YIELD PERFORMANCE AND ECONOMIC RETURN OF MAIZE AS AFFECTED BY NUTRIENT MANAGEMENT STRATEGIES ON FERRALSOLS IN COASTAL WESTERN AFRICA

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Abstract

We assessed maize (*Zea mays* L.) grain yield and associated economic returns of four soil fertility management strategies in a 2-yr study (four growing seasons). The Ikenne maize cultivar was used and the fertilization treatments included: no fertilizer application (control, T1), application of farmyard manure (FYM) at the rate of 6 Mg ha^{-1} (T2), the agricultural services recommended maize-based fertilization consisting of 200 kg $N_{15}P_{15}K_{15}$ plus 100 kg urea (46% N) ha^{-1} (T3) and application of 3 Mg of FYM plus 100 kg $N_{15}P_{15}K_{15}$ plus 50 kg urea (46% N) ha^{-1} (T4). On the 2-yr period basis, four-season cumulative grain yields under T4, T3 and T2 were 40, 25 and 22% higher as compared with T1, respectively, those under T4 and T3 were 15 and 3% higher as compared with T2, respectively, while the yield under T4 was 12% higher than that under T3. For the 2-yr period, on a per hectare basis, economic profits under T4, T3 and T2 were 69 and 31% higher and 10% lower as compared with T1, respectively, profits under T4 and T3 were 87 and 46% higher as compared with T2, respectively, while profit under T4 was 28% higher than that under T3. In the current context of degraded soils in coastal western Africa, T4 reflecting a combined application of mineral fertilizer at the rate of $N_{38}P_{15}K_{15}$ ha^{-1} plus organic amendment as FYM at the rate of 3 Mg ha^{-1} should be advised towards sustaining enhanced maize crop productivity and profitability.

Keywords: Maize, mineral fertilizer, organic fertilizer, grain yield, profitability

Introduction

In Sub-Saharan Africa (SSA) and particularly in the coastal western Africa, agriculture remains the principal source of revenue, food and energy for the majority of the population. For few decades, the agricultural sector has been faced with challenges primarily including the fact that it has to meet food requirements for a continuously growing population under unfavorable conditions of land resources. In the region, food production should increase by 70% by 2050 to meet the necessary caloric requirements (Liniger et al., 2011). However, producing enough food, in a sustainable manner to meet the needs of the increasing global population is one of the greatest challenges we face (Burns et al., 2010). The ability to achieve this goal is compounded by the decrease in arable land through environmental degradation and urban encroachment (Baulcombe et al., 2009; Challinor et al., 2007), increased cost and potential shortages of fertilizers (Baulcombe et al., 2009; Cordell et al., 2009) and climate change. Efforts towards improving agricultural productions to enhancing food security in the region should therefore address major constraints with focus on reversing nutrient depletion from soils, mitigating the effect of drought spells and erosion, increasing nutrient and water use efficiency and adaptation of improved crop cultivars. These constraints contribute to the fact that SSA is the only continent that has grown poorer in the past 35 years (IFPRI, 2002) and may be expected to remain primary concerns during the coming decades with increasingly negative consequences, unless technological, economical and socio-political measures are taken to curtail further soil degradation and to accelerate agricultural growth. It is well established that soil fertility depletion in smallholder farms is the fundamental biophysical cause for declining per capita food production in SSA (IFDC, 2013; Bationo et al., 2012). There is ample evidence that the most significant biophysical constraint to increased production of both crops and livestock in SSA is the poor mineral and organic content of the soils. This constraint leads to inadequate availability of metabolizable energy, protein and phosphorus for livestock production and not enough nitrogen, phosphorus and organic matter for crop production (IFDC, 2009). Hence, there is no way out of the poverty cycle for farmers in the region unless strong emphasis is placed on reversing nutrient depletion and increasing nutrient and water use efficiency for each particular farming system.

Presumably because maize is one of the main staple foods crop in coastal Western Africa, its production has received tremendous supports since the early 1970', primarily through heavy subsidies on mineral fertilizers which have facilitated their access and affordability by resource-poor farmers. Atchou (1988) and MAEP (2013) reported subsidies by national governments and the international community ranging from 50 to

84% of fertilizers' real prices to foster maize production. Furthermore, NGOs and national agricultural services in the region along with international agriculture-related organizations have successfully undertaken consolidated efforts to enhance the technical capacity of smallholder farmers in the production and the use of organic inputs (composts, FYM etc,...) to improve their productions.

The use of low external input sustainable agriculture (LEISA), promoted by many donors and NGOs, presumes that organic resources are efficient in sustaining production and the natural resource base. Studies in West Africa (Detchinli and Sogbedji, 2014; Detchinli, 2013; IFDC, 2013; SARI, 2005) reported that cropping systems involving legumes cover cropping or short duration planted tree fallow as a means of organic matter input improved soil fertility and maize yields. Such cropping systems however result in a land use based competition between the cereal and legume crops leading in some cases to a complete loss of the cereal cropping season. Achieng et al. (2010) indicated that due to the fact that smallholder farmers are not likely to afford large amount of fertilizer and liming, use of FYM is their best bet for maize production as there is no significant yield advantage from N, NP or NPK over FYM. They concluded that in view of un-affordability of fertilizer due to escalating prices, more smallholder farmers in SSA are anticipated to turn to the use of organic sources that are not only available but also affordable, rather than inorganic fertilizers for enhancing crop productivity. Controversially, other studies (Place et al., 2003; Sanchez and Jawa, 2002) found that questions remain about the potential of the organic matter technology alone to sustain high maize yields. Several other studies (Azam et al., 2010; IFDC, 2013; Adjei-Nsiah et al., 2007) concluded that the integrated soil fertility management (ISFM), consisting of applying judicious combinations of mineral and organic fertilizers, together with methods to conserve organic matter may be the most promising strategies for improving soil fertility and sustaining maize yields.

In addition to the controversial debate on nutrient management for maize production in coastal Western Africa, seasonal variation in the rainfall is an issue of increasing concern. Indeed, Amouzou et al. (2013) demonstrated the evidence of climate change and variability leading to a significant reduction of the second growing season rainfall as compared to that of the first season in the region. Other studies (Laba and Sogbedji, 2015; Poss et al., 1988; Sogbedji et al., 2006) reported 40 to 60% maize grain yield decrease in the second season as compared with yield in the first season primarily as a result of lower rainfalls in the second season; they advised cautions in the use of inputs particularly fertilizers for maize cropping in the second season. Overall, under the current conditions of increased food needs, controversial debate on crop nutrient management and seasonal rainfall variation in coastal Western Africa, quantitative research efforts are needed to identify and recommend technically, socially, economically and environmentally justified fertilization practices for staple crops like maize.

The overall objective of this study was to promote improved and sustainable maize production through appropriate soil fertilization approaches. Specifically, the study quantitatively evaluated maize grain yield performance and associated economic returns under fertilization practices including the use of inorganic and organic nutrient sources and their combinations. The aim was to identify soil and crop management practices that fit the current context of degraded lands and climate change towards improving and sustaining maize crop productivity and profitability.

Materials And Methods

Experimental Site

The study was conducted at the University of Lomé Research Station near Lomé, Togo (6°22'N, 1°13'E; altitude = 50 m). The soil type was a rhodic Ferralsol locally called "Terres de Barre" that developed from a continental deposit (Saragoni et al., 1991). This soil type covers part of the arable lands in Togo, Bénin, Ghana, and Nigeria (Raunet, 1973) and is commonly used for maize production in coastal Western Africa. It is a well-drained soil, very low in organic matter (< 10 g kg-1) and K (< 0.2 meq 100g-1), and has total P contents ranging from 250 to 300 mg kg-1, cation exchange capacity of 3 to 4 ceq kg-1, and pH of 5.2 to 6.8 (Raunet, 1973; Tossah, 2000). Sand content is approximately 80% at the 0 to 0.20 m depth, and decreases to less than 60% at the 0.50 to 1.20 m depth (Lamouroux, 1969). The experimental site has a slope of less than 1%. The site is located in the guinea savanna agro ecological zone. The climate of the region has a tropical regime and the rainfall has a bi-modal distribution which allows for two maize growing seasons, one from April to July and another from September to December with annual precipitation typically ranging from 800 to 1100 mm. Prior to this study, the experimental site was under a 1-yr grass fallow.

At the onset of the experiment (at maize planting in April), initial soil properties including total C and N contents, exchangeable bases (Ca^{++}, Mg^{++}, Na^{+} and K^{+}), pH, total cation exchange capacity (CEC) and particle size distribution were measured for the first 20 cm soil layer (0-20 cm depth) on the experiment site from twenty four composite soil samples using the standard methods of the International Institute for Tropical Agriculture (IITA, 2014). The soil of the experimental site was moderately acidic with a pH of 6.70 and very low total C and N contents of 0.73 and 0.06%, respectively (Table 1). The soil texture results showed that the soil was sandy, with a total sand content of 80% for the top 20 cm soil profile, indicating that the site was a well-drained soil with low and fairly low P and K contents of 12.60 and 74.20 mg kg^{-1}, respectively. The CEC was low (2.90 cmol kg^{-1}) with exchangeable bases Ca^{++}, Mg^{+}, Na^{+} and K^{+} of 28.80, 8.20, 6.90 and 4.23 cmol kg^{-1}, respectively (Table 1). Overall, the soil properties indicated that the experimental site was low in inherent fertility as demonstrated earlier by Tossah (2000), and, therefore, will require additional fertilizer for optimum maize grain yield. It was thus expected that maize crop would respond to fertilizer application on the site.

Table 1: Soil properties at the onset of the experiment

Parameter	Value
pH (H_2O)	6.70
Total C (%)	0.73
Total N (%)	0.06
NO_3-N (mg kg^{-1})	2.30
Labile P (mg kg^{-1})	12. 60
Available K (mg kg^{-1})	74.20
Exchangeable bases (cmol kg^{-1})	
Ca++	28.80
Mg++	8.20
Na+	6.90
K+	4.23
Total CEC (cmol kg^{-1})	2.90
Sand content (%)	80.0
Silt content (%)	7.0
Clay content (%)	13.0

Soil and Crop Management

A 2-yr period (2014-2015) with four growing seasons experiment was established with four fertilizer levels and three replicates. The site was manually plowed and 12 plots (4 m x 3 m) were laid out in a completely randomized design. Four fertilizer treatments were applied: (i) no fertilizer application corresponding to N0P0K0 as the control (T1), (ii) application of FYM at the rate of 6 Mg ha-1 (T2), (iii) application of 200 kg of N15P15K15 + 100 kg of urea (46% N) corresponding to N76P30K30 ha-1 (T3), and (iv) application of 100 kg of N15P15K15 + 50 kg of urea (46% N) + 3 Mg ha-1 of FYM) corresponding to N38P15K15 + 3 Mg of FYM ha-1 (T4). Treatment T2 is a recommended FYM-based organic amendment by IFDC (2013) and T3 is a recommendation by the national agricultural extension services in Togo. The chemical composition of the FYM used for the experiment is presented in Table 2. The four treatments are presented in Table 3 in terms of nutrient form applied and corresponding quantity of N. Fertilizer N15P15K15 and FYM rates were applied two weeks after maize planting (just after the first weeding) while urea was applied five weeks after planting as recommended by the national agricultural research and extension services in the region. In each growing season of each of the two years, all fertilizers were manually point-placed at approximately 8 cm depth. Maize

(Ikenne, the most commonly used improved variety) was planted in April and harvested in July during the first growing season, and was planted in September and harvested in December during the second season at a density of 50,000 plants ha-1. The crop was manually weeded three times during each growing season.

Table 2: Chemical composition of the FYM used for the experiment

Parameter	Value
pH (H_2O)	7.20
Total C (%)	9.33
Total N (%)	0.76
Exchangeable bases (cmol kg^{-1})	
Ca^{++}	294.13
Mg^{++}	79.62
Na^{+}	25.50
K^{+}	15.75
Total CEC (cmol kg^{-1})	18.57

Table 3: Fertilizer treatments in terms of nutrient form applied (kg ha^{-1}) and corresponding quantity of N (kg ha^{-1})

Treatment	N Form			N quantity
	FYM	N15P15K15	Urea (46% N)	
T1	0	0	0	0
T2	6000	0	0	45.6
T3	0	200	100	76
T4	3000	100	50	60.8

Data Collection

Maize grain yield was determined under each treatment from four 3-m long rows of maize from the center of each plot that were harvested and adjusted to 14% moisture content for the two growing seasons in 2014 and the first season in 2015. Maize grain yield data for the second growing season in 2015 were simulated with a regression model developed on the basis of a 20-yr period (1995-2014) of historical field-measured yield data (Sogbedji, personal communication). The GENSTAT statistical software package was used to run the analysis of variance (ANOVA) on the yield data sets and the Duncan test at 5% was used to discriminate among mean maize grain yields.

Economic Analysis

The profitability of maize grain production in the 2-yr period (four growing seasons) from each of the four fertilization schemes was estimated through a partial budget analysis. Output consisted of the amount of cash corresponding to the cumulative maize grain produced in the four seasons, which was assumed to be sold at 160 F CFA (US$0.32) kg^{-1}, the average sale price in the country. The inputs consisted of the production costs under each fertilization treatment, including those for soil preparation, seed, crop planting and related tasks, fertilizer purchase and application, crop weeding and crop harvesting and associated tasks. Labor costs were determined to be 2 000 F CFA (US$4.0) per person day, and fertilizer costs were based on current prices which were determined to be 220 F CFA kg^{-1} (US$0.44). Farmyard manure cost was determined to be 20 000 F CFA Mg^{-1} (US$40). Estimates for production labor under each fertilization treatment in a growing season are presented in Table 4, and are based on labor records from the experiment.

Results And Discussion

Maize Grain Production

Maize grain yield data are presented in Table 5. Maize grain yield was responsive to fertilization treatment during each growing season of the first year. Mean grain yield from all fertilization treatments ranged from 4.71 to 8.27 and 3.28 to 5.13 Mg ha^{-1} during the first and the second seasons, respectively (Table 5). In the first year, during the first growing season, yields under T4, T3 and T2 were 76, 48 and 35% higher as compared with T1, respectively, yields under T4 and T3 were 30 and 9% higher as compared with T2, respectively, while yield under T4 was 19% higher than that under T3. During the second growing season, yields under T4, T3 and

Table 4: Estimated labor associated with a season of maize crop under each fertilization strategy

	T1	T2	T3	T4
	person day ha^{-1}			
Soil preparation	30	30	30	30
Planting and related tasks	35	35	35	35
Weeding	90	90	90	90
Fertilizer application	0	10	20	30
Harvesting and related tasks	70	70	70	70
Total labor	225	235	245	255
Total labor cost¶ (F CFA§)	**450 000 (US$900)**	**470 000 (US$940)**	**490 000 (US$980)**	**510 000 (US$1020)**

¶ Total cash based on the cost of 2000 F CFA per person-day.
§ On average 1US$ = 500 F CFA.

Table 5: Mean maize grain yields (Mg ha^{-1}) for each growing season, year and the 2-yr period

Treatment	Year 1			Year 2			Total
	GS^{T}1	GS2	Total	GS1	GS2	Total	
T1	4.71a	3.28a	7.99a	4.93	3.39	8.32	16.31a
T2	6.38b	4.15b	10.53b	5.59	3.74	9.33	19.86b
T3	6.95b	4.45b	11.40b	5.37	3.63	9.00	20.40b
T4	8.27c	5.13c	13.40c	5.63	3.76	9.39	22.79c
Mean	**6.58**	**4.25**	**10.83**	**5.38**	**3.63**	**9.01**	**19.84**

T Growing season
Means within the same column not followed by letters or followed by the same letter are not significantly different at $\alpha = 0.05$.

T2 were 56, 36 and 27% higher as compared with T1, respectively, yields under T4 and T3 were 24 and 7% higher as compared with T2 respectively, while yield under T4 was 15% higher than that under T3. In the second year, the effects of fertilization treatment on maize yield were not significant. Grain yield from all fertilizer treatments ranged from 4.93 to 5.63 and 3.39 to 3.76 Mg ha^{-1} during the first and the second seasons, respectively. The lack of grain yield response to fertilization treatment in the second year as compared with the first year, presumably resulted from lower rainfall (280 mm in the first season 2015) as compared with the first year (405 mm in the first season 2014) and the five-year average for the last twenty five years (1990-2014) in the region (Table 6). The lower rainfall might have hampered an effective use of the applied nutrients. In both the first and the second years, grain yields under the control treatment (no fertilizer application) appeared high given the low inherent fertility of the experimental site. Such high yields might be explained by the mineralization of the grass sod from the 1-yr grass fallow at the onset of the experiment and/or the inter-season grass sod.

On a 2-yr period basis, four-season cumulative grain yields under T4, T3 and T2 were 40, 25 and 22% higher as compared with T1, respectively, cumulative grain yields under T4 and T3 were 15 and 3% higher as compared with T2 respectively, while the cumulative grain yield under T4 was 12% higher than that under T3.

Maize grain yield data sets from this study indicated that T4 which reflected the integrated soil fertility management (ISFM) or the combined application of mineral and organic nutrient sources provided a better nutrient use by the crop. Such an improvement of nutrient use under T4 might have resulted not only from the mineralization of the added FYM but also from an enhancement of the crop use of applied mineral nutrients by the applied FYM. This led to improved yield as compared with the other fertilization treatments. The improving capacity of the ISFM technology was demonstrated by several other studies including those by Detchinli and Sogbedji (2014), IFDC (2013), Ngome et al. (2011) and Sogbedji et al. (2006). However, those research efforts did not explicitly indicate the quantity of each nutrient source to be combined because they involved short-duration improved fallows with cover crops like *Mucuna* sp. or rotation with food grain legumes like *Cajanus cajan* and *Arachis hypogea*. In the savanna region of northern Ghana, IFDC (2013) conducted a maize-based experiment typically similar to our study in terms of fertilization treatments T1, T2, T3 and T4: it reported that maize grain yield under T1 was 100%, 66% and 109% lower as compared with T2, T3 and T4, respectively, yield under T2 was 15% and 34% lower than those under T3 and T4, respectively, while yield under T3 was 16% lower than that under T4. The results of our study agreed reasonably well with those published by IFDC (2013). Achieng et al. (2010) used FYM plus 30 kg N ha^{-1} and found that the combination resulted in maize grain yields 108 to 103% higher as compared with mineral only fertilization treatments. Abebe et al. (2013) documented similar performance of the combination FMY-mineral fertilizer, and Azam et al. (2010) concluded that combination of 75% mineral N source and 25% organic N sources is the best combination for sustainable maize yield.

The maize grain yield data showed also a systematic yield depression in the second growing season of the year in comparison with the first growing season, ranging typically from 30 to 40% (Table 5). Across fertilization treatments, average yields during the second growing season were 35, 32 and 34% lower than that in the first growing season for the first year, the second year and the 2-yr period basis, respectively. The fertilization treatments were similarly affected by the yield depression in the second season. In the first year, the yield depression in the second growing season was 30, 35, 36 and 38% under T1, T2, T3 and T4, respectively, and 31, 33, 32 and 33% under T1, T2, T3 and T4, respectively, in the second year. On a 2yr-period basis, yield depression in the second growing season was 31, 34, 34 and 36 % under T1, T2, T3 and T4, respectively. Such a yield depression in the second growing season observed during the whole period of the study presumably resulted from lower rainfall in the season in comparison with rainfall in the first growing season (Table 6). Indeed, the five-year average rainfall data for the 1990 to 2014 period ranged from 402 to 535 and 124 to 182 mm for the first and the second seasons, respectively, indicating that the first season has 200 to 230% more rainfall than the second season. Previous studies (Poss et al., 1988; DRA, 1985) reported similar maize grain yield trends in the region. This suggests that maize cropping in the second growing season of the year may require cautions.

Table 6: Five-year average cropping season and annual rainfall (mm) for the period 1990 - 2014 and seasonal rainfall (mm) for the 2014 and 2015 years

	1990-1995	1996-2000	2001-2004	2005-2009	2010-2014	2014	2015
GS^T1	402	407	420	535	459	405	280
GS2	182	124	137	153	178	158	-
Annual	654	668	656	808	715	762	-

T Growing season

Partial Budget Analysis

Results of the balance of inputs (total costs associated with maize grain production under each fertilization treatment) and corresponding outputs (cash values of maize grain yield) for the four growing seasons are presented in Table 7. Because maize grain was assumed to be sold at the same price, the outputs' trend was the same as that of yields. On a 2-yr period basis, outputs under T4, T3 and T2 were 40, 25 and 22% higher than that for T1, respectively, outputs under T4 and T3 were 15 and 3% higher as compared with T2, respectively, while the output under T4 was 12% higher than that under T3.

Inputs associated with each treatment were identical for both the first and the second growing seasons. Inputs for T4, T3 and T2 were 33, 23 and 30% higher as compared with T1, respectively, inputs under T4 and T3 were 2% higher and 6% lower as compared with T2 respectively, while input under T4 was 8% higher than that under T3.

On a per hectare basis, the balance was positive in all cases, indicating that there was profit or net gain. For the 2-yr period, the balance was lowest under T1 (733 600 F CFA = US$1 467.2) and T2 (741 600 F CFA = US$1483.2), intermediate under T3 (964 000 F CFA = US$1 928) and highest under T4 (1 155 400 F CFA = US$2 310.8). In clear, for the 2-yr period, on a per hectare basis, the profits under T4, T3 and T2 were 57, 31 and 1% higher as compared with T1, respectively, profits under T4 and T3 were 56 and 30% higher as compared with T2, respectively, while profit under T4 was 20 % higher than that under T3. Fertilization treatment T2 resulted in similar profit in comparison with T1, indicating that the strategy of organic amendement alone was not economically advised.

Table 7: Partial budget analysis for each of the four fertilization treatments

	T1	T2	T3	T4
	____F CFA ha^{-1} ______			
Total Output	+2 609 600	3 177 600	3 264 000	3 646 400
Total Input	-1 876 000	2 436 000	2 300 000	2 488 000
Labor	(1 800 000)	(1 880 000)	(1 960 000)	(2 040 000)
Seeds	(76 000)	(76 000)	(76 000)	(76 000)
Fertilizer	(0)	(480 000)	(264 000)	(372 000)
Balance	**+733 600 (US$1467.2)**	**741 600 (US$1483.2)**	**964 000 (US$1928)**	**1 155 400 (US$2310.8)**

Conclusion

The current context of degraded lands in coastal Western Africa requires appropriate additions of nutrient to soil towards achieving the goal of sustainable maize productivity and profitability. The best bet soil fertility management in this regard is the integrated soil fertility management that implies a combined use of organic and inorganic nutrient sources. From this study, the combination of 3 Mg of FYM and 100 kg of $N_{15}P_{15}K_{15}$ plus 50 kg of urea (46% N) per ha appeared to be a very promising maize crop fertilization scheme from both productivity and economic perspectives. Organic amendement alone may not be a suitable soil fertility management strategy on a short term basis for maize cropping. Furthermore, investments in maize cropping during the second growing seaon of the year in the region should be limited.

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