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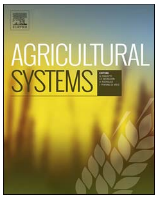

Livelihood and climate trade-offs in Kenyan peri-urban vegetable production

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ABSTRACT

Trade-offs between livelihood and environmental outcomes due to agricultural intensification in sub-Saharan Africa are uncertain. The present study measured yield, economic performance and nitrous oxide (N_2O) emissions in African indigenous vegetable (AIV) production to investigate the optimal nutrient management strategies. In order to achieve this, an on-farm experiment with four treatments – (1) 40 kg N/ha diammonium phosphate (DAP), (2) 10 t/ha cattle manure, (3) 20 kg N/ha DAP and 5 t/ha cattle manure and (4) a no-N input control – was performed for two seasons. Yields and N_2O emissions were directly measured with subsampling and static chambers/gas chromatography, respectively. Economic outcomes were estimated from semi-structured interviews (N = 12). Trade-offs were quantified by calculating N_2O emissions intensity (N_2OI) and N_2O emissions economic intensity (N_2OEI). The results indicate that, DAP alone resulted at least 14% greater yields, gross margin and returns to labour in absolute terms but had the highest emissions ($p = 0.003$). Productivity-climate trade-offs, expressed as N_2OI, were statistically similar for DAP and mixed treatments. However, N_2OEI was minimized under mixed management ($p = 0.0004$) while maintaining productivity and gross margins. We therefore conclude that soil fertility management strategies that mix inorganic and organic source present a pathway to sustainable intensification in AIV production. Future studies of GHG emissions in crop production need to consider not only productivity but economic performance when considering trade-offs.

1. Introduction

Africa accounts for 16.4% of the world's N_2O emissions, of which 42% (excluding grassland and savannah burning) results from agriculture (Hickman et al., 2011). Agriculture generates N_2O emissions due to chemical fertiliser and animal manure use (Syakila and Kroeze, 2011). N_2O is released when N in the fertiliser materials is converted to N_2O gas through two microbial-mediated processes: nitrification and denitrification. Nitrification is the oxidation of ammonia to nitrate and denitrification is the reduction of nitrate and nitrite to dinitrogen gas (Mosier et al., 1998; Robertson and Groffman, 2007). The amount of N_2O produced during nitrification and denitrification depends on management and environmental factors, including the amount of N in the fertilising material, soil temperature, soil moisture/precipitation, soil physical properties, pH, available soil carbon and tillage practice (Shcherbak et al., 2014; Kim et al., 2016).

However, the climate impacts of fertiliser use need to be considered in relation to its benefits to society. This is particularly important in Africa, where agriculture supports both livelihoods and economies. The livelihoods of two thirds of the population come from agriculture (IFDC, 2006) and on average it contributes 25% of gross domestic product (Africa Agriculture Status Report, 2016). Furthermore, the importance of fertiliser in African agricultural production is predicted to increase. Population trends and dietary patterns due to urbanisation and affluence are expected to increase food demand, driving agricultural intensification and additional fertiliser use (Tilman and Clark, 2014). Intensification of nutrient use may stimulate higher N_2O emissions by comparison with current levels. It is essential to have an improved understanding of the potential trade-offs between the N_2O emissions and productivity of farming systems in the development of environmentally friendly farm management strategies that also meet livelihood needs.

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The extent of livelihood and environmental trade-offs from fertiliser use is uncertain, especially in farming systems in sub-Saharan Africa (SSA). Only a few studies have investigated N_2O emissions from African soils. These studies report N_2O emissions per unit land area and range from − 0.1 to 113 kg N_2O-N ha^{-1} yr^{-1}. For instance, Dick et al. (2008) measured N_2O emissions from a cereal/legume rotation growing in alfisol soils in Mali and found N_2O emission levels of 0.6–1.5 kg N_2O-N ha^{-1} yr^{-1}. This was on average 20% lower than N_2O emissions from ten fields in humic nitisol soils with vegetables, pasture, tea, maize, cassava and forage feed on smallholder farms in east Africa (Rosenstock et al., 2016). However, N_2O emissions from intensive urban vegetable gardens tend to be high and are the sources of the high cumulative N_2O fluxes reported in African soils, *i.e.* 34–113.4 kg N_2O-N ha^{-1} yr^{-1} (Predotova et al., 2010; Lompo et al., 2012).

Of those studies that have been produced *in situ* measurements of emissions in SSA, few accompany measurements of emissions with yield data of which all are from soils treated with chemical N (Nyamadzawo et al., 2014a; Hickman et al., 2014; Hickman et al., 2015; Pelster et al., 2017). The results from some of these studies indicate greater N_2OI, calculated by expressing N_2O emission as a function of yield, from soils treated with no or high N inputs. For example, Nyamadzawo et al. (2014a) reported a 94% reduction in N_2OI of rape (*Brassicas napus*) in Zimbabwe from soils amended with 65 kg N ha^{-1} compared to adjacent plots treated with no N and N fertilisation at 240 kg N ha^{-1}. N fertilisation at 75 and 100 kg N ha^{-1} reduced N_2OI of maize yield in Kenya by 7% and 28.6% when compared to no N and N fertiliser application at 200 kg N ha^{-1} respectively, although there was no response to fertiliser addition in crop yields (Hickman et al., 2014). In general, these studies demonstrate that moderate nutrient intensification increases crop yields without necessarily increasing N_2O emissions, as was suggested by Shcherbak et al. (2014) based on a global meta-analysis. However, the underlying dataset only contained one study from Africa indicating that despite increased attention being paid to N_2O and yield trade-offs globally (van Groenigen et al., 2010; Linquist et al., 2012), our understanding of the extent of livelihood and climate trade-offs due to soil fertility management in SSA is limited.

The shift in focus to include productivity with climate objectives is promising. However, productivity is only a small part of what drives on-farm decision-making. Farmers, especially those that are market-oriented such as African indigenous vegetable (AIV) producers in peri-urban systems, typically make production decisions based on economics (Okello et al., 2014). No previous studies in SSA or elsewhere globally have investigated the trade-offs between economics and GHGs due to farm management practices in the same way as N_2OI. This is problematic because productivity and economic viability do not always follow the same pattern, *e.g.* yields might increase but net revenues fall due to increased costs of production (Pimentel et al., 2005). Therefore it is imperative to examine trade-offs not only between productivity and emissions, but between the economic viability of farming systems and emissions.

The present study investigated productivity and economic and climate trade-offs in soil fertility management strategies in smallholder AIV production in Kiambu county, Kenya. The importance of vegetables, particularly AIVs, has increased in Kenya due to their contribution to food security, human nutrition and income diversification for smallholder farmers (Ngugi et al., 2007; Abukutsa-Onyango et al., 2010). AIVs in Kenya are characterised by multiple planting and harvesting cycles throughout the year, diverse production systems depending on their location (urban, peri-urban or rural), use of either organic, inorganic or a mix of N inputs, and their degree of market integration (Shackleton et al., 2009). Therefore, the importance of AIVs to Kenya's food security and their intensive production practices make them a good model system for studying economic and climate trade-offs in soil fertility management strategies. Kiambu was chosen because it is a centre of peri-urban AIV production. We hypothesised that current N fertilisation strategies commonly used in smallholder AIV production do not generate significantly different N_2O emission profiles and thus can be optimised to meet yield, economic outcome and environmental goals.

2. Materials and methods

2.1. Study site

An on-farm experiment was established in Wangige, Kiambu county, Kenya (1°13′12.672″ N, 36°41′54.936″E, altitude: 1940 m) on a site that is representative of peri-urban smallholder AIV production in the area. The site has been under smallholder AIV cultivation for the past six years. During that period, vegetables have been grown during the two rainy seasons each year. The 'long rains' are from mid-March to mid-June while the 'short rains' fall from October to mid-December. The region receives a mean annual rainfall of about 950 mm and has an average monthly maximum and a minimum temperature of 23.8 °C and 12.6 °C respectively. The soils are broadly classified as Humic Nitisols (Kimetu et al., 2006).

2.2. Experimental design and treatments

The experiment spanned two growing seasons: short rains in 2015 (season I) and long rains in 2016 (season II). The experiment was completely randomised with three replicates of four treatments. The treatments were a no-input control and three nitrogen sources: (1) diammonium phosphate (DAP, 18:46:0) at a rate of 40 kg N ha^{-1}, (2) manure at a rate of 10 t fresh cattle manure ha^{-1} (29.5 kg N ha^{-1}), and (3) a mixture of DAP and manure applied at 34.7 kg N ha^{-1} (20 kg N from DAP and 14.7 kg N derived from 5 t of fresh cattle manure ha^{-1}) for each season. The treatments were applied once at the beginning of each rainy season (20/10/15-season I and 9/4/16-season II) at the same time as fertilisation was being undertaken by other farmers in the area. The selected treatments and application rates represented soil fertility strategies commonly practised by smallholder AIV farmers in Kiambu (HORTINLEA household survey, 2014). Each plot measured 9 m^2 (3 m × 3 m) with a 1-m buffer. African nightshade (*Solanum scabrum*) seeds were incorporated 15 cm apart in rows with 40 cm between the rows. Plot management was in line with local practice and is summarised in Table 1.

2.3. Productivity

Vegetables in N-treated plots were harvested twice in season I and

Table 1
Agronomic practices for African nightshade vegetable production during both growing seasons.

Season	Land preparation	Planting/fertiliser application	Thinning	Weed/pest management	Harvesting
1	12/9/15-1st ploughing by hand, 19/10/15-2nd ploughing (making soils fine for planting)	20/10/15-Sowing seeds and fertiliser application by hand	11/11/15-Thinning	17-18/11/15-Weeding by hand, 19/11/15-application of pesticide	26/11/15-1st harvesting, 19/12/15-2nd harvesting
2	26/3/16-Ploughing by hand	9/4/16-Sowing seeds and fertiliser application by hand	23/4/16-Thinning and gapping	30/4/16- Weeding by hand, 3/5/16-application of pesticide	13/5/16-1st harvesting, 11/06/16-2nd harvesting, 23 July-3rd last harvest