EFFECT OF FIELD APPLICATION OF *Cubitermes* (ISOPTERA, TERMITIDAE) MOUND SOIL ON GROWTH AND YIELD OF MAIZE IN CENTRAL AFRICAN REPUBLIC

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ABSTRACT

This work was undertaken at two different sites (A and B) in the field in Central African Republic (4°23 N, 18° W) during a two years-period. The objective of the work is to show the effect of termites (*Cubitermes* sp.) mounds on the growth and yield of maize. Samples of 250 g (T1) and 1000 g (T2) of mounds materials were applied before maize sowing and plant growth parameters were monitored. Results show that the application of 1 kg of termites mounds (containing, on average, 1.46 - 1.60 g mineralizable N) produced significant maize growth 30 days after sowing. Yield also increased by 45.1 % for a planting density of 31 250 plants ha^{-1}, is a significant difference 0,92 t / ha ($p < 0.05$) as compared to the control. The effect of the mounds on the growth which became significant after 30 days, suggests that from this period, maize root zone would explored a certain volume of soil. Although the turn-over of Cubitermes mounds was fast, their intensive use industrially would certainly raise the issue of availability.

Key words : *Cubitermes*, mounds, fertilizer, amendment maize.

RESUME

TERMITIERES DE Cubitermes *COMME AMENDEMENT NATUREL*

Ce travail a été effectué sur deux sites (A et B) en plein champs en République Centrafricaine (4°23 N and 18° IE) sur une période de deux ans. L'objectif est de montrer l'effet des sols de termitières de Cubitermes *sp. sur la croissance et le rendement du maïs. Des échantillons de 250 g (T1) et 1000 g (T2) de sols de termitières appliqués avant semis, ont été appliqués autour des pieds de maïs. Les résultats montrent que l'application de 1000 g de sol de termitière (contenant en moyenne 1.46 à 1.60 g de N minéralisable) est susceptible d'entrainer une croissance significative des plants de maïs 30 j après semis. Une augmentation en rendement graines de 45.1 % ont également été enregistrés, avec une densité de plantation de 31 250 plants ha^{-1}, soit une différence significative 0,92 t ha^{-1} ($p<0.05$), relativement au témoin. L'effet du sol de termitière sur la croissance des plants devenant significatif après 30 j, suggère qu'à partir de cette période, la rhizosphère s'est bien développée dans un volume de sol important. Bien que le turn-over des termitières Cubitermes soit rapide, l'utilisation des sols de termitière en agriculture, à l'échelle industrielle ou intensive risque de poser des problèmes de disponibilité.*

Mots clés : Cubitermes*, termitières, engrais, amendement, maïs.*

INTRODUCTION

Because of the pressures exercised by man, directly and indirectly, on the environment (such as the use of slash and burn cultivation, and the reduction in length of fallow periods) the soil of tropical regions is becoming depleted in nutrients, which represents a major impediment to agricultural production (Kombele et Boloy, 1995). Therefore, important measures to guarantee sustainable agriculture are necessary. Maize cropping, which is one of the basic forms of food production in tropical regions, must be conducted as part of an integrated programme of agricultural production. In numerous regions of Africa, small-scale agriculture is generally carried out without the use of fertilizer (Rouanet, 1984), and production depends strongly on soil fertility. This practice of farming without using inputs is often carried out with traditional plant varieties which are preferred by some farmers because of their price, the availability of seed, and the fact that improved-maize varieties have a higher demand for N-P-K mineral manure, which is expensive (Houdenou, 2001).

With traditional varieties, farmers in African regions where rainfall is between 900 and 1 600 mm per year grow one or two crops of maize per year depending on climatic zones, and this produces yields below 1 ton/ha per crop cycle (Marquette, 1986). In these regions, rainfall is often the most important factor affecting the planting schedule. In the Guinean forest climate, as found in the Central African Republic, an initial planting is done in February and the harvest occurs in April, while the second planting is done in May and is harvested in July. These periods of farming correspond to seasons when precipitation is high and steady, and thus can meet water needs during the stages of growth and maturation. In Togo, Poss *et al.* (1988) estimated the water requirement for a crop cycle of hybrid corn (110 days) at between 350 and 400 mm.

Because of difficulties of access to chemical inputs and their high cost in tropical regions, an alternative must be sought.

Long regarded as pests because of their destructive activities against crops, some termites, according to recent research on the use of termite material as a natural soil additive, would seem to be of environmental and agricultural interest for developing countries (Boga *et al.*, 2000a, Boga *et al.,* 2000b, Boga 2007, Ndiaye *et al.*, 2003, Lepage et Duponois, 2006, Mokossesse *et al.,* 2009 et Yapi *et al.,* 2010).

Soil-feeding termites of the *Cubitermes* genus ingest organic matter mixed with mineral soil particles (Brauman *et al.,* 2000), creating favourable conditions in their nests for development and operation of micro-organisms (Brauman and Fall, 1998). The role of termites in the evolution of environmental components (materials recovery) has been highlighted (Tano and Lepage, 1990). The above-ground nests of several species are known for their high content of clay, increasing the holding capacity of organic matter, water and nutrients (Kombele, 2002). In particular, it has been shown that the walls of termite mounds belonging to the Cubitermes genus contain more organic matter than the adjacent land and up to 100 times more ammonium (Ndiaye *et al.,* 2004).

So far in Central Africa, most studies on the effect of *Cubitermes* mound soil (hereafter quoted as ‘termite soil’) have been carried out on plants grown in pots and have only been related to the initial development of the plants. Our goal was to examine whether the use of termite soil in the field would result in better plant growth and increased grain production. We used maize for this test because of the importance of this crop as a local staple food.

MATERIALS AND METHODS

GEOGRAPHICAL SITUATION OF SITES

The study location in 2007 was within the Institut Supérieur de Développement Rural (ISDR) in the Central African Republic, situated three km from the town of M’Baïki, and spread over an area of 260 ha (3°53' N, 17°58' E at an altitude of 480 m) (Figure 1).

In 2008, the experiments were transferred to a field setting in the village of Pissa II, 35 km NW of M’Baïki (4°02' N, 18°07' E, at 370 m altitude).

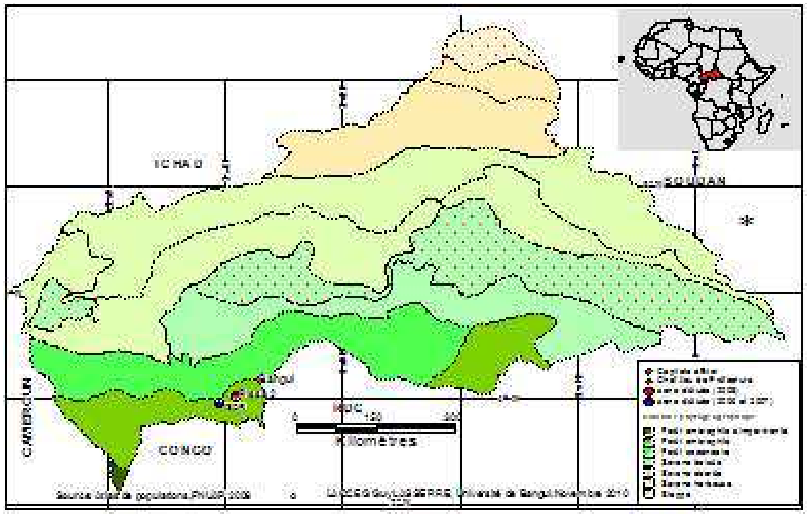

Figure 1 : Geographical location of study sites in the Centre African Republic.

Situation géographique du site de l'étude en République Centrafricaine.

CLIMATE OF THE STUDY SITES

The climate is of the Guinea forest type, characterised by two seasons ; a long rainy season lasting eight months (March to October) and a dry season lasting four months (November to February). The annual rainfall varies between 1 500 and 1 600 mm (www.weatherbase.com consulted to 2012). The relative humidity of the air is very high : > 70 %. The average monthly temperature varies between 24 and 27 °C.

SOIL OF THE STUDY SITES

The soil of the study site of 2007 (ISDR) is a red sandy, clay type characteristic of ferralitic soils. This type of soil is usually rich in nutrients but it is acidic and fragile (Boulevert, 1986). The soil at the 2008 site has a texture of clay loam and sand, is grey and slightly hydromorphic

VEGETATION OF THE SITES STUDY

In 2007, the natural vegetation of the sites is tropical rain forest. Our initial observations carried out before the start of the field trial showed that the herbaceous strata were dominated by *Imperata cylindrica* (L.) (Poaceae) and *Chromolaena odorata* (L.) King and Robinson (Asteraceae). We also noted a significant amount of *Pennisetum purpureum* (Schum) (Poaceae). Several woody species were also encountered : *Mangifera indica* (L.) (Moraceae), *Elaeis guineensis* (L.) (Palmaceae), *Ceiba pentandra* (L.) (Malvaceae).

The site of study in 2008 was characterised by herbaceous vegetation interspersed with a few shrubs. It was dominated by *Brachiaria* sp and some examples of *Chromolaena odorata* were present. The site had been fallow for a long time (10 years).

MATERIALS

Used plant material

Zea mays L varieties CMS 87 and CMS 84 (Cameroon Selection Maize) are the used plant in the tests were purchased from the seed centre of the ISDR. The hybrid variety CMS87 which has a short cycle (90 days), gives a potential yield of 6 to 7 tons of grain per hectare under a fertilization of 250 kg/ha of N-P-K 14-24-14 and 250 kg/ha of urea (for a density of 50 000 plants/ha), and requires a minimum rainfall of 800 mm (Feujio and Yuri, 2004). The local variety CMS 84 which is an open pollinated population had a long cycle (105 - 115 days). These varieties are chosen because he is vulgarised in Central African Republic.

Material used as amendment

The termites mounds which served as amendment is a nest of *Cubitermes.* These termites nests appear in the form of big mushroom, characterized by a surmounted column by one or many hats. Termites mounds used in 2007 is *C. ugandensis* Fuller collected from Boaka, village situated in a forest savanna in 37 km to ISDR.

In 2008, termites mounds used as amendment is *C. sankurensis* Wasmann collected in savanna arbustive in Pissa village.

METHODS

Plot

The experimental sites measured de 2080 m^2 of area (52 x 40 m) subdivide in 6 blocks of 6 small experimental plots. The small experimental plot measured 40 m² (10 x 4 m). The experimental (Figure 2) design was that of the split plot with six repetitions in randomized complete blocks, with varieties as main plots treatments and doses of termite soil as small plots treatments.

Groung preparation

Trees and shrubs were cut down to avoid their shade affecting the growth of the maize. The debris from clearing the ground was removed and burned off-site. Work involving turning the soil to a depth of 10 cm to remove the rhizomes of *Imperata* and other fast-growing weeds came after clearing the ground with hoes and machetes.

Soil preparation for planting points

At the planting points, circular holes about 15 cm deep with a diameter of 30 cm were dug.

The termite mounds were cut at ground level and then transferred and stored on the test site the day after collection. They were broken up using sledgehammers and sieved to 2 mm. The powders thus obtained were stored in piles for two days under cover before use. The soil piled at the edge of the hole and the termite soil (250 g and 1 kg) was placed in a container and mixed by repeatedly turning it by hand. This mixture was used to fill the planting holes. In the case of the control seedlings, the original soil was placed back in the planting hole. The centre of the prepared area was marked with a thin stick.

The small plot treatments tested in this study were thus composed of the control (denoted T0 = ground plot soil without termite soil), treatment T1 (mixture of 250 g of termite soil and plot soil) and treatment T2 (a mixture of 1 kg of termite soil and plot soil). The experiment therefore did not involve the substitution of soil types but the addition of termite soil.

Sowing method

Each plot was planted with five rows of maize, each containing 25 seedlings. The rows were separated by 80 cm and the seedlings were 40 cm apart on the rows, giving a density of 31 250 plants per ha. The blocks (a set of basic plots) were separated by 2 m.

The doses of termite soil (250 g and 1 kg) were weighed and poured into Minigrip ® bags and deposited in front of each hole according to the experimental design. A small hole 2 cm in diameter and 5 cm deep (at a point marked with a thin stick) was made by hand, and 3 or 4 corn seeds were sown and the hole filled in.

A thinning to one plant per planting point was made 21 days after sowing.

Monitoring Parameters

The growing : five plants per small plot (20 % of plants) were chosen at random to be monitored during growth. The five chosen plants were marked by labels which were inserted in the ground at their base.

The production : the height measurements were made from the ground to the last leaf with a visible tip in the plant, whorl using a measuring tape (accuracy : ± 1 cm). The decision to harvest was made when the colour of the leaves was brown and when the grains could no longer be indented with a fingernail. The biomass of grain was weighed (accuracy : ± 0.01 g) after drying for 21 days in free air at room temperature.

Statistical treatments

The data were subjected to various ANOVAs (according to the design of the experiment as indicated above) followed by multiple comparisons of means (Tukey test) using Statistica ® 8.0 software. Also in the case of growth measurement (growth in height) taken at successive times on the same plants the ANOVAs were conducted including the time effect (analysis on measurements repeated through time). This was not the case of the grain yields where only one measurement (per trial) was made. The block effect was not taken into account in the case of yield because the plants were grouped per plot for weight measurement per plot.

The results are expressed as mean and standard deviations. Error bars in the figures are standard deviations. For the sake of readability, error bars are not all represented.

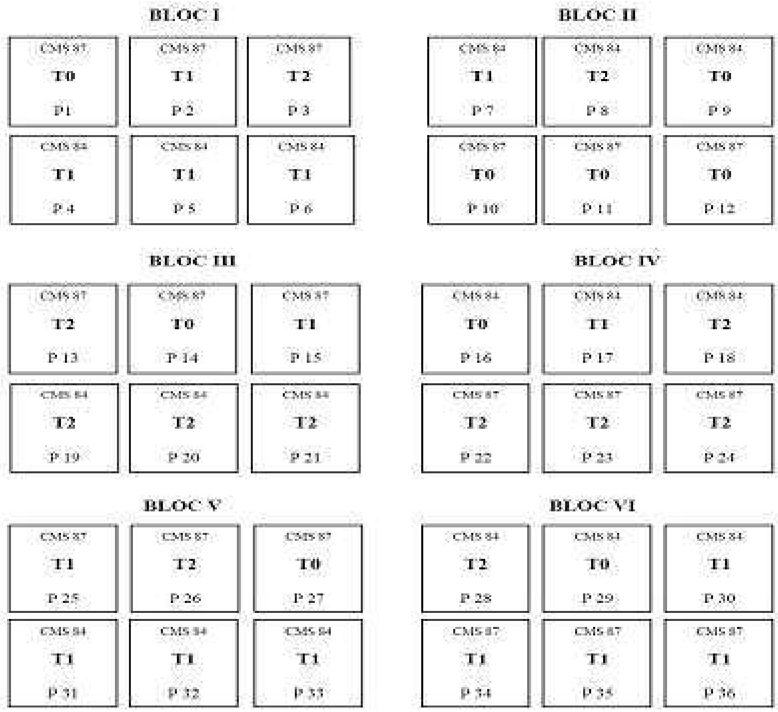

Figure 2 : Plot layout.

Planche expérimentale.

RESULTS

CHARACTERISATION OF PLOT SOIL AND MOUNDS TERMITE

Plot soil and termite mounds were collected in 2007 and 2008 for analysis. They were taken from 20 different locations of the plots using a root probe to depths up to 20 cm. By sample, 100 g was taken for chemical analysis by the Agronomic Center and Agro-industry (CARAH) in the province of Hainaut in Belgium. The results are consigned into tables 1 and 2.

The determination of ammonium and nitrate nitrogen was made by extraction with KCL, and measured by colorimetry. Potential nitrogen was measured by dray combustion with the Dumas method. The other elements were measured by ICP after extraction with EDTA

The analysis showed that in 2007 (Table 1) the content of ammonium nitrogen (NH4+-N) and nitrogen mineralizable were respectively 42 and almost two times more concentrated in the termite mounds than in the surrounding soil ($p < 0.001$) ; the concentrations of nitrate (NO3—N) were 14 times more concentred in mounds termite than control ($p < 0.001$). The phosphorus content was slightly higher in the termite mounds than in the soil of the plots (no significant). Potassium ions were 1,7 times more concentrated in the termite mounds ($p < 0.01$).

Chemical analysis of samples from 2008 (Table 2) showed that all the major mineral elements were significantly more abundant in the termite mounds than in the savannah soil. The ammonium nitrogen (NH4+-N) was 50 times more concentrated ($p<0.0001$), the nitrate nitrogen (NO3—N) was 20 times more concentrated ($p < 0.0001$) and the mineralizable nitrogen was about twice as concentrated in the termite mounds ($p < 0.001$) than in the surrounding soil. Potassium was four times higher and phosphorus was twice as high in the termite mounds than in the control soil. All these differences were highly significant.

Table 1 : Chemical characteristics of the soil from the plots and *Cubitermes ugandensis* mounds in 2007.

Caractéristiques chimiques des sols des parcelles et des matériaux issus des nids de Cubitermes ugandensis en 2007.

Simple soil	assim P. (mg/100g)	exchang K. (mg/100g)	C (g/100g)	Total N (g/100g)	NH_4-N(mg/kg)	NO_3-N(mg/kg)
Control	0,48±0,04	11,7±2,02	1,07±0,34	0,61±0,21	2,85±1,81	0,66±0,33
Termite mound	0,55±0,12	19,98±2,92	2,19±0,07	1,6±0,06	118,6±18,5	9,36±0,16
p- values*	Ns	p< 0,01	p= 0,035	p= 0,007	p< 0,0001	p< 0,001

* The p-values of one-way ANOVAs ; numbers followed by the same letter in the column are not significantly different (Tukey).

Table 2 : Chemical characteristics of the soil from the plots and the *Cubitermes sankurensis* mounds in 2008.

Caractéristiques chimiques des sols des parcelles et des matériaux issus des nids de Cubitermes sankurensis en 2008.

Soil sample	assim P. (mg/100 g)	exchang K. (mg/100 g)	C (g/100 g)	Total N (g/kg)	NH_4-N (mg/kg)	NO_3-N (mg/kg)
Control (0-10 cm)	0.41 ± 0.01^c	3.10 ± 0.10^c	1.10 ± 0.03^b	0.83 ± 0.03^b	5.05 ± 0.5^b	1.46 ± 0.26^b
Control (10-20 cm)	0.36 ± 0.006^b	5.32 ± 0.04^b	0.91 ± 0.01^c	0.69 ± 0.01^c	4.61 ± 0.2^b	0.68 ± 0.07^b
Termite mound	0.72 ± 0.01^a	20.3 ± 0.13^a	1.92 ± 0.02^a	1.46 ± 0.02^a	242.5 ± 4.2^a	14.98 ± 0.11^a
p-values *	p < 0.0001	p < 0.0001	p < 0.001	p < 0.001	p < 0.0001	p < 0.0001

* The p-values of one-way ANOVAs; numbers followed by the same letter in the column are not significantly different (Tukey).

INFLUENCE OF TREATMENTS ON GROWTH

A two-way ANOVA (with treatment and block as criteria) repeated in time (measures on the same plants through time), in 2006, showed very significant effects of the treatments and blocks ($p < 0.001$) without interaction. The influence of the treatments on the height of corn became significant 45 days after sowing. The height of the plants followed the order: T0 < T1 = T2 (Tukey).

In 2007, there were different varieties and the design was a split plot (three criteria : block, treatment and variety). Differents measurements were also measured through time on the same plants. The analysis showed a very highly significant difference between treatments and maize varieties ($p < 0.0001$). With CMS 84 variety, the plant height became significant 30 days after sowing. At 45 days, we obtained 112.7 cm of height on T2 treatment compared to control (82 cm) (Figure 3a). With CMS 87 variety, the plant height became significant 45 days after sowing without 127 cm of the height compared to control (98 cm) (Figure 3b). The height of the plants followed the order : T0 <T1 <T2 (Tukey) and CMS84 < CMS87.

In 2008, the design of the experiment was also a three-way anova with measures repeated in time. The analysis showed very highly significant differences ($p < 0.0001$) between treatments and varieties, and the interaction was not significant. The height of the plants followed the order : T0 < T1 < T2 (Tukey) and CMS84 < CMS87. The influence of the treatments on plant height became significant 30 days after sowing. At 45 days, we obtained with CMS 84 variety 107 cm of height on T2 treatment compared to control (72 cm) (Figure 4a). With CMS 87 we obtained 117 cm of the height on T2 treatment compared to control (94 cm) (Figure 4b).

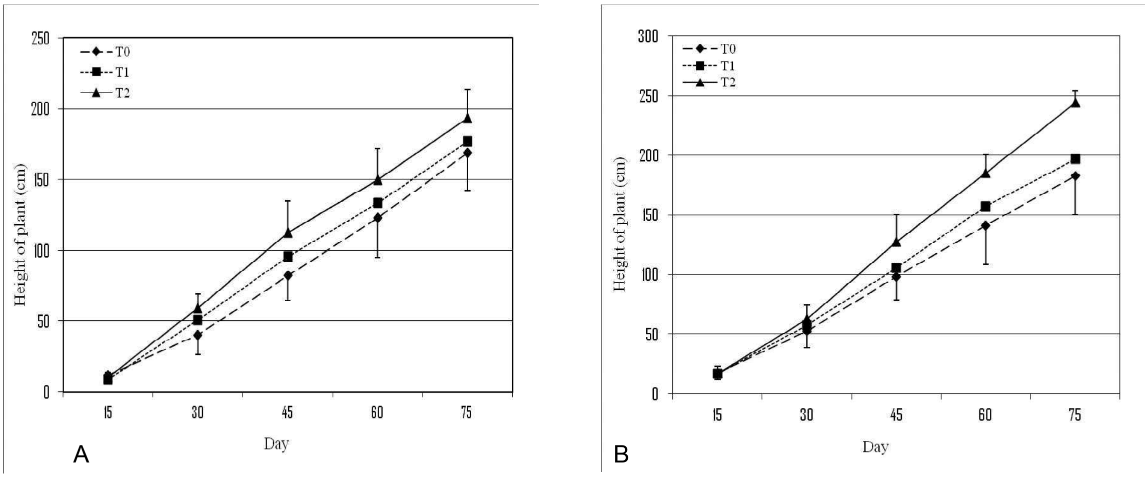

Figure 3 : Growth in height of the corn according to treatments : average of three years for the A) variety CMS84 and B) variety CMS87 in 2007 (T0 : control, T1 : addition of 250 g and T2 : addition of 1 kg of termite soil per plant).

Croissance en hauteur du maïs selon les traitements : moyenne des 3 années pour A) variété CMS84 et B) variété CMS87 en 2007 (T0 : controle, T1 : 250 g et T2 : 1 kg de sol de termitière par plant).

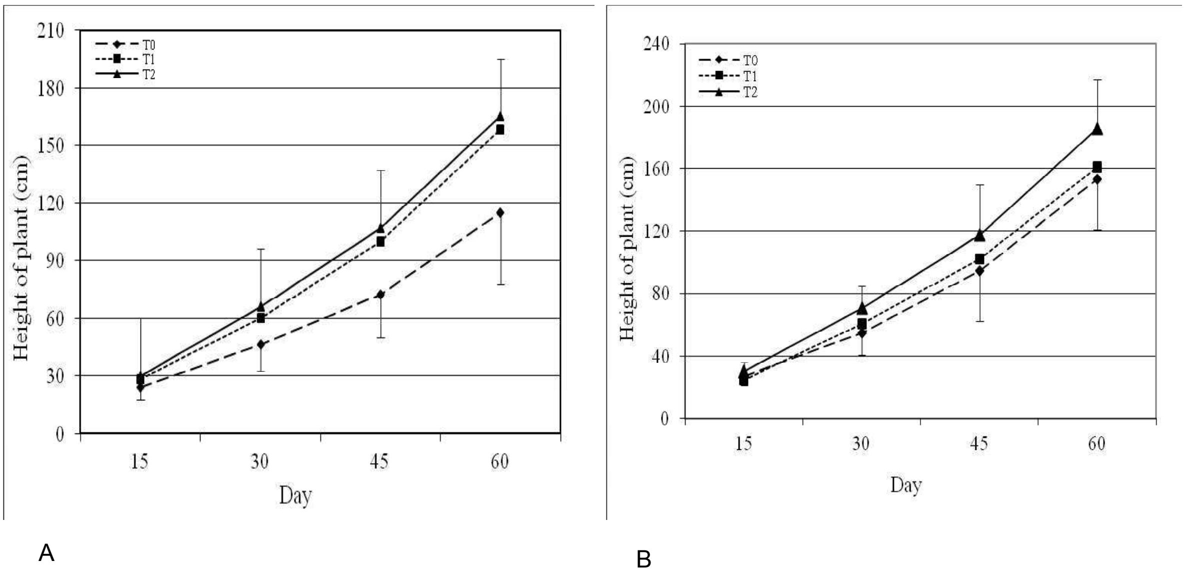

Figure 4 : Growth in height of the corn according to treatments : average of three years for the A) variety CMS84 and B) variety CMS87 in 2008 (T0 : control, T1 : addition of 250 g and T2 : addition of 1 kg of termite soil per plant).

Croissance en hauteur du maïs selon les traitements : moyenne des 3 années pour A) variété CMS84 et B) variété CMS87 en 2008 (T0 : controle, T1 : 250 g et T2 : 1 kg de sol de termitière par plant).

INFLUENCE OF TREATMENT ON PRODUCTION

Table 3 summarizes the contributions of N, P and K and compares these with recommended doses reported in the literature. Table 4 presents the production data of both varieties for the two years of the experiment.

The addition of 1 kg of termite soil (T2) per plant increased grain production by 53.4 % and 44.7 % compared to the control (T0) in 2007 and 2008 respectively. With an addition of 250 g of termite soil per plant, increased grain production was 31 % and 17.9 %. On the 2007 data, ANOVA showed a highly significant difference ($p < 0.001$) between treatments and varieties without interaction. The production of grain mass followed the order T0 < T1 < T2 (Tukey) and CMS84 < CMS87. In 2008, a significant difference was observed (two-way ANOVA) between treatments ($p = 0.008$). The production of grain mass followed the order : T0 < T1 < T2 (Tukey) and CMS84 < CMS87.

Table 3 : Comparison of amounts of mineral elements recommended or reported in the literature and provided by 1 kg of termite soil per maize plant in this study *.

Comparaison des quantités d'éléments mineraux recommandés et reportés dans la littérature et fourni par 1 kg de sol de termitière par plant de maïs.

	Wey (1995)	Akanvou (1995)	Rouanet, 1984	Feujio & Youri, 2004 CMS87 variety	Feujio & Youri, 2004 CMS87 variety	This work, 2007 CMS87 variety	This work, 2008 CMS87 variety
Lieu	Burkina Faso	Côte d'Ivoire	Gabon	Cameroon	Cameroon	Central Africa (M'Baïki)	Central Africa (Pissa)
Density (plants/ha)	25 000	50 000	50 000	50 000	50 000	31 250	31 250
Nitrogen (N)* (g)	Mineral + urea 0.71	Mineral + urea 0.77	Mineral 1.2	Mineral + urea 2.3	Mineral + urea 3.0	Organic 1.60	Organic1.46
Phosphorus (P)* assimilable (g)	0.21	0.24	0.39	0.31	0.52	0.006	0.007
Potassium (K)* (g)	0.24	0.45	0.42	0.35	0.58	0.20	0.20
Grain production (t/ha)	<u>2.4 - 3.7</u>	2 - 3	3 - 4	4 - 5	6 – 7	<u>2.89</u>	<u>3.17</u>

* All data are expressed as g of elemental N, P and K per plant.
The figures for obtained production are highlighted ; those that are not underlined indicate expected production.

Table 4 : Production of corn (in g DM per plantof the CMS84 and CMS87 varieties from 2007 and 2008.

	2007		2008	
	CMS84	CMS87	CMS84	CMS87
T0	51.79 ± 2.15	57.72 ± 6.72	53.29 ± 2.85	66.8 ± 7.50
T1	66.25 ± 7.25	76.15 ± 4.84	69.16 ± 5.77	79.19 ± 9.00
T2	78.95 ± 7.06	88.95 ± 5.38	87.38 ± 9.08	97.46 ± 8.52

* For production in kg/ha, multiply these values by 31.25.

DISCUSSION

COMPARATIVE ANALYSIS OF THE QUANTITIES OF N, P AND K AVAILABLE TO PLANTS

For comparison purposes, all data are expressed as g of N, P (not P_2O_5) and K (not K_2O) per plant, since the seedling density varied between 25 000 and 50 000 plants/ha. We discuss mainly the minerals added with 1 kg of termite soil. We can immediately see that the contributions per plant were very similar over the three years of study although the termite soil came from mounds produced by different species and from different environments.

The recommended doses of fertilizers for the CMS87 variety vary depending on the expected yield : 250 kg/ha of N-P-K (14-24-14) and 250 kg/ha urea for an expected return of 6 - 7 tons/ha and 50 000 plants/ha, or 150 kg/ha of N-P-K and 200 kg/ha of urea to yield 4 - 5 tons/ha (Feujio and Yuri, 2004). If one expresses all these data per plant (Table 3), the supplements of minerals contained in 1 kg of *Cubitermes* termite soil appear weak in terms of potassium and very low in terms of phosphorus compared to the recommended dose. Regarding nitrogen, the supplements seem larger than many of those suggested by the literature. But in fact, it was mainly potential nitrogen (not immediately available to the plant) that first had to be mineralized by micro-organisms. Since there will always be a recalcitrant fraction, it is difficult to estimate what our additions really represented compared to nitrogen doses recommended in the literature. One can nevertheless expect that these additions will have a positive effect on growth and production of maize.

INFLUENCE OF THE TERMITE SOIL ON GROWTH

The addition of termite soil had, each year, a significant and positive effect on height of the two varieties of maize after 60 days of growth. The experimental plants (T1 and T2) had sizes 9.9 % and 21.4 % greater than controls respectively (average of three years). These results confirm those of Mokossesse *et al.* (2009) who showed that the termite soil significantly influenced the growth of *Sorghum* sp and *Crotalaria ochroleuca* in pots and this difference became statistically significant only 30 days after sowing. The fact that this difference was observed only 30 to 45 days after sowing, as was also the case for maize, can probably be explained by the progressive availability of organic nitrogen content in the termite soil. Similar observations were made by Ndiaye *et al.* (2003) in an experiment of growth in pots of *C. ochroleuca* on substrates supplemented with *Cubitermes niokoloensis* soil. The study revealed two types of effects : a direct effect by the addition of inorganic nitrogen, mainly as ammonium already present in the added material, and then a more gradual effect from the mineralization of organic matter contained in the termite soil and thus requiring the intervention of bacteria. The acceleration of growth seen at 30 - 45 days appears to correspond to a period of rapid plant development when needs for minerals and elements are increasing (Girardin, 1999) and which is known as 'shooting' (fast growth phase).

INFLUENCE OF THE TERMITE SOIL ON THE PRODUCTION OF GRAIN

The addition of termite soil had, each year a significant positive effect on the production of grain of the two varieties of maize, but with some variations : treatment T2 on the variety CMS87 achieved, compared with T0, yields 2.89 against 1.87 t/ha in 2007 and 3.17 against 2.17 t/ha in 2008. The yield increases in 2007 and 2008 (34 and 54 %) appeared significantly different. Between these first two years of experimentation, the characteristics of the soil (from the plot and termite mounds) were the same. Each plant thus received an additional 1.6 g of total nitrogen and it was expected that the increases in production would be similar.

In 2007 and 2008, the methods of soil preparation were identical. On the other hand, the termite mounds and locations were different, as were the chemical characteristics of the soil. The control soil of 2008 (Pissa) was slightly lower in exchangeable bases and total nitrogen than that of 2007 (M'Baïki). Nevertheless the Pissa yields were higher, possibly because the pH was lower (5.4) in M'Baïki than in Pissa (6.4) or perhaps because of another parameter, rainfall, which was not measured.

The lowest production that we obtained - 1,684 kg/ha in 2007 with the variety CMS84 under control T0 - was nevertheless superior to those obtained by traditional methods of corn cultivation in Central Africa, which is of the order of 900 kg/ha with a density 25 000 plants/ha, using a farming method without inputs and with watering only from rainfall' (Bonomatepat, personal communication). The difference may have resulted, in addition to the difference in density of sowing, from land preparation and the elimination of some weeds, whose competitive impacts are well known (Wey 1995).

The highest production that we obtained, 3 167 kg/ha in 2008 with the variety CMS87 using treatment T2, was less than can be expected from that variety, which can range from 4 to 7 t/ha according to Feujio and Yuri (2004) but at a density 50 % higher than we used and with application of fertilizers (see Table 3). The period these researchers recommend for the first application of N-P-K is between 7 and 10 days after germination, followed by urea application 30 days after sowing. The application of termite soil obviously does not follow this pattern; however most of the nitrogen is supplied in organic form and mineral forms that are usable by the plants are released gradually ; the termite soil thus functions as a slow-release fertilizer.

The use of improved varieties is recommended for sustainable agriculture on acid soils (pH < 6, Oost, 1996) which are phosphorus-deficient, such as the soils of sub-Saharan countries (Hocking *et al.,* 2000). Such acidic soil is indeed found at M'Baïki (pH = 5.4) but soil is less acidic at Pissa (pH = 6.4).

The benefit of improved varieties (Date *et al.,* 1995) was confirmed by this study. Compared with the local variety, CMS84, the improved variety, CMS87, produced on average (T0, T1 and T2 combined) 13 and 16 % additional grain in 2007 and 2008 respectively.

CONCLUSIONS

The results - an increase in production of almost 50 % compared to cultivation without inputs - are very positive and show that termite soil may be of interest as a natural fertilizer for poor soils and for extensive cultivation. However, this raises several questions.

Is this method sustainable ? Although it is true that the soil from *Cubitermes* nests provides a mineral supplement, we also saw that it was unbalanced and deficient in phosphorus. Repeated use of termite soil alone may therefore create a phosphorus deficiency, which could quickly become a limiting factor.

Is this method cost-effective ? This was not evaluated in this work, but it is clear that we must take into account the extra work and transportation that are involved. The application of one kg of termite soil per plant would involve the preparation of 31 tonnes of termite soil per hectare (assuming a density of 31 250 plants/ha) and transportation from the collection area to the farming location, which has significant logistical implications. Note that in intensive European agriculture it is not uncommon to make applications of additives (e.g. manure) of this order of magnitude in weight but this is done using adequate motorized equipment.

The dramatic effects observed may be astonishing but if one considers the total amount of nitrogen applied (1.46 to 1.6 g of nitrogen per plant) that represents (for 31 250 plants/ha) 46 to 50 kg of total nitrogen per hectare. In intensive agriculture and in plantations of about 100 000 plants/ha, inputs of around 100 to 200 kg of N as mineral fertilizer are common in Europe (depending on the richness of the soil and the desired yield).

In conclusion it may be attractive to farmers in areas where *Cubitermes* termite mounds are found in abundance in and near their fields to use these mounds for soil improvement. Feasibility in the longer term and on a larger scale is not yet proven and it seems reasonable at this stage of knowledge not to apply this method to major cultivation but rather to reserve it for use on an occasional basis to small plots of food crops or nurseries.

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