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RESEARCH ARTICLE

VARIATION IN NUTRIENT USE EFFICIENCY UNDER VARYING SOIL CONDITIONS IN MAIZE GROWING AREAS IN NORTHERN ZONE, TANZANIA- EAST AFRICA

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ABSTRACT

Sub-Saharan Africa (SSA) is plagued by low maize productivity due to climate change, poverty and poor agronomic practices by smallholder scale farmers. The objective of this study was to explore the attainable maize grain yields under various nutrient use in a varying soil conditions..In order to execute the study, in year 2016/2017 maize planting season, performance trials (PTs) were extracted from the Nutrient Omission Trials (NOTs) of the season 2015/16. The PTs was an advanced of NOTs to understand the variation in nutrient use efficiency of maize under varying soil conditions. The performance Trials (PTs) were conducted in 10 different districts of main maize growing areas Northern Tanzania. The PTs sites were introduced in the same grids in which NOTs were planted. The aim of this study was to verify the performance of newly developed site specific nutrients management recommendations by Taking Maize Agronomy to Scale in Africa (TAMASA) project against the blanket recommendation. The PTs were based on nutrient expert tool and soil test (ST) based fertilizer recommendations. The treatments used were nutrient expert (NE) recommendation, soil test (ST) based fertilizer recommendation, region fertilizer recommendation (RE) and control in which no fertilizer was applied. The fertilizer rates and their ranges was as follows; RE-NPK (100-20-0), NE-standard NPK (100-20-0), Soil Test ST- NPK (102-50-46).The parameters considered were grain and biomass yields. The results showed that performance of these treatments varied within and across locations. Generally the results in Siha district showed that the grain yield was higher for NE>ST> control>RE. In Mbulu district NE and ST performed highest than RE and the control. In Babati although the difference was small still NE and ST were better than the control treatment. Grain yield in Monduli was also better for NE, ST and RE in relation to the control treatment. The treatments revealed significant variation in biomass yield as indicated in the results followed with discussion section of this study report. The study concluded that NE and ST treatments were significant that showed comparable high grain yield of maize, therefore farmers could make significant yield upon adopting of NE and ST treatments fertilizer for site specific nutrient management.

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INTRODUCTION

Maize is the main food crop of Tanzania averaging 6.7 million metric tons in 2013/2014 seasons. The crop is grown by about 4.5 million smallholder farmers (Minot, 2010; Keya and Rubaihayo, 2013) accounting for over 90% of the total maize production (Minot, 2010; Lyimo*et al*., 2014, Magehema*et al*., 2014). Tanzania is endowed with more than 4.0 million hectares land with suitable climate (medium-high elevation) for the production of specialty maize that commands high prices on the world market (URT 2018).

Despite the importance of maize in Tanzania its productivity is considerably low and highly variable. On average, maize yield ranges between 1.2 and 1.6 t/ha (Mrutu *et al*., 2014; Magehema *et al*., 2014) which is extremely low to contain the available food demand and importation. Food insecurity also were reported in Sub-Saharan Africa (SSA) being a serious challenge at household levels, where the majority of production is below the expected potential (Lobell *et al*., 2009). Evidences show that yields for maize can be as low as 1.4ton ha^{-1}againist the potential yields of improved varieties of 4-13 ton ha^{-1} (Saka *et al*. 2006; Mviha *et al*., 2011; Mueller et al. 2012). Crop yields also varies from place to place at global, regional and local scale (Yengoh, 2012). Tanzania has the capacity to produce more metric tons per hectare annually if small-scale farmers were to adopt improved farming practices. Maize production has been increasing from year to year due to priority set by the government (URT 2018). The study was the outcome of the project known as Taking Maize Agronomy to Scale in Africa (TAMASA) which was a 4-year (2014-2019) project covering three countries of Tanzania, Nigeria and Ethiopia. The main goal of this project is to improve productivity and profitability for small-scale maize farmers in Africa using agronomic geospatial and socio economic data collected at scale. Thus efforts of different service providers such as input suppliers, government and private research, extension services, agro-dealers, and farmers were highly considered especially in data collection, co-development and promotion of new agronomic practices or tools. It also adopted a use-case model or approach that enables users to examine production/system challenges and options for solving them.In Tanzania, this project covers only two agro-ecological zones namely Southern Highlands and Northern Zones. However, this study highlights only one activity namely performance trials (PTs) which were conducted in Northern Zone in 2016/2017 seasons. PTs were essentially verification trials for TAMASA newly developed nutrient expert tool and soil based fertilizer recommendations from the Nutrients Omission Trials (NOTs) in 2015/2016 season. One of the major factors contributing to low maize productivity includes limited intensification of proper maize agronomic practices and outbreaks of random stresses which are magnified by the climatic changes. Therefore initiatives like TAMASA, which aimed at scaling out all possible agronomic practices/agricultural technologies is necessary for ensuring sustainable improved maize yield productivity and returns to investment to all target individual household farmers and the whole country at large.

Objectives

The objectives of this study were

- To verify the performance of newly developed site specific nutrient management recommendations using nutrient expert tool, against the soil test, regional fertilizer recommendations
- To enlighten maize smallholder farmers with developed decision support tools suitable site specific nutrient management to terminate the usage of blanket fertilizer rate recommendations

MATERIALS AND METHODS

The study area: The Northern Zone is located between latitudes 1.5° and 6.0° S and longitudes 34.5° and 38.5°E (Figure 1).The population is about 4.8 million (2012 census).The population is about 4.8 million (2012 census). Northern Zone consists Arusha Manyara and Kilimanjaro regions and Lushoto district of Tanga region. The Northern Zone occupies approximately 12 percent of the total maize area in the country. Northern Zone accounts for 10% of the total national production of the cereal (Nkonya *et al.,* 1991) and is one of the nation’s maize surplus areas. Total area under maize production in the zone in the 2014/15 was 527864 ha that was about 8% of total maize growing area (URT, 2016). The major maize producing districts are Mbulu, Babati, Hanang, and Arumeru; other maize producing districts of less importance are Moshi, and Rombo. Remaining districts - Mwanga, Same, Kiteto, Monduli, Ngorongoro, and Simanjiro are maize deficit areas because of their unreliable rainfall.

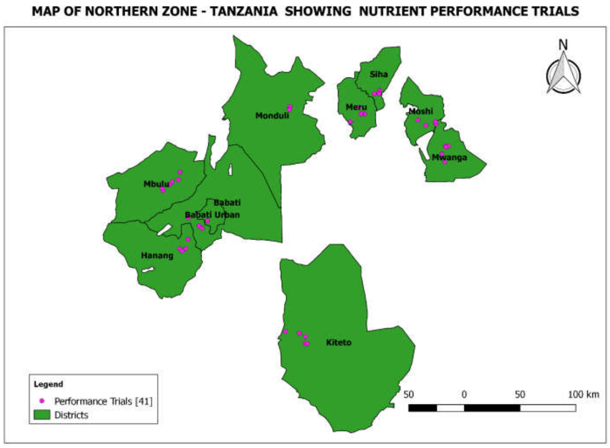

Figure 1. Location of trials and study area in Northern Zone of Tanzania, East Africa

Trial layout, design and planting: A Pythagoras approach of 3 x 4 x 5 sides were used to layout the trial fields. Pegs, ropes and tape measures were used. The trials were planted in a10 x 10 m square plot size with each farmer acting as a replicate. Plant spacing was 0.75 and 0.25 m between and within rows, respectively. Fourteen rows with 1 plant per hill were planted. At each site treatments were arranged in such a way that the control was planted at the upper side of the slope to block any runoff or seepage of fertilizer towards the control plot.

Plant nutrient elements, fertilizer sources, calculation and application: The fertilizer rates and their ranges was as follows Regional-NPK (100-20-0), NE-standard NPK (100-20-0), Soil Test NPK (102-50-46).The key plant nutrients considered in this project were N, P and K. The treatments constituted with different levels these plant nutrients. The main sources of these elements are Urea, TSP and MOP for N, P and K, respectively. Before application, calculation was done to estimate the right amount of N, P and K to apply from their respective sources. The rates/levels were calculated based on site-specific fertilizer requirements. TSP and MOP fertilizer sources were applied at once during planting (basal application). Urea was divided into 3 groups. 1/3 of which was applied during planting, the other 1/3 was applied when the plants had 6 to 8 leaves and the last 1/3 was applied one week before flowering (i.e. 1^{st} and 2^{nd} top dressing, respectively). Weeding and other cultural field management practices were done accordingly.

Harvesting processes: Trials harvesting was done at the right physiological maturity, grain yields and moisture content (%) data were recorded in harvesting form using Open Data Kit (ODK) software with Smart Cell Phone (SCP). Weighing balance, tape measure, ropes and bags were among the tools used during collection of harvesting data. From each trial plot area of 10m x 10m planted, a net plot of 5m x 5m area was harvested. The following data were recorded: farm codes, farmers name, the location, plot size, stand count, total no of plants within net plot, no of cobs within net plot, weight of stalks within net plot, weight of cobs within net plot, weight of sub sample crop cuts with respective weight of 5 cobs from sub sample.

Sample processing: The PT'smaize cobs and stover's samples collected from NZ were processed at Tanzania Agricultural Research Institute (TARI) –Selian Center. The key samples collected were maize cobs and maize plant stovers. These samples were properly received, documented and sun dried to acceptable moisture content and after that were reweighted.

Data analysis: Grain and fresh biomass yields data of subsamples recorded per each site were subjected to analysis of variance (ANOVA) using Genstat (15^{th} Edition) software. Unbalanced ANOVA Test wereapplied for all sites to determine the most yielding site and the most performing fertilizer rate recommendations. The treatment means were separated using Duncan Multiple Range Test (DMRT) at P=0.05 significance level. The percent of coefficient of variations (%CV), standard error (SE), and LSD (0.05) and other important statistics were summarized.

RESULTS AND DISCUSSION

Grain and biomass yield performance in Siha District: The highest gain yields were observed in the Nutrient Expert (NE) treatment which were 5.98 tonha^{-1} followed by soil test (ST) treatment 5.53 tonha^{-1}The regional fertilizer recommendations performed 4.97 tonha^{-1}higher than the control trail check which had grain yield of 3.16 tonha^{-1}. Biomass yield also showed a similar trend that of grain yield in Siha district as shown in Table 1. Therefore the results indicated the significant variation in grain yield in Siha district.

Grain and biomass yield performance in Moshi District: The biomass yield was observed to high have compared to grain yields. The control treatment did not differ much with the rest of the treatments. The high prevalence means that there were low response of any addition of fertilizers implies that the soil were fertile and any additional of fertilizer resulted into the crop to grow vegetative. The result revealed that there was no significant variation in grain yield performance among the treatments evaluated in Moshi district (table 1).

Grain and biomass yield performance in Mwanga District: The ST and NE performed highest beyond the overall mean 4.23 tonha^{-1}with yields values of 5.05 tonha^{-1}and 4.32 tonha^{-1}respectivelywhile the biomass yield was slightly progressively increased in yield from RE, Control, ST and NE. Generally the result revealed that there was no significant variation in grain and biomass yield performance (table 1).

Grain and biomass yield performance in Mbulu district: The highest gain yield 6.44 tonha^{-1} was observed for RE treatment followed by ST treatment (6.09 tonha^{-1} while the lowest maize grain yield were 3.88 tonha^{-1} has was observed in the control treatment. Table 2the biomass yield also showed a similar trend in performance as that of grain yield. That implies that grain and biomass yield performance were related.

Grain and biomass yield performance in Babati District: The PTs planted in Babati district showed significant variation in both grain biomass yield performance among the treatments evaluated in table 3 and figure 6. ST treatment performed highest 7.77 tonha^{-1}compared with the control treatment 3.73 tonha^{-1}. Treatments RE and NE performed far from the check with average yield of 6.78 tonha^{-1} and 6.68 tonha^{-1} respectively. The biomass yield also showed similar trend as observed in grain yield (table).

Grain and biomass yield performance in Hanang District: The ST and NE treatments performed slight the same as the control treatment in terms of grain yield. However, the RE treatment performed so poorly in this particular variable. Biomass yields were highest for RE and ST compared to all other treatments evaluated had 8.17 tonha^{-1}and 8.09 tonha^{-1} respectively (table).

Grain and biomass yield performance in Kiteto District: All treatments evaluated in Kiteto performed poorly on grain yield. Grain yield ranged from 0.95 tonha^{-1} for the control treatment, while 1.98 tonha^{-1}were the ST treatment. The overall mean was 1.45 t/ha with SD of 0.49. Biomass yield showed highest SD value of 30.05 with regional recommendation treatment showing lowest (4.46 tonha^{-1}) compared to the rest treatments including the control, which had 5.40 tonha^{-1}(Table).

Grain and biomass yield performance in Karatu district: The analysis of variance detected significant differences in grain yield performance. The regional recommendation (RE) treatment produced highest grain and biomass yield of 8.10 tonha^{-1} and 6.95 tonha^{-1} respectively. NE and ST performed slight the same with grain yield values of 7.67 and 7.85 tonha^{-1} respectively. The lowest grain and biomass yields were 4.76 tonha^{-1} and 5.56 tonha^{-1}were observed to the control treatment (table)

Grain and biomass yield performance in Arumeru district: The results of analysis revealed that performance of grain and biomass yields in Arumeru did not differ significantly among the treatments**.** Grain yield varied from 4.28 (control) to 4.57 tonha^{-1} (ST-treatment) with overall mean 4.45 tonha^{-1}and standard deviation of 0.177. Biomass yield was slightly lower in NE treatment than in the control treatment (table 1).

Grain and biomass yield performance in Monduli District: In Monduli, grain and biomass yields had SD of 0.72 and 0.99, respectively. ST and NE treatments performed far better of 2.77 tonha^{-1} and 2.65 tonha^{-1} than control treatment, which had 1.19 tonha^{-1}. However biomass yield was better in ST and RE treatments than in control and NE.

DISCUSSION

The trials were established in maize growing season 2016/2017 in northern zone Tanzania to validate the recommendations made by the country- based NE version. This validation was seen as a confidence building measure and evidence for partners who were interested in using NE. Approximately 65 trials were established, each with a control (zero fertilizer), the regional blanket recommendation, the nutrient expert (NE) generated recommendation based on site-specific field history, and soil-test-based nutrients recommendations. A wide variability in crop response to nutrients application was observed both within and between sites, reflecting a high degree of heterogeneity in soil characteristics and crop growing conditions at various spatial scales. This adds support to the need for tailoring soil fertility management practices to site-specific conditions to sustainably increase crop productivity in SSA (Giller *et al*., 2011; Vanlauwe *et al*., 2015). Three crop response categories that distinguish soils as responsive and non-responsive to fertilizer application (i.e. responsive, fertile non-responsive and degraded

Table 1. Grain and biomass yields mean performance of maize in study districts in Northern Tanzania

District	Parameter	Treatments					
		RE	Control	ST	NE	Mean	SD
Siha	Grain yield ton ha^{-1}	4.97	3.16	5.54	5.98	4.91	1.24
	Biomass kg ha^{-1}	11.99	12.86	13.20	13.94	13.0	0.81
Moshi	Grain yield ton ha^{-1}	5.37	4.43	5.00	5.11		
	Biomass kg ha^{-1}	17.77	14.40	17.32	18.33		
Mwanga	Grain yield ton ha^{-1}	3.95	3.59	5.05	4.32		
	Biomass kg ha^{-1}	13.35	14.51	15.96	16.31		
Mbulu	Grain yield ton ha^{-1}	3.88	6.44	6.09	5.65	5.52	1.14
	Biomass kg ha^{-1}	4.73	6.95	6.88	6.49	6.26	1.04
Babati	Grain yield ton ha^{-1}	3.73	6.60	7.70	6.76	6.20	1.72
	Biomass kg ha^{-1}	4.63	6.19	7.21	6.22	6.06	1.07
Hanang	Grain yield ton ha^{-1}	2.92	4.10	4.01	4.20		
	Biomass kg ha^{-1}	8.17	6.80	8.09	6.20		
Kiteto	Grain yield ton ha^{-1}	0.95	1.14	1.98	1.74	1.45	0.49
	Biomass kg ha^{-1}	5.40	6.30	6.47	4.46	5.41	0.05
Karatu	Grain yield ton ha^{-1}	4.76	7.67	7.85	8.10	7.09	1.57
	Biomass kg ha^{-1}	5.56	6.24	6.24	6.95	6.25	0.57
Monduli	Grain yield ton ha^{-1}	2.70	1.19	2.77	2.65	2.33	0.72
	Biomass kg ha^{-1}	5.56	3.46	5.56	5.01	4.90	0.99
Arumeru	Grain yield ton ha^{-1}	4.28	4.64	4.57	4.33	4.45	0.18
	Biomass kg ha^{-1}	7.68	7.36	8.20	7.85	7.70	1.65

non-responsive) have often been used to simplify the complex yield response patterns that are characteristic of smallholder farms in SSA (Zingore *et al*., 2011; Tittonell *et al*., 2010). In general N-rates were similar reflecting the low N status of most soils. Phosphorus and K rates did vary across the districts and between recommendations, with soil-test NE application recommending higher rates of P and K in Tanzania refers to fertilizer rates and their ranges ; RE-NPK (100-20-0), NE-standard NPK (100-20-0), Soil Test ST- NPK (102-50-46). The grain yields were not significant with the other three recommendations ranged between 1.78 and 7.9 ton/ha. The soil-test based NE marginally gave the best yields. Agronomic efficiencies were also improved. The advantage of NE, compared to the Regional recommendation, is that it recommends less P and K, and this reduces input costs by up to $80/ha. The farmers recognize this and the feedback is usually positive.

Conclusion

The performance trials assisted to provide information relevant for yield gap data and maize production strategies, identified also possible solutions to improve crop productivity. A high degree of variability in crop response to nutrients were observed in maize growing areas in Northern Zone (NZ), Tanzania. The findings were associated with variability in site characteristics including soils within and between sites. In line with this, there is need to develop fertilizer formulations that address site-specific limiting nutrients. Research is needed to further establish crop response patterns and underlying characteristics, and to define the extent of micronutrient elements limitation to crops in Tanzania and Africa at large. The study also recommend that it is better to apply the amount of fertilizers based on site specific requirements and the historical background per plot to avoid over or under dosing of the plant. Therefore the study suggest Nutrient Expert (NE) tool for site specific nutrient managements of maize smallholder farmers in northern Tanzania.

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