EFFECT OF TERMITE MOUNDS AND CHEMICAL FERTILIZER ON THE COTTON AND MAIZE YIELD: AN EVIDENCE FROM THE PENDJARI REGION (NORTH WEST BENIN)

G. P. C. OGOUDEDJI[1A], J. A. YABI[1B], R. N. YEGBEMEY[1C]

[1a] Laboratoire d'Analyses et de Recherches sur les Dynamiques Economiques et Sociales (LARDES). Université de Parakou. E-mail : atagano@yahoo.fr; georges.ogoudedji@gmail.com

[1b] Laboratoire d'Analyses et de Recherches sur les Dynamiques Economiques et Sociales (LARDES). Université de Parakou. E-mail : ja_yabi@yahoo.com; jacob.yabi@fa-up.bj

[1c] Laboratoire d'Analyses et de Recherches sur les Dynamiques Economiques et Sociales (LARDES). Université de Parakou. E-mail : ynerice@gmail.com

ABSTRACT

Like in many other developing countries, smallholder farmers in the Pendjari region located in North-Benin have low crop productivities and further earn low income. This is due in a large part to soil fertility decline and expensive chemical fertilizers. In these settings, the soil fertility potential of termite mounds is a free-of-charge option to explore. A study is conducted in Tanguieta and Materi to analyse possible effect of termite mound and chemical fertilizer on cotton and maize yield. A Generalized Power Production Function is used on farming system and household data collected on a random sample of 152 farmers with questionnaire. The results suggest that cotton and maize yield functions are elastic to the quantity of chemical fertilizers and to the density of termite mounds. Termite mound and chemical fertilizer are shown to have effect on cotton yield. In addition, 79.2% of cotton producers in the study area have the optimal factor combination according to these two inputs while the opposite is true for maize producers. These results also suggest that farmers may know how to valuate termites' fertility effect without knowing how to combine it with the chemical fertilizer.

Key words: Generalized Power Production Function, Termite, Fertilizers, Pendjari, Benin.

RESUME

EFFET DES TERMITIERES ET DE L'ENGRAIS CHIMIQUE SUR LES RENDEMENTS DE COTON ET DE MAIS : CAS DE LA REGION DE LA PENDJARI (NORD-BENIN)

Comme dans de nombreux autres pays en développement, les petits producteurs de la région de Pendjari, située dans le nord du Bénin, ont une faible productivité agricole avec de faibles revenus. Cela est dû en grande partie à la baisse de fertilité des sols et au coût élevé des engrais chimiques. Dans ces environnements, la fertilité potentielle des sols par les termitières est une option gratuite à explorer. Une étude a été menée pour analyser les complémentarités possibles entre les engrais chimiques et la présence de termitières en agriculture. La fonction de production de puissance généralisée a été utilisée sur des données personnelles et de production, recueillies au hasard sur 152 producteurs à l'aide de questionnaire. Les fonctions de production du coton et du maïs sont élastiques à la quantité d'engrais chimiques et à la densité des termitières. Les résultats révèlent les effets des termitières et de l'engrais chimique sur le rendement de coton. De plus, la plupart des producteurs de coton (79,2 %) de la zone d'étude ont la combinaison optimale de facteurs en fonction de ces deux intrants, alors que tel n'est pas le cas pour les producteurs de maïs. Ces résultats suggèrent aussi que les agriculteurs peuvent savoir comment évaluer l'effet fertilisant des termitières sans savoir comment le combiner avec l'engrais chimique.

Mots clés : *Fonction de Production Puissance Généralisée, Termite, Engrais, Pendjari, Benin*

INTRODUCTION

Termites are important components of agro-ecosystems, particularly in developing economies, where they are an alternative to expensive agro-inputs (Pardeshi and Prusty, 2010). This study is designed to analyze possible complementarity between chemical fertilizers and presence of termite (mounds) in the fields. A transcendental production function analysis is used, based on empirical data collected on cotton and maize plots in different villages in the Pendjari region located in North West Benin.

The Pendjari region, both inside and outside the Pendjari park, shows a particular richness in termite mounds. Despite this unique advantage, previous studies in the region highlighted that one of the main challenges farmers are face with is soil fertility decline (Biaou *et al.,* 2016; Yabi *et al.,* 2016; Sermé *et al.*, 2015; Verbree *et al.,* 2014). Considering that chemical fertilizers are typically expensive for smallholder farmers who have low income and limited savings, we argue that it is possible to explore conservation agriculture. In this respect, the fertility effect of termite mounds is an option free-of-charge which farmers can exploit. Indeed, numerous ecosystem services are provided by termites. Termites influence resource availability to other organisms such as soil macro and micro fauna (Dangerfield, McCarthy, Ellery, 1998; Jouquet *et al.*, 2006) by collecting and processing live and dead plant material to feed themselves (Collins, 1981a; Ohiagu, 1979) as well as by manipulating and translocating soil particles to build mound, nests and galleries (Bagine, 1984; Jouquet *et al*, 2002). Termites concentrate nutrients in their mounds, which may re-enter soil through leaching (Rückamp *et al,* 2009) and contribute to regenerate soil fertility.

Economic aspects of termite ecosystem services are investigated by several studies (Mando and Van Rheenen, 1998; Batalha *et al,* 1995; Evans *et al,* 2011; Karak *et al,* 2014). However, there are very few studies that investigated the socioeconomic implications of termite mounds in Benin in relation with the agricultural production. Dossou - Yovo (2007) research in the Pendjari region analyzed the relationship between termite mounds and floristic diversity. Saliou (2005) research in the Pendjari region highlighted the sociocultural and environmental roles played by the termites and their mounds. Nouhoheflin (2006) research in the Lama forest highlighted the diversity and the cultural roles of termites. Our study elaborates of these previous works while focusing on the possible complementarities between chemical fertilizers and presence of termite mounds in agriculture. We also elaborate on the experiment by Batalha *et al.* (1995) who combined the termite nests as a source of organic matter with mineral fertilizers to grow okra and eggplant.

MATERIAL AND METHODS

STUDY AREA

Located in the department of Atacora (North-West of Benin), the Reserve of Biosphere of Pendjari (RBP) includes the municipalities of Materi, Tanguieta and Kerou, between 10°30' and 11°30' latitude North and 0°50' and 2°00' longitude East (Vodouhe *et al*, 2011). The rainy season begins in April with a rainfall ranging from 750 to 1100 mm per year, followed by a dry season from November to March (Montcho *et al,* 2011). Three (3) types of soils define the geology of the area: the ferruginous tropical soils washed or less washed, hydromorph with intrusion of soils ferruginous tropical washed highly concretionned, the ferruginous tropical soils washed hydromorph on schist made of quartz or without concretion on micaschist made of quartz, and the soils boarding the rivers with alluvial contributions hydromorphic in fine sand material (Faure, 1977). The altitude of the landscape is ranging from 150 to 513 m (Nago *et al.*, 2016). Pendjari River with a total length of about 380 km is the only one river in the RBP (Houinato and Sinsin, 2000). The vegetation, a mixture of open grass with tree savannahs and the forest vegetations is typically soudanian, (Verschuren, 1988; Oumorou *et al,* 2013).

SAMPLING AND DATA COLLECTION

We collected primary data in seven villages of Tanguieta and Materi municipalities because of their proximity to the park. Data were collected during the 2009-2010 agricultural campaign in the villages of Batia, Tanougou Pessegou, Tchafarga, Sangou, and Kollegou in Tanguieta municipality and the village of Dassari in Materi municipality. Our sample includes 178 cotton plots and 126 maize plots belonging to 152 farmers selected at random (Table 1). We collected data on crop plots, farmer's socio-economic characteristics, farming systems and density of termite mounds through a survey with a questionnaire.

Table 1: Number of plots and crop acreage for the research villages in Pendjari region.

Nombre de parcelles et surfaces cultivées dans les villages d'enquête dans la Région de Pendjari.

Villages	Number of maize plots	Maize plots (ha)	Maize plots (%)	Average size of maize plot (ha)	Number of cotton plots	Cotton plots (ha)	Cotton plots (%)	Average size of cotton plot (ha)
Batia	54	79.00	38.00%	1.46	43	53.0	23.79%	1.26
Kollegou	8	15.00	7%	1.88	27	35.5	15.94%	1.31
Pessegou	12	13.75	7%	1.15	27	36.5	16.39%	1.35
Sangou	6	10.50	5%	1.75	26	32.75	14.70%	1.26
Tanougou	12	24.50	12%	2.04	26	27.5	12.35%	1.06
Tchafarga	16	21.75	11%	1.36	26	32.5	14.59%	1.25
Dassari	18	41.50	20%	2.31	03	05	2.24%	1.67
TOTAL	126	206.00	100.00%	-	178	222.75	100%	-

MODEL SPECIFICATIONS

From Transcendental Production Function to Generalized Power Production Function

Cobb Douglas production function was the most popular method used until the mid-1950s, when both economists and agricultural economists began recognizing its limitations. Cobb Douglas production function suggests a fixed production elasticity, which require that average product of the production (*APP)* and marginal product of the production (*MPP)* be at a fixed proportion to each other for the production factors concerned. Consequently, Cobb Douglas production function did not very well represent the neoclassical three stage production function.

Halter, Carter and Hocking (1957) made slight modifications in the Cobb Douglas production function to allow an easy estimation from agricultural data resulting in the three stages of production and variable production elasticities.

The two-input function suggested by Halter *et al.* (1957) was:

$$y = Ax_1^{g(x_1,x_2)}x_2^{h(x_1,x_2)}e^{f(x_1,x_2)} \quad (1)$$

In the continuation of Halter *et al.* (1957), de Janvry (1972) suggested the generalized power production function (GPPF), which had, as special cases, the Cobb Douglas with variable input elasticities, and the transcendental.

The generalized power production function (GPPF) was suitable for the present problematic because of its flexibility. In addition to the description of the three stages of production provided, it allows for non-homogeneity and also for variability of the returns to scale, marginal productivities, elasticities of production, marginal rates of substitution, and elasticities of substitution (de Janvry, 1972). Under behavioral assumption of maximization of expected profits, direct estimation of the production function from cross-section data is always free from simultaneous equation bias, whatever the functional form.

The GPPF can be written as:

$$Y = F(X) = A\prod_{k=1}^{K} X_k^{f_k(X)} e^{g(X)} \quad (2)$$

where $f_k(X)$ and $g(X)$ are polynomials of any degree in the arguments of the K-dimensional input vector X.

In the special case of three inputs ($X1$ = quantity of fertilizer and $X2$ = density of inhabited termite mound, X3 = labor)

$$f_k(X) = \alpha_k \text{ and } g(X) = \sum_i \sum_j LnX_i LnX_j \text{ and } k=3$$

$$Ln(Y) = Ln\,[F(X)] = \alpha_0 + \alpha_i + \sum_{i=1}^{K} LnX_i + ½ \sum_{i=1}^{K}\sum_{j=1}^{K} \alpha1_{ij}\, LnX_i LnX_j + \sum_{i=1}^{K}\sum_{j=1}^{K} \alpha2_{ij}\, X_i LnX_j \quad (3)$$

and

$$Ln(Y) = \alpha_0 + \alpha_1 LnX_1 + \alpha_2 LnX_2 + \alpha_3 LnX_3 + ½\,[\alpha_4 (LnX_1)^2 + \alpha_5 LnX_1 LnX_2 + \alpha_6 LnX_1 LnX_3 + \alpha_7 (LnX_2)^2 + \alpha_8 LnX_2 LnX_3 + \alpha_9 (LnX_3)^2] + \alpha_{10} X_1 LnX_1 + \alpha_{11} X_1 LnX_2 + \alpha_{12} X_1 LnX_3 + \alpha_{13} X_2 LnX_1 + \alpha_{14} X_2 LnX_2 + \alpha_{15} X_2 LnX_3 + \alpha_{16} X_3 LnX_1 + \alpha_{17} X_3 LnX_2 + \alpha_{18} X_3 LnX_3 \quad (4)$$

Marginal Physical Product (MPP), Elasticity (Ep), and Optima factor combination zone

As regard to the neoclassical production function, the marginal physical product (MPP) refers to the change in output y associated with an incremental change in the use of an input x (Debertin, 2012).

$$MPP = \Delta y/\Delta x \quad (5)$$

where Δy denotes the change in output y and Δx the change in input x.

In case of a given marginal product function (y= $f(X)$), the MPP ($\Delta y/\Delta x$) represents the slope or rate of change in the production function. The production function itself is sometimes referred to as total physical product (or TPP) function.

Average physical product (APP) is defined as the ratio of output to input (Debertin, 2012).

APP= y/x or *APP=TPP/x* *(6)*

Average physical product (APP) also changes as the use of input x increases, although APP is never negative.

The elasticity of production (Ep) is defined as the percentage change in output (y) divided by the percentage change in input (x), as the level of input use is changed (Jeyle and Reny, 2011). It is defined by the formula:

$$Ep = [\Delta y/y]/[\Delta x/x] \quad (7)$$

The elasticity of production can also be defined in terms of the relationship between *MPP* and *APP (*Debertin, 2012*)*.

Equation (7) might also be written as:

$$Ep = (\Delta y/\Delta x)/(x/y) \quad (8)$$

Notice that $\Delta y/\Delta x$ = *MPP* and that *x*/*y* = 1/*APP.*

Thus, *Ep = MPP*/*APP* (9)

The elasticity of production is one way of measuring the production function response to changes in the use of input. It helps defining the three stages of production as regard to the neoclassical production function (Debertin, 2012).

Stage 1: An elasticity of production greater than 1 (*Ep>1*) implies that the output y responds strongly to increases in the use of the input x and indicates that *MPP* has a very high value relative to *APP*. In other words, the output occurring from the last incremental unit of input (*MPP*) is very great relative to the average output obtained from all units of input (*APP*).

Stage 2: An elasticity of production between 0 and 1 (*0<Ep<1*) suggests that output y will increase as a result of the use of *x*, but the smaller the elasticity, the less the response in terms of increased output. In other words, the value of the output from the last incremental unit of input (*MPP*) is small relative to the average productivity of all units of input (*APP*).

Stage 3: A negative elasticity (*Ep<0*) of production implies that as the level of input use increases, output will actually decline, not increase.

Micro-economic theory indicates that economic input use occurs at levels at which the input's marginal product is positive and less than the corresponding average product i.e. Stage 2 of production zone, (Debertin, 2012). Consequently, this zone is called « *Economic region of production* » or « *optimal factor combination zone'* » (Losinger, Dasgupta, Engle and Wagner, 2000).

The present paper analyzes the marginal product of cotton and maize yields by identifying the economic and non-economic regions of production and characterizing the impact of increased termite mound density on the cotton and maize yields.

RESULTS

SOCIO-ECONOMIC CHARACTERISTICS

Table 1 presents some characteristics of the crop plots sampled. It may be noted that the number of cotton and maize plots was significantly higher in the village of Batia compared to other villages. Due to its location (in a hunting area near the Pendjari Park) the village is under great pressure on land, which requires producers to develop strategies to maintain or increase the fertility of their soil. This could explain the relatively high number of crop fields where there are active termite mounds.

DETERMINATION OF THE OPTIMAL FACTOR COMBINATION

Estimation of the coefficients for the production functions

Maize production function estimates

Table 2 shows some characteristics of maize plots in the study area. In general, the Acreage of crop plot varies from 0.25 to 4 ha with an average of 1.64 ha for all plots. The quantity of chemical fertilizer used on maize plots varies from 83.33 to 300 kg / ha with an average of 196.13 kg / ha. The quantity of family human labor varies from 180 to 1800 human-days / ha with an average of 815.73 human-days. The density of termite mound per hectare varies from 1 to 8 tm/ha with an average of 3.16 tm / ha. It's important to note that the average of maize yield is 1123.93 kg/ha for all plots.

Table 2: Descriptive Statistics for maize producers.

Statistiques Descriptives sur les producteurs de maïs.

Variables	Minimum	Maximum	Mean	Std. Deviation
Acreage of crop plot (ha)	0.50	4	1.64	0.84
Crop yield (kg/ ha)	600	1700	1123.93	299.84
Quantity of fertilizer on the crop plot (kg/ha)	83.33	300	196.13	36.67
Density of termite mound per ha	1	8	3.16	1.87
Human labor on the crop plot (man-days)	180	1800	815.73	356.49

The coefficients of the production function of maize were estimated through a multiple linear regression model and the results are presented in Tables 3, 4 and 5.

Table 3: Model summary for the maize yield function.

Résumé du modèle pour la fonction de production du maïs.

Model	R	R Square	Adjusted R Square	Durbin-Watson
1	0.493	0.243	0.148	2.160

Table 4: ANOVA for the maize yield function.

Analyse de variance pour la fonction de production de maïs.

Model		Sum of Squares	df	Mean Square	F	Sig.
1b	Regression	2.399	14	0.171		
	Residual	7.463	111	0.067	2.549	0.003a
	Total	9.862	125			

a. Predictors: (Constant), Ln(Lab), Ln(Tm), Ln(Fer), Lab×Ln(Lab), Fer×Ln(Lab), Ln(Lab)_square, Tm×Ln(Tm), Lab×Ln(Tm), Fer×Ln(Tm), Fer×Ln(Fer), Ln(Tm)_square, Lab×Ln(Fer)
b. Dependent Variable : Ln (y_maize)

Table 5 : Estimated coefficients for the maize yield function.

Coefficients estimés pour la fonction de production de maïs.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta (*β*)		
	(Constant)	-1.827	4.839	-	-0.378	0.706
	Ln(Fer)	*1.481*	*0.575*	*1.089*	*2.576*	*0.011*
	Ln(Tm)	*4.219*	*2.321*	*8.843*	*1.817*	*0.072*
	Ln(Lab)	0.139	0.585	0.242	0.237	0.813
	Ln(Tm)_square	*-0.731*	*0.361*	*-3.169*	*-2.023*	*0.045*
	Ln(Tm) ×Ln(Lab)	*-0.814*	*0.428*	*-11.424*	*-1.903*	*0.060*
	Ln(Lab)_square	*0.009*	*0.003*	*0.275*	*2.943*	*0.004*
1a	*Fer×Ln(Fer)*	*-0.004*	*0.002*	*-3.315*	*-1.794*	*0.075*
	Fer×Ln(Tm)	0.002	0.001	0.907	1.653	0.101
	Fer×Ln(Lab)	0.003	0.003	2.589	1.190	0.237
	Tm×Ln(Tm)	-0.180	0.225	-2.790	-0.797	0.427
	Tm×Ln(Lab)	0.160	0.126	7.192	1.269	0.207
	Lab×Ln(Fer)	0.000	0.001	-5.348	-1.267	0.208
	Lab×Ln(Tm)	0.000	0.000	0.745	0.696	0.488
	Lab×Ln(Lab)	0.000	0.000	4.283	1.130	0.261

a. Dependent Variable: Ln (y_maize)

Table 4 shows that the resulting model is significant at 1%. The variables included in the model explained 24.3% of the changes in maize yield (Table 3).

One can write the model as follow (referring to equation 4).

$$\text{Ln (y\_maize)} = 1.481 \times \text{Ln(Fer)} + 4.219 \times \text{Ln(Tm)} - (1/2) \times (0.731) \times [\text{Ln(Tm)}]^2 - (1/2) \times (0.814) \times \text{Ln(Tm)} \times \text{Ln(Lab)} + 0.009 \times [\text{Ln(Lab)}]^2 - 0.004 \times \text{Fer} \times \text{Ln(Fer)} \quad (10)$$

Marginal product of the quantity of fertilizer per hectare (Fer)

The formula for the elasticity of the maize yield according to the quantity of fertilizer is:

$$\epsilon_{Fer} = \frac{\partial [Ln\ E(Y)]}{\partial Ln\ [Fer]} = 1.481 - 0.004 \times \text{Fer} - 0.004 \times \text{Fer} \times \text{Ln(Fer)}$$

The elasticity varying from 0 to 1, the quantity of fertilizer (Fer) varies from 27.8 to 70.5

Marginal product of the density of termite mound (Tm)

The formula for the elasticity of the maize yield according to the mound density is:

$$\epsilon_{Tm} = \frac{\partial [Ln\ E(Y)]}{\partial Ln\ [Tm]} = 4.219 - 0.731 \times \text{Ln(Tm)} - 0.407 \times \text{Ln(Lab)}$$

$\overline{Lab} = 815.73$

The elasticity varying from 0 to 1, the mounds density (Tm) varies from 1.95 to 7.68

Percentages of farmers operating in stage I, stage II and stage III according respectively to fertilizer and termite mound

The optimal factor combination zone of maize production is boarded by the values of quantities of chemical fertilizer of 27.8 and 70.5 *kg.ha*$^{-1}$ and the density of termite mound of 1.9 and 7.7 *mound.ha*$^{-1}$. So, Optimal conditions of maize production are possible with quantities of fertilizer between 27.8 and 70.5*kg.ha*$^{-1}$ when the density of termite mound may take values between 1.95 and 7.68 *mound.ha*$^{-1}$.

All (100%) the maize producers are operating in stage **III** with respect to quantity of fertilizer and 6.4% with respect to the density of termite mound. With respect to density of termite mound, 27.2% of the maize producers were operating in stage **I** and 66.4% were operating in stage **II**. Finally, we have any maize producer operating in the optimal factor combination zone (stage **II** with respect to fertilizer and density of termite mound simultaneously). That means that any of the maize producers are growing maize in the optimal condition according to the two inputs concerned.

Quantity of fertilizer (kg/ha)

	stage I (termite mound); stage III (fertilizer) (27.2%)	stage II (termite mound); stage III (fertilizer) (66.4%)	stage III (termite mound); stage III (fertilizer) (6.4%)
70.5	stage I (termite mound); stage II (fertilizer) (0.0%)	stage II (fertilizer); stage II (termite mound) (0.0%)	stage III (termite mound); stage II (fertilizer) (0.0%)
27.8	stage I (termite mound); stage I (fertilizer) (0.0%)	*stage II (termite mound); stage I (fertilizer) (0.0%)*	stage III (termite mound); stage I (fertilizer) (0.0%)
	1.9	*7.7*	

Density of termite mound (mound/ha)

Figure 1: The optimal factor combination for maize production with respect to fertilizer doze and density of termite mound.

La combinaison optimale de facteur de production de maïs, en fonction de la dose d'engrais et de la densité de termitière.

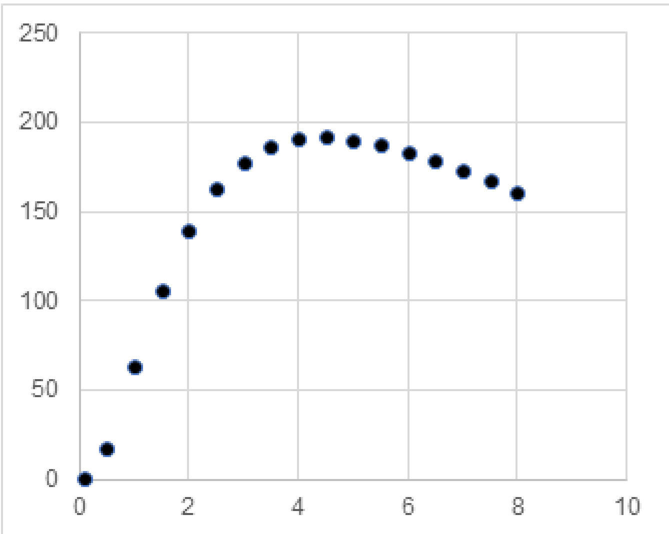

Figure 3: Maize yield response to the density of termite mound.

Réponse du rendement de maïs à la densité de termitière.

The optimal factor combination zone for maize production according to the field data goes from 27.8 to 70.8 kg/ha lower than the doze of 150 kg/ha recommended by the extension services.

Cotton production function estimates

Table 6 shows that the acreage of cotton plot varies from 0.25 to 3 ha with an average of 1.26 ha for all plots. The quantity of family human labor varies from 114.75 to 982.50 human-days/ha with an average of 411.92 human-days/ ha. The quantity of chemical fertilizer used on cotton plots varies from 150 to 400 kg / ha with an average of 213.52 kg / ha. The density of termite mound per hectare varies from 0 to 9 tm / ha with an average of 4.02 tm / ha. The average of cotton yield is 1683.85 kg/ha for all plots.

Table 6. Descriptive Statistics for cotton producers

Statistiques descriptives sur les producteurs de coton

Variables	Minimum	Maximum	Mean	Std. Deviation
Acreage of crop plot (ha)	0.25	3.00	1.26	0.76
Crop yield (kg/ ha)	500.00	2833.00	1683.85	661.75
Human labor on the crop plot (human-days/ha)	114.75	982.50	411.92	195.86
Quantity of fertilizer on the crop plot (kg/ha)	150.00	400.00	213.52	49.18
Density of termite mound per ha	0	9.00	4.02	2.37

The coefficients of the production function of cotton were estimated through a multiple linear regression model using the stepwise method. Due to the place of cotton production in the economy of West Africa countries this cash crop has been subject to a lot of studies and researches related to the determination of the factors affecting the cotton yield which has to be taken into account. The latter justifies the use of the stepwise regression model to explore the determinants of the cotton yield in the present study.

The results of the regression model are presented in Tables 7, 8 and 9.

Table 8 shows that the resulting model (model 3) is significant at 1%. The variables included in the model explained 29.1% of the changes in cotton yield (Table 7).

Table 7: Model summary for cotton yield function.

Résumé du modèle pour la fonction de production de coton.

Model	R	R Square	Adjusted R Square	Durbin-Watson
1	0.478	0.229	0.192	-
2	0.506	0.256	0.217	-
3	0.539	0.291	0.248	1.711

Table 8: ANOVA for cotton yield function.

Analyse de variance pour la fonction de production de coton.

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	7.526	8	0.941		
	Residual	25.355	169	0.150	6.270	0.000a
	Total	32.881	177	-		
2	Regression	8.432	9	0.937		
	Residual	24.448	168	0.146	6.438	0.000b
	Total	32.881	177	-		
3	Regression	9.560	10	956		
	Residual	23.321	167	0.140	6.846	0.000c
	Total	32.881	177	-		

a. *Predictors: (Constant),* Tm×Ln(Fer), Lab×Ln(Fer), Fer×Ln(Fer), Ln(Fer) ×Ln(Tm), Ln(Fer) ×Ln(Lab), Ln(Fer), Fer×Ln(Tm), Fer×Ln(Lab)

b. *Predictors: (Constant)*, Tm×Ln(Fer), Lab×Ln(Fer), Fer×Ln(Fer), Ln(Fer) ×Ln(Tm), Ln(Fer) ×Ln(Lab), Ln(Fer), Fer×Ln(Tm), Fer×Ln(Lab), Lab×Ln(Tm)

c. *Predictors: (Constant),* Tm×Ln(Fer), Lab×Ln(Fer), Fer×Ln(Fer), Ln(Fer) ×Ln(Tm), Ln(Fer) ×Ln(Lab), Ln(Fer), Fer×Ln(Tm), Fer×Ln(Lab), Lab×Ln(Tm), Ln(Tm) ×Ln(Lab)

Dependent Variable : Ln(y_cotton)

Table 9: Estimated Coefficients for cotton yield function.

Coefficients estimés pour la fonction de production de coton.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta (β)		
1a	Constant)	10.479	5.812	-	1.803	0.073
	Ln(Fer)	-1.460	1.416	-0.629	-1.031	0.304
	Fer×Ln(Fer)	0.004	0.002	3.230	2.298	0.023
	Lab×Ln(Fer)	0.000	0.000	-0.173	-0.588	0.557
	Ln(Fer)×Ln(Tm)	0.552	0.119	4.407	4.649	0.000
	Ln(Fer) ×Ln(Lab)	0.060	0.071	0.427	0.845	0.399
	Fer×Ln(Tm)	-0.015	0.003	-5.394	-4.673	0.000
	Fer×Ln(Lab)	-0.001	0.002	-1.089	-0.914	0.362
	Tm×Ln(Fer)	0.009	0.005	0.268	1.726	0.086
2b	(Constant)	14.370	5.933	-	2.422	0.016
	Ln(Fer)	-2.298	1.435	-0.990	-1.602	0.111
	Fer×Ln(Fer)	0.005	0.002	3.528	2.538	0.012
	Lab×Ln(Fer)	0.000	0.000	0.450	1.177	0.241
	Ln(Fer) ×Ln(Tm)	0.669	0.126	5.346	5.311	0.000
	Ln(Fer) ×Ln(Lab)	0.038	0.070	0.274	0.547	0.585
	Fer×Ln(Tm)	-0.016	0.003	-5.733	-5.007	0.000
	Fer×Ln(Lab)	-0.001	0.002	-0.957	-0.815	0.416
	Tm×Ln(Fer)	0.005	0.005	0.150	0.940	0.349
	Lab×Ln(Tm)	0.000	0.000	-0.747	-2.496	0.014
3c	(Constant)	-1.635	8.093	-	-0.202	0.840
	Ln(Fer)	2.681	2.246	1.155	1.194	0.234
	Fer×Ln(Fer)	0.004	0.002	2.926	2.124	0.035
	Lab×Ln(Fer)	0.001	0.000	2.547	3.078	0.002
	Ln(Fer) ×Ln(Tm)	-0.958	0.586	-7.649	-1.635	0.104
	Ln(Fer)×Ln(Lab)	-0.289	0.134	-2.062	-2.154	0.033
	Fer×Ln(Tm)	-0.011	0.004	-4.024	-3.163	0.002
	Fer×Ln(Lab)	-0.002	0.002	-1.624	-1.384	0.168
	Tm×Ln(Fer)	0.010	0.006	0.295	1.793	0.075
	Lab×Ln(Tm)	-0.004	0.001	-4.014	-3.383	0.001
	Ln(Tm)×Ln(Lab)	1.521	0.535	13.606	2.842	0.005
Dependent Variable : Ln (y_cotton)						

Then, the model could be written as follow.

$$\text{Ln (Y\_cotton)} = 0.004 \times \text{Fer} \times \text{Ln(Fer)} + 0.001 \times \text{Lab} \times \text{Ln(Fer)} - 0.144 \times \text{Ln(Fer)} \times \text{Ln (Tm)} - 0.011 \times \text{Fer} \times \text{Ln(Tm)} + 0.01 \times \text{Tm} \times \text{Ln(Fer)} - 0.004 \times \text{Lab} \times \text{Ln(Tm)} + 0.760 \times \text{Ln(Tm)} \times \text{Ln (Lab)} \quad (11)$$

Marginal product of the quantity of chemical fertilizer (Fer)

The formula for the elasticity of the cotton yield according to the quantity of fertilizer is:

$$\epsilon_{Fer} = \frac{\partial\,[\text{Ln E(Y)}]}{\partial\,\text{Ln [Fer]}} = 0.004 \text{ x Fer} + 0.004 \text{ x Fer x Ln(Fer)} + 0.001 \text{ x } \overline{\text{Lab}} - 0.144 \text{ x Ln(}\overline{\text{Lab}}\text{)} - 0.011 \text{ x Ln(}\overline{\text{Tm}}\text{) x Fer} + 0.01 \text{ x } \overline{\text{Tm}}$$

With the mean value of mound density ($\overline{Tm}$ = 4.02) ; the mean value of quantity of fertilizer (Fer = 213.52); and the mean value of quantity of labor force ($\overline{Lab}$ = 411.92).

The elasticity varying from 0 to 1, the the quantity of fertilizer (Fer) equals 69.5

Marginal product of the density of termite mound (Tm)

The formula for the elasticity of the cotton yield according to the mound density is:

$$\epsilon_{Tm} = \frac{\partial\,[\mathrm{Ln}\,E(Y)]}{\partial\,\mathrm{Ln}\,[Tm]} = -\,0.011 \times \overline{Fer} + 0.01 \times \mathrm{Ln}\,(\overline{Fer}) \times Tm - 0.004 \times \overline{Lab} + 0.760 \times \mathrm{Ln}\,(\overline{Lab})$$

$$\epsilon_{Tm} = 0.579 + 0.054 \times Tm$$

With the mean value of mound density ($\overline{Tm}$ = 4.02) ; the mean value of quantity of fertilizer ($\overline{Fer}$ = 213.52); and the mean value of quantity of labor force ($\overline{Lab}$ = 411.92).

The elasticity varying from 0 to 1, the mound density (Tm) varies from 0 to 7.8.

The optimal factor combination zone of cotton production is boarded by the values of quantities of chemical fertilizer of 69.5 and 200 *kg ha⁻¹* and the density of termite mound of 0 and 7.8 *mound ha⁻¹*. So, optimal conditions of cotton production are possible with quantities of fertilizer between 69.5 and 200 *kg ha⁻¹* when the density of termite mound may take values between 0 and 7.8 *mounds ha⁻¹*.

12.3% of the cotton producers are operating in stage III with respect to quantity of fertilizer and 10.6% with respect to the density of termite mound. With respect to density of termite mound, 0% of the cotton producers operating in stage I and 89.3% were operating in stage II. With respect to dose of chemical fertilizer, 0% of the cotton producers were operating in stage I and 87.6% were operating in stage II.

Finally, we have 79.2% of cotton producer operating in the optimal factor combination zone (stage II with respect to fertilizer and density of termite mound simultaneously).

Quantity of fertilizer (kg/ha)			
	stage I (termite mound); stage III (fertilizer) (0.0%)	stage II (termite mound); stage III (fertilizer) (10.1%)	stage III (termite mound); stage III (fertilizer) (2.2%)
200.0	stage I (termite mound); stage II (fertilizer) (0.0%)	stage II (fertilizer); stage II (termite mound) (79.2%)	stage III (termite mound); stage II (fertilizer) (8.4%)
69.5	stage I (termite mound); stage I (fertilizer) (0.0%)	stage II (termite mound); stage I (fertilizer) (0.0%)	stage III (termite mound); stage I (fertilizer) (0.0%)
		0.0	*7.8*

Density of inhabited termite mound (mound/ha)

Figure 2: The optimal factor combination for cotton production with respect to fertilizer doze and density of termite mound.

La combinaison optimale de facteur de production de coton, en fonction de la dose d'engrais et de la densité de termitière.

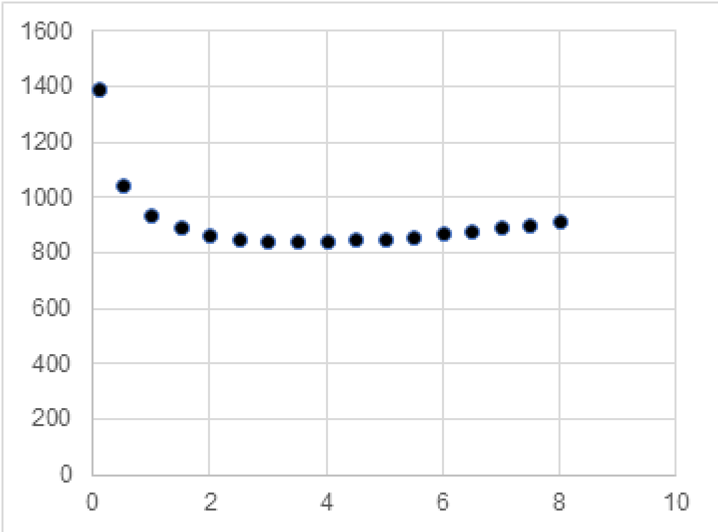

Figure 4: Cotton yield response to the density of termite mound.

Réponse du rendement de coton à la densité de termitière.

DISCUSSION

USEFULNESS OF THE DENSITY OF TERMITE MOUND IN AGRICULTURE

According to the density of termite mound, the optimal factor combination zone for maize production in Pendjari region extends from *1.24* to 1*.54 mounds ha*$^{-1}$ (figure 3) when for cotton it is at *0.0 mound ha*$^{-1}$. (figure 4) Pomeroy (1977) research on abundance of large termite mound found that the density of termite mound in most part in Uganda is *1* to *4 mounds ha*$^{-1}$, only a small proportion of the country having more. Abe (2012) research on soil particles accumulation in termite mound in the Southern Guinea Savanna agro-ecological zone concerned a study plot of *4 ha* including 6 mounds of *Macrotermes bellicosus* (density = *1.5 mound ha*$^{-1}$). This low frequency of *M. bellicosus* mounds was explained as follows: (i) the mound density correlates with the mound size becoming less than two mound ha^{-1} when the mound becomes over *2 m* tall (Collins 1981a), and (ii) anthropogenic disturbance such as bush clearing and subsequent farming reduces the mound density (Hullugale and Ndi, 1993; Ekundayo and Aghatise, 1997). Moreover, the preliminary survey by means of field observation and farmer interview revealed that the majority of *M. bellicosus* mounds in Niger State (Central Nigeria) were over *2 m* tall and that the savanna plateau is increasingly over-exploited due to lengthened cultivation periods and shortened fallow duration driven by the demands of a rapidly growing population. Korb and Linsenmair (2000) classification of *M bellicosus* termite mound is adopted for the typology of the mounds concerned in the Pendjari region. This classification states that small inhabited termite mounds with height lower than $1.5m$ corresponded to the less stable, initial stage [according to Oster and Wilson (1978) this includes mainly the subterranean stage, but small mounds are also less stable, for example due to a reduced capacity for thermoregulation (Korb and Linsenmair, 1998a & 1999)]. Hence, according to inhabited termite mounds, only the medium (height: 1.5-3.95 m) and large (height: $\geq 4m$) inhabited termite mounds are taken into account. According to the uninhabited termite mounds, the entirely eroded mounds (height $\leq 0.5m$) are not considered. So, according to the results of mound frequency in the Southern Guinea Savanna and the similarity of agro ecological conditions, low frequency of *M. Bellicosus* may be expected in Pendjari region. However, Pendjari region is a protected area with a high impact of biodiversity projects interventions (almost 89% of the survey sample farmers have participated to a biodiversity project). Rahman (2005) research results in Bangladesh reveal that the level and duration of involvement with modern technology raises farmers' environmental awareness, and that farmers' environmental awareness reduces resource use including chemicals. This latest could justify the density registered on maize plots. The density of 1.24 to 1.54 *mound ha*$^{-1}$ on maize plots combined with the fact that it is more likely to find termite mound on a plot hosting mixed crops confirms the results of Sileshi *et al*, (2005) research on termite damage on maize production in which maize grown in *L. leucocephala*, *G. sepium*, *A. anguistissima* and *S. sesban* fallows suffers less termite damage and produces maize yields comparable with conventionally tilled and fully fertilized monoculture maize.

According to the quantity of chemical fertilizer, cotton plot requires more quantity than maize plot when referring to the extent of their optimal factor combination zone. Kamara *et al*, (2014) research on new cultivars of *Zea maysL* in Nigeria concluded that these cultivars can be grown with application of less N fertilizer thereby reducing investment on fertilizers and reduction in environmental pollution. Moreover, the extent of the optimal factor combination zone according to the density of termite mound is larger for maize than cotton.

AGRONOMIC AND ECONOMIC EFFECTIVENESS OF THE DENSITY OF TERMITE MOUND IN CROP PRODUCTION

The effect of termite mound density on crop production is analysed through the response of maize and cotton yields derivate from the production function.

Maize yield response

With reference to equation 11, maize yield function is rewritten only function of the density of termite mound with the mean values *Fer* = 196.13, *Lab* = 815.73 (Table 2).

According to maize yield (figure 3) variation, the optimum yield (200 kg/ha) is reached with a density of mounds of 4 mounds per hectare when for the same density the minimum yield is reached for cotton yield (800 kg/ha) (figure 4). The yield value varies from 150 to 200 kg/ha for the maize and from 800 to 1400 kg/ha for the cotton. When comparing the optimum yield values with the sample means values (1124 kg/ha and 1684 kg/ha), the difference is more significant for maize than for cotton. Then, the optima yields values are closer to the mean values for the cotton than for the maize. But the extent of the interval of variation of the optimum values is larger for cotton (1400-800 = 600) than for maize (200-150 = 50).

Cotton yield response

With reference to equation 12, maize yield function is rewritten only function of the density of termite mound with the mean values *Fer* = 213.52, *Lab* = 411.92 (Table 6).

According to the cotton, its yield is decreasing as the density of termite mound increases. The minimum yield (800 kg per hectare) is reached at the density of termite mound of 2 mounds per hectare. Then, the cotton yield increases from 800 kg/ha to 900 kg/ha from 4 to 8 mounds/ha. Between 2 and 4 mounds/ha, the cotton yields is stable at 800 kg/ha (figure 4).

With reference to the form of the curves, the maize yield curve is creasing when the cotton curve is decreasing the two with optima. Then, termite mound density is shown to have a positive influence on maize yield and a negative influence on cotton yield.

In Amazonia, the experiment on termite nest used in combination with mineral fertilizer results to best crop yield than only mineral fertilizer (Batalha *et al,* 1995). Termite mound soil is used in experiment in addition to crop residue and cow dung to build compost responding to good standard in India (Karak *et al,* 2015). Evans *et al.* (2011) experiment in the arid extreme of wheat production in Australia shows that ants and termites increase wheat yield by 36%. These three findings above confirm the one in Pendjari region (Benin) regarding the maize yield response to the termite fertility effect but not for the cotton yield.

CONCLUSION

Cotton and maize yield functions are elastic to the quantity of chemical fertilizer and to the density of termite mound. Consequently, optimal combination of chemical fertilizer and fertility effect of termites is possible for maize and cotton productions. In addition, the results show that most of maize farmers in the study area are not operating in the optimal factor combination zone while it is not the same for cotton producers according to the combination of the two factors. Nevertheless, when considering only the factor density of termite mound, most of the maize farmers (66.4%) and the cotton farmers (89.3%) are operating in the optimal zone of production (Figures 1 & 2). In addition, the density of termite mound has a positive influence on the maize yield when the influence is negative on cotton yield even if the yield optima values interval of variation is larger for cotton yield function than for maize yield function.

It suggests the conclusion that farmers may know how to valuate termites' fertility effect in agriculture but may not know how to combine it with the chemical fertilizer.

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