Examensarbeten **2012:11**
Institutionen för skogens ekologi och skötsel

Soil organic carbon and infiltrability in relation to distance from trees (Vitellaria paradoxa) with and without termite mounds in a parkland of central Burkina Faso

Foto: Klara Hedemyr Joelsson

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Sveriges Lantbruksuniversitet Jägmästarprogrammet
Examensarbete i markvetenskap, 30 hp, avancerad nivå A2E ISSN 1654-1898
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Infiltrationskappacitet och organiskt kol i marken som funktion av avstånd till träd (Vitellaria paradoxa) med och utan termitstackar i agroforestrylandskap i centrala Burkina Faso

Klara Hedemyr Joelsson

Nyckelord / ***Keywords:***
Burkina Faso, parkland, agroforestry, trees, Vitellaria paradoxa, termites, steady-state infiltrability, double-ring infiltrometer, bulk density, carbon content, macro-porosity

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ISSN 1654-1898 Umeå 2012

Sveriges Lantbruksuniversitet / *Swedish University of Agricultural Sciences*
Fakulteten för skogsvetenskap / *Faculty of Forest Sciences*
Jägmästarprogrammet / *Master of Science in Forestry*
Examensarbete i markvetenskap / *Master thesis in Soil Science*
EX0177, 30 hp, avancerad nivå/ *advanced level* A2E

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Abstract

In semi-arid Burkina Faso access to water is crucial for crop-growth. Most common cropping system in the region is parklands, where crops are grown in association with trees. This study investigates if trees and termites influence steady-state infiltrability, soil carbon content, bulk density and macro-porosity in a specific parkland in Saponé, Burkina Faso. Infiltrability was measured with a double-ring infiltrometer and steady-state infiltrability was estimated by Philip's equation. Bulk density, macro porosity and carbon content were sampled and analysed. Measurements were conducted in 11 transects; five transects in small openings (20–31 m between trees) and six in large openings (68–127 m between trees). Each transect went from one tree with a termite mound to a tree without termites.

The results showed significantly higher steady-state infiltrability close to trees, with and without termites compared to the centre of the openings. Infiltrability decreased with increased distance from trees. No such decrease occurred when small openings was analysed separately. Bulk density increased with increased distance from trees. Bulk density had a reversed linear relation with steady-state infiltrability. Carbon content in top soil was higher under trees than in openings. At 30-35 cm depth macro porosity decreased with increased distance to trees, with and without termites. Measurements from trees with termites had high variance for all variables.

Trees improve soil structure by lowering bulk density, increase the amount of macro-pores, raise the carbon content and thus improve infiltrability. Maintaining parkland can be a good way of maintaining trees in a landscape and tree density is shown to matter for soil quality and may have large importance for groundwater recharge.

Keywords: Burkina Faso, parkland, agroforestry, trees, *Vitellaria paradoxa,* termites, steady-state infiltrability, double-ring infiltrometer, bulk density, carbon content, macro-porosity

Sammanfatting

I semi-arida Burkina Faso är tillgång till vatten avgörande för att upprätthålla ett produktivt jordbruk. Det vanligaste odlingssystemet för regionen är”parklands” där grödor odlas under och mellan träd. I examensarbetet undersökdes huruvida träd och termiter påverkar infiltrationen, halten organiskt kol, bulkdensiteten och mängden makroporer i ett parklandsystem i Saponé, Burkina Faso. Infiltrationen mättes med dubbelringsinfiltrometer och konstanta infiltrationshastigheten beräknades enligt Philips ekvation. Bulkdensiteten, mängden makroporer samt kolhalten analyserades. Mätningarna utfördes i 11 transekter, fem transekter i små (20-31 m mellan träd) och sex i stora öppnnigar (68-127 m mellan träden). Transekterna gick från ett träd med termitstack till ett träd utan termiter.

Resultaten visade signifikant högre infiltration nära träd, med eller utan termiter jämfört med i centrum av öppningarna samt att infiltrationen avtog med ökat avstånd från träd. I små öppningar fanns inget samband mellan avtangande infiltration och avstånd från träd. Bulkdensiteten ökade med ökat avstånd från träd. Infiltrationen ökade med minskad bulkdensitet. Kolhalten på 0-10 cm djup var högre under träd än i öppningar. På 30-35 cm djup minskade makroporositeten med ökat avstånd från träd, med och utan termiter. Träd med termiter hade hög varians för alla variabler.

Träd förbättrar jordstrukturen genom att sänka bulkdensitet, öka mängden av makroporer, höja kolhalten och därmed förbättra infiltrationen. Parklands kan vara ett bra sätt att behålla träd i ett landskap och trädtäthet påverkar jordens kvalitet och kan ha stor betydelse för grundvattenbildning.

Nyckelord: Burkina Faso, parkland, trädjordbruk, träd, termiter, *Vitellaria paradoxa,* dubbelringsinfiltrometer, infiltrationen, bulkdensitet, kolhalt, makroporer

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1 Introduction

1.1 Burkina Faso, demographics and vulnerability

Burkina Faso is a landlocked country within the semi-arid tropical region, in west sub-Saharan Africa. It constantly ranks, according to most development indicators, among the five bottom countries in the world, (Ingram *et al.* 2002). Population size is about 15.2 million, whereof more than half survives on less than 1 US $ per day. The annual population increment is 3.2% and almost half of the population is under the age of 15 (WHO 2011).

Agriculture is the main occupation and about 90 % of the population is depending on it for their livelihood. Nearly all (80%) of the crops are produced for the own household (Ingram *et al.* 2002). The dominating farming system is agroforestry parklands, which broadly can be defined as areas where scattered trees occur in cultivated or recently fallowed fields (Bayala *et al.* 2011). Most of the cultivation takes place during rainfed conditions, only 15 000 ha of Burkina Faso's ca 300 million ha cultivated land is irrigated (Ingram *et al.* 2002). The parkland systems are maintained since long or created by maintaining trees when natural woodland is converted into farmland (Teklehaimanot 2004; Bayala *et al.* 2011). The trees serve as sources of wood, food, fodder and medicine (Teklehaimanot 2004; Bayala *et al.* 2011; Sanou *et al.* 2010). Locals often rely on NTFPs (non timber forest products) for subsistence and economic needs (Gustad *et al.*, 2004). *Vitellaria paradoxa* has nuts that are rich in fatty acids and makes up Burkina's third largest export industry (Teklehaimanot, 2004)

As a consequence of the rapid population growth, the amount of arable land per capita decreases (Auyk 1996) which leads to intensified production, and often to different environmental tradeoffs, for example fewer trees kept on the fields and depletion of soil nutrient (Gray 2004).

Livelihood, such as agriculture, closely related to environmental conditions are vulnerable to environmental stress or change (Simonsson 2005). One characteristic for the semi-arid tropics is seasonality with respects of rainfall, with one or two distinct rain periods a year (Murphy & Lugo 1986). Burkina Faso makes no exception, the rains fall during a single wet season of 3 to 5 months, shorter in the northern parts of the country and longer in the south (Ingram *el al.* 2002). The extended dry period and a high year to year variability in amount, timing and location of rainfall makes it difficult to secure the water supply (Simonsson 2005). Access to clean drinking water is considered a basic human right but still around one-third of the burkinabés lack access to safe drinking water (WHO 2010). Furthermore, climate change models for West Africa predicts that variability in rainfall will increase but the total amount of rain to decrease, which probably will result in more water shortages and health problems (IPPC 2003). Burkina Faso will be vulnerable to climate change due to the widespread poverty, recurrent droughts, inequitable land distribution and dependence on rainfed agriculture (Simonsson 2005).

1.2 Water, trees and termites in parklands

It is important to understand the relationship between forests and human water supply in the tropics, an issue that has been discussed and debated (Malmer *et al.* 2010). Available hydrological and ecosystem models can be powerful tools for modelling water fluxes through diverse landscapes. Nevertheless, empirical data for validation is scarce, not at least concerning change in soil properties associated with land-use and vegetation changes (Ilstedt *et al.* 2007; Malmer *et al.* 2010). Research concerning water-balance has mostly been performed in subtropics or higher-latitude areas (Malmer *et al.* 2010).

Infiltrability is defined as the rate of vertical water flow into the soil. This rate sets the limit for the amount of water enters the soil (Bouwer 1986; Hillel, 1998) and limits the amount of water available for roots and soil fauna (Susswein *et al.* 2001; Ilstedt *et al.* 2007). High infiltrability is crucial for groundwater recharge in a semi-arid regions (Malmer *et al.* 2010). A large amount of the annual precipitation should be infiltrated under a short period of time (Hillel 1998; Ingram *et al.* 2002). Water that do not infiltrates becomes surface-runoff and a low infiltrability has therefore a direct effect on erosion and stream flooding (Susswein *et al.* 2001; Brady & Weil 2008).

Infiltrability is affected by slope, rainfall characteristics and soil properties such as structure, texture, total porosity, pore-size distribution, soil fauna and vegetation (Hillel 1998; Sanou *et al.* 2010). The infiltrability is greater if the soil is porous or aggregated than if it's compacted and dense. Pore size distribution is also important, a high fraction of large pores gives a higher infiltration than small pores, even if the total porosity is equal (Hillel 1998).

Most soils need biological activity and organic material to maintain a structure with sufficiently large pores. Soil organic matter (SOM) stabilizes soil aggregates and root activity enlarge or creates new pores by growth, which empties as roots decays (Grimaldi *et al.* 2003; Schroth *et al.* 2003b; Mariscal *et al.* 2007). Bulk density, i.e. the ratio of dry mass to volume soil (Blake & Hartge 1986), is closely related to organic matter and porosity. High values of organic matter and porosity gives low bulk density (Mariscal *et al.* 2007). Consequently, for example Mbagwa (1997) showed that a high bulk density led to decreased infiltrability. Bulk density tends to increase when land-use is changed from natural ecosystem to cultivated areas, both through mechanical disturbance and decreasing SOM (Mbagwa 1997; Yimer *et al.* 2005). Over-used vegetation leads to reduced litter-fall and thereby declining infiltrability (Malmer 2010). In the tropics this process is fast due to rapid decomposition of organic matter (Schroth *et al.* 2003b).

Reestablishing forests has become a frequently used strategy for soil rehabilitation (Sanou *et al.* 2010). Trees provide the soil with organic matter and nutrients. Tree-roots bind soil and improve soil structure (Grimaldi *et al.* 2003). Tree-crowns and litter decreases evaporation, diminish the effect of raindrops breaking down aggregates and reduces crust-formation (Grimaldi *et al.* 2003; Teixera *et al.* 2003; Brady & Weil 2008; Sanou *et al.* 2010). Trees can also maintain biological activity in the soil by creating suitable microclimate and providing biomass (Schroth & Sinclair 2003). Taroré *et al.* (2007) saw that tree regeneration occurred to larger extent on the termite mounds, and an association between trees and termites may be possible. Soil macro-fauna itself affects soil properties through lowering bulk density, increasing the amount of organic matter, creating macro-porosity connected to the soil surface and improving the infiltration (Fall *et al.* 2001; Léonard *et al.* 2003; Jouquet *et al.* 2011). Colloff *et al.* (2010) suggested invertebrate macro-pore formation to be an important ecosystem function and the increased infiltration due to macro-pores to be particularly crucial during storms.

Agroforestry parklands are, as mentioned before, cropping under a sparser or denser tree cover (Bayala *et al.* 2011) and a commonly used soil conservation strategy in the region (Bayala *et al.* 2012). Trees in parklands are considered to have positive influence on the soil properties (Rhoades 1997; Malmer et al. 2010; Sanou et al. 2010). Trees can recycle nutrients and make them available for crops (Grimaldi *et al.* 2003). In all agroforestry system trees compete more or less with crops for water, nutrient, light and space (Grimaldi *et al.* 2003; Schroth *et al.* 2003a) and are highly likely to decrease harvest (Bayala *et al.* 2012). How much competition that is accepted depends both on trees value per se and as soil improvers, in proportion to values of associated crops (Schorth *et al.* 2003a Bayala *et al.* 2012). Lack of water limits crop growth and trees consume large quantities of water (Teixera *et al.* 2003; Malmer 2010; Sanou *et al.* 2010). However in the semi-arid parklands of Burkina Faso it is likely that the infiltration is higher and thus runoff, erosion and nutrient leakages is lower under trees than in the openings (Hansson 2006; Brady & Weil 2008). Sanou *et al.* (2010) showed higher soil moisture under trees crowns, which is important for plant growth. Whether trees affects water balance negatively or positively depends on if the increased infiltration is sufficient for compensate for the increased transpiration. Empirical data on water-balance from the seasonally dry areas is scarce (Ilstedt 2007; Malmer *et al.* 2010; Malmer 2010). Nevertheless, intensification of the agriculture leads to a decrease in the tree-cover (Gray 2004).

It is important to deepen the understanding of how trees in parklands affects soil properties, not at least water balance, as one action in the battle of securing food and water supply for a growing population in a changing future.

1.3 Trees, carbon and water – on going project

The “Tree, carbon and water project” is a multidisciplinary collaboration between University of Gothenburg, Linköping University, SLU and two research institutes in Burkina Faso and Costa Rica. The projects’ aim is to clarify whether increased tree cover leads to both high carbon sequestration and improved adaptive capacity to climate change, especially groundwater recharge. The central study area is in Burkina Faso were the field research is conducted at Saponé field site close to Ouagadougou. The research team has shown a general connection between reforestation and infiltrability and has made observations of the importance of macro pores associated to termites (Trees Carbon and Water 2011 [online]).

1.4 Objective and Hypotheses

The objective of this thesis was to investigate what effects trees and termite mounds has on the infiltrability and related soil properties (soil carbon content, bulk density and porosity) in a specific semi-arid parkland area of Saponé.

The hypotheses are that within *Vitellaria* parkland infiltrability 1) is higher under than in-between trees and highest close to trees with termite mounds 2) decreases with increasing distance from the tree and 3) increase with increasing amount of carbon, macro pores and decreasing bulk density.

2 Material and Methods

2.1 Study site

The study was carried out in Saponé, 35 km south of Ouagadougou (lat 12˚803'N, long 1˚843'W) in central Burkina Faso (Figure 1) during August and September 2011.

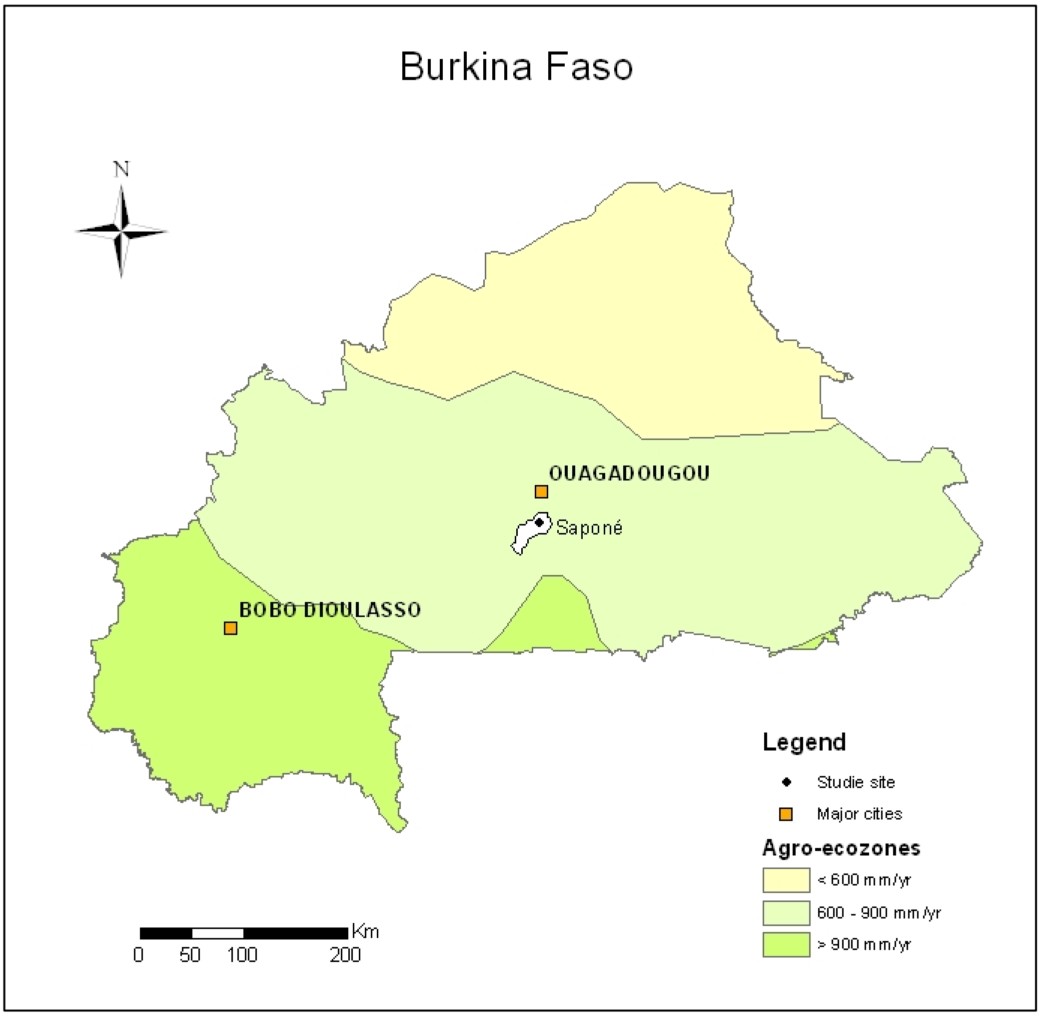


Figure 1 *Map over Burkina Faso showing the three different ecozones, administrative border of Saponé. Black dot marks the study site.*

Mean annual precipitation for Saponé is around 728 mm/yr (Bayala *et al.* 2006). The rain is distributed during one single wet period and the rains fall in short intense storms (Figure 2; Ingram *et al.* 2002).

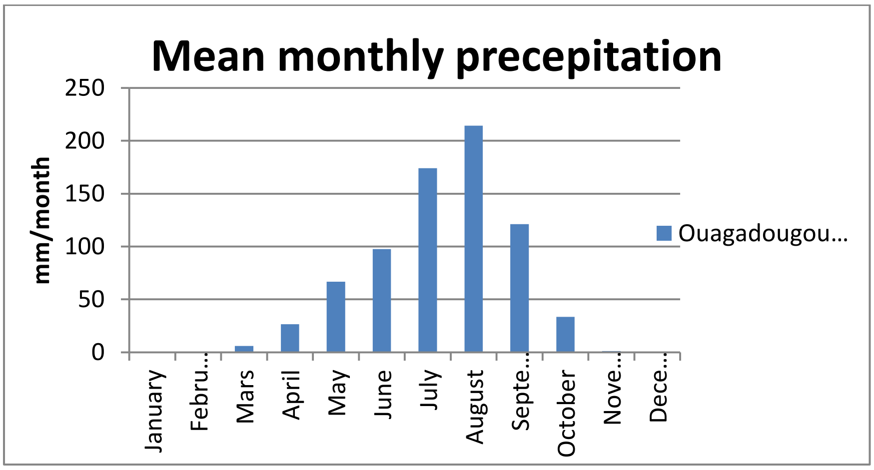


Figure 2 *Mean monthly precipitation for Ouagadougou, for the period 1971-2000. The weather station is approximately 35 km from the study site (modified from Institut Géographique du Burkina 2008).*

Precipitation in the Sahel region varies over time on a long-term perspective as well as inter-annual. The years 1950-1969 were unusual wet and the 1970:s and 1980:s was dry (Lebel and Ali 2009). Lebel and Ali (2009) compared those two periods to the period 1990-2007 and a recovery from the drought were seen, especially further east in the Sahel region even if rain levels did not reach those of the wet period.

The temperature varies over the year and two colder periods are notable (Figure 3), but fluctuations are small (Sivakumar and Gnoumou 1987) and the temperature generally high all year round. For Ouagadougou mean annual temperature is 28.6 (years 1974-2004) degrees C and the mean annual maximum and minimum are 34.9 and 21.9 respectively (Institut Géographique du Burkina 2008)

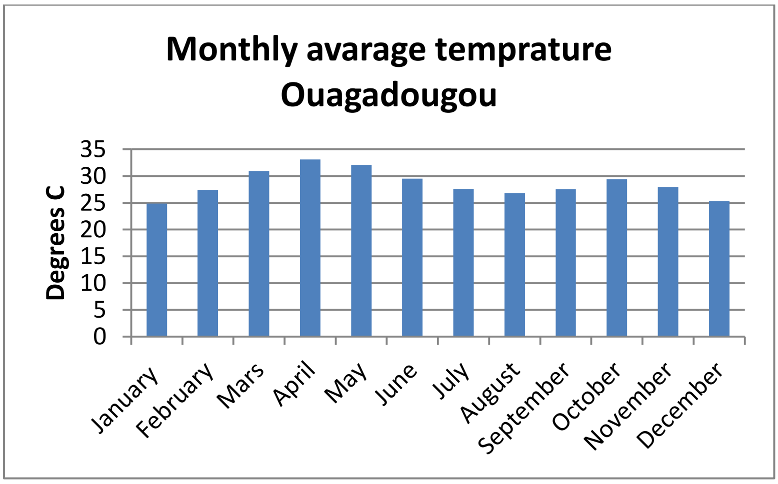


Figure 3 *Mean monthly temperature for Ouagadougou, for the period 1971-2000. The weather station is approximately 35 km from the study site (modified from Institut Géographique du Burkina 2008)*

Parkland systems are the dominant land-use in the study area (Figure 4), were crops are cultivated under trees. The dominant tree species are *Parkia biglobosa* (néré or locust bean) and *Vitellaria paradoxa* (karité or shea butter tree) (Bayala *et al.* 2002; 2006). The most common crops are sorghum and millet, cultivated without fertilizers (Bayala *et al.* 2006). The soils are sandy loamy regosols, generally low in nutrient (Jonsson *et al.* 1999)

Figure 4 *Parkland in Saponé, at fallow. When cultivated, the crops are grown in between and beneath* Vitellaria paradoxa.

2.2 Experimental design

The measurements was conducted in 11 transects; five transects in small openings (20–31 m between trees) and six in large opening (68–127 m between trees). A transects went from one tree close a termite mound and one tree without a termite mound and along the opening between them (Figure 5). All trees were of the species *Vitellaria paradoxa*, karité.

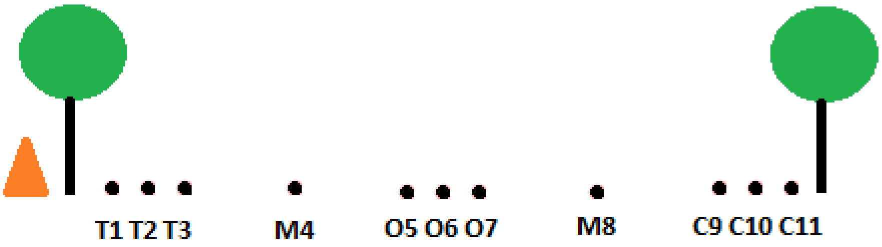


Figure 5 *The experimental design. T = tree with termites, C = trees without termites, M = intermediate distance, O = center of opening*

Each transect contained 11 measurement points. Two of the points T2 and C10 were placed in the crown edge and T1, T3, C9 and C11 with a distance equal to half the crown radius from them, one closer to and one further away from the tree. O6 were placed the centre of the opening flanked by O5 and O7, one meter apart. M4 and M8 (here after referred to as "intermediate distance") were placed halfway between T3 and O5 resp. O7 and C9.

Studied variables in each measuring point were infiltrability (mm/h), bulk density (g/cm^3), organic matter (g/kg) and porosity (volume %).

The study area was approximately 2 ×1 km. Most of the transects were located within 500 m from each other but distance varied from 1 km to 300 m. Openings would be defined by *Vitellaria paradoxa* and be either under 30 m or above 60 m wide. One tree would be closely related to a termite mound and one tree on the other side of the opening would be without termites. After these conditions suitable transects were subjectively chosen.

2.3 Method

Steady-state infiltrability was measured with the double ring infiltrometer method. The principle behind the double ring infiltrometer is to minimize the divergence and edge effects by keeping an even water level in both rings while infiltration only is measured in the inner ring (Bouwer 1986). The main advantages with this method are the simplicity and the low costs (Teixera *et al.* 2003). Under field conditions in Burkina Faso, Hansson (2006) suggested that double ring infiltrometer may be preferable compared to tension disc infiltrometer because of its simplicity.

Cylindrical metal rings, 28 respective 50 cm in diameter were pushed down a proper distance, approximately 5 cm, in the ground. They were filled with 40 mm of water, the level read and refilled to 40 mm every 5 min for one hour or until a steady infiltration were reached. In some case of fast infiltration the reading and refilling was closer in time.

Bulk density and pF-curve were sampled according to core method (Blake & Hartge, 1986) with volume-set sample rings. Rings with a diameter of 50 mm and height 50 mm was used, except in transect TS3 were rings with a diameter of 72 mm and height of 50 mm was used.

Soil samples were taken inside the infiltrometer rings after infiltration measurements in different depths:

- 0-10 cm resp. 30-40 for carbon content
- 0-5 cm resp. 30-35 cm for bulk density and pF curve

At the deeper depth, below 30 cm, the samples were intended to fall below crops and grass root level. Crops in these systems has maximum root density at 0-10 cm depth (Bayala *et al.* 2006)

Organic carbon was determined using wet acidified dichromate oxidation method known as Walkley and Black method (Walkley & Black 1934 -in Nelson & Sommers 1982) measuring dichromate reduction after organic carbon oxidation (Zang *et al.* 2005). The method is widely used because of its rapidity and simplicity (Grewal *et al.* 1991).

Porosity was determined by gradually saturating the samples (water level was raised 0.5 cm ones every half hour) and weighed, before they were drained by gravity and weighed again. After oven drying in 105 degrees for 24 h or until all water was gone, they were weighed again. The difference between the wet weight and the dry weight were used to calculate weight % of water in the different wetting stages (Klute 1986) and transformed to vol% by multiplying with bulk density. Macro pores characteristically allow drainage of water (Brady and Weil 2008). Thus macro porosity was calculated as the difference in water content (vol%) in the samples saturated and after draining.

Dry weight and volume of samples were used for determine bulk density (Blake & Hartge, 1986).

2.4 Calculations

Infiltrability is the rate of which water enters, or infiltrates, the soil (Brady & Weil, 2008) and is defined as “the volume flux of water flowing into the profile per unit soil area” (Hillel, 1982) Typically the infiltration rate is initially high, especially in dry soils, and decreases over time for finally level off to a constant rate, known as steady-state infiltrability (Hillel, 1982).

In an unsaturated soil, the driving force for downwards movement is matric suction (or pressure head) and gravitation potential, explained in Darcy’s law (1):

$$q = -k(h)\frac{\delta \mathrm{H}}{\delta z} \tag{1}$$

were

- q (mm/h) = flux density
- k(h) (mm/h) = hydraulic conductivity
- δH/δz (m/m) = hydraulic head = sum of matric suction and gravitational head

Under a pounded surface the water infiltrations proceeds and the wetting front is moving downward deeper into the soil. As the soil approaches saturation, matric suction decreases and gravitation potential becomes the driving force and hydraulic conductivity sets the limit for infiltrability. The gravitational potential is constant, changing 1/1 and infiltrability stabilizes at a constant rate, the steady-state infiltrability. Steady-state infiltrability can be considered equal to saturated hydraulic conductivity in the surface (Hillel 1998)

Steady-state infiltrability was estimated by Philip’s equation (2) (Bouwer 1986; Hillel 1998):

$$i = i_c + (s/2t^{1/2}) \tag{2}$$

were:

- i = infiltrability (mm/h)
- i_c = steady-state infiltrability (mm/h)
- s = sorptivity (mm/$h^{1/2}$)
- t = time

Excel solver tool, Microsoft Office 2010 (Microsoft Corporation, Washington, USA) was used to curved-fitted measured values to Philip’s equation by minimising sum of the absolute difference. Philip’s equation has two characteristic constants, sorptivity (s) and steady-state infiltrability (ic). Its apply to soils with infinitely deep uniform soil of constant initial wetness, which at time zero should be submerged under a thin water layer that immediately increase soil moisture at the surface to near saturation, and is thereafter maintained constant (Hillel 1998). Sorptivity depends on soil porosity, initial soil water content and saturated water content (Bouwer 1986).

2.5 Statistics

Dataset was divided in four or six groups. When the data was divided in six groups, the intermediate- and centre points were divided into small and large openings.

1. Tree with termites
2. Trees without termites
3. Intermediate distance
4. Centre

Or

1. Tree with termites
2. Trees without termites
3. Intermediate distance small opening
4. Intermediate distance large opening
5. Centre point small opening
6. Centre point large opening

All statistical analyses were conducted in Minitab 16 (Minitab Inc., Pennsylvania, USA). Statistics analyses was conducted for steady-state infiltrability, organic matter 0-10 and 30-40 cm, bulk density 0-5 and 30-35 cm, macro porosity 0-5 and 30-35 cm. The mean value, minimum, maximum, standard deviation, lower quartile, median and upper quartile were calculated both when the data was grouped in four and in six groups.

Mean values for the groups was tested for significance levels using General Linear Model and means separated with Tukey’s pairwise comparison. A 95% confidence interval was used. Measurements were blocked in transects and groups (small and large openings), an unbalanced incomplete block design. Each variable was analysed divided into four or six groups.

Fitted line plot regression was used to test for change with distance from tree for each variable. All data was used but variables were also divided into small or large openings and trees with termites to centre were separated from trees without termites. For each variable the measurements within 10 m from the trees, with or without termites, were plotted against “tree-index”. The reason for using these indexes was to analyse whether tree-size matted e.g. if tree influence increased with increased diameter in breast height (DBH) or crown-diameter. The tree indexes used were following:

$\frac{diameter\ breast\ heigh}{distance\ from\ tree}$ or $\frac{crown\ radius}{distance\ from\ tree}$

Accumulated frequency histograms were created for all variables using percentage of accumulated values. The data was then divided into four groups:

1. Trees with termites
2. Trees without termites
5. Centre point small openings
6. Centre point large openings

Steady-state infiltrability was tested against the other variables using fitted line regression

3 Results

3.1 Steady-state infiltrability

Steady state infiltrability was significantly lower in the centre of the openings compared to under trees, with or without termites. Median was up to four times larger under trees compared to the openings. Small openings had approximately 60% higher steady-state infiltrability than large openings (Table 1). Steady-state infiltrability decreased with increased distance from tree.

Table 1 *Steady -state infiltrability (mm/h) from the double ring measurements. The measurements are divided into six groups; 1 = tree and termite, 2 =tree, 3= intermediate distance small opening, 4 = intermediate distance large opening, 5 =centre small opening, 6 = centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Steady state infiltrability	**Group**	**N**	**Mean**	**Standard deviation**	**Minimum**	**Lower quartile**	**Median**	**Upper quartile**	**Maximum**
tree with termites	1	33	264,0	755,8	0	37,0	56,0	160,0	4150
tree	2	33	85,8	109,7	1,3	28,5	60,0	113,3	591,0
intermediate distance small opening	3	10	39,7	34,6	6,2	10,9	29,9	64,0	117,0
intermediate distance large opening	4	12	63,1	59,4	12,8	20,4	46,0	76,7	215,5
centre small opening	5	15	37,1	31,0	1,7	13,0	23,2	54,6	92,3
centre large opening	6	18	27,9	33,5	0	6,8	14,6	32,3	130,5

The data was divided in two different ways (see 2.5 in Material and methods), either in four or six groups (Table 1). When the data was split into four groups, group 1 and 2 was significantly larger than group nr 4 (Figure 6; Table 2). If the data instead was divided into six groups no difference occurred between trees and centre points of small openings even though medians were approximately two and a half times larger under trees (Figure 7; Table 2). Trees with and without termites was only higher than centre point of large openings. Medians were four times higher for group 1 and 2 than for group 6. Thus the steady-state infiltrability was lowest in centre of the large openings.

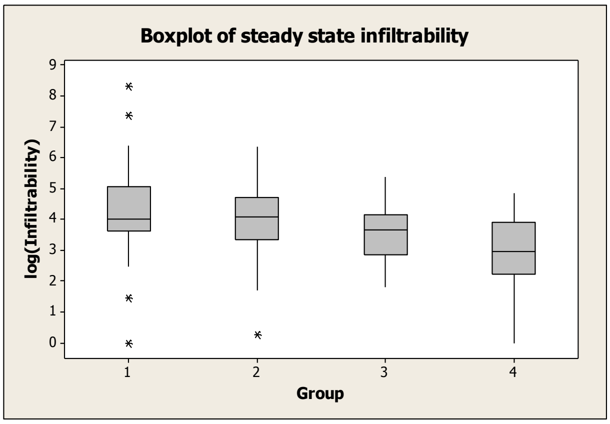


Figure 6 *Logarithmic values of steady state infiltrability divided in four groups: 1=termite + tree, 2=tree, 3=intermediate distance, 4=centre-point. Boxes are showing the interval between upper and lower quartile and the line in the boxes median value. Lines outside the box represent the highest and lowest values.* = outliers.*

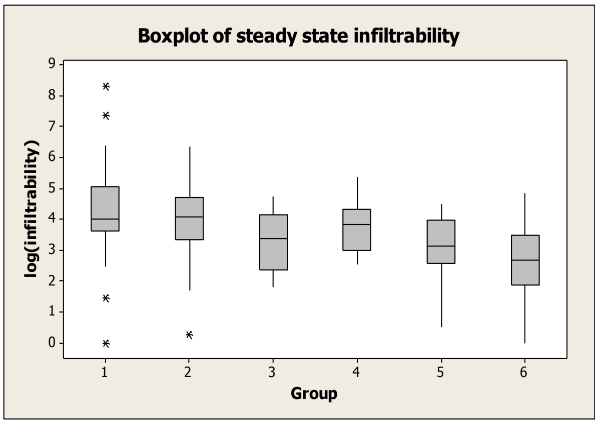


Figure 7 *Logarithmic values of steady state infiltrability, divided in six groups. (1= tree + termite, 2=tree, 3= intermediate distance small opening, 4=centre point small opening, 5= intermediate distance large opening, 6= centre point large opening)*

Table 2 *Logarithm of steady state infiltrability (mm/h) divided into either four or six group,s meaning that mid- and centre-points either are separated into large and small openings (six groups) or not (four groups). Mean values that do not share a letter are significantly different*

Group	N	Mean	Grouping
1	33	4.2	A
2	33	3.9	A
3	22	3.6	A B
4	33	2.9	B

Group	N	Mean	Grouping
1	33	4.2	A
2	33	3.9	A
3	10	3.6	A B
4	12	3.5	A B
5	15	3,4	A B
6	18	2.4	B

Accumulated frequency distributions indicated that trees with termite had highest values, followed by trees without termites (Figure 8). Eight of the total 121 measurements had values above 200 mm/h and are not included in Figure 8. Even though the graph not shows all values, it still displays large differences between openings and trees. In group 6, large opening 80 % of the values had steady-state infiltrability below 40 mm/h. Equal number for group 1, 2 and 5 were 80, 100 and 60 mm/h respectively.

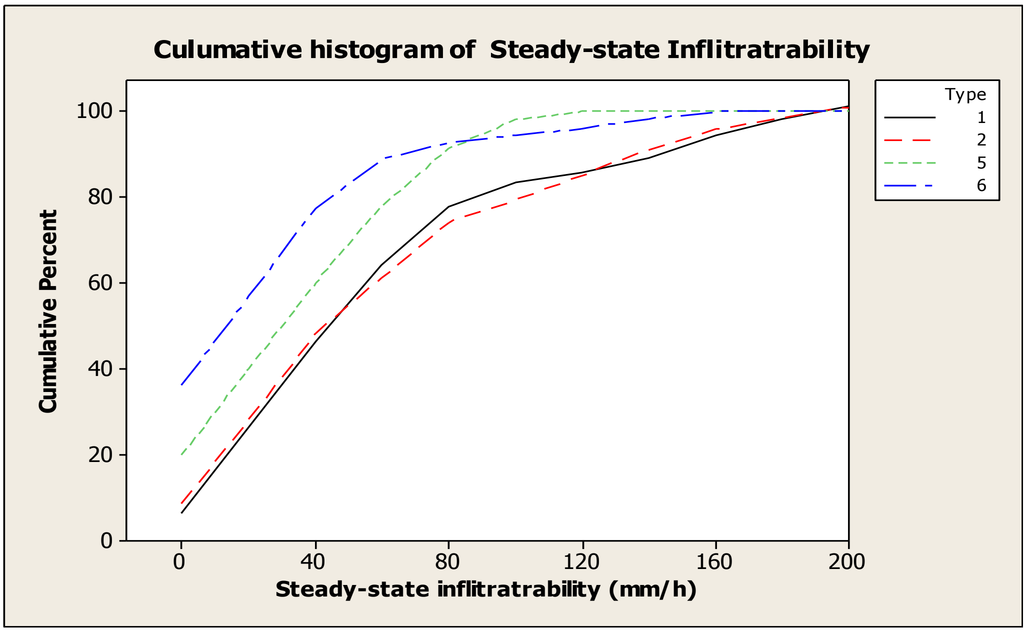


Figure 8 *Histogram over steady-state infiltrability (mm/h) showing accumulated percentage of infiltrability levels. Group 1=termite +tree, group 2=tree, group 5=small opening, group 6=large opening. The X – axis was cut at 200 mm/h. For group 2 the highest value were 591 mm/h and 4150 mm/h for group 1*

Steady-state infiltrability decreased with increased distance from the trees. When dataset was plotted together had significant decrease (P=0.001) but the fit was low, 8% (Figure 9). Values close to trees, both with and without termites had large variability. Standard deviation (SD) for trees with termite was 756 mm/h which gives a coefficient of variation (CV) of 286 %. For trees without termites the corresponding numbers were 109 mm/h and 127 %.

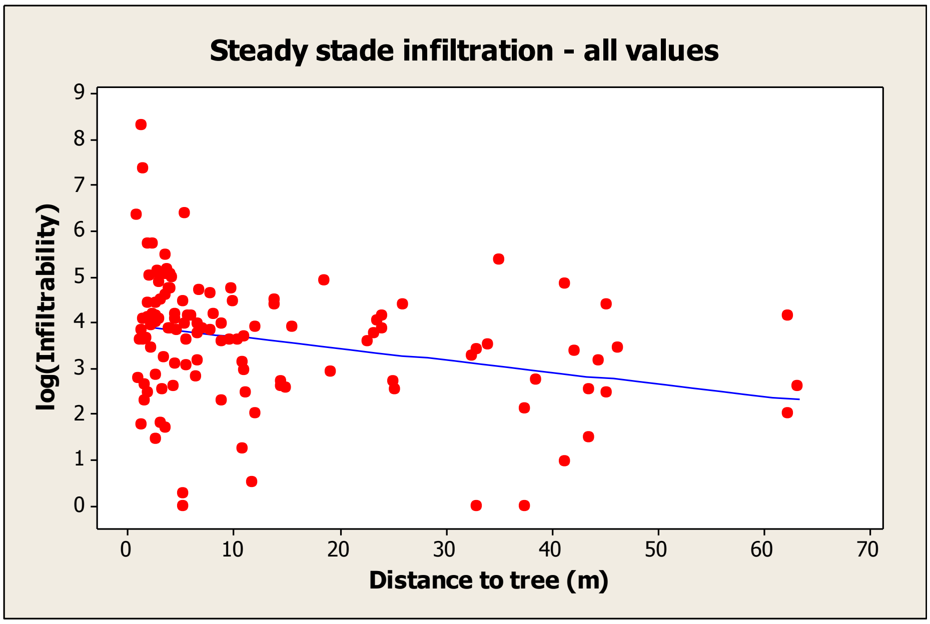


Figure 9 *Logarithmic values of steady state infiltrability (mm/h) plotted against distance from tree, both small and large opening are included.* R^2*= 8% and P= 0.001*

Level of explanation (R^2 = 0.018) was higher when large openings were plotted alone (Figure 10). Within the large openings the measurements from trees with termites out to the centre was separated from measurements from tree without termite out to centre. In both cases steady-state infiltrability decrease with increased distance from trees, but trees with termites had a larger variability in the steady state infiltrability and linear regression had lower level of explanation (Figure 12 and Figure 11).

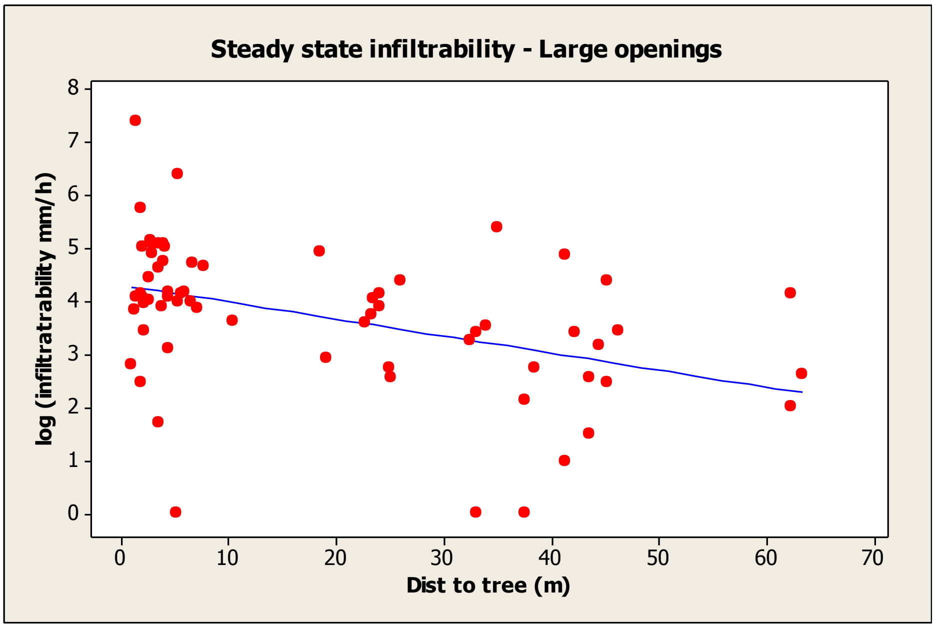


Figure 10 *Logarithm of steady state infiltrability (mm/h) plotted against distance from tree. Both trees with and without termite-mound are included.* R^2 *=0.18 and P = 0.000*

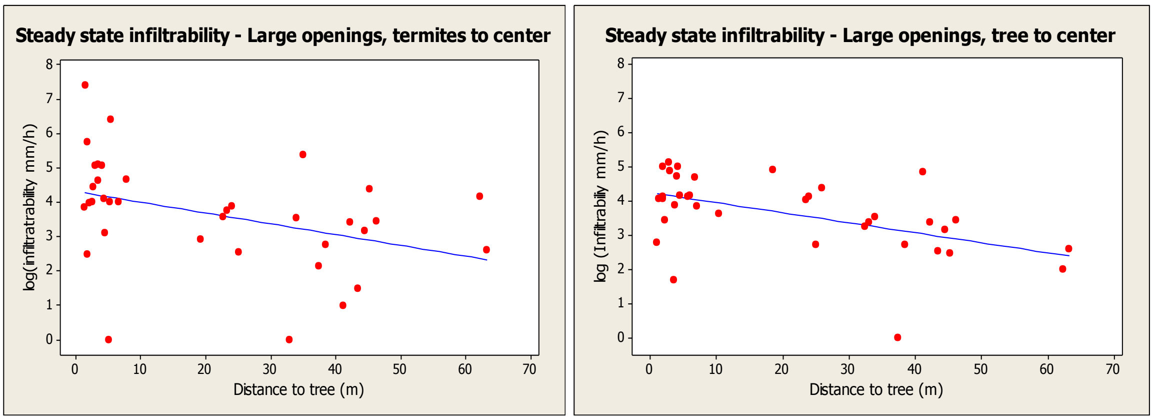


Figure 12 *Trees with termite mounds. R2 = 0.15 and P = 0.019*

Figure 11 *Trees without termite mounds. R2 = 0.27 and P = 0.001*

In small openings steady-state infiltrability did not change significant with increased distance from trees. In the centre of the small openings, the median value of steady-state infiltrability was nearly 60% higher than in large openings (Table 1). Steady-state infiltrability within 10 meter from the trees did not change with changing tree-index.

Steady state infiltrability had no singificat relation to carbon content or macro porosity. Neither was it affected by bulk density at 30-35 cm depth. It did however decrease with increased top soil bulk density (P = 0.039) (Figure 13).

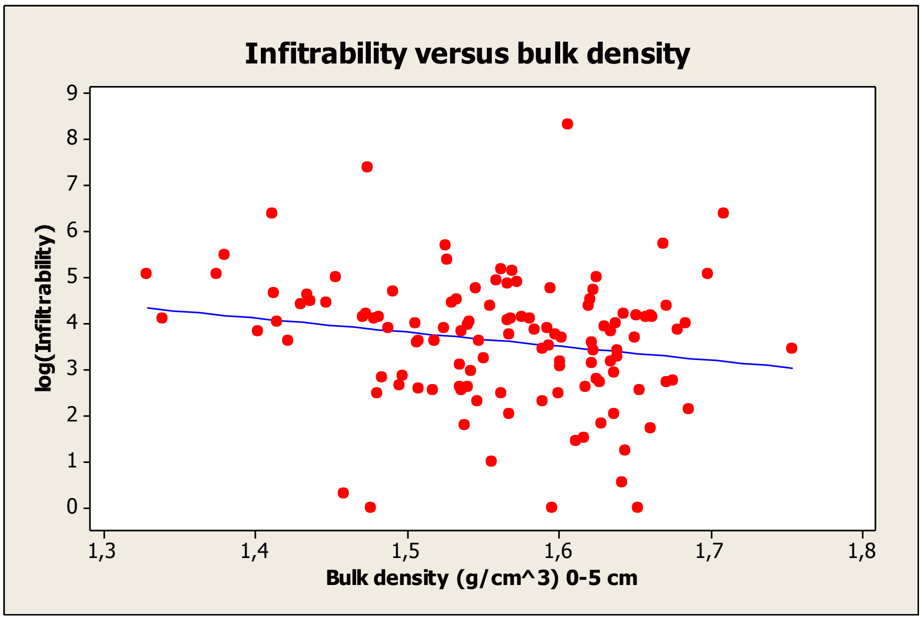


Figure 13 *Logarithmic values of steady state infiltrability plotted against top soil bulk density.* R^2*=0.03 and P=0.039*

3.2 Soil Carbon

Soil carbon content was measured at two depths 0-10 cm and 30-40 cm depth. All carbon data is presented as g kg^{-1} soil.

3.2.1 Soil carbon at 0-10 cm depth

At 0-10 cm depth the carbon content was higher under trees compared to openings. Median values were 6.8 and 6.2 g/kg under trees with and without termites respectively compared to 5.6 g/kg in small and 4.3 g/kg in large openings (Table 3). Carbon content decreased with increased distance from trees. Two samples were missing from the top soil, 0-10 cm, both from trees with termites.

Table 3 *Content carbon (g/kg) at 0-10 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= intermediate distance small opening, 4= intermediate distance large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Carbon (g/kg) 0-10 cm depth	Group	N	Mean	Standard deviation	Minimum	Lower quartile	Median	Upper quartile	Maximum
tree with termites	1	30	7,288	3,115	2,829	4,904	6,808	8,753	16,728
Tree	2	33	6,227	1,528	3,274	5,254	6,228	7,408	9,365
intermediate distance small opening	3	10	5,155	1,270	3,324	4,21	4,978	6,172	7,310
intermediate distance large opening	4	12	4,766	1,434	2,549	3,893	4,432	5,296	8,001
centre small opening	5	15	5,414	0,859	3,889	4,306	5,643	6,010	6,436
centre large opening	6	18	4,465	0,659	3,737	3,904	4,381	5,006	6,019

Group 1 and 2, trees with or without termites, had significantly higher carbon content than group 3 and 4, intermediate distance and centre point, (Figure 14; Table 4). When the data was divided in 6 groups, small and large openings was separated, group 1 was still higher than group 3-6. Group 2 did not differ from any other group (Figure 15; Table 4). Median for carbon content was about 50% higher under trees with termites than in centre of large opening. For trees without termites this difference was about 40%. The variability was high close to trees; 43% for trees with termites and 25% for trees without termites. Centre of small openings had nearly 30% more soil carbon than large openings (Table 3)

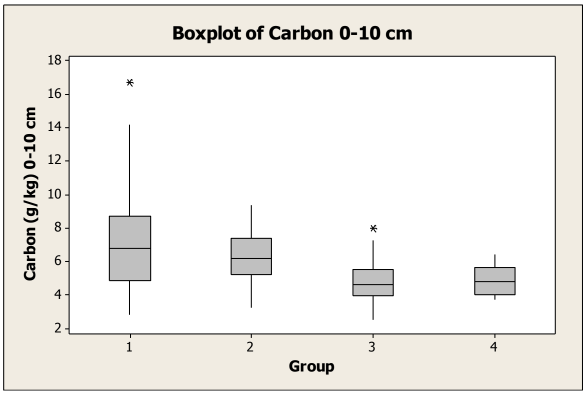


Figure 14 *Content organic matter (g/kg) divided in four groups: 1=termite + tree, 2=tree, 3=intermediate distance, 4=centrum-point Boxes are showing the interval between upper and lower quartile and the line in the boxes median value. Lines outside the box represent the highest and lowest values. * = outliers.*

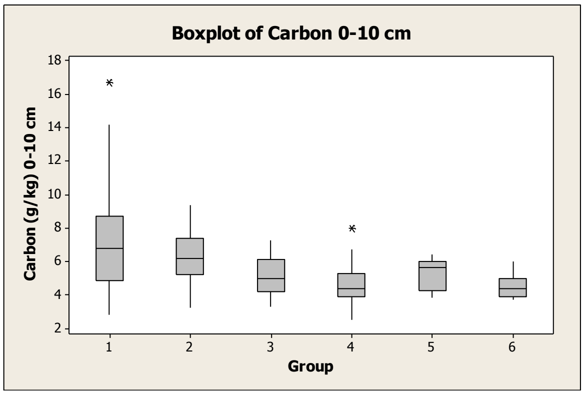


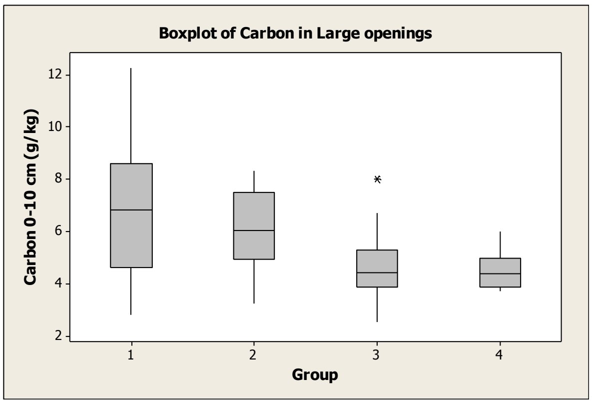
Figure 15 *Content organic matter (g/kg) divided in six groups: 1=termite + tree, 2=tree, 3=intermediate distance small openings, 4= intermediate distance large openings 5=centrum small openings, 6=centrum large openings*

Table 4 *Soil carbon (g/kg) divided into either four or six groups- meaning that mid- and centrum-points either are separated into large and small openings (six groups) or not (four groups). Mean values that do not share a letter are significantly different.*

Group	N	Mean	Grouping
1	30	7.2	A
2	33	6.2	A
3	22	4.9	B
4	33	4.9	B

Group	N	Mean	Grouping
1	30	7.2	A
2	33	6.2	A B
3	10	4.9	B
4	12	5.0	B
5	15	5.2	B
6	18	4.7	B

Large openings had a gradual decrease in carbon content between the groups. Trees with termite had the highest carbon content and the centre had the lowest (Figure 16, Table 5).



Group	N	Mean	Grouping
1	15	7.1	A
2	18	6.0	A B
3	12	4.8	B C
4	18	4.5	C

Figure 16; Table 5 *Soil carbon (g/kg) in large openings. Mean values that do not share a letter are significantly different.*

*Boxes are showing the interval between upper and lower quartile and the line in the boxes median value. Lines outside the box represent the highest and lowest values. * = outliers.*

Accumulated frequency histogram indicated differences between groups. For trees with termites 80 % of the values were below 8.5 g/kg. The other groups, large openings, small openings and trees without termites, had lower content of carbon. 80% of values were below 5.6 and 7 respectively.

Carbon content decreased with increased distance from trees. When the whole dataset were analysed, R^2 was 0.13 and P=0.000. Large openings had an R^2 of 0.21 and P=0.000 (Figure 17). When transects were split in half between trees with and without termite mounds, content of carbon still decreased with increased distance. Trees with termites, compared to those without had a higher level of explanation, 27 % versus 16 % (Figure 18; Figure 19). Small openings did not have any significant change in carbon content with changed distance from tree (P = 0.061)

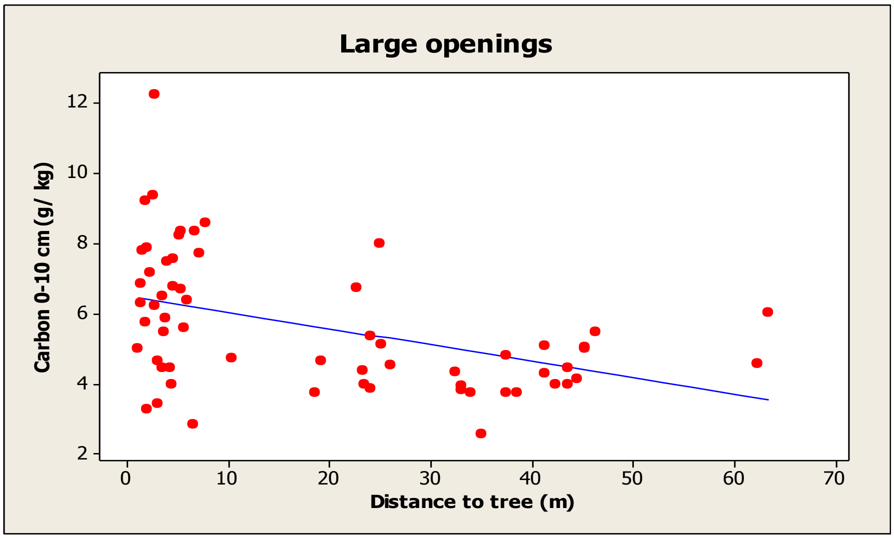
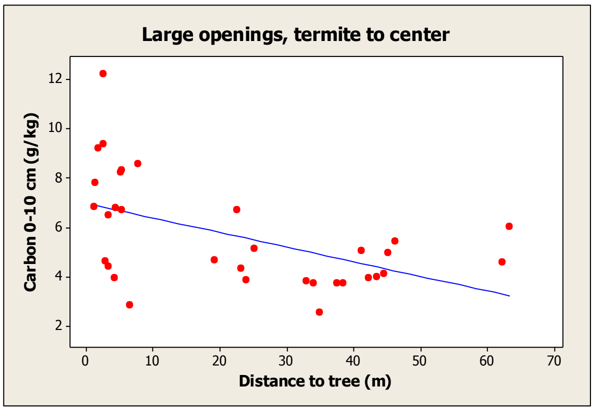


Figure 17 *Large openings –soil carbon (g/kg) versus distance from tree. Both trees with and without termites is included. R^2=21% and P=0.000*



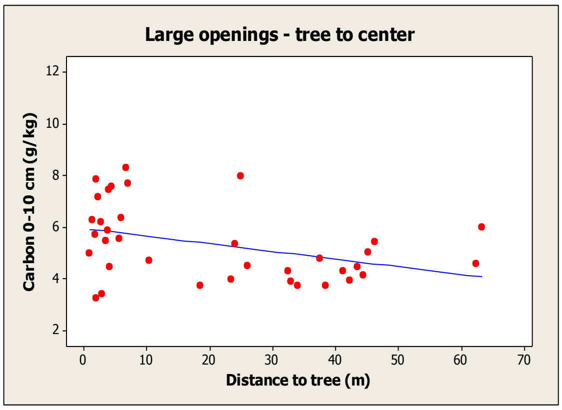


Figure 18 *Only values from trees with termite mounds and out to centre are included.* R^2*=0.27 and P=0.002*

Figure 19 *Only values from trees without termite mounds and out to centre are included.* R^2*=0.16 and P=0.017*

Measurements within 10 meter from trees were not influenced by crown-diameter. DBH/distance to nearest tree had however a significant impact on the carbon content (Figure 20).

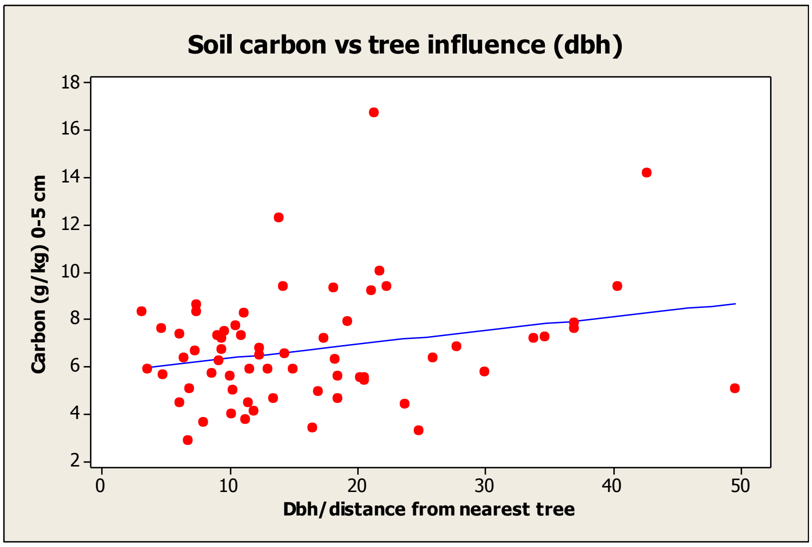


Figure 20 *Content of carbon in the top soil (g/kg) versus tree influence index = diameter breast height divided by distance from nearest tree. R-Sq = 0.062 and P = 0,047*

3.2.2 Soil Carbon at 30-40 cm depth

The carbon content at 30-40 cm depth did not differ between the groups (Table 6). Neither was it affected by the distance from trees, or by tree-size. Two samples were missing, both from trees without termites.

Table 6 *Carbon content (g/kg) at 30-40 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= midpoint small opening, 4= midpoint large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Carbon (g/kg) 30-35 cm depth	Group	N	Mean	Standard deviation	Minimum	Lower quartile	Median	Upper quartile	Maximum
tree with termites	1	33	4,857	1,795	2,645	3,633	4,418	5,765	12,417
Tree	2	30	4,478	1,527	2,483	3,177	4,092	5,15	7,978
intermediate distance small opening	3	10	4,213	1,364	2,502	3,433	4,026	4,422	7,659
intermediate distance large opening	4	11	4,215	1,243	2,682	3,003	4,044	5,011	6,394
centre small opening	5	15	3,961	0,777	2,917	3,375	3,786	4,748	5,406
centre large opening	6	18	4,257	2,752	1,526	3,018	3,644	4,255	14,662

3.3 Bulk density

3.3.1 Bulk density at 0-5 cm depth

Bulk density in top soil was significantly lower under trees with termites compared to centre and intermediate distances. Median values were 1.54 g/cm^3 under trees with termites, 1.55 g/cm^3 under trees without termites compared to 1.60 cm^3 in centre of large and small openings (Table 7). Bulk density was not affected by tree crown-diameter/distance from tree or DBH/distance from tree.

Table 7 *Bulk density (g/cm^3) for 0-5 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= midpoint small opening, 4= midpoint large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Bulk density 0-5 cm	Group	N	Mean	Standard deviation	Minimum	Lower quartile	Median	Upper quartile	Maximum
tree with termites	1	33	1,531	0,107	1,3294	1,441	1,535	1,624	1,710
Tree	2	33	1,547	0,078	1,4030	1,494	1,546	1,583	1,754
intermediate distance small opening	3	10	1,610	0,051	1,4811	1,588	1,626	1,638	1,658
intermediate distance large opening	4	12	1,596	0,068	1,4879	1,530	1,617	1,660	1,672
centre small opening	5	15	1,582	0,062	1,4367	1,535	1,602	1,628	1,644
centre large opening	6	18	1,590	0,059	1,4714	1,555	1,597	1,627	1,686

When data was divided in four groups, (Table 8; Figure 22), group 1 had lower bulk density than group 3 and 4. Group 2, however is not significantly different from any other group. If the measurements were divided into six groups– only group 3 and group 1 was significantly different – 1.63 g/cm^3 versus 1.54 g/cm^3 group 1 had lower bulk density (Figure 21; Table 8).

The variability for trees with termites was higher 7% compared with 5% for trees without termites. For the other groups the variability was between 3.2-4.3%.

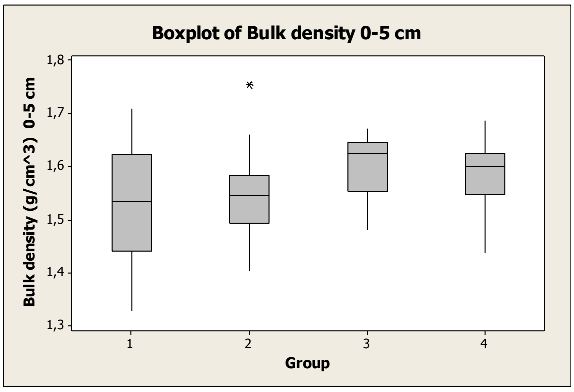


Figure 22 *Bulk density (g/cm3) for the top soil (0-5 cm) along transects, divided in four groups 1=termite + tree, 2=tree, 3=midpoint, 4=centre-point. Boxes are showing the interval between upper and lower quartile and the line in the boxes median value. Lines outside the box represent the highest and lowest values. * = outliers.*

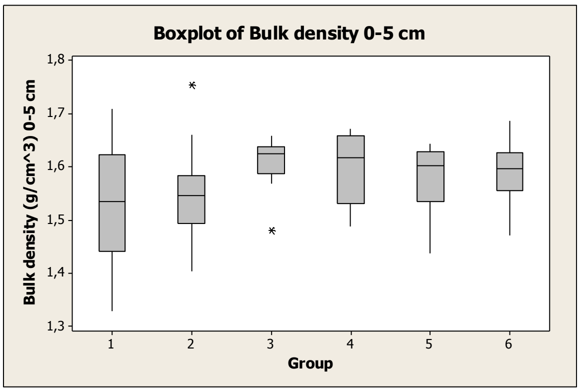


Figure 21 *Bulk density (g/cm3) for top soil 0-5 cm, divided in six groups: 1=termite + tree, 2=tree, 3=midpoint small openings, 4= midpoint large openings 5=centre small openings, 6=centre large openings*

Table 8 *Bulk density (g/cm3) divided into either four or six groups- meaning that mid- and centrum-points either are separated into large and small openings (six groups) or not (four groups). Mean values that do not share a letter are significantly different.*

Group	N	Mean	Grouping
1	33	1.5	B
2	33	1.5	A B
3	22	1.6	A
4	33	1.6	A

Group	N	Mean	Grouping
1	33	1.5	B
2	33	1.6	A B
3	10	1.6	A
4	12	1.6	A B
5	15	1.6	A B
6	18	1.6	A B

Large openings did not differ significant between the groups (Figure 24). Small openings had significant difference between group 2, being lower in bulk density then group 3 and 4. Group 1 had lower bulk density than group 3 but did not differ from group 4 or 2 (Figure 23; Table 9).

Among the large openings only two out of six transect was at fallow, the rest was cultivated and ploughed this year. For the small openings four out of five transect were at fallow.

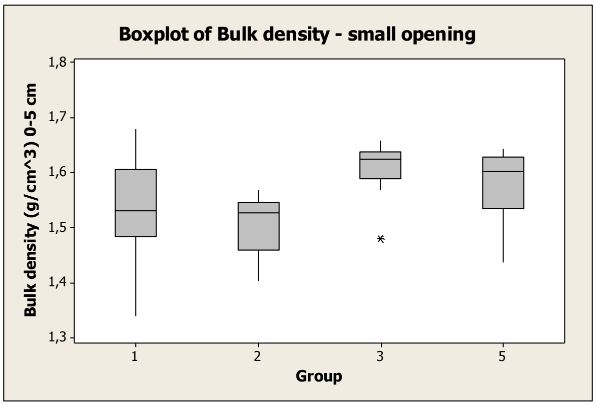


Figure 23 *Bulk density (g/cm^3) for top soil in small openings – there was significant difference between groups*

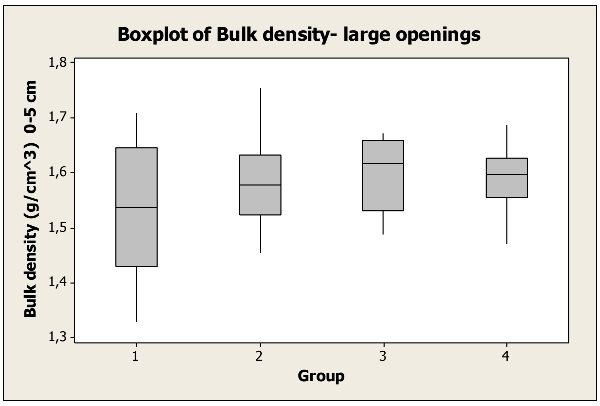


Figure 24. *Bulk density (g/cm3) for top soil in large openings – there was no significant difference*

Table 9 *Bulk density (g/cm^3) for top soil in small openings. Mean values that do not share a letter are significantly different.*

Group	N	Mean	Grouping
1	15	1.5	B C
2	15	1.5	C
3	10	1.6	A
4	15	1.6	A B

Bulk density increased with increased distance from trees (Figure 25). When small openings were analysed separately bulk density increased with increased distance from trees (P = 0.013). In large opening no change in bulk density occurred with increased distance from trees.

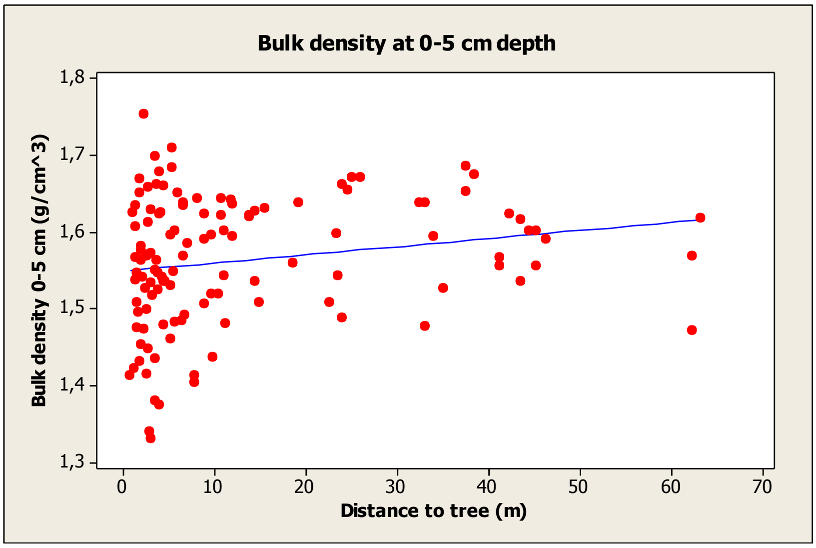


Figure 25 *Bulk density (g/cm^3) plotted against distance from tree. R^2 = 0.04 and P = 0.036*

3.3.2 Bulk density at 30-35 cm depth

Bulk density for 30-35 cm depth did not differ significant between groups (Table 10). Accumulate frequency histogram showed a trend of higher bulk density for group 6. It is notable that this group only contains 9 measurements. However, it increased with increased distance from trees. For 30 – 35 cm depth, 9 centrum points, 5 intermediate distances, 8 trees and 6 termite points no samples were collected. All of the missing values were from large openings.

Table 10 *Bulk density (g/cm^3) for 30-35 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= midpoint small opening, 4= midpoint large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Bulk density 30-35 cm	Group	N	Mean	Standard deviation	Minimum	Lower quartile	Median	Upper quartile	Maximum
tree with termites	1	27	1,578	0,118	1,331	1,518	1,566	1,677	1,814
Tree	2	25	1,584	0,115	1,289	1,422	1,609	1,652	1,775
intermediate distance small opening	3	10	1,579	0,117	1,422	1,589	1,594	1,660	1,773
intermediate distance large opening	4	7	1,674	0,084	1,589	1,590	1,654	1,734	1,813
centre small opening	5	15	1,565	0,119	1,323	1,498	1,557	1,623	1,790
centre large opening	6	9	1,632	0,132	1,437	1,489	1,689	1,710	1,822

Bulk density, however, decrease with increased distance from tree. The level of significance was 0.031 and R^2=0.05 (Figure 26). Measurement 10 m or closer to the tree was not dependent on crown-diameter/distance from tree or DBH/distance from tree.

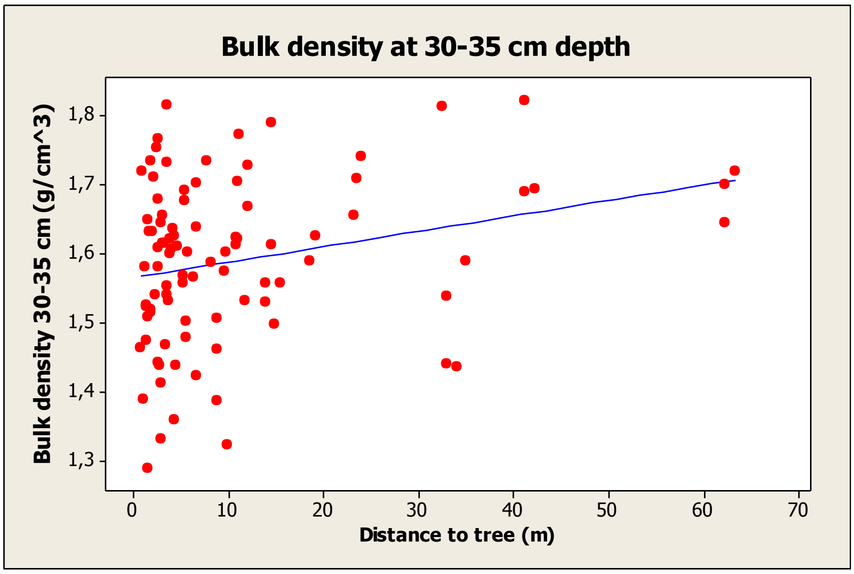


Figure 26 *Bulk density (g/cm^3) plotted against distance from tree. R^2 = 0.07 and P = 0.011*

3.4 Porosity

There were no missing measurements of macro porosity at 0-5 cm depth. At 30-35 cm depth 9 centrum points, 5 intermediate distances, 8 trees without and 6 trees with termite points were not sampled. Macro porosity did not differ significant between groups at any of the depths cm depth (Table 11; Table 12).

Table 11 *Macro porosity (%) for 0-5 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= midpoint small opening, 4= midpoint large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Macro pores (volum %) 0-5 cm	**Type**	**N**	**Mean**	**SD**	**Minimum**	**Q1**	**Median**	**Q3**	**Maximum**
tree with termites	1	33	4,42	1,95	2,03	3,05	4,07	6,11	9,17
tree	2	33	3,46	1,76	1,01	2,04	3,07	4,08	8,35
intermediate distance small opening	3	10	4,38	1,24	3,05	3,06	4,08	5,25	6,66
intermediate distance large opening	4	12	3,74	1,76	1,02	3,06	3,57	4,08	8,15
center small opening	5	15	4,57	1,43	2,04	3,93	4,09	6,10	7,13
center large opening	6	18	3,68	1,06	2,03	3,06	3,57	4,09	6,12

Table 12 *Macro porosity (%) for 0-5 cm depth. The measurements are divided into six groups; 1= tree and termite, 2=tree, 3= midpoint small opening, 4= midpoint large opening, 5=centre small opening, 6= centre large opening. Table is showing average (mean) values, minimum and maximum values, first, second (median) and third quartile.*

Macro pores (volume %) 30-35 cm	**Group**	**N**	**Mean**	**SD**	**Minimum**	**Q1**	**Median**	**Q3**	**Maximum**
tree with termites	1	28	4,73	2,54	2,03	3,05	4,08	6,11	12,47
tree	2	25	3,83	2,05	1,02	3,05	3,06	4,08	8,83
intermediate distance small opening	3	10	4,86	2,09	3,06	4,07	4,08	4,81	10,18
intermediate distance large opening	4	8	3,20	1,81	2,03	2,03	3,04	3,06	7,13
center small opening	5	15	4,33	1,66	2,02	3,06	4,16	6,11	7,14
center large opening	6	9	2,91	1,35	0,74	2,03	3,05	4,07	5,10

Variability in macro porosity was high within the groups. For 0-5 cm depth the variance was 44% and 51% for trees with and without termites, respectively. Lowest variation had the centre point of large openings, 29% and intermediate distance in small openings 28%. At 30-35 cm depth, trees with and without termites had variance of 53% and 52%, respectively. The variance was similar for the other groups.

Porosity at 0-5 cm depth did not change with distance from tree. At 30-35 cm depth there was significant decrease of macro-pores with increased distance from tree. When trees with and without termites were plotted together the fit was 7% (Figure 27). By separating trees with termite the fit increased slightly, 12% (Figure 28). There was no significant decline in macro porosity from trees without termites to the centre of the opening (R^2 = 0.062 and P=0,083) (Figure 29). Median value for trees with termites was 4 vol-% compared to 3% for trees without termites and 3 vol-% for centre of large openings. No differences occurred if measurements were separated in small and large opening. Measurement 10 m or closer to the tree did not change with DBH or crown diameter.

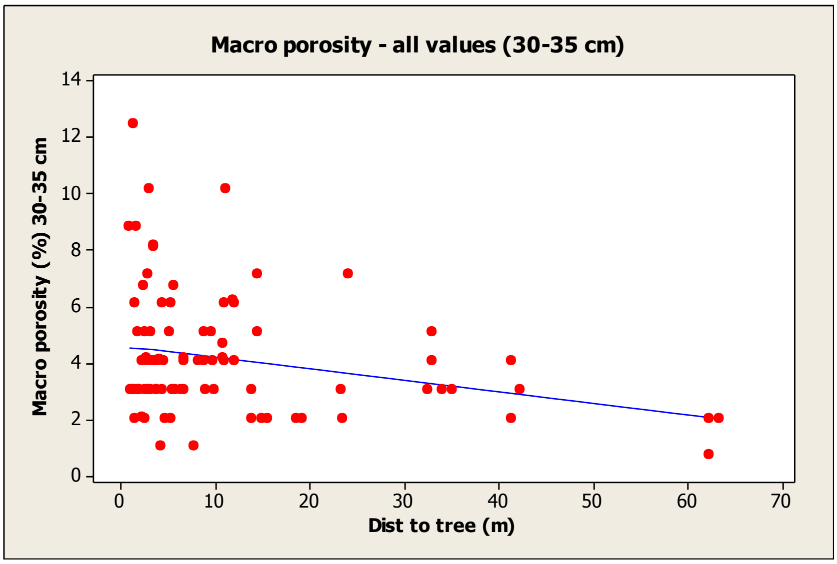


Figure 27 *Amount macro pores (%) plotted against distance from tree.* R^2 *= 6.8% and P = 0.011*

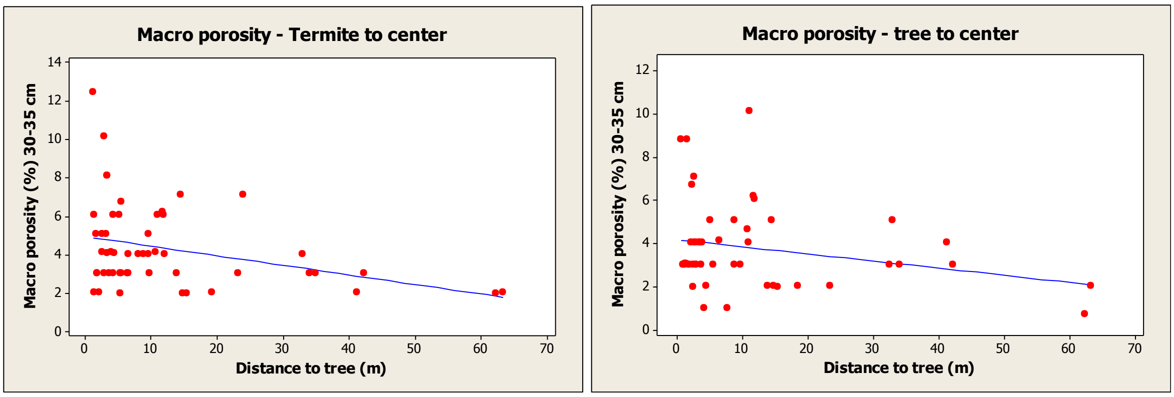


Figure 28 *Only values from trees with termite mounds and out to centre are included.*R^2*=10.9% and P=0.017*

Figure 29 *Only values from trees without termite mounds and out to centre are included. R2=6.2% and P=0.083*

4 Discussion

Trees had large impact on their environment in this study. Median steady-state infiltrability was fourfold under trees, with and without termites, compared to centre of large openings and more than twofold compared to small openings. Large openings had nearly 60% lower infiltration than small openings. Carbon content in top soil was approximately 50% respective 40% larger under trees with and without termites compared to centre of large openings. Small openings had carbon 10-20% lower content than trees with or without termites. Difference between large and small openings was nearly 30%. Bulk density was lower (4% lower in the top soil and 7% in the subsoil) under trees compared to openings. Macro porosity was significantly higher under trees with termites than in large openings, 4 vol% compared to 3 vol% of the total porosity was macro-pores.

4.1 Large variation in transects

Different crops and tillage methods were used at the different transects. Four of the six large openings and one of the five small openings were ploughed. The rest had been at fallow for the last 1-3 years. Tillage can lower bulk density, change porosity and pore-size distribution and thus the steady-state infiltrability (Lipiec *et al.* 2006).

Termite mounds were a source to heterogeneity in and between transects. Ideally, they were placed in the direction towards the other tree, but that was not the case for all transects. Termites enriches clay in soil (Fall *et al.* 2001) and change the soil structure by buildings galleries and thereby lowering bulk density (Jouguet *et al.* 2011). Fine-texture material from termite mounds can form a soil crust (Jouquet *et al.* 2011). The termite mounds differed in in size and activity level. Termites have periodicity in their activity, from the scale of year to hours and macro-pores can be sealed and reopened (Léonard *et al.* 2004). Some measurements landed right up on macro pores. In other measure-points the surface had a complete crust cover.

Trees without termites varied both in measured values and in appearance. Even if the transects was ploughed, the furrows did not always went all the way in under trees. Ground-nesting ants were spotted close to some of the trees, and as termites they create macro-pores (Collof *et al.* 2010). Shadow under trees is often used by humans and animals, as shelter from the sun (Sanou *et al.* 2010) which can make the soil more compact. The utilization of trees as shelter might vary both over time and between trees.

All these differences can at least partly explain the consistently low R^2 values in the result. However, the variables differed between groups or with distance from trees had generally high significant levels. This indicates that trees have strong enough influence on their environment to make significant difference despite all other influences on soil properties.

4.2 Infiltrability

Steady-state infiltrability did decline with increased distance from trees and was lowest in the centre of large openings. These results are in line with Mapa (1995), Hansson (2006) and Ilstedt *et al.* (2007) who suggest trees influence infiltrability positively. Steady-state infiltrability decreased with increased top soil bulk density which is consistent with studies by Mbagwu (1997), Yimer *et al.* (2008)

When the data was divided in four groups the centre point had significantly lower steady-state infiltrability than trees, with or without termites. When the data were divided in six groups and the large openings was separated from the small; only the centre point in large openings was significantly lower compared to under trees. One explanation can be too few measurements were available in each group and a too high variation for significant levels to be stated. However, even if steady-state infiltrability in under the trees differed from both small and large openings, the difference was largest between trees and centre of the large openings. Median values for steady-state infiltrability is four and two and a half times lower in large and small openings respectively compared to trees, with and without termites.

This point to the conclusion, that areas with denser tree-cover have higher average steady-state infiltrability than areas with sparser tree cover.

A higher proportion of the large openings were ploughed, compared to the small openings. Ploughing can increase the infiltrability (Lipiec *et al.*2006). The differences between large and small openings may have been even larger if they had been treated identically

Trees with termites had higher average steady-state infiltrability than tree without termites, 264 mm/h and 86mm/h, in that order. Yet only four of the measurements from trees with termites were above the average. Trees with termites had a variance of 286%. The medians were almost equal for trees with and without termites 56 mm/h and 60 mm/h respectively. Even so, if termites mounds would have been separated into different groups, for examples termite mounds with and without surface crust, the variance within the group would likely decrease. It might even led to significant difference in steady-state infiltrability between trees with and without termites. However, Léonard *et al.* (2004) advise against such a division and argues that high variability is characteristic for termite mounds and this should be included when one study the effect termites has on infiltrability since it is caused by the natural behaviour of termites. Such division would therefore not have been appropriated for this study.

Double-ring infiltrometer affects soil surface when inserted. If the soil crust breaks and cracks are created can it lead to an over estimation of steady-state infiltrability (Hillel 1998). Soil crust only occurred on some termite mounds and in one large opening. Furrows were a larger problem since most of the large openings were ploughed. However, even if initial infiltration is higher in furrows since the water could flow sideward as well as downward. The effect once the soil has been saturated is, according to Hillel (1998), negligible. Infiltration measurements on the termite mounds landed sometimes right on macro-pores and those could open up and close during the measurements. In a few cases macro-pores connected the outer and inner ring and water flowed from between.

Philips equation applies to infinitely deep uniform soil (Hillel 1998). Termites can create a non-uniform soil by creating macro pores and collecting building material such as clay and sealing the surface (Fall *et al.* 2001; Jouquet *et al.* 2011). Applicability of Philip´s equation under such condition might be questionable.

4.3 Soil Carbon

Soil carbon content was up to 50% higher under trees than in openings. The results are supported Bayala *et al.* (2006). When measurements were divided in six groups, trees with termite were significantly higher than intermediate and centre points. Trees without termites did not differed from any group. Variance was higher for trees with than without termites, 43% compared to 25%. Fewer values in group 3-6 could be a reason why trees without termite did not difference from those.

Carbon content did decrease with increased distance from trees in large openings but not in the small ones. The trend-line was steeper from trees with termites out to the centre compared to from trees without termite to the centre, suggesting that termites increase soil carbon content. According to Fall *et al.* (2001) soil feeding termites, which is 75% of species (Brauman 2000), can contribute to a tree to fivefold increase of SOM. Neither the species nor the feeding habits are known for termites included in this study. Accumulated frequency histogram over carbon showed a trend of lowest values in large opening and highest for trees with termites

Carbon content was influenced by tree size. Within ten meters from the tree the carbon content increased with increased diameter in breast height/distance to tree. Diameter growth is often related to growth of crown and root-system, (Albrektsson *et al.* 2008) increase in diameter would mean increased biomass and therefore litter production. Bigger tree can also mean older tree and then more time to build up a carbon pool beneath it.

At 30-40 cm depth no significant difference in carbon content was detected. Bayala *et al.* (2006) studied the soil carbon content and its origin and showed that at 0-10 cm depth higher percentage of total carbon stem from trees and carbon content was higher close to trees but on 10-30 cm depth a higher proportion came from crops and no significant difference between trees and the open occurred. Their explanations were that carbon from crops either is more movable or the carbon present at this depth is older, more decomposed and origin not possible to track (Bayala *et al.* 2006). If carbon deeper down in soil is ancient it could origin from older land-use system, possible with more trees present.

4.4 Bulk density

Top soil bulk density increased with increased distance from trees, a result that fall in line with Mariscal *et al.* (2007) who showed lower bulk density close to trees. These results also agree with the general assumption that trees affect bulk density through creating macro pores (Grimaldi *et al.* 2003; Schroth *et al.* 2003a).

However when comparing the groups to each other, bulk density from trees without termites did not differed significantly from any other group. One explanation to that could be that animals or humans resting under trees and compacts the soil (Sanou *et al.* 2010). Trees with termites had a lower bulk density than intermediate and centre points. Thus termites had impact on bulk density as pointed out by Jouquet *et al.* (2011). When the data was divided in six groups, differences only occurred between group 1 and 3. High variability and fewer measurements in each group could be part of an explanation. Trees with termites had ones again the highest variability.

When small and large openings were separated, only the small openings had a significant difference between groups, were trees without termites had the lowest bulk density. It was also only the in the small openings that bulk density increasing with increased distance from trees.

It should be remembered that four out of six transects in the large openings were ploughed this season, which affects the soil. Tillage soil has generally a lower bulk density and higher total porosity than untilled soil (Lipiec *et al.* 2006). Tillage can also destroy tree roots in top soil (Schroth *et al.* 2003a) and have a negative impact on termites (Ayuke *et al.* 2011). This could lead to a more even bulk density over transect. If the large openings had been ploughed to lesser extent it is possible that bulk density would have increased with increased distance from trees.

There were no differences in bulk density between groups at 30- 35 cm depth. It did, however, increased with increased distance from trees. Roots and termites are a large source to macro-pores (Grimaldi *et al.* 2003; Lipiec *et al.* 2006; Collof *et al.* 2010) and thus lowering bulk density. At 30-35 cm depth tillage does not have such strong influence (Lipiec *et al.* 2006). Since crops has maximum root density at 0-10 cm depth (Bayala *et al.* 2006), tree roots and soil fauna may be the largest contribution to porosity at 30-35 cm depth. It is therefore credible that bulk density would decreases with distance from trees. However 29 of the measuring points at 30-35 cm depth were not sampled; 9 centre points, 5 midpoints, 8 trees and 6 trees with termites had missing values. All of the missing samples were from large openings.

The reason for the missing samples at 30-35 cm depth was occurrence of hardened subsoil impossible to sample. This only occurred in large openings and two and a half transect were not sampled. One large transects, impossible to sample, laid next to a small transect which was sampled without problem. It makes is likely to assume a higher tendency of hardened subsoil in large openings compared to small.

4.5 Macro porosity

Amount of macro-pores in the top soil did not decrease with increased distance from trees. McGarry *et al.* (2000) showed a higher proportion of macro-pores from termites and earthworms in zero till systems compared to traditionally tillage and according to Lipiec *et al.* (2006) macro porosity generally decreases with tillage. As mentioned before, tillage has a more pronounced effect on top soil (Lipiec *et al.* 2006) and deeper down macro-pores may be more intact. However it is highly depended on soil type (Lipiec *et al.* 2006). Higher termite taxonomic richness has been reported for fallows compared to cultivated soils (Ayuke *et al.* 2011). Termite abundance, though, did not decrease significant when soils were cultivated (Ayuke *et al.* 2011). Roots are destroyed by tillage (Schroth *et al.* 2003a) and can thus not create pores. The fact that a high proportion of large than the small were openings cultivated can thus have affected the results.

Macro porosity at 30-35 cm depth decreased with increased distance from trees. Trees without termites, when separated, had no significant decrease with increased distance, contradicting theories of trees as creators of macro-pores (Grimaldi *et al.* 2003; Schroth *et al.* 2003b; Mariscal *et al.* 2007). However trees with termites had such relation. Termites were thus important for macro porosity, a result which is supported by studies of Collof *et al.* (2010) and Jouquet *et al.* (2011).). However it should be remembered that 29 measurement points had missing values. There is possibility that trees without termites lowered the bulk density, but that the results not were significant due to few observations.

4.6 Trees influence soil properties

Improved infiltrability increases the amount of water that moves down through the soil (Hillel 1998). Water can, if not taken up by plants, lead to recharge of groundwater (Susswein *et al.* 2001; Ilstedt *et al.* 2007). In semi-arid areas water is precious and recharge of groundwater during rainy season is important (Simonsson 2005). This study showed higher infiltration in denser areas of parklands. Considering that precipitation mostly comes as intensive storms were intensities of 50-100 mm/h is not uncommon (Ingram *et al.* 2002; Malmer *et al.* 2010) infiltrability needs to be high to minimize surface runoff (Susswein *et al.* 2001; Brady & Weil 2008; Malmer *et al.* 2010). The high variation in steady-state infiltration makes generalizations harder and causes to the variance would be interesting to study further. The variation was not as high in openings as it was for trees with termites (286%) but still between 80 and 120%.

Bulk density has been proven important for infiltrability (Mbagwu 1997; Yimer *et al.* 2008) and could in this study explain some of the variation. Steady-state infiltrability did decrease with increased bulk density (P = 0.049) and bulk density increased with increased distance from trees. Bulk density is known to be affected by amount of SOM, and thus carbon content (Grimaldi *et al.* 2003; Schroth *et al.* 2003b; Mariscal *et al.* 2007. High carbon content is also beneficial for the amount of macro pores through stabilization of aggregates (Mapa 1995).

Marco-porosity decreased with increased distance from trees. A high number of macro pores can increase the amount of infiltrated water to deeper layer of the soil (Mapa 1995) and thus increase ground-water recharge.

Carbon content was higher close to trees and higher in small than in large openings, the same pattern as for steady-state infiltrability and macro porosity. It supports the theory that increased SOM decreases bulk density which in turn improves infiltrability (Mbagwu 1997; Grimaldi *et al.* 2003; Schroth *et al.* 2003b; Mariscal *et al.* 2007; Yimer *et al.* 2008). Soil carbon content is interesting per se, since sequestration is of interest in the climate change debate (Sands 2005) and can be another reason for keeping tree cover dense. Parkland-system makes it possibility to combine trees and carbon sequestration with cropping.

In denser parkland areas the tree-crowns are shading a larger proportion of the ground. Shading from trees can diminish evaporation and enhance soil moisture. Sufficient soil moisture is important for growth of crops (Sanou *et al.* 2010). Higher soil moisture can furthermore prevent crust from establish (Brady & Weil 2008) and thus keep up a good infiltrability. Tree litter can decrease evaporation and reduce crust-formation as well as contribute to SOM (Grimaldi *et al.* 2003; Teixera *et al.* 2003). In small openings litter affects a larger part of the opening compared to large openings. However, another fact to take into account is that transpiration is likely to be higher in small openings due to denser stands. Trees are large water consumers and before it is known how much water they transpire, their effect on the total water balance remains unknown.

Maintaining parkland can be a good way of maintaining trees in a landscape and tree density is shown to matter for soil quality and may have large importance for groundwater recharge.

4.7 Experimental Design

This study was conducted in parkland used by villagers and reality is seldom simple. Despite this fact, the results were significant and trees proven to have a visible effect in parklands. Nevertheless a lot of variables were investigated. If the design had been simpler and had less that influenced the measurement the results might have been clearer.

One way of changing the design could have been to place the double-ring infiltrometer in three replicates with the same distance from the tree, for examples at the crown edge. More replicates could maybe have lowered the variance and given significant difference that do not shows here. However it would only have given a mean for how the crown edge affects the soil properties, not a mean value for the entire tree. The rings could also have been placed with the same distance from each other to ease the comparison. But if the rings would been placed on a certain distance from trunk, it could have resulted in that all measurements would have fallen under a wide crown meanwhile all, or most of the measurements would have fallen outside a narrow crown. If the midpoint always would have been placed under the crown edge, some rings would have fallen on opposite side of the tree in cases of narrow crowns and for wide crowns, the ring closest to the steam would still be far away and impact from tree and termite maybe smaller.

However the current design gives all rings close to tree slightly different condition and even if the groups from under trees with and without termites give an estimation of the mean impact trees and termite have, the actual effect may differ. A more accurate estimation of difference might be given from spatial statistics. Another aspect of the current design is that influence from termites might be more restricted in area than the general influence from trees. A comparison of the rings closest to termite mounds separated might have given significantly differences compared to those from trees without termites

5 Conclusions

The results showed significant differences with increased distance from trees for infiltration, bulk density, carbon content (at 0-10 cm depth) and macro-porosity (at 30-35 cm depth).

Steady-state infiltrability was, as expected in the hypothesis, higher close to trees. However there were no significantly differences between trees with and without termites. Steady-state infiltrability increased with decreased bulk density. Steady-state infiltrability, carbon content and macro-porosity had high variance near trees with termites.

Keeping trees can thus contribute to improved soil structure, increased infiltration, decreased surface runoff and may be importance for groundwater recharge. The influence decreased as the distance from trees and termites increased. In small openings there was no significant decrease in steady-state infiltrability, carbon content or macro porosity with increased distance from trees. Bulk density though, increased with increased distance from trees in small openings.

Carbon content was higher in small openings which can raise the interest of keeping an adequate amount of trees in parklands to meet future requirement of carbon sequestration. These soil improvements add to other positive effect for trees e.g. products such as timber, fodder and fruits but can also lowering crop harvest.

What trees density that would optimize positive influence is still to be investigated.

Acknowledgement

This Graduate thesis was carried out within the framework of the Minor Field Studies (MFS) Scholarship Programme, which is funded by the Swedish International Development Cooperation Agency (Sida).

Thanks to my supervisors Anders Malmer, Ulrik Ilstedt and associated supervisor Aida Bargués Tobella for all their help and support during this entire process. Thanks also to Sören Holm and Magnus Ekström for help with statistics.

A great thanks to all people at INERA and Buna Sol whose help and support was of great importance during my stay in Burkina Faso. A special thanks to Hugues Baize and the field workers in Saponé.

To Aida and Elsa, thanks for all your support and help, and for all the joy. It wouldn’t have been the same without you!

Finally to all people in Burkina Faso that help me along the way in so many different ways and made my stay in the country unforgettable.

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