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Updating fertilizer formulation for maize cultivation (*Zea mays* L.) on Ferric Luvisols and Gleysols in the municipality of Tanguiéta, North-West Benin

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The improvement of soil fertility management is of great concern in Benin where deforestation and erosion lead each year to a decline of the productive capacity of agriculture land. In order to increase maize productivity in Northern Benin a field experiment was carried out from July 5 to November 20, 2012 on two main soils type namely ferric Luvisols and Gleysols. The study aimed at validating on farmer, ten different mineral and organo-mineral formulas of N, P and K (115-30-75 ; 88-30-35 ; 88-30-35+Manure; 42-30-35+Manure; 74-20-23 ; 74-20-23+Manure ; 51-20-23 ; 51-20-23+Manure ; 0-0-0 ; 0-0-0+Manure) simulated by DSSAT model in order to improve EVDT ETR-97 maize grain yield in northern Benin. In total, sixteen farmers' fields were involved in this study. In each field, the experimental design was a randomized completed bloc design with four replications. Maize seed yields were subjected to one-way analysis of variance (fertilizer formulation) by soil type. The highest soil organic carbon and phosphorus content were recorded on ferric Luvisols. In addition, grain yield on ferric Luvisols was higher compared with Gleysols. The formula $N_{42}P_{30}K_{35}F$ presented the highest grain yield regardless the soil type. In fact, the highest grain yields were 2940.25 ± 383.60 and 2923.60 ± 653.26 kg/ha for ferric Luvisols and Gleysols respectively. The formula $N_{42}P_{30}K_{35}F$ could enable to improve maize productivity on ferric Luvisols and Gleysols in the North-West of Benin. The present study showed the importance of updating the different fertilizers combinations for different soils types in order to improve maize productivity.

Keywords: DSSAT model, soil fertility, optimum dose, mineral fertilizer, Benin.

INTRODUCTION

In Sub-Saharan African countries, agriculture is characterized by low productivity, partly due to the steady depletion in soil fertility (Saïdou *et al.,* 2012). In Benin, low crops yield are often due to unfavorable rainfall conditions, low soil fertility and low use of external inputs (Mrabet and

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Moussadek, 2012). Agriculture is an important sector in Benin and it contributes to about 37% of the Gross Domestic Product. Diverse crops are grown and cereals, particularly maize, are the prevailing crops encountered in production systems. However, the productivity of these crops is hampered by low soil fertility. This results in negative soil nutrient balances (Saidou *et al.,* 2003).

In fact, the misuse and inappropriate use of tillage equipment, uptake of crop residues and short fallow periods have favored the depletion of soil organic matter, degradation of soil structure (Robert, 1996) and therefore the decline in soil fertility (Lal, 2002; Mrabet et al., 2001). This affects Luvisols, occupying 60% of the total area of Benin (Agossou, 1983) and Gleysols encountered in depression zones. These soil types are known to be poor in nitrogen and phosphorus (Sanchez and Jama, 2002).

Coping with depletion in soil fertility requires sound management of agricultural land through application of mineral and organic fertilizers to restore the stock of organic matter and nutrient supply. The role of organic matter in improving the soil quality is widely recognized. Indeed, the organic matter is the main indicator and determinant of soil biological activity (Lal, 2002). It has a major influence on the physical and chemical properties of soils (Robert, 1996).

In Benin, the doses and fertilizer formulations (150 kg / ha NPK 14-23-14 and 50 kg / ha urea) currently recommended to farmers by extension agents for maize cultivation are mostly outdated and did not take into account the specificities of cropping systems in each agro-ecological zone (Igué *et al*., 2013). Given the fact that maize cultivation is demanding in nutrients, there is a need to update the NPK fertilizer formulation in order to improve soil productivity. Towards this end, the simulation model Decision Support System for Agrotechnology Transfer (DSSAT) has generated various fertilizer options for maize on two types of soil in North West of Benin (Ezui *et al*., 2011;Ezui *et al.,* 2012).

This study intended to validate on farm the fertilizer formulations and doses generated. It aimed at: (1) characterizing the state of the natural fertility of ferric Luvisols and Gleysols, (2) determining on farm maize grain yield for the different levels of fertilizer formulas generated by the DSSAT model and (3) assessing the added value of a combined application of mineral and organic fertilizers on ferric Luvisols and Gleysols.

MATERIALS AND METHOD

Study area

The field trial was conducted in the village of Nanebu, in the municipality of Tanguiéta, Department of Atacora located between 10°40' and 10°45' N and 1°20 'and 1°22' E (Figure 1).The study area is characterized by a Sudano-Guinean climate with a long dry period from November to April and a rainy season from May to October. The average monthly rainfall varies from 6 mm to 240 mm. The maxima are reached in August and September (229 and 240 mm). The average temperature is 26.5°C and varies slightly during the year (24.2°C) (Igué, 2012). Ferric Luvisols and Gleysols are the major soils type in the study area.

Field experiment

The trial was a researcher-designed and farmer-managed experiment. Sixteen fields composed of eight farms located on ferric Luvisols and eight located on Gleysols were selected for the experiment. Farmers involved in the experiment were selected based on criteria such as land availability, accessibility of their farm all season round and their willingness to work with the research team. Experimental plots were selected based on exploratory survey involving local community.

In each field, the experiment was laid out in a randomized complete block with four replications. The dimensions of the experimental unit were 5.6 m x 8 m. The organic fertilizer used consisted of an amount of 22.4 kg/ha of manure. The major nutrients content of the manure was 1.57% N,0.24% P and 1.56% K. Simple urea (46% N), TSP 46% P_2O_5) and KCl (60% K_2O) were used in the formulation of fertilizers doses. Ten fertilizer formulas were validated. Table 1 shows the total amount of nutrients N, P and K containing in mineral and organic fertilizers for the different treatments.

The maize variety EVDT ETR-97, 90-day cycle (average yield 3 t/ha and 6 t/ha potential yield) was used in the experiment. The preparation of the seedbed at all the plots was a ridge plowing with hoe. Across all the experimental fields, sowing was done from July 5 to 7, 2012. Two seeds per hill were sowed at a spacing of 80 cm between rows and 40 cm within row (density of 62,500 plants/ha). All plots were weeded twice.

For each treatment, the amounts of TSP and KCl were applied 15 days after sowing. Urea was split into two identical amounts and they were applied 15 and 45 days after sowing, respectively. The application was done mad in hole, at 5 cm from each plant. The hole was then closed after the application to avoid N losses by volatilization.

Maize ear was harvested at physiological maturity recognized with the appearance of black spots at the end of the seed and the drying of the entire stem. Harvest was done after removal of borders rows. The total number of harvested maize plant was counted and the ears were weighted using a balance ‘’TESTUT’’ with a capacity of 20 kg. From each plot, 300 g of ears were sampled for the determination of the dry matter in the laboratory. The drying was performed in an oven at 70°C until constant weight was observed after 72 hours. Maize yield was

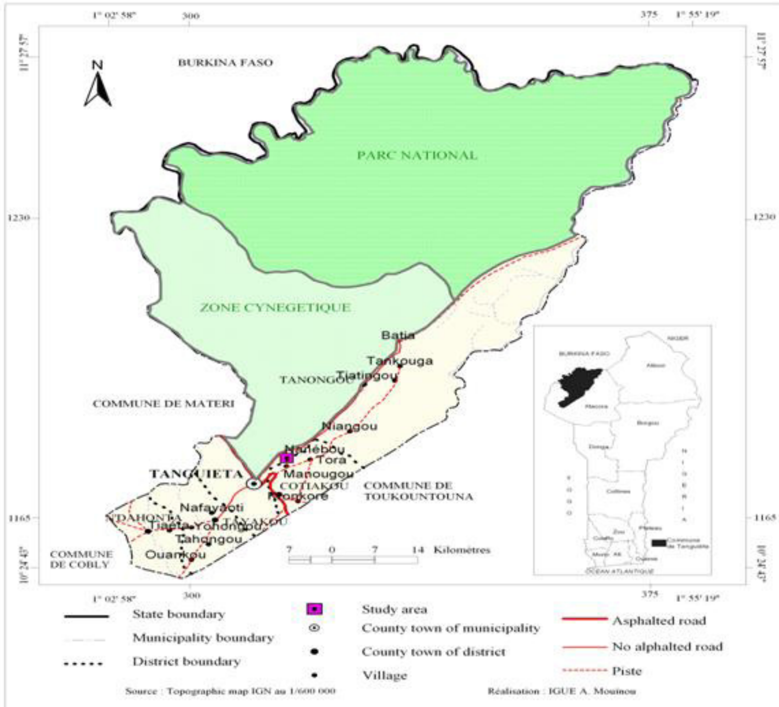

Figure 1: Location of the study area

Table 1: Simulated fertilizer formulations by DSSAT model used as treatments

Treatments	Nutrient doses (kg/ha)				Amount of weighted fertilizer (kg) per experimental unit			
	N	P	K	F	Urea	TSP	KCl	Manure
Simulated dose 1	115	30	75	0	1.120	0.292	0.560	0
Simulated dose 2	88	30	35	0	0.860	0.292	0.261	0
Simulated dose 2 + manure	88	30	35	22.4	0.860	0.292	0.261	0.100
Simulated dose 3 + manure	42	30	35	22.4	0.409	0.292	0.261	0.100
Simulated dose 4	74	20	23	0	0.720	0.194	0.171	0
Simulated dose 4 + manure	74	20	23	22.4	0.720	0.194	0.171	0.100
Simulated dose 5	51	20	23	0	0.496	0.194	0.171	0
Simulated dose 5 + manure	51	20	23	22.4	0.496	0.194	0.171	0.100
Absoluteccheck	0	0	0	0	0	0	0	0
Absolute check + manure	0	0	0	22.4	0	0	0	0.100

calculated following the formula developed by Saidou (1992).

$$Rg = \frac{10,000 \times P \times MS \times n}{SI}$$

With R: grain yield (kg DM / ha)
P: Total weight of maize ear weighed on farm (kg)
DM: dry matter rat of ears
SI: interpretable area (m^2)

Soil samples were collected at the depth of 0 – 20cm on each plot before setting up the experiment. Chemical analyzes were performed at the Soil Science, Water and Environment Laboratory (LSSEE) of the National Institute of Agricultural Research of Benin (INRAB). Organic carbon following Walkley-Black method and total nitrogen using Kjeldahl method were determined. pH (water) was measured by a glass electrode in a ratio soil/water of 1/2.5.

Table 2: chemical properties of soil before the experiment

Sol types	OM (%)	Nitrogen (%)	Saturation in base	pH (%)	CEC (%)	Pass (%)	Ca/Mg (%)	Mg/k (%)
FS	2.28	0.092	90.50	5.7*	6.75	12.00	3.25	4.87
HS	1.79	0.067	81.50	5.4*	5.15	6.93	2.50	4.58
Standard deviation	0.9653	0.03030	8.29	0.1620	2.206	5.569	0.7906	2.922

***P< 0,05**

The exchangeable cations using the method of ammonium acetate at pH 7, followed by reading at the atomic absorption spectrophotometer and the cation exchange capacity using the method of ammonium acetate 1 N pH 7 followed by a second extraction with KCl and the available phosphorus following Bray 1 method were determined.

The General Linear Model procedure of SAS software version 9.2 was used for analysis of variance of yield. Student Newman Keuls means separation test was performed at α= 5%.

RESULTS AND DISCUSSION

Soils chemical properties

Table 2 depicts the chemical properties of the different types of soil before the experiment. The organic matter content was higher in ferric Luvisols than in Gleysols. The low rate of organic matter and total nitrogen observed in hydromorphic soils was due to their continuous exploitation, without any restitution of nutrients by either direct incorporation of crop residues or by supplying mineral fertilizers (Igué, 2012). Igué (2009) and Yallou *et al.*,(2010) substantiated this finding emphasizing that not only the land cultivation decreases organic matter content but also the duration of tillage. Igué *et al.,*(2008) showed that the organic matter content of cultivated soils depended on cropping systems. In the unbalanced system (poor farmers), organic matter constitutes a very severe limitation as compared to other systems (average and balanced). Igué, (2009) also indicated that the organic matter in the layer (0-20 cm) decreases from 0.05 to 0.08% per year depending on soil type. According to Worou, (1998) the low content of organic matter in Gleysols of the site may be explained by dry soil conditions. Ferric Luvisols showed higher phosphorus content than Gleysols. It was found that in the Department of Collines, in Benin, phosphorus content might increase by 10% after 10-25 years of continuous maize/cotton cultivation (Igué, 2009). This could be due to a steady supply of phosphoric fertilizers. Ca/Mg and Mg/K ratios in ferric Luvisols and Gleysols showed good cationic balance and no statistical significant difference (P> 0.05) were observed in both types of soil. The type of tillage showed statistically significant effect (P <0.05) on the pH (Table 2), it is slightly higher in ferric Luvisols compared to Gleysols that are less acid.

According Viennot (1969), acid soils have negatively effects on maize yield and are classified as moderately suitable for this crop. Gleysols in the study area were under strong pressure characterized by continuous cultivation and inappropriate agricultural practices. The low productivity of these types of soils was also related to their topography in the landscape that leads to water stagnation contributing to the asphyxiation of root system of plants (Igué, 2012). This result is confirmed by Fikri *et al.*, (2004) who stated that the organic material has a major influence on the physical and chemical properties of soils and indirectly crop yields.

Effect of different fertilizer formulation on the maize grain yield for each soil type

The results of the Analysis of variance showed that the effect of the fertilizer formulations was highly significant (P <0.01) on the yield of maize grain regardless of soil type (Table 3).

Figure 2 shows the effect of different combinations of fertilizers on maize grain yield for each soil type. It revealed that the formulation $N_{42}P_{30}K_{35}F$ fertilizers induced the best maize grain yield regardless of soil type. The highest grain yields were 2940.25±383.60 and2923.60±653.26 kg/ha for ferric Luvisols and Gleysols, respectively.

Productive capacity of plots ($N_0P_0K_0$) without external nutrients supply revealed drastic deficiency in macro-elements N, P and K with yields equivalent to 1246.88±359.39 and 1327.60±165.05 kg/ha for ferric Luvisols and Gleysols, respectively. These results

Table 3: One-way analysis of variance (fertilizer formulation) for each soil type with maize grain yield as respondent

Source of variation	Df	F Value	
		Concretionned soils	Hydromorphic soils
Formulation of fertilizer	9	2.80**	2.88**
Replication	7	5.93***	7.45***

df : degree of freedom ; ** : P < 0,01 ; *** : P < 0,001

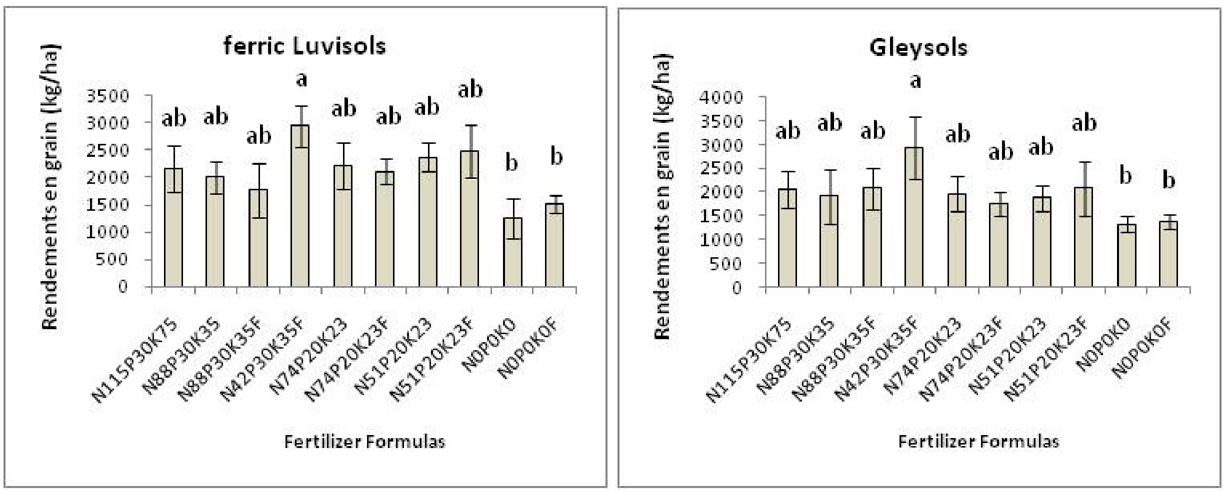

Figure 3: Effect of different fertilizer combinations on the yield of maize grain for each soil type
Bars with the same letter (s) represent treatment, which are not significantly different
Error bars represent standard errors

corroborated the findings of Saïdou *et al.* (2012) who showed that nitrogen is the main limiting factor for crop grain yield. These observations stressed the importance of nitrogen fertilization to increase grain yield (Walkley and Black, 1934). Application of mineral fertilizers without organic restitution affects chemical soil characteristics while use over several cropping seasons (Koulibaly *et al.,* 2010). Low crop yield is often due to land degradation caused by agricultural practices involving low use of external inputs (Saïdou *et al.,* 2003). Obtain good crop yield depends not only on the nature of the soil, but also the amount of nitrogen available for the plant.

CONCLUSION

Our findings revealed that ferric Luvisols showed good potential for maize grain yield in the municipality of Tanguiéta. Different combinations of inorganic and organo-mineral fertilizers were predominant in soils productivity. Only the fertilizer formulation $N_{42}P_{30}K_{35}F$ induced a high yield of maize grain on both ferric Luvisols and Gleysols. Further investigations are needed in order to identify the optimal doses of N, P and K simulated by the model DSSAT to increase maize productivity in the region.

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