Assessment of endogenous soil fertility to update fertilization of maize (Zea Mays L) crops in the savannah region of Togo

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ABSTRACT

The diagnosis of soil fertility is a prerequisite for the formulation of balanced and site-specific fertilizer recommendations. Macro elements (nitrogen – N, phosphorous – P and potassium – K) based nutrient omission trials were conducted in the districts of Oti, Tandjouaré, Tône and Kpendjal of the Savannah region. The objective was to assess endogenous soil fertility under maize cropping to further develop updated site-specifique fertilization schemes for the crop. A total of twenty-five producers were selected in the region (eight in Tandjouaré, seven in Tône, five in Oti and five in Kpendjal) for the study in a paticipatory approach. The approach was participatory in order to involve the end user in the exercise. A randomized complete block design was adopted with five fertilization treatments including $N_0P_0K_0$ (T_1), $N_0P_{60}K_{70}$ (T_2), $N_{120}P_0K_{70}$ (T_3), $N_{120}P_{60}K_0$ (T_4) and $N_{120}P_{60}K_{70}$ (T_5) kg ha-1 for the trial. The unit plot size was 100 m^2 (10 m x10 m).

Grain yield, yield response to nutrients, Agronomic Efficiency (AE) and profitability were determined. Genstat Edition 12th was used to discriminate means.The average yields were 0.56, 0.83, 3.18, 3.44 and 4.57 Mg ha^{-1} respectively for T_1, T_2, T_3, T_4 and T_5 in Tandjouaré, 0.32, 0.52, 1.06, 2.39 and 3.02 Mg ha^{-1} respectively for T_1, T_2, T_3, T_4 and T_5 in Tône, 1.01, 1.35, 2.56, 3.16 and 4.39 Mg ha^{-1} respectively for T_1, T_2, T_3, T_4 and T_5 in Oti and 0.39, 0.75, 1.54, 2.33 and 3.31 Mg ha^{-1} respectively for T_1, T_2, T_3, T_4 and T_5 in Kpendjal. The ranking of yield data by fertilizer treatment indicates that all three macronutrients (N, P and K) are required for maize production in the Savannah region, with a priority ranking of N>P>K. The results also showed that the best Agronomic Efficiency is obtained when all macronutrients are supplied in all four prefectures. The results of this diagnostic will be used as a basis for formulating balanced, site-specific fertilizer recommendations for intelligent, environmentally-friendly agriculture.

Keywords: Maize, mineral fertilization, yield, macroelement, nutrient use efficiency, Togo

1. INTRODUCTION

Cereal production is one of the highest in the world, with corn being the most widely grown cereal. Production is estimated at 1.4 billion tonnes (FAOSTAT, 2020). Maize is the main crop in the West African sub-region and the staple food of the region's populations (Sogbedji et al., 2006). In Togo, once considered essentially a food crop, maize has been increasingly positioned as a cash crop in recent years and constitutes the staple food of the population to such an extent that the question of food security seems to be restricted to its spatio-temporal availability and accessibility for households (Detchinli et al., 2017; ITRA, 2019), which raises its importance from a nutritional, economic and political point of view.

Maize production occupies almost 20% of Togo's total farmed area, with production of 912,086 tonnes i (FAOSTAT, 2020). Despite its importance, maize production in Togo is characterized by low productivity. The average yield has been 1.2 t/ha for two decades (FAOSTAT, 2020). Productivity has not kept pace with production, which has evolved following the increase in production areas, which is a general observation in Africa (MAEH, 2015;

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Rakotoarisoa et al., 2011). Generally speaking, this low productivity can be explained by the effects of climate change and variability, but above all it is due essentially to soil degradation and the difficulties farmers face in responding to it (Laurent et al., 2015). This widespread state of soil degradation in Africa can be explained by long-standing practices. For Adden et al., 2016, soil fertility loss is the main constraint on yield decline. Studies have shown that in sub-Saharan Africa, farmers have often applied mineral fertilizers at doses lower than the recommendations established during the Green Revolution period (Maraux et al., 2007) while overexploiting the soil. In Togo, most agricultural soils are degraded, thus penalizing production. Crop management techniques have evolved little and, above all, have not been widely adopted by farmers (Adesina & Baidu-Forson, 1995). As a result, the soil does not receive back what it has lost. And yet, for optimal, sustainable production, the balanced supply of nutrients is becoming a necessity. Obtaining balanced and specific fertilization formulas requires prior knowledge of the soil's endogenous fertility. Several approaches are available, including soil chemical analysis, visual analysis and mapping, to determine endogenous soil fertility in terms of the major elements N, P and K. But the question is whether these methods take into account the soil's capacity to supply nutrients to the plant. For this reason (Sogbedji, 2006; Maba, 2007), the use of the subtractive test approach would be a good method for estimating the soil's capacity to supply nutrients to the plant.

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The aim of the present study is to determine the endogenous fertility of soils in the Savanes region of Togo.

2. MATERIAL AND METHODS

Experimental site
The study was carried out in the Savanes region (latitude: 10.423868; longitude: 0.409638), in four prefectures: Tandjouare, Tône, Oti and Kpendjal. This is Togo's northernmost region. The region has a Sudano-Sahelian climate, with a rainy season from May to October and a dry season from November to April. Rainfall ranged from 787 to 1194 mm, with considerable inter-annual variability. The dominant soils are leached tropical ferruginous soils (Lamoureux, 1969).

Plant material
The maize variety Ikenne 9449-SR was used in the experiment. It is a composite variety, bred by CIMMYT / IITA, introduced into Togo in 1980 and grown in all regions of the country. The sowing-maturity cycle (50%) varies from 100 to 105 days. This variety has an average height of 2.10 m and an ear insertion height of 90 cm. Its grain is hard and whitish in color. It has good ear coverage and good resistance to drought, stripe virus and lodging. The average yield of the Ikenne variety is 5 Mg ha-1 (CEDEAO-UEMOA-CILSS, 2016).

Experimental setup
The set-up was a 5-treatment block, including 4 subtractive treatments (NPK, NP, NK and PK) and a fifth reference treatment (Figure 1). The trials set up are called subtractive or "omission" trials, requiring the use of simple fertilizers to identify the deficiency of each element in the soil. The tests are based on a treatment corresponding to a complete and sufficient supply of NPK and treatments without N, P or K. The NPK treatment was reasoned in such a way as to provide the maximum N, P and K requirement for maize. The doses generated by APNI as part of Togo's agricultural exercise in 2021 were used for the study.

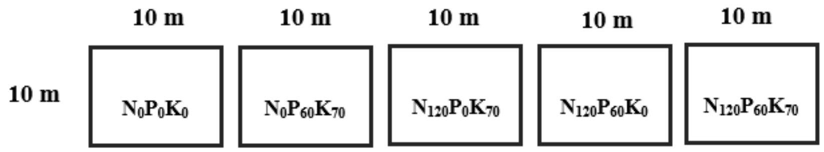

Figure 1 : Experimental setup

Trial conduct
The trial was conducted in the prefectures of Kpendjal, Tandjouare, Tône and Oti from June - November 2022. Growers were strategically selected for capacity building and potential adoption of advanced technologies, as well as to serve as pilot sites for the region. A total of 8; 7; 5; 5 growers were selected in the prefectures of Tandjouare, Tône, Kpendjal and Oti respectively. Each grower was allocated a 600 m^2 plot. The elementary plot was 10 m X 10 m, i.e. an area of 100 m^2. A cultivation pattern of 0.8 m x 0.4 m was adopted, with 2 plants per plot, giving a density of 62,500 plants/ha. The maize crop was hand-weeded three times and treated as required with Emmamectin Benzoate 50% to control armyworm. Fertilizer application consisted of a spot application of $N_{120}P_{60}K_{70}$ kg ha^{-1}, with half of the nitrogen dose (60 kg N ha^{-1}) and full doses of P and K applied around 15-21 days after maize planting and the remaining half of the nitrogen applied 40-45 days after maize planting. N fertilizers were applied as urea (46% N), and P and K were applied as triple superphosphate (TSP 46% P_2O_5) and potassium chloride (KCl 60% K_2O), respectively.

Data collection

Maize grain yield

The average corn grain yield for each fertilization treatment in each prefecture was determined by harvesting the cobs from the useful area (3.2 m x 5 m) in the middle of the 100 m^2 treatment plot. The harvested corn kernels were sun-dried to a moisture content of around 14%.

Yield was calculated using the following formula:

R = (M*10000)/Sp

R = yield (in Mgha^{-1})

M = fruit mass (in Mg)

Sp = plot area (in m^2)

Determination of yield response to N, P and K nutrients

Based on the average yields obtained under each treatment in each prefecture, the yield response to nutrients was determined for each of the macroelements (N, P and K).

This response is the difference in yield between the treatment that received all the macronutrients (NPK) and a treatment where one element (N, P or K) is omitted. The yield response to nutrients is calculated using the following expressions:

N yield response = NPK treatment yield - N-free treatment yield

P yield response = NPK treatment yield - P-free treatment yield

K yield response = NPK treatment yield - K-free treatment yield (Dobermann, 2005).

Determining agronomic efficiency (AE)

Agronomic efficiency (AE) reflects the increase in yield per unit of nutrient applied. It is calculated using the following formula

EA = (Y-Y0)/F

(Dobermann, 2005)

F = amount (of fertilizer) applied (kgha^{-1})

Y = crop yield with fertilizer applied (kgha^{-1})

Yo = crop yield (kgha^{-1}) in a control treatment without fertilizer

Data analysis

All yield data were subjected to analysis of variance (ANOVA) using GENSTAT version 12.0 software, and mean yield values were discriminated by Duncan's test at the 5% threshold.

3. RESULTS AND DISCUSSION

Effect of fertilization approaches on corn grain yield

Average maize grain yield data are presented in Table 1.

Table 1 : Table summarizing average maize grain yields (Mg ha^{-1}) for each fertilization treatment in each prefecture.

Fertilizationtreatments	**Rendements en grains par préfecture**(Mg ha^{-1})			
	Tandjouaré	**Tone**	**Oti**	**Kpendjal**
$N_0P_0K_0$	0,56**c**	0,32**b**	1,01**c**	0,39e
$N_0P_{60}K_{70}$	0,83**c**	0,52**b**	1,35**c**	0,75d
$N_{120}P_0K_{70}$	3,18**b**	1,06**b**	2,56**b**	1,54c
$N_{120}P_{60}K_0$	3,44**b**	2,39**a**	3,16**b**	2,33b
$N_{120}P_{60}K_{70}$	4,57**a**	3,02**a**	4,39**a**	3,31a
Moyenne	**2,52**	**1,46**	**2,49**	**1,66**
PPDS	***0,6282***	***0,785***	***0,742***	***0,2839***

Analysis of variance revealed that fertilization approaches had a significant effect on maize grain yield. Means with the same letter in the same row are not statistically different at the 5% level according to Duncan's test.

The data set across the different prefectures indicates that yield trends related to fertilization treatments are generally identical. Ranking the data according to fertilization treatment clearly indicates that all three macroelements (N, P and K) are required for maize production in the Savanes region, the order of importance being N > P > K. However, the data show that grain yields based on fertilization treatments are consistently varied between prefectures. Within the region, although yield trends were similar with regard to fertilization treatment, and the ranking of importance of the three nutrients was N > P > K, average maize grain yields were higher in the prefectures of Oti and Tandjouare than in the prefectures of Tône and Kpendjal. This highlights the variability of yield response to nutrients in different prefectures. This indicates that site-specific nutrient management is needed in the region across prefectures to specifically address crop nutrient requirements and thus maximize nutrient use efficiency. The results of the subtractive trials thus obtained make it possible to apprehend or appreciate soil fertility status even in the absence of soil analysis results, as previous studies have shown that soil chemical characteristics are insignificant in crop response to nutrients (Akanza, 2018; S. Njoroge et al., 2017).

The results of this study corroborate those of (Maba, 2007; IFDC , 2013a; Mawussi et al., 2015) in terms of yield trends and nutrient importance in the Plateaux, Centre and Savanes regions of Togo. The results are also in line with the findings of Badiane (2021) for whom Nitrogen is the most limiting element for maize cultivation followed by P and K in one area of Senegal.

The variation in yield response to the same fertilization treatments in different prefectures would be due to endogenous soil fertility, or either to the amount of rainfall, or to the spatio-temporal distribution of rainfall. For Igué et al. (2016) soil organic matter constitutes a very severe limitation for good assimilation of mineral fertilizers. It should be noted that, despite the beneficial effect of mineral fertilizers in achieving higher yields, a statuary quantity of organic matter would be a solution to ensure better productivity and the sustainable maintenance of agricultural soil fertility in certain prefectures. Thus Recous et al. (2015) asserted that the nitrogen cycle, like that of other mineral elements, is then under the control of carbon dynamics within the so-called "internal" nitrogen cycle in soils. For Faye et al. (2018), the spatio-temporal distribution of rainfall influences yield trends.

Ultimately, for effective and sustainable soil fertility management and the maintenance of high crop yields, it is necessary to take all three agricultural entities (soil, climate and plant material) into account when drawing up fertilization recommendations.

Determination of yield response to macronutrients N, P and K

The yield response to nutrients is the difference between the yield achievable with the $N_{120}P_{60}K_{70}$ treatment and the nutrient-limited yield (0N, 0P and 0K). It may reflect to some extent the endogenous supply of nutrients from the soil. The higher the yield response for a given nutrient, the poorer the soil is for that element. Yield responses for N, P and K in the four prefectures showed different amplitudes (Figure 2). The trends were identical from one prefecture to another.

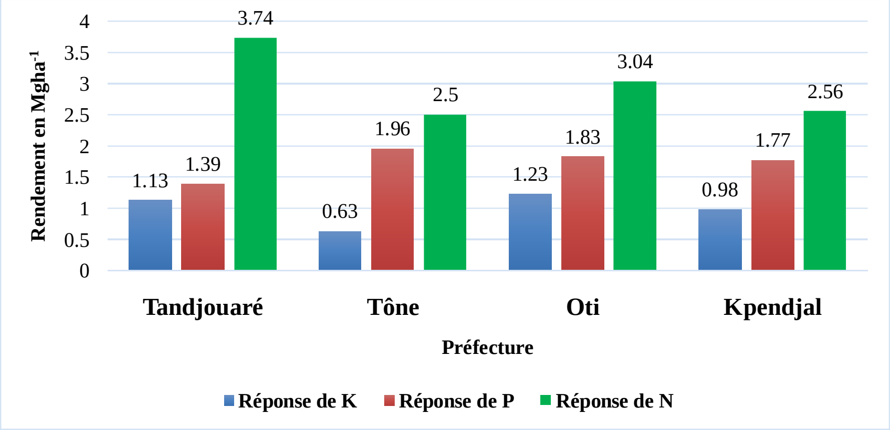

Figure 2 : Yield response to N, P and K nutrients

The observed variability in yield response to N, P and K nutrients is thought to be due to the plant's need for each of the nutrients applied, and to the fact that uptake of each nutrient is a function of the plant's physiological state, endogenous soil fertility and climate. Indeed, for Pampolino et al. (2012), yield response depends on soil fertility, but also on climate, soil characteristics and residual nutrients from the previous crop.

Indeed, the nutrient N induced a greater yield response, followed respectively by the nutrients P and K. This shows that endogenous soil N is the weakest, followed by P and K in the different prefectures. These results could be confirmed by studies by ITRA (2021) on the characterization of soil physico-chemical parameters in the Savanes region, showing a nutrient deficiency in the region. These results are in line with those of (Vanlauwe et al., 2011; Badiane, 2021), for whom nitrogen is recognized as the most limiting nutrient in cereal cropping systems over large areas of sub-Saharan Africa. However, the observed soil nutrient deficiency could be due to the absence of innovative efficient soil management practices, the disappearance of fallow land, the lack of compensation for nutrients depleted by crops and inadequate application of fertilizer doses. The results thus corroborate the findings of Badiane (2021) and Kamara (2017), who assert that soil nutrient deficiencies are due to the disposal of crop residues after harvest by burning or transport, and to intensive, long-term cultivation of the soil without adequate nutrient replenishment. Studies by Detchinli (2017) have also shown that soils in sub-Saharan Africa are originally nutrient-poor, and inappropriate use of these soils intensifies their poverty.

Determining the agronomic efficiency of nutrients

Agronomic efficiency (AE) defined as the increase in yield per unit of nutrient applied, depends largely on nutrient management practices (Xinpeng et al., 2017). It more accurately reflects the direct impact on production of an applied fertilizer and is directly linked to economic return. A difference in yield between treatments on control is explained by the agronomic efficiency (AE) of all nutrients applied. The agronomic efficiencies of N (AE_N), P (AE_P) and K (AE_K) for the four prefectures are recorded in Table 2. A wide variation was noted between treatments with regard to AE_N, AE_P and AE_K from one prefecture to another.

Fertilizationtreatments	**Tandjouare**			**Tône**			**Oti**			**Kpendjal**		
	N	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**	**N**	**P**	**K**
$N_0P_0K_0$	**0**	0	0	**0**	0	0	**0**	0	0	**0**	0	0
$N_0P_{60}K_{70}$	0	2	3	0	1	2	0	2	4	0	3	4
$N_{120}P_0K_{70}$	22	0	31	6	0	9	13	0	18	10	0	14
$N_{120}P_{60}K_0$	24	21	0	17	15	0	18	16	0	16	14	0
$N_{120}P_{60}K_{70}$	33	29	48	23	20	32	28	25	40	24	21	35

Our study showed that the agronomic efficiency of N, P and K varied from one treatment to another and from one prefecture to another. In general, the $N_{120}P_{60}K_{70}$ treatments in the four prefectures recorded the best AEs for N, P and K, compared with the $N_{120}P_{60}K_0$, $N_{120}P_0K_{70}$ and $N_0P_{60}K_{70}$ treatments. The $N_{120}P_{60}K_{70}$ treatment in Tandjouaré prefecture achieved better AEs for N, P and K than the $N_{120}P_{60}K_{70}$ treatments in the other prefectures. The same scenarios apply to $N_{120}P_{60}K_0$ and $N_{120}P_0K_{70}$ treatments. For the $N_0P_{60}K_{70}$ treatments in the four prefectures, there was a very low AE for P and K, with different amplitudes. The NEA recorded for the $N_{120}P_{60}K_{70}$ treatments is in line with the results of Dobermann (2007), who states that for modern cereal cropping systems, management should aim to achieve an EA_N of 20 to 30 kg of grain per kg of nitrogen applied. However, he disagrees with the results of Badiane (2021), who obtained very low AE_N values with high variability. On the other hand, the AE_N values recorded under the $N_{120}P_{60}K_0$ and $N_{120}P_0K_{70}$ treatments in the Tône, Oti and Kpendjal prefectures are slightly lower than the range given by Dobermann (2007). These results show that the agronomic efficiency of nitrogen is better when P and K are supplied to the plant. For Banerjee et al (2014), EA_N is a function of the cropping system and is more important for nutrient application based on the recommendation obtained from the decision support system than for nutrient application based on farmers' practice in India on maize. With regard to AE_P, the results obtained under the $N_{120}P_{60}K_{70}$ treatment in the four prefectures and the $N_{120}P_{60}K_0$ treatment in the Tandjouaré prefecture are in line with Dobermann's (2007) results. For the other treatments, however, his results disagree with those of Dobermann (2007). But in agreement with the work of Badiane (2021). For AE_K, the results also showed different amplitudes, with data superior to Dobermann (2007) and in agreement with Badiane (2021).

The best interpretation of the results shows that the combined effect of the main nutrients for maize production improves the agronomic efficiency of each of the elements. The variability of the AE of N, P and K in the different prefectures attests to the need for each prefecture to have its own fertilization formula.

4. CONCLUSION

Soil fertility diagnosis is an essential part of developing recommendations for crop fertilization formulas. The aim is to determine endogenous soil fertility in the Savanes region. The results vary in importance. The three macronutrients (N, P and K) are necessary for maize production in the Savanes region. They also show that nitrogen is the main nutrient limiting maize grain yield, followed by phosphorus and potassium under the soil and climate conditions of our study. It also shows that the agronomic efficiency of nutrients varies according to endogenous soil fertility and element combinations, and that the best AE is obtained when all macroelements are supplied in all four prefectures. This efficiency of N, P and K varies from prefecture to prefecture. This highlights the need for specific fertilization recommendations for each prefecture.

Comment [I3]: Compare the results with similar studies.

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