Results from the fertilizer demonstration experiment with maize at Farm for the Future Tanzania in Iringa, in 2020

Working Paper No. 335

CGIAR Research Program on Climate Change,
Agriculture and Food Security (CCAFS)

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Abstract

In 2020, an experiment was run for the third consecutive season at the Farm for the Future Tanzania Ltd. (FFF), which is part of Ilula Orphan Program's (IOP) Farm, Ilula, Iringa Region, in Tanzania. The FFF farm is training farmers in 16 villages with a focus on dissemination activities at regional and national levels. The purpose of the experiment is to test and demonstrate crop fertilization strategies that combine high maize yields with high nutrient use efficiency (NUE) and low greenhouse gas (GHG) emissions. Five nutrient management treatments were combined in a full factorial setup with two tillage options. Highest yields were obtained with reduced tillage combined with NPK fertilizer to target 70% of water-limited yield (Yw) and micro-nutrients (Mg, S, Zn combined), and with half NPK fertilizer and half composted manure. The lowest maize yields were obtained from both the treatment without fertilizer application and the fertilizer treatment with only P and K applied at reduced and conventional tillage.

Results showed no significant differences in both agronomic N use efficiency (N-AE, additional grain yield per kg N applied when correcting for the P and K applied) and fertilizer use efficiency (additional grain yield per kg N applied when including yield effects from P and K) between reduced and conventional tillage. N-AE obtained in the experiment of 34.0 kg yield/kg N was much higher compared to the current average N-AE in sub-Saharan Africa of 14.3 kg yield/kg N. When targeting 70% of Yw for maize, this improved N-AE value could result in 58% reduction in GHG emission per hectare (ha) from fertilizer application (direct and indirect emissions). Despite the cancellation of the farmers field days, due to the Covid-19 pandemic, ten young farmers still took part in the experimental setup and trial planting.

Keywords

Tanzania; experiment; nutrient management; tillage; maize; yields; greenhouse gas emissions; mitigation strategies.

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The authors would like to thank their respective organizations and CCAFS for their support of this work. Our thanks also go to IOP for providing needed on-site supervision of the Trial and arranging for labor. Farm for the Future supported and advertised this Trial very much; they also adopted the complete dose regime that has proven successful even during the first year of maize production on their farm. During the third year of the Trial, FFF took up the Trial supervision through the Company's farm Manager, Ms. Grace Kimonge: we greatly thank them. Towards the end of the second season, we received services of final year BSc (Agronomy) students. They helped with harvesting and, later, root depth analysis. Their contribution is very much appreciated. The picture is not complete without thanking the clients and users of the Trial results: Regional Commissioner, District Commissioner, the Village Leaders, Farmers and Single mothers. To them, we say *asante sana* for patronizing us.

Contents

Acronyms

FFF	Farm for the Future Tanzania Ltd
GHG	Greenhouse gas
GYGA	Global Yield Gap Atlas
Ha	Hectare
IOP	Ilula Orphan Program
Kg	Kilogram
N	Nitrogen
N-AE	Agronomic N use efficiency
NPK-AE	Fertilizer use efficiency
O	Oxygen
P	Phosphorous
RT	Reduced tillage
Yw	Water-limited yield

1. Introduction

Large parts of land suitable for agriculture in Tanzania are currently not under cultivation, presenting both threats and opportunities. In places where agriculture is practiced, yields are low because of inherent low soil fertility, low use of costly inputs and unpredictable weather (resulting in a very narrow planting window). As a result, farmers' yields are usually 20% or below potential yields under rainfed conditions (yieldgap.org). A field experiment was set-up to address farmers' dilemmas by introducing demonstrations on reduced tillage, and proper, efficient fertilization.

The objectives of the (large-scale) experiment are to: test fertilization and tillage practices in maize and their potential to close the yield gap with reduced greenhouse gas (GHG) emissions; analyze nutrient use efficiencies; and use the trial as demonstration and discussion object for other farmers in the region.

2. Location

The experimental location of Farm for the Future Tanzania Ltd (FFF, ffftanzania.com) is on the Ilula Orphan Program's (IOP) Farm, Ilula, Iringa Region, in Tanzania (ioptanzania.org/home) (Fig. 1). IOP is a non-governmental organization in Tanzania dealing with impact mitigation to 1) determine the root cause of and help the most vulnerable children (orphans from extremely poor families, children from poor single parents); 2) empower the elderly; 3) empower young mothers and youth through training. IOP owns the FFF modern commercial farm that started operation in 2018, which is also used as a training center. It is a registered farm aimed to generate income, empower single mothers through training (socio-economic and agriculture) and encourage school children (kindergarten to secondary school) to develop a love for agriculture by providing visits and activities to encourage them to grow a positive image of this top employer in Tanzania. This experiment is part of the FFF.

Figure. 1 Map of Tanzania showing the experimental location

3. Trial layout

3.1 Trial set-up and treatments

Five nutrient management options were combined with two tillage options, resulting in ten different treatment combinations (Table 1). The trial has a split-plot design with tillage as main plots and the five fertilizer treatments as split plots. There are four replications of each treatment with a plot size of 10.4 m by 10.8 m (16 rows at 65 cm, and 36 planting holes placed at 30 cm apart, resulting in a plant density of 5.13 plants/m^2). Net plot (harvesting) size is 9.75 m x 10.5 m, equivalent to 102.375 m^2. Liming was not required since former soil analysis showed an average pH of 5.5 (4.6-6.3).

Table 1. Experimental treatments, which are a combination of the nutrient management and tillage options.

			Nutrient application rates (kg nutrient/ha)					
Treatment	**Tillage**	**Compost applied**	**N**	**P_2O_5**	**K_2O**	**MgO**	**S**	**Zn**
CT-F1	Conventional	No	0	0	0	0	0	0
CT-F2	Conventional	No	98	42	42	0	0	0
CT-F3	Conventional	No	98	43	42	9	13	1
CT-F4	Conventional	Yes	49	21	21	0	0	0
CT-F5	Conventional	No	0	42	42	0	0	0
RT-F1	Reduced	No	0	0	0	0	0	0
RT-F2	Reduced	No	98	42	42	0	0	0
RT-F3	Reduced	No	98	43	42	9	13	1
RT-F4	Reduced	Yes	49	21	21	0	0	0
CT-F5	Reduced	No	0	42	42	0	0	0

[1] Yw is the water-limited potential yield, and is estimated as 7.0 t/ha, the yield target is 70% of Yw which is 4.9 t/ha (85% dry matter).

3.2 Fertilizer treatments

The fertilizer treatments include a control treatment without any fertilizer application (F1), which is required to assess crop response to fertilizer application and to calculate fertilizer use efficiency. The unfertilized control is also close to current farmer practice. The F2 and F3 treatments supply nitrogen (N), phosphorus (P), and potassium (K) at a rate that could accommodate NPK uptake of maize at 70% of its water-limited yield potential (Yw) identified for the site at IOP Farm. Based on a combination of both the Global Yield Gap Atlas (GYGA) and expert judgement, the water-limited yield potential was estimated at 7 tons (t) maize grain per hectare (ha) (at 85% dry matter) (i.e., resulting in a target yield of 4.9 t/ha maize yield (70% of the yield potential)). We assumed 20 kg N uptake per ton of grain produced, which resulted in 98 kg N/ha application rate (Table 1). P and K rates were determined by the N-P-K ratio of the recommended fertilizer product YaraMila Cereal (used in F3). The F3 treatment investigates the potential benefit of applying the additional plant nutrients sulphur (S), magnesium (Mg) and zinc (Zn), knowing from previous soil analysis that these nutrients are frequently in deficiency. This treatment also represents the current Yara recommendation for maize grown in the Southern Highlands of Tanzania.

The fourth fertilizer treatment (F4) includes the use of organic material (composted manure). This treatment assumes that farmers can afford at least half the recommended rate of industrial fertilizer and supplement it with the readily available composted manure. Further, it is assumed that after a few years of application, the manure should be able to replace 50% of the mineral fertilizer and lead to better soil physical conditions (i.e., increased soil organic matter content, a very important soil attribute that is generally low in tropical soils). The fifth fertilizer treatment (F5) includes the supply of P and K only; this treatment is required to assess crop response to N fertilizer and to calculate N use efficiency.

The N-AE is the additional grain yield per kg N applied when correcting for the P and K applied (by comparing yields in the NPK treatment [F3] with yields in the PK treatment [F5], divided by the N applied).

$$N\text{-}AE = \frac{yield_{NPK} - yield_{PK}}{N_{applied}} \qquad \text{Equation (1)}$$

The fertilizer use efficiency (NPK-AE) is the additional grain yield per kg N applied when including yield effects from P and K (by comparing yields in the NPK treatment [F3] with yields in the control treatment [F1], divided by the N applied).

$$NPK\text{-}AE = \frac{yield_{NPK} - yield_{control}}{N_{applied}} \qquad \text{Equation (2)}$$

By subtracting the N-AE from the NPK-AE, the P and K fertilizer effects on yields are revealed.

3.3 Tillage treatments

All fertilizer treatments were combined with one of two different tillage practices, (1) conventional (CT; Fig. 2a) or (2) reduced tillage (RT; Fig. 2b). Conventional tillage represents common farmer's practice. At IOP Farm this means using a disc plough on the whole field. Reduced (or conservation) tillage means, for this experiment, using a ripper instead of a disc plough, and ploughing only the planting lines, leaving the remainder of the field untouched.

This minimizes soil exposed to the effects of weather (reduces erosion), minimizes destruction of soil flora and fauna (encouraging biodiversity). It ensures exact placement of fertilizer (in the furrow) and better use of the fertilizer by the plant, presumably, leading to bigger harvests. It reduces the use of fossil fuel, hence a cleaner environment and cheaper farming operations (fewer runs than when whole field is tilled). Ripping results in better water harvesting and storage due to less soil exposure (no inversion or turning of the soil) and the deep strips that are formed collect and store more water. In the long run, this might enable minimum use of herbicides and tillage.

Figure 2. a) Conventional tillage through disc ploughing, and b) reduced tillage through ripping.

4. Activities and measurements

At the start of the season, land preparation (tillage) was done, and trial set up, seeding, herbicide application (both pre-and post-emergence), application of well decomposed manure and fertilizer activities were executed (Fig. 3). Planting was done on 10 January 2020, which was late for the specific place and season. The season rains started in mid-November and most farmers, including FFF, planted their maize crop by the first week of December 2019 (05/12/2019 for FFF). This resulted in a poor crop establishment due to cold soils and high nutrient leaching in our trial.

In a second stage of the experiment, from 15 February 2020, the following management activities were performed: weeding, fertilizer top dressing, spot herbicide application (selective, post-emergence). In a third stage of the experiment, the following management activities were performed: final top dressing (15 March), pesticide application (January, February and March 2020). Finally, root measurements were made and the maize plants in the trial experiment were harvested on 17 June 2020.

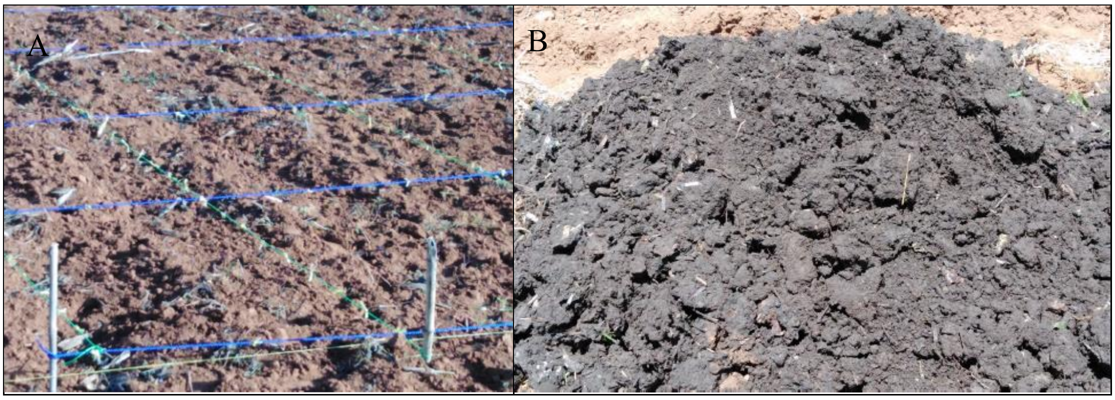

Figure 3. a) Planting hole markers to enhance precise planting hole digging, b) heap of well decomposed compost manure.

5. Greenhouse gas emissions calculation

Required N input under different levels of N-AE was estimated using the approach of Ten Berge et al. (2019). GHG emissions from fertilizer application (application only, not from fertilizer production) were estimated based on IPCC (2019). Those consisted of direct N_2O-N emission from fertilizer application, indirect N_2O emission through NH_3 and NO_x volatilization, and indirect N_2O-N emission from leaching and run-off. All emissions were converted to CO_2 equivalents.

The direct N_2O-N emission from fertilizer application was estimated as the mineral fertilizer N applied multiplied by the emission factor for direct N_2O emission (0.01 kg N_2O-N/kg N applied). The indirect emission of N_2O-N by volatilization of N as NH_3 and NO_x, was estimated as the mineral fertilizer N applied multiplied by the fraction of NH_3 and NOx volatilized (0.11) and the emission factor for N volatilization (0.01 kg N_2O-N/kg N_2O-N volatilized). The indirect emission of N_2O-N by leaching and run-off from land of N was estimated as the mineral fertilizer N applied multiplied by the fraction of N leached and run-off (0.24) and the emission factor for leaching and run-off (0.01 kg N_2O-N/kg N leached or run-off).

6. Results

There was a significant interaction between tillage and fertilizer treatment (*P*=0.01). Highest yields were obtained with reduced tillage combined with NPK fertilizer and micro-nutrients (Mg, S, Zn combined) and with half NPK fertilizer and half composted manure (RT-F3, RT-F4) (Fig. 4). The lowest maize yields were obtained at both the control fertilizer treatment (no fertilizer applied) and the fertilizer treatment with only P and K applied at the reduced and the conventional tillage (F1, F5) (Fig. 4). The extremely low yields in these treatments were partly because of the relatively high number of rotten cobs, as in those treatments an average three out of ten cobs were rotten compared to one out of ten in the other treatments. The relatively low yields in the 2020 season were also a result of nutrient leaching, leading to severe nutrient deficiency symptoms. These included severe yellowing of the crop, especially in the F1 and F5 treatments (see Fig. 5) as well as pink coloration due to P deficiency.

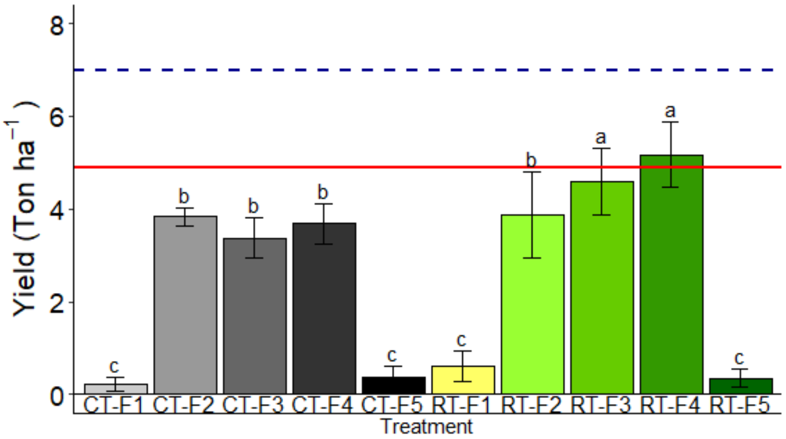

Figure 4. Average maize yield (at 85% dry matter) with standard deviation for the different treatments (see Table 1 for treatment explanations). Bars labelled with different letters indicate significant differences in yield between the treatments (P<0.05). Blue dashed line indicates the estimated water-limited potential yield, and the red continuous line is 70% of the water-limited yield.

The amount of fertilizer applied was targeting 70% of Yw of an average year (ca. 5 t/ha), but only reduced tillage fertilizer treatments F3 and F4 obtained yields around this target (Fig. 4). The average agronomic N-AE (Eq. 1, the additional grain yield per kg N applied when correcting for the P and K applied) was lower than what was targeted. Namely, the average N-AE were 34.0 (30.5 – 37.6, lower and upper range), and 34.4 (26.7 – 44.6, lower and upper range) under conventional tillage and reduced tillage respectively compared to the targeted N-AE of 50 kg yield/kg N (blue line Fig. 6a). However, the observed values are still high compared to the current average N-AE in sub-Saharan Africa of 14.3 kg yield/kg N (Ten Berge et al., 2019; red line Fig. 6a). If farmers in Tanzania manage to increase the N-AE from 14.3 to 34.0, it could have huge consequences for mitigation of GHG emissions (Van Loon et al., 2019). When targeting 70% of Yw for maize, GHG emission from fertilizer application (direct and indirect emissions) is estimated 1771 kg CO_2eq per ha with NAE=14.3, while it would be 745 kg CO_2eq per ha if NAE=34.0 (Fig. 7). So, a reduction of 58% is achieved with the improved nutrient management, as fewer nutrient inputs are needed to get the same yield level (Fig. 7a). Apart from GHG emission savings, there will be other emission savings (e.g., nitrate).

Results show no significant difference in N-AE (*P*=0.93) (Fig. 6a) between reduced and conventional tillage, and no significant difference in fertilizer use efficiency between reduced and conventional tillage (*P*=0.47) (NPK-AE, Eq. 2, the additional grain yield per kg N applied when including yield effects from P and K; Fig. 6b), and also no significant difference in the yield effect from P and K fertilizer under conventional tillage and reduced tillage (*P*=0.09) (NPK-AE – N-AE; Fig. 6c).

Figure 5. Photos from some of the experimental treatments (F1 – F5 respectively) on 15 March 2020 (2 months after crop emergence). See Table 1 for explanation on the treatments.

The experiment will be repeated with the same set-up in 2021 and then the data from all four years of the experiments will be analyzed jointly.

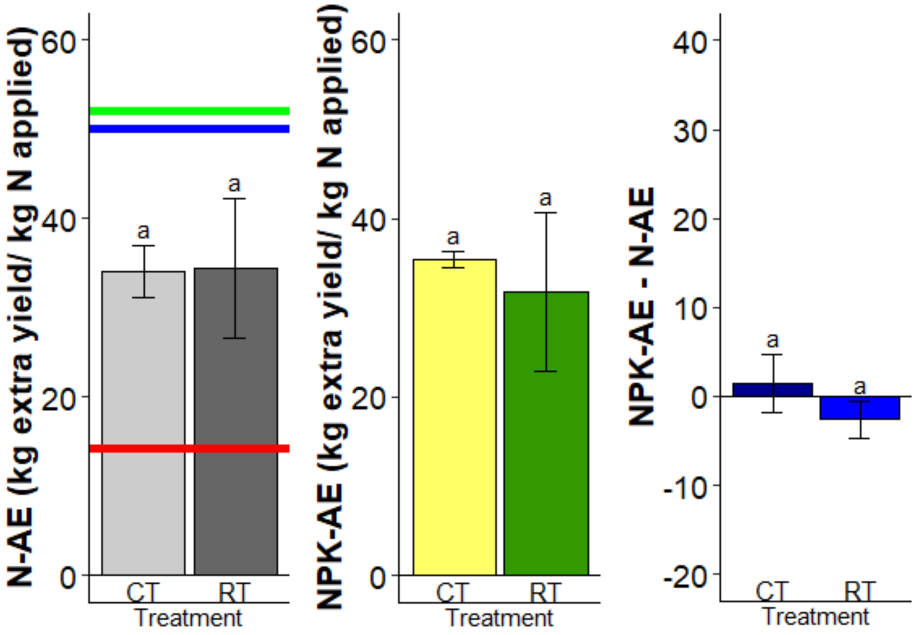

Figure 6. A) Agronomic N use efficiency (N-AE, i.e., yield of treatment F3 - yield of treatment F5 / N applied at treatment F3; see Table 1 for treatment explanations), red line is the current average N-AE in sub-Saharan Africa (Ten Berge et al., 2019), blue line is the assumed N-AE, and green line is the estimated optimum N-AE (Ten Berge et al., 2019); b) fertilizer use efficiency (NPK-AE, i.e., yield of treatment F3 - yield of treatment F1 / N applied at treatment F3); c) PK efficiency (i.e., NPK-AE - N-AE) for conventional tillage (CT) and reduced tillage (RT) with standard deviation. Bars labelled with different letters indicate significant differences between the treatments (P<0.05).

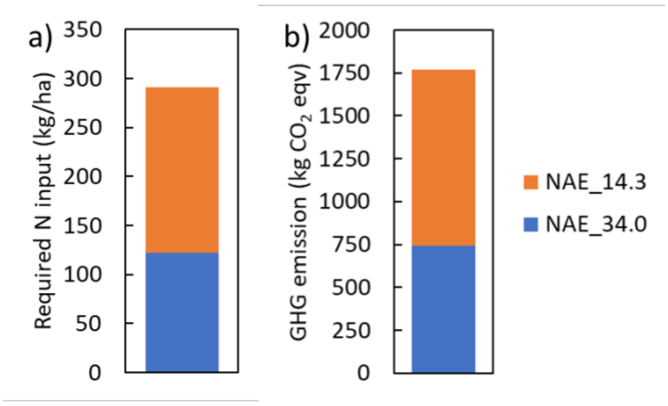

Figure 7. A) Required N input to target 70% of Yw with a NAE of 14.3 or 34.0, and b) the GHG emissions from fertilizer application related to those application rates.

7. Communication and outreach

Combining commercial farming and training is a completely new approach in Tanzania. Involving children is very much hailed by the regional authorities as the right way forward. The experiment at the IOP farm supports creating a knowledge base on nutrient management and tillage options to improve maize yields.

Although a number of field visits and a major Farmers Field Day were planned, they were called off due to the emergence of the Covid-19 pandemic. However, ten young farmers took part in the experimental set-up and trial planting. For the fourth and final Trial season in 2021, outreach activities are planned, not only to farmers, but also to school children to help them learn more about agriculture. After the fourth season we will perform an overall analysis of the four seasons and plan to publish a report and disseminate the results.

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