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Dynamics of the Reconstruction of Termite Mounts of the Genus Cubitermes in the Bondoe Savannah Forest, Central African Republic

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The use of termite mounds as an alternative to chemical fertilizers has grown in tropical developing countries. Termite mounds also play an important role in ecology and these studies were conducted on dynamic of the reconstruction of termite mounds of the genus Cubitermes in the Bondoé savannah from Central African Republic (CAF). The focus on this particular group may be due to their abundance and conspicuous mounds, compared with the diffuse belowground nests inhabited by soldier less soil-feeding termites. The hypothesis of this work was that the termite mounds of Cubitermes (*Cubitermes sankurensis* and *Cubitermes ugandensis*) could be reconstructed after removal of hats, trunks at ground level or when termite mounds are dug up 10 cm below the ground. Five (5) experiments were set up to follow the dynamics of the reconstruction of termite mounds during the dry and rainy seasons. The results show that termite mounds with hats removed in one operation rebuild better the following year (25-30% in the rainy season, 50-60% in the dry season). When the removal was done at ground level, an average of 22.5% reconstruction was recorded in the rainy season and 25-30% reconstruction observed in the dry season after one year. Termite

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mounds dug 10 cm below the ground did not perform better. The removal of hats during the dry season is an option for the rational management of Cubitermes termite mounds in agriculture in CAR.

Keywords: Termite mound; Reconstruction; Cubitermes.

1. INTRODUCTION

Termites are considered to be part of the terrestrial microfauna while playing an important role in ecology [1,2,3].

In tropical rainforests, termites constitute an important part of the soil fauna biomass, and as for other soil arthropods, variations in soil composition create opportunities for niche partitioning. Termites are important contributors to carbon and nitrogen cycling in tropical ecosystems. Higher termites digest lignocellulose in various stages of humification with the help of an entirely prokaryotic microbiota housed in their compartmented intestinal tract [4,5,6].

Some authors have shown that termite mounds are resistant to erosion [5,7].

The building and foraging activities of termites are known to modify soil characteristics such as the heterogeneity. In tropical savannas the impact of the activity of soil-feeding termites (*Cubitermes niokoloensis*) has been shown to affect the properties of the soil at the aggregate level by creating new soil microenvironments [8-10]

These environmental virtues of termite mounds lead us to think precisely about the means to put in place to avoid the irreversible destruction of termite mounds in an agrosystem [3].

The precise biological mechanism by which termite construction behavior and mound morphology are coupled is not yet fully understood, but a sizable literature of past work typically assumes the existence of some information-carrying field of odor particles, such as secreted pheromones or metabolic gases [11,12]

Few studies have looked at the growth of African termite mounds and the population dynamics of termites.

The observations [13] on *Cubitermes fungifaber* suggested that Cubitermes only healed the lesions without regenerating the lost parts. They qualify these termite mounds as "mosaic nests" where "each territory once built cannot be remade". Nests that were experimentally although partially destroyed were abandoned and the company migrated to a new nest that was built a short distance away.

The hypothesis of this work was that the termite mounds of Cubitermes (*Cubitermes sankurensis* and *Cubitermes ugandensis*) could be reconstructed after removal of hats, trunks at ground level or when termite mounds are dug up 10 cm below the ground.

2. MATERIALS AND METHODS

2.1 Choice of Studied Site

The locality of Bondoé (5 ° 16 N, 17 ° 37 E) is located at 142 km north-west of Bangui, capital of the CAR. This locality was chosen because of the abundance of termite mounds established on non-cultivable land (lateritic soil); which will allow us to follow the evolution of the termite mound population for several years. The climate is tropical characterized by a rainy season from May to October and a dry season from November to May. Rainfall ranges from 700 to 2000 mm, while the average annual temperature is around 26 ° C. The vegetation is an alternate sequence of forest and savannah; this savannah is traversed each year by bush fires, only trees and shrubs resistant to very high fire survive. The part of the area where our work was carried out is dominated by *Hyparrhenia sp.* [14]

2.2 Delimitation of plots and experiences

The 10 x 10 m plots experiment were conducted at 20 m from the road to avoid human disturbance and were delimited using a laser rangefinder by iron stakes fixed into the ground and stabilized with cement. The study was consisted of 31 plots weed management practices laid out in randomized block design in three blocks of 12, 12 and 7 plots respectively. Five (5) experiments were set up to follow the dynamics of the reconstruction of termite mounds during the dry and rainy seasons (Table 1).

In addition, there are five control plots: two (2) in block 1; two (2) in block 2 and one (1) in block 3.

When a nest is decapitated or cut near its base there are only a small number of openings between the interior of the nest (what remains of it) and the atmospheric air: 18 openings have for example were counted on the section of a nest 12 cm in diameter. These openings, which are about 2 cm in diameter, are quickly closed with soil or droppings brought in by workers. It is only later that termites eventually begin to build new structures. We will therefore speak of "reconstruction" only if the termites have built a new hat or a dome on the cut surface. The recording of data on the plots was done every six (6) months in order to follow the reconstruction dynamics of each termite mound in each plot (Donovan *and al*., 2001; Jouquet *and al*., 2002; [15]

2.3 Data Analysis

The nest growth data follow a normal distribution according to the Shapiro test. The comparison of the growth of the nests according to the blocks was therefore carried out on Analysis of Variances with 1-factor (ANOVA1), followed by Tukey's tests in the event of significant differences. The results are expressed as means ± standard deviation. Nest reconstruction rates were compared by Chi-square tests (*Chi²*). All tests were performed using R software (version 3.4.4).

3. RESULTS

3.1 Nests Dynamics on Control Plots

Concerning the 70 termite mounds in the control plots, 10 could not be identified (mostly dilapidated nests), 54 were occupied by *C. sankurensis* and *C. ugandensis*. In terms of apparent age, in 2007 there were 9 fresh nests, 43 eroded nests and 18 dilapidated nests. The control plots therefore fairly correctly represent the population of termite mounds in the three studied blocks. It is quite remarkable that all nests measured in 2006 were still present and active in 2009 except one. Only one was abandoned and a few new nests had appeared. The sizes of the control nests per block in 2006 and 2009 were compared by a one-sided Student's t test and for paired data. The average volumes of nests in block 1 (316 ± 206 dm^3), block 2 (276 ± 144 dm^3) and block 3 (211 ± 155 dm^3) in 2009 are very significantly greater than those of the same nests in 2006 with 189 ± 129 dm^3, 226 ± 139 dm^3 and 167 ± 127 dm^3, respectively (34 *df*, $p < 0.001$, n = 35; 12 *df*, $p < 0.01$, n = 13 and 20 *df*, $p < 0.01$, n = 21 respectively, Fig. 1). New nests that appeared between 2006 and 2009 are not taken into account in the calculation of these averages.

3.2 Dynamics of Nests Subjected to Interventions

Experiment 1 consisted of removing the caps from termite mounds in the rainy season for the first time in July 2006 in blocks 1 and 2 and in July 2007 in block 3. The dynamics reconstruction are shown in Fig. 2. 25-30% of nests that undergo a single intervention were reconstructed in the following year and very few other nests reconstructed in subsequent years. There are fewer reconstructions of nests with caps cut two or three times (<20%). An example of a nest with a hat reconstructed after surgery is shown in Fig. 3.

Experiment 2 consisted in removing the termite mound at ground level during the rainy season for the first time in July 2006 in blocks 1 and 2 and in July 2007 in block 3. The results are very heterogeneous: among the nests which were cut only once 15% were reconstructed in blocks 1 and 2 but none in block 3; among the nests intended to be cut several times, more than 30% reconstruction is observed in block 3 after the first intervention and a few (5%) managed to reconstruct themselves after two interventions (Fig. 2). On the other hand, in blocks 1 and 2, the reconstruction rate is less than 10% after the first intervention and zero after the second. The example of a nest cut low to the ground and which has been reconstructed is shown in Fig. 3.

Experiment 3 consisted of removing the termite mound including its base to a depth of 10 cm for the first time in July 2006 in blocks 1 and 2 and in July 2007 in block 3. The results are also here very heterogeneous. Indeed, among the nests which were removed only once 12% of the nests were able to reconstruct after one year and this rose to 16% in two years in blocks 1 and 2 but no reconstruction has been done in block 3. Among the nests intended to be removed several times, it been noted that more than 10% succeed in reconstruction themselves after two interventions in blocks 1 and 2 but no reconstruction is noted in block 3 after the second intervention (Fig. 2, experiment 3). The example of a nest that has been removed 10 cm deep and has been reconstructed is given in Fig. 3.

Experiment 4 consisted of removing the cap during the dry season for the first time in January 2007 in blocks 1 and 2. This experiment does not concern block 3. The reconstruction dynamics are shown in Fig. 2: we can see that 50 to 60% of the nests were rebuilt during the year following the first intervention, 25% after a second intervention and less than 10% after the third.

Experiment 5 consisted of removing the termite mound down to the ground during the dry season for the first time in January 2007 in blocks 1 and 2. The dynamics of reconstruction is shown in Fig. 3A: it can be seen that 25 to 30% of the nests were reconstructed during the year following the first intervention and this percentage increases after two and again after three years to exceed 40%. After a second procedure the reconstruction rate is just under 20% and just under 15% after the third intervention.

3.3 Dynamic of Nest According to Species and Comparisons of the Effects of Interventions

The comparison between *C. sankurensis* and *C. ugandensis* nests did not reveal any significant difference for the five experiments (Chi^2 = 7.93, df = 4, p = 0.09) because the two species reacted in the same way to the interventions. The comparison between the different experiments carried out in the rainy season showed a significant difference between experiments 1 and 3 (Chi^2 = 7.1, df = 2, p = 0.02) but the difference is not significant between 1 and 2 (Chi^2 = 0.009, df = 2, $p\text{-value}$ = 0.92) or between 2 and 3 (Chi^2 = 2.417, df = 2, $p\text{-value}$ = 0.088).

Table 1. summary of the method used for the implementation of the experiments on the three blocks

	Actions	Block concerned (date of intervention)	Different season of intervention
Experiment 1	Take off the hats of termite mounds	Blocs 1 et 2 (July 2006) Bloc 3 (July 2007)	Rainy season
Experiment 2	Remove termite mounds at ground level	Blocs 1 et 2 (July 2006) Bloc 3 (July 2007)	Rainy season
Experiment 3	Remove termite mounds completely and dig 10 cm deep	Blocs 1 et 2 (July 2006) Bloc 3 (July 2007)	Rainy season
Experiment 4	Take off the hats of termite mounds	Blocs 1 et 2 (January 2007)	Dry season
Experiment 5	Remove termite mounds at ground level	Blocs 1 et 2 (January 2007)	Saison sèche

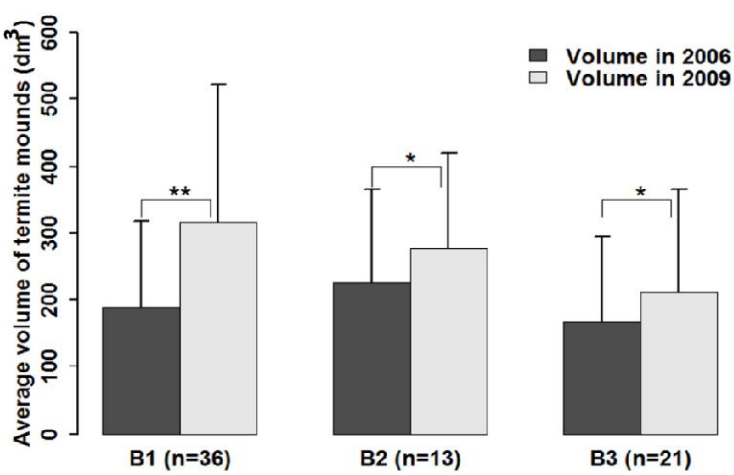

Fig. 1. Volume growth of control nests per block from 2006 to 2009 (means ± standard deviations). Asterisks indicate significant differences (ANOVA, ** = P <0.001; * = P <0.01). The entries B1, B2 and B3 respectively indicate blocks 1, 2 and 3; the number of termite mounds measured in each block is indicated in brackets

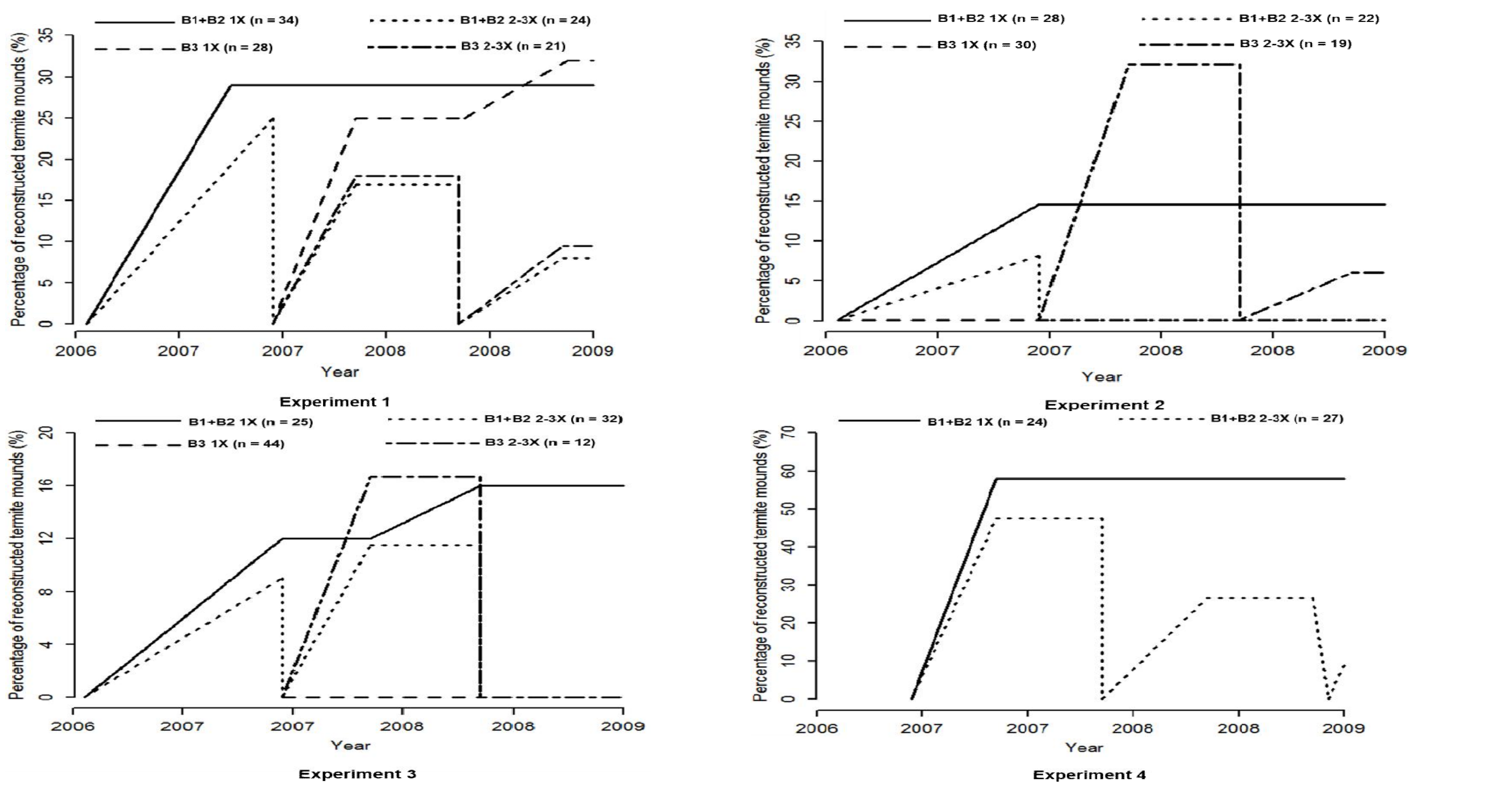

Fig. 2. Evolution of the percentage of reconstructed nests as a function of time after intervention. Experiment 1: removal of the hat in the rainy season; Experiment 2: removal of the nest at the level of the soil surface in the rainy season; Experiment 3: removal of the nest to a depth of 10 cm in the rainy season; Experiment 4: removal of the cap in the dry season. The entries B1, B2 and B3 respectively indicate block 1, block 2 and block 3; "1X" and "2-3X" indicate the number of interventions the nests undergo. The number of nests used for each intervention is indicated in brackets

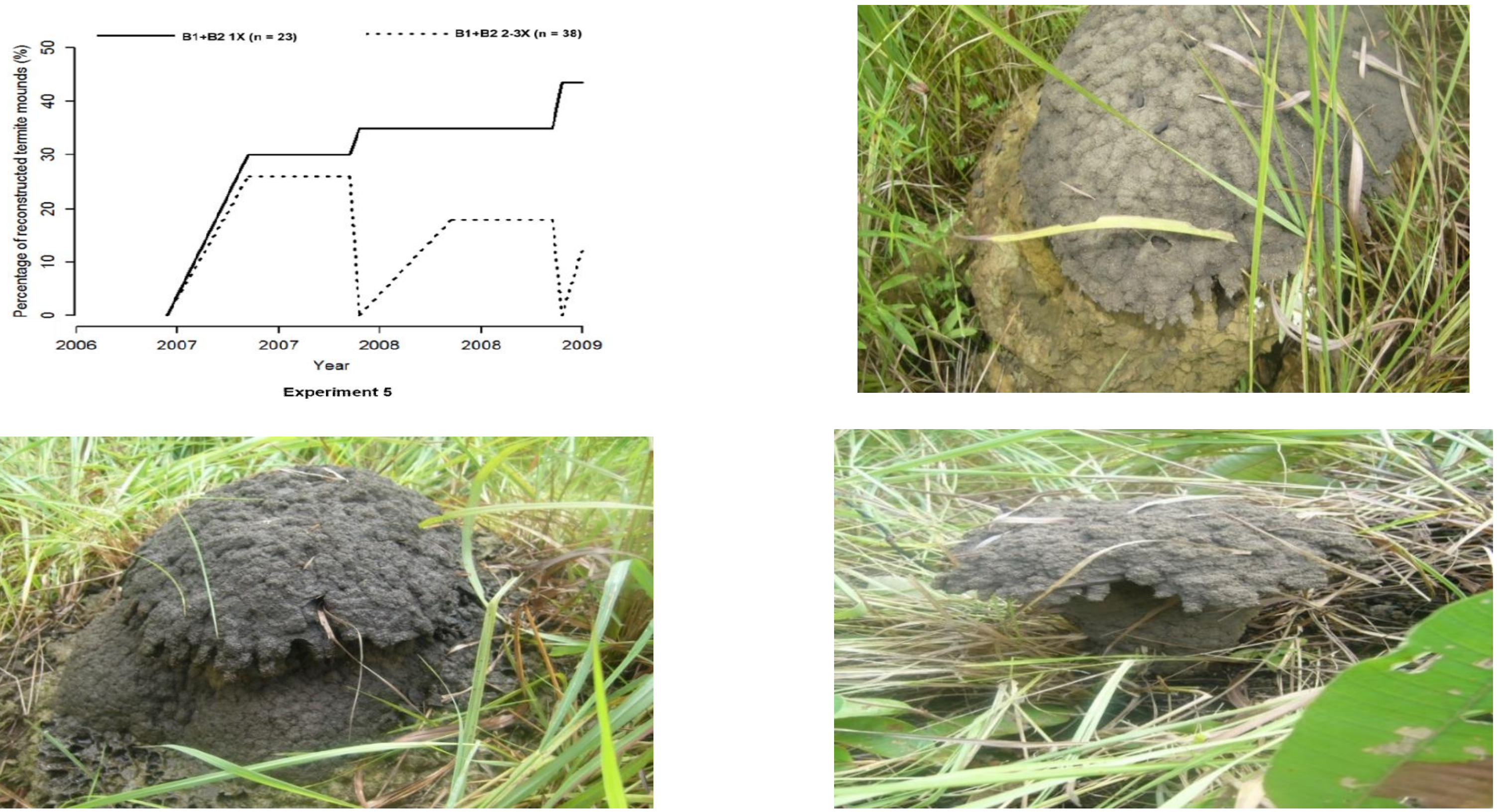

Fig. 3. (A) Evolution of the percentage of reconstructed nests as a function of time after removal of the nest at ground level in the dry season. The entries B1, B2 and B3 respectively indicate block 1, block 2 and block 3; "1X" and "2-3X" indicate the number of interventions the nests undergo. The number of nests used for each intervention is indicated in brackets. (B) Example of a nest whose hat was reconstructed after an intervention (Intervention made in July 2006 and the photo is taken in July 2007; T16P12B1). (C) Example of a nest reconstructed after having been cut low to the ground (intervention made in July 2007 and the photo taken in July 2008; T1P1B3). (D) Example of a nest reconstructed after being cut 10 m deep (Intervention made in July 2006 and the photo taken in July 2007; T3P8B2

Table 2. Percentages of reconstruction by species at July 15, 2007 in blocks B1 + B2

Experiments \ Species	C.sankurensis	C. ugandensis	Undetermined	All nests
Experiment 1: N = 38 Cs + 15 Cu + 5 Undetermined = 58	29.0	33.3	0.0	27.6
Experiment 2: N = 23 Cs + 13 Cu + 14 Undetermined = 50	17.4	15.4	0.0	12.0
Experiment 3: N = 33 Cs + 17 Cu + 19 Undetermined = 69	12.1	11.8	5.36	10.1
Experiment 4: N = 34 Cs + 13 Cu + 4 Undetermined = 51	50. 0	69.2	25.0	52.9
Experiment 5: N = 17 Cs + 8 Cu + 36 Undetermined = 61	35.3	12.5	27.8	27.9

Cu = C. ugandensis; Cs = C. sankurensis; undet = species not determined. Data were collected 12 months after the first intervention (experiments 1, 2 and 3) and 6 months after the first intervention (experiments 4 and 5)

Table 3. Comparative effects of interventions with Chi^2 test

Effect of test during rainy season		
	***Value of* Chi^2**	***Value P***
Experiment *1* X **Experiment** *2*	0,009	0,92
Experiment *2* X **Experiment** *3*	2,417	0,088
Experiment *1** X **Experiment** *3*	7,1	**0,02**
Effect of test during dry season		
*Expérience 4** X *Expérience 5*	12,41	**0.025**
Comparison of effect of test between according the rainy and dry season		
Take off the hats of termite mounds *(***Experiment** *1* X **Experiment** *4*)*	7,37	**0.002**
Remove termite mounds at ground level *(***Experiment** *2* X **Experiment** *5)*	1.2	0,27

Experiment 1 = removal of hats (rainy season); Experiment 2 = removal of termite mounds at ground level (rainy season); Experiment 3 = removal of termite mounds up to 10 cm below the ground (rainy season); Experiment 4 = removal of hats (dry season); Experiment 5 = removal of termite mounds at ground level (dry season); (*) Experiment where reconstruction of nests is significantly better

The nests with caps removed reconstruct the most and those excavated to 10 cm deep reconstruct the least (Table 3). The comparison between different interventions carried out in the dry season showed a significant difference between experiments 4 and 5 (Chi^2 = 12.41, *df* = 2, *p* = 0.025). The nests with caps removed were more reconstructed than those removed down to ground level (Table 3). The comparison between different seasons for the removal of the hat (experiment 1 versus experiment 4) showed a significant difference (Chi^2 = 7.37, *df* = 2, p = 0.002). On the other hand, it is not significant for the removal of the termite mound at ground level (experiment 2 versus experiment 5; Chi^2 = 1.204, *df* = 2, *p* = 0.27). The reconstruction is much more frequent when the intervention was performed in the dry season (Table 3).

4. DISCUSSION

This study focused on the capacity of the two species of the genus Cubitermes (*C. sankurensis* and *C. ugandensis*) to reconstruct the termite mounds in Bondoé (CAF). This approach cannot be approached without looking at the very growth of termite mounds over time. Among the 70 nests present in 2006 in the control plots (arranged in 3 blocks) only one was abandoned in 3 years and 7 new termite mounds appeared in the same period. The significant growth was recorded in these termite mounds from 2006 to 2009. Some information collected in the forest estimates that the life expectancy of Cubitermes specious nests at around 35 years [16] and that the renewal rate of *Anoplotermes banksi* nests is between 30 and 50% [17] The very low mortality observed in our control plots is thought to be due to the low predation pressure in the grassy savannas of Bondoé. Our results also showed that the two species of Cubiterms (*C. sankurensis* and *C. ugandensis*) at Bondoé reconstruted new nests at the beginning and during the rainy season (between April and October). This same observation had already been made by Bodot [18] on *Cubitermes severus* in the savannas of

Lower Ivory Coast, by Aloni and Soyer [19] and by Soki [20] on Cubitermes specious in primary forest in the Democratic Republic of Congo. The approach of the rainy season seems to be a determining factor or a triggering stimulus for the construction of shelters in tropical Cubiterms.

During this study, the nests of the two species of Cubitermes (*C. sankurensis* and *C. ugandensis*) whose caps had been cut were frequently reconstructed with percentages ranging from about 30% (when the intervention is carried out in the rainy season) to more than 50 % (when done in the dry season). The removal of the hat therefore does not significantly reduce the company's workforce and its capacity to build. On the other hand, hats play an essential role in the functioning of the termite mound. Indeed, the role of the hat would be that of an umbrella which protects the whole nest against bad weather [21,9] thus allowing it to ensure better respiratory exchanges [22]

After the intervention, the termites begin by plugging the holes; the freshly reconstructed parts could be recognized by the darker coloration of the clay still wet from having been shaped. The reconstructions occur later and generally consisted in our observations a new hat or a bulging mass located on the injured part which looked like the outline of a future new hat. The dynamics of repairing nests in species of the genus Macrotermes (M.) were the best known. Maldague [23] after having opened the nest of *M. bellicosus* noted the next day that the workers had closed the openings created. He had observed rows of workers next to each other kneading the clay with their mouthparts and depositing it in the form of small balls which they piled on top of each other and after a few minutes several lodges had been closed. The stimulus that calls the workers to close near the holes is the air turbulence. Indeed, at the slightest gash in the termite mound, the outside air rushes in and alerts its occupants who are eager to come and see the damage. The breach then becomes a plugging stimulus [24,25] The construction of the nest takes place in two stages: first in the incoordination under the constructive impulse and then under the action of the fragrant stimuli of the queen and of the objects created by the workers themselves. The worker must therefore be in a physiological state suitable for receiving construction stimulation [24,26].

The nests that were removed down to ground level or up to 10 cm deep did not show significantly different percentages of reconstruction. Nevertheless, we had detected a trend similar to that observed in the experiments where only the hats were removed: they vary from 12 to 17% for operations and carried out in the rainy season and from 12 to 35% for operations carried out in the dry season. Darlington et al. [27] had completely removed the nests of *M. jeanneli* in Kenya after a fumigation intended to kill the whole society: their interventions were in fact intended to estimate the total numbers of the nests and the fumigation was justified by the great escape capacity of the Macroterms from their termite mound. Despite such drastic treatment some nests survived and reconstructed the termite mound over the next four years. This shows that a not insignificant part of the population was not in the nest when it was removed and probably that the replacement sexs allowed the society to develop again. However, complete removal from the nests of other Macroterm species did not shown such capacity [28,29,25] Sometimes when a large part of the termite mound is removed or in the case of termite mounds overturned or removed at a depth of 10 cm, the whole "trunk + hat" construction scheme is used (in the case of this study). Individuals rebuild once or even twice; and prefer to leave because they find it dangerous for society. In some cases, individuals were killed and eaten by the ants [30,7] Perhaps this is the reason that some nests have not been reconstructed after two interventions: the reconstruction of the nests varies according to the damage and the needs of the termite mound. The experiments at Bondoé showed that the activity of reconstruction or enlarging nests mainly had started at the beginning and during the rainy season (between April and October). In some termites (including Cubitermes), workers stop all construction in some case of the year. The histograms of Cubitermes the activity of construction were compiled by [18,31,12,26, 32,33] and indicated that these termites reconstruct seasonally. Bodot [18, 34,35] found a significant correlation between the activity of construction and the number of rainy days. We observed also in Bondoé that the rain is the trigger for nest building activities. These observations are generally avoided, but it should be remembered that some nests remain for two to three years and perhaps longer without any construction activity being detectable (observation on some control nests). The greatest activity occurs after swarming and before the appearance of sexual nymphs [18,26,36,37,38] Our observations on the capacity of reconstruction of the nests show that during the two seasons, the termite mounds whose caps were removed in one intervention rebuild better the following year (25-30% in the rainy season, 50 to 60% in the dry season). When the removal was done at ground level, an average of 22.5% reconstruction was recorded in the rainy season and 25-30% reconstruction observed in the dry season after one year. These results showed that, in order to preserve the environment, it would be better to remove the caps from termite mounds for soil supplementation for agricultural purposes. This harvest should be done in the dry season because of the large capacity of termite mounds to reconstruct during this season. The use of termite mound caps rather than full termite mounds helps preserve Cubiterma populations while using their shelters for better agricultural production.

5. CONCLUSION

The study on the dynamic of reconstruction of termite mounds showed that termites of the genus Cubitermes are able to reconstruct their nests when a part has been removed or when the nest is removed entirely or even when the removal of the nest is carried out with a certain depth (10 cm). However, the rebuilding capacity of termite mounds is even greater if only the hats are removed. The comparison of their reconstruction dynamics with that of Cubiterms from nearby shrub savannas would undoubtedly be very instructive.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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