Termite abundance, taxonomic richness and soil properties in conventional and conservation tillage systems in Western Kenya

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MSc thesis Soil Quality (SOQ-80436), Wageningen University
October, 2010

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Table of Contents

Abstract

Conservation Agriculture, based on minimum soil tillage, crop residue retention and crop rotation, is being promoted to improve soil quality and crop production in Sub Saharan Africa. However, the contribution of ecosystem engineers, especially termites, to improved soil and crop performance under different tillage and residue management is not clear.

The agronomic field experiment in Western Kenya compared tillage (+/-) and crop residue (+/-) management in a full factorial design. In 2005, a macrofauna exclusion experiment (using selective insecticides) was established within the field trial to study the specific role of soil macrofauna in affecting soil quality and crop growth. Our objectives were:

1) to quantify the effects of different tillage and residue management on the abundance and diversity of termites, soil properties and crop growth.
2) to assess how termite abundance and soil quality and crop growth are affected by macrofauna exclusion.
3) to compare different methods to quantify termite abundance and diversity in agricultural field experiments.

Termite abundance was measured by monolith and soil core sampling methods and termite taxonomic richness was measured by those two methods plus transect sampling. Crop residue cover, soil moisture, and soil compaction were measured several times during one cropping season. Soil chemical properties were measured at different depths.

Tillage and residue management did not significantly affect termite abundance and taxonomic richness. Total soil carbon (TSC) at 0-5 cm, and to a lesser extent, at 5-15cm depth, was increased by residue retention, especially under no-till. There was no consistent effect of tillage and residue management on soil moisture. Soil compaction was increased under no-till, especially when residues were removed. Macrofauna exclusion significantly reduced termite abundance, but not taxonomic richness. As a consequence the residue cover was significantly higher in residue amended plots that had received insecticides than without insecticides. TSC and nitrogen (N) contents at 0-5cm depth were significantly increased by insecticide application. Apparent termite induced pest damage to soybean and maize at 18 weeks after planting was significantly reduced by macrofauna exclusion. The cause of crop damage could, however, not clearly be attributed to termites, because the possibility of other causes or combining causes. The soil core and monolith samples were combined and monolith samples that contained termite nests were omitted to estimate termite abundance. In conclusion, positive and negative effects of termites occurred in the cropping systems depending on tillage and residue management. The quantification of termite abundance and taxonomic richness in small agricultural plots, especially under no-till, has several complications. Further improvement of methods for the study of termite diversity and the trade-offs between positive and negative impacts on cropping systems is recommended.

1. Introduction

1.1 Problem description

Due to the rapid population growth and increasing land degradation throughout many parts of Sub Saharan Africa, more productive and sustainable farming system are needed. Low soil fertility constrains the food security and income of smallholder farmers, and the restoration of soil productivity is a major challenge to the international research, development and donor communities (Sanchez, 2002). In order to overcome this challenge, many scientists have studied soil quality in smallholder crop production systems. In this context, "Integrated Soil Fertility Management (ISFM)" has been adopted by The Tropical Soil Biology and Fertility (TSBF) Institute, its African Network for Soil Biology and Fertility (AfNet) and various other organizations as a research and development paradigm (Vanlauwe and Sanginga, 2004, Mugwe et al. 2009). ISFM "relies more on biological processes by adapting germplasm to adverse soil conditions, enhancing soil biological activity and optimizing nutrient cycling to minimize external inputs and maximize the efficiency of their use" (Sanchez, 1994) To follow this paradigm technically, external input is needed of both organic and inorganic material. As a positive effect, ISFM increases the soil organic matter content compared to the application of inorganic fertilizer only (Vanlauwe and Sanginga, 2004).

Another, related, concept that has been proposed to revert soil degradation in tropical cropping systems is Conservation agriculture (CA) which originally evolved in the US and Latin American, through farmers who faced soil erosion problems. Using crop rotation, residue mulch and reduced tillage, CA has attracted worldwide attention as a sustainable way of agriculture and for restoring degraded soils. International organizations promote the adoption of CA in southern Africa and claim positive results in terms of labour, farming costs such as fuel or equipment and agroecological aspects such as soil erosion and water use efficiency (the IRRI-CIMMYT alliance Cereal Knowledge Bank, 2007). However this claim is based largely on research in the Americas or other continents and documented studies from SSA are scarce (Giller et al. 2009). Both management concepts promote the application of organic inputs, and in addition, CA involves less mechanical soil disturbance. These practices have been found to enhance soil faunal activity. Soil fauna feed on soil organic matter so abundance and diversity of soil fauna generally increases after organic matter application (Mando. 1997, Huerta-Lwanga et al. 2008). In addition, no-till systems reduce the disturbance of soil physical and biological environment compared to conventional systems with subsequent positive impact on soil fauna community (Kladivko. 2001).

Soil macrofauna, especially earthworms, termites and ants, play an important role in enhancing soil quality (Lavelle et al. 1997). These organisms are also called soil ecosystem engineers because they create soil structure and affect the availability of resources to other organisms through modification and bioturbation of the physical environment (Bignell, 2006). Biogenic structures like galleries, net, chambers and faecal pellets are created by soil engineers (Mando 1997, Aquio et al. 2008). The biogenic formation of micro-aggregates within macro-aggregates contributes to physical protection of soil carbon and nitrogen (Six et al., 1999). A well developed structure is also important for soil physical properties such as water holding capacity, drainage capacity and aeration rate (Mando. 1997). Earthworms and termites are considered the most important soil ecosystem engineers in tropical soils, because of their high abundance (termites, ants) or biomass (earthworms) and impact on soil structure formation and organic matter dynamics. The effects of earthworms on soil quality have been studied a lot (Lavelle et al, 1994, Pulleman et al, 2005a,b). However, despite their quantitative

importance in many parts of the tropics, the effects of termites are less well understood, especially in agricultural soils (Mando, 1997, Ouédraogo et al. 2008, Sileshi et al, 2009).

In East and Southern Africa, local people consume termites themselves or use the soil of termite mounds for soil amelioration or other benefits encouraged by indigenous belief systems (Sileshi et al, 2009). It means that termites are really close to the life of local people. Judicious management of the activity of termites in cropping systems can contribute to improved soil fertility (Mando. 1997). However, the role of termites in agricultural soils and how this is affected by soil and crop management practices has not been studied well. The suitability and profitability of CA for smallholder farmers in SSA has been debated (Hobbs et al. 2008, Giller 2009) and uncertainties about the effects of termites on the performance of CA systems have been identified as an important aspect that requires further research (Giller et al 2009). Positive effects of termites (in combination with mulching) on water permeability, nutrient availability and organic matter decomposition have been found in different studies (Mando et al, 1997; Bignell, 2006), mostly in West Africa. Studies in East Africa are less common and previous studies have not focused on CA systems. Moreover, local farmers mainly recognize termites as a pest causing damage to buildings and crops (Ayuke, 2010). According to Wood (1996) and Black et al. (1997) termite pest problems occur when humans destroy the habitat of termites or introduce exotic crops. Additionally, the negative effects of termites in cropping systems depend on field management and several environmental factors. For instance, Black et al. (1997) mentioned that adding organic matter like manure, crop residue and green manure can reduce pest damage. Reddy et al. (1994b) found that no-tillage reduced termite pest species. A major challenge in SSA cropping systems is therefore to enhance the positive effects from beneficial termite species, while reducing the negative effects from harmful species through the manipulation of their macro- and micro-environment via agronomic management practices.

There are some important challenges when studying termites and their activities, especially in agricultural systems. These are: (i) the lack of standardized protocols for termite assessments in small agronomic trial plots, in combination with: (ii) the high mobility of termites and their sensitivity to disturbance; and (iii) the high spatial variability in termite distribution and their associated impact on soil characteristics. Although standard methods for assessment of soil fauna abundance and below ground biodiversity have been developed (Anderson and Ingram, 1993; Moreira et al. 2008), these protocols have been designed for relatively large areas of (semi-)natural ecosystems, not for small-sized experimental agricultural plots. Most sampling methods underestimate numbers and biomass of termites due to their behavioral patterns (Eggleton and Bignell,1995). Monolith sampling methods have been designed to minimize the escape of termites during soil sampling (Dangerfield, 1990). However, termite numbers can still be underestimated due to the depth of the habitat of Macrotermitinae (Fredrick Ayuke, personal conversation). Some termite taxa have a high mobility and the level of mobility between nest-inhabiting and foraging individuals can be different throughout a day (Wood, 1978). Additionally, the disturbance of soil or vegetation during sampling also influences the abundance of termites (Stork and Brendell, 1993). Especially Macrotermitinae move fast and form polycalic sub-terranean networks in deeper soil layers, even though soil feeding termites have been reported to be relatively slow compared to litter feeders (Eggleton and Bignell, 1995).

An additional complication when studying the impact of termites are the limitations to manipulate the presence of termites in experimental studies. These highly mobile, social organisms can not be used in small microcosms studies in a laboratory or greenhouse setting.

Ouédraogo et al. (2007) tested the use of insecticides to manipulate macrofauna abundance in the field and found that the effect of insecticides (Endocoton against earthworms and Dursban against termites) was 99.6% effective in eliminating termites from small plots (2.5 x 2 m). This method has successfully been used to study the effects of termites or other macrofauna groups on soil properties, such as soil macroporosity (Dawes 2010).

To address the above-mentioned knowledge gaps, my thesis work focused on the role of termites in affecting soil quality and crop performance in agricultural systems under different crop management (no-tilage versus conventional tillage, with and without residue retention). My work included an evaluation of termite sampling methods for small experimental plots, adapted from the TSBF standard termite sampling procedure (Anderson and Ingram, 1993).

1.2 Context

This study falls within the scope of the NWO-WOTRO Integrated Programme "More crop per drop, more cropping per dropping" (www.morecrop.nl), which is coordinated by Prof. Lijbert Brussaard and Dr. Mirjam Pulleman. The aim of this programme is to increase our understanding of the effects of agricultural management on soil aggregation, carbon sequestration, nitrogen- and water use efficiency and crop performance and specifically about the role of soil macrofauna diversity in these processes. The effects of soil macrofauna abundance and diversity on soil properties and crop performance have been examined by Mirjam Pulleman, Fredrick Ayuke, Zida Zacharie, Telesphore Ndabamenye, Tunsisa Taffe Hurisso, and Marianne Hoogmoed since 2006. My MSc thesis project focused on some specific aspects of this overall research programme.

1.3 Objectives

The aim of this MSc thesis study was threefold:

1) To quantify the effects of different tillage and residue management on the abundance and diversity of termites, crop residue cover, chemical and physical soil properties.
2) To see how termite, soil properties and crop damage are affected by macrofauna exclusion through the use of specific insecticides.
3) To compare and discuss different methods to quantify termite abundance and diversity in agricultural field experiments (transect, monolith and core sampling).

More specifically, I evaluated the following set of termite, soil and crop parameters (Table 1)

Termite indices*	**Soil residue cover***	**Chemical soil properties**	**Physical soil properties***	**Crop damaga*‡**
Termite abundance and taxonomic richness in the soil profile, monolith and core methods (quantitative)	Change in residue cover with time since planting	Soil C and N at different soil depths	Soil compaction (bulk density & penetrometer resistance)	Termite damage by visual assessments
Termite and taxonomic richness and relative abundance at the soil surface, transect method (semi-quantitative)			Gravimetric soil moisture content	

* as measured at 3 different times during one cropping season

‡ yield data were not yet available at the end of the field work period but will be reported elsewhere (Pulleman et al., 2010).

1.4 Hypotheses

Hypothesis 1 (refers to objective 1)
No tillage with residue application (NT+R) is expected to have the highest termite abundance and taxonomic richness, because NT+R, when compared to conventional tillage (CT) and residue removal (-R), leads to higher soil moisture, less damage of subterranean networks and more availability of organic matter in the form of crop residues. Termite abundance and taxonomic richness are expected to decrease with time after planting, depending on the rate of residue removal during the season.

Hypothesis 2a (refers to objective 2; termite indices)
Macrofauna exclusion (application of insecticides) will reduce the abundance and taxonomic richness of termites. The effect will decrease with soil depth because the active ingredient of the pesticide will be diluted or adsorbed by the soil while the liquid infiltrates into the soil. As a result, termites which forage on the soil surface will be affected more strongly than the ones that are subterranean.

Hypothesis 2b (refers to objective 2; soil performance indices)
Soil macrofauna exclusion increases organic residue retention on the soil surface due to reduced termite activity, especially so in the NT+R treatment. This leads to a higher soil moisture content due to less evaporation and less runoff from the soil surface (short-term effect). In addition, the maintenance of a soil residue cover in the absence of tillage and termites results in higher retention of soil organic matter than non-covered or tilled soil thus having positive effects on soil C and nutrient contents, and soil physical conditions (long-term effect).

Hypothesis 2c (refers to objective 2; crop performance indices)
The chances of crop damage due to pest termites will be higher in the – insecticide treatment.

A conceptual diagram illustrating these hypotheses is given in Figure 1. For further explanation on the theoretical background behind these processes and the role of termites and management I refer to Section 1.5. Note that the conceptual diagram focuses only on the effects that are related to the role of termites and does not show effects of management practices that are occurring irrespective of termite activities.

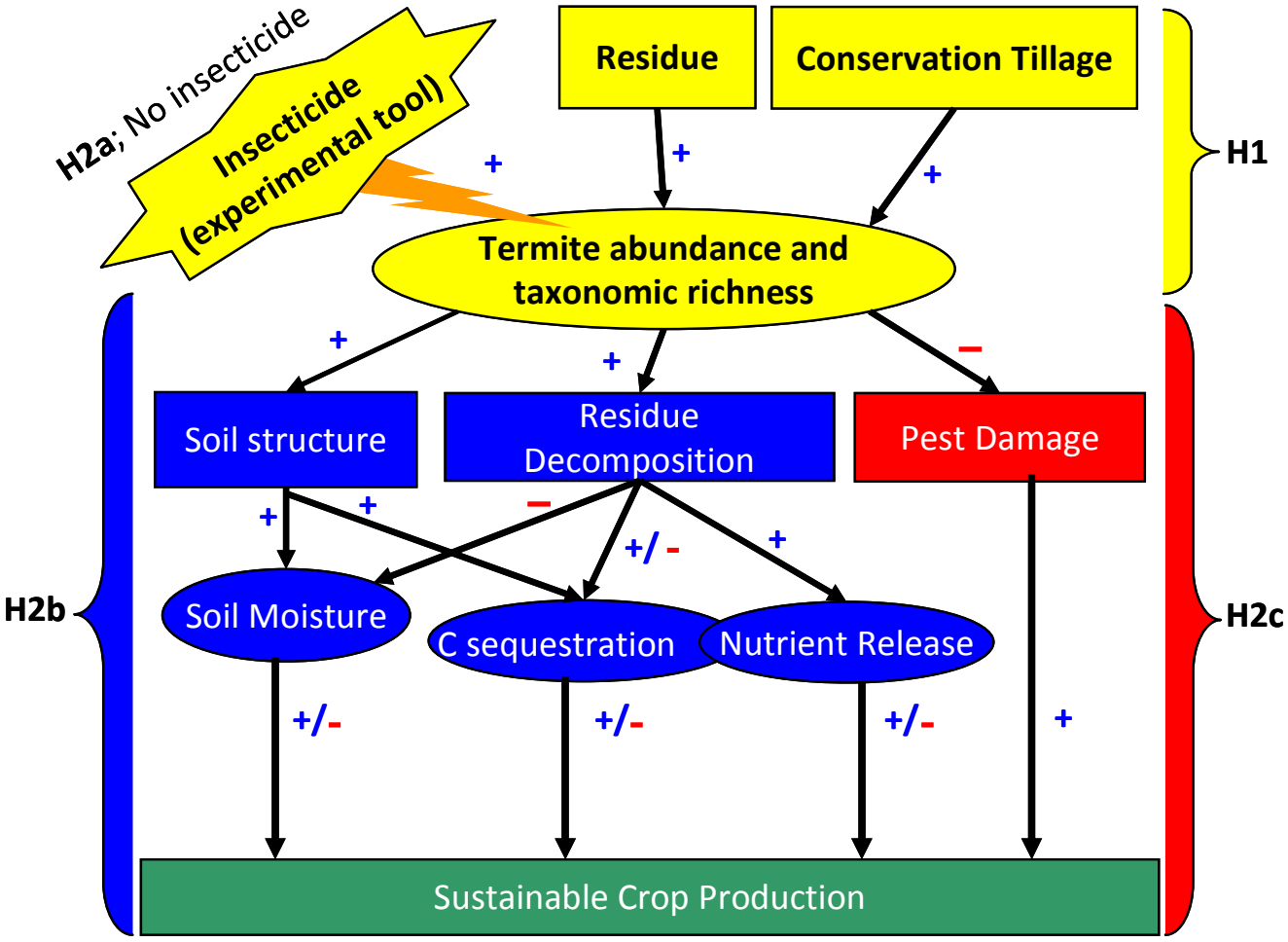


Figure 1. Conceptual model that delineates the possible trade-offs in the effects of management practices on termite activities and associated soil and crop performance. '+' means positive, and '—'means negative effect of factor, respectively. Hypotheses 1 to 2c were abbreviated as H1 to H2c.

1.5 Theoretical background

Termite behavior and functional groups

Different termite feeding groups have been defined based on the location of foraging galleries, type of organic materials carried to the nest for storage or processing, the colour of the worker abdomen, the consumption of specific feed and the location of colony centres of non mound-building species (Bignell and Eggleton 2000).

Feeding groups are sometimes overlapping for some species but five major feeding groups are generally distinguished (Bignell and Eggleton 2000):

- *Soil-feeders*: feed on mineral soil. Ingested material is rich in soil organic matter and silica and poor in recognizable plant tissue. Found only in the Apicotermitinae, Termitinae and Nasutitermitinae.
- *Soil/wood interface-feeders:* feed on strongly decomposed wood which has become friable and soil-like, soil under logs. Workers have a darker coloured body. Found only in the Apicotermitinae, Termitinae and Nasutitermitinae.
- *Wood-feeders:* feed on wood, woody litter and dead branches. These species occur in all subfamilies of the Termitinae except the Apicotermitinae.
- *Litter-foragers:* forage on leaves and small woody items, which are often transported to, and stored in, the nest. Litter feeders belong to the Macrotermitinae, Apicotermitinae, Termitinae and Nasutitermitinae.
- *Grass-feeders:* forage for standing dried dead grass and other low vegetation, usually cutting it and removing it to the nest. They are found in the Hodotermitinae, Macrotermitinae, Termitinae and Nasutitermitinae.

Minor feeding groups include termites that feed on fungi, algae, lichens, carton, dung, vertebrate corpse, and termite mounds built by the other species (Black et al. 1997, Bignell and Eggleton. 2000).

In Nyabeda, Western Kenya, local farmer have recognized ten species with their local name (Table 1.1; Ayuke 2010)

Table 1.1 Termite taxonomic richness around Nyabeda experimental field in Kenya according to local farmers knowledge (Ayuke, 2010).

S/N	Type(s)	Local name(s)	Pest
1	*Macrotermes herus*	Agoro (Build wide round mounds)	Yes
2	*Macrotermes* spp.	Riwo (Build sharp-some tall mounds)	Yes
3	*Amitermes* spp.	Orudho	Yes
4	*Pseudacathotermes spiniger*	Oyala/Oyal	Yes
5	*Pseudacathotermes militaris*	Sisi- small white in colour, no mounds	Yes
6	*Cubitermes ugandensis*	Aming (Climb trees-do not make mounds)	No
7	*Microtermes* spp.	Ogawo (smaller mostly feed on foliage/leaves)	Yes
8	*Trinevitermes oeconomus*	Thuk (small hills)	No
9	*Odontotermes kibarensis*	Oduwere-grey in colour ; Monge-are black in colour	Yes
10	*Odontotermes* spp.	Ogwe	Yes

Habitats of termites

Termites are not distributed randomly within habitats because they are colonial insects. They concentrate around colony centers of different sizes, and in turn these colony centers are scattered unevenly across microhabitats (Eggleton and Bignell, 1995). Eggleton and Bignell (1995) have split the termite species into 12 separate microhabitat groups although it is very difficult to sample each colony in each different microhabitat separately due to the difficulty of defining the exact limits of a colony. The location of the mounds is also important for the distribution of termites. In addition, mounds contribute to the diversity of termites due to the frequent presence of secondary termite inhabitants within them (Eggleton and Bignell, 1995).

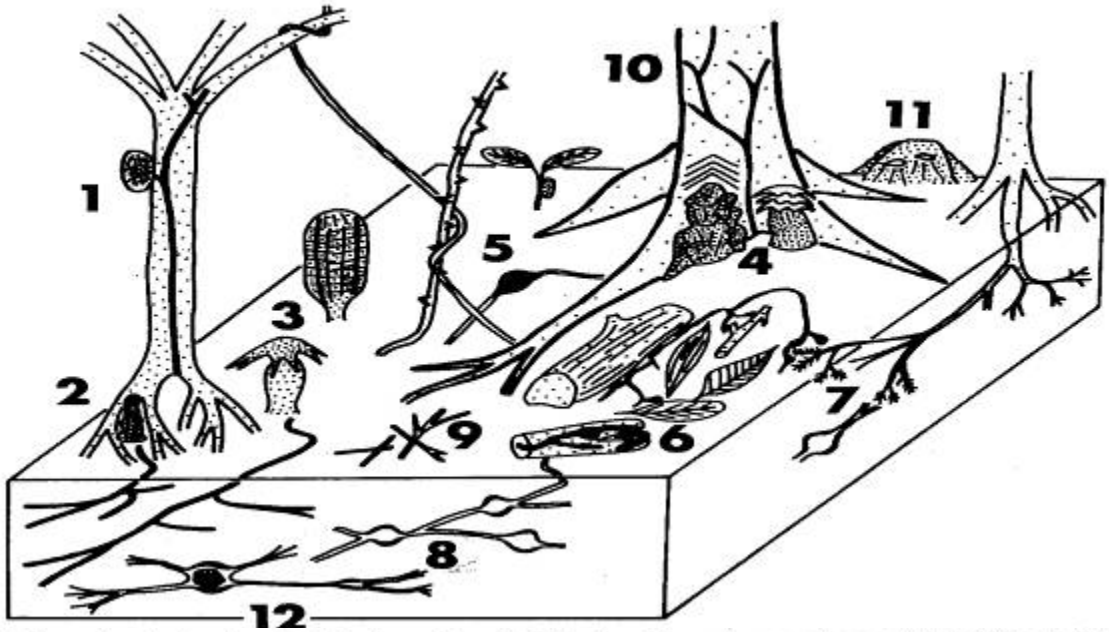


Fig. 1. The principal microhabitats and probable functional groupings of termites in the humid forest zone of southern Cameroon (diagram schematic and not to scale). 1. Termites nesting arboreally and foraging widely (normally within runways) within the canopy and on the ground (also includes termites nesting and feeding on dead wood that remains attached to trees in the canopy, i.e. Kalotermitidae); typically active wood-feeders. 2. Termites constructing epigeal mounds associated with stilt roots; typically soil feeding Termitinae foraging widely in the soil profile. 3. Termites constructing free-standing epigeal mounds not obviously associated with trees; typically soil feeding Termitinae foraging widely in the soil profile. 4. Termites in large epigeal mounds, frequently multiple constructions containing large colonies with many secondary inhabitants, associated with buttress roots; typically soil-feeding Termitinae foraging widely in the soil profile, but secondary species may include Apicotermitinae, soil and wood feeding Nasutitermitinae and Macrotermitinae. 5. Purse nests constructed with soil but attached to low vegetation and connected to the soil by runways on plant stems; typically soil-feeding soldierless Apicotermitinae, some possibly feeding at the root/soil interface. 6. Termites associated with decaying wood and other organic matter; a very diverse assemblage including wood-feeding Termitidae such as some Termitinae and Macrotermitinae that colonize whole logs and branches, and many colonies of Apicotermitinae apparently confined to the wood/soil interface. 7. Termites associated with root hairs; a speculative group possibly including some Apicotermitinae and some species of *Microtermes*. 8. Macrotermitinae forming polycalic subterranean networks, often at considerable depth and foraging widely at the surface of the ground. 9. Very fine twigs and dead plant stems may be hollowed out by small termites, especially *Microtermes* (see text); 10. Wood-feeding termites foraging in the high canopy but nesting underground, or termites establishing large colonies in heartwood; 11. Large but generally well-spaced hard carton mounds of wood-feeding Termitinae. 12. Entirely subterranean termites with diffuse or concentrated nests; typically soil-feeding Apicotermitinae (and ?Termitinae) foraging widely in the soil profile.

Termites as "ecosystem engineers"

Termites, as ants and earthworms, are considered to be "soil ecosystem engineers" who affect the availability of resources to other, generally smaller, organisms through the modification and bioturbation of the physical environment (Bignell, 2006). They have the ability to move through soil and create organo-mineral complexes (biogenic structures) due to their feeding and excretion activities (Bignell. 2006). Termites significantly affect pedogenesis, soil properties and soil functions over large areas of the tropics and sub-tropics (Bignell, 2006), and thereby enrich the chemical soil fertility in natural ecosystems and agricultural fields. Kooyman and Onck (1987) reported that certain types of termite mounds have higher organic carbon, nitrogen, exchangeable Ca, Mg, CEC and total phosphorus content than the adjacent topsoil. When termite mounds erode, their distributed mound material enriches the topsoil.

The extent to which termites affect soil properties varies with temperature, rainfall, seasonality, parent geology, and so on. Termites can decompose a wide range of types of organic detritus from fresh dead wood and dried grass to highly humified organic matter-rich soil material. This activity also stimulates the activity of other decomposers (Bignell, 2006).

Effects of agricultural management on termite activity and taxonomic diversity

Regarding the effects of tillage, soil feeding termites are generally most strongly negatively affected because of the location of their nest, while termites with adaptable subterranean nesting systems are less affected (Black et al, 1997). A reduction in mechanical soil disturbance, on the other hand, promotes higher termite activity. No-till, shallow-till and fallow systems maintained higher termite species abundance and diversity than deep- till (Holt et al. 1993, Black et al, 1997). No-till soil also maintained significantly more gallery structures than conventionally tilled soil (Holt et al. 1993). Residue application in the form of mulching has been found to attract termites and residue with low nutritional quality was consumed quicker than the residue with high nutritional quality by termites in Nigeria (Tian et al., 1993). A significantly higher incidence of galleries in the residue applied plot was found compared to the plots without residue application, both under no-tillage. This may be a reflection of increased termite activity (Holt et al. 1993) Soil moisture is also an important factor to consider with respect to termite behavior and distribution because water is required for body functions, building nests and tunnels, regulating temperature and feeding other termites and the young (Pearce, 1997). The organic matter in the soil contributes to the retention of soil moisture. The water holding capacity of the pathways of some termites, e.g. Odontotermes, was found to be higher than in mound soil. This can enable foraging for long periods in drier conditions outside the nest (Pearce, 1997). Additionally, soil moisture content affects the stability of the openings of galleries which termite build in the soil, which is important to increase water infiltration rates when the soil surface has become saturated (Mando, 1997). Bignell 2006 also reported that termites improve drainage and promote hydraulic conductivity through the maintenance of macropores and the mixing of organic and mineral materials. The effects of fertilizer type, application rates and timing on termite population are unknown (Black et al. 1997). Nutrient release from crop residues is influenced by the interactions between termite activity, soil microclimate and litter quality (Black et al. 1997).

Termite pest damage and effects on crop yield

Termites can become agricultural or silvocultural pests when humans destroy or modify their natural habitats via the introduction of non-indigenous crops or clear or burn off the natural mulches (Wood, 1996). The large majority of termite species are not pests under any circumstances and termite abundance does not necessarily correlate with crop attack or yield

losses (Black et al. 1997). Four termite species groups encountered in Nyabeda have been classified as potential pest species: *Macrotermes herus, Microtermes pusillas, Microtermes spp., Pseudacanthotermes spiniger* (Ayuke, 2010). Beneficial species of termite may restrain the activity of pest species due to competition for similar resources. According to Black (1995), a decrease in species richness lead to a large increase in the relative abundance of pest species of Amitermes and Microtermes in maize, which are non-native to Africa and among the crops is the most susceptible to termite attack (Ayuke 2010). Different tillage practices may also affect termite pest problems when this affects termite diversity. In India, termite damage to maize was greater in deep and shallow-till systems than under no-till (Reddy et al. 1994b).

Soil moisture has been shown to affect termite pest incidence. Termite attack was found to be less on irrigated crops, depending on crop type (Verma 1980, Malik et al. 1985, Bhanot et al. 1994). A direct link between higher crop yields and reduced termite attack due to improved water availability, however, has yet to be established (Black et al. 1997). Organic matter may also work positively in terms of reducing pest problems. In a review article, Black et al. (1997) pointed out that nutrient release from manure, mulches, green manures and crop residues is influenced by termite activity in conjunction with the soil micro climate and litter quality. The retention of crop residues may also reduce termite attack. Gold et al. (1991) suggested that organic matter may repel pest termites although it is influenced by the type of organic amendment used.

Macrofauna exclusion using insecticides

The insecticides Dursban and Endosulfan have been used to establish soil macrofauna exclusion plots for studying the effects of termites and earthworms on soil properties and crop production (Mando 1997, Ouédraogo 2004, Kumar et al. 2008). Endosulfan, which is main components of ENDOTAF, is used to eliminate or reduce earthworm activities, and also control Maize Stalk Borer (*Busseola fusca*), Pink Stalk Borer (*Sesamia calamistes*) and Spotted Stalk Borer(*Chilo partellus*) in tropical agriculture (MacDonald and Low, 1984). A polychlorinated compound is included. This is practically water-insoluble, but readily adheres to clay particles and persists in soil and water for several years (Comp Biochem Physiol ©, 1993). There is no indication that it affects soil aggregation in the Nyabeda field experiment (Hoogmoed, 2009).

Dursban® insecticide (O,O -diethyl O -3,5,6-trichloro-2- pyridyl phosphorothioate (Chlorpyrifos)) has been used to eliminate or reduce termites (Brock et al. (1992), Baskaran et al. (2003)) but is also generally used in cropping systems to control termite pest problems. This chemical also forms complexes with soil and organic matter and volatilization and leaching losses are limited. Microorganisms, fertilizers and growing plants do not affect the effectiveness of termite exclusion with Dursban (Whitney et al, 1967). The pH of diluted Dursban (10%) in solution is 4.9 (Dow AgroSciences, 2007). This insecticide also decreases other pests, for example, fruit fly larvae and nematodes (Clements et al. 1986, Cranshaw and Zimmerman 2010, Dutta et al. 2010).

Termite sampling methods

Different methods have been used for soil macrofauna sampling, and for termite sampling in particular. The most widely used method is the TSBF method for macrofauna sampling, which combines single monoliths, a set of pitfall traps and at least one transect sampling of 20 × 2 m (Anderson and Ingram. 1993) per sampling location. However this method has been developed for (semi)natural ecosystems covering large areas and not for small agricultural plots, let alone agronomic field experiments with limited plot sizes of e.g. 3×4m. In addition, soil samples give more accurate estimates of overall termite abundance

than mounds samplings (Eggleton and Bignell, 1995), but probably underestimate species richness unless researchers also sample from mounds and dead woods (Eggleton and Bignell, 1995). The effectiveness of termite sampling also depends on the sampling method because termites are sensitive for disturbance of area, i.e. cutting vegetation and trembling of the ground (Eggleton and Bignell, 1995). It is quite difficult to get a natural distribution of termites in a small experimental plot because the distribution of termites is highly spatially variable and the mobility of some termites is high so they can escape quickly after disturbance. The different methods that have been proposed for termite sampling each have their own advantages and disadvantages and have been used individually or have been combined to complement each other. The table below shows the comparison of such advantages and disadvantages for monolith, core, transect and baits sampling methods. (Eggleton and Bignell, 1995)

	Advantage	Disadvantage
Monolith sampling	▪ Precise data about termite abundance (quantitative data) ▪ Low number of samples containing zero termites facilitates statistical analysis	▪ Under- or overestimating termite abundance due to patchiness ▪ The large area of disturbance when monolith samples are sampled
Core sampling	▪ Precise data about termite abundance (quantitative data) ▪ Less possibility of termite escape due to rapid soil extraction ▪ Deeper sampling than monolith, down to 50-100cm (Wood et al, 1982)	▪ Small sample size; cores with zero termites can complicate statistical analysis and motivation of field assistants. ▪ Less disturbance of the experimental plot.
Transect approach	▪ Very suitable for sampling of different species present in different microhabitats (Taxonomic Richness)	▪ Not suitable for absolute quantitative assessments of termite abundance.
Baits sampling	▪ Rough species richness estimates and relative estimates of abundance of biomass.	▪ Not suitable for absolute quantitative sampling. ▪ Only samples species feeding primarily on cellulosic resources (excluding soil-feeding species) or those actively foraging at the soil surface (excluding permanently subterranean or arboreal). ▪ Selects only foraging casts, excluding reproductive casts and soldiers.

2. Materials and Methods

Site description

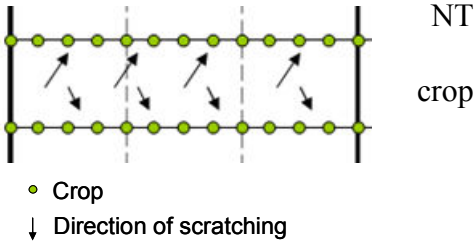
The research was conducted at a field site managed by the Tropical Soil Biology and Fertility Institute (TSBF-CIAT), situated near Nyabeda sub-location in Nyanza province, Western Kenya. The site is located at latitude 0°07' N and longitude 34 °25' E and at an altitude of 1333 masl. The mean annual precipitation is 1800 mm, with two rainy seasons, from March till July (long rains) and from September till January (short rains). In 2003, a long-term Conservation Tillage experiment was established on farmers-fields and managed by the TSBF-CIAT office in Maseno. From 1997 to 2003, the site was used as a local farm. At that time, the farmers applied DAP (Diammonium phosphate) and used oxen-ploughing. No pesticides or herbicides were applied. Before 1997, the area was partially used for growing vegetables and for grazing by local cows. The remaining area was under green fallow with native vegetation of trees and shrubs (Mr. Opondi, previous manager of this field; personal communication). The soil has been classified as a Ferralsol (FAO, 1990) with an average particle size distribution of 64% clay, 21% silt and 15% sand, a pH range of 4.7 to 5.3 and an average bulk density of 1.16g/cm^3 in the plow layer (0-20 cm depth; Hoogmoed, 2009).

Experimental design

The field trial consisted of continuous maize, intercropping (maize-soybean), and rotation (soybean-maize) trials and includes different fertilizer treatments. For the current study the plots under soybean (short rains)- maize (long rains) rotation were used, with inorganic fertilizer application at a rate of 60 kg N, 60kg P and 60kg K ha^{-1} in the form of Urea, Triple Super Phosphate (TSP) and Muriate of Potash (MOP), respectively. The present study was conducted during the 2009 short rains.

The experiment included the following treatments:

Tillage: Conventional (CT) vs. No tillage (NT). In NT, planting rows are seeded without further land preparation using a hand-hoe. Weeds between the rows are scratched out using the hand hoe. CT consisted of manual ploughing of the whole surface to approximately 15 cm depth, with the hand hoe. Weeding was also done with the hoe.



Organic Residue management: Crop residues were removed (-R) or retained (+R). When residues are retained (+R), 2 tons ha^{-1} of maize stover was incorporated into the soil, if tilled (CT), or applied on the surface (NT). Soybean residues were always retained on the surface in NT, and incorporated in CT, irrespective of the residue treatment. So in the soybean phase of the rotation, maize stover is applied only in residue treatments before soybean planting in short rains.In the maize phase of the rotation, soybean residues are retained in all treatments before maize planting in the long rains.

The treatments were laid out in a full factorial, randomized complete block design (RCBD) with 4 replicates. Plots were 4.5 m wide and 7 m long.

Macrofauna Exclusion: Superimposed on the existing tillage and residue management treatments, a '+/- Insecticide' treatment was initiated in the short rainy season of 2005 as a split plot factor in order to establish soil macrofauna exclusion plots. The treatments were replicated four times. The +insecticide plots (+Ins) were treated with ENDOTAF 35E, with endosulfan 35% EC as the active ingredient (Hurisso 2007), at a rate of 450g a.i. ha^{-1} (approx. 0.9 l ha^{-1}) to eliminate or reduce earthworm activity. Similarly, the insecticide Dursban, with chlorpyrifos 480 g l^{-1} as the active ingredient (Brooks et al., 1973), was used at a rate of 400g a.i. ha^{-1} (approx. 0.8 l ha^{-1}) to eliminate termites. Metal sheets (Figure 2, Appendix 1) were inserted at the border between the sub-plots with and without insecticide application, to reduce cross contamination between with/without insecticide plots with minimal disturbance of soil moisture dynamics. The insecticides were applied every 3 weeks during the whole year. The application rates of the insecticides were based on effect levels found in the study of draogo (Ouédraogo 2004). The net area of microplots used for '+ insecticide' treatment was set to be 3×4.5 m.

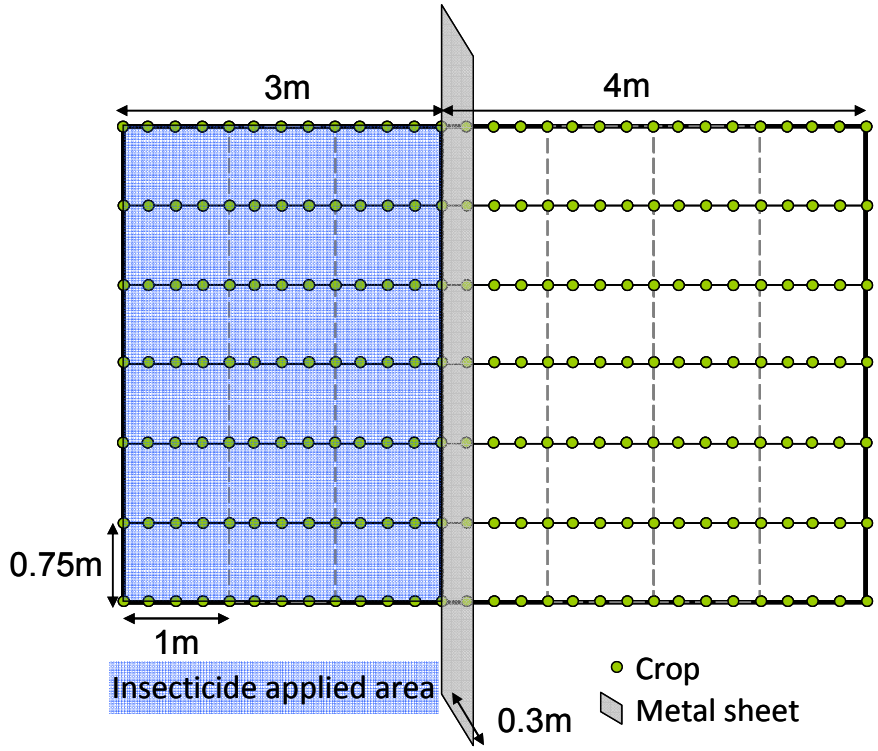


Figure 2. Macrofauna exclusion subplots. The blue colored area is the subplot in which the insecticide is sprayed. A metal plate was inserted into the soil at the border between the subplots with and without insecticide application.

In total there were 2 (tillage) × 2 (residue management) treatments × 4 replicates, each subdivided by 2 insecticide treatments (+/-), which made a total of 32 experimental units.

Macrofauna Collection and Analysis

To sample the soil macrofauna, a methodology adapted from the TSBF protocol was used (Anderson and Ingram, 1993, Moreira and Bignell, 2005). The baited pit-fall trap sampling was excluded, because of possible confounding effects when studying the effects of

residue application on termites. The number of soil core and monolith samples and the lay out of the transect sampling were adjusted to account for the small plot sizes.

Soil macrofauna was sampled in the short rainy season, in the 1st, 6th and 12th week after planting of soybean. Sampling was done in the morning because termite activity decrease during the day when temperature increases. One monolith sample, 17 composite soil core samples (taken with a 5 cm diameter soil auger) and 2 transect samplings (2m x 1m) were taken from each experimental unit (Fig. 3). The monolith and soil auger samples were subdivided into 0-15 cm and 15-30 cm depth layers and hand sorted. Termites were preserved in 70% ethanol and sent to the Department of Invertebrate Zoology of the National Museum of Kenya, Nairobi, for taxonomic identification based on the soldier termites. Termites sampled by monolith, core and transect sampling within one treatment were combined into one sample for taxonomic identification. When the termites sampled in one treatment combined 4 replicates were all workers and no species could be identified they were placed in the category: "other".

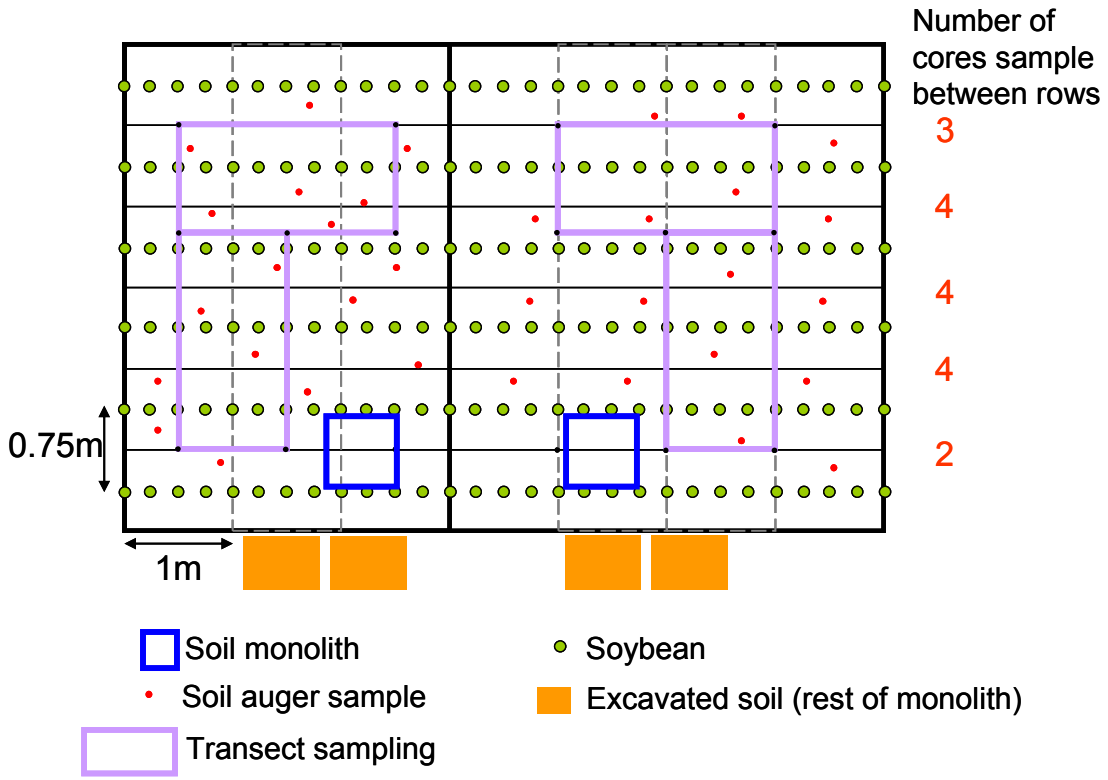


Figure 3. Schematic overview of the termite sampling scheme, including 1 monolith sampling, 17 core samplings and 2 transect samplings.

Residue cover

The residue cover was monitored within a fixed area of 1 × 1m, in week 0, 1, 3, 5, 8, 9 and 12 after planting in the NT + Residue +/- insecticide plots, using digital photographs and image analysis software (Image J). In week 0 and 1, the residues were distributed almost evenly across the plots so I took the pictures in a fixed area, at a randomly chosen location within the plots. However, in week 3 and 5, the residues had moved away from the fixed plots due to strong winds and surface water runoff. In addition, the soybean canopy had developed and the shadow of the leaves started to affect the image analysis (See picture in Appendix 2). To solve this problem, in week 8, I took pictures of the residue cover using a smaller frame (40cm*60cm), selecting a location where the residues were present, but the problem of shadows still remained and calculation of the average residue cover for the whole plot was no

longer possible due to lack of representativeness. To solve these problems, from week 9 onwards, I collected all the residues in the plot and placed them in one location that was completely shaded (See pictures in Appendix3) After collecting the residues I took a picture and also measured the field moist weight of the residues. Due to these methodological problems, residue cover data from week 3, 5 and 8 were removed from the data set before further analysis. The rest of data were analyzed with Image J. The residue weight in week 12 after planting was compared among treatments assuming that the moisture content of the residues was similar in all plots. However, absolute amounts of residue dry weight remaining after 12 weeks could not be calculated.

Chemical and physical properties

Samples for soil chemical analysis were taken from 0-15cm depth in the 6th week after planting. After drying in the open air, samples were sieved with a 2mm sieve and sent to the Plant Nutrition Laboratory, Nairobi. Soil pH, Olsen-P, Exchangeable K, Ca, Mg, Na were measured. Exchangeable Ca and Mg were measured by Atomic absorption spectrophotometer (Buck Scientific 200A). Exchangeable Na was measured by Flame photometer (Corning 410). K and P were measured using modified Olsen extraction. Soil for soil organic carbon (SOC) and total nitrogen (N) measurement was sampled from 0-5, 5-15 and 15-30cm depth at 6 weeks after planting. After air drying, samples were sieved with a 2mm sieve and grinded <0.5 mm. After grinding, Kjeldahl digestion method for N and the colorimetric method for SOC were used.

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Soil compaction

Soil for Bulk Density measurement was sampled from 0-5, 5-15 and 15-30 cm depth with bulk density rings (diam. 5 cm; volume 100 cm^3) at 6 weeks after planting. Because of a shortage of rings, soil was transferred from the metal rings to plastic bags as careful as possible to avoid soil loss. In the laboratory, samples were dried at 105 ^{0}C for 24 hours. After oven drying, samples were weighed and bulk density (g/cm^3) was calculated. Soil compaction was also measured with a soil penetrometer which consists of a cone-tip, a metal shaft, and a gauge that measures resistance in pounds per square inch (psi) at 2, 3, 5, 7, 9, 11, and 13 weeks after planting from 6 different points in each experimental unit. I measure soil penetrometer resistance at 0-5cm, 5-15cm and 15-30cm depth when soil moisture was at approximately field capacity, 1 or 2 days after a rain event.

Soil moisture

Soil moisture was measured in week 2,4,7,9,11 and 13. A composite sample consisting of 3 soil cores, taken randomly across each experimental plot, was taken at 4 different depths: 0-5, 5-15, 15-30,and 30-50 cm. The samples were weighed in the field and air dried. In the laboratory, samples were dried at 105□ for 24 hours. The calculation of the gravimetric soil moisture content was done by the following formula

Soil moisture content (%) = (the weight of field moist soil – the weight of oven dry soil) / the weight of oven dry soil.

Termite Damage

In the 3rd week after planting, 20 maize and soybean plants were marked in each experimental unit. Observations on nutrient deficiency, the number of plants attacked or lodged due to termite, wind and other biotic or abiotic factors was measured in 4, 8, 10, 14, 18 week after planting. However, only the number of plants attacked due to termite was measured in 18 week after planting.

Statistical analysis

The data were subjected to analysis of variance (ANOVA) using PASW statistics 17 (SPSS Inc.). Although the procedure Generalized Linear Mixed Model would offer the most suitable procedure for analyzing my experiment, i.e. a Randomized Complete Block Design with insecticide treatments laid out as a split plot and repeated measurements (i.e. the factors time and depth should be treated as dependent factors), these models require more advanced statistical skills. For the purpose of this Masters thesis I used the following procedure: The dataset was first split according to different soil layers and sampling times and analyzed separately. I used the procedure Univariate General Linear Model to test significant effects of the factors Tillage, Residue and Insecticide (fixed factors) and their interactions. Replicate (block) was included as a random factor. In line with the experimental design the AVOVA model included.

Univariate General linear model
- Fixed factor: Till, Res, Ins
- Random factor: Rep(replication)
- Custom model
  - Replication
  - Tillage
  - Residue
  - Till*Res
  - Rep*till*Res
  - Insecticide
  - Ins*Till
  - Ins*Res
  - Ins*Till*Res

Homogeneity of variance was assessed by the graph (x = Predicted vale, Y = Standardized Residual). The data transformed according to Log(x+1) showed a better result than non transformed data so log transformed data were used for statistical analysis of termite abundance. For the sake of clarity, non transformed data were used to present mean values and standard errors.

3. Results

3.1 Termite sampling method

Termite abundance was measured by the monolith and the core method. Five (out of 96) monolith samples, however, included termite nests and those samples contained a huge number of termites, resulting in an extremely high variability among the replicates. Additionally, TSBF recommended an integrated sampling method which combine monolith and soil core sampling (Huising et al. 2008). To compare the different sampling methods, five different data sets were prepared: i) data sampled by monolith sampling without correcting for the presence of termite nests ii) data sampled by the soil core method based on a total number of 17 cores per plot, iii) data sampled by monolith sampling corrected for nests, iv) data which combined data from monolith sampling without correction for nests and soil core sampling, v) data which combined data from monolith sampling corrected for nests and soil core sampling . Different sampling methods were compared based on the surface area sampled per sampling unit (plot), percent of sampling units without termites, average number of termites sampled and the average standard deviation of the replicates as a percent of the average number of termites (Table 3.1). This table 3.1 shows that the method integrating the monolith method, corrected for nests and the soil core method has the lowest relative standard deviation. This data also covered the highest surface area sampled per sampling unit and a low percentage of sampling units without termites. Based on these three criteria, we assumed that this data may best be used to compare the number of termites in the different management treatments.

Table 3.1. Comparison of termite sampling methodologies in terms of the average number of termites per sample and the relative standard error of 4 replicates. This assessment was done for all treatments without insecticide application (2 tillage * 2 residue * 4 replicates * 2 depths * 3 sampling times = 96 samplings, so all values are averages of 96 samples).

Sampling method	**Surface area sampled per sampling unit**	**% of sampling units without termites**	**Average nr of termites sampled**	**Coefficient of variation**
	(m2)	**(%)**	**Number m^{-2}**	**(%)**
Monolith	0.063	0	359	110
Cores	0.033	12.5	276	162
Monolith (corrected for nests)	0.063	0	198	100
Monolith+cores	0.096	0	349	103
Monolith+cores (corrected for nests)	0.096	0	245	93

Termite abundance sampled by the transect sampling method is also shown in the Results section on termite abundance and should be considered as semi-quantitative data, used to compare relative differences among treatments only.

3.2 Termite abundance

Monolith and core sampling

Table 3.2.1 shows termite abundance data as determined by the soil monolith samples without nests, combined with the soil core method. Regarding the effect of tillage, no significant effect was found on termite abundance at any of the sampling times at 0-15cm depth. However, at 15-30cm depth, a significant effect of tillage was found in week 12 after

planting, when termite abundance was three times higher in the no-till treatments (331 #/m^2) than in the tilled treatments (107 #/m^2) (Table 3.2.1). Residue application tended to result in higher termite abundance at 0-15cm depth (Fig. 3.1), but this effect was significant ($p = 0.043$, Table 3.2.1) only in week 6 after planting. At this sampling time, the number of termites in the residue applied treatment (537 termites per m^2), was more than three times higher than in residue removed treatment (174 termites per m^2).

Regarding the effect of insecticide application, a significant reduction in termite abundance was found in all treatments, depths and weeks after planting. At 0-15 and 15-30 cm depth respectively, termite abundance was reduced by 97% and 77% due to insecticide application (averaged for all 3 sampling times). The effectiveness of insecticide decreased with depth. A significant interactive effect between tillage application and insecticide was found at 15-30 cm depth in 6 weeks after planting, showing that the effect of insecticides on termite numbers was significant in plots with tillage but not without tillage. A significant interactive effect between residue and insecticide application was found at 15-30cm depth in week 12 after planting. In plots without insecticide application, residue application had a negative effect on termite abundance. In plots with insecticide application, residue application had a positive effect on termite abundance.

Although sampling time was not a factor in the ANOVA model, I assessed the effect of time graphically. However, I could not found any clear changes in termite abundance with time since planting, for any depth. The effectiveness of the insecticide treatment did not seem depend on sampling time (Figure 3.1).

Transect sampling

The (semi-quantitative) results for the transect sampling show almost the same trend as the results of the monolith and core method. Tillage treatment did not significantly affect termite numbers collected at all sampling times (Table 3.2.2). Termite numbers in the treatments with residues tended to be higher in the treatments with residues in week 1 and 6 (Fig. 3.2), but this effect was significant only in week 6 after planting. The effect of insecticides was significant at all sampling times. Termite abundance was reduced by more than 99% (averaged across all sampling times).The termite numbers in +R-Ins plots decreased with time after planting (Fig. 3.2).

Termite taxonomic richness

The genera *Pseudacanthotermes* and *Microtermes* were found in all treatments (Table 3.2.3). Other genera included a genus which is different from *Pseudacanthotermes* and *Microtermes* but was not identified because the identification of this species requires dissection of the termite. Identification down to the species level was not available. With time after planting, termite taxonomic richness increased from 1 genus to a maximum of 3 genera at 0-15cm depth. However, at 15-30cm depth, the trend disappeared (Table 3.2.3). *Pseudacanthotermes* was found at every sampling time, but *Microtermes* was more frequently found later in the cropping season. Statistically differences between treatments could not be evaluated because I put four replications together every sampling time due to my misunderstanding of experimental design for statistical analysis.

Table 3.2.1 Termite abundance in different treatments, soil depths and sampling times. NT means No tilll, CT means Conventional till, R represents Residue and INS represents Insecticide. + or – means ‘applied’ or ‘not applied’. SE means standard error.

0-15 cm			Mo+Co-nest					
			1 week		6 week		12 week	
Tillage	Residue	Insecticide	number/m2	SE	number/m2	SE	number/m2	SE
NT-R	-R	-Ins	117	72	172	120	129	17
NT+R	+R	-Ins	308	249	318	160	224	138
CT-R	-R	-Ins	42	27	175	128	313	106
CT+R	+R	-Ins	102	32	756	376	540	299
NT-R	-R	+Ins	8	5	7	6	10	10
NT+R	+R	+Ins	8	8	0	0	13	13
CT-R	-R	+Ins	5	5	0	0	39	39
CT+R	+R	+Ins	0	0	8	8	3	3
ANOVA report			Sig.		Sig.		Sig.	
Replicate			0.195		0.406		0.602	
Tillage Practice			0.344		0.209		0.993	
Residue application			0.241		***0.043***	*	0.706	
Tillage Practice*Residue application			0.986		0.959		0.643	
Tillage*Residue*Replicate			0.652		0.874		0.113	
Insecticide			***0.001***	*	***0.000***	*	***0.000***	*
Tillage Practice*Insecticide			0.818		0.693		0.975	
Residue application*Insecticide			0.062		0.306		0.914	
Tillage*Residue*Insecticide			0.861		0.570		0.239	

15-30 cm			Mo+Co-nest					
			1 week		6 week		12 week	
Tillage	Residue	Insecticide	number/m2	SE	number/m2	SE	number/m2	SE
NT-R	-R	-Ins	139	91	224	33	379	44
NT+R	+R	-Ins	164	108	318	284	282	106
CT-R	-R	-Ins	133	17	224	73	172	62
CT+R	+R	-Ins	266	57	334	147	42	19
NT-R	-R	+Ins	13	8	45	13	31	25
NT+R	+R	+Ins	159	61	81	71	107	73
CT-R	-R	+Ins	65	47	23	17	0	0
CT+R	+R	+Ins	5	3	0	0	37	33
ANOVA report			Sig.		Sig.		Sig.	
Replicate			0.455		0.459		0.827	
Tillage Practice			0.676		0.467		***0.009***	*
Residue application			0.348		0.093		0.794	
Tillage Practice*Residue application			0.165		0.582		0.878	
Tillage*Residue*Replicate			0.717		0.494		0.207	
Insecticide			***0.047***	*	***0.006***	*	***0.001***	*
Tillage Practice*Insecticide			0.153		***0.041***	*	0.485	
Residue application*Insecticide			0.908		0.764		***0.015***	*
Tillage*Residue*Insecticide			0.451		0.233		0.982	

Table 3.2.2 Termite abundance sampled by transect sampling. NT means No tilll, CT means Conventional till, R represents Residue and INS represents Insecticide. + or – means 'applied' or 'not applied'. SE means standard error.

0-5 cm			Transect sampling					
			1 week		6 week		12 week	
Tillage	Residue	Insecticide	number/4m2	SE	number/4m2	SE	number/4m2	SE
NT-R	-R	-INS	393	240	4	4	45	38
NT+R	+R	-INS	698	238	328	227	59	24
CT-R	-R	-INS	282	151	57	34	17	12
CT+R	+R	-INS	865	384	117	56	72	53
NT-R	-R	+INS	1	1	0	0	0	0
NT+R	+R	+INS	0	0	1	1	0	0
CT-R	-R	+INS	22	22	0	0	0	0
CT+R	+R	+INS	0	0	0	0	0	0
ANOVA report			Sig.		Sig.		Sig.	
Tillage Practice			0.418		0.570		0.441	
Residue application			0.852		***0.033***	*	0.137	
Tillage Practice*Residue application			0.935		0.290		0.759	
Insecticide			***0.000***	*	***0.000***	*	***0.000***	*
Tillage Practice*Insecticide			0.811		0.272		0.539	
Residue application*Insecticide			0.275		0.110		0.225	
Tillage*Residue*Insecticide			0.668		0.391		0.809	

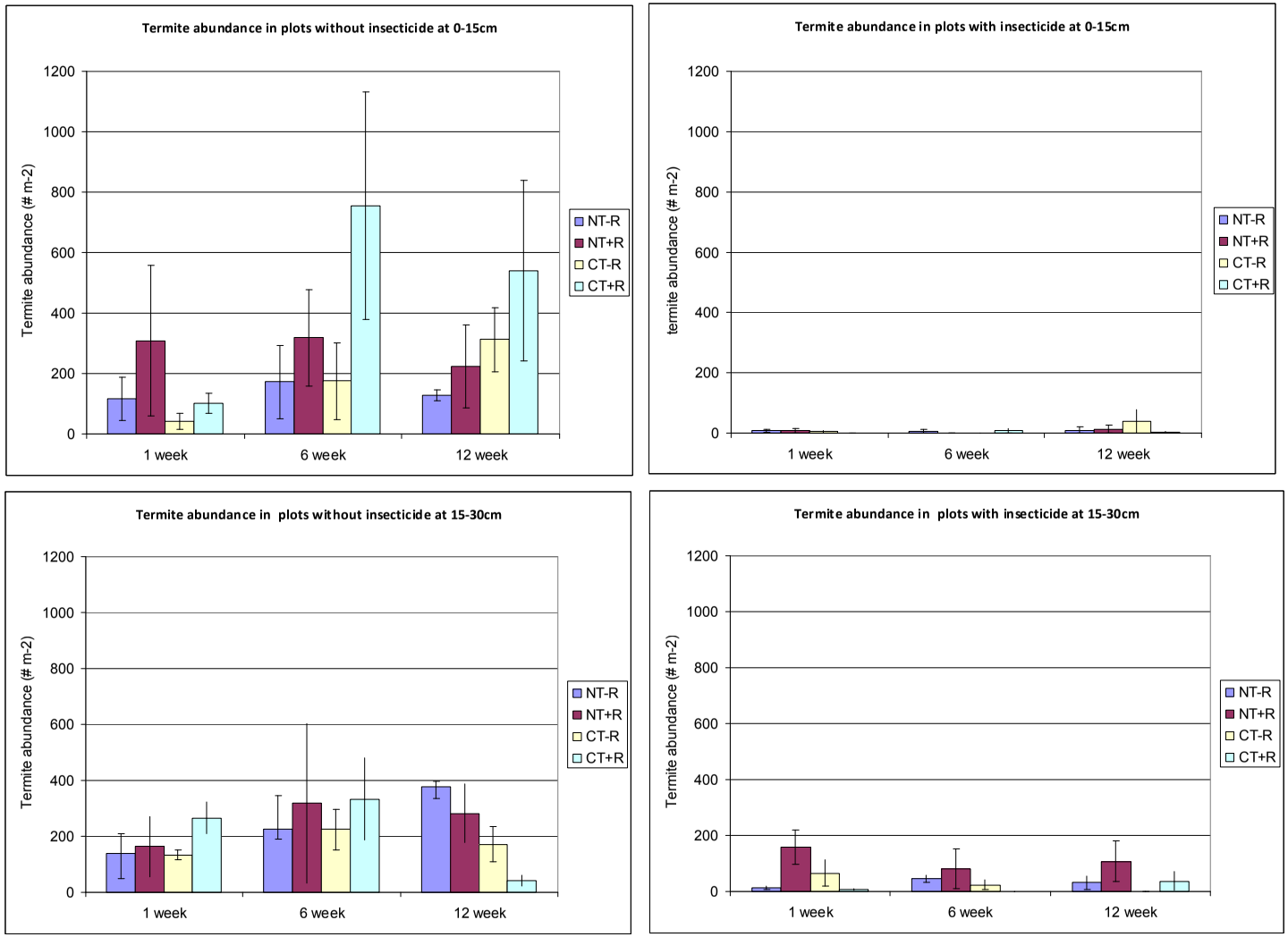


Figure 3.1 The effect of tillage/residue management on termite abundance at different sampling times. Termites were sampled by the soil monolith + core-nest method. NT means No till, CT means Conventional till, R represents Residue and INS represents Insecticide. + or – means 'applied' or 'not applied'. Error bars indicate standard errors. The results for the plots that were treated with insecticides are shown on the right hand side.

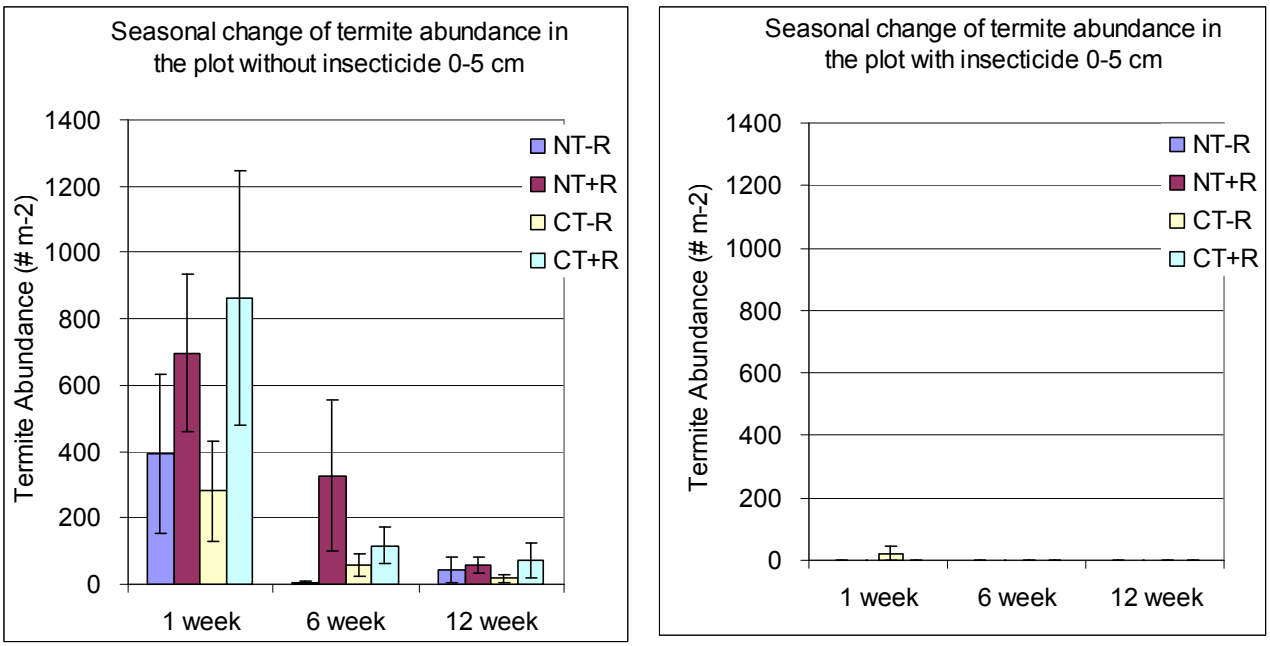


Figure 3.2 The effect of tillage/residue management on termite abundance at different sampling times. Termites were sampled by the transect sampling method. NT means No tilll, CT means Conventional till, R represents Residue and INS represents Insecticide. + or – means 'applied' or 'not applied'. Error bars indicate standard errors. The results for the plots that were treated with insecticides are shown on the right hand side.

Table 3.2.3. Termite taxonomic richness based on transect, monolith and soil core samples. NT means No tilll, CT means Conventional till, R represents Residue and INS represents Insecticide. + or – means 'applied' or 'not applied'.

	0-15 cm			Genus			
	Tillage	Residue	Insecticide	Pseudacanthotermes	Microtermes	Other	Total
1 week	NT	-R	-Ins	-	+	-	1
	NT	+R	-Ins	+	-	-	1
	CT	-R	-Ins	+	-	-	1
	CT	+R	-Ins	+	-	-	1
	NT	-R	+Ins	-	-	+	1
	NT	+R	+Ins	+	-	-	1
	CT	-R	+Ins	+	-	-	1
	CT	+R	+Ins	-	-	-	0
6 week	NT	-R	-Ins	+	-	-	1
	NT	+R	-Ins	+	-	-	1
	CT	-R	-Ins	+	+	-	2
	CT	+R	-Ins	+	-	-	1
	NT	-R	+Ins	+	-	-	1
	NT	+R	+Ins	+	-	-	1
	CT	-R	+Ins	-	-	-	0
	CT	+R	+Ins	-	-	+	1
12 week	NT	-R	-Ins	+	+	-	2
	NT	+R	-Ins	+	-	-	1
	CT	-R	-Ins	+	+	+	3
	CT	+R	-Ins	+	+	-	2
	NT	-R	+Ins	+	-	-	1
	NT	+R	+Ins	-	-	+	1
	CT	-R	+Ins	+	+	-	2
	CT	+R	+Ins	+	-	-	1

	15-30cm			Genus			
	Tillage	Residue	Insecticide	Pseudacanthotermes	Microtermes	Other	Total
1 week	NT	-R	-Ins	+	-	-	1
	NT	+R	-Ins	+	-	-	1
	CT	-R	-Ins	+	+	-	2
	CT	+R	-Ins	+	-	-	1
	NT	-R	+Ins	+	-	-	1
	NT	+R	+Ins	+	-	-	1
	CT	-R	+Ins	+	-	-	1
	CT	+R	+Ins	+	+	-	2
6 week	NT	-R	-Ins	+	-	-	1
	NT	+R	-Ins	+	-	-	1
	CT	-R	-Ins	+	-	-	1
	CT	+R	-Ins	+	+	-	2
	NT	-R	+Ins	+	-	-	1
	NT	+R	+Ins	-	-	+	1
	CT	-R	+Ins	+	-	-	1
	CT	+R	+Ins	-	-	-	0
12 week	NT	-R	-Ins	+	-	-	1
	NT	+R	-Ins	+	+	-	2
	CT	-R	-Ins	-	+	-	1
	CT	+R	-Ins	+	-	-	1
	NT	-R	+Ins	+	-	-	1
	NT	+R	+Ins	+	+	-	2
	CT	-R	+Ins	-	-	-	0
	CT	+R	+Ins	+	-	-	1

3.3 Crop residue cover

At the time of planting, the residue cover in NT+R was approximately 25% and there was a rapid decrease in residue cover during the first week after planting (Fig. 3.3). Residue cover in CT+R treatment was approximate 50 % of residue cover in NT+R at the time of planting and in week 1 (Fig. 3.3). A marginally significant effect of insecticide application was found in 9 and 12 weeks after planting ($p = 0.053$ and 0.069 respectively). At 12 weeks after planting, the residue cover area in NT+R with insecticide was 5.4% and the one in a treatment without insecticide was only 1.3%. These results (week 0 and 12) in terms of their absolute amounts must be interpreted with care due to methodological problems (see Materials and Methods), but relative differences between treatments area valid. The moist weight of the remaining residues at week 12 in the plots with insecticide application was on average about 2.6 times higher than in the plots without insecticide ($p = 0.56$) (Fig. 3.4). Again these results have to be interpreted with care and can only be used for relative comparisons between + and – INS treatments.

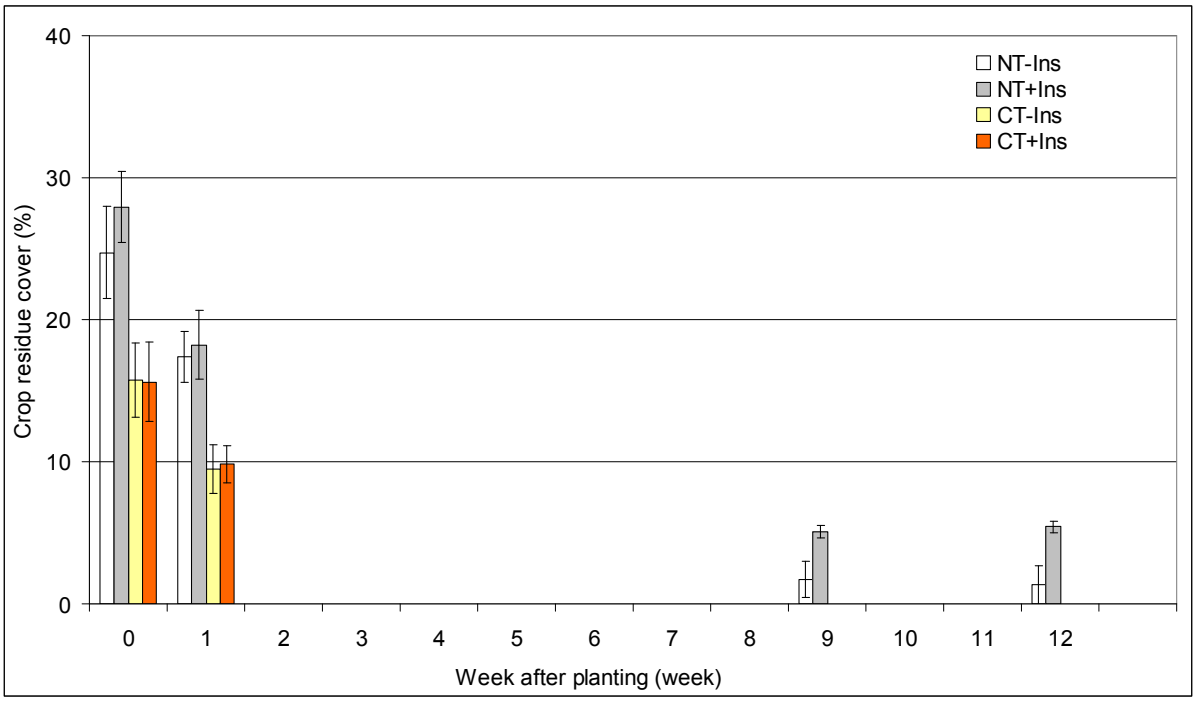


Figure 3.3. Change of crop residue cover (% of area) with time after planting in the different tillage and insecticide application plots. Error bars indicate standard errors.

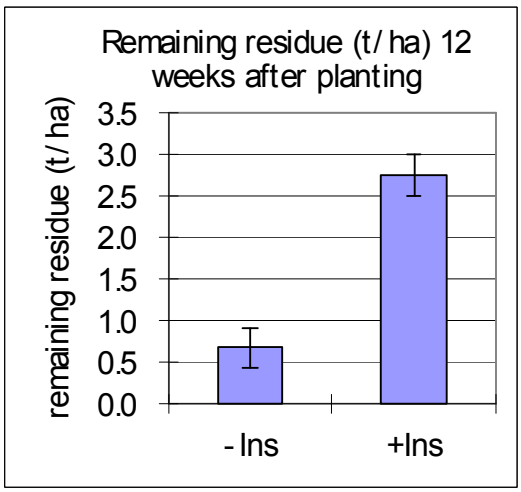


Figure 3.4 The effect of insecticide application on the moist weight of residues in NT+/- Ins plots per ha, respectively at 12 weeks after planting. Error bars indicate standard errors.

3.4 Soil Carbon and Nitrogen

Tillage did not have any significant effect on soil C and total N content at any depth layer between 0 and 30cm (Table 3.3). A marginally significant effect of Residue application was found at 0-5 cm depth ($p = 0.058$ and 0.057 for C and N, respectively, Table 3.3). On average for the different tillage treatments, the percentage of soil C and N increased by 5 and 13 % of Nitrogen and 7 and 14% of Carbon in the plot: +R-Ins, +R+Ins, respectively. A significant interactive effect was found between tillage and residue application of soil C and N at 5-15cm depth. Residue application positively affected soil C and N under the no-till treatment, but not for the conventional tillage treatment (Table 3.3, Fig. 3.5a, b).

Regarding the effect of insecticide application, a significant positive effect on soil C and N content was found at 0-5cm depth. On average across the different tillage treatments, the N content increased with 2 and 9% in – R and +R plots at 0-5 cm depth, respectively. The C content also increased with 2 and 8 % in –R and +R plots respectively (Table 3.3, Fig. 3.6 a,b). In case of soil C there was also a significant interactive effect of residue and insecticide application. The positive effect of insecticide application on soil C content in the upper 5 cm was strongest when crop residues were retained ($p = 0.007$, Table 3.3, Fig. 3.6b). At 15-30cm depth, the interaction among tillage, residue and insecticide application was significantly found in both soil C and N.

Table 3.3 The effect of tillage, residue and insecticide treatment on soil carbon (C) and nitrogen (N) at different depths. An asterisk(*) means that the p value is less than 0.05. This mark (~) means that the p value is less than 0.06. SE means standard error.

0-5 cm			**N**		**C**	
Tillage	Residue	Insecticide	g $100g^{-1}$	SE	g $100g^{-1}$	SE
NT	-R	-Ins	0.190	0.018	1.765	0.051
NT	+R	-Ins	0.213	0.015	2.042	0.162
CT	-R	-Ins	0.190	0.011	1.868	0.061
CT	+R	-Ins	0.187	0.013	1.855	0.040
NT	-R	+Ins	0.193	0.019	1.791	0.046
NT	+R	+Ins	0.222	0.014	2.244	0.139
CT	-R	+Ins	0.195	0.013	1.923	0.071
CT	+R	+Ins	0.215	0.004	1.978	0.029
ANOVA report			Sig.		Sig.	
Tillage Practice			0.358		0.557	
Residue application			***0.057***	~	***0.058***	~
Tillage Practice*Residue applicatic			0.290		*0.085*	
Insecticide			***0.009***	*	***0.000***	*
Tillage Practice*Insecticide			0.164		0.525	
Residue application*Insecticide			0.073		***0.007***	*
Tillage*Residue*Insecticide			0.275		0.180	

5-15 cm			**N**		**C**	
Tillage	Residue	Insecticide	g $100g^{-1}$		g $100g^{-1}$	
NT	-R	-Ins	0.184	0.013	1.769	0.081
NT	+R	-Ins	0.199	0.014	1.921	0.037
CT	-R	-Ins	0.188	0.011	1.883	0.051
CT	+R	-Ins	0.181	0.013	1.815	0.010
NT	-R	+Ins	0.185	0.015	1.852	0.051
NT	+R	+Ins	0.192	0.016	1.888	0.033
CT	-R	+Ins	0.177	0.008	1.837	0.080
CT	+R	+Ins	0.194	0.010	1.934	0.037
ANOVA report			Sig.		Sig.	
Tillage Practice			0.827		0.073	
Residue application			0.750		0.852	
Tillage Practice*Residue applicatic			***0.011***	*	***0.008***	*
Insecticide			0.073		0.438	
Tillage Practice*Insecticide			0.507		0.449	
Residue application*Insecticide			0.872		0.807	
Tillage*Residue*Insecticide			0.909		0.264	

15-30 cm			**N**		**C**	
Tillage	Residue	Insecticide	g $100g^{-1}$		g $100g^{-1}$	
NT	-R	-Ins	0.161	0.012	1.345	0.113
NT	+R	-Ins	0.174	0.010	1.492	0.082
CT	-R	-Ins	0.175	0.007	1.658	0.083
CT	+R	-Ins	0.165	0.005	1.513	0.156
NT	-R	+Ins	0.168	0.011	1.380	0.027
NT	+R	+Ins	0.179	0.009	1.625	0.140
CT	-R	+Ins	0.178	0.010	1.734	0.053
CT	+R	+Ins	0.168	0.007	1.439	0.103
ANOVA report			Sig.		Sig.	
Tillage Practice			0.279		0.855	
Residue application			*0.097*		0.319	
Tillage Practice*Residue applicatic			0.520		0.462	
Insecticide			0.650		0.275	
Tillage Practice*Insecticide			0.504		0.835	
Residue application*Insecticide			0.190		0.659	
Tillage*Residue*Insecticide			***0.013***	*	***0.023***	*

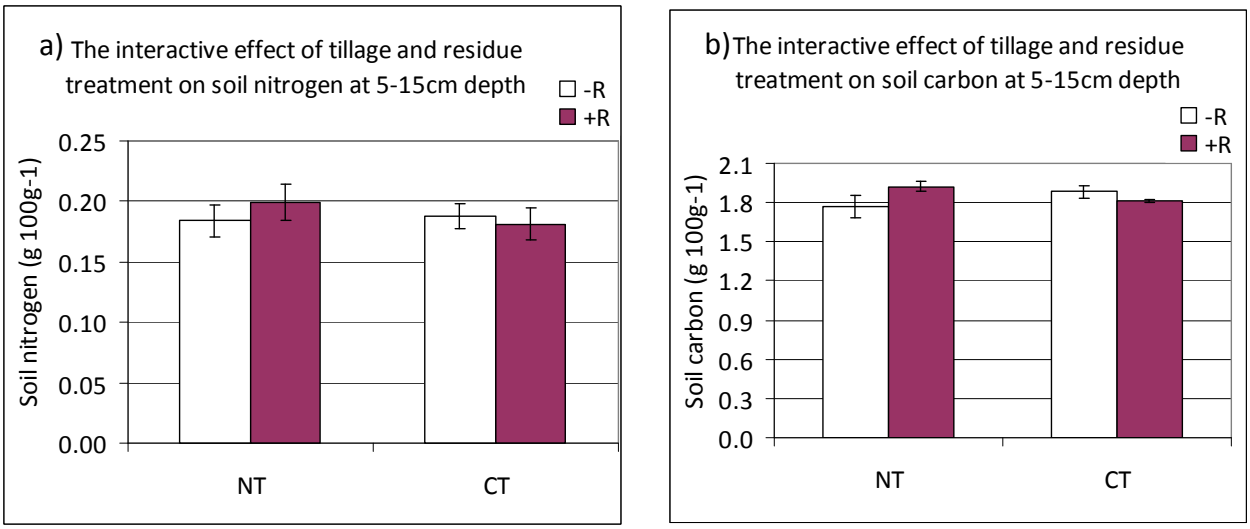


Figure 3.5a,b The interactive effect of tillage and residue treatment on soil nitrogen and carbon at 5-15cm depth.

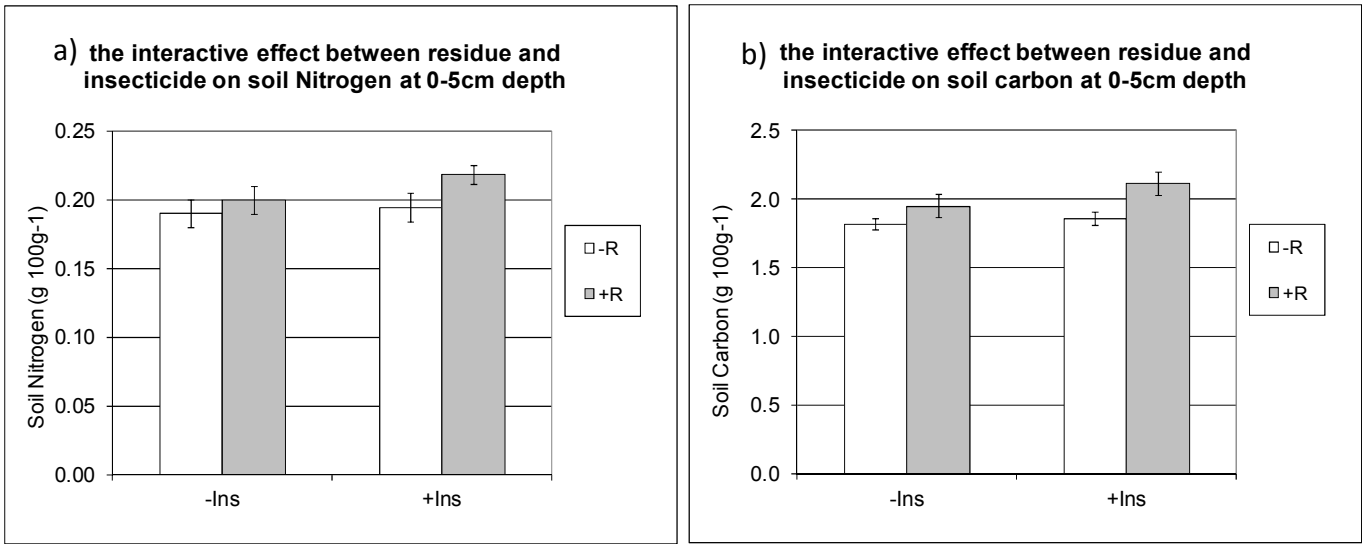


Figure 3.6 a,b The interactive effect between residue and insecticide treatment on soil nitrogen and carbon at 0-5 cm depth.

3.5 Soil Compaction

A significant effect of tillage on penetrometer resistance was found in all depth layers: 0-5, 5-15 and 15-30cm in almost all weeks after planting, except for week 2 at 5-15cm and week 9 at all depths (Table 3.5.2, 3.5.3, Figure 3.7). The effect of tillage on bulk density was marginally significant (p=0.059) at 15-30cm depth but not in the upper layers (Table 3.5.1). On average across the different residue treatments, the penetrometer resistance was 1.4, 1.5, 1.2 times higher under the no-till treatment compared to conventional tillage, at 0-5, 5-15, 15-30 cm depth respectively (Table 3.5.2). A significant effect of residue application on penetrometer resistance was found at 0-5 cm depth in 2 weeks after planting and 15-30cm depth in 5 weeks after planting (table 3.5.2). When the effect of residues application was statistically significant, soil was more compacted when residue were removed. Regarding the effect of insecticide application on soil compaction, a significant effect was found at 0-5cm in week 13 and at 5-15 cm in week 3 and 13 after planting. At 15-30 cm depth, a significant effect was found in week 11 and 13 after planting (Table 3.5.2, 3.5.3, Fig. 3.7). When the effect of insecticide application was statistically significant, soil was less compacted when insecticides were applied. Regarding the effect of the interaction between tillage and insecticide application on penetrometer resistance, a marginally significant effect was found only at 0-5cm in 9 week after planting (table 3.5.2). Regarding the effect of the interaction between residue and insecticide application on penetrometer resistance, a significant effect was also found only at 15-30 cm depth in week 7 after planting (table 3.5.3). The effect of the interaction among tillage, residue and insecticide application was found at 0-5 cm depth in 11 and 13 week after planting and at 5-15cm depth in 3, 11 and 13 week after planting.

The time effect was not tested statistically but graphically; there seemed to be a trend of increasing penetrometer resistance with time after planting (Fig. 3.6, 3.7).

Table 3.5.1 Bulk density of the different depth layers under different management treatments with and without insecticide application. Values followed by (~) have a p value < 0.1

			0-5 cm		5-15cm		15-30cm	
			Bulk Density		Bulk Density		Bulk Density	
Tillage	Residue	Insecticide	g/cm3	SE	g/cm3	SE	g/cm3	SE
No-Till	No Residue	No	1.10	0.02	1.08	0.02	1.11	0.01
No-Till	Residue	No	1.10	0.02	1.12	0.03	1.12	0.02
Conventioa	No Residue	No	1.09	0.04	1.03	0.03	1.12	0.02
Conventioa	Residue	No	1.05	0.03	1.03	0.01	1.12	0.03
No-Till	No Residue	Insecticide	1.12	0.03	1.06	0.04	1.15	0.02
No-Till	Residue	Insecticide	1.07	0.01	1.06	0.02	1.13	0.03
Conventioa	No Residue	Insecticide	1.07	0.04	1.04	0.03	1.07	0.06
Conventioa	Residue	Insecticide	1.01	0.02	1.03	0.02	1.12	0.02
ANOVA report			Sig.		Sig.		Sig.	
Tillage Practice			0.081		0.241		***0.059***	~
Residue application			0.108		0.466		0.673	
Tillage Practice*Residue application			0.587		0.268		0.512	
Insecticide			0.332		0.829		0.326	
Tillage Practice*Insecticide			0.472		0.168		0.313	
Residue application*Insecticide			0.287		0.693		0.486	
Tillage*Residue*Insecticide			0.799		0.269		0.684	

Table 3.5.2. Soil compaction as measured by penetrometer resistance (pounds per square inch) in different treatments at 0- 5 and 5 – 15 cm depth. 1 psi corresponds to 0.069 kg cm^{-2}.

0-5 cm			2		3		5		7		9		11		13	
			(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)	
Tillage	Residue	Insecticide	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE
No-Till	No Residue	No	201	15	302	30	262	21	349	14	332	25	355	15	400	26
No-Till	Residue	No	157	19	272	12	231	33	307	20	273	42	351	39	385	36
Conventioanl Till	No Residue	No	141	11	179	24	155	16	270	15	243	27	274	9	329	21
Conventioanl Till	Residue	No	127	2	175	22	153	14	268	24	266	25	274	17	326	18
No-Till	No Residue	Insecticide	209	31	263	27	260	12	336	18	319	14	354	34	404	34
No-Till	Residue	Insecticide	151	23	251	15	187	10	324	19	264	37	289	27	317	31
Conventioanl Till	No Residue	Insecticide	136	12	159	15	151	11	247	16	270	22	249	17	304	17
Conventioanl Till	Residue	Insecticide	109	8	150	13	132	20	265	20	278	24	280	14	314	15
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			***0.004***	*	***0.000***	*	***0.000***	*	***0.003***	*	0.175		***0.007***	*	***0.020***	*
Residue application			***0.026***	*	0.234		0.088		0.580		0.373		0.646		0.275	
Tillage Practice*Residue application			0.270		0.529		0.243		0.320		0.133		0.233		0.217	
Insecticide			0.635		0.120		0.900		0.613		0.555		0.065		***0.010***	*
Tillage Practice*Insecticide			0.592		0.814		0.581		0.510		***0.059***	~	0.317		0.396	
Residue application*Insecticide			0.542		0.831		0.150		0.276		0.712		0.471		0.101	
Tillage*Residue*Insecticide			0.960		0.737		0.533		0.808		0.490		***0.045***	*	***0.024***	*

5-15 cm			2		3		5		7		9		11		13	
			(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)	
Tillage	Residue	Insecticide	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE
No-Till	No Residue	No	202	39	255	44	231	24	349	16	275	29	316	16	371	35
No-Till	Residue	No	143	26	236	19	196	45	288	27	230	38	305	27	359	36
Conventioanl Till	No Residue	No	93	15	162	28	118	15	271	15	213	28	254	5	301	35
Conventioanl Till	Residue	No	67	10	129	22	106	10	252	26	216	25	260	21	288	27
No-Till	No Residue	Insecticide	144	31	230	12	231	22	308	18	271	14	290	23	348	27
No-Till	Residue	Insecticide	108	28	195	16	145	7	311	18	236	35	269	26	298	36
Conventioanl Till	No Residue	Insecticide	93	19	137	17	111	8	232	17	236	27	217	13	274	20
Conventioanl Till	Residue	Insecticide	67	16	95	10	63	10	260	26	238	28	237	10	280	22
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			0.066		***0.014***	*	***0.011***	*	***0.010***	*	0.330		***0.042***	*	***0.049***	*
Residue application			0.439		0.136		0.104		0.101		0.327		0.554		0.293	
Tillage Practice*Residue application			0.690		0.073		0.124		0.269		0.094		0.290		0.176	
Insecticide			0.139		***0.008***	*	0.155		0.108		0.204		0.128		***0.015***	*
Tillage Practice*Insecticide			0.786		0.204		0.253		0.175		0.132		0.120		0.116	
Residue application*Insecticide			0.370		0.492		0.177		0.860		0.690		0.200		0.073	
Tillage*Residue*Insecticide			0.962		***0.002***	*	0.213		0.577		0.860		***0.017***	*	***0.011***	*

Table 3.5.3. Soil compaction (ponds per square inch) in different treatment at 15- 30 cm depth. 1 psi corresponds to 0.069 kg cm^{-2}.

15-30 cm			2		3		5		7		9		11		13	
			(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)		(ponds/inch2)	
Tillage	Residue	Insecticide	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE	average	SE
No-Till	No Residue	No	292	8	393	38	425	35	502	26	523	46	510	41	559	42
No-Till	Residue	No	285	10	357	22	376	44	457	19	415	70	508	70	515	61
Conventioanl Till	No Residue	No	251	21	313	20	299	25	453	11	391	37	389	13	437	18
Conventioanl Till	Residue	No	258	9	296	8	298	26	433	19	430	23	386	9	439	8
No-Till	No Residue	Insecticide	279	10	394	30	425	14	503	24	490	30	523	64	563	57
No-Till	Residue	Insecticide	250	35	286	4	290	23	448	18	376	54	386	42	420	39
Conventioanl Till	No Residue	Insecticide	247	24	274	15	296	29	403	23	401	24	366	22	415	19
Conventioanl Till	Residue	Insecticide	228	18	307	7	291	29	402	24	426	35	410	13	438	11
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			***0.009***	*	***0.000***	*	***0.000***	*	***0.012***	*	0.166		***0.009***	*	***0.031***	*
Residue application			0.108		0.069		***0.036***	*	0.544		0.329		0.914		0.474	
Tillage Practice*Residue application			0.628		0.744		0.437		0.414		0.272		0.387		0.556	
Insecticide			0.121		0.061		0.074		0.308		0.208		***0.002***	*	***0.045***	*
Tillage Practice*Insecticide			0.121		0.940		0.994		0.786		0.241		0.950		0.370	
Residue application*Insecticide			0.679		0.685		0.111		***0.034***	*	0.813		0.869		0.723	
Tillage*Residue*Insecticide			0.679		0.903		0.776		0.695		0.776		0.475		0.304	

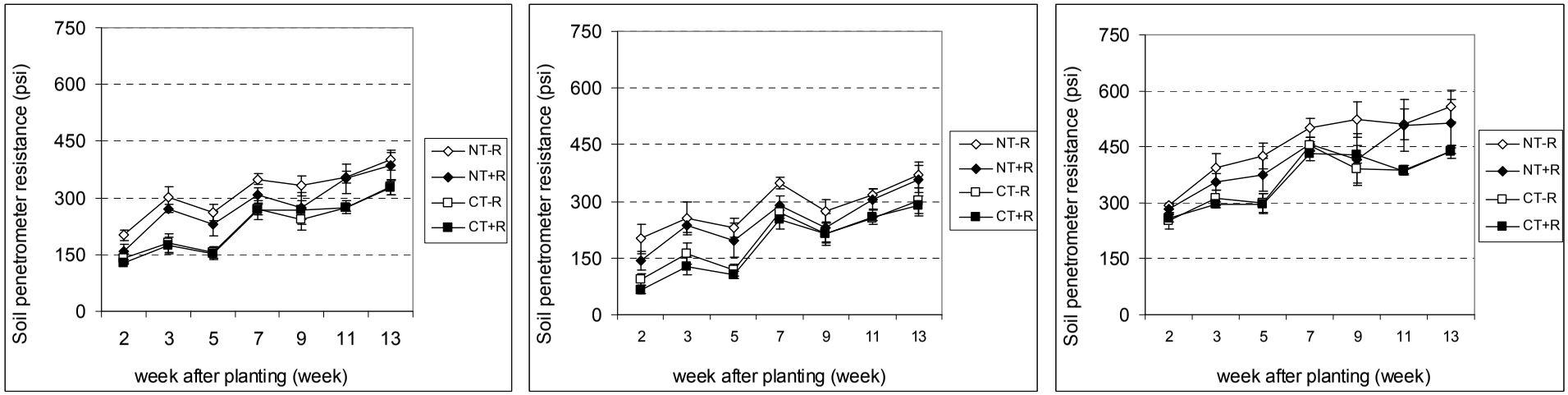


Figure 3.6 The effect of tillage and residue on soil penetrometer resistance at all depth and sampling times. NT means No till, CT means Conventional till, R represents Residue. + or – means 'applied' or 'not applied'. Error bars indicate standard errors

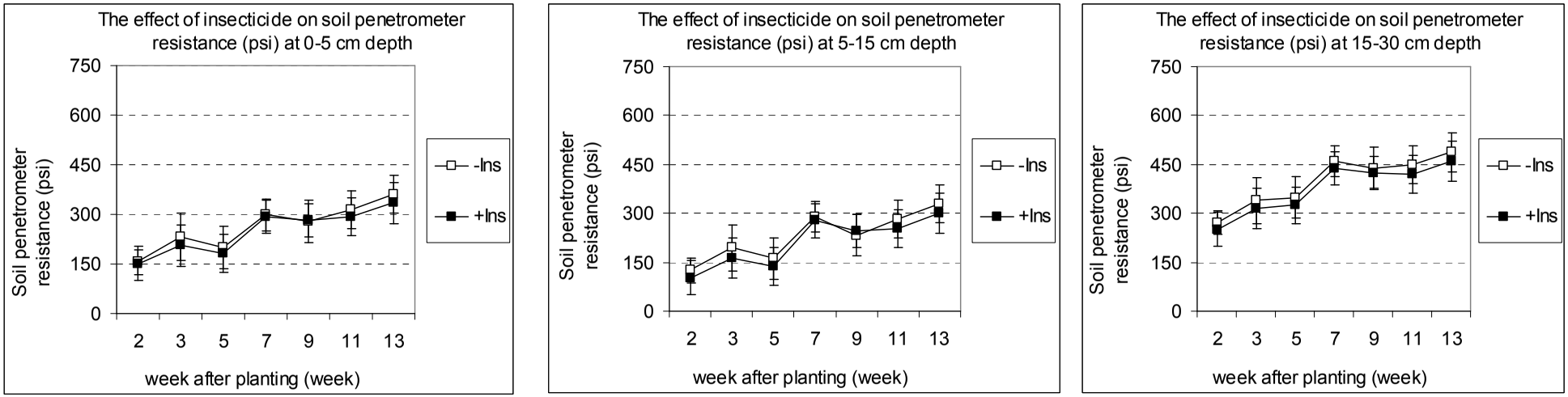


Figure 3.7 The effect of insecticide on soil penetrometer resistance. There is, however, significant interaction between tillage and residue and insecticide. The trend of insecticide effect can be estimate but averaged tillage and residue application may influence this figure. Error bars indicate standard errors.

3.6 Soil moisture

Statistically significant effects of tillage, residue and insecticide application were found only for specific sampling times and depths (Table 3.6.1, 3.6.2). Fig. 3.10 a,b,c,d show that, when differences were observed between treatments, the soil moisture content tended to be lowest in NT-R, in all 4 depth layers. This is also clear when soil moisture content is averaged across sampling times (Fig 3.11). Without residue application, tillage treatment tended to have a clear effect on soil moisture. The soil moisture without tillage was lower than with tillage in –R-Ins plot. When residue was applied, the effect of tillage became less clear. Regarding the effect of residue, soil moisture in NT+R plot was higher than in NT-R plot. The effect of residue in CT plot was unclear (Fig. 3.11).

There was no clear affect of insecticide application on the average soil moisture content across all sampling times, although soil moisture in NT+R-INS tended to be lower than in NT+R+INS (Fig. 3.11).

Table 3.6.1 Gravimetric soil moisture content at 0-5 and 5-15cm depth for different treatments and sampling times.

0-5 cm			Week 2		Week 4		Week 7		Week 9		Week 11		Week 13	
			Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)	
Tillage	Residue	Insecticide	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.
No-Till	No Residue	No	27.7	3.5	18.9	5.6	22.6	1.7	30.4	0.9	26.1	2.1	23.1	2.5
No-Till	Residue	No	31.3	2.1	25.6	0.7	25.0	0.9	31.6	0.5	27.9	1.0	24.9	0.8
Conventioanl Till	No Residue	No	31.7	1.3	27.3	0.9	25.8	1.3	35.4	0.9	30.2	1.2	25.2	1.4
Conventioanl Till	Residue	No	32.2	0.7	27.1	0.8	25.5	0.5	33.7	0.7	29.4	1.0	23.2	0.7
No-Till	No Residue	Insecticide	28.6	0.3	23.7	1.6	24.9	1.0	29.3	1.4	25.0	1.8	23.6	3.5
No-Till	Residue	Insecticide	34.3	2.2	27.1	1.1	27.1	1.2	34.3	0.5	28.9	1.6	26.4	1.0
Conventioanl Till	No Residue	Insecticide	33.0	2.6	27.8	0.9	29.9	7.7	33.6	0.5	30.0	1.8	24.0	0.5
Conventioanl Till	Residue	Insecticide	27.6	3.0	29.3	1.0	24.7	1.4	34.3	0.5	30.3	0.5	26.0	1.0
Rainfall			40.30		1.30		7.90		30.00		0.00		0.00	
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			0.184		0.097		0.766		0.119		0.122		0.626	
Residue application			0.879		0.267		0.601		0.916		0.799		0.844	
Tillage Practice*Residue application			***0.048***	*	0.144		0.221		***0.040***	*	0.105		0.330	
Insecticide			0.317		0.231		0.396		0.427		0.788		0.631	
Tillage Practice*Insecticide			0.136		0.405		0.789		0.096		0.971		0.708	
Residue application*Insecticide			0.473		0.594		0.363		0.084		0.736		0.359	
Tillage*Residue*Insecticide			0.348		0.395		0.554		0.674		0.744		0.408	

5-15 cm			Week 2		Week 4		Week 7		Week 9		Week 11		Week 13	
			Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)	
Tillage	Residue	Insecticide	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.
No-Till	No Residue	No	30.3	1.1	28.0	1.0	25.1	0.9	28.5	1.4	26.8	1.8	23.9	1.7
No-Till	Residue	No	30.0	1.1	28.2	0.4	25.0	1.2	31.0	1.0	29.3	1.2	26.1	0.8
Conventioanl Till	No Residue	No	33.1	1.3	29.4	0.7	25.7	0.4	33.8	0.9	30.9	0.8	27.7	1.8
Conventioanl Till	Residue	No	30.6	1.8	28.5	0.8	25.4	0.5	31.7	0.8	31.0	0.9	28.5	0.6
No-Till	No Residue	Insecticide	31.2	1.9	26.6	1.9	23.0	2.2	28.0	2.0	27.2	2.3	22.3	1.8
No-Till	Residue	Insecticide	32.6	2.0	29.7	0.6	22.9	3.0	32.2	1.2	29.7	0.7	28.6	1.1
Conventioanl Till	No Residue	Insecticide	32.0	2.4	28.7	0.5	24.0	1.1	33.3	1.2	30.6	0.6	28.3	0.8
Conventioanl Till	Residue	Insecticide	34.0	0.9	30.3	0.7	24.0	0.7	32.3	1.1	28.8	1.1	27.6	1.3
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			0.658		0.455		0.415		0.889		0.297		0.081	
Residue application			0.583		0.235		***0.029***	*	0.367		0.458		0.306	
Tillage Practice*Residue application			0.321		0.993		0.894		0.172		0.742		0.210	
Insecticide			0.437		0.348		0.493		0.528		0.870		0.758	
Tillage Practice*Insecticide			0.538		0.091		0.517		0.127		0.896		0.551	
Residue application*Insecticide			0.603		***0.023***	*	0.420		0.270		0.775		0.702	
Tillage*Residue*Insecticide			0.767		0.189		0.699		0.487		0.815		0.586	

Table 3.6.2 Gravimetric soil moisture content at 15-30 and 30-50 cm depth for different treatments and sampling times.

15-30 cm			Week 2		Week 4		Week 7		Week 9		Week 11		Week 13	
			Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)		Field moisture (g 100g -1)	
Tillage	Residue	Insecticide	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.
No-Till	No Residue	No	29.4	2.7	30.1	1.2	26.9	0.6	29.6	0.4	29.2	2.7	25.9	1.7
No-Till	Residue	No	31.1	2.4	30.4	0.6	27.3	0.4	31.5	1.4	31.5	2.3	28.9	1.5
Conventioanl Till	No Residue	No	29.0	3.3	32.7	0.9	26.3	1.9	32.6	1.0	31.8	0.5	29.5	2.5
Conventioanl Till	Residue	No	27.5	2.5	31.3	1.0	27.6	0.8	31.4	0.6	32.6	0.3	27.3	3.2
No-Till	No Residue	Insecticide	27.6	3.0	30.2	2.0	26.3	0.7	28.0	1.5	28.6	2.1	23.9	1.6
No-Till	Residue	Insecticide	32.4	1.5	32.8	1.1	29.4	1.0	33.7	3.6	30.9	2.1	26.5	2.8
Conventioanl Till	No Residue	Insecticide	32.1	1.5	31.0	0.8	27.2	0.7	31.9	1.0	33.3	0.5	29.5	0.8
Conventioanl Till	Residue	Insecticide	30.1	0.9	33.4	0.3	28.1	0.8	29.9	1.2	32.6	0.1	29.7	2.4
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			0.554		0.835		0.841		0.171		0.566		0.120	
Residue application			0.433		0.146		0.982		0.286		0.459		***0.036***	*
Tillage Practice*Residue application			0.282		0.208		0.818		***0.024***	*	0.177		***0.030***	*
Insecticide			0.370		0.622		***0.009***	*	0.650		0.171		0.716	
Tillage Practice*Insecticide			0.993		0.112		0.286		0.601		0.714		0.822	
Residue application*Insecticide			0.539		***0.053***	~	0.685		0.697		0.197		0.674	
Tillage*Residue*Insecticide			0.400		0.889		0.694		0.943		0.634		0.154	

30-50 cm			Week 2		Week 4		Week 7		Week 9		Week 11		Week 13	
			Field moisture (g/cm3)		Field moisture (g/cm3)		Field moisture (g/cm3)		Field moisture (g/cm3)		Field moisture (g/cm3)		Field moisture (g/cm3)	
Tillage	Residue	Insecticide	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.	Average	s.e.
No-Till	No Residue	No	29.3	2.4	32.4	1.7	28.3	1.3	29.5	1.3	30.3	3.2	25.4	3.5
No-Till	Residue	No	32.4	1.8	33.6	0.7	29.6	0.9	32.4	3.0	31.3	1.6	27.5	3.6
Conventioanl Till	No Residue	No	34.6	0.8	35.3	0.5	31.3	1.9	34.1	1.0	34.3	0.6	32.5	1.2
Conventioanl Till	Residue	No	26.4	3.5	35.3	0.6	29.6	0.9	32.3	1.5	33.0	0.4	30.1	0.6
No-Till	No Residue	Insecticide	28.7	2.8	32.2	2.3	29.8	1.8	30.9	1.9	29.3	2.5	23.5	3.4
No-Till	Residue	Insecticide	32.1	3.1	35.0	1.1	30.7	1.3	32.2	2.5	33.8	3.0	29.4	0.4
Conventioanl Till	No Residue	Insecticide	32.3	2.2	33.8	0.8	29.9	0.4	33.4	1.3	34.6	0.7	32.0	1.1
Conventioanl Till	Residue	Insecticide	26.2	3.5	35.6	0.6	30.6	1.0	30.4	1.5	32.7	1.3	31.1	1.5
ANOVA report			Sig.		Sig.		Sig.		Sig.		Sig.		Sig.	
Tillage Practice			0.689		0.160		0.548		0.476		0.231		***0.041***	*
Residue application			0.323		0.237		0.807		0.935		0.759		0.589	
Tillage Practice*Residue application			***0.019***	*	0.635		0.494		0.236		0.285		0.213	
Insecticide			0.674		0.985		0.425		0.730		0.609		0.910	
Tillage Practice*Insecticide			0.855		0.260		0.313		0.339		0.614		0.891	
Residue application*Insecticide			0.760		0.142		0.502		0.501		0.344		0.247	
Tillage*Residue*Insecticide			0.818		0.948		0.321		0.911		0.180		0.697	

Figure 3.10 a,b,c,d. Gravimetric soil moisture content for different tillage and residue treatments. NT means No till, CT means Conventional till, R represents Residue. + or – means 'applied' or 'not applied'. Error bars indicate standard errors.

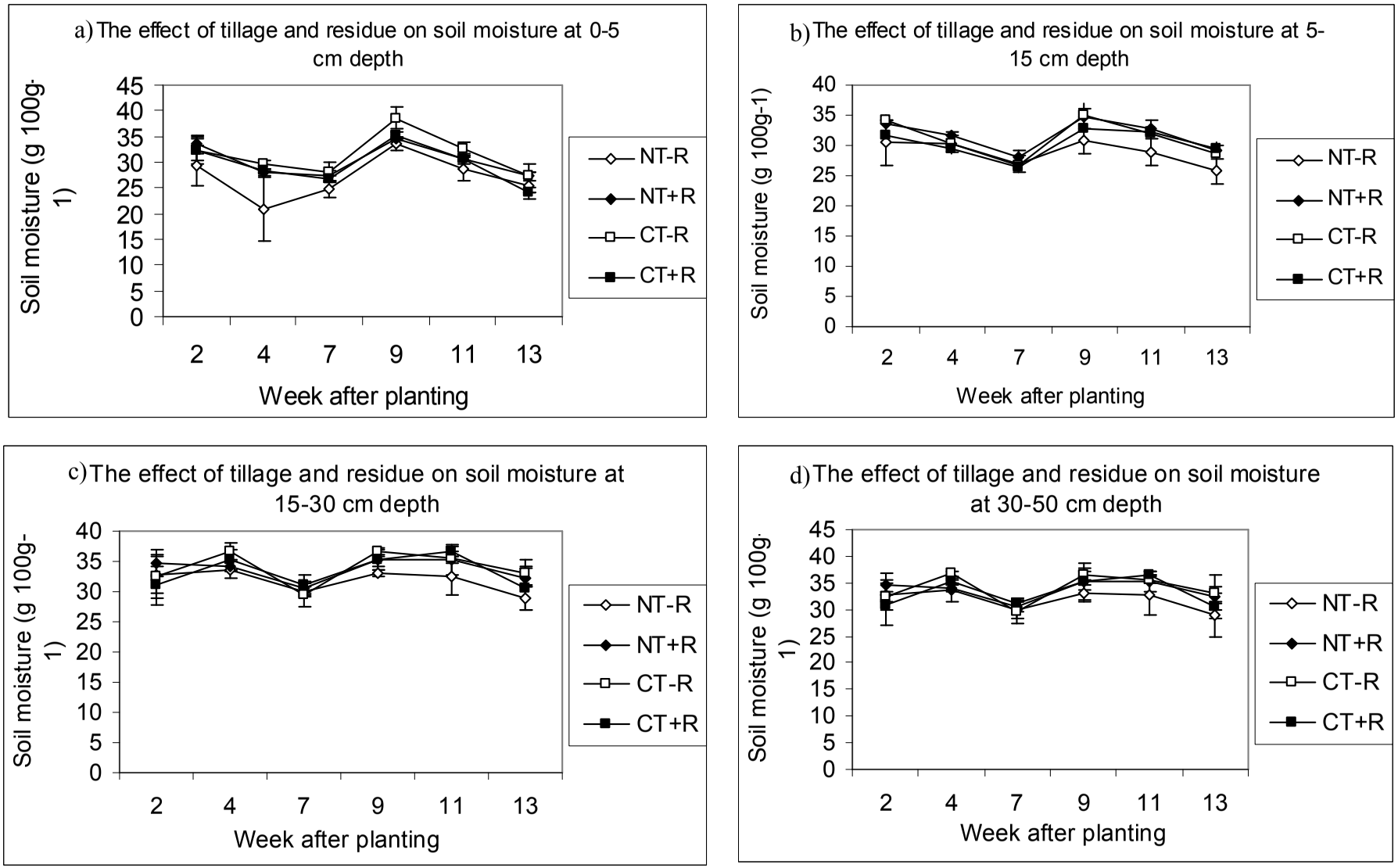
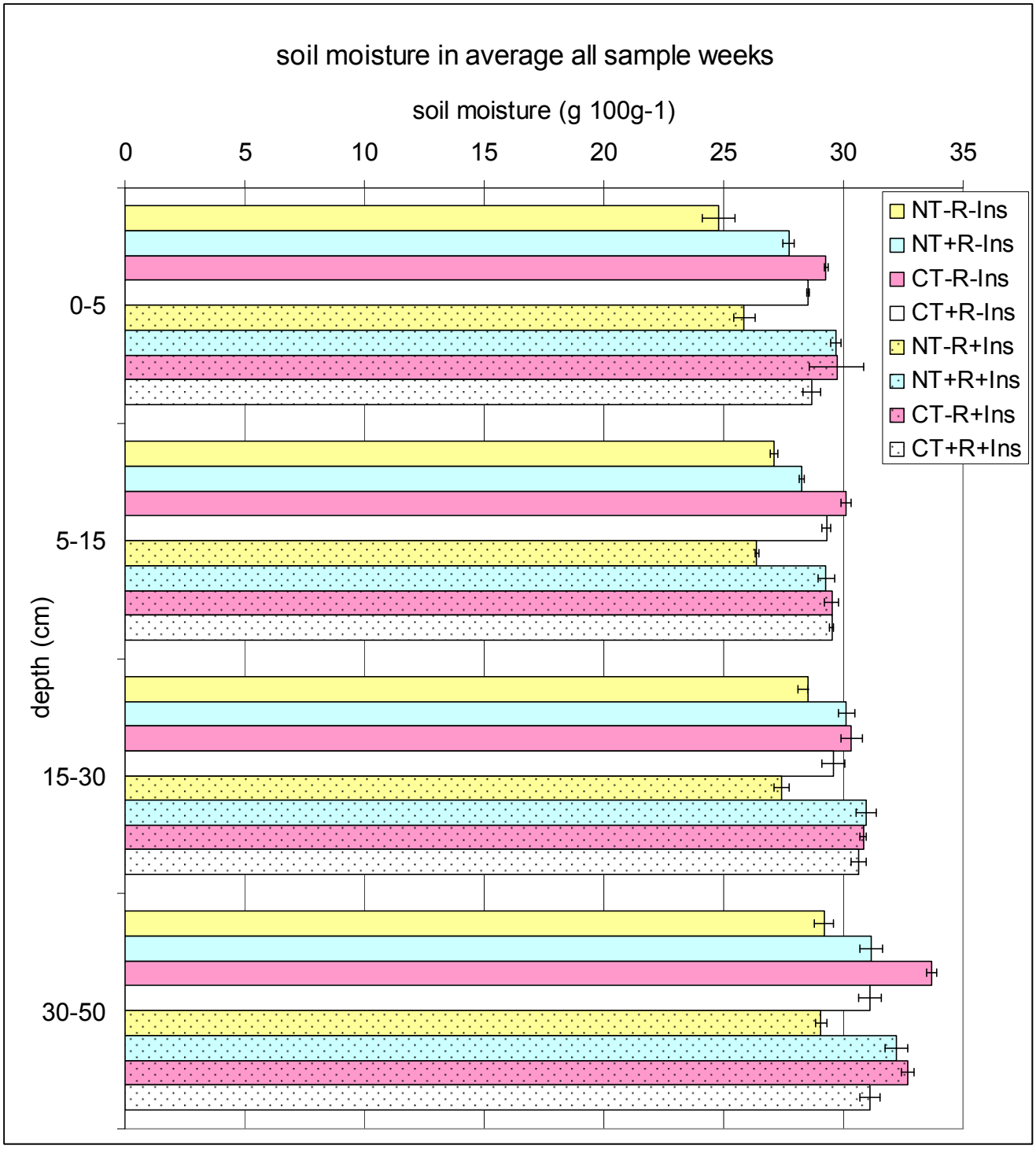


Figure 3.11 Graphical analysis of soil moisture in different depth in average week.



3.7 Crop damage due to termites

In week 4, 8, 10 and 14 after planting, the number of lodged plants due to termite attack assessed with the field observation of termite crust was less than 2 plants per 640 observed plants. However, plants damaged by other reasons were observed a lot. For instance, stem borer, leaf roller, aphid, caterpillar, and corn streak virus in maize, and damage from wild mammals, and soybean mosaic virus in soybean. In addition, human activity like weeding also resulted in damaged plants due to the use of the hoe to remove weed. John Mukalama, Reserch assistant of TSBF, mentioned that the region of the field experiment has sometimes strong winds and rain showers, which also causes lodging. After plants were lodged because of several reasons, termites started to decompose the plants.

Regarding the effect of insecticide application on crop damage due to termites in week 18 after planting, a significant effect was found in both soybean and maize (Table 3.7). On average across the different tillage and residue treatments, both crops got seriously damaged when insecticides were not applied (Figure 3.11).

Table 3.7 The termite damage of maize and soybean in 18 weeks after planting.

0-5 cm			% of attacked maize		% of attacked soybean	
Tillage	Residue	Insecticide	average	s.e.	average	s.e.
No-Till	No Residue	No	22.5	10.3	30.0	10.2
No-Till	Residue	No	8.8	7.2	16.3	6.3
Conventioanl Till	No Residue	No	6.3	3.8	43.8	11.3
Conventioanl Till	Residue	No	8.8	2.4	36.3	4.3
No-Till	No Residue	Insecticide	1.3	1.3	6.3	3.8
No-Till	Residue	Insecticide	0.0	0.0	3.8	1.3
Conventioanl Till	No Residue	Insecticide	0.0	0.0	0.0	0.0
Conventioanl Till	Residue	Insecticide	0.0	0.0	1.3	1.3
ANOVA report			Sig.		Sig.	
Tillage Practice			0.271		0.207	
Residue application			0.424		0.252	
Tillage Practice*Residue application			0.271		0.600	
Insecticide			***0.004***		***0.000***	
Tillage Practice*Insecticide			0.259		***0.034***	
Residue application*Insecticide			0.445		0.284	
Tillage*Residue*Insecticide			0.259		0.891	

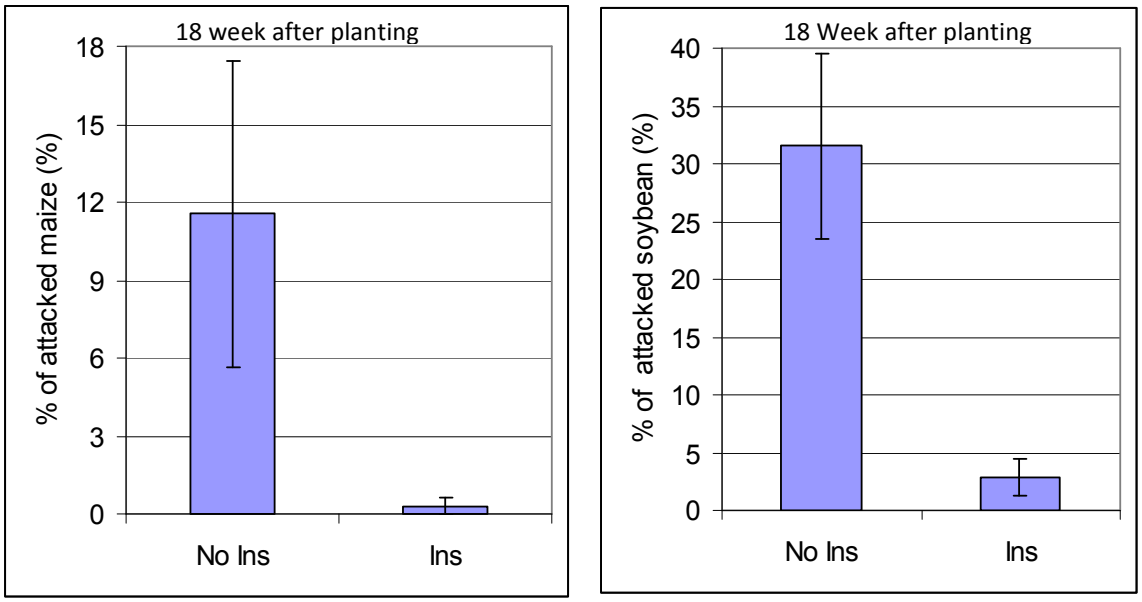


Figure 3.11 The effect of Insecticide application (INS) on the percentage of plants visually attacked by termites in week 18 after planting, shortly before harvesting. 'No Ins' means without insecticide application. 'Ins' means with insecticide application. Error bars indicate standard errors.

4. Discussion

4.1 Sampling methods for termite abundance in agricultural fields (refers to objective 3)

The recommended method for soil fauna sampling of the Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture (TSBF-CIAT) includes a single monolith, a set of pitfall traps and at least one transect of 20m. When the plot is small, the transect can be laid out in a angle of 90^0 (Huising et al. 2008). I followed the TSBF-CIAT method for monolith and transect sampling (Huising et al, 2008, Ayuke 2010), but replaced the baited pitfall method with an additional soil core sampling, since the introduction of baited-pitfalls may interfere with the effect of residue treatments on termite abundance and taxonomic richness.
Initially we thought that one monolith sampling per experimental unit could not give representative results, because it does not properly account for the high spatial variability of termites within the plots. More than two monolith samplings per plot was not acceptable if I would sample two monoliths per plot in three different weeks, about 10% of the experimental plot would be disturbed. Combining soil monolith data and soil core samples to quantify termite abundance in soil was preferred because of the advantage of having a larger surface area sampled per sampling unit, but less disturbance than two monolith samplings. Moreover, individual core samples were distributed randomly across the plot, thereby better accounting for the high spatial variability of the termite populations. Combining the two methods also reduced the percentage of sampling units without termites, thereby increase statistical power. In addition, the way to treat outliers of data which must include termite nests was also important because some of monolith samples included a termite nest of which I confirmed the existence visually in the field.

However, termite sampling in small scale experimental plots, especially in case of reduced tillage, has still several problems. This is because the disturbance of surface soil is really serious, comparable to ploughing of the soil. Damage to the crop is also unavoidable, due to the required working space for sampling of the monoliths. Thus the size of experimental plots should be big enough to allow repeated sampling of termites, which was hardly the case. When the TSBF method for monolith sampling is followed, the smaller size of hand hoe should be used (less than 10cm width) to dig a small pit. Alternative methods to assess termite abundance, diversity and their impact on crop residues that are less destructive should be developed. These could include small sized unbaited pitfalls to monitor the number of termites in a plot (Huising et al 2008), or the use of litter bags to quantify the effect on residue decomposition rates (Ouédraogo et al., 2004).

The timing of sampling should be after rainfall because termites become really active and soil feeders and wood feeders come to the surface soil. However, based on my result, no clear effect of sampling time (week) on termite numbers was found. I suppose that termite sampling in 6-7 week after planting and 1 week before harvesting is enough because my results show high termite abundance and more significant effects of residue management at 6-7 week after planting. Sampling in 1 week before harvesting is also important to measure the termite taxonomic richness at times when residues have largely disappeared and the potential attack of the crop by termites is high. Farmers mentioned that termites attack maize just before harvesting, which is around week 18. With unbaited pitfall sampling, every 3 or 4 weeks, we may assess the termite taxonomic richness throughout the season without disturbance of the soil.

4.2 The effect of different tillage and residue management on termites and soil chemical and physical properties (relates to objective 1)

Termite abundance and taxonomic richness

Significant effects of tillage treatments on termite abundance were only confirmed in few cases (combinations of specific sampling times and soil depths). Whether this indicates that the relation between termite abundance and tillage is not very strong or that the high spatial variability and mobility of termites decreases statistical power given the small area sampled remains to be investigated (Eggleton and Bignell, 1995, Hurisso 2007, Hoogmoed 2009). The positive effect of residue application on termite numbers in transect samples and the upper soil layer was significant at 6 weeks after planting. No such effect was found at the end of the season, which can be explained by the negative feedback between termites and residue cover. At the end of the season they had "terminated" their own resources. The actual residue cover in the NT+R–Ins treatment was 17.4, 1.7 and 1.3%, in week 1, 9 and 12 after planting, respectively. Although these residue cover data have to be interpreted with caution in terms of their absolute values due to methodological problems, it does indicate that their availability as a food source declines rapidly, as was also found by Ouédraogo et al., (2004). Local farmers in Nyabeda also reported that termites tend to invade the fields after rain showers and quickly decompose crop residues (Wycliffe Omondi, current experimental field manager; personal communication).

Effects of tillage and residue management on termite taxonomic richness could not be assessed, because of three reasons: i) termite identification was restricted to the genus level, no species were identified. ii) no differences in termite taxonomic richness were found between the management treatments, and iii) samples from replicate plots were combined into one sample. Previous studies, however, have shown that tillage reduces termite taxonomic richness and abundance (Wood and Johnson. 1978, Hold et al. 1993, Reddy et al. 1994a). Ayuke (2010) also found 1 taxon in CT+R and 2 taxa in NT-R in Nyabeda field.

The maximum number of sampled termite genera was 3 in my study. Ayuke (2010) reported 5 species from 4 genera in the same field experiment in Nyabeda with similar tillage and residue treatments under maize cultivation and a nearby fallow shrubland. Ayuke (2010) sampled termites 6-8 weeks after planting of maize in the long rainy season of 2007. I sampled termites three times in week 1, 6 and 12 after planting in the fields planted to soybean in the short rainy season of 2010. The fallow shrubland Ayuke (2010) sampled had not been disturbed for at least 10 years. Ayuke (2010) found *Cubitermes* in the fallow shrubland. This was the reason why the data of Ayuke (2010) shows more genera than mine. Additionally, Sekamatte et al. (2003) mentioned that termites may be attracted more by maize than by soybean and that termite taxonomic richness in maize fields may be higher than in soybean fields.

Both *Pseudacanthotermes* and *Microtermes* are classified as Feeding group II-higher termites (wood litter and grass feeders) by Donovan et al. (2001) and Eggleton et al. (2002). Ayuke (2010) classified these termites as wood, leaf litter and soil feeders. The identification of termites to the species level was difficult. This is because of the most termites I sampled were workers, but the soldiers are needed for identification. Soldiers remain in their nest and protect it. According to Kooyman et al. (1987), the actual nest and habit of both *Pseudacanthotermes* and *Microtermes* is subterranean but *Pseudacanthotermes* construct their conical mound outside the cultivated area because on farms, the conical mounds are

regularly destroyed. *Microtermes* is strictly subterranean. A nest consists of a large number of chambers and those are in between 10 cm and 2 m below the surface, but more than 80% occur between 10 and 50 cm depth (Kooyman et al., 1987). Termite samples which were taken in the agricultural fields rarely included the nest of termites in my study because the nest can exist deeper than 30cm depth or outside the plots.

I observed flying termites coming to our research field more than 3 weeks after planting. *Microtermes* were observed more in week 12 after planting. Some of *Microtermes* were workers which came from other fields in flight.
I observed more than 10 termite nests constructed by *Macrotermtes* and *Pseudacanthotermes* around the experimental field, but never observed *Macrotermes* inside the fields. Local farmers mentioned that *Macrotermes* (bigger size of termite compared to *Pseudacanthotermes* and *Microtermes*) come to the field when crops dry up before harvest and that this group attacks the crop (Wycliffe Omondi, current experimental field manager; personal communication).

In conclusion, the first part of hypothesis 1, which stated that no-tillage with residue application (NT+R) was expected to have the highest termite abundance and taxonomic richness and that termite abundance and taxonomic richness would reduce with time after planting, was partly confirmed. A significant effect of residue management on termite abundance (Objective 1) was indeed found in week 6 for the upper soil depth (0-15cm and transect samples), and this effect reduced with time due to the disappearance of crop residues. On the other hand, no significant effect of tillage on termite abundance was found in all but one case (week 12, 15-30 cm depth). Both tillage and residue management did not show any effects on termite taxonomic richness, at least not at the genus level.

Soil chemical and physical properties

Tillage did not have any significant effects on soil C and N contents. However, residue retention positively affected soil C and N at 0-5 cm depth in both tillage systems, and at 5-15 cm only in case of NT. Tunsisa (2007) did not find the effect of residue at 0-15cm depth but only 15-30cm depth in NT plot in the same experimental plot. Hoogmoed (2009) found the positive effect of residue at both 0-15 and 15-30cm depth on both soil C and N in the same experimental plot. Thus, the residue application increased soil C and N at specific depth but did not result in a consistent trend. The interactive effect between tillage and residue on soil carbon and nitrogen was found only at 5-15cm depth. Residue application increased soil carbon and nitrogen in NT plost but decreased or did not changed them in CT plots. Tunsisa (2007) found an interactive effect between tillage and residue application at all depths on soil C but not soil N. Hoogmoed (2009) did not find this effect at any depth. Thus, this interactive effect may not be consistently present.

Heavy clay soil is easily compacted and farming activities also promote it. The soil under no-tillage was more compacted than conventional by tilled soil as indicated by the differences in soil penetrometer resistance graphically but not statistically. This seems to contrast with previous data on soil physical properties in this field experiment showing that the percentage of stable macroaggregates at 0-15cm was higher in no-till treatments than in conventional tillage (Hurisso, 2006; Hoogmoed, 2009). Differences in soil penetrometer resistance were not reflected in differences in soil bulk density as measured in the present study. The reasons why both soil penetrometer resistance and bulk density did not show statistically significant

effect of tillage and residue may be threefold: i) no effect of management on soil compaction in my study time, ii) the accuracy of data is low due to the measurement error, iii) highly spatially variable conditions decrease statistical power. Any confounding effect of soil moisture on the soil compaction measurements can be excluded because the soil penetrometer resistance measurements were done at two days after rainful.

Effects of tillage and residue application on soil water retention was shown only in a few cases, but no consistent pattern was observed across sampling dates. Although not significantly in most cases, soil moisture tended to be lowest in no-till without residue retention at all depths, which may be explained by lower water infiltration (increased water loss through runoff) due to increased soil compaction and/or higher evaporation of soil moisture due to the absence of a residue layer. In the field, I observed the residue which was run off in a plot to a different plot. This may prove that the residue became a resistance to protect soil against run-off water. I measured soil moisture at field capacity in this study. Therefore, the negative effects of no-till without residue retention on soil moisture could have shown even more clearly when I would have measured also during dryer periods (Appendix 4). In conclusion, the second part of hypothesis 1, which stated that no tillage with residue application (NT+R) would lead to higher soil moisture contents was partly confirmed. However, the same was true for CT, irrespective of residue management. However, such differences in soil moisture did not result in any significant reduction in termite abundance or taxonomic richness in the NT-R treatment as compared to other treatments.

4.3 The effect of macrofauna exclusion on the termite activity and soil chemical and physical properties and termite damage (relates to objective 2)

Insecticide effects on termite abundance and taxonomic richness and residue cover

The effect of the insecticide application on termite abundance and taxonomic richness was clear for all depths and sampling times. Insecticide application reduced termite abundance by 97 and 77% (averaged across time) at 0-15 and 15-30 cm depth, respectively. This indicates that the insecticides effectively controlled termite abundance and provides a good methodology for evaluating the effects of termite abundance on soil and crop performance. Although termite taxonomic richness could not be analyzed statistically, the taxonomic richness was higher in –Ins plot than +Ins plot at 0-15cm depth in all weeks after planting (Table 3.2.3). This also proved the effectiveness of insecticide macrofauna exclusion.

Hypothesis 2a, which stated that Macrofauna exclusion (application of insecticides) would reduce the abundance and taxonomic richness of termites especially at low soil depth was confirmed. A significant effect of macrofauna exclusion on termite abundance and taxonomic richness was clearly found in both depths with higher effect in the upper soil depth than in the lower soil depth. The effectiveness decreased with soil depth because the active ingredient of the pesticide will be diluted or absorbed by the soil while the liquid infiltrates into the soil (Rache 1993, Baskaran et al. 2003). Therefore, termites which forage on the soil surface were affected more strongly than the ones that are subterranean.
Insecticide treatment also clearly affected crop residue cover from 9 weeks after planting. Residue cover declined rapidly, both with and without insecticide application but more rapidly when no insecticides were applied. Although absolute values have to be interpreted with care due to methodological problems, it can be concluded that on a relative basis, residue cover at 9-12 weeks after planting was approximately 2.5 times higher in NT+R with as

compared to insecticide application. The initial residue cover in NT+R, at the time of planting, was approximately 25% and this percentage decreased rapidly during the growing season was a cause of decrease of the residue cover. The strong wind and surface water run off after heavy rain according to the field manager of the Nyabeda experimental field. Additionally, termite activity may also decrease the residue cover on the surface soil due to incorporation of residue. According to the definition of Conservation Tillage a permanent organic soil cover should be maintained that covers at least 30% of the soil (Giller et al. 2009). The amount of residue application in the Nyabeda experiment (2t $ha^{-1}$of maize stover) is not enough to meet this criteria even at the start of the growing season, and termite activities and displacement of residues by water and wind are a further factor that limit the residue cover. These results indicate that residue retention in NT+R may have to be increased substantially to make this practice more successful in terms of soil quality and crop performance.

Insecticide effects on soil chemical and physical properties

A positive effect of insecticide application on soil C and N content was found at 0-5 cm depth, especially in NT. The reason why soil carbon and nitrogen increase after insecticide application may be : i) remaining of residue on the surface, ii) high biomass return due to high yield in +Ins treatment, iii) increase of microbial biomass C and N due to energy and nutrient source (Sivasithamparam. 1969, 1970, Tu. 1970, 1972, Sylvestre and Fournire. 1979, Pandey and Singh. 2004, Handa et al. 1999, Dutta et al. 2010.
Microbial activities in this experimental field have not been measured so I explain only first and second reason. i) the incorporated residue may be decomposed quicker than the residue on the surface (Abiven and Recous, 2007). The residue at the surface will gradually be decomposed and enrich soil C and N in the shallow depth (ex. 0-5cm). Abiven and Recous (2007) mentioned that incorporated residues decomposed faster at the beginning of decomposition, but generally no significant differences were observed although no or small difference were observed in the C mineralisation kinetics between incorporated and surface-applied residue. Four years experiment in this field did show the effect of incorporation of residue on decomposition rate by termite at 0-5cm depth (Abiven and Recous, 2007). Tunsisa (2007) and Hoogmoed (2009) did not find an effect of insecticide on soil C and N at both 0-15 and 15-30 cm depth. ii) Higher yield was observed in +Ins plot than - Ins plot (Pulleman et al, 2010). This means higher root biomass and higher organic matter returns to the topsoil in + Ins plot.

No activity of termite controlled by insecticides application decreased soil penetrometer resistance at some depths and sampling times significantly but the effect was not constant and did not show any trend in time. This relation between insecticide application and soil penetrometer resistance needs further study in terms of timing of sampling, the effect of insecticide application on soil moisture content.

An effect of termite activity controlled by insecticide on soil moisture was not found at 0-5 and 5-15 cm depth and the effect was found in only week 7 after planting at 15-30cm depth. This may be because the effect of termites on soil infiltration is small in Ferralsol with Nitic properties in Humid Tropic agro-ecological zone. In crusted soil in arid area, termite tunnels galleries increase water infiltration rate (Mando, 1997). The soil moisture in – Ins plot become higher than in + Ins plot. However, this effect was not significant in my study due to small size of galleries or the high infiltration rate of initial soil.

Thus, hypothesis 2b, which stated that "insecticide application would increase organic residue retention on the soil surface due to reduced termite activity, especially in the NT+R treatment was confirmed. In line with the hypothesis we found that the maintenance of a soil residue cover in the absence of termites resulted in a higher retention of soil organic matter, thus having positive effects on soil C and N contents was found, at least for the No-till soil. However, no significant effects of soil macrofauna exclusion on soil moisture content, which may be partly explained by the fact that soil moisture was only measured shortly after a rainy period.

Insecticide effects on crop damage by termite

The insecticides were effective in reducing termite attack of both maize and soybean. However, until 13 weeks after planting the termite damage was almost zero although a few lodging plants caused by other were sometimes observed in both +/- Ins plot. This means that termite damage only becomes serious shortly before harvest which takes place around 17-18 weeks after planting. In addition, attributing the crop loss to the activities of termites is not straight-forward because the experimental field was often attacked by strong wind and showers. For example, plants were lodged by wind and heavy rain first, after which termites may start to decompose the lodged plant. When I assessed the crop damage due to termite attack, I observed the plants that were covered by a crust made by termite and termite were decomposing the organic matter inside in week 13 after planting, but it was not clear if the termites caused the lodging in the first place. I don't have the data of lodged plant caused by strong wind and shower in week after planting. I have less confidence about the assessment of causes of lodging in week 18 after planting because of this lack of data. If other insect attacks and lodge plant first then termite made crust to decompose the lodged plant, I cannot distinguish the type of pest through field observation.

In conclusion, hypothesis 2c, which stated that the chances of crop damage due to pest termites will be higher in the –ins plot which could further explain increases in crop yield, could not be confirmed with certainty. The number of lodged plant was much higher in the plots without insecticides. However the assessment of cause of lodging is complicated because of several possible causes not only termite attack. Further research about monitoring of crop damage is needed to clarify the causes. Using other kind of fungicide or pesticide may avoid the first attack from other insects to cut root. Enclosing the experimental field may avoid the plant lodging by mammals. Weeding by hand hoe in early stage of crop development should be careful to avoid damage to the crop. The effect of heavy rain and strong wind can be assessed if the number of lodged plant in +/- Ins plot is the same or not.

Conclusion

In this study I studied (i) the effect of tillage and residue management on termite abundance and taxonomic richness and soil chemical and physical properties, and ii) the specific role of termites in affecting soil properties and crop damage through a soil macrofauna exclusion experiment. In addition, (ii) I explored the suitability of sampling methods for quantification of termite abundance and diversity in agricultural field experiments.

i) No consistent effect of tillage on termite abundance and taxonomic richness was found. An effect of residue on termite abundance was found at 6 week after planting but not later, probably due to the fact that most residue had disappeared by then. Soil carbon and nitrogen contents at 0-5 cm soil depth were positively affected by residue application but not by tillage. The effect of tillage and residue management on soil moisture was not confirmed but soil moisture in NT-R treatment was the lowest at all depths when sampling time was averaged. Soil moisture was measured after 1-2 days rainfall. The timing of soil moisture measurement should be representative in future study.

ii) The macrofauna exclusion using specific insecticides was succesfull at all depths and sampling times, in that termite abundance was controlled effectively although side-effect of microbes needs to be considered. A positive effect of macrofauna exclusion on residue cover was found from 9 week after planting. Soil carbon and nitrogen contents had also increased in the treatments that had received insecticides since 2005, accompanied by a reduction in soil penetrometer resistance. No effects of macrofauna exclusion on soil moisture were found. Macrofauna exclusion significantly deceased termite attack of the crops in week 18 after planting. However, field observations in 18 weeks after planting did not assess the possibility of combined cause, ex. Strong wind + termite attack, so more detail field observation, monitoring is needed to clarify this negative effect of termite on crop. As recommendations, using other kind of fungicide and pesticide to avoid the damage from other insects which cut root of plant, enclosing the field to avoid mammal damage to crop and measuring crop damage before and after heavy rain and/or strong wind.

iii) The experimental plots in this study were too small to use the recommended termite sampling method of TSBF-CIAT. I therefore integrated soil monolith, soil core and transect sampling and corrected the results in case of the presence of a termite nest in the monolith. However, this method still disturbed 8.1% of area in three times sampling with high variability of data. Further study on the effects of termites on soil and crop performance in small agricultural plots needs to account for the high spatial variability of termite populations, while minimizing the disturbance of experimental plots. I suggest the use of unbaited pitfalls and litter bags.

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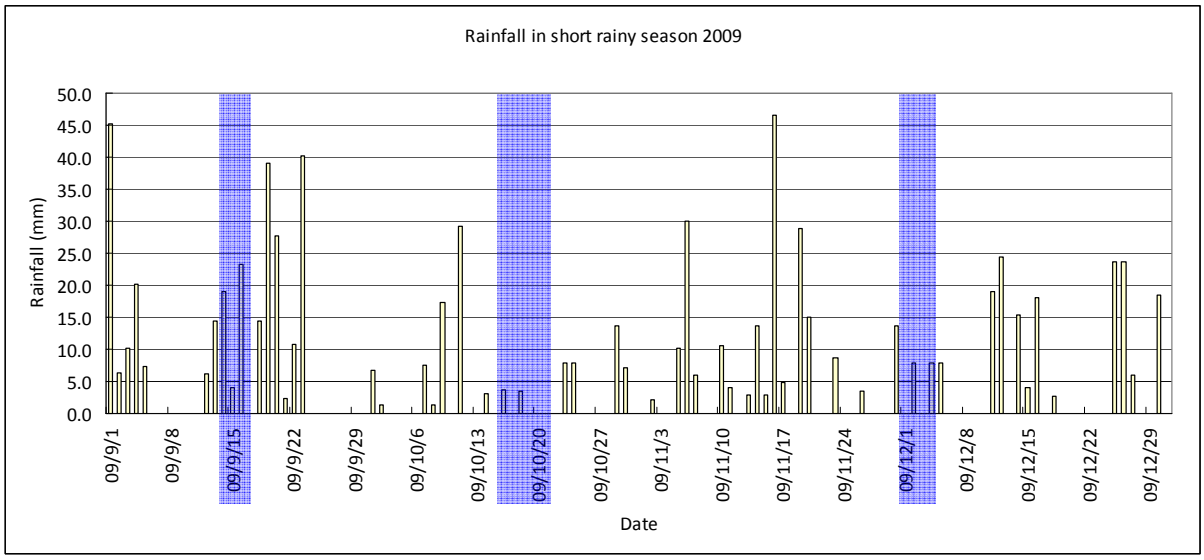
Appendix

Appendix 1 Experimental design in Nyabeda in the end of August, 2009.

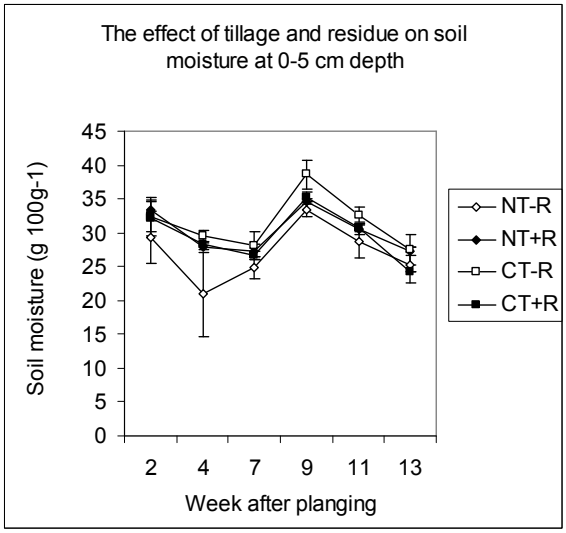
Appendix 2 Shade of leaves decrease the accuracy of residue cover analysis with picture.

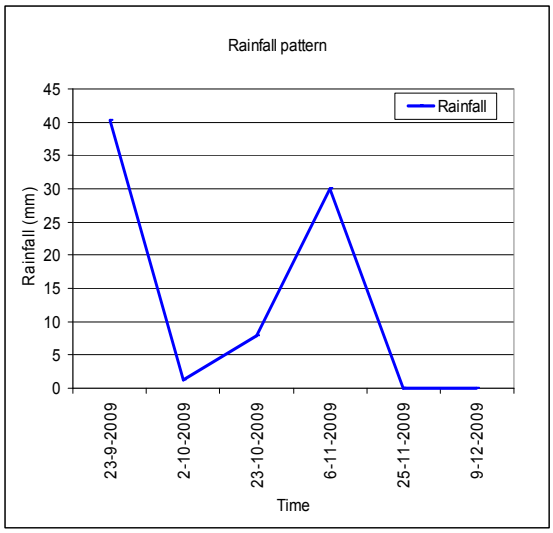
Appendix 3 the modified method for residue cover measurement. Picture taken in shade shown high accuracy of image analysis software (ImageJ).

Appendix 4 The annual rainfall in 2009 with red arrow which shown termite sampling time.



Appendix 5 Comparison of the pattern between soil moisture at 0-5cm depth and rainfall at the same day.





planning

Date	17/8	24/8	31/8	7/9	14/9	21/9	28/9	5/10	12/10	19/10	26/10	2/11	9/11	16/11	23/11	30/11	7/12	14/12	21/12	4/1	11/1	18/1	25/1
Weeks	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24-25	26	27	28	29
Weeks after sowing				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15					
Discussion with supervisor																							
Writing research proposal																							
Presentation with examinars																							
Preparation for experiment																							
Sowing & Applying residue and insecticide			3/9	10/9	17/9	24/9	1/10	8/10	15/10	22/10	29/10	5/11	12/11	19/11	26/11	3/12	10/12	17/12					
pre training of termite sampling																							
termite sampling				14-17/9					15,16,19,21/10														
gravitmetric soil moisture and soil temperature					23/9		2/10			23/10		6/11											
Residue cover & Crop cover				16/9		29/9		14/10			31/10												
Soil compaction					18/9	28/9		12/10		26/10													
Direct infiltration						25/9		12/10		26/10													
soil sampling and air-drying									15,16,19,21/10														
Soil pH, Olsen-P, Exchangeable cation, CEC											I already asked measurement on 1/11/09												
TC, TN in the soil of 0-5, 5-15, 15-30 cm depth											grinding may start from 9/11so measurement will finish at 1st week of Dec.												
seed germination rate						27/9																	
Pest damage obseration						30/9	6/10			27,28,29,30/10													
crop development observation						30/9	7/10			27,28,29,30/10													
Harvest & yield measurment																							
Data analysis																							
Writing final thesis																							
Preparation for presentation																							
Final presentation																							

sowing and harvest week depends on weather conditions

Soil pH, Olsen-P, Exchangeable cation, micronutrient, CEC are measured by outside laboratory: Crop Nutrition Laboratory Services, Nairobi, Kenya
TC, TN are measured by TSBF Nairobi, Kenya

The cell with date means that the factors were already measured on that day.
The cell without date means planning.
Chemical analysis were already asked through Wilson (TSBF lab. expert) to outside laboratory, Nairobi.
TC, TN analysis were still discussed because of shortage of available lab. experts. Today (9/11), I'll mail to Wilson and confirm the availability of lab. experts in Nairobi. If they are too busy to do that, I may order casual staff to grind soil (it will take 3 days) or I'll go to Nairobi and do it.

Budget

	estimation
travelling expenses	
Bus ticket of Nairobi - Maseno (12 euro/one way) 2 times use	24
Transportation cost at Nairobi (my accomodation to Nairobi bus station)	20
Total cost of service at Maseno	390
Transportation cost at Maseno (station to field)	
subtotal	434
Experimental analysis	
TC and TN (7.7 euro/sample), 96 samples	739.2
soil pH, Olsen-P, exchanable cation, S, Fe, Mn, Cu, B, Zn, CEC (25 euro/sample), 32 sample	800
termite identification	80
oven use (100ksh/sample, 48samples)	
Trowel (3 Euro/trowel)	12
Sample bag	11
Plastic or metal trays (1 Euro/tray)	8
Camel hair brushes (less than 1 euro/brush)	2
marker	5
ribbon or tag	5
fine forceps	4
wash bottle	3
field staffs (1.70 euro/person/day) (**10 persons, 12 days + practice 1 day**)	221
TSBF staffs and foreman (3 euro/person/day) (**3 person, 12 days + practice 1 day**)	117
4 m2 plastic sheet	3
watering can	6.5
wire	1
scale	0.2
manira tape 0.4 euro/tape	5
battery for GPS	4.5
bowls	13
sample transportation from maseno to nairobi	50
subtotal	2090.4
total subtotals	2524.4
unexpected costs (5% of total budget)	126.22
total costs	**2650.62**
2600 - total costs	-50.62