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Land Degradation and Climate Change Resilient Soil and Crop Management Strategies for Maize Production in Coastal Western Africa

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Abstract: *A 2-yr (four cropping seasons) trial was conducted with nine maize (Zea mays L.) varieties and four fertilization treatments in three replicates to determine the appropriate variety-fertilization combinations. Fertilization treatments were: no fertilization (T1), 6 t ha^{-1} of farmyard manure (FYM) (T2), the national recommendation of 200 kg $N_{15}P_{15}K_{15}$ plus 100 kg urea (46% N) ha^{-1} (T3) and 3 t of FYM plus 100 kg $N_{15}P_{15}K_{15}$ plus 50 kg urea ha^{-1} (T4). Across fertilization treatments, 2-yr average grain yields were highest (6.41 to 6.76 t ha^{-1}) for Bassar, TZEE and Obatampa varieties and lowest (4.63 and 5.07 t ha^{-1}) for Wahala3 and Agoèbli in the first cropping season. TZEE, Dapaong, Obatampa and Bassar performed better (4.0 to 4.39 t ha^{-1}) during the second season. Across varieties, grain yields for T4, T3 and T2 increased by 92 to 58, 69 to 42 and 57 to 34% in comparison with T1, respectively, those under T4 and T3 were 22.6 to 18 and 8 to 6% higher than that for T2, respectively, and the yield for T4 was 11 to 13.5% superior over that for T3. Fertilization treatment T4 proved suitable for improved grain yield and five varieties were no more recommended for the second cropping season.*

Keywords: *climate change, fertilizer, maize, soil fertility, yield*

I. Introduction

One of the major challenges in Sub-Saharan Africa (SSA) is how to sustainably increase food production in order to meet the needs of the continuously growing population [1, 2]. Achieving this food security-based goal is further complicated by several factors the most important of which include increased cost and scarcity of fertilizers [3, 4] , the decrease in arable land as a result of land degradation and competing land use demands, and climate change. Concrete research-development efforts are therefore needed in the region to overcome these constraints through soil fertility restoration, maximization of nutrient and water use efficiency and identification of resilient crop varieties. Studies in SSA [5, 6] indicated that soil fertility degradation particularly in terms of poor mineral and organic content of the soils is the major cause of food shortages, decreased livestock productions and poverty. Thus, curtailing soil fertility decline should be emphasized if sustainably improved agricultural productions, food security and global social welfare are to be achieved in the region. Studies by [5] and [7] reported that organic matter based practices such us legume-cereal crops rotation and short duration improved fallows are key to soil fertility improvement and increased maize yields. Nevertheless, such cropping systems often have the drawback of taking cropping seasons away from the cereal crops. Smallholder farmers in SSA have been more inclined to using organic matter namely FYM toward restoring soil fertility than the use of synthetic fertilizers because of their unavailability and/or inaccessibility together with increasing costs [8]. On the other hand however research results [9, 10] showed that organic nutrient sources are not likely to alone sustain increased maize yields, and [11, 12] pointed out that combining mineral and organic nutrients is a promising practice for sustainable soil fertility management and improved crop yields.

In addition to the negative effects of land degradation on food security in SSA, it is further impacted by the phenomenon of climate change as demonstrated by [13] and [14]. The phenomenon has become an increasing worldwide concern and raised issues related to its mitigations and the need to develop new paradigms for sustainable development. Several studies [15, 3] clearly indicated that climate change and variability is a threat to global socio-economic development especially through its negative impact on the agricultural sector. Thus adaptation of agricultural production systems to climate change has become a new challenge to be addressed to secure a sustainable growth for the sector. Research results by [4] and [15] emphasized the need for such an adaption toward synchronizing food production and demand. Given the complexity of the overall agricultural production system, sustainable adaptation of the system to climate change may more likely be a myth if the scientific community keeps addressing separately issues related to the three major entities (soil, climate and crop) of the agricultural production system. Approaches for the adaptation to climate change in agriculture should simultaneously account for the various components of these three entities [1, 16, 17]. However, research studies with such approaches under maize crop in West Africa are very limited.

The objective of this study was to evaluate the performance of various crop variety-fertilization combination scenarios for maize grain yield. It aims at identifying resilient soil and crop management practices for sustainable improved maize production.

II. Materials And Methods

2.1. 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 and covers part of the arable lands in Togo, Bénin, Ghana, and Nigeria [18]. Annual precipitation at the site is between 800 and 1100 mm and provides two maize cropping seasons, one for the period April to July and another for the September to December period. The site has usually been used by farmers for unfertilized continuous maize cropping, but was under a 1-yr grass fallow prior to the experiment.

At maize planting in April in 2014, 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 [19]. 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). It 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).

Table I. 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

2.2. Crop and soil Management

A split-plot trial was conducted in three replicates for two years (2014 and 2015, four cropping seasons). Maize variety and fertilization were at the main plot and the subplot levels, respectively. Twenty seven main plots (10 x 7 m) and 108 subplots (4 x 3 m) were laid out in a spatially-balanced complete block design [20]. Spatially-balanced complete block (SBCB) designs are a model-based approach that guarantees that the experiment is insensitive to trends, spatial correlation, or periodicity in the research domain [21]. It aims to equalize variances among treatment contrasts and allows for conventional statistical analysis methods. Nine maize varieties were involved in the trial and include: Ikenne (V1), TZEE (V2), Wahala 3 (V3), Tchamba (V4), Bassar (V5), Agoèbli (V6), Dapaong (V7), Wahala2 (V8) and Obatampa (V9), with variable major traits (Table 2). Four subplots under each of the varieties were treated with four fertilization treatments: no fertilization (T1), FYM at a rate of 6 t ha^{-1} (T2), 200 kg $N_{15}P_{15}K_{15}$ and 100 urea at 46% N ha^{-1} (T3) and FYM at a rate of 3 t plus 100 kg of $N_{15}P_{15}K_{15}$ plus 50 kg urea at 46% N ha^{-1} (T4). Treatment T2 is a recommended FYM-based organic amendment by [22] and T3 is a recommendation by the national agricultural extension services in Togo. Table 3 shows the chemical composition of the FYM used for the trial. During each of the four growing seasons, fertilizer $N_{15}P_{15}K_{15}$ and FYM rates were manually point-placed two weeks after maize planting while N rates were manually point-placed as urea five weeks after planting at approximately 8 cm depth. In each year, maize 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}.

Table II. Major traits of each of the nine maize varieties involved in the study

Traits	Variety								
	Ikenne	TZEE	Wahala3	Tchamba	Bassar	Agoèbli	Dapaong	Wahala2	Obatampa
Height (cm)	204	220	260	290	250	205	235	215	230
Height of ear insertion (cm)	72	82	130	130	90	75	100	80	80
Growth cycle duration (day)	90	80	90	115	100	80	90	80	100

2.3. Data collection and analysis

For each cropping system scenario maize grain yield was measured from four 3-m long rows of maize from the center of each subplot that were harvested and adjusted to 14% moisture content. Maize grain yield data were analyzed using the general linear mixed model with rep and rep*variety as random, and fertilizer level and variety as fixed effects. Significant effects were followed by multiple comparisons adjusted with a Bonferoni correction. The MIXED procedure in [23] was used to execute the analysis.

Table III. 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

III. Results And Discussion

3.1. Yearly effects on maize grain yield

Maize grain yield data are compiled in Table 4. Across varieties and fertilization treatments in the first year, mean maize grain yield typically ranged from 4 to 8 and 3 to 5 t ha^{-1} in the first and the second growing season, respectively. In the second year, mean grain yields were between 3 to 6 and 2 to 4 t ha^{-1} during the first and the second cropping season respectively. The results showed yield depression of 25% and 20 to 33% in the first and the second growing season, respectively, in the second year in comparison to yield in the first year. Such a yield decrease in the second year (2015) primarily resulted from the fact that 2015 was a particularly dry year with 280 and 126 mm rainfall in the first and second cropping season, respectively versus 405 and 158 mm in the first and second cropping season, respectively in 2014 and an average of 438 and 155 mm in the first and second cropping season, respectively for the 1990 to 2014 period (Table 5). The most sensitive varieties to rainfall decrease were Tzee, Tchamba, Bassar, Dapong and Obatampa with yield depression in the dry year typically ranging from 24 to 38 and 20 to 33% in the first and second cropping season, respectively (Table 4). The results on the yearly variability in terms of rainfall and its effects on maize grain yield from this study corroborated research results in the region published by [24].

Table IV. Mean maize grain yields (t ha^{-1}) for each growing season, year and the 2-yr average

Treatment	**Variety**									
	V1	**V2**	**V3**	**V4**	**V5**	**V6**	**V7**	**V8**	**V9**	**Mean**
Year 1										
First growing season										
T1	4.17a¶	5.21a	3.41a	4.49a	5.41a	3.30a	4.52a	4.07a	4.78a	4.37a
T2	6.38b	8.31b	5.25b	5.59b	8.76b	4.82b	7.36b	7.23b	6.85b	6.73b
T3	6.95b	8.15b	6.16b	7.75c	8.45b	6.22c	7.72b	6.57b	9.19c	7.46bc
T4	8.27c	10.53c	6.26b	10.38d	10.82c	6.06c	8.34b	7.26b	8.71c	8.51c
Mean	**6.44**	**8.05**	**5.27**	**7.05**	**8.36**	**5.10**	**6.99**	**6.28**	**7.38**	**6.77**
Second growing season										
T1	3.28a	3.85a	2.72a	3.40a	3.98a	2.65a	3.42a	3.13a	3.58a	3.33a
T2	4.15b	5.15b	3.56b	3.74a	5.39b	3.34ab	4.66b	4.59b	4.39ab	4.33ab
T3	4.45b	5.07b	4.04b	4.60ab	5.22b	4.07b	4.85b	4.25b	5.61b	4.68b
T4	5.13b	6.30c	4.09b	6.23b	6.46c	3.98b	5.17b	4.61b	5.36b	5.26b
Mean	**4.25**	**5.09**	**3.60**	**4.49**	**5.26**	**3.51**	**4.53**	**4.15**	**4.74**	**4.40**

Year 2										
First growing season										
T1	3.26a	3.20a	3.21a	3.23a	3.29a	2.74a	3.40a	3.19a	3.66a	**3.24a**
T2	5.19b	5.31b	4.99b	5.38b	5.36b	4.35b	5.72b	5.11b	5.47b	**5.21b**
T3	5.75bc	5.53bc	5.19b	5.54bc	5.74bc	4.38b	5.76b	5.34b	5.72b	**5.44b**
T4	6.15c	6.04c	6.06c	6.09c	6.21c	5.18c	6.42c	6.01c	6.90c	**6.12c**
Mean	**5.09**	**5.02**	**4.86**	**5.06**	**5.15**	**4.16**	**5.32**	**4.91**	**5.44**	**5.00**
Second growing season										
T1	2.53a	2.50a	2.50a	2.51a	2.54a	2.26a	2.60a	2.49a	2.74a	**2.52a**
T2	3.53b	3.59b	3.28b	3.63b	3.62b	3.09b	3.81b	3.49b	3.67b	**3.52b**
T3	3.82b	3.71b	3.53b	3.71b	3.82b	3.11b	3.83b	3.61b	3.80b	**3.66b**
T4	4.03b	3.97b	3.98b	4.00b	4.06b	3.52b	4.17b	3.96b	4.42c	**4.01b**
Mean	**3.48**	**3.44**	**3.32**	**3.46**	**3.51**	**3.00**	**3.60**	**3.39**	**3.66**	**3.43**
2-yr average										
First growing season										
T1	3.72a	4.21a	3.31a	3.86a	4.35a	3.02a	3.96a	3.63a	4.22a	**3.81a**
T2	5.79b	6.81b	5.12b	5.49b	7.06b	4.59b	6.54b	6.17b	6.16b	**5.97b**
T3	6.35b	6.84b	5.68bc	6.65c	7.10b	5.30c	6.74bc	5.96b	7.46c	**6.45b**
T4	7.21c	8.29c	6.16c	8.24d	8.52c	5.62c	7.38c	6.64b	7.81c	**7.32c**
Mean	**5.77**	**6.54**	**5.07**	**6.06**	**6.76**	**4.63**	**6.16**	**5.60**	**6.41**	**5.89**
Second growing season										
T1	2.91a	3.18a	2.61a	2.96a	3.26a	2.46a	3.01a	2.81a	3.16a	**2.93a**
T2	3.84b	4.37b	3.42b	3.69b	4.51b	3.22b	4.24b	4.04b	4.03b	**3.93b**
T3	4.14b	4.39b	3.79b	4.16b	4.52b	3.59b	4.34b	3.93b	4.71b	**4.17b**
T4	4.58b	5.14c	4.04b	5.12c	5.26c	3.75b	4.67b	4.29b	4.89b	**4.64b**
Mean	**3.87**	**4.27**	**3.46**	**3.98**	**4.39**	**3.25**	**4.06**	**3.77**	**4.20**	**3.92**

¶ Means within the same column not followed by letters or followed by the same letter are not significantly different at $\alpha = 0.05$. The comparisons were adjusted by a Bonferoni correction for multiple comparisons.

Table V. Five-year average growing season and annual rainfall (mm) for the 1990 -2014 period and 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	126
Annual	654	668	656	808	715	762	406

T Growing season

3.2. Effects of variety on grain yield

On a 2-yr average basis and across fertilization treatments, mean maize grain yields ranged from 4.63 to 6.76 and 3.25 to 4.39 t ha^{-1} for the first and second growing seasons, respectively. Grain yields were highest (6.41 to 6.76 t ha^{-1}) for the TZEE, Bassar and Obatampa varieties, intermediate (5.6 to 6.16 t ha^{-1}) for Ikenne, Tchamba, Dapaong and Wahala2 and lowest (4.63 and 5.07 t ha^{-1}) for Wahala3 and Agoèbli during the first growing season (Table 4). In the second growing season, TZEE, Bassar, Dapaong and Obatampa varieties performed better (4.06 and 4.29 t ha^{-1}) as compared with the five other varieties (3.25 to 3.98 t ha^{-1}).

These results clearly showed a systematic superiority of maize grain yield during the first growing season over that in the second growing season with a yield depression of typically 30 to 35% during the latter season. The yield depression phenomenon differently affected the varieties, being lowest for the Agoèbli (Table 4). The lower performance of the varieties during the second cropping season as compared with the first growing season presumably resulted from lower rainfall in the second season (Table 5) that might have hampered an effective use of the applied nutrients. Indeed, the 5-year mean rainfall data for the 1990 to 2014 period ranged from 402 to 535 and 124 to 182 mm for the first and the second growing seasons, respectively, indicating that the first season has 200 to 224% more rainfall than the second season. These results on the dynamics of rainfall and their effects on maize grain yield in the two growing seasons reasonably agreed with [25]. The results indicated that in the current context of climate change and variability as demonstrated by [24], the use of all the varieties during the first growing season is appropriate. On the other hand and on the basis of grain yield values, only Ikenne, Wahala3, Agoèbli and Wahala2 varieties appear appropriate for the second growing season because they proved capable enough of mitigating the adverse effects of climate change and variability, in particular with regard to change in rainfall, with a greater chance of success for the Wahala3 and Agoèbli varieties.

3.3. Effects of fertilization treatment on maize grain yield

On a 2-yr average basis, the response of the nine varieties to fertilization treatment in terms of grain yield was positive during the two growing seasons with a more pronounced discrimination among treatments during the first growing season (Table 4). Across varieties and during the first growing season, mean maize grain yields were highest (7.32 t ha^{-1}) under treatment T4, intermediate (5.97 and 6.45 t ha^{-1}) under treatments T3 and T2 and lowest (3.81 t ha^{-1}) under treatment T1. Mean yields for treatments T4, T3 and T2 increased by 92, 69 and 57% as compared with T1, respectively, those under T4 and T3 were 23 and 8% higher than that for T2, respectively, and the yield under T4 was 13% higher than that for T3 (Table 4). During the second growing season and across varieties, the trend of the mean maize grain yield under the different fertilization treatments was statistically altered as compared with the trend observed in the first growing season. In the second season, mean grain yields were statistically similar under treatments T2, T3 and T4, but superior to that for treatment T1. However, yields for treatments T4, T3 and T2 increased by 58, 42 and 34% as compared with the yield under T1, respectively, those for T4 and T3 were 18 and 6% higher than that under T2, respectively, and the yield under treatment T4 was 11% superior over that for T3 (Table 4). Such an alteration of the mean grain yield data during the second cropping season presumably resulted from the low rainfall that might hampered an effective use of the applied nutrients. This general trend of the yield data demonstrate that the combined application of organic and inorganic nutrient sources in the proportion of 50% of the recommended full rate for each source led to a net improvement of grain yield in comparison to recommended full rates for each nutrient source.

3.4. Effects of variety-fertilization treatment interactions on maize grain yield

The magnitude of the trend of grain yields on a 2-yr average basis under the different individual variety-fertilization treatment combination varied, indicating that the variety-fertilization interactions effects were measurable during the two cropping seasons (Table 4).

For the Ikenne variety, mean grain yields under T4, T3 and T2 fertilization treatments increased by 94 to 57, 71 to 42 and 56 to 32 % as compared to yield under treatment T1, respectively, those for T4 and T3 were 25 to 19 and 10 to 8% higher than that under T2, respectively, and the yield under T4 was 14 to 11% superior over that for T3. With the TZEE variety, mean grain yields for T4, T3 and T2 fertilization treatments increased by 97 to 61, 62 to 38 and 62 to 37% as compared to yield under treatment T1, respectively, those for treatments T4 and T3 were 22 to 17 % higher and identical to that under T2, respectively, and yield for T4 was 21 to 17% superior over that under T3. For the Wahala3 variety, mean grain yields under T4, T3 and T2 fertilization treatments increased by 86 to 55, 72 to 45 and 55 to 31% as compared to yield under treatment T1, respectively, those for T4 and T3 were 20 to 18 and 11% higher than that under T2, respectively, and the yield under T4 was 8 to 7% superior over that for T3.

Mean grain yield values under the Tchamba variety were 113 to 73, 72 to 41 and 42 to 25% higher as compared to value for T1, respectively, those under T4 and T3 were 50 to 39 and 21 to 14 higher than that for T2, respectively, and yield under T was 24 to 23% superior over that for T3. With the Bassar variety, mean grain yields for T4, T3 and T2 fertilization treatments increased by 96 to 61, 63 to 39 and 62 to 38% as compared to yield under treatment T1, respectively, those for treatments T4 and T3 were 21 to 16 % higher and identical in comparison to that under T2, respectively, and yield for T4 was 20 to 16% superior over that under T3. For the Agoèbli variety, mean grain yields under T4, T3 and T2 fertilization treatments increased by 86 to 52, 75 to 46 and 52 to31% as compared to yield under treatment T1, respectively, those for T4 and T3 were 22 to 16 and 15 to 11% higher than that under T2, respectively, and the yield under T4 was 6 to 4% superior over that for T3. Mean grain yield values with the Dapaong variety were 86 to 55, 70 to 44 and 65 to 41% higher than the value for T1, those for T4 and T3 increased 12 to 10 and 3 to 2% as compared to that of T2, and yield under T4 was 9 to 8% higher than that for T3. For the Wahala2 variety, mean grain yields under T4, T3 and T2 fertilization treatments increased by 83 to 53, 64 to 40 and 70 to 44% as compared to yield under treatment T1, respectively, those for T4 and T3 were 8 to 6% higher and 3% lower than that under T2, respectively, and the yield under T4 was 11 to 9% superior over that for T3. With the Obatampa variety, mean grain yields for T4, T3 and T2 fertilization treatments increased by 85 to 55, 77 to 49 and 46 to 27% as compared to yield under treatment T1, respectively, those for treatments T4 and T3 were 27 to 21 and 21 to 16% higher in comparison to that under T2, respectively, and yield for T4 was 5 to 4% higher than that under T3. Results on the individual performance of each of the varieties under each of the fertilization treatments indicated that three (TZEE, Bassar and Tchamba) out of the nine varieties were more responsive to the fertilization treatment combining organic and inorganic nutrient sources (T4) in comparison to the other treatments. For the three varieties, the superiority of the response to T4 ranged from 96 to 113, 62 to 72 and 42 to 62% as compared to T1, T2 and T3, respectively, during the first growing season. For the second growing season, the superiority of the response varied from 61 to 73, 38 to 41 and 25 to 38% as compared to T1, T2 and T3 fertilization treatments, respectively.

The results of this study demonstrated that the integrated soil fertility management approach implying the combined use of inorganic and organic nutrient sources proved capable of providing balanced maize crop nutrition during the crop cycle presumably through synchronization between nutrients' availability and crop needs. [25] and [26] also discussed this capability of the approach; however, their works failed to explicitly quantify the amount of each nutrient source to be combined because they involved improved short duration fallows or food grain legumes in rotation with maize. In a similar study in northern Ghana, [22] reported maize grain yield under T1 100, 66 and 109% lower in comparison to yields for T2, T3 and T4, respectively, yield under T2 15 and 34% lower as compared to those for T3 and T4, respectively, and yield under T3 16% lower than that for T4. Results from our study reasonably corroborated the findings by [22]. With a fertilization treatment of FYM plus 30 kg N ha^{-1}, [27] reported maize grain yields 108 to 103% higher than yields under mineral only fertilization treatments. A similar performance was found by [28] for the combination FMY-mineral fertilizer, and [11] concluded that combination of 75% mineral N source and 25% organic N sources is the best combination for sustainable maize yield.

IV. Conclusion

Currently, improved maize production in coastal western Africa is subject to judicious additions of nutrient to soil and careful choice of crop varieties. The best bet approach for soil fertility management is the combination of nutrients from organic and mineral sources. The combination of 3 t of FYM and 100 kg $N_{15}P_{15}K_{15}$ plus 50 kg urea (46% N) ha^{-1} appeared to be a promising maize crop fertilization scheme. Under this fertilization approach, the use of all the varieties involved in this study is appropriate with regard to grain yield during the first growing season with a greater performance of the Ikenne, TZEE, Bassar and Tchamba varieties. Only four varieties (Ikenne, Wahala3, Agoèbli and Wahala2) can be used in the second cropping season. More research is needed to assess the economic aspects of the soil and crop management recommendations from the study.

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