslassie et al., 2005), and could result in soil nutrient mining (van der Pol and Traore, 1993).

Due to economic, infrastructure and policy related constraints (Haileslassie et al., 2005; Spielman et al., 2010), the current level of fertilizer input is much lower than required to maintain soil fertility and ensure sustainable yield (Abegaz and van Keulen, 2007). Although organic inputs, such as farmyard manure and crop residues are potential sources of plant nutrients, there is competition from alternative uses for these resources, such as

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manure for fuel and crop residues for animal feed and construction (Haileslassie et al., 2005; Abegaz and van Keulen, 2009). Under such conditions, the combined use of smaller amounts of inorganic and organic nutrient resources such as compost is an alternative option for restoring soil fertility as it is an affordable investment in resource poor farming systems (Vanlauwe et al., 2010). Fertilizers currently used in Ethiopia supply only primary plant nutrients, whereas organic inputs replenish soil organic matter (SOM) fractions that contain different soil micro- and macronutrients. SOM is also known to improve soil structure and water holding capacity. This approach has the potential of replenishing soil fertility, maintaining SOM and enhancing productivity (Vanlauwe et al., 2011; Bedada et al., 2014). A decline in soil fertility can be assessed in three ways (Hartemink, 2006): (i) by expert knowledge (local observation of changes in visible soil properties and function); (ii) through monitoring soil chemical properties over time; and (iii) via calculations of the nutrient flows and balances. Expert knowledge is mainly qualitative and the monitoring of nutrient status over time requires long-term studies. Therefore, the calculation of nutrient balances is a convenient and widely used approach for quantitatively assessing changes in soil fertility (Hartemink, 2006). In this approach, the amount of nutrients entering and leaving a system, with predefined boundaries, over time is estimated (Stoorvogel et al., 1993). Nutrient balances are useful as sustainability indicators for agricultural production systems (van der Pol and Traore, 1993) and reflect current soil fertility management (Lesschen et al., 2007). A negative balance indicates depletion of nutrients (van Reuler and Prins, 1993), whereas a positive balance suggests the system is accumulating nutrients (van Reuler and Prins, 1993). Therefore, the balance is considered a logical consequence of current agricultural practices (van der Pol and Traore, 1993).

Soils with negative nutrient balance are widespread in sub-Saharan Africa (Smaling, 1993; Stoorvogel et al., 1993; Stoorvogel and Smaling, 1998). Average nutrient balances were estimated to $-47\,kg\,N\,ha^{-1}\,yr^{-1}$, $-7\,kg\,P\,ha^{-1}\,yr^{-1}$, and $-32\,kg\,K\,ha^{-1}\,yr^{-1}$ in Ethiopia (Stoorvogel et al., 1993), and even more strongly negative nutrient balances ($-112\,kg\,N\,ha^{-1}\,yr^{-1}$, $-13\,kg\,P\,ha^{-1}\,yr^{-1}$, and $-83\,kg\,K\,ha^{-1}\,yr^{-1}$) have been reported for farming systems at both national and regional levels (Haileslassie et al., 2005). Although soil nutrient depletion is considered evident under smallholder farming systems in the Ethiopian highlands, this is not generally true. Positive or nearly balanced N and P balances in three cropping systems and strongly negative N balances in one cropping systems in the southern highlands of Ethiopia are reported. The positive P balance in the highlands was due to application of relatively larger volume of manure to the homestead fields and due to lower removal of P in crop produces and residue in the lowland farms. A more positive N balance under enset (*Enset ventricosum*) based garden systems was also recorded in the highlands. This was due to continuous application of manure (though this varied across socio-economic groups) and due to lower harvesting frequency of the enset plant (Elias et al., 1998).

Declining soil fertility was in our previous work identified as an obstacle to increased productivity (Karltun et al., 2013; Lemenih et al., 2005a,b). Thereafter, we have, together with the farmers, tried to identify, implement and evaluate locally acceptable integrated soil nutrient management options. As an outcome of those thorough discussions, on-farm experiments with compost addition alone or in combination with mineral fertilizer was initiated and implemented on four farms with the aim of using locally available composting materials. In these experiments there was an apparent synergy that showed that crop harvests were higher from the combined use of compost and NP fertilizer compared to the other treatments (Bedada et al., 2014).

The aims of this study were: (i) to test if long-term addition of compost and NP fertilizer, alone or in combination, results in differences in available soil nutrient status; (ii) to assess and quantify the differences in grain/tuber harvests and agronomic N use efficiency due to the treatments; and (iii) to examine differences in plot level N and P balances with respect to compost and fertilizer additions. The effects were assessed through measuring soil nutrient status and crop harvests and input-output balances were quantified based on measured data complemented with data from literature. The hypothesis was that addition of moderate amounts of compost would have specific benefits if combined with NP fertilizer and/or added separately, thereby, complementing the low addition of mineral fertilizer in low-input smallholder crop production system.

2. Materials and methods

2.1. Site description

The field study was conducted in Beseku village, Arsi Negele district, in the south-central highlands of Ethiopia. The village and fields are situated between 7°20′ and 7°25′N and 38°45′ and 38°50′E at an altitude of about 2100 m above sea level. Rainfall has a bimodal distribution, with a short rainy season between March and early of June and the main rainy season between late July and the beginning of October (Lemenih et al., 2005b). The mean annual rainfall in the area is 932 mm, with an annual mean minimum temperature of 9.4 °C and maximum temperature of 22.7 °C. The rainfall and temperature data are averages for seven years and are collected through an automatic weather station established in the village near the experimental area, as described in Bedada et al. (2014).

The soils in the experimental area are developed from volcanic lava and ash through quaternary volcanic activity in the Rift Valley and its surroundings, and are classified as Humic Andosols (Wrb, 2014) with a loam texture, with a CEC_{pH7} ranging between 25 and $32\,cmol_c\,kg^{-1}$, and a base saturation ranging between 48 and 68% (Lemenih et al., 2005a). Natural forests in the area have in the recent 70 year period been subjected to extensive deforestation. Most of the crop land in the village has been converted from forest to agriculture through this process (Lemenih et al., 2005b). After deforestation, the fields were turned over to agriculture, with a resulting depletion in soil fertility that is one of the primary constraints to sustainable crop production in the area (Lemenih et al., 2005a).

2.2. Farming system

The farming system in the area is a mixed crop-livestock production system (Lemenih et al., 2005a). The two major cultivated crops are maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.), 43% and 33% of crop land area, respectively. Sorghum (*Sorghum bicolor* L. Moench) and barley (*Hordeum vulgare* L.) are also cultivated but with less areal coverage, 11% and 10% of crop land area, respectively. Between May and August, farmers may cultivate potato (*Solanum tuberosum* L.) as a food security crop to provide staple food between August and November until other crops (mainly maize and wheat) are harvested (Karltun et al., 2013). Late maturing varieties of maize are planted in late April/early May during the short rainy period: harvesting is during late November to early December. Wheat is planted in August and harvested four months later in November. Livestock, predominately cattle, have an important role in the farming system, as they support crop production by providing draught and threshing power and manure as an input to restore soil fertility (Lemenih et al., 2005a). Manure is often applied to the fields close to the