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Effect of organic and conventional farming systems on nitrogen use efficiency of potato, maize and vegetables in the Central highlands of Kenya

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ABSTRACT

Increased per capita food production in the tropics is closely tied to soil organic matter and water management, timely nitrogen (N) supply and crop N use efficiency (NUE) which are influenced by farming systems. However, there is lack of data on the effect of organic farming systems on NUE and how this compares to conventional farming systems under tropical conditions. Therefore, the objectives of this study were to determine the effect of conventional and organic farming systems at low and high management intensities on N uptake and N use efficiency of potato (*Solanum tuberosum* L.), maize (*Zea mays* L.), cabbage (*Brassica oleracea* var. Capitata), kale (*Brassica oleracea* var. Acephala) and Swiss chard (*Beta vulgaris* sub sp. Cicla). The organic high input (Org-High) and conventional high input (Conv-High) farming systems are managed as recommended by research institutions while organic low input (Org-Low) and conventional low input (Conv-Low) farming systems are managed as practiced by small scale farmers in the Central highlands of Kenya. The study was conducted during three cropping seasons between October 2012 and March 2014 in an ongoing long-term trial established since 2007 at Chuka and at Thika, Kenya. Synthetic N-based fertilizer and cattle manure were applied at ~225 kg N ha^{-1} yr^{-1} for Conv-High and at ~50 kg N ha^{-1} yr^{-1} for the Conv-Low. Composts and other organic inputs were applied at similar N rates for Org-High and Org-Low. Nitrogen uptake efficiency (NUpE) of potato was highest in Conv-Low and Org-Low at Thika and lowest in Org-High and Org-Low at Chuka site where late blight disease affected potato performance. In contrast, the NUpE of maize was similar in all systems at Chuka site, but was significantly higher in Conv-High and Org-High compared to the low input systems at Thika site. The NUpE of cabbage was similar in Conv-High and Org-High while the NUpE of kale and Swiss chard were similar in the low input systems. Potato N utilization efficiencies (NUtE) and agronomic efficiencies of N use (AE_N) in Conv-Low and Conv-High were 11–21 % and 1.4–3.4 times higher than those from Org-Low and Org-High, respectively. The AE_N of maize was similar in all the systems at Chuka but was 3.2 times higher in the high input systems compared to the low input systems at the Thika site. The AE_N of vegetables under conventional systems were similar to those from organic systems. Nitrogen harvest index (NHI) of potato was similar between Conv-High and Org-High and between Conv-Low and Org-Low. N partitioned into maize grain was similar in all the system at Chuka, but significantly lower ($P < 0.001$) in Conv-low and Org-Low at Thika site. The NHI of cabbage in Org-High was 24 % higher than that of Conv-High. The study concluded that for maize and vegetables, conventional and organic farming systems had similar effects on NUpE, AE_N, NUtE and NHI, while for potato conventional systems improved NUE compared to organic systems. The study recommends that management practices for potato production in organic systems should be improved for a more efficient NUE.

1. Introduction

There is an immediate need to increase per capita food production to match high population growth while maintaining environmental stability (Ciampitti and Vyn, 2014). Since nitrogen

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(N) plays a critical role in food, feed and fiber production, and its increased application resulted in tripling per capita food production in the last 50 years (Prasad, 2013), an adequate N management is essential in food production. However, N remains one of the major limiting nutrients to food production especially in Sub-Saharan Africa (SSA) (Bekunda et al., 2010). In most farming systems, N management poses a major challenge due to its high mobility and propensity for loss from the soil-plant system into the environment. Efficient N management techniques are required to improve N-delivery and -retention in soils in order to increase N-use efficiency (N-uptake and N-utilization), improve economic yields, reduce cost of production and improve the economic sustainability of most farming or cropping systems (Van Eerd, 2005; Garnett et al., 2009).

Nitrogen use efficiency (NUE) in crops is determined by uptake, assimilation, translocation and, when plants are ageing, recycling and remobilization. As a concept, NUE is expressed as a ratio of output (biological yield or economic yield) and input (total soil N, fertilizer N applied, or available soil N plus fertilizer N applied) (Dobermann, 2005; Fageria and Baligar, 2005; Ladha et al., 2005). The biological yield may include total aboveground plant dry matter, whereas the economic yield includes part of the crop with economic value e.g. grain or tuber yield.

Several techniques, such as use of slow release fertilizer (Ghosh et al., 2015) as well as adoption of appropriate soil fertility management practices including use of manure or rate and timing of fertilizer applications have been used to improve NUE (Fageria and Baligar, 2005; Ghosh et al., 2015; Kumar et al., 2015). Similarly, crop management practices such as crop rotation, use of catch crops, crop residues and the use of N efficient genotypes can also improve NUE (Fageria and Baligar, 2005; Ladha et al., 2005; Alva et al., 2006; Hirel et al., 2011). Current agricultural production systems like conservation agriculture, organic farming and combined organic and conventional farming that make use of crop varieties with highly efficient use of N have been perceived to have major effects on NUE (Fageria and Baligar, 2005; Ladha et al., 2005; Hirel et al., 2011). N application levels and timing of application play a critical role in improving NUE (Hirel et al., 2007). Studies comparing low external input farming systems with conventional farming systems at different input levels in Kenya reveal that both systems may result in N mining or a positive N balance depending on the agro ecological zone in which they are cultivated (De Jager et al., 2001; Tripp, 2006; Tambang and Svensson, 2008). Organic farming systems in Europe have been associated with low N use efficiency (Kirchmann and Ryan, 2004; Bergström et al., 2008; Alaru et al., 2014) possibly due to slow mineralization of applied organic inputs and poor synchrony between supplied N and crop demand (Berry et al., 2002; Mikkelsen and Hartz, 2008; Alaru et al., 2014). Nitrogen supply in these systems is often limited by mineralization-immobilization processes and may be unpredictable resulting in excess or deficient asynchrony (Mallory and Griffin, 2007) which eventually affects NUE. In addition, low input and organic farming systems have different N sources, cycling and management options compared to conventional systems that heavily rely on synthetic fertilizers and these in turn affect N availability and use efficiency (Dawson et al., 2008). On the other hand, application of conventional fertilizers that are readily available may be prone to losses such as leaching and denitrification, reducing NUE of conventional farming systems (Chien et al., 2009; Hirel et al., 2011). Assessments of low input and organic agriculture (Badgley et al., 2007a; Badgley et al., 2007b) reveal that there is potential of supplying enough N through fixation by legumes, cover crops and other organic sources in organic farming systems.

Most small holder farming systems in SSA are associated with low nutrient inputs due to limited access to synthetic fertilizers as well as poor agronomic practices such as sporadic pest and weed control, and this may affect NUE (Keating et al., 2010). Nitrogen use efficiency of maize in Africa small holder' farms has been reported to be very low, ranging from 5 to 18 kg for every kg of N applied, with the NUE being mainly dependent on resource endowment, management ability, soil conditions, drought, pest and diseases as well as maize varieties (Snapp et al., 2014). On the other hand, research indicates that organic farms have lower soil and plant nitrate levels even though yields are comparable to those of conventional systems (Arihara and Srinivasan, 2013). Thus, nutrient acquisition and uptake patterns may differ between conventional and organic farming systems. In temperate regions, studies comparing long-term organic and conventional farming systems suggest that agronomic efficiency of N use is lower in organic than conventional systems (Kirchmann et al., 2007). However, the comparison of such results is hampered because the studies were performed in regions of different climatic conditions, soil types and farming practices. In addition, long-term trials that compare different farming systems in the tropics are scarce, and where they exist they are faced with inconsistencies in management and data collection due to funding constraints (Kibunja et al., 2011; Bationo et al., 2012; Kihanda and Warren, 2012).

In summary, it is envisaged that organic or conventional farming systems may affect nitrogen cycle (mineralization, volatilization, denitrification and immobilization) in soils differently and consequently crop N uptake and utilization in the long-term. Based on current evidence, this study hypothesized that organic farming systems may promote plant nutrient uptake comparable to conventional systems, but differ in the effect on crop NUE. The objectives of this study were to determine the effect of four farming systems i.e. Org-High, Conv-High, Org-Low, Conv-Low on N-uptake, NUE (i.e. N-uptake efficiency, N-utilization efficiency, agronomic efficiency of N-use, N-Harvest index) of potato, maize and vegetables in two agro-ecological zones in the Central highlands of Kenya.

2. Materials and methods

2.1. Field site

The study was conducted between October 2012 and March 2014 within the ongoing Long-term Farming Systems Comparison Trials (SysCom). The trials were established in April 2007 at Chuka and Thika in the Central highlands of Kenya. Both sites have bimodal rainfall patterns. Long rain season (LS) occur in April and August while short rain season (SS) occurs between October and February. Thika site lies at 1500 m above sea level (m a.s.l.) with an annual mean temperature of about 20 °C and mean annual rainfall of 900–1100 mm yr^{-1}. The site is situated in the upper midlands 3 (UM 3) agro-ecological zone (Sunflower–Maize zone) according to Jaetzold et al. (2006a) in Murang'a County about 50 km north-east of Nairobi (longitude 037°04.747′ and latitude 01°00.231′). Chuka site lies at 1458 m a.s.l. with an annual mean temperature of 20 °C and mean annual rainfall of 1500 mm yr^{-1}. According to Jaetzold et al. (2006b), Chuka site lies within the upper midland 2 (UM2) agro-ecological zone (Main Coffee Zone) and is located at Tharaka Nithi County (longitude 037°38.792′ and latitude 00°20.864′), about 150 km north-east of Nairobi. The soil at Thika is classified as Rhodic Nitosol (Wagate et al., 2010a) while that of Chuka site is classified as Humic Nitisol (Wagate et al., 2010b) based on FAO World reference system of soil classification (IUSS Working Group WRB, 2006). The two zones were selected due to differences in rainfall and soil fertility status with Chuka having higher rainfall and comparatively higher soil organic carbon and soil extractable phosphorus compared to Thika. Soil characteristics during the establishment of the trials in 2007 were similar across the systems at each site as shown in Table 1. The soil characteristics of the two research sites at the start of data collection in 2012 are presented in Table 2.