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Yield Response of Maize to Integrated Soil Fertility Management on Acidic Nitosol of Southwestern Ethiopia

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ABSTRACT

Poor crop productivity, high cost of inorganic fertilizers and low crop response to inorganic fertilizers are major problems that affect sustainability of crop production in Southwestern Ethiopia. Application of inorganic fertilizers at rates much below the recommendation, which is mainly due to the limited economic capacity of smallholder farmers, has become the underlying cause of poor crop productivity along with the worsening soil acidity condition in the region. Hence, the effect of integrated soil fertility management on the productivity of maize was investigated on acidic nitosols of the region as a cheaper and sustainable alternative to the sole application of inorganic fertilizers. Different proportions of inorganic fertilizers, compost and *Tithonia* biomass were therefore tested on-farm using RCB design. Grain yield of maize (kg ha^{-1}) was significantly affected by soil fertility management practices ($p<0.05$). Data collected in 2010 indicated that 50% recommended NP and 50% compost gave the highest grain yield of maize (4360 kg ha^{-1}) compared to the control which gave the lowest yield (1920 kg ha^{-1}). Similar yield response pattern was also observed in 2011. Integrated use of inorganic fertilizers and organic sources of plant nutrients has therefore, shown remarkable potential for efficient nutrient supply in maize based cropping systems on acidic nitosols of Southwestern Ethiopia. However, the potential role of various organic materials including *Tithonia* to ameliorate soil acidity or mitigate its effects on crop productivity need to be further investigated.

Key words: Compost, grain yield, nitosol, ISFM, maize, *Tithonia diversifolia*

INTRODUCTION

Maize (*Zea mays* L.) is an important cereal crop in South Western Ethiopia produced mainly by subsistent smallholders. Productivity of most crops including maize has declined in the region due to a number of factors among which poor socio-economic condition which is mainly related to the financial capacity of farmers to purchase the required amount of fertilizers appears to be the major one. As a result, most farmers do not apply the recommended rates of fertilizers needed for maximum productivity of the crops.

Most African farmers practice low-input agriculture that depends on organic matter in the soil to sustain production (Gruhn *et al*., 2000). In many parts of Africa including Ethiopia repeated cultivation of land with inappropriate farming methods is causing severe depletion of nutrients and soil organic matter posing a serious threat to agricultural productivity and sustainability. In East African Highlands (Ethiopia, Kenya, Malawi and Rwanda), the annual net losses of N and P were estimated to be 42 and 3 kg ha^{-1} $year^{-1}$, respectively from 1982-1984 (Stoorvogel *et al*., 1993). Early nutrient balance studies have therefore shown negative balance of nitrogen, phosphorus and potassium in most Sub-Saharan African countries (Stoorvogel *et al*., 1993; Hilhorst *et al*., 2000). Similarly, studies indicating annual nutrient losses equivalent to 7.9 t of NPK in Africa, six times the annual fertilizer consumption (Sanchez *et al*., 1997), strongly underscore the gravity of the problem. Soil fertility depletion in smallholder farms was also described as the fundamental biophysical factor responsible for the declining per-capita food production in Sub-Saharan Africa. This description exactly suits to the situation in Ethiopia where extra-ordinary measures are urgently required to curb the declining food production potential of the mainly cereal producing smallholder farming systems.

In general, soil fertility decline remains the single most important bio-physical factor constraining food security in Africa (Sanchez *et al*., 1997). It is also important to note that even in low-productivity situations, the quantity of nutrients available for recycling via plant and animal residues is rarely sufficient to compensate for the amounts removed in agricultural products. Thus, mineral fertilizers have to play a key role in areas with low fertility soils where increased agricultural production is required. Mineral nutrients generally remain to be vital in enhancing crop production and maintaining soil productivity. Although it is well recognized that application of mineral fertilizers plays an important role in intensification of crop production, lack of affordable and adequate supplies of fertilizers in many parts of the tropics and subtropics remains the major constraint to crop production.

The use of organic resources has also been suggested as the most feasible option for addressing the soil fertility crisis in Sub-Saharan Africa (Amoding *et al*., 2011). Integrated use of organic residues and mineral fertilizers reduced the cost of mineral fertilizer need by 25% (Bokhtiar and Sakurai, 2005) and by up to 50% (Kiani *et al*., 2005). Management methods that reduce the use of agricultural chemicals are also needed to avoid adverse environment impacts (Bilalis *et al*., 2009). It is therefore important to investigate cropping and nutrient management systems to optimise the use of all nutrient sources including fertilizers, organic manures, soil reserves and biological nitrogen fixation for the maintenance of soil fertility and crop productivity.

The positive impact of integrated plant nutrient management on crop productivity appears to be well established. However, effectiveness of various organic materials in supplying nutrients is highly variable and the amount needed to supply the required level of nutrients varies significantly across locations and depending on the type of organic resource used. Application of organic manure alone to sustain cropping has been reported to be inadequate due to their relatively low nutrient contents and their inability to provide a sufficient amount of nutrients (Palm *et al*., 1997). Integrated nutrient management approaches in which both organic manure and inorganic fertilizers are used, have therefore been suggested as an efficient approach for crop production (Palm *et al*., 1997).

The main aim of integrated plant nutrient management is to increase and sustain soil fertility to provide a sound basis for flexible food production systems that, within the constraints of soil and climate, can grow a wide range of crops to meet changing needs.

It is believed that the recovery fraction of nutrients from applied fertilizers is very low in Ethiopia where only a small proportion of the applied fertilizer is recovered in plants. As a result, the value to cost ratio of fertilizers is also insufficient and farmers become less motivated to invest in soil fertility. Integrated plant nutrient management may be helpful to farmers in several ways, inter alia, improving nutrient use efficiency and lessening the huge financial burden from fertilizers.

Several studies have shown that grain yield and nutrient use efficiency was better under integrated nutrient management than that expected from mere additive effects of sole applications (Amoah *et al*., 2012; Buresh *et al*., 1997). In this regard, research on the determination of optimum combination of inorganic and organic N sources in Eastern and Southern Africa have shown an optimum combination ratio of 50% organic (e.g., *Tithonia* and *Sesbania*) and 50% mineral N sources (e.g., urea) (Palm *et al*., 1997). Similar cases of increased and sustained crop yields were reported from trials involving integration of mineral fertilizers and *Tithonia* (Nandwa and Bekunda, 1998; Jama *et al*., 1997). *Tithonia* biomass contains relatively high levels of nitrogen, phosphorus and potassium compared to other locally available organic sources of plant nutrients (Palm *et al*., 1997).

It was therefore, found essential to evaluate and demonstrate integrated nutrient management technology on acidic nitosol of Southwestern Ethiopia using locally available and under-utilized organic resources and inorganic commercial fertilizers. Therefore, this study presents data from a participatory on-farm trial that was set up to test the suitability and performance of organic resources (e.g., compost and green biomass of *Tithonia*) for use in integrated nutrient management on acidic nitosol of Southwestern Ethiopia.

MATERIALS AND METHODS

Study area: The study was carried out for two consecutive years from 2010-2011 on three locations near the town of Asendabo (longitude: 37.23", latitude: 7.73" and altitude: 1870 m) in Omo-Nada district (Fig. 1) of Jimma zone, South Western Ethiopia. The soil type of the area is generally nitosol with slight acidity and medium fertility. Data on long-term average values of rain fall (mm) and temperature (°C) (Table 1) is obtained using the software New_LocClim (FAO., 2005). The crop growing period of the area is from March to mid October. Depending on the onset of rain fall in the area maize is sown from mid April to May.

Soil samples were collected in both years initially and analyzed for chemical properties to select appropriate sites for the experiment (Table 2 and 3). Soil samples were air-dried and ground to pass through a 2 mm sieve before analysis. Soil analysis was carried out as outlined in Van Reeuwijk (2002).

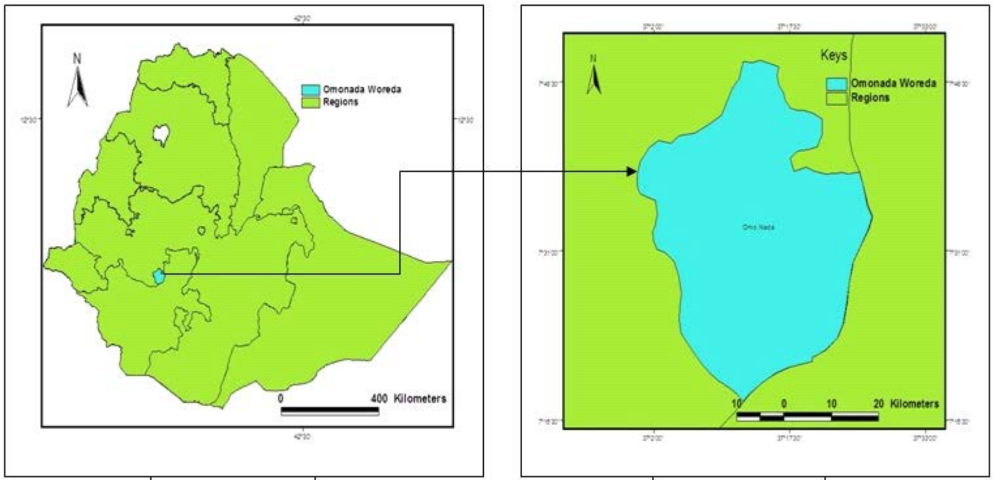

Fig. 1: Map showing the study area

Table 1: Long-term average agro-climatic data for the area (source: LocClim (Local climate estimator, FAO., 2005))

Parameters	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul	Aug.	Sep.	Oct.	Nov.	Dec.
Mean temperature (°C)	18.7	19.87	20.67	20.53	20.03	18.93	18.4	18.13	18.03	18.43	18.17	18.03
Maximum temperature (°C)	28.73	29.33	29.5	29.1	28.17	26.33	24.70	24.8	25.47	26.2	27.53	27.87
Minimum temperature (°C)	8.87	10.73	12.13	13.17	13.27	13.13	13.13	13.17	12.50	10.97	9.03	8.33
RF (mm)	26.67	41.00	96.33	111.00	142.0	204.0	226.0	214.33	174.33	78.33	45.67	26.00
PET (mm)	107.3	103.63	133.3	121.87	115.3	98.13	88.03	91.3	96.93	111.53	100.7	100.87

RF: Rain fall

Table 2: Initial soil chemical properties (2010)

	Experimental sites		
Soil chemical properties	Burka	Wenji	Waktola
Organic carbon (%)	1.98	2.18	2.45
Nitrogen (%)	0.13	0.16	0.15
Available phosphorus (ppm)	5.78	4.96	5.00
pH	4.73	4.55	4.60

Table 3: Initial soil chemical characteristics (2011)

	Experimental sites		
Soil chemical properties	Burka	Wenji	Waktola
Organic carbon (%)	2.11	1.90	2.24
Nitrogen (%)	0.15	0.16	0.15
Available phosphorus (ppm)	4.19	7.48	5.50
pH	5.16	4.69	5.17
K (meq/100 g soil)	1.04	0.85	0.94

The pH of the soils (pH H_2O) was potentiometrically measured in the supernatant suspension of a 1:2.5 soil: water mixture. Soil organic carbon content was determined by the wet combustion procedure of Walkley and Black as outlined in Van Reeuwijk (2002). Total nitrogen content of the soil was determined by wet-oxidation procedure of the Kjeldahl method (Bremner and Mulvaney, 1982). Available phosphorus content of the soil samples was determined by the Bray (No. 2) procedure (Bray and Kurtz, 1945).

Several cereal crops are cultivated in the area including maize which is the major staple mainly grown with mineral fertilization and sometimes with compost when grown at backyards.

Experimental procedures: The treatments investigated were 50% recommended NP+50% Compost (T1), 100% recommended NP (T2), 50% recommended NP+50% *Tithonia* biomass (T3) and control (T4). The recommended rates of nitrogen and phosphorus are 92 kg ha^{-1} N and 20.1 kg ha^{-1} P (46 kg ha^{-1} P_2O_5), respectively. The rate of compost was determined based on its mineral fertilizer equivalence.

Hybrid maize (variety: BH 660) was used as the test crop. Sowing was done during the first week of May 2010 and 2011 by placing two seeds per hill in rows at spacing of 0.5 and 0.8 m within row and between rows respectively. Compost and *Tithonia* were applied three weeks before sowing while the inorganic phosphorus fertilizer and half of the nitrogen fertilizer were applied at the time of sowing. The remaining half of the nitrogen fertilizer was applied at knee-height stage. In all cases, farmers (owners of the respective experimental farms) were involved throughout the trial period. Land preparation, sowing, treatment application, weeding and all other practices were accomplished by the farmers themselves with some technical supervision and help when necessary.

Finally, data on grain yield was collected and subjected to ANOVA using GenStat Discovery Edition 4 (VSN International, 2011) and means were separated using $LSD_{0.05}$ tests to determine significant differences.

RESULTS

Grain yield: Mean grain yield of maize was significantly affected ($p<0.05$) by soil fertility management both in the year 2010 and 2011. The first year's data indicated that the highest grain yield at Burka was in response to the full dose of recommended mineral NP fertilizers followed by Integrated Soil Fertility Management (ISFM) treatment (50% recommended NP+50% compost) resulting in grain yield of 4772.8 and 4643.7 kg ha^{-1} $year^{-1}$, respectively (Table 4). At Wenji and Waktola the highest records of grain yield were 4684.3 and 3936.8 kg ha^{-1} $year^{-1}$ from the application of 50% recommended NP+50% *Tithonia* biomass and 50% recommended NP+50% compost respectively (Table 4).

The results generally indicated superior performance ISFM treatments to the sole application of recommended inorganic NP fertilizers in two of the three locations and in one location the recommended NP fertilizer treatment resulted in the highest yield followed by the application of 50% recommended NP+50% recommended compost. Combined application of 50% recommended NP with 50% compost gave 5% higher yield than the sole application of inorganic NP fertilizers. In addition, application of 50% *Tithonia* biomass in combination with 50% recommended NP gave the same yield as the application of the full dose of the recommended nitrogen and phosphorous fertilizers for the area.

The yield advantage of ISFM treatments over the recommended inorganic NP and the control ranged from 3-22 and 72-154%, respectively. The data recorded in the second year was also similar to that of the previous year. Hence, there was a significant ($p<0.05$) maize yield difference in response to the treatments tested across the different locations of the trial.

At Burka, the highest grain yield was obtained from the application of 100% recommended NP followed by 50% recommended NP+50% *Tithonia* biomass and 50% recommended NP+50% compost corresponding to 4852, 4725 and 4010 kg ha^{-1} $year^{-1}$, respectively (Table 5).

The study has successfully demonstrated that integrated soil fertility management practices gave similar amount of grain yield to that of the full NP recommendation on acidic nitosols of the region. The very high biomass yield of *Tithonia* on acidic nitosols of the region and the high contents of N and P in its foliage and suitability to easily supply or recycle the nutrients as green manure for maize indicated great potential as a component of integrated soil fertility management. Resource poor farmers can therefore benefit from this practice if they are able to follow the recommendations properly. It was also interesting that similar results from the use of either on-farm prepared compost or fresh biomass of *Tithonia* in combination with mineral fertilizers which gives farmers the flexibility to choose from what is easily available in their surroundings. In general, the effect of soil fertility management on yield response of hybrid maize was highly significant and consistent across the trial sites in the region (Table 4 and 5).

Soil chemical properties: None of the soil chemical parameters have shown significant differences at 5% probability (Table 6 and 7). Since, the treatments were applied on different plots each year and the trial was conducted only for two years which was not enough to bring about noticeable change in soil chemical properties might be the reason for the lack of statistical significance among the treatments.

Table 4: Effect of soil fertility management on grain yield of maize (2010)

	Yield (kg ha^{-1} $year^{-1}$)		
Treatments	Site 1 (Burka)	Site 2 (Wenji)	Site 3 (Waktola)
50% recommended NP+50% compost	4643.7	4504.8	3936.8
Recommended NP	4772.8	4471.1	3239.4
50% *Tithonia* biomass +50% recommended NP	3683.0	4684.3	3281.9
Control	1640.1	1843.5	2294.9
CV (%)	16.60	15.46	14.12
$LSD_{0.05}$	1852	1814	899.6

CV: Coefficient of variation, LSD: Least significant difference

Table 5: Effect of soil fertility management on grain yield of maize (2011)

	Yield (kg ha^{-1} $year^{-1}$)		
Treatments	Site 1 (Burka)	Site 2 (Wenji)	Site 3 (Waktola)
50% recommended NP+50% Compost	4010	3622	3836
Recommended NP	4852	4512	4267
50% *Tithonia* biomass +50% recommended NP	4725	4149	3464
Control	1541	1744	1127
CV (%)	14.01	15.8	18.59
$LSD_{0.05}$	1058	1108	1178

CV: Coefficient of variation, LSD: Least significant difference

Table 6: Effect of integrated nutrient management on soil chemical properties (2010)

	Soil properties			
Treatments	pH	N (%)	P (ppm)	OC (%)
50% recommended NP+50% Compost	4.7	0.11	6.17	2.10
Recommended NP	4.8	0.11	6.17	2.02
50% *Tithonia* biomass +50% recommended NP	4.9	0.12	5.78	2.23
Control	5.0	0.13	6.18	2.07

Table 7: Effect of integrated nutrient management on soil chemical properties (2011)

	Soil properties			
Treatments	pH	N (%)	P (ppm)	OC (%)
50% recommended NP+50% Compost	4.9	0.14	6.28	2.33
Recommended NP	5.0	0.12	7.11	2.13
50% *Tithonia* biomass +50% recommended NP	5.1	0.13	6.20	2.14
Control	5.0	0.14	5.78	2.10

DISCUSSION

Optimization of nutrient inputs and production costs is among the best options in creating sustainable and improved crop production system for the subsistent smallholder producer using adaptable and cheap soil fertility and plant nutrient management practices. The use of compost and fresh biomass of plants such as *Tithonia* complemented with inorganic fertilizers serves such strategic goals. Most farmers in the study area have limited financial resources to afford commercial inorganic fertilizers for the production of food crops like maize, which normally does not fetch much financial return in the local markets. Hence, reducing the cost of production without compromising much on the final yield would undoubtedly be a highly suitable and reasonable approach to promote a sustainable and feasible crop production system in the region.

Though, the total yield recorded during the study was not high which might be due to the low soil pH (4.2-5.2) of the study area (Table 2 and 3), the yield response was consistent throughout the study period. The integration of *Tithonia* biomass and mineral fertilizer resulted in higher maize grain yield than the recommended rate of mineral fertilizer in the year 2011. This could be as a result of the provision of additional benefits (besides N and P) by the *Tithonia* biomass (organic source). The content of N, P and K in the biomass of *Tithonia* is relatively high (Palm *et al*., 1997), which makes it among the best options as a source of plant nutrients for use in biomass transfer.

Gicheru (2012) reported similar results from Kenya where different treatments tested in long-term trials significantly increased average maize yields compared to the control, but there were no significant differences between various treatments such as inorganic fertilizer rates and manure and also between the integrated nutrient sources at different rates. In addition, productivity of maize from combined organic and inorganic treatments was reportedly at par with the sole inorganic fertilizer treated plots indicating the potential of organic manures to supply nutrients to substitute for those of inorganic fertilizers for crop productivity (Amoah *et al*., 2012). Integration of inorganic and organic nutrient inputs can be considered as a better option in increasing fertilizer use efficiency and providing a more balanced supply of nutrients (Janssen, 1993). The use of combined organic/inorganic soil amendments produced similar maize grain yields to those obtained where inorganic sources are used alone (Gitari and Friesen, 2001). In addition, organic matter commonly improves the use efficiency of fertilizer (Vanlauwe *et al*., 2001).

Integrated soil fertility management recognizes the absolute necessity of mineral fertilizer use, but aims at maximizing the agronomic efficiency of moderate quantities of fertilizer (Vanlauwe *et al*., 2010) as it is an expensive commodity for most farmers. Therefore, the assumption that integrated nutrient management practices result in improved maize grain yield has been successfully demonstrated under the smallholder maize production in Southwestern Ethiopia. In general, there is a vast array of literature from different countries and regions supporting our findings (Amoah *et al*., 2012; Gicheru, 2012; Gachengo *et al*., 1999; Buresh *et al*., 1997; Janssen, 1993).

Soil chemical analysis at the end of each experiment did not show significant differences (Table 6 and 7). Since, the experiment was not stationary where treatments are applied on the same plots each year and the fact that the whole experiment lasted only two years which is not enough to bring about noticeable changes in soil chemical properties might be the reason for the lack of statistical significance among the treatments.

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