Chapter 2
Termite Damage in Agriculture Areas and Implanted Forests: An Ecological Approach

Luciane Kern Junqueira and Daniela Faria Florencio

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Abstract Termites are significant soil fauna components in tropical forests and play an essential role in organic matter decomposition, nutrient cycling, soil airing, and draining. They also contribute to the establishment of new soil in eroded areas. However, they can cause significant economic losses in commercial plantations and implanted forests. Therefore, the correct identification of the termite species and evaluation of the richness, abundance, and functional groups of the community is critical for control, of any species that acquired and/or could reach a pest status. This identification will contribute for the preservation and endurance of beneficial

L.K. Junqueira (✉)
Faculty of Biological Science, Pontifícia Universidade Católica de Campinas, Campinas, São Paulo, Brazil
e-mail: lkjunque@puc-campinas.edu.br

D.F. Florencio
Center of Social and Applied Human Sciences, Universidade Federal Rural do Semi-Árido, Mossoró, Rio Grande do Norte, Brazil

Post-Graduation in Ecology and Conservation, Universidade Federal Rural do Semi-Árido, Mossoró, Rio Grande do Norte, Brazil

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species, as some species appear more sensitive to soil usage and agricultural activities than others. In this chapter, the impact of termites in agricultural areas and implanted forests will be addressed. The importance of the taxonomic and ecological studies will be highlighted as a premise to the use of control agents and technical management.

Keywords Isoptera • Commercial plantations • Agroecosystem

2.1 Introduction

Termites (Blattodea: Isoptera), though less visible and attractive, are decisive for the functioning and yield of tropical terrestrial ecosystems, by increased soil water infiltration due to tunnels and enrichment in soil nitrogen. They are thus important for agricultural sustainability (Evans et al. 2011). These activities also sustain a greater biodiversity by an increase in richness and abundance of other organisms (Dangerfield et al. 1998; Florencio et al. 2013; Pringle et al. 2010).

Most species live in tropical environments and only a few ones survive in temperate regions. Krishna and Weesner (1970) identified some factors as important to the global distribution of termites: feeding exclusively on cellulosic materials; low sclerotin and consequently a soft body, a limiting factor for mobility; natural dispersion only during flutter period, although only for short distances; and high susceptibility to predators. Conversely, Wood and Johnson (1986) suggest the variety of dietary resources and different nesting areas favor the distribution of termites, over various regions of the world.

Due to these factors, termites are found in both tropical and temperate regions, between parallels 45°–48° N and 45° S (Wood 1975). In tropical ecosystems, termites cause impact due to their abundance, social behavior, and great diversity of species (Wood and Sands 1978). Roughly 10% of all described species have caused damage to human activity (McMahan 1986; Verma et al. 2009). In South America there are reports that 19% of species cause structural and/or agricultural damage (Constantino 2002).

Currently, the most appropriate integrated strategies to control pest termite species include preventive practices, such as less drastic changes in the environment and/or the introduction of termite-specific agents (see review by Rouland-Lefèvre 2011). These practices are complementary to reduce the use of toxic chemical products (insecticides).

In this review, the possible damages caused by termites in forest and agricultural areas are presented, focusing on commercial *Eucalyptus* forests and sugarcane plantations. Moreover, it includes a brief report on plantations of cocoa, corn, and rice. Finally, we highlight how the accurate identification of termite species and the evaluation of the community's ecological attributes (richness, abundance, functional groups, etc.) are a critical point for controlling those species that have acquired and/or may acquire pest status. At the same time, this approach sustains the preservation and maintenance of beneficial termite species, as some of them appear more sensitive than others to land use and agricultural or forestry activities.

2.2 Termites in Commercial *Eucalyptus* Forests

In forests, which make use of exotic species in tropical areas, termites have already caused such significant damage that, according to Harris (1971) and Cowie et al. (1989), they were considered as a limiting factor for the development of commercial *Eucalyptus* forests.

The termite species damaging *Eucalyptus* forests have been divided into two groups. In the first one, those that attack seedlings from plantation up to 1 year of age were included, also known as seedling, root, or soil termites (e.g., *Syntermes molestus*, *S. insidians*, and *Cornitermes cumulans*). They cause the destruction of the radicular system or the seedling girdling at the stem, damages that often cause the death of the plant. If the soil conditions are favorable, the seedlings may resist the attack and form a callus, which in turn originates a new radicular system over the destroyed tissue or even a sprout, forming a new aerial branch, in the case of girdling at the stem region. Consequently, the trees may develop a deficient radicular system and insufficient support, or will become dominated trees, due to their delayed initial development. In these cases mortality rates are high, accounting for the occurrence of damage up to 18% of *Eucalyptus grandis* seedlings in Brazil due to the attack of *Cornitermes* sp. For commercial plantations, the percentage of acceptable failure is from 2 to 5% since, and above this level, the replantation is costly (Wilcken 1992; Wilcken and Raetano 1995).

The other group is formed by the termites that attack *Eucalyptus* trees aged over 2 years and destroy their interiors, named heartwood termites (e.g., *Coptotermes testaceus*). They penetrate through the root, building their chambers within the trunk, destroying the heartwood, and making the trees hollow, thus causing loss of productivity. The internal damage only appears during harvest, and this hampers prevention (Wilcken and Raetano 1998). Nair and Varma (1985) already suggested that factors such as termite species present, population density, seasonal trends, buildup of litter fall and wood, soil conditions, physiological state of the plant, age, and establishment state were all related to the termite × *Eucalyptus* interaction. Wardell (1987) also pointed out that the lack of research programs to study the ecological relations between termites, host trees, and possible correlations with edaphic factors aggravated this situation.

According to Mill (1982), deforestation and isolation directly affected the ecology of termites from neotropical forests. Since most termites from primary forests are very sensitive to such effects and do not survive habitat changes, the few species which manage to adapt may become important pests in forestry. The available data, though limited, suggested that wood removal or certain agricultural practices reduce termite richness and lead to the selective loss of certain functional groups, especially the soil-feeding ones (Wood et al. 1982). However, the effects of forestry practices, which are considered less drastic, were still unknown (Mill 1982; Eggleton et al. 1995). These cited references described the termite problem in *Eucalyptus* plantations for roughly three decades. Conversely, more recent works have questioned the role of termites as a pest in this forest system.

Calderon and Constantino (2007), evaluating the termite diversity in a tillage of *Eucalyptus urophylla*, found only 0.2% of cut trees damaged at core, caused by *Coptotermes* sp., thus suggesting that termites do not cause significant problems in the studied region. Moreover, it was possible to highlight that the importance of termites as a pest to *Eucalyptus* has been overstated. One of the factors involved is due to the fact that the areas selected for study were therefore chosen due to the previous evidence of damage by termites.

Junqueira et al. (2009) studied the richness and abundance of termites in seven forest areas in Anhembi, São Paulo. The areas ranged from *Eucalyptus* plantations of different species/ages to forest fragments, in different stages of development and succession. The highest species richness (13) was found in the area in the stage of advanced succession and the lowest (8) in the implanted forest of *E. urophylla* of 3 years, with no sub-forest. The abundance of some species (Apicotermitinae sp.1, Apicotermitinae sp.2, Apicotermitinae sp.4, *Cornitermes cumulans*, *Diversitermes diversimiles*, and *Embiratermes* sp.) varied greatly between areas and indicated a lower diversity of termites in implanted *Eucalyptus* forests, when compared to forest fragments. The authors also pointed out that the presence of some termite species appeared to be associated to that of fallen wood on the forest floor. The permanency of this wood on the floor could favor the termite community in the area, without affecting seedlings or trees, since the termites identified feed and nest in the wood itself.

When evaluating the effects of *Eucalyptus* plantation on soil arthropod communities in a conservation area of the Atlantic forest, Camara et al. (2012) verified that 61% of the taxa found were common to *Eucalyptus* areas and to forest fragments, whereas the Isoptera group was only present in two plantations but did not have its species specified nor the possible damage caused by them. Nevertheless, it is important to highlight that the authors used pitfall traps, which is unsuitable for termite sampling, and this justifies the low presence of this group in the samples.

2.3 Termites in Sugarcane Commercial Plantations

In Brazil, planting of sugarcane is dedicated to the production of ethanol, which occupies an extensive land area of 4.9 Mha in 2011, with the estimate that by 2021 this area will reach 6.4 Mha (Goldemberg et al. 2014). Land use changes (LUC) and the agricultural methods undertaken for the introduction and upkeep of this monoculture contribute to the loss of biodiversity, especially of soil macrofauna, which includes termites (Franco et al. 2016). These losses result in soils of low fertility and sandy texture. These factors contribute to the occurrence of subterranean termites, a group which may cause damage to the various growth phases of the sugarcane culture (Campos et al. 1998).

Recently, a number of ecological aspects of the species found in sugarcane crops and other cultures, as well as their pest potential and the need of basic studies on the reproductive biology and population dynamics of various termite species, were discussed (Miranda et al. 2004; Junqueira et al. 2008; Menzel and Diehl 2008, 2010; Ackerman et al. 2007). According to Batista-Pereira et al. (2004), termites called the attention of the scientific community because they are important pests in sugarcane crops. At this regard, Mill (1992) already referred to a fall of up to 65% in production in Brazil, due to termite attack in sugarcane plantations.

In the Brazilian northeast, termites are considered as one of the main soil pests in sugarcane plantations, and a high occurrence of the *Heterotermes* and *Neocapritermes* genus is registered. Miranda et al. (2004) found four termite species in a single sugarcane plantation in the northeast, but only one type caused damage (*Cylindrotermes nordenskioeldi*), whereas a second one (*Amitermes nordestinus*) was possibly considered as a potential pest. According to the authors, the abundance and the vertical and horizontal spatial distribution of these insects were mainly influenced by the root biomass of the crops and by the amounts of organic matter in soil. In the southeast region, Novaretti and Fontes (1998) identified 14 termite species in sugarcane crops, while Almeida and Alves (1999), in studies carried out in northern São Paulo, considered *Heterotermes tenuis* as the main crop pest, due to its broad distribution and high number of individuals.

According to Junqueira et al. (2015), the lack of solid taxonomic and ecological data on termite communities in Brazilian sugarcane plantations led to the attribution of a pest category to species with low prevalence, with an indiscriminate use of insecticides for termite control, in spite of their central ecological role in soil fertility. The authors performed sampling of soil termites in commercial sugarcane crops in 53 counties in the state of São Paulo. The richness obtained accounted for 22 taxa, and the most frequent functional group was the humus feeders (37%), followed by wood (34%), litter (25%), and intermediaries feeders (4%). Finally, in contrast to what is pointed out in other studies, the results suggested that the greater part of the termite community registered in sugarcane plantations of São Paulo was potentially beneficial to the cultivation, considering the high frequency of soil-feeding species.

2.4 Termites in Other Cultures

Dibog et al. (1999) studied the impact of vegetation shelter on termite communities in commercial forests of *Terminalia ivorensis* (Combretaceae), aged from 6 to 18 years, in the southern regions of the Republic of Cameroon where the understory of these trees is used for growing banana and cocoa. In 18 years of *T. ivorensis* plantation, the highest abundance of termites occurred in locations with a denser canopy, regardless of the type of understory (banana or cocoa), the cultivation system (mixed or individual), or the soil preparation method (conserving or burning biomass, in this case specifically for growing bananas). For 6-year-old plantations, there was no significant difference in the abundance of termites when compared to lesser or greater canopy density, whereas in the latter, a higher frequency of termites did occur. Conversely, the crop yield was not directly related to the abundance of termite population, though the yield in cocoa production was positively related to the abundance of soil-feeding termites (the greater part of the community). This was probably due to improved soil conditions resulting from the presence of this group. Of the 82 total termite species found, 67 were soil feeders.

Some species of fungus-growing termites (Termitidae: Macrotermitinae) are one of the main pests of corn (*Zea mays* L.) in the African continent. Researchers have attempted to comprise suitable techniques in soil management, emphasizing the availability of nutrients (nitrogen) and termite activity (Sileshi and Mafongoya 2003; Sileshi et al. 2005; Nyagumbo et al. 2015). In a field experiment carried out at Msekera Research Station in Chipara (Zambia), Sileshi and Mafongoya (2003) studied the presence and activity of four termite types, namely, *Microtermes*, *Hodotermes*, *Odontotermes*, and *Pseudacanthotermes.* Root and stem base damage in the corn crops were identified following a short drought period. Productivity and total crop biomass were negatively associated to damage caused by termites. The losses resulting from termite action in conventional corn crops (natural fallow) were five to eleven times greater than corn crops associated to i) *Tephrosia* (*Tephrosia vogelii*) + pigeon pea (*Cajanus cajan*) and ii) *Sesbania* (*Sesbania sesban*) + pigeon pea (*C. cajan*), respectively. The authors suggested that the introduction of these legumes may alter the physical or chemical characteristics of soil, affecting the susceptibility of corn to pest attacks, therefore reducing losses.

In evaluating the occurrence of termites in corn through an experiment performed in the province of Manica, Mozambique, Nyagumbo et al. (2015) verified that the activity (number of individuals and proportion of tunnels) of *Macrotermes falciger*, *Pseudocanthotermes* sp., and *Odontotermes* sp. (Termitidae: Macrotermitinae) adjacent to the corn plantations was directly related to the availability of residues in furrows. Moreover, the increase in termite activity did not result in damage to the culture, and, provided that there were resources for the termites, these did not attack the crops. This research highlighted the importance of the development of management techniques that contribute to the quality and availability of soil nutrients. In rice (*Oryza sativa* L.), Mahapatro and Sreedevi (2014) registered *Odontotermes obesus* and *Microtermes obesi* (Termitidae: Macrotermitinae) as causing damage to crops, in dry land and irrigated farming, in India. The attack on live plants occurred mainly in the final phase of growth and in the absence of decomposing matter in the area.

2.5 Modification of Natural Habitat: Effects on Termite Community

The richness and abundance of soil invertebrates are influenced by the biogeographic history, latitude, altitude, and climate variables such as temperature, humidity, and rainfall and by the characteristics of the habitat involving soil type and depth (Hulugalle et al. 1997; Bignell and Eggleton 2000; Eggleton 2000; Ellis et al. 2001). Natural and anthropic disturbances can cause changes in environmental variables such as soil aeration, humidity, food resource availability, and height of the tree canopy. Consequently, there are changes in the composition, abundance, and/or richness of termites (DeSouza and Brown 1994; Jones et al. 2003). They may lead to a loss, a negative impact in the functioning of ecosystems, altering ecological processes as the carbon and nitrogen cycles, therefore reducing soil quality and its productivity (Black and Okwakol 1997; Okwakol 2000; Evans et al. 2011).

As the replacement of natural ecosystems with commercial forests occurred, reports emerged of damage caused by native and exotic termites. These modifications can favor certain limited species which, in the absence of predators, may reach a pest status (Mill 1982; Wood et al. 1982). According to Constantino (2002), 77 termite species have been reported as pests in South America, of which 53 were related to damage exclusively in agriculture and 15 were noxious both for structures and agriculture. Among them, *Heterotermes*, *Nasutitermes*, *Cornitermes*, *Procornitermes*, and *Syntermes* were highlighted as the main prompters of damage. Often, the damage caused by termites in commercial forests is indirect, and this hampers identification. In this sense, various authors report a damage by observing the termites feeding off parts of plants or just by their presence in that area. These reports cause part of the damage in commercial plantations to be incorrectly attributed to termites. Additionally, according to Eggleton (1999) and Constantino (2002), the taxonomic study is central to the understanding of the importance of these insects in ecosystems.

In Central Amazon area, Bandeira (1979) studied the effect of deforestation on termite populations by evaluating the distribution and diversity of these insects in primary forest areas, shrubland, and pastures. Most types presented equivalent distributions in all three areas. Members of *Nasutitermes* were the most common and diverse, with more frequency in pastures where a greater number of nests were observed. The soil termites were found in greater numbers in shrubland, followed by pastures and lastly in forests. The author suggested that the removal of the primary vegetation and the resulting microclimatic changes were responsible for the distribution of some groups.

Working in four locations in the surroundings of Manaus (Brazil), Mill (1982) found a greater density of termites in islands than in dry land, probably due to the competition for food. According to the author, the termites which are adapted to life in the bush, in islands, and in blackwater-flooded forests (Igapos) are the species that can become pests in commercial forests (e.g., *Coptotermes* and *Nasutitermes*). The termite fauna in dry land and whitewater-flooded forests (varzea) of the

Brazilian Amazon was distinct, with a low index of similarity. The composition of species and diversity varied greatly among locations, with no apparent correlation to climate or vegetation type. Part of these differences also occurred due to the collecting efforts and sampling methods. Constantino (1992) analyzed the termite fauna in primary forests of two locations in the Brazilian Amazon and observed that the subfamily *Nasutitermitinae* (especially the *Nasutitermes* type) was the predominant group, both in the number of species and abundance. The humus feeders were the second group as the number of species. The composition and diversity of species varied among the different locations and, apparently, did not present correlation to climate or vegetation type.

DeSouza and Brown (1994) studied the termite communities in the Amazon forest and in neighboring isolated, reservation fragments. The soil-feeding group was predominant in the forest, with greater species richness and lower proportion of rare species. In the fragments however, the species which use litter fall and those with intermediary feeding habits between soil and wood feeding were predominant. Moreover, the termites in the first area made a more equitable use of the forest, when compared to the fragments, suggesting a growing inadequateness of habitat due to fragmentation. The composition of termite communities in the fragments would hence be the result of an intrinsic pattern of forest and losses caused by fragmentation.

Eggleton et al. (1995) qualitatively evaluated the termite communities of five areas with different levels of forest disturbance in the Mbalmayo Forest Reserve, in the south of the Republic of Cameroon. When compared to primary forest, the areas with severe disturbances presented a significant reduction in richness of species, while the areas under process of regeneration showed a slight increase in richness. The soil-feeding termites predominated in the areas under process of regeneration and in primary forest, though the species richness decreased in areas that suffered severe disturbances. The wood-feeding type appeared to be more resistant to the disturbances than the soil-feeding type, although the richness of species was low in the more affected areas.

In the same forest reserve, Eggleton et al. (1996) evaluated the diversity, abundance, and biomass of termite communities in five locations with different levels of disturbance, over a 2-year period. The abundance and biomass were high in the locations where the forest was very similar to the primary area and in the forest in advanced process of succession. The disturbances had little effect on the abundance and biomass in the forest areas. There was, however, a clear reduction of these components in open areas. Differences were also found in the composition of taxonomic groups, in the abundance of different nesting areas, and in the composition of the functional groups among study areas, the latter affecting mainly soil-feeding termites. The area similar to the primary forest presented a more heterogeneous community of termites when compared to the areas with more disturbances, possibly resulting from the greater number of microhabitats available for the termites.

Davies et al. (1999) investigated the successional response of the termite community to the experimental disturbances in forests in the Republic of Cameroon, evaluating the implications to forest recovery. Even in treatments which involved severe disturbances to the soil and canopy cover, the richness and abundance of termites quickly recovered when dead wood was left on the forest floor. This wood availability also led to the occupation by a different group of termites of the compost sampled in other treatments, highlighting that this group included wood and soil-feeding termite species.

Bandeira et al. (2003), studying the termite fauna present in six environments with different disturbance levels, located at the Brejo dos Cavalos (PE, Brazil), observed a reduction in termite diversity as the disturbances increased, apart from not finding these insects in a monoculture area. The termites, which feed on humus, were more affected than those with an intermediary feeding. In parallel, the wood feeders presented more resilience, while some species, favored in secondary forest areas, tended to disappear in agricultural areas which presented little wood availability.

Sena et al. (2003) investigated the termite fauna in a fragment of savannah (cerrado) at the Guaribas Biological Reserve in Mamanguape (PB, Brazil). The richness was of 20 species, the majority of which was the wood feeders. The highest frequency in the sampling transects was for species which feed on humus. The richness was inferior to what reported in the savannah vegetation, probably due to the isolation time and distance of this specific fragment in the vast savannah areas in Brazil central region.

Jones et al. (2003) evaluated the impact of intensified soil use in termite communities in humid tropical forests in the province of Jambi, Sumatra (Indonesia). Therefore, the composition of the communities was identified using a gradient of seven areas with disturbances, which included primary forest, different commercial plantation systems, and areas with cassava plantations. In the seven environments, 54 species were collected: the primary forest presented the highest termite richness with 34 species and the cassava plantation the lowest richness, with only one species. The relative abundance of soil-feeding termites presented a greater fall over the gradient in comparison to the wood-feeding type. It was found that the basal area of trees was strongly correlated to the richness and relative abundance of termites, thus reflecting the adaptive response of these insects to the progressive simplification of the habitat physical structure. This was due to a reduced canopy cover, microclimatic changes, and reduction of feeding and nesting locations. The authors also analyzed work from other researchers where all, or a great part of communities, were evaluated over a local disturbance gradient. Data generally indicated a declining trend in richness and abundance of species, as land use increases. This trend was more apparent when more contrasting gradients were analyzed, ranging from primary forests to treeless areas.

Lavelle et al. (1997) refer to soil invertebrate as “engineers of soil ecosystems” since they ingest or manipulate organic and mineral material and form microstructures. The authors cite worms and termites as the most important engineers of earthly ecosystems because, as mediators of nutrient transformation, they influence the diversity and activity of the biota and subordinate trophic levels. They also consider the hypothesis that the vegetation affects not only the abundance but the richness of these organisms through the quality and quantity of litter fall, among other effects. Changes in vegetable communities would therefore affect soil engineers. According to Lavelle et al. (1997), land use and forest disturbances are responsible for the more immediate changes in the functional groups of these engineer communities. The disturbances affect the termites through the reduction of diversity, especially of those who feed off soil, and some species can become pests due to changes in the availability of organic material. The reduction in the abundance of these engineers leads to a decrease of carbon stock in soil and inequality among functional groups (compaction × decompaction) and may result in physical degradation of soil.

Jones et al. (2003) proposed actions toward the recovery of termite communities. The author suggests that by leaving dead wood in the forest floor following the disturbance, the recovery process of the termite communities is accelerated, due to the increased abundance and richness of wood- and soil-feeding termites. Moreover, the increase in fragment size and reduction of edge effects would have a positive effect in the survival of species that depend on the forest. Finally, the adoption of corridors connecting these fragments could assist termite recolonization and therefore increase their dispersion potential.

According to Calderon and Constantino (2007), the use of Brazilian savannah areas for planting *Eucalyptus* eliminated soil-feeding termites and favored the occurrence of wood and litter feeders. The authors suggest that the change in the structure of the termite community resulted from changes of microclimate, habitat structure, and quality and diversity of litter fall.

Carrijo et al. (2009) showed that the simplification of the savannah habitat led to the extinction of termite populations as well as other members of the fauna and flora, by the loss of specific resources due to the application of pesticides. Junqueira et al. (2008) published a wide bibliographic review that sought to discuss how intensified land use and deforestation for the implantation of commercial *Eucalyptus* forests caused changes in termite diversity, mostly affecting the soil-feeding group, and suggested that the decrease of this group could provoke likewise a decrease of organic matter in decomposition.

Finally, Dosso et al. (2013) investigated, in a transitional forest-savannah zone of Côte d'Ivoire, the termite assemblage structure across a sequence of differing land-use systems. The authors suggested that forest conversion to agricultural systems changes the termite assemblage structure, including loss of species and changes of feeding groups. The mean termite species richness declined from the semi-deciduous forest to the teak plantation, 4-year-old fallow, food crop, cocoa plantation, and *Jatropha* plantation. The soil and wood feeders showed response to disturbance with abundance of changes along the distinct land-use types: i) the soil feeders declined the semi-deciduous to all man-modified sites and ii) the wood-feeding species reduced their abundance to monospecific and modified sites without high trees. The fungus growers were considered the feeding group most adapted to disturbances, with dominant species *Ancistrotermes cavithorax*, *Microtermes toumodiensis*, and *Pseudacanthotermes militaris* found in all land-use systems. Thus, changes of land use can promote the loss of some termite species, reduce biological functions, and establish species that can become pests.

2.6 Conclusion

Currently, a number of works have highlighted that the damages caused by termites in planted forests and/or agriculture are directly related to the use and modification of soil for the implantation of crops. This promotes the simplification of the environment's physical structure, which alters the termite communities and leads to the maintenance and establishment of limited termite as well as pest species.

In plantations where soil is uncovered and the area is completely clean, the occurrence of termites can cause damages, since there will be no other resource apart the introduced culture. In contrast, plantations associated to the adoption of certain strategies which i) maintain the presence of sub-forest and adjacent forest fragments, ii) protect soil, and iii) present the availability of litter fall may reduce the loss of water and nutrients and promote the maintenance of soil-feeding species, as well as of wood and litter feeders. These species can consume other available resources and bring about improvements for the implanted culture with low impact on negative activities. In these environments, the use of pesticides and agents may be avoided, and the diversity of termites might contribute to productivity. In this sense, adequate handling practices, which promote the availability of cellulosic residue, may transform the termites into important components for the increase of productivity in agricultural areas, pastures, and commercial forests.

References

Ackerman, I. L., Teixeira, W. G., Rihab, S. J., Lehmann, J., & Fernandes, E. C. M. (2007). The impact of mound-building termites on surface soil properties in a secondary forest of Central Amazonia. *Applied Soil Ecology, 37*, 267–276.

Almeida, J. E. M., & Alves, S. B. (1999). Controle de *Heterotermes tenuis* (Hagen, 1858) (Isoptera: Rhinotermitidae) em cana-de-açúcar com iscas TERMITRAP® associadas ao fungo entomopatogênico *Beauveria bassiana* (Bals.) Vuill. e/ou a inseticidas em época de seca. *Arch Instituto Biol, 66*, 85–90.

Bandeira, A. G. (1979). Ecologia de cupins (Insecta: Isoptera) da Amazônia Central: efeitos do desmatamento sobre as populações. *Acta Amazonica, 9*, 481–499.

Bandeira, A. G., Vasconcellos, A., Silva, M. P., & Constantino, R. (2003). Effects of habitat disturbance on the termite fauna in a highland forest in the Caatinga domain, Brazil. *Sociobiology, 42*, 117–127.

Batista-Pereira, L. G., Santos, M. G., Correa, A. G., Fernandes, J. B., Arab, A., Costa-Leonardo, A. M., Dietrich, C. R. R. C., Pereira, D. A., & Bueno, O. C. (2004). Cuticular hydrocarbons of *Heterotermes tenuis* (Isoptera: Rhinotermitidae): Analyses and electrophysiological studies. *Zeitschrift für Naturforschung, 59*, 135–139.

Bignell, D. E., & Eggleton, P. (2000). Termites in ecosystems. In T. Abe, D. E. Bignell, & M. Higashi (Eds.), *Termites: Evolution, sociality, symbioses, ecology* (pp. 363–387). Dordrecht: Kluwer Academic Publishers.

Black, H. I. J., & Okwakol, M. J. N. (1997). Agricultural intensification, soil biodiversity and agroecosystem function in the tropics: The role of termites. *Applied Soil Ecology, 6*, 37–53.

Calderon, R. A., & Constantino, R. (2007). A survey of the termite fauna (Isoptera) of an eucalypt plantation in central Brazil. *Neotropical Entomology, 36*, 391–395.

Camara, R., Correia, M. E. F., & Villela, D. M. (2012). Effects of eucalyptus plantations on soil arthropod communities in a Brazilian Atlantic forest conservation unit. *Bioscience Journal, 28*, 445–455.

Campos, M. B. S., Alves, S. B., & Macedo, N. (1998). Seleção de iscas celulósicas para o cupim Heterotermestenuis (Isoptera: Rhinotermitidae) em cultura de cana-de-açúcar. *Scientia Agricola, 55*, 480–484.

Carrijo, T. F., Brandao, D., Oliveira, D. E., Costa, D. A., & Santos, T. (2009). Effects of pasture implantation on the termite (Isoptera) fauna in the Central Brazilian savanna (Cerrado). *Journal of Insect Conservation, 13*, 575–581.

Constantino, R. (1992). Abundance and diversity of termites (Insecta: Isoptera) in two sites of primary rain forest in Brazilian Amazonia. *Biotropica, 24*, 420–430.

Constantino, R. (2002). The pest termites of South America: Taxonomy, distribution and status. *Journal of Applied Entomology, 126*, 355–365.

Cowie, R. H., Logan, J. W. M., & Wood, T. G. (1989). Termite (Isoptera) damage and control in tropical forestry with special reference to Africa and indo-Malaysia: A review. *Bulletin of Entomological Research, 79*, 173–184.

Dangerfield, J. M., McCarthy, T. S., & Ellery, W. N. (1998). The mound building *Macrotermes michaelseni* as an ecosystem engineer. *Journal of Tropical Ecology, 14*, 507–520.

Davies, R. G., Eggleton, P., Dibog, L., Lawton, J. H., Bignell, D. E., Brauman, A., Hartmann, C., Nunes, L., Holt, J., & Rouland, C. (1999). Successional response of a tropical forest termite assemblage to experimental habitat perturbation. *Journal of Applied Ecology, 36*, 946–962.

DeSouza, O., & Brown, V. K. (1994). Effects of habitat fragmentation on Amazonian termite communities. *Journal of Tropical Ecology, 10*, 197–206.

Dibog, L., Eggleton, P., Norgrove, L., Bignell, D. E., & Hauser, S. (1999). Impacts of canopy cover on soil termite assemblages in an agrisilvicutural system in southern Cameroon. *Bulletin of Entomological Research, 89*, 125–132.

Dosso, K., Deligne, J., Yéo, K., Konaté, S., & Linsenmair, K. E. (2013). Changes in the termite assemblage across a sequence of land-use systems in the rural area around Lamto reserve in central Côte d'Ivoire. *Journal of Insect Conservation, 17*, 1047–1057.

Eggleton, P. (1999). Termite species description rates and the state of termite taxonomy. *Insectes Sociaux, 46*, 1–5.

Eggleton, P. (2000). Global patterns of termite diversity. In T. Abe, D. E. Bignell, & M. Higashi (Eds.), *Termites: Evolution, sociality, symbioses, ecology* (pp. 25–51). Dordrecht: Kluwer Academic Publishers.

Eggleton, P., Bignell, D. E., Sands, W. A., Waite, B., Wood, T. G., & Lawton, J. H. (1995). The species richness of termites (Isoptera) under differing levels of forest disturbance in the Mbalmayo Forest reserve, southern Cameroon. *Journal of Tropical Ecology, 11*, 85–98.

Eggleton, P., Bignell, D. E., Sands, W. A., Mawdsley, N. A., Lawton, J. H., Wood, T. G., & Bignell, N. C. (1996). The diversity, abundance and biomass of termites under differing levels of disturbance in the Mbalmayo Forest reserve, southern Cameroon. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 351*, 51–68.

Ellis, L. M., CS Crawford, M. C., & Molles, J. R. (2001). Influence of annual flooding on terrestrial arthropod assemblages of a Rio Grande riparian forest. *Regulated Rivers: Research and Management, 17*, 1–20.

Evans, T. A., Dawes, T. Z., Ward, P. R., & Lo, N. (2011). Ants and termites increase crop yield in a dry climate. *Nature Communications, 2*, 262.

Florencio, D. F., Marins, A., Rosa, C. S., Cristaldo, P. F., Araujo, A. P. A., Silva, I. R., & DeSouza, O. (2013). Diet segregation between cohabiting builder and inquiline termite species. *PloS One, 8*(6), e66535.

Franco, A. L. C., Bartz, M. L. C., Cherubin, M. R., Baretta, D., Cerri, C. E. P., Feigl, B. J., Wall, D. H., Davies, C. A., & Cerri, C. C. (2016). Loss of soil (macro) fauna due to the expansion of Brazilian sugarcane acreage. *Science of the Total Environment, 563*, 160–168.

Goldemberg, J., Mello, F. F. C., Cerri, C. E. P., Davies, C. A., & Cerri, C. C. (2014). Meeting the global demand for biofuels in 2021 through sustainable land use change policy. *Energ Policy, 69*, 14–18.

Harris, W. V. (1971). *Termites: Their recognition and control* (2nd ed.p. 186). London: Longman.

Hulugalle, N. R., Lobry De Bruyn, L. A., & Entwistle, P. (1997). Residual effects of tillage and crop rotation on soil properties, soil invertebrates numbers and nutrient uptake in an irrigated vertisol sown to cotton. *Applied Soil Ecology, 7*, 11–30.

Jones, D. T., Susilo, F. X., Bignell, D. E., Hardiwinoto, S., Gillison, A. N., & Eggleton, P. (2003). Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *Journal of Applied Ecology, 40*, 380–391.

Junqueira, L. K., Diehl, E., & BertiFilho, E. (2008). Termites in eucalyptus forest plantations and forest remnants: An ecological approach. *Bioikos, 22*, 3–14.

Junqueira, L. K., Diehl, E. M. O., & BertiFilho, E. (2009). Termite (Isoptera) diversity in eucalyptus-growth areas and in forest fragments. *Sociobiology, 53*, 805–827.

Junqueira, L. K., Gonçalves, E. R., & Teixeira, L. M. C. (2015). Termite communities in sugarcane plantations in southeastern Brazil: An ecological approach. *Entomo Brasilis, 8*, 105–116.

Krishna, K., & Weesner, F. M. (1970). *Biology of termites (Vol 2)* (p. 643). New York: Academic Press.

Lavelle, P., Bignell, D., Lepage, M., Wolters, V., Roger, P., Ineson, P., Heal, O. W., & Dhillion, S. (1997). Soil function in a changing world: The role of invertebrate ecosystem engineers. *European Journal of Soil Biology, 33*, 159–193.

Mahapatro, G. K., & Sreedevi, K. (2014). Indigenous approaches for the management of termite and white grub in upland rice. *Current Biotica, 8*, 97–108.

McMahan, E. A. (1986). Beneficial aspects of termites. In S. B. Vinson (Ed.), *Economic impact and control of social insects* (pp. 144–164). New York: Praeger.

Menzel, L. V. A., & Diehl, E. (2008). Reproductive strategies of *Cortaritermes fulviceps* (Silvestri) (Isoptera, Termitidae, Nasutitermitinae) under laboratory conditions. *Sociobiology, 51*, 719–731.

Menzel LVA, Diehl E (2010) Soil choice for colony foundation by *Cortaritermes fulviceps* (Isoptera, Termitidae, Nasutitermitinae). Sociobiology 55:471–487.

Mill, A. E. (1982). Populações de térmitas (Insecta: Isoptera) em quatro habitats no baixo rio Negro. *Acta Amazonica, 12*, 53–60.

Mill, A. E. (1992). Termite as agricultural pests in Amazonia, Brazil. *Outlook and Agriculture, 21*, 41–46.

Miranda, C. S., Vasconcellos, A., & Bandeira, A. G. (2004). Termites in sugar cane in Northeast Brazil: Ecological aspects and pest status. *Neotropical Entomology, 33*, 237–241.

Nair, K. S. S., & Varma, R. V. (1985). Some ecological aspects of the termite problem in young eucalypt plantations in Kerala, India. *Forest Ecology and Management, 12*, 287–303.

Novaretti, W. R. T., & Fontes, L. R. (1998). Cupins: Uma grave ameaça à cana-de-açúcar no Nordeste do Brasil. In E. Berti Filho & L. R. Fontes (Eds.), *Cupins: O desafio do conhecimento. FEALQ, Piracicaba* (pp. 163–172).

Nyagumbo, I., Munamati, M., Mutsamba, E. F., Thierfelder, C., Cumbane, A., & Dias, D. (2015). The effects of tillage, mulching and termite control strategies on termite activity and maize yield under conservation agriculture in Mozambique. *Crop Protection, 78*, 54–62.

Okwakol, M. J. N. (2000). Changes in termite (Isoptera) communities due to the clearance and cultivation of tropical forest in Uganda. *African Journal of Ecology, 38*, 1–7.

Pringle, R. M., Doak, D. F., Brody, A. K., Jocqué, R., & Palmer, T. M. (2010). Spatial pattern enhances ecosystem functioning in an African savanna. *PLoS Biology, 8*(5), e1000377.

Rouland-Lefèvre, C. (2011). Termites as pests of agriculture. In D. E. Bignell, Y. Roisin, & N. Lo (Eds.), *Biology of termites: A modern synthesis* (pp. 499–517). London/New York: Springer.

Sena, J. M., Vasconcellos, A., Gusmao, M. A. B., & Bandeira, A. G. (2003). Assemblage of termites in a fragment of cerrado on the coast of Paraíba state, Northeast Brazil. *Sociobiology, 42*, 753–760.

Sileshi, G., & Mafongoya, P. L. (2003). Effect of rotational fallows on abundance of soil insects and weeds in maize crops in eastern Zambia. *Applied Soil Ecology, 23*, 211–222.

Sileshi, G., Mafongoya, P. L., Kwesiga, F., & Nkunika, P. (2005). Termite damage to maize grown in agroforestry systems, traditional fallows and monoculture on nitrogen-limited soils in eastern Zambia. *Agricultural and Forest Entomology, 7*, 61–69.

Verma, M., Sharma, S., & Prasad, R. (2009). Biological alternatives for termite control: A review. *International Biodeterioration & Biodegradation, 63*, 959–972.

Wardell, D. A. (1987). Control of termites in nurseries and young plantations in Africa: Established practices and alternative courses of action. *Commonwealth Forest Review, 66*, 77–89.

Wilcken, C. F. (1992). Danos de cupins subterrâneos *Cornitermes* sp. (Isoptera: Termitidae) em plantios de *Eucalyptus grandis* e controle com inseticidas no solo. *An Soc Entomol Bras, 21*, 329–338.

Wilcken, C. F., & Raetano, C. G. (1995). Controle de cupins em florestas. In E. Berti Filho & L. R. Fontes (Eds.), *Alguns aspectos atuais da biologia e controle de cupins* (pp. 141–154). Piracicaba: FEALQ.

Wilcken, C. F., & Raetano, C. G. (1998). Atualidades no controle de cupins em florestas de eucalipto. In L. R. Fontes & E. Berti Filho (Eds.), *Cupins: o desafio do conhecimento* (pp. 173–185). Piracicaba: FEALQ.

Wood, T. G. (1975). The effects of clearing and grazing on the termite fauna (Isoptera) of tropical savannas and woodlands. In J. Vanek (Ed.), *Progress in soil zoology* (pp. 409–418). Prague: Academia.

Wood, T. G., & Johnson, R. A. (1986). The biology, physiology and ecology of termites. In S. B. Vinson (Ed.), *Economic impact and control of social insects* (pp. 1–68). New York: Praeger.

Wood, T. G., & Sands, W. A. (1978). The role of termites in ecosystems. In M. V. Brian (Ed.), *Production ecology of ants and termites* (pp. 245–292). Cambridge: Cambridge University Press.

Wood, T. G., Johnson, R. A., Bacchus, S., Shittu, M. O., & Anderson, J. M. (1982). Abundance and distribution of termites (Isoptera) in a riparian forest in the southern Guinea savanna vegetation zone of Nigeria. *Biotropica, 14*, 25–39.