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CARATTERIZZAZIONE PEDOLOGICA DI TERMITAI IN DIFFERENTI REGIONI AGRO-ECOLOGICHE DEL MOZAMBICO

Pedological Characterization of Termite Mounds in different Agro-ecological Regions of Mozambique

TIPO TESI: sperimentale

Studente:
ANDREA SALVUCCI

Relatore:
PROF. GIUSEPPE CORTI

Correlatori:
PROF. ROGÉRIO BORGUETE ALVES RAFAEL

PROF. STEFANIA COCCO

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ABSTRACT

Le termiti sono ampiamente riconosciute come ingegneri ecosistemici, data la capacità di modificare l'ambiente circostante adattandolo alle proprie esigenze. Durante la costruzione del nido e strutture atte alla ricerca di cibo, arricchiscono il suolo di particelle fini e sostanza organica con lo scopo di creare un ambiente più favorevole alle necessità della colonia e più ricco in acqua, data la bassa ritenzione idrica della cuticola. Questo arricchimento si traduce nella creazione di patch ricche in nutrienti, inserite all'interno di una matrice caratterizzata da bassa fertilità. L'obiettivo generale di questo studio è stato quello di valutare il contributo delle termiti nel miglioramento della fertilità del suolo in differenti regioni agro-ecologiche del Mozambico. Dai risultati si evince che non è possibile generalizzare riguardo l'effetto delle termiti sulle proprietà chimico-fisiche del suolo, dipendendo esso dalla specie, dalle caratteristiche dell'ambiente, dal materiale parentale e uso del suolo. Interessante è il differente contenuto in carbonati riscontrato nei due termitai presi in analisi; essendo l'arricchimento presente solo in un termitaio, questo dato suggerisce che le termiti non raccolgono selettivamente carbonati per incrementare la stabilità del nido, ma potrebbe essere legato alla necessità di trovare nuove fonti d'acqua. Essendo il materiale parentale di difficile penetrazione, la possibile presenza di vene di calcite di natura più tenera, risulterebbe essere l'unica via di accesso per la ricerca di acqua negli orizzonti più profondi. Questa ipotesi potrebbe far luce sulla ricorrente domanda del perché il nido venga fatto in un determinato punto e se questo debba essere casuale o frutto di una qualche scelta. La sopravvivenza di una colonia in un'area caratterizzata da un materiale parentale resistente alla penetrazione potrebbe dipendere dalla presenza di vene di materiale più tenero, quindi più adatto all'attività di ricerca di fonti di acqua.

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ACRONYMS AND ABBREVIATIONS

C	Control Soil
CEC	Cation Exchange Capacity
EC	Electric Conductibility
pXRF	Portable X-ray Fluorescence Spectrometer
OC	Organic Carbon
OM	Organic Matter
TB	Termite mound section below general soil surface
TU	Termite mound section up than general soil surface

INTRODUCTION

Ecosystem engineers are entities (e.g. trees, animals, insects) which, through physical transformation of biotic and abiotic material by disturbance processes can control the availability (quality, quantity, distribution) of resources utilised by other organism modifying, creating or maintaining habitat (Jones et al., 1994, 1997; Lawton and Jones, 1995). Jones et al., 1997 distinguished between two different ecosystem engineers: autogenic and allogenic. Autogenic modify environment by changing their physical structures and remain part of the engineered habitat e.g. plants grow and become larger, their living and dead tissues create habitats for other organisms to live on or in. Allogenic take living or non-living material from the environment and engineer it from a physical state into another, in some cases in order to survive (Dawkins, 1982).Termites are widely recognized by authors as ecosystem engineers, specifically as soil engineers, in capacity to construct mound that affect the surrounding environment (De Bruyn and Conacher,1990; Black and Okwakol, 1997; Lavelle et al., 1997; Dangerfield et al., 1998; Bignell and Eggleton, 2000; Jouquet et al., 2006). According to Jones's 1997 classes they may be considered allogenic soil engineers since mound construction is an ecological requirement to protect themselves against predator, rainfall and sunlight and to maintain needed temperatures and humidity (Lüscher, 1955; Bagine, 1984; Jouquet et al., 2002; Bignell, 2005; Eggleton, 2011). They modify the environment via nutrient enrichment in mounds and allowing plant decomposition. The termites play a key role in nutrient cycling since are the most important litter decomposers in tropical ecosystem (Keya et al., 1982; Holt, 1987; Conventry et al., 1988; Whitford et al., 1992; Bignell and Eggleton, 2000; Donovan et al., 2000; Murgerwa, 2015). Aided from a complex mutualistic relationship with gut microbes and protozoa or fungi and prokaryotes in some Termitidae, termites are able to digest up to 90% of ingested plant material, which returns in the environment as faeces, pellets or litter due to death (Lawton and Jones, 1995; Dangerfield et al., 1998; Eggleton and Tayasu, 2001; Bignell, 2005; Lo et al., 2006; Negassa and Sileshi, 2018). Therefore, termites create regulated environments that are suitable to their needs since they are vulnerable insects, especially to desiccation due to cuticle poor water-retaining properties (Turner et al., 2006). To survive they must control humidity rate in the mound through different strategies such as water transport in their labial glands from deep layers upward, descending down to 70 m (Lee, 1983). Further strategy is related to clay water retain property, since mound is enriched in fine-size particle through selective collecting of clay in sub-soil during termite nest construction. Several studies reported mound enrichment, commonly followed by higher CEC and base saturation rate probably due to the presence of cations such as Ca, Mg and K that are the main cations among the mineral constituents of plants, accumulated in termite mounds as faecal secretions (Nye, 1955; Sheikh and Kayani, 1982; Akamigbo, 1984; Hulugalle and Ndi, 1993; Brossard et al., 2007; Sarcinelli et al., 2009; Jouquet et al., 2015a,2016). Soil particles are cemented together with faecal and salivary secretions, as a result, mound generally has higher bulk density and OM content than surrounding soil, despite there are divergent points of view about higher OM content. Several studies reported non-significance provision or lower organic matter content in nest due to feeding habits and behaviour, since some species use only salivary and other salivary and faecal secretions to cementing, or due to fine-size particle selection poor in OM content (Sall et al.,2002; Arveti et al., 2012; Jouquet et al., 2015a-b). It is difficult to generalize about the influence of termite activity on soil chemical and nutritional properties because the effects vary with soil properties, termite species, age of the termite mound, vegetation and land use (Lal, 1988). However, because poor soil fertility in some tropical ecosystem, termite nest may be considered as patch of high available nutrient due to termite activity, which may improve surrounding matrix fertility through mound erosion process (Holt et al., 1980; Arshad, 1982; Salick, 1983; Bagine, 1984; Konaté et al., 1999; Diaye et al., 2003; López-Hernández et al., 2006; Ashton et al, 2019).

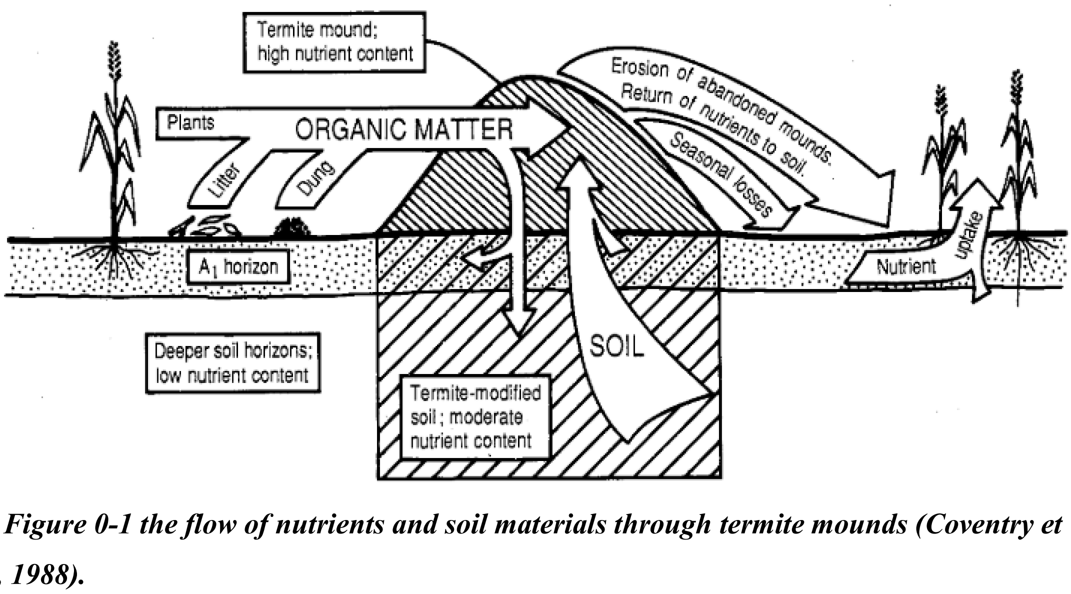

Figure 0-1 the flow of nutrients and soil materials through termite mounds (Coventry et al., 1988).

Farmer are already aware of this, as the mound become an integral part of the cropping system as a cheaper alternative fertilizer, supported by many authors which found increase in crop yield near and on the mound (Miedema and Van Vuure, 1977; Hulugalle and Ndi, 1993; Okwakol and Sekamatte, 2007; Sileshi et al., 2009; Evans et al., 2011). Therefore is required to improve the knowledge on this topic since termites are commonly seen as crop pest, but is widely acknowledged that only few of about 3000 known species are important agricultural pests (Bignell and Eggleton, 2000; Rouland-Lefèvre, 2011; Yêyinou Loko et al., 2017; Negassa and Sileshi, 2018; Govorushko, 2019) and their attack mainly involves non-indigenous crop such as rice (*Oryza sativa*), potato (*Solanum tubersum*), while indigenous crop are hardly susceptible (Mielke and Mielke, 1982). Researched were performed to study termite behavior linked to land use change and it was reported an increase damage in crop yield due to decrease food availability, indeed termites prefer to feed on OM and dead plants usually rich in cellulose but in absence of them start to feed on living crops (Mitchell, 2002; Attignon et al., 2005; Mugerwa et al, 2011; Nyagumbo et al., 2015).

The general objective of this study was to evaluate the contribution of termite mound on improving soil fertility in different agro-ecological regions from Mozambique. Specifically, we aim to i) To make pedological characterization of termites mounds from different agro-ecological regions from Mozambique; ii) To make physic-chemical characterization of termites mounds from different agro-ecological regions from Mozambique; iii) To determine the effect of termite mounds on soil fertility properties from different agro-ecological regions from Mozambique.

CHAPTER 1
MATERIALS AND METHODS

1.1 **Study site**

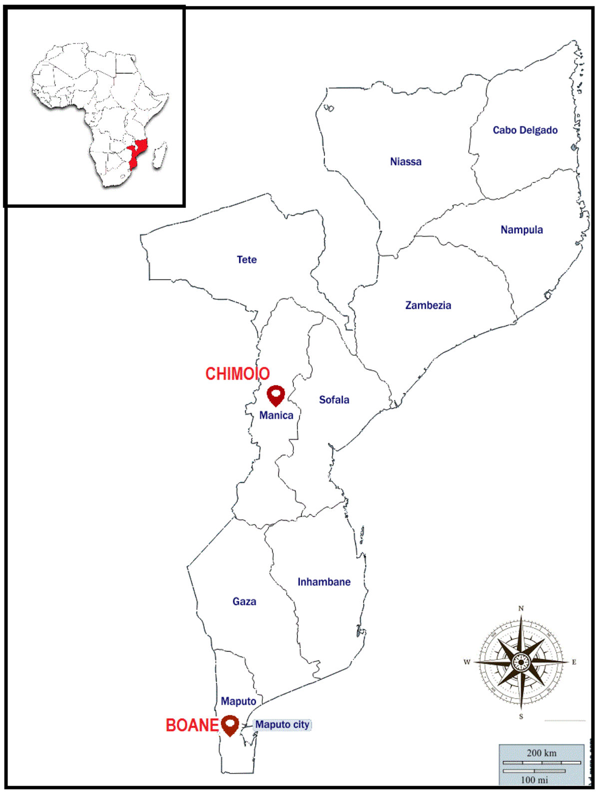

Figure 1-1 Schematic map of Mozambique and localization of the study sites.

The study was performed in two different agro-ecological zones of Mozambique (Fig.1-1) in the South and Center of the Country which are differentiated by two annual rainfall rates, 677 mm and 1143 mm respectively.

1.1.1 *Boane District*

The first site is located in Boane District, Maputo Province. Maputo Province is located in the south of the country, covering the agro-ecological zone R1, with dry semi-arid climate, characterized by an annual rainfall between 400 and 800 mm, with soils mostly Arenosols (Entisols) and Nitisols (Ultisols) type. The mound was located in geographic coordinates Latitude S26°04'09.8'', Longitude E32°16'38.9'', at 51 m altitude and almost flat topography, with a low slope (0.5-2%).The geology of the region consists of alluvium, while the mean annual temperature is 22.9 °C, max in January 32.4°C and min in July 10.2°C, the mean annual rainfall is 677 mm, max in January (137mm) and min in July (11mm). The samples were collected in the highest of the interest hill, characterized by regular slope, without differences in short distances. The area is rarely flooded because close to Umbeluzi River, followed by a slow movement of water, because of a slow external drainage and moderate internal drainage (0,6-6 cm/hour). The land use are characterized by pasture with presence of goats, typical savannah vegetation with coverage greater than 80% (of which <20% shrub) and for this reason there was not evident signs of surface erosion. Soil are formed by alluvial sedimentation, so has moderate deep, and on the surface are present high density (15-40% of the surface) of fine-size stones (0,2-0,6 cm), medium-sized soil surface crusts(2-5 mm), without rock outcrops. The selected mound was 1, 10 m in height and 2 m in diameter (Fig. 1-2).

1.1.2 *Chimoio*

The second site is located in Chimoio, in Manica Province. Manica province is located in the central zone of the country, covering the agro-ecological zones R4 and R10, with sub-humid and tropical of altitude climate, characterized by average annual rainfall between 1000 and 1800 mm, and with soils ranging from Ferralsols (Oxisols) and Nitisols (Ultisols). The mound was located in geographic coordinates Latitude S19°08'33.6"S, Longitude E 33°23'29.1"E. The geology of the region consists of granulite-gneiss complex while the mean annual temperature is 21.5°C, max in February (29.2°C) and min in July (11,1°C), mean annual rainfall is 1143 mm, max in January (231mm) and min in September (17mm) (Maria and Yost, 2006). The site is characterized by a 638 m altitude and wavy topography; the samples were collected in the highest of the interest hill, characterized by uniform and regular slope of 4-8%, with a low difference in altitude (<20cm) in short distance. Actually utilized as fallow, usually as corn (*Zea mays* L.) plantation, the site has a coverage of 40-60% and the most representative species are: *Cissampelos mucronata* A. Rich., *Corchorus olitorius* L., *Hugonia busseana* Engl., *Impomoea sp.* L., *Lannea schweinfurthii* Engl., *Rhus natalensis* Ex Krauss., *Schefflera umbellifera* Sond., *Thespesia garckeana* F. Hoffm.

The soil moderately deep (~ 100 cm) is derived from the weathering in situ of parental material, with low density (2-5% of the surface) of fine-size stones (0.2-0.6 cm), without rock outcrops and erosion evidence. Rainfall water movement is regularly, but no rapid, because of a moderate external drainage and moderate internal drainage (0.6-6 cm/hour). The selected mound was 3 m in height and 15 m in diameter (Fig.1-2).

 

Figure 1-2 Boane (left) and Chimoio (right) mound

Table 1-1General features of the study sites: Boane (Maputo), Chimoio

	Boane, (Maputo province)	Chimoio (Manica province)
Latitude	26°04'09.8"S	19°08'33.6"S
Longitude	32°16'38.9"E	33°23'29.1"E
Altitude, m	51	638
Mean slope, %	1	6
MAAT*, °C	22.9	21.5
MAP**, mm	677	1143
Vegetation	*Andropogoneae*	*Cissampelos mucronata* A. Rich, *Corchorus olitorius* L., *Hugonia busseana* Engl., *Impomoea sp.* L., *Lannea schweinfurthii* Engl., *Rhus natalensis* Bernh. Ex Krauss, *Schefflera umbellifera* Sond., *Thespesia garckeana* F. Hoffm.
Parent material	Alluvium	Granulite-gneiss complex
Soil classification		

*MAAT, mean annual air temperature; ** MAP, mean annual precipitation

1.2 **Soil sampling**

Samples were collected on October-November and as a result of a preliminary survey, the most representative mound in shape and size was selected for each site, followed by a pedological description of that and the control soil without evidence in bioturbation, about 6 m from the termite mound, following “Field Book for Describing and Sampling Soils” (Schoeneberge,et al. 2012). Termite samples was randomly collected to identify the site species.

1.3 **Soil analysis**

Soil pH was determined potentiometrically in water (pH_{H2O}) and potassium chloride (KCl) with a solid-liquid (w:v) ratio of 1:2.5. Pipette method was used for texture (Day, 1965), the samples were pretreated with hydrogen peroxide and dispersing solution to eliminate organic cements and to dissolve inorganic bonds, respectively. Organic Carbon was determined by Walkley Black method (Pansu and Gauthey rou, 2006), while Cation Exchange Capacity and base saturation (Soil Survey Staff, 2009) were estimate with ammonium acetate 1M method. Mehlich 3 was used for Available-Phosphorus (Mehlich, 1984) and Total Nitrogen was determined following Kjeldahl method (Bremmer, 1996). Samples were also analyzed with portable X-Ray Fluorescence (Weindorf et al., 2012).

1.4 **Statistical analysis**

Analysis of variance (ANOVA) was carried out , using R software, to test the effect of termites on physico-chemical soil properties. To apply the ANOVA, the normal distribution of the data and successively the equal variances were previously verified. When data were not parametric (non-normal distribution and heterogeneity of the variance), each numerical variable was transformed by the Box and Cox (1964) procedure. The improvement of the assumption to normality and homoscedasticity was verified on residuals by the Shapiro-Wilk statistical test (“stats” package) and by Levene’s test (“car” package) both at 5% significance level. When normality was not respected, the Kruskal-Wallis test was applied to assess if the differences were significant. In case of heteroscedasticity of the transformed data, the Welch one-way ANOA test was performed. ANOVA tests were deemed significant when $P \leq 0.05$; differences between means were compared using a post-hoc *Tukey’s Honest Significant Difference (HSD)* test with $P \leq 0.05$.

CHAPTER 2
RESULTS

2.1 **Soil and Mound Description**

2.1.1 *Boane District*

Table 2-1Main descriptive elements obtained from observation of Control soil profile site in Boane. Codes according to Schoeneberger et al. (2002). For symbols see legend.

Boane, Maputo (26°04'09.8"S 32°16'38.9"E). Altitude: 51; MAAT*: 22.9°C; MAP**: 677 mm; Parent rock: Alluvium

Slope:1%, Management: Pasture, Soil cover:80% Vegetation: *Andropogoneae*

Soil: Typic Haplotorrox, very-fine, mixed, isohyperthermic (Soil Survey Staff, 2014)

Control

Horizon	Depth cm	Texture[a]	Dry Color[b]	Wet Color[b]	Structure[c]	Consistence[d]	Roots[e]	Termite Channels[f]	Boundary[h]	Other observations[i]
A1	0-23	sl	2.5YR 3/3	2.5YR 2/3	1f,m gr 1f,m sbk	d(sh), m(vfr)	1co; 3f	1f	G,W	
A2	23-41	sl	2.5YR 2/3	2.5YR 2/2	1co,vc abk-sbk	d(vh), m(fi)	1f	1c	G,W	
Bo1	41-62	scl	2.5YR 3/4	2.5YR 3/2	1co,vc abk-sbk	d(vh), m(vfr)	1f	n	G,W	

Bo2	62-90+	cl	2.5YR 3/3	2.5YR 3/2	1m cpr,abk,sbk	d(vh), m(vfr)	0	n	-

*MAAT, mean annual air temperature.

** MAP, mean annual precipitation.

[a] sl=sandy loam, scl=sandy clay Loam, cl=clay loam, sc=sandy clay.

[b] Dry and Wet, according to the Munsell Soil Color Chart (1954 edition).

[c] 1=weak, 2=moderate, 3=strong, vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse, gr=granular, abk=angular block, sbk=subangular block, cpr=columnar.

[d] d=dry, m=moist, so=soft, sh=slightly hard, vh= hard, very hard, eh=extr. hard, vfr= very friable, fr=friable, fi=firm, vfi=very firm.

[e] 0=absent, v_1=very few,1=few, 2=common, 3=many, vf=very fine, f=fine, m=medium, co=coarse.

[f] 1=fine, 2=medium, 3=coarse, 4=very coarse, 5=extremely coarse, n=absent, f=few, c=common.

[h] C=clear, G=gradual, W=wavy.

[I] FMN=iron-manganese nodules, so=soft consistence.

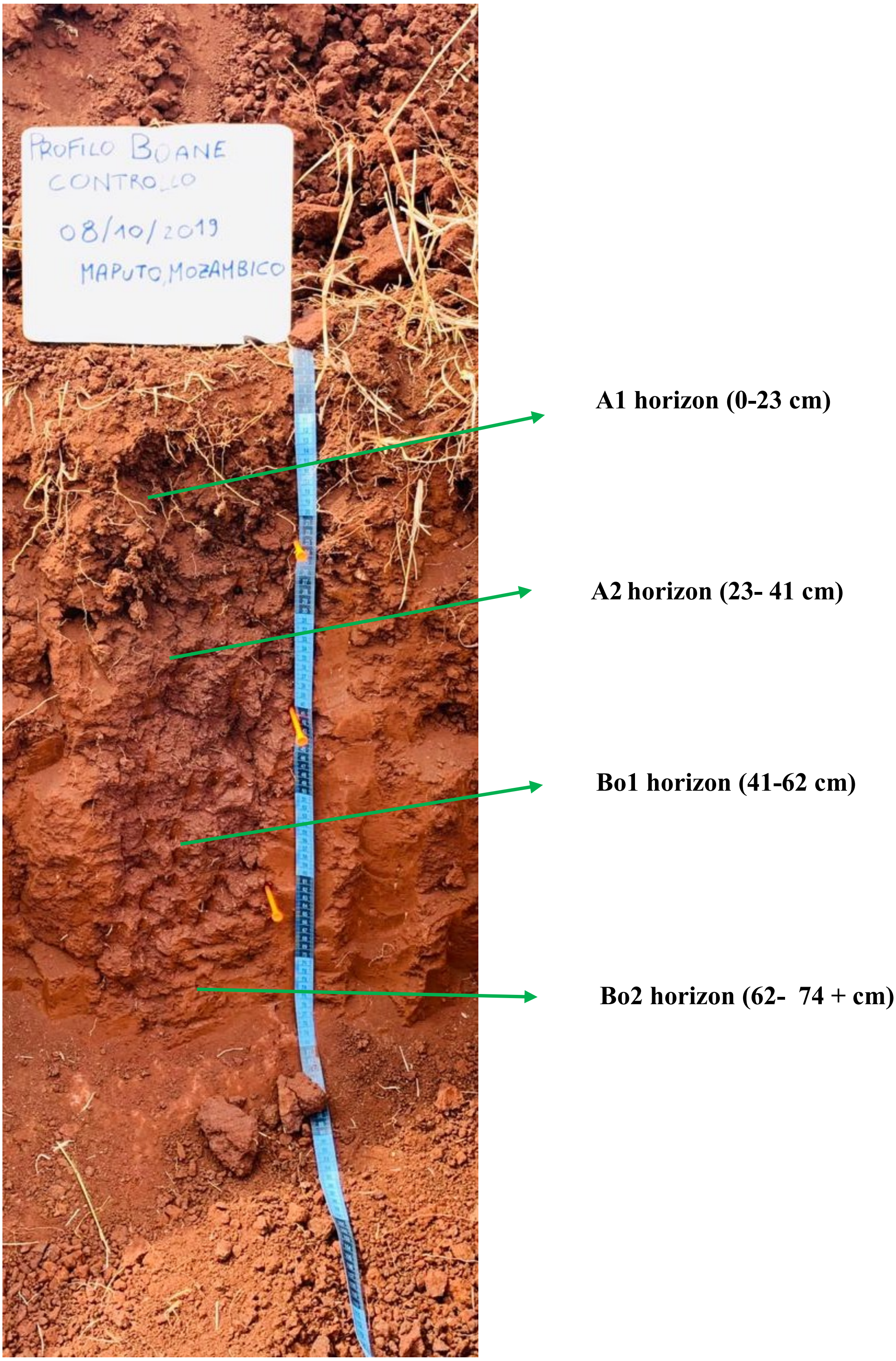

Figure 2-1 Boane Control Profile

Table 2-2 Main descriptive elements obtained from observation of Termite Mound profile site in Boane. Codes according to Schoeneberger et al. (2002). For symbols see legend.

Boane, Maputo (26°04'09.8"S 32°16'38.9"E). Altitude: 51; MAAT*: 22.9°C; MAP**: 677 mm; Parent rock: Alluvium

Slope:1%, Management: Pasture, Soil cover:80% Vegetation: *Andropogoneae*

Height: 1,10 m; Diameter: 2m; Shape: Pyramidal.

Soil: Typic Haplotorrox, very-fine, mixed, isohyperthermic (Soil Survey Staff, 2014)

Termite Mound

Horizon	Depth cm	Texture[a]	Dry Color[b]	Wet Color[b]	Structure[c]	Consistence[d]	Roots[e]	Termite Channels[f]	Boundary[h]	Other observations[i]
Azo1	+30-+40+	sl	2.5YR 3/3	2.5YR 2/4	1m,co abk-sbk	d(sh), m(fr)	2co;1vf,f	2c	G,W	
Azo2	+20-+30	sl	2.5YR 3/3	2.5YR 3/3	1m,co abk-sbk	d(h), m(vfr)	1m,co;2f	2c;3f	G,W	
Azo3	+10-+20	sl	2.5YR 2/4	2.5YR 3/3	1m,co abk-sbk	d(eh), m(fr)	2vf,f	2c;3f	G,W	Hard penetrate-resistance
Azo4	0-+10	scl	2.5YR 2/4	2.5YR 2/3	1co abk-sbk	d(vh), m(fi)	1m;2f	2c;3f;4f	G,W	Hard penetrate-resistance
A	0-20	cl	2.5YR 2/4	2.5YR 2/3	1m,co abk-sbk	d(vh), m(fi)	1vf,f	2c;3f	C,W	Hard penetrate-resistance
Bo1	20-40	scl	2.5YR 3/4	2.5YR 2/4	1m,co abk-sbk	d(vh), m(fr)	1vf,f	2f;3f;5f	G,W	Hard penetrate-resistance
Bo2	40-50	scl	2.5YR 3/4	2.5YR 3/3	1co abk-sbk	d(vh), m(fr)	0	2f;3f;5f	G,W	Hard penetrate-resistance
Bo3	50-60	scl	2.5YR 3/4	2.5YR 2/4	1co abk-sbk	d(vh), m(fr)	0	2f;3f	G,W	Hard penetrate-resistance
Bo4	60-70+	cl	2.5YR 3/3	2.5YR 3/4	1m,co abk-sbk	d(sh), m(vfi)	0	2f;3f	-	Hard penetrate-resistance

*MAAT, mean annual air temperature.

** MAP, mean annual precipitation.

[a] sl=sandy loam, scl=sandy clay Loam, cl=clay loam, sc=sandy clay.

[b] Dry and Wet, according to the Munsell Soil Color Chart (1954 edition).

[c] 1=weak, 2=moderate, 3=strong, vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse, gr=granular, abk=angular block, sbk=subangular block, cpr=columnar.

[d] d=dry, m=moist, so=soft, sh=slightly hard, vh= hard, very hard, eh=extr. hard, vfr= very friable, fr=friable, fi=firm, vfi=very firm.

[e] 0=absent, v_1=very few,1=few, 2=common, 3=many, vf=very fine, f=fine, m=medium, co=coarse.

[f] 1=fine, 2=medium, 3=coarse, 4=very coarse, 5=extremely coarse, n=absent, f=few, c=common.

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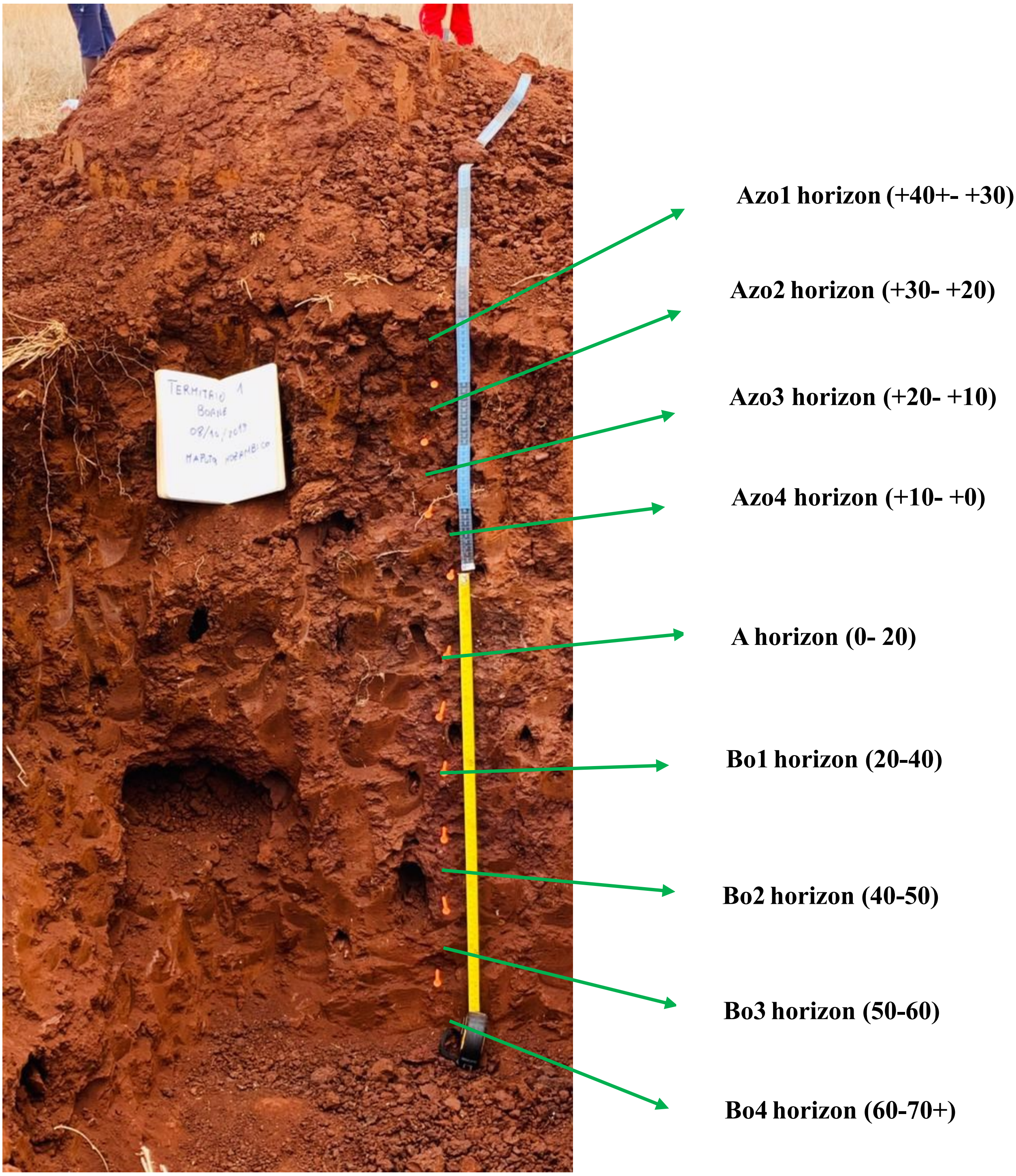

Figure 2-2 Boane Termite Mound Porfile

Control soil color ranged from dark reddish brown in the upper horizon to dusky red in the lower ones. The A1 horizon showed weakly-developed granular and sub-angular blocky very friable structure, while underneath this horizon weakly-developed angular and sub-angular blocks prevailed (with the exception of the Bo2 horizon that was characterized by columnar very hard structure when dry). This soil contained few thin fragments, with particle-size distribution dominated by clay that represented 58-70 % of all horizons. Sand content decreased from the A1 to the Bo2 horizons, while clay followed the opposite trend. The upper horizons showed termite channels as biological activity, especially A2 horizon characterized by a common presence of those foraging tunnels (Table 2-1).

All termite mound horizons had a dark reddish brown color and texturally, clay content varied between 60 and 70% whereas sand was higher only in the upper horizons except for Azo1. All horizons showed weakly-developed angular and sub-angular blocks and below 20-30 cm from the surface, the horizons were characterized by hard penetrate-resistance. Termite channels were observed in all horizons increasing in size and abundance from the upper one to Bo1 and Bo2 that presented few extremely coarse termite cavities as biological activity, while below that horizons were characterized by decrease of channels size (Table 2-2). According to Référentiel pédologique was attributed –zo suffix to indicate zoogenic genesis, for the horizons up than surface layer that were "constructed" by termite accumulating activity (Baize and Girard, 2008).

2.1.2 *Chimoio*

Table 2-1 Main descriptive elements obtained from observation of Control Soil profile site in Chimoio. Codes according to Schoeneberger et al. (2002). For symbols see legend.

Chimoio (19°08'33.6"S 33°23'29.1"E) Altitude:638 m; MAAT*: 21.5°C; MAP**: 1143 mm Parent rock: granulite-gneiss complex

Slope: 6%, Management: Fallow, usually as corn (*Zea mays*) plantation, Soil cover: 50% Vegetation: *Cissampelos mucronata* A. Rich, *Corchorus olitorius* L., *Hugonia busseana* Engl., *Impomoea sp.* L., *Lannea schweinfurthii* Engl, *Rhus natalensis* Ex Krauss, *Schefflera umbellifera* Sond., *Thespesia garckeana* F. Hoffm.

Soil: Inceptic Haplustox, coarse-loamy, mixed, isothermic (Soil Survey Staff, 2014)

Control

Horizon	Depth cm	Texture[a]	Dry Color[b]	Wet Color[b]	Structure[c]	Consistence[d]	Roots[e]	Termite Channels[f]	Boundary[h]	Other observations[i]
Ap	0-19	sl	10YR 4/3	5YR 3/1	3vf,co sbk	d(so), m(vfr)	1co; 2m; 3vf,f	n	C,W	
Bo	19-48	scl	10YR 4/2	5YR 3/2	3vf,co,vc sbk	d(sh), m(vfr)	1vf,f	1f	G,W	
Bos1	48-63	scl	10YR 4/4	5YR 4/2	3vf,m,co sbk	d(vh), m(vfr)	0	1f	G,W	10%FMNso
Bos2	63-90+	sc	10YR 4/6	5YR 4/3	3vf,m sbk	d(eh), m(vfr)	0	n	-	10%FMNso

*MAAT, mean annual air temperature.

** MAP, mean annual precipitation.

[a] sl=sandy loam, scl=sandy clay Loam, cl=clay loam, sc=sandy clay.

[b] Dry and Wet, according to the Munsell Soil Color Chart (1954 edition).

[c] 1=weak, 2=moderate, 3=strong, vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse, gr=granular, abk=angular block, sbk=subangular block, cpr=columnar.

[d] d=dry, m=moist, so=soft, sh=slightly hard, vh= hard, very hard, eh=extr. hard, vfr= very friable, fr=friable, fi=firm, vfi=very firm.

[e] 0=absent, v_1=very few,1=few, 2=common, 3=many, vf=very fine, f=fine, m=medium, co=coarse.

[f] 1=fine, 2=medium, 3=coarse, 4=very coarse, 5=extremely coarse, n=absent, f=few, c=common.

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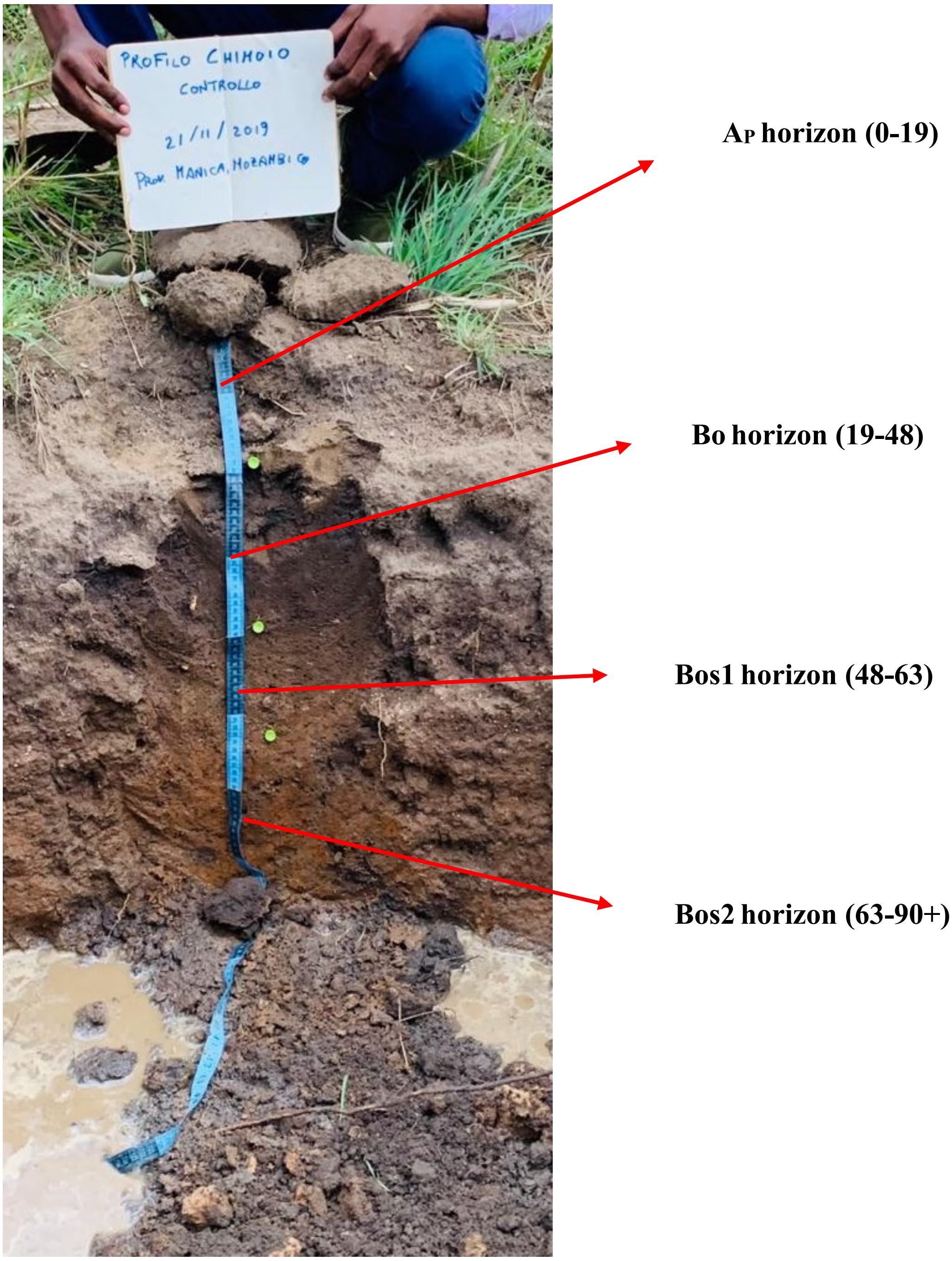

Figure 2-3 Chimoio Control Profile

Table 2-2Main descriptive elements obtained from observation of Termite Mound profile site in Chimoio. Codes according to Schoeneberger et al. (2002). For symbols see legend.

Chimoio (19°08'33.6"S 33°23'29.1"E) Altitude:638 m; MAAT*: 21.5°C; MAP**: 1143 mm Parent rock: granulite-gneiss complex

Slope:6%, Management: Fallow, usually as corn (*Zea mays*) plantation, Soil cover: 50% Vegetation: *Cissampelos mucronata, Corchorus olitorius, Hugonia busseana, , Impomoea sp., Lannea schweinfurthii, Rhus natalensis, Schefflera umbellifera, Thespesia garckeana.*

Height:3 m; Diameter: 15 m; Shape: Sub-spheroidal.

Soil: Inceptic Haplustox, coarse-loamy, mixed, isothermic (Soil Survey Staff, 2014)

Termite Mound

Horizon	Depth cm	Texture[a]	Dry Color[b]	Wet Color[b]	Structure[c]	Consistence[d]	Roots[e]	Termite Channels[f]	Boundary[h]	Other observations[i]
A_p	+90-+95+	scl	7.5YR 4/3	7.5YR 4/3	2m,co,vc sbk	d(s), m(fr)	1co; 2m; 3f,vf		G,W	
Bzo1	+80-+90	cl	7.5YR 4/3	7.5YR 4/3	2m,co,vc sbk	d(vh), m(fr)	1f, 2vf		G,W	
Bzo2	+70-+80	cl	7.5YR 4/4	7.5YR 4/2	2m,co sbk	d(vh), m(fi)	$v_1$vf,f		G,W	
Bzo3	+60-+70	cl	7.5YR 4/4	7.5YR 4/3	2vf,f,m sbk	d(vh), m(fr)	$v_1$vf,f		G,W	
Bzo4	+50-+60	cl	7.5YR 4/3	7.5YR 4/3	2,f,m,co sbk	d(vh), m(fr)	2vf,f		G,W	
Bzo5	+40-+50	scl	7.5YR 4/4	7.5YR 4/2	2,f sbk 2,co abk	d(vh), m(fi)	$v_1$vf,f		G,W	
Bzo6	+30-+40	cl	7.5YR 4/4	7.5YR 4/3	2,m sbk 2,co abk	d(vh), m(fr)	$v_1$vf		G,W	Hard penetrate-resistance
Bzo7	+20-+30	cl	7.5YR 4/4	7.5YR 4/2	2f,m sbk 2m,co abk	d(eh), m(fi)	$v_1$vf		G,W	Hard penetrate-resistance
Bzo8	+10-+20	scl	7.5YR 5/3	7.5YR 4/3	2m abk-sbk	d(eh), m(fi)	0		G,W	Hard penetrate-resistance

Bzo9	0-+10	scl	7.5YR 5/4	7.5YR 4/3	2f,m sbk	d(vh), m(fr)	0		G,W	Hard penetrate-resistance
Bo1	0-20	scl	7.5YR 5/4	7.5YR 4/4	2f,m sbk	d(vh), m(fi)	$v_1$vf		G,W	Few fungal activity
Bo2	20-40	cl	7.5YR 6/4	7.5YR 4/4	2f,m sbk	d(vh), m(fr)	$v_1$vf		G,W	Common fungal activity
Bo3	40-60	cl	7.5YR 6/4	7.5YR 4/4	2f,m sbk	d(vh), m(fr)	0		G,W	High fungal activity
Bo4	60-80	scl	7.5YR 6/4	7.5YR 4/2	2f,m sbk	d(sh), m(vfr)	0		G,W	High fungal activity
Bo5	80-90+	scl	7.5YR 6/4	7.5YR 4/2	2f sbk	d(vh), m(vfr)	0		-	High fungal activity

*MAAT, mean annual air temperature.

** MAP, mean annual precipitation.

[a] sl=sandy loam, scl=sandy clay Loam, cl=clay loam, sc=sandy clay.

[b] Dry and Wet, according to the Munsell Soil Color Chart (1954 edition).

[c] 1=weak, 2=moderate, 3=strong, vf=very fine, f=fine, m=medium, co=coarse, vc=very coarse, gr=granular, abk=angular block, sbk=subangular block, cpr=columnar.

[d] d=dry, m=moist, so=soft, sh=slightly hard, vh= hard, very hard, eh=extr. hard, vfr= very friable, fr=friable, fi=firm, vfi=very firm.

[e] 0=absent, v_1=very few,1=few, 2=common, 3=many, vf=very fine, f=fine, m=medium, co=coarse.

[f] 1=fine, 2=medium, 3=coarse, 4=very coarse, 5=extremely coarse, n=absent, f=few, c=common.

[h] C=clear, G=gradual, W=wavy.

[I] FMN=iron-manganese nodules, so=soft consistence.

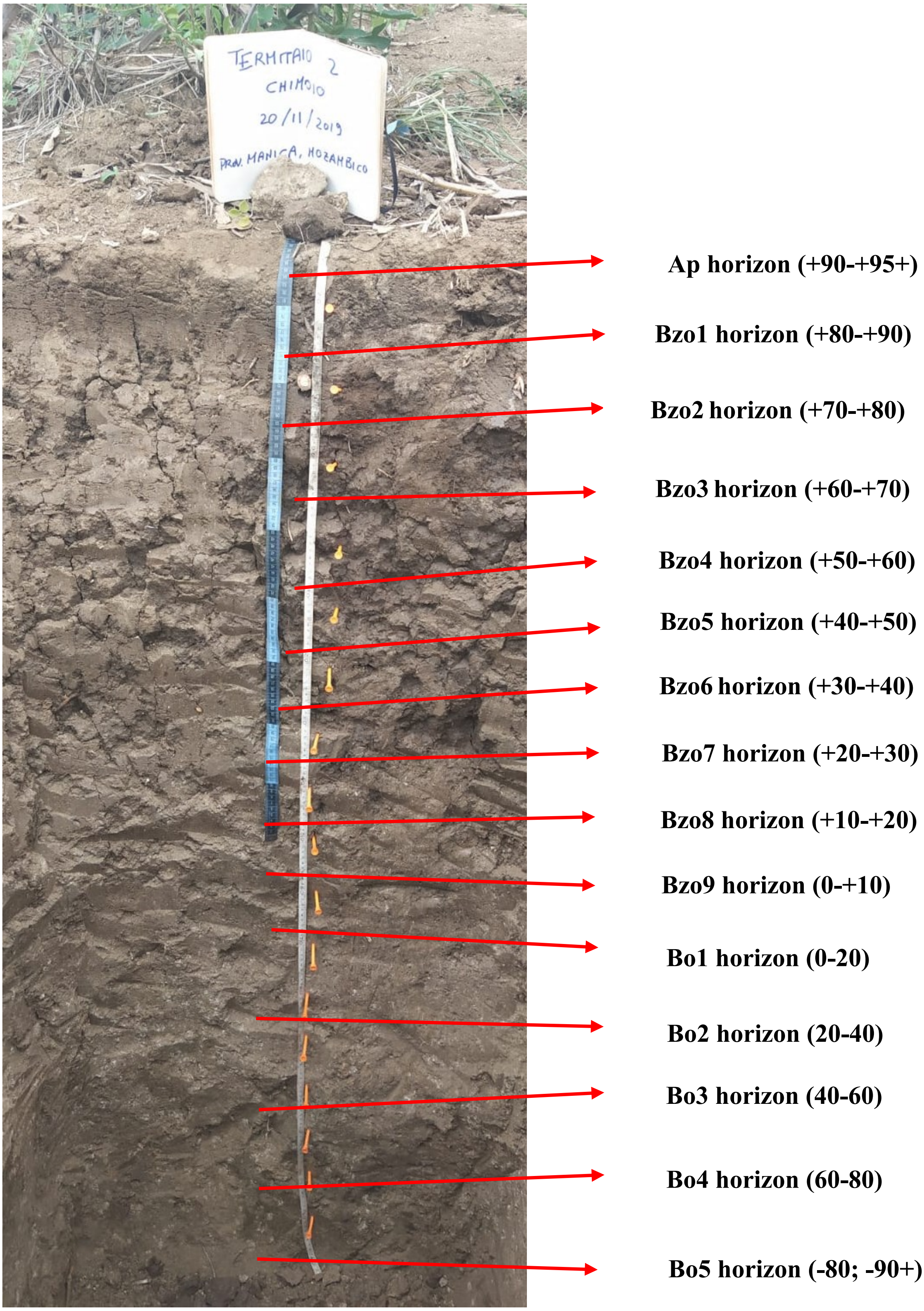

Figure 2-4 Chimoio Termite Mound Profile

Control soil color gradually ranged along the profile from very dark gray in the upper horizon to dark reddish brown-gray until reddish brown in the lower one. Below 50-60 cm, redoximorphic features (soft consistence and black color Mn nodules) were present due to alternating periods of reduction and oxidation. All soil horizons showed very friable sub-angular blocks which ranged from strongly-developed structures in upper horizons to moderately-developed in the lower ones. This soil contained few thin fragments, with particle-size distribution dominated by sandy while clay content increased with increasing depth, reaching highest percentage in lower horizon. Middle horizons (Bo and Bos1) showed few termite channels as biological activity (Table 2-3).

All termite mound horizons had brown color and a clay content that was higher than 40% except in Ap horizon, where sand represented more than 50 % of size-particle distribution. All horizons showed moderate-developed sub-angular blocks and as regard Bzo5, Bzo6, Boz7 and Bzo8, also angular blocky structure were identified. Middle horizons (from Bzo6 to Bzo9) showed hard penetrate-resistance. Fine-size termite channels were common along all the mound and horizons below the layer showed fungi presence which increased with depth, indeed lowest horizons (Bo3, Bo4 and Bo5) were characterized by high fungal activity(Table 2-4). According to Référentiel pédologique was attributed –zo suffix to indicate zoogenic genesis, for the horizons up than surface layer that were "constructed" by termite accumulating activity (Baize and Girard, 2008).

2.2 **Physico-chemical analysis**

2.2.1 *Boane District*

Results of physico-chemical analysis not showed significant differences (Fig.2-5) between control soil, termite mound section up than general soil surface, and termite mound section below general soil surface, except for total calcium and available-phosphorus. Total Calcium content was higher in the mound than control, especially in TU was 4-times higher than surrounding soil (Fig.2-6). Available-phosphorus followed a different trend since in control was higher than TB and lower than TU.

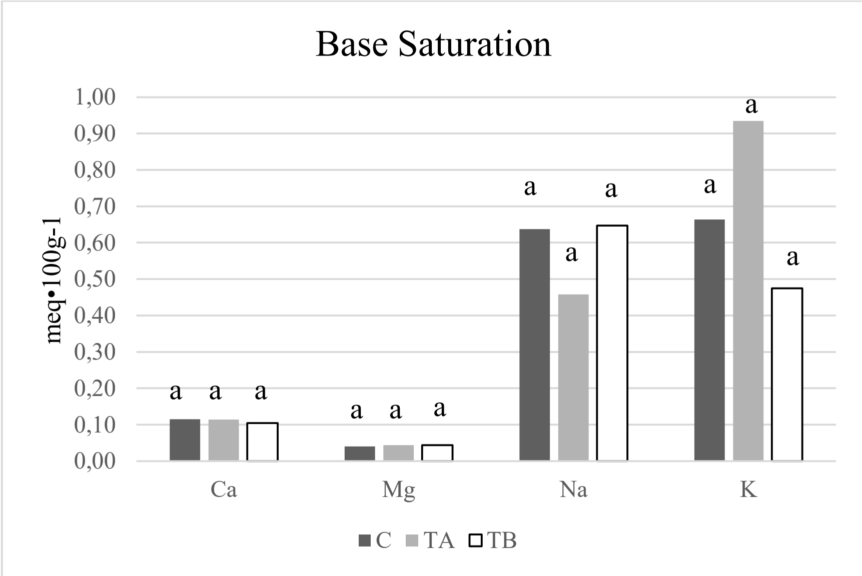

Figure 2-5Variation in Base Saturation in Control (C), termite mound section up than general soil surface (SU) and termite mound section below general soil surface (TB)

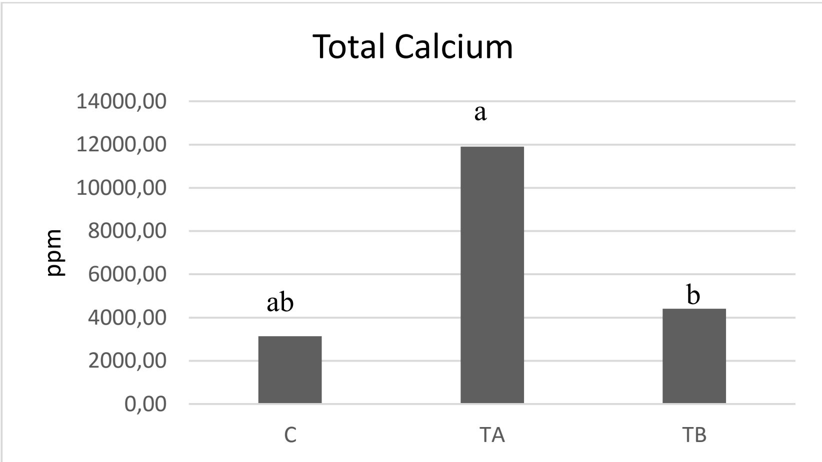

Figure 2-6 Variation of Total Calcium in Control (C), termite mound section up than general soil surface (SU) and termite mound section below general soil surface (TB)

Table 2-5 Table 0 1 Main physico-chemical parameters of the control soil (C), termite mound below general soil surface (TB) and termite mound up than general soil surface (TU) in Boane. The numbers in parentheses are the standard deviations. For each column and variable, mean values with different letters significantly differ for P ≤ 0.05 for the Tukey's post-hoc test.

Boane	Sand (%)	Silt (%)	Clay (%)	pH KCl	EC	OC	CEC	Ex._Ca	Ex._Mg
C	19[a]	16 [a]	65 [a]	6.07 [a]	109.57 [a]	1.41 [a]	15.90 [a]	0.12 [a]	0.04 [a]
	(4)	(1)	(5)	(0.29)	(12.01)	(0.40)	(1.76)	(0.01)	(0.01)
TU	18[a]	19 [a]	63 [a]	5.83 [ab]	86.91 [a]	0.98 [a]	16.72 [a]	0.10 [a]	0.04[a]
	(3)	(6)	(6)	(0.07)	(18.25)	(0.26)	(2.38)	(0.01)	(0.01)
TA	22[a]	28 [a]	51 [a]	5.75 [b]	111.31 [a]	1.22 [a]	17.45 [a]	0.11 [a]	0.04[a]
	(1)	(18)	(19)	(0.05)	(33.04)	(0.21)	(1.94)	(0.01)	(0.01)
	Ex._Na	Ex._K	P	N	Al	K	Ca	Mn	Fe
C	0.64 [a]	0.66 [a]	13 [ab]	0.08 [a]	75721.25 [a]	14765.00 [a]	3130.71 [ab]	0.28 [a]	234360 [a]
	(0.23)	(0.46)	(17)	(0.04)	(2298,79)	(2481.16)	(6259.53)	(0.01)	(13339.79)
TU	0.65 [a]	0.47 [a]	8 [b]	0.09 [a]	74473.20 [a]	13772.50 [a]	4403.76 [b]	0.28 [a]	235730 [a]
	(0.20)	(0.26)	(2)	(0.02)	(1160.54)	(1126.70)	(6030.75)	(0.03)	(4469.70)
TA	0.46 [a]	0.93 [a]	15 [a]	0.10 [a]	73111.00 [a]	15221.50 [a]	11902.50 [a]	0.28 [a]	226860 [a]
	(0.04)	(0.05)	(2)	(0.01)	(1201.64)	(587.49)	(591.87)	(0.01)	(8231.60)

EC= electric conducibility (µS/cm); OC= organic carbon (%); CEC= cation exchange capacity (meq•100g^{-1}); Ex._Ca= exchangeable Calcium (meq•100g^{-1}); Ex._Mg= exchangeable Magnesium (meq•100g^{-1}); Ex._Na= exchangeable Sodium (meq•100g^{-1}); Ex._K= exchangeable Potassium (meq•100g^{-1}); P= available-Phosphorus (mg•kg^{-1}); N= total Nitrogen (%); Al= total Alluminum (ppm); K= total Potassium (ppm); Ca= total Calcium (ppm); Mn= total Manganese (ppm); Fe= total Iron (ppm).

2.2.2 *Chimoio*

pH was higher in mound than surrounding soil and showed an increase with depth, indeed TB was 0.6 higher than TU(Fig.2-7). The same trend was observed in base saturation, except for exchangeable-potassium (Fig. 2-8). Clay content resulted statistically equal between control soil and termite mound as also observed for Total Nitrogen and Organic Carbon while nest showed an enrichment in silt content, more in TB than TU (Fig.2-9). Available-phosphorus resulted higher in C and TU than TB, though without significant differences. Regarding pXRF results, only the main elements were statistical analyzed and were observed different contents between control, TB and TU. Manganese (Fig. 2-10) and Calcium increased in nest, especially in the section below general soil surface, while Potassium followed the opposite trend.

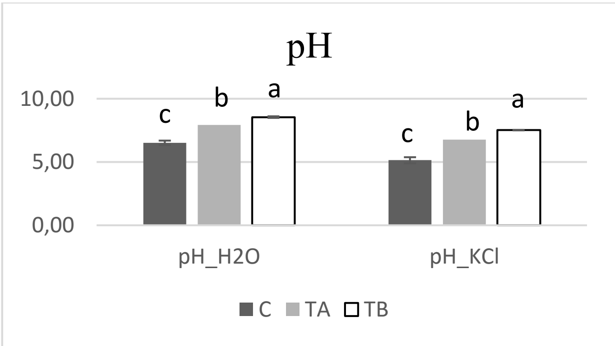

Figure 2-7 pH variaton in Control (C), termite mound section below general soil surface (TB) and termite mound section up than general soil surface (TU)

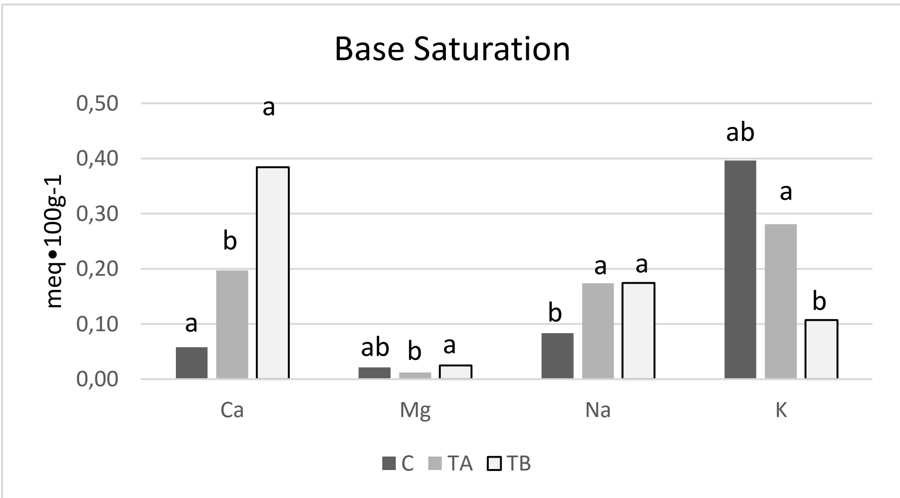

Figure 2-8 Variation of Base Saturation in Control (C), termite mound section up than general soil surface (TU) and termite mound section below general soil surface (TB).

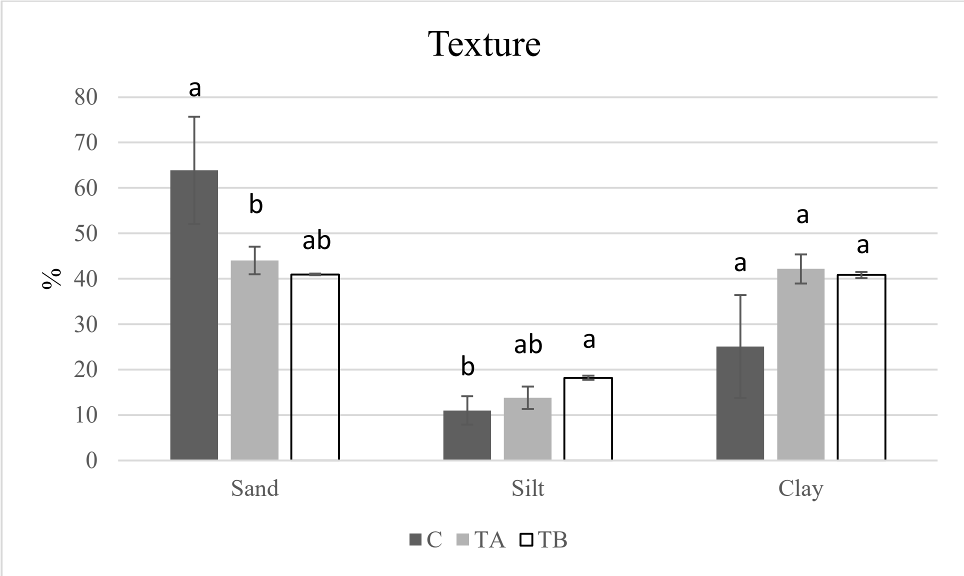

Figure 2-9 Variation of Texture in Control (C), termite mound section up than general soil surface (TU) and termite mound section below general soil surface (TB)

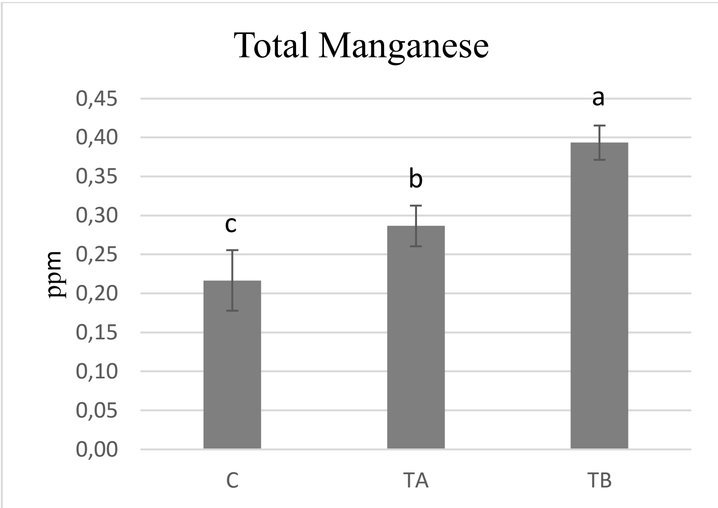

Figure 2-10 Variation of Total Manganese in Control (C), termite mound section up than general soil surface (TU) and termite mound section below general soil surface (TB).

Table 2-6 Main physico-chemical parameters of the control soil (C), termite mound below general soil surface (TB) and termite mound up than general soil surface (TU) in Chimoio. The numbers in parentheses are the standard deviations. For each column and variable, mean values with different letters significantly differ for P ≤ 0.05 for the Tukey's post-hoc test.

Chimoio	Sand (%)	Silt (%)	Clay (%)	pH H_2O	pH KCl	EC	OC	CEC	Ex._Ca	Ex._Mg
C	64 [a]	11 [b]	25 [a]	6.53 [c]	5.14 [c]	70.31 [b]	0.78 [a]	5.48 [b]	0.06 [a]	0.02 [ab]
	(12)	(3)	(11)	(0.18)	(0.24)	(16.54)	(0.26)	(1.77)	(0.01)	(0.01)
TB	41 [ab]	18 [a]	41 [a]	8.54 [a]	7.52 [a]	128.52 [a]	0.57 [a]	9.25 [a]	0.38 [a]	0.02 [a]
	(0)	(1)	(1)	(0.06)	(0.02)	(15.13)	(0.14)	(0.82)	(0.01)	(0.01)
TU	44 [b]	14 [ab]	42 [a]	7.92 [b]	6.78 [b]	108.76 [a]	0.53 [a]	8.55 [a]	0.20 [b]	0.01 [b]
	(3)	(3)	(3)	(0.28)	(0.42)	(16.39)	(0.25)	(0.42)	(0.06)	(0.01)
	Ex._Na	Ex._K	P	N	Al	K	Ca	Mn	Fe	
C	0.08 [b]	0.40 [ab]	18 [a]	0.04 [a]	85418.75 [ab]	44492.75 [a]	20523.25 [a]	0.22 [c]	130686.80 [a]	
	(0.05)	(0.06)	(15)	(0.01)	(4437.83)	(4567.40)	(2569.63)	(0.04)	(50424.79)	
TB	0.17 [a]	0.11 [b]	13 [a]	0.04 [a]	20264.09 [b]	29496.40 [c]	169610.70 [c]	0.39 [a]	150073.50 [a]	
	(0.05)	(0.01)	(7.45)	(0.02)	(33975.24)	(1342.06)	(35074.36)	(0.02)	(3431.28)	
TU	0.17 [a]	0.28 [a]	12 [a]	0.05 [a]	88710.90 [a]	36393.90 [b]	35228.40 [b]	0.29 [b]	154838.00[a]	
	(0.03)	(0.32)	(10)	(0.03)	(3686.20)	(2609.64)	(21702.74)	(0.03)	(8706.88)	

EC= electric conducibility (µS/cm); OC= organic carbon (%); CEC= cation exchange capacity (meq•100g^{-1}); Ex._Ca= exchangeable Calcium (meq•100g^{-1}); Ex._Mg= exchangeable Magnesium (meq•100g^{-1}); Ex._Na= exchangeable Sodium (meq•100g^{-1}); Ex._K= exchangeable Potassium (meq•100g^{-1}); P= available-Phosphorus (mg•kg^{-1}); N= total Nitrogen (%); Al= total Alluminum (ppm); K= total Potassium (ppm); Ca= total Calcium (ppm); Mn= total Manganese (ppm); Fe= total Iron (ppm

CHAPTER 3
DISCUSSION

3.1 **Soil and Mound Description**

Suffix –zo attributed to horizons "built" by termites up than general soil surface, may be considered as an integration of Référentiel Pédologique to Soil Taxonomy proposed by USDA used in this study, since American classification not presents a suffix for horizons literally constructed by soil fauna as those described (USDA, 1999). French soil classification system and most of available literature attributed the suffix to organic horizon characterized by fauna activity, thus was necessary an adaption because constructed horizon by termite may not be considered as organic because low OC content (Baize and Girard, 2008; Ponge et al., 2010; Andreetta et al., 2018). In conclusion this study may be one of the first that introduced a new vision of zoogenic origin horizons, proposing suffix –zo in mineral horizons description.

3.2 **Physico-chemical analysis**

3.2.1 *Boane District*

Non-enrichment in mound clay content may be due to high fine-size particle percentage in control soil, so termites did not need selective clay collection (Pomeroy, 1983; Jouquet et al., 2005; Ackerman et al., 2007).

Lower pH in Boane termite mound than control contrasts with other studies that found an increase (Garnier-Silliam, 1991; Contour-Ansel et al., 2000; Fall et al, 2001b; Mujinya et al., 2010). Acidification may be as a consequence of organic acids apport by saliva.

No significant differences in Cation Exchange Capacity and nutrients content in Boane mound and control soil may be explained as follow:

- Clay that is the main responsible of absorption processes, not change its content between nest and control;
- non-enrichment in nutrient content in contrast with several studies may be a defending strategy against geophagy, in fact Mills et al. reported that termites need to minimize nutrient enrichment of the mounds in order to reduce geophagy benefits, therefore

material loss. (Mills et al., 2009). This hypothesis is in according with site characteristics indeed area present low food availability and human disturbance that may promote wild fauna attack.

High total Calcium content in TU may be due to a collection of mineral rich in Ca such as Plagioclase from deep horizons (Jouquet, Lepage and Velde, 2002).

3.2.2 *Chimoio*

Texture results in Chimoio are in agreement with several authors that found a fine-particle size (especially silt) enrichment due a preferentially selection or use of soil from deep horizons in the construction of their mounds (Garnier-Sillam and Harry, 1995; Contour-Ansel et al., 2000; Fall et al., 2001a; Van Ranst et al, 2010; Menichetti et al., 2014; Seymour et al, 2014). No significant difference in clay is probably due to statistical analysis since the mean value of control soil included also deep horizon rich in clay as the termite mound, supported by high standard deviation (11).

Mound showed higher pH, due to a collection of silt rich in carbonates (mostly calcium carbonate) supported by an increase of exchangeable calcium, exchangeable sodium and total calcium in termite nest than control soil. Considering parental material, increase in carbonates content may be due to presence of calcite veins in the granulite-gneiss complex, result of diagenesis process (Morrison and Valley, 1988; Huber et al., 2007).Therefore, assuming the presence of calcite veins, enrichment may be explained as a selective transport of carbonates or a need related to higher water-requirement in the mound. Indeed, during water exploration activity, calcite probably represent the only way to reach deep horizon, due to low termite excavation capacity in granulite-gneiss complex. Excavated material must be re-collocated and probably constitutes part of the nest as reported by Bala et al. that found a relation between ground water table depth and mound height, since increasing in ground water table depth leads to greater amount of excavated soil material used in mound construction that thus increases in height (Bala et al., 2019).

Higher available-phosphorus in control and termite mound section up than general soil surface may be interpreted as result of chemical fertilize application.

Non-enrichment in organic matter content in Chimoio mound indicates that termites collect fine-size particles poor in OM without using faeces to improve their stability, while increasing in the TU horizon characterized by greater fungal activity shows their ability to incorporate more C in fungus chamber walls to maintain microclimatic conditions required from exosymbiosis (Garnier-Sillam, 1991; Contour-Ansel et al., 2000; Jouquet et al., 2002; Sall et al., 2002). Manganese accumulation in termite nest, especially in the section below general soil surface characterized by great exosymbiosis, may be result from fungal activity indeed it is strong oxidant used by fungi to degrade lignin (Mills et al., 2009). In addition to fungi, authors found high microbial activity such as bacteria in termite mounds (Holt, 1998; Ndiaye et al., 2004; Duponnois et al., 2005), involved in nutrient cycle and litter decomposition. However biological analysis were not performed in this study

3.3 **Influence of agro-ecological Regions characteristics on termite impact**

Results suggest that local conditions play a key role on termite impact on soil fertility. Altough Boane mound not showed a significant enrichment on some physico-chemical properties as in Chimoio, higher fertility of Boane site may explain this data. Termites probably not need to enrich nest material since surrounding soil shows properties that already satisfy colony requirements. Different pH trend showed in termite nests may suggest that enrichment in carbonates content is not due to a termites selective strategy but to need to find a way to reach water. Indeed Boane mound, characterized by alluvium parental material that is easily penetrable by termite, not showed high pH, synonym of low carbonates content. However, is not possible to generalize because thus termite species and feeding-behavior play a key role on the impact of this engineer on soil properties (Contour-Ansel et al., 2000; Sall et al., 2002).

CONCLUSION

The put forward hypothesis on enrichment carbonates origin in mound, might shed light on spatial distribution of termites, since survival of a colony in an area characterized by strong parental material might depend by the presence of soft material veins, more suitable for water search activity.

Data emphasize that is not possible to generalize about termites effect on soil proprieties since the influence varies according to termite species, local environmental conditions, parental material and land use as result of organism requirement. Although the results not showed an evident enrichment in nutrient content in all termite mounds as reported in several studied, available literature encourages to keep on in this topic. The performed physico-chemical characterization represent a foundation to biological analysis that may explain the higher production on mounds observed during sites survey and supported by local farmers knowledge, due to a key role of microbial activity on soil fertility.

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