Abstract

The challenge of maintaining a permanent soil cover using crop residues under conservation agriculture (CA) among smallholder farmers in Zimbabwe is mainly attributed to competing uses such as livestock grazing the residues. There is also a belief that the residues attract termites which damage crops leading to yield loss. This study therefore investigated the effectiveness of using repellents as a residue management option, for protecting crop residues from grazing livestock during the dry season as well as the effects of retained residues on termite prevalence in CA systems. To address these objectives, two broad experiments were conducted. The first experiment identified, screened and tested the effectiveness of repellents in protecting the grazing of crop residues by livestock during the dry season through on-station and on-farm trials. The identified repellents were screened at Domboshawa and further tested in Madziwa and Hereford smallholder communal areas. In the second experiment, effects of different crop residue application rates (0 to 6 t/ha under CA) on termite abundance, crop lodging (damage) due to termite attack and soil properties compared to a control of conventional mouldboard ploughing system (CMP), were tested on two sites namely Kadoma and Chikombedzi in 2008/9 and 2009/10 seasons. Maize residues were applied in Kadoma whilst sorghum residues were applied in Chikombedzi as a surface mulch.

On-station trials at Domboshawa in 2009 showed that cowdung, goat droppings, tobacco and chilli were possible livestock repellents since >50% of initially treated residues were not consumed after up to 3 weeks of cattle grazing. The optimum concentrations of cow dung (3 t/ha), goat droppings (0.5 t/ha), chilli (0.4 t/ha), tobacco scrap (1.2 t/ha) and soaked tobacco (0.3 t/ha), were established at Domboshawa. When these repellents were later tested on-farm in Hereford and Madziwa communally grazed fields in 2010, it became apparent that at Hereford, where there was alternative livestock feed, after 5 weeks, cowdung, soaked tobacco and tobacco scrap treatments, retained significantly higher residue amounts of 66.4%, 64.5% and 60.7%, respectively compared to the untreated control with 49.7%. On the contrary, at Madziwa, where there was no alternative feed, all residues were consumed within three days, irrespective of treatment. In the second experiment, the study showed that mulching fields with maize residues at application rates at 4 and 6 t/ha and sorghum residues at 6 t/ha under CA, increases termite numbers compared to CMP and CA with no mulching. On both sites, results showed no significant difference (p>0.05) in crop lodging as residue application rates increased within CA systems. However, significant differences in lodging between CA (42-48%) and CMP (30-34%) were observed in Kadoma from both seasons. In Chikombedzi, only 8.4% of crop lodging was observed under CMP compared to between 13 and 25% under CA in the second season. With respect to soil properties, no significant relationship was observed between increasing crop residue amounts and soil organic carbon (SOC) and aggregate stability (measured as mean weight diameter (MWD) and Middleton's dispersion ratio (MDR) in Kadoma over the two seasons (p>0.05). However, in Chikombedzi, results showed that an increase in sorghum residue amount, resulted in a significant linear increase (p<0.05) in SOC ranging from 9.8 to 11.0 mg-C g⁻¹ within two seasons of implementation. With respect to crop yields, results from Kadoma (2008/9), revealed significantly higher yields under CA ranging from 2 900 - 3 348 kg/ha compared to CMP with 2 117 kg/ha. However, there was no pattern observed on yield as residues increased under CA. In Chikombedzi, during the first season, residue effects were inconsistent across farmers though CA increased crop yield compared to CMP depending on other factors such as weeding and annual rainfall. The study thus demonstrated that crop residues can be protected from grazing livestock using repellents in Hereford with high biomass production that offers alternative feed for livestock but, ineffective in Madziwa with acute shortage of alternative winter feed. The study also demonstrated that increasing crop residue application rates under CA increases termite prevalence in Kadoma and Chikombedzi. However, there was no observed effect of increasing residue application rate on crop lodging but, a shift from CMP to CA increases lodging due to termites, leading to severe crop damage on maize crops, although much lower damage is observed on sorghum crops.

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Dedication

I dedicate this work to my mom and family.

Abbreviations

С	Carbon
CA	Conservation Agriculture
СМР	Conventional Mouldboard Ploughing
CRBD	Complete Randomise Block Design
DTC	Domboshawa Training Centre
LSD	Least Significant Difference
MDR	Middleton Dispersion Ratio
MWD	Mean Weight Diameter
Ν	Nitrogen
RMS	Residual Mean Square
SOC	Soil Organic Carbon
SOM	Soil Organic Matter

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Chapter 1: General Introduction

1.1 Background

Increasing food insecurity and poverty in Africa relates directly to the decline in soil productivity (Sanchez *et al.*, 1997) and the negative impacts of climate change (Jones and Thornton, 2003). Zimbabwe's communal areas suffer from severe land degradation caused mainly by poor vegetation cover, poor and erodible soils (Nyamangara *et al.*, 2000), as well as unsustainable management practices (Nyamadzawo *et al.*, 2007). With little or no replenishment of soil organic matter (SOM) and plant nutrients, soil quality continues to decline (Mtambanengwe *et al.*, 2006). Amongst other indicators, a decline in soil quality is evidenced by soil compaction and erosion (Elwell and Stocking 1988). Increasing soil productivity for enhanced agricultural production thus, offers a potential tool for reducing poverty in Zimbabwe.

Various soil and water management practices that sustain and enhance soil productivity have been attempted in the last few decades through practising organic farming, integrated soil fertility management and conservation agriculture (CA) among others. Conservation agriculture is the application of minimal soil disturbance, permanent soil cover and crop rotations (FAO, 2009) and other good agronomic management so as to improve production, while concurrently protecting and enhancing the land resources (soil, water and biological resources) on which production depends (Dumanski *et al.*, 2006). It has the potential to address some of the issues leading to a decline in agricultural productivity by increasing soil fertility through use of organic materials as soil cover and precise application of fertilisers. Inclusion of legumes and agro-forestry species in rotations also increases soil fertility (Mafongoya *et al.*, 2003). Soil degradation is also minimised through reduced soil disturbance which promotes soil biological activities (Nhamo, 2007) and improves soil physical structure (Elwell, 1989; Nyamadzawo *et al.*, 2007). Minimal soil disturbance also means SOM lasts longer in the soil, slowly releasing plant nutrients. In addition to minimal soil disturbance, crop residues also increase soil biological activity by providing energy source and a habitat for soil fauna and flora (Kladivko, 2001; Reicosky, 2008). Some of the soil organisms such since termites are beneficial as they produce soil pores while other species attack crop pests (predators). In contrary, soil inversion enhances the decomposition of SOM (Chivenge *et al.*, 2007), leading to soil compaction, reduced water infiltration (Nyagumbo, 2002; Eggleton *et al.*, 2002), reduced aeration and exposure of soil fauna to solar radiation.

In conventional agricultural systems, residues are usually fed to animals, taken off the field for other uses, incorporated into the soil during ploughing or burned (Lal, 2002). However, various studies have shown that the retention of at least 30% ground cover has benefits of cushioning raindrop impact on the soil surface resulting in reduced crusting and surface sealing (Chuma and Hagmann, 1995). Soil cover also increases rain water infiltration hence reduces water loss through runoff and evaporation (Nyagumbo, 2002). Infiltration under CA is increased due to the presence of soil pores caused by biological activity as the pores are rarely disturbed under minimal tillage. Crop water availability is thus increased (Thierfelder and Wall, 2009; Verhulst *et al.*, 2011). Crop residues are also known to reduce both wind and water erosion directly by affecting the physical force involved either in erosion or indirectly by modifying the soil structure through the addition of SOM. Soil structure thus remains very good with enhanced drainage, porosity, adsorption capacity and structural stability (Lavier *et al.*, 1997). Soil cover also mitigates temperature variations on and in the soil (Vogel, 1994; Chuma and Hagmann, 1995; Nyamudeza and Nyakatawa, 1995). The residues shield the soil surface from solar radiation which heat up the soil during the day causing water evaporation (Vogel, 1992). Evaporation by wind is also minimised due to presence of soil cover (Papendick *et al.*, 1978). At night, the residues act as a blanket by keeping the soil warm. This leads to favourable soil microbial activity hence good soil health. Therefore, CA-based practices can result in more resilient agronomic systems than conventional tillage with or without residues (Verhulst *et al.*, 2011).

1.2 Statement of the problem

The retention of crop residues under CA in most communal areas is constrained by competition between using the residues as livestock feed and its use as soil cover during the long dry winter season (Mapfumo and Giller, 2001; Mazvimavi and Twomlow, 2008). Livestock grazing is communal in both grazing and arable areas during this period. Farmers who do not own livestock are disadvantaged by the communal grazing of livestock which subsequently generates manure for the livestock owners. Livestock owners then regularly replenish the soil fertility status of their arable fields through manure applications (Mtambanengwe, 2006) at the expense of non-livestock owners.

In spite of their benefits, the retention of crop residues is believed by many farmers to contribute to increased termite prevalence in semi-arid regions. This is more pronounced towards crop physiological maturity, resulting in yield losses through crop damage (Logan *et al.*, 1990). On the other hand, other schools of thought suggest that the presence of dry crop residues may actually reduce termite attack on growing crops as they prefer dry stover

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compared to fresh biomass (Nhamo, 2007). To date, no conclusive studies have been carried out to prove or disprove these two schools of thought.

1.3 Justification

Previous studies showed the lack of innovative ways of keeping livestock away from CA fields during winter other than the use of fencing (Mazvimavi and Twomlow, 2007) yet soil cover is an important principle of CA. New and innovative ways of managing crop residues in communal crop-livestock systems where residues are under pressure from livestock during the dry winter season need to be explored.

Since a few farmers can afford fencing and staking residues in preparation for next season, there is need to assess changes in termite populations and resultant crop damage particularly lodging under CA systems at different soil cover levels. This will also enable determination of residue rates resulting in termite attack reaching pest proportions. This study therefore sought to address these two bottlenecks to CA adoption by coming up with suitable and locally available repellents that can be used to keep livestock away from grazing crop residues and establishing the linkage between different residue amounts, termite prevalence and crop lodging. Through these interventions, the study sought to contribute to the purpose of increasing CA adoption and to the goal of increased food security in smallholder farming areas of Zimbabwe.

1.4 Hypotheses

Based on these problems, the study tested the following hypotheses:

- i. Locally available substances exist that can be used as repellents to grazing of crop residues by livestock in conservation agriculture systems during the dry winter season of Zimbabwe.
- ii. Termite prevalence in conservation agriculture systems is significantly influenced by increasing surface crop residue amounts.
- iii. Increasing surface applied crop residues in conservation agriculture systems reduces crop damage due to termite attack
- iv. Soil aggregate stability and organic carbon are positively correlated to crop residues in conservation agriculture systems.

1.5 Objectives

Overall Research Objective

To investigate the effectiveness of repellents as a residue management option in order to protect crop residues from grazing livestock during dry season and the effects of retained residues on termites' prevalence in smallholder CA farming systems.

Specific objectives

- To identify, screen and test locally available resources that can be used by farmers as repellents to grazing of crop residues by livestock during the non-cropping dry season of Zimbabwe.
- To establish the influence of surface applied crop residues on termite prevalence in CA systems

- To determine the contribution of crop residues applied as a surface mulch to crop damage by termites in CA systems.
- iv. To determine the effects of crop residues in CA systems on soil organic carbon, aggregate stability and subsequent crop yield in highly termite infested fields.

1.6 Roadmap of the thesis

The thesis is made up of 6 chapters. Chapter 1 gives the general introduction of the study, the problem statement, justification, hypotheses and specific objectives of the study. Chapter 2 reviews literature of related studies carried before and gives the gap and justification to carry out this study. It reviews information on benefits of residues on soil properties, crop-livestock interactions, repellents characteristics, benefits of termites to soil properties, factors affecting termite prevalence and the effects of termites on growing crops. Chapter 3 describes the general sites' characteristics, experimental design and treatments used and the statistical methods used to analyze the data. The results are presented and discussed in three separate chapters. Chapter 4 presents results on the effectiveness of repellents in crop management during dry winter season. Results on termite prevalence and crop lodging under CA in Zimbabwe are presented and discussed in chapter 5 while results on contribution of crop residues to soil organic carbon, soil aggregate stability and crop yield under CA are presented and discussed in chapter 6. Chapter 7 brings together issues from the three results chapters and gives recommendation to farmers and for further studies.

Chapter 2 Literature Review

This chapter reviews literature on benefits of crop residues on soil properties, crop-livestock interactions, repellents characteristics, benefits of termites to soil properties, factors affecting termite prevalence and the effects of termites on growing crops.

2.1 Crop residues management under Conservation Agriculture (CA)

CA embraces a range of sustainable soil management practices. Soil cover is one of the most critical factors in ensuring proper implementation of CA. Materials used to cover the soil can be grass, leaf litter or crop residues. Crop residues consist of dead plant parts, or stover that remain from the previous crop. In many environments, especially in semi-arid tropical locations, crop residues are used for making compost, as fuel, construction material or as animal feed, but rarely retained as mulch (Sandford, 1989, McIntire *et al*, 1992, Mrabet, 2008). When these crop residues are retained as mulch, they tend to have beneficial effects on soil physical and chemical properties.

2.1.1 Benefits of residues on soil physical and chemical properties

Beneficial effects of residues depend on distribution, quality and quantity of residues. If residues are standing, they might not adequately intercept vertically falling raindrops compared to flat residues. Quality of residues, which is defined on the basis of the carbon to nitrogen (C:N) ratio determine turnover rates and precursors for SOM build up (Giller *et al.*, 1998). Depending on the chemical composition particularly C:N of crop residues and organic matter, decomposition is rapid if it is dominated by sugars, starches and proteins; slow when dominated by cellulose, fats, waxes and resins or very slow when dominated by lignin

(Mafongoya and Nair, 1997, Benites, 2008). Maize, the staple food crop in Zimbabwe, is a readily available residue in most smallholder farming communities. Maize stover has a high C:N ratio of 75 (Wingeyer, 2007) implying that its nutrient release pattern is slow, and with proper management, the residues could play an important role in SOM formation (Mapfumo, 1995, Palm *et al.*, 2001).

When left in fields after harvest, crop residues play important roles in nutrient cycling, erosion control, water conservation and maintenance of favourable soil physical properties (Powell and Unger, 1998; Moyo, 2003). Crop residues may increase infiltration by reducing surface sealing and decreasing runoff velocity (Nyagumbo, 2002; Reicosky, 2008). In Hungary, research showed that under CA, the following were reduced: runoff by 62%, soil loss reduced by 96.3%, total organic carbon loss by 91.4%, nitrogen loss by 84.3%, phosphorus loss by 94% and potassium loss by 68.1% relative to measured values on the conventional ploughed plots (Kertesz et al., 2008). Rainfall simulation experiments indicated that soil protection from plant residues under conservation tillage reduced the number and volume of rills (Kertesz et al., 2008). With respect to soil moisture, data from the latter showed that about 40% of the rain season period experienced a complete profile recharge under mulch compared to 10% of the same season under conventional tillage. In Zimbabwe, mean annual runoff lost were 22% and 6% of seasonal rainfall from conventional mouldboard ploughing systems and conservation tillage techniques, respectively over a period of 5 seasons (Nyagumbo, 2002). In Kenya, mulching reduced water loss during single heavy storm from 21% under conventional to 12% under mulch and mulching only lost 1% of the seasonal rainfall as runoff compared to 8% under conventional tillage (Gitonga et al., 2008).

Soil moisture conditions in the upper 20 cm were found to be higher under conservation tillage as the soil cover reflects a large part of solar energy back into the atmosphere, thus reduces the temperature at the soil surface (Vogel, 1992). This results in a lower maximum soil temperature and a reduced diurnal fluctuation in mulched compared with unmulched fields (Benites, 2008). Model simulation showed that on average, direct evaporation loss from the soil surface was 44% of the seasonal rainfall under mulch compared to 65% under conventional tillage (Moyo, 1996).

After 3 years of direct seeding in residues in Cameroon, the SOC increased from 0.69% for conventional tillage to 0.87% with no tillage and the water-stable macro-aggregate increased from 150 to 300 g/kg under no tillage (Diallo *et al.*, 2008). Increases in residue level helped to sequester the greatest amount of C in the top 50 mm of soil, a lesser amount in the 50-100 mm depth and no significant amount in the 100-200 mm depth in no-till systems (Mrabet *et al.*, 2004). Known consequences of SOM loss include the reduction in soil nutrient supply and storage capacity, reduced soil aggregate stability, reduction in soil biological activity and increased susceptibility to erosion (Srivastava and Singh, 1989).

2.1.2 Crop Residues – Livestock Interactions

Despite the known benefits of crop residues to protect the soil, farmers feed the crop residues from harvested fields to their livestock in different ways. These include open grazing, harvest and removal of stalks with subsequent open access to stubble, transport and storage of residues for feed or sale (McIntire *et al.*, 1992). In Zimbabwe's smallholder farming areas, cattle generally graze freely during the non-cropping season. Hence, farmers may require considerable time in collecting and transporting the residue from fields to protected areas, and

back to the fields towards the onset of the rainy season if mulching is to be practiced. Thus, one of the problems faced by CA farmers is to ensure enough residues remain in the field to meet the threshold level of mulching at the start of the rain season (Mazvimavi and Twomlow, 2008). There is thus need to determine new ways of protecting crop residues whilst in fields from livestock grazing during the non-cropping season.

Generally, fencing was identified in preliminary work preceding this study as the most common option of residue protection practiced by farmers (Nyagumbo *et al.*, 2009). However, smallholder communal farmers poorly adopted it as it was expensive and most farmers could not afford it (Wall, 2009). Live fencing was another option but generally takes long to establish and they occupies much of arable land. Conservation farming plots that are not adequately protected or fenced are thus susceptible to grazing livestock which eat most of the stover intended for mulch (Mazvimavi and Twomlow, 2008).

When animals graze crop residues, more nutrients are removed than returned via cow dung (Powell and Williams, 1993) since manure and urine voidings are distributed unevenly in fields during grazing. In contrary, fields regularly receiving manure applications from cattle kraals benefit from increase in soil pH, infiltration rate, water holding capacity and decreased bulk densities (Murwira, 1993). Vulnerable groups of farmers without livestock thus find themselves struggling to maintain or improve their soil fertility status. Innovative ways of managing crop residues during non-cropping seasons in the field, for example by use of livestock repellents, will thus ensure that farmers embarking on CA without losing the residues from cattle grazing.

2.1.3 Repellents characteristics

Any locally available and cheap materials or substances that can be used to repel or reduce the palatability of crop residues to livestock, form a potentially feasible approach to address the problem of insufficient residues as mulch. Repellents fall into two categories: those that repel by taste and those that repel by a disagreeable odour (VAPM, 2002). The repellents with a disagreeable odour tend to be more effective in controlling damage than the ones that repel by taste (Hill, 2002). For more fragrant plants, repellents made with essential oils such as peppermint are effective. Repellents can be brushed or sprayed. Contact repellents applied directly to plants, tend to repel by taste.

A naturally occurring chemical in chilli peppers (*Capsicum oleoresin*) called capsaicin $(C_{18}H_{27}NO_3)$ causes a heat sensation when it reaches nerve receptors. This heat deters mammals from grazing on chilli peppers or on crops that have been sprayed with chilli pepper extract (Osborn, 2002; Map 2002). Osborn (2002) also recorded that elephants were repelled from fields significantly faster by the chilli spray than by traditional methods such as beating drums or pans, shining torches and throwing rocks' as many people are killed by elephants in the process. Several specific chemicals in cowdung are also believed to be involved in inhibiting cattle from ingesting grass near cowdung (Dohi *et al.*, 1999). There is therefore, a need to test whether such substances as chilli, cow dung and goat droppings can also exhibit the same repelling characteristics to cattle when they are sprayed on crop residues during dry periods.

Factors affecting efficacy of repellents include rainfall, atmospheric temperature and appetite of the livestock. What an animal eats depends largely on its nutritional needs, past experience and available food resources (Osko, 1993). Most repellents last for three to five weeks when applied at temperatures between 4-26°C on dry weather followed by 48 hours without rain (Hill, 2002). Unfortunately, little is known about such methods of using repellents to deter cattle from consuming residues in fields. There is therefore a need to further explore the use of these repellents as an innovative option for residue retention under CA.

2.2 Termites prevalence under CA

Application of the three CA principles namely permanent soil cover, minimum soil disturbance and crop rotation influence soil fauna through improving the soil microclimate, fauna energy source availability (in form of SOM and diverse crops in rotations) and reduced disturbance of fauna habitats. An increase in soil biological activity due to addition of soil organic matter (through crop residues) can thus have further beneficial effects on soil properties, crop growth and subsequently yield.

2.2.1 Benefits of termites to soil physical and chemical properties

Macrofauna communities dominated by termites are the main agents of primary breakdown of surface mulches under CA (Nhamo, 2007). Termite activity after the application of mulch resulted in a change from a compact grain structure (original structure) to a chamber and channel structure, where these channels and chambers accounted for over 60% of the macroporosity in the 0–10 cm layer (Mando and Miedema, 1997). Termites perforate sealed surfaces resulting in many visible open voids and fine soil material transported to the soil

surface. Bare plots mostly have very few macro-pores, packing voids with equivalent circle diameter (ECD) <2 mm and one-third the number of voids have ECD >100 μ m compared with the plots with termite activity in the 0–10 cm layer (Mando and Miedema, 1997).

Although infiltration increases with termite activity, at least 30 foraging holes per square meter are necessary for the effect to be significant (Mando, 1997). Tension infiltration measurements and simulated rainfalls with aqueous methylene blue showed that the termite effect significantly persists through the degradation of the soil surface crust. In addition, it was shown that the influence of the large macropores made by termites is better described as a runoff interception process than by ponded infiltration (Leonard and Rajot, 2001). Termite activity in mulch results in a statistically significant improvement in the humidification and water conservation of crusted soil whilst mulch without termites does not have a statistically significant effect on the water status of structurally crusted soil (Mando, 1997). Despite these known benefits of termites to soil properties, farmers believe the retention of crop residues attracts termites and increases crop lodging (damage) at crop physiological maturity. It also still remains unknown what residue application rates lead to termite populations that can be classified as pests.

Termites are also reported to potentially innoculate the soil with *Termitomyces* fungi which in turn increase distribution of beneficial macrobiotic species throughout the soil horizons (Jouquet *et al.*, 2005). Addition of termitaria soil to arable lands has also been reported to increase the calcium, magnesium and top-soil clay contents (Nhamo, 2007, Ayuke, 2012). The feeding habits of termites determine the quality of the termitaria soil. Wood, grass or litter feeding termites of the Termitidae family may consume large proportions of organic matter in their surroundings and the non-digested part of this material is accumulated in mounds and

gallery walls (Dangerfield, 1990). The gallaries then contribute clay, silt and organic matter to sandy soils and has a lower pH, higher structural stability and higher concentrations of organic carbon and inorganic nutrients (Cammeraat *et al.*, 2001). The correlation between termite populations and soil organic carbon and aggregate stability as the crop residue amounts increase thus remains a research gap in Zimbabwe.

2.2.2 Factors affecting termite prevalence

Termites have been reported to prevail under diverse environmental conditions (Uys, 2002). In cultivated fields, termite abundance is highly influenced by biophysical site characteristics and management factors. According to farmers, major factors affecting termite prevalence and activities are temperature (Papendick *et al.*, 1978), humidity, water, soil moisture and soil types (Doran *et al.*, 1994; Jouquet *et al.*, 2006). Other studies have also shown that the effect of reduced tillage on water, SOM and temperature also has a bearing on the survival and reproduction of soil fauna (Kladivko, 2001).

An increase in termites was reported during mid-season drought periods on cropping lands, which suggests soil moisture and temperature affect their prevalence (Kladivko, 2008). The activities of termites are thus influenced by soil moisture as their densities were found to be low in high rainfall areas and wetlands (Nhamo, 2007). Prevalence of soil fauna in the top soil layer is also believed to be as a result of a favorable auto-ecological environmental conditions particularly in the rhizosphere. Farmers have reported the presence of grass, crop residues, composts, weeds and animal manure to attract termites. Where crop residues were heaped, termite activities were seen in the form of termite gallaries, and attack on maize. At very high residue load rates, anaerobiosis could occur at the surface as well as within the soil but this is still not well understood in CA systems. It was also shown that the organic matter quantity

and quality also affects termites' abundance (Sileshi and Mafongoya, 2006). It is therefore important to understand changes in termite populations as maize and sorghum crop residue amounts increases.

Tillage also affects trends in termite densities, and there is a negative correlation between degree of disturbance of fauna habitats and species richness (Eggleton *et al.*, 2002). Minimal soil disturbance could mean that termites' nesting sites are not destroyed and mechanical ripping of the soil may influence moisture profiles due to interaction between the top and the sub- surface layers. In addition, gallery construction by termites was also found to be influenced by tillage treatments and soil type (Nhamo, 2007). Farmers also confirmed that, compared to sandy soils, heavier red clays hosted more termites (Nhamo, 2007). Thus, there is need to understand the effects of CA at increasing crop residue application rates on termite prevalence on different soil types

2.2.3 Effects of termites on growing crops

The most damaging termite species are known to fall under the Macrotermitinae subfamily in the Termitidae family (Engel *et al.*, 2009) as shown in Fig 2.1. Some of the major termite species which damage crops are identified because of specific structures they construct the following structures for example, *Macrotermes* species build large closed mounds, *Ancistrotermes* species build nests, in the form of scattered chambers \pm 1m below soil surface and *Odontotermes* species build small open mounds. *Microtermes* species make above and belowground tunnels that can extend many metres, probably a strategy to avoid harsh conditions while foraging (Wood *et al.*, 1986, Engel *et al.*, 2009).



Figure 2. 1 Classification of termite species mainly observed in the field

With respect to crop damage, termite attack has been reported on spots where remains of maize stover have been incorporated as these present a major food source (Logan, 1992). Research by Nhamo (2007) showed that conventional ploughing, direct seeding and ripping treatments, had similar effects on termite attack on growing maize as measured by the number of lodged plants. This could have been as a result of low termite prevalence and insignificant amounts of residues on the study sites. Although it is suggested that where dry residues are available low termite attack on live plants will occur, suggesting that maize can be attacked after maturity especially when dry (Lavell and Spain, 2001; Uys, 2002; Nhamo, 2007). Farmers believe that termites are pests, and crop residues should be burnt to reduce termite infestation. Hence, there is need for further investigations on termite prevalence in CA systems where different crop residue amounts are applied as surface mulch in termite infested fields in order to prove the pest theory. Ultimately, there is need to determine the optimal application rate of crop residues under CA that prevents crop lodging due to termites in comparison to conventional mouldboard ploughing (CMP) in areas with high termite infestation.

Chapter 3: General Materials and Methods

3.1 Site description

The study was carried out between 2008 and 2010 in four sites namely Bindura,

Domboshawa, Kadoma and Chikombedzi in Zimbabwe (Fig 3.1)



Figure 3. 1: Zimbabwean map showing geographical location of study sites

3.1.1 Domboshawa Training Centre (DTC) and Bindura

Work to identify and screen repellents to be used as a residue management option to grazing of crop residues by livestock was carried out at DTC (17°35'S; 31°10'E) located about 33 km north of Harare. DTC is in Natural Region IIa (NR IIa) and experiences a subtropical climate

with an annual rainfall range of 750 – 1000 mm and a mean annual temperature of 15-20°C. The soils are shallow to moderately deep, gleyic granite derived sands generally classified as Paraferralitic soils (Nyamapfene, 1991). Intensive crop farming is the recommended farming activity (Vincent and Thomas, 1960). DTC is a centre for national agricultural training and research.

Testing of the screened repellents was carried out in Bindura from August – September 2010 at Hereford Farm $(17^{0}25^{\circ}S; 31^{0}26^{\circ}E)$ and Madziwa communal area $(16^{0}55^{\circ}S; 31^{0}32^{\circ}E)$. Hereford farm is in NR IIa, thus has similar climatic conditions as for DTC but has red clays soils. The soils are deep, well drained red clay soils, locally classified under the Zimbabwean classification system as 5E2 fersiallitic soils (Thompson & Purves, 1978). They have high clay content and bulk densities. Farmers were resettled in this area since 2000 through the government's agrarian reform programme. Madziwa in NR IIb, receiving 750 -1000 mm annual rainfall, is a communal area with depleted sandy soils. The soils in Madziwa are medium grained sandy soils belonging to the paraferrallitic group (Nyamapfene, 1991). They are generally of low pH and are deficient in nitrogen and phosphorous (Shumba, 1985). Maize *(Zea mays)* is the major cereal crop grown in both Domboshawa and Bindura hence maize residues were used for the experiment.

3.1.2 Kadoma and Chikombedzi

Work to determine effects of crop residues on termite abundance, soil properties and crop lodging was carried out on two sites namely Kadoma (18⁰21'S; 29⁰55'E) in Mashonaland West Province and Chikombedzi (in Chiredzi district) in the south east lowveld in Masvingo Province. Kadoma is in Natural Region III at an elevation of about 1156 metres above sea

level (masl), receiving an annual rainfall of 650-800 mm. Semi-intensive mixed farming is generally practiced (Vincent and Thomas, 1960). The soils are dominated by kaolinitic fersiallitic red clay soils derived from mafic rocks (Nyamapfene, 1991). Maize is the major cereal crop grown in Kadoma. The site is a resettled area which was under commercial farming before the agrarian reform of 2000. Each household occupies an average of 15 hectares. Average population density is lower in comparison to typical Zimbabwean communal areas; hence, pressure on natural resources is not as intense as in most old communal areas. Conventional systems of land preparation (based on animal draught power) are practised. Gold panning is the dominant off farm activity which contributes to additional household income.

The fourth site, Chikombedzi (21⁰45'S; 31⁰19'E), is in Natural Region V; located at elevation of 500 masl and receives <450 mm mean annual rainfall. It is mainly dominated by extensive livestock farming (Nyamapfene, 1991). The soils are mainly calcimorphic vertisols. Sorghum *(Sorghum bicolor L)* is the major cereal grown. The area is occupied by smallholder communal farmers. In this area, trials were set up in villages near Chikombedzi growth point. Human population and pressure on natural resources are relatively higher 25 persons/km² (Cumming, 2003) compared to the Kadoma site with less than 10 persons/km². Land owned by each household ranges between 2 to 6 hectares. Natural vegetation is subjected to overgrazing by livestock, cutting down of trees for firewood and harvesting of natural grasses for thatching huts. Most of the youthful men have migrated to South Africa. Soil samples were taken prior to trial establishment in August 2008, for site characterisation in Kadoma and Chikombedzi (Table 3.1).

Soil property	Field 1 (Rusono)	Field 2 (Machikiche)	Field 3 (Gonda)	Average
Organic carbon (mg-Cg ⁻¹)	9.7	9.1	9.6	9.5
Clay %	29.4	20.5	24	24.6
Silt %	55.4	49.6	48.9	51.3
Sand %	15.2	29.9	27.1	24.2
pH (CaCl ₂)	4.3	4.3	4.2	4.3

 Table 3. 1 Characteristics of soils from Kadoma before setting up of the experiments in August 2008

Table 3. 2 Characteristics of soils from Chikombedzi before setting up of the experiments in August 2008Soil propertyField 1Field 2Field 3Average

Son property	(Ndawi)	(Chawani)	(Zawa)	Average
Organic carbon (mg-Cg ⁻¹)	10.1	10.4	10	10.2
Clay %	29.7	29	30.5	29.8
Silt %	52	54.3	46	50.8
Sand %	18.1	16.7	23.5	19.4
pH (CaCl ₂)	7.6	7.8	7.4	7.6

3.2 Experimental design and treatments

Determining termite prevalence

Four treatments of surface residue cover amounts of 0, 2, 4 and 6 t ha⁻¹ under conservation agriculture (CA) and a control (CMP) with no residue cover were tested. A complete randomised block design (CRBD) experiment with 4 replicates per treatment was laid out in Kadoma and Chikombedzi for the CA treatments. Plot sizes of 6 x 6 m² were laid out in the experiment with an inter-block spacing of 1m. The CMP plots were adjacent to the CA plots on both sides of each block to allow free movement and turning of cattle during ploughing. Trials were established on 3 farmers' fields for both seasons in Kadoma and Chikombedzi.

3.3 Tillage treatments in Kadoma and Chikombedzi

Conventional mouldboard ploughing (CMP) mimicked the current common farming practice where residues are grazed by livestock during the non-cropping season, followed by ploughing to a depth of about 20 cm, incorporating any ungrazed residues into the soil at the start of the season. Farmers will then follow-up using the same plough to open planting furrows. Weeding can be done using a plough, a cultivator or hand hoes between the crop rows during the cropping season.

Land preparation under CA was done by digging planting basins and applying crop residues in the field before the onset of the season. Planting basins were prepared between September and October and application of crop residue cover was done late October – early November to prevent freely grazing animals from eating the mulch. Planting basins were spaced at 0.90 m inter-row x 0.60 m in row spacing. The dimensions of each basin was 15 cm long x 15 cm wide x 15 cm deep.

Basal dressing fertilizer application rate in Kadoma was 300 kg ha⁻¹ Compound D (7% N, 14% P₂O₅, 7% K₂O), and was applied at planting in the furrows and basins under CMP and CA, respectively. Top dressing was applied at 200 kg ha⁻¹ using ammonium nitrate (34.5 % N) at 4 weeks after emergence. In Chikombedzi, only top dressing was applied to sorghum at 100 kg ha⁻¹ AN (34.5 % N) because farmers in the area are generally reluctant to use fertilizers. Weeding in CA plots was done manually using a hand hoes.

During the first year (2008/9) of practising CA, farmers gathered remaining crop residues used for the experiment from their fields. Crop residues harvested in the first season, were stacked on raised platforms and used for the second season 2009/10. The test crops used were

sorghum and maize in Chikombedzi and Kadoma respectively, and their residues were used in subsequent seasons.

3.4 Statistical analysis

Within each site, a combined analysis of variance across farmers' fields was conducted using Genstat 11 statistical package (2008) to analyse differences among treatment means. The least significant difference (LSD) at p=0.05 was used to differentiate between statistically different means. Generalised linear model and simple regression analysis was performed on crop yield, crop lodging and termite numbers to examine how they we,-re influenced by increasing crop residues.

Chapter 4 : Dry Season Crop Residue Management using Livestock Repellents under Conservation Agriculture in Zimbabwe

4.1 Introduction

In Zimbabwe, most smallholder farmers (> 90 %) rely on rain-fed farming, thus suffer from periodic and recurrent droughts which often result in complete crop failure. In addition, production is also constrained by the fact that the majority of Zimbabwean soils are granite derived, thus are inherently poor (Nyamapfene, 1991; Nyamangara *et al.*, 2000). Use of mineral fertilisers by these farmers has also been minimal due to the fertilisers' prohibitive costs and inaccessibility (FAO, 2006). Farming methods that increase water harvesting and replenishment of soil fertility status are therefore necessary to increase crop productivity.

The conservation agriculture (CA) principle of maintaining permanent soil cover has been found to increase soil water retention (Nyagumbo, 2002; Moyo, 2003; Kertesz *et al.*, 2007; Reicosky, 2008) and increase soil fertility (Chivenge *et al.*, 2007; Nyagumbo *et al.*, 2009). Mulching increases soil water retention by increasing water infiltration, reducing water runoff, and by reducing the soil water evaporation rate. Despite the benefits of mulching (Nyagumbo, 2002; Thanachit *et al.*, 2011), adoption of this principle has largely remained low (Twomlow *et al.*, 2008, Chiputwa *et al.*, 2010). The low adoption has been attributed to constrains such as labour shortage and livestock grazing the mulch in communal grazing farming systems.

The communal open livestock grazing of crop residues during the dry season has led to insufficient or no residues being available as mulch at the start of the rain season (Mazvimavi and Twomlow, 2008. A reduction in field surface mulch by 30-46 % as a result of dry winter

season grazing by livestock, leaving less than 0.2 t/ha of biomass, have been recorded in Zimbabwe (Mtambanengwe and Mapfumo, 2005). The main reason for the decline in crop residues during the dry season is mainly due to communal livestock grazing in arable areas in most smallholder farming areas. To protect these residues, various options like wire fencing, live fencing and carrying the residues to raised platforms and back to the field towards the onset of the rainy season have been employed by some farmers in Zimbabwe. However, these options were poorly adopted as most farmers could not afford wire fencing whilst live fencing takes long to establish and the high labour demand to carry residues from the fields an back to the fields at the beginning of the season.

One approach to address the problem of inadequate residues used as mulch could be through the use of livestock repellents applied to such crop residues. This study thus sought to investigate and establish the feasibility of such repellents as a new approach for livestock grazing control in CA systems using locally available resources that repel livestock from grazing residues in the field during the dry season. The research hypothesised that effective locally available organic substances exist that can be used as repellents to grazing of crop residues by cattle under CA, during dry winter season. The objectives of this study were thus to identify, screen and test locally available organic resources that can be used as repellents to grazing of maize residues by cattle during dry seasons.

4.2 Materials and Methods

4.2.1 Sites description

The study was carried out at Domboshawa Training Centre (Domboshawa) and at Hereford farm and Madziwa communal area in Bindura (see chapter 3, section 3.1.1 for full site description). The two areas in Bindura were used to compare the behaviour of livestock on residues treated with repellents, after initial screening at Domboshawa.

From observations and informal discussions with local people, it became apparent that livestock grazing at Domboshawa is controlled by farm management whilst in Bindura, grazing is communal in both pastures and arable land during the dry season. Hereford farm by virtue of its being in a higher potential region, harvests more crop residues and has supplementary animal feed such as grasses and shrubs persisting during the dry season. From observations and consultations with farmers, a considerable amount of crop residues is left in the field up to the beginning of the next agricultural season. In contrast, Madziwa has much lower annual biomass yield and all the crop residues in the field are consumed by July with little alternative grass and shrubs available for livestock grazing. Farmers usually collect crop residues from their fields and store them as dry season animal feed.

4.2.2 Experimental design and treatments

Potential repellents were identified through consultations with farmers, livestock experts and other key informants by asking for names of local plants or materials that were shunned by livestock, but were known to be non poisonous to the livestock. The names of possible repellents were suggested by 1) farmers in Kadoma, Chikombedzi, Domboshawa and Bindura; 2) livestock experts at the University of Zimbabwe (Animal Science and Veterinary Science Departments) and 3) key informants, mainly extension workers in the same areas as farmers. A total of eight potential repellents were identified. These were garlic (*Allium sativum*); onions (*Allium cepa*); mixture of garlic and onion; cow dung; goat droppings; cow dung mixed with goat droppings; chilli (*Capsicum* spp.); tobacco (*Nicotiana* spp.); crotalaria (*Crotalaria grahamiana*) and *mutovoti* plant (*Spirostachys africana*). The suggested

repellents then screened using a completely randomised block design (CRBD) with 3 replicates at Domboshawa.

Each plot measuring 5 m x 5 m received 10 kg of maize residues (equivalent to a residue application rate of 4 t/ha) at the beginning of the experiment. The dry residues were initially weighed using a digital hanging scale and then evenly applied and spread by hands on the surface of marked plots. For the repellents that were soaked, the pure form of repellents was put in a bucket and the desired amount of water was added. The mixture was then stirred thoroughly until a perfect mixture was made and was left to soak overnight. To apply the repellents to the maize stover, a sweeping broom was used to spray and spread wet chilli on the residues while hands were used for the other soaked ones. Dry repellents were manually broadcasted onto the residues uniformly until the desired amount was finished on each plot. The residues remaining in the field after grazing were weighed using a digital scale. The effectiveness of these substances suggested as potential repellents was determined by measuring the period taken to consume 50% of sprayed residues after releasing cattle. Any substance that repelled or reduced the palatability of crop residues for livestock grazing for a period of at least 3 weeks, leaving more than 50% maize stover was considered as a potentially effective repellent. This initial screening was carried out using a medium application rate of each repellent (Table 4.1).

Further tests were carried out at Domboshawa on four screened repellents between September - November 2009, to determine their optimum application rate. For the best four screened resources (cow dung, goat droppings, chilli and tobacco), a split plot design was laid out in three randomized blocks to determine their optimum application rate. The four repellents

were assigned at random to the main plots within each block at three application rates (Table 4.1) as subplots. A control where nothing was sprayed was also assigned at random to the main plot in each block. The efficacy of repellents (compared to the control) was indicated by non-consumption period of residues by livestock and the amount of residues left after a given period. The repellent's application rate with the least consumed residues was considered as the optimum application rate.

Repellent	Concentration	Weight of repellent (kg)	Concentrati on (kg/l)	Application rate (kg/ha)
Chilli powder	Low	0.25	n/a	100
	Medium	0.5	n/a	200
	High	1	n/a	400
Soaked cow dung	Low	7.5	1.5	3000
	Medium	10	2	4000
	High	12.5	2.5	5000
Tobacco scrap	Low	0.75	n/a	300
	Medium	1.5	n/a	600
	High	3	n/a	1200
Soaked goat droppings	Low	1.25	0.17	500
	Medium	2.5	0.33	1000
	High	3.75	0.5	1500
Soaked chilli	Low	0.25	0.03	100
	Medium	0.5	0.05	200
	High	1	0.1	400
Soaked tobacco	Low	0.75	0.05	300
	Medium	1.5	0.1	600
	High	3	0.2	1200
control	No treatment	0	0	0

Table 4.1: Application rates tested for each repellent to determine optimum level at Domboshawa

n/a: The respective repellents were applied in dry form (unsoaked), thus no concentrations were made

The optimum application rates obtained from the Domboshawa trials (Table 4.2) were then tested in Madziwa and Hereford to determine their efficiency on communally grazed areas. At Hereford farm and Madziwa, efficiency was based on non-consumption days and reduction in residue amount over time. CRBD layouts were used in Bindura.
Repellent	Application
	rates
Soaked cow dung	3 t/ha
Soaked goat droppings	0.5 t/ha
Chilli (soaked and	0.4 t/ha
powder)	
Tobacco scrap	1.2 t/ha
Soaked tobacco	0.3 t/ha

Table 4.2: Repellents' application rates applied in Hereford and Madziwa communities in Bindura

4.3. Results

4.3.1 Identification and screening of potential repellents

Cowdung, goat droppings, chilli and tobacco were found to be effective repellents to grazing of crop residues by livestock at Domboshawa (Table 4.3) as greater than 50% of initial residues were left after consumption by cattle for up to 21 days.

Table 4.3: Efficacy of suggested resources as livestock repellents at Domboshawa in 2009

Repellent	Number of days when more than 50% of initial residues were consumed
Soaked garlic	5 days
Soaked onions	5 days
mixture of soaked garlic and onion	4 days
Soaked cow dung	up to 21 days
Soaked goat droppings	up to 21 days
mutovoti plant (Spyrostakis africana)	6 days
chilli (both powder and soaked)	up to 21days
tobacco (both soaked and scrap)	up to 21 days
Soaked Grahamiana spp	4 days
Control	4 days

Results of the best four resources at different concentrations showed that soaked cow dung, tobacco and goat droppings were more efficient at low concentrations (Fig 4.1). Overall, the results indicated that the low concentration (3 t/ha) of cowdung was the most effective compared to others and the control had the least amount of residues left after three weeks



Figure 4. 1 Efficacy of different application rates of each repellent at Domboshawa in 2009

Note: Error bars =+/- standard error of means and to be used to compare means of each repellent at the 3 concentrations levels and not across repellents

Low, medium and high, represents the three application rates (levels) for each repellent as stated in Table 4.1

4.3.2 Efficacy of repellents

Results collected from Hereford farm showed that cowdung and tobacco (both soaked and scrap) were effective to repel the livestock for a longer time. There were no significant differences between chilli, goat droppings and control (Fig 4.2).



Figure 4. 2 Efficacy of repellents at Hereford farm in 2010

Note: Error bars =+/- standard error of means used to compare treatment means, lsd = 10.7, p=0.2

In terms of the non-consumption period, the control was eaten the very day the experiment was set up (day 0) whilst cow dung and soaked tobacco were the last to be eaten (Table 4.4). Tobacco and chilli powder were easily blown away by wind to underneath the residues or away from residues, hence residues treated with them were eaten earlier than soaked repellents (Table 4.4).

Name of repellent	Non-consumption period (days after
	application)
Chilli powder	4
Soaked chilli	7
Soaked tobacco	10
Tobacco scraps	6
Cow dung	10
Goat droppings	7
Control	0

Table 4.4: Efficacy of repellents in terms of non-consumption period at Hereford farm in 2010

In Madziwa, all the residues were consumed within three days of setting up the trial. Thus, no data on weights of remaining residues was collected after that period.

4.4. Discussion

4.4.1 Effectiveness of repellents to deter grazing livestock

The screened repellents (tobacco, chilli, cowdung and goat droppings) used in this study reduced grazing intensity in Hereford but did not eliminate grazing entirely. Ideally, repellents should be designed to be so irritating to a specific animal or type of animal that the targeted animal will avoid the protected objects or area (Osko et al., 1993). A study in Zimbabwe by Mtambanengwe et al., (2010) showed that fields that are unprotected from livestock grazing during dry season periods had residue amounts declining by up to 93% over the 5-6 months dry season compared to less than 25% in protected/fenced fields. However, in this study at Hereford, use of repellents resulted in a decline of initial crop residues by 36-45% compared to the control with a 50% over five weeks. Therefore, repellents in Hereford provided a better retention of crop residues during winter than unfenced fields but were less effective than exclusion of grazing by fencing crop residues. The repellents with a disagreeable odour (smell) and choking effect (chilli, cowdung and tobacco) tended to be more effective in controlling grazing than the ones that repelled by taste (onions, garlic, mutovoti plant, and Grahamiana spp). This finding is also supported by Hill (2002) who also found that substances that repel by taste were less effective compared to those that repel by a disagreeable odour when deterring elephants from crop fields.

From the three levels of concentrations used at Domboshawa, soaked cow dung, tobacco and goat droppings proved to be more efficient when the solution was more dilute compared to

highly viscous slurry. The efficacy of low concentrations could have been due to the fact that the residues would absorb more of the solution thus adding a bad taste on the residues for a longer time. The repellents could then be deterring livestock through both the smell and taste effect. With respect to chilli, which was more effective at high concentration, Osborn (2002) reported that capsaicin a naturally occurring chemical in chili peppers, causes a heat sensation when it reaches nerve receptors. This heat deters mammals from grazing on chilli peppers or on crops that have been sprayed with chilli pepper extract. This could then support the efficacy of chilli to deter cattle from treated crop residues where there is alternative livestock feed.

Although the repellents proved to be more efficient via the smelling and choking effect as opposed to taste, chilli and tobacco scrap which had the choking effect were easily blown away from the residues by wind. Stains from soaked chilli, cow dung and goat droppings, tended to disappear from residues with time, hence, their efficacy was now due to taste and livestock would bite and spit. This supports findings by Dohi et *al.*, (1999) that taste repellents only work after the animal has taken a bite out of the plant.

The difference in results obtained at Hereford and Madziwa confirms that what an animal eats largely depends on available feed resources (Osko *et al.*, 1993 and Hill, 2002). The repellents proved to be effective at Hereford where there was alternative feed whilst in Madziwa, lack of alternative feed apart from treated residues, rendered the repellents ineffective. The effectiveness of cow dung in Hereford is supported by Marten (1978) who reported refusal of dairy cattle to graze on brome (*Bromus* spp) growing over areas dressed

with cow dung yet they accepted same vegetation when it was harvested and offered as fresh fodder.

4.4.2 Challenges in using repellents

Most of the tested repellents lasted for at most three to five weeks, with the least consumed treated residues declining by 35%, and thus needed re-application after a certain period to deter grazing livestock. This was enhanced by the fact that the efficacy of these repellents largely depended on factors such as rainfall, atmospheric temperature and appetite of the livestock. In terms of weather, there is need for dry weather when one applies the repellent for about 48 hours without rain (Hill, 2002). Apart from these challenges, livestock can become adapted to the repellents and end up grazing protected/sprayed residues.

4.5 Conclusion

Cowdung and tobacco proved to be the promising repellent options that could be used to keep livestock away from residues during the winter, but their efficiency largely depended on the availability of alternative feed.

Repellent's effectiveness was generally found to be temporary as the residues were eaten with time thereby suggesting the need for repeated applications at least every 3 weeks. From the study, it can also be concluded that odour and choking repellents were more effective compared to taste based repellents.

Chapter 5: Termite prevalence and crop lodging under Conservation Agriculture in semi-arid Zimbabwe

5.1 Introduction

Conservation agriculture (CA) is based on three main principles namely minimal soil disturbance, crop rotations and permanent soil cover (FAO, 2009). The principle of provision of soil cover through crop residues under CA ultimately results in a more favourable environment beneficial to soil fauna, which in turn enhances soil fertility. Termites (Isoptera) are usually the dominating macrofauna group in agricultural land in Kadoma and Chikombedzi (Mutema, 2009). Benefits of termites to farmers include use as food (Nyeko and Olubayo, 2005) and use of soils from termite mounds into planting basins (Siame 2005, Nyamapfene, 1986) and arable fields for soil fertility replenishment (Nyamangara and Nyagumbo, 2008).

Despite the promotion of CA principles, the majority of the smallholder farmers in areas with high levels of termite infestation hesitate to fully adopt the principle of permanent soil cover, as they believe that crop residues attract termites which would cause crop damage. These farmers believe that the detrimental effects of termites in Zimbabwe far outweigh their beneficial effects and are thus classified as pests (Logan *et al.*, 1990). This is more apparent towards the end of the rainy season at crop maturity (Wood *et al.*, 1980) where resultant lodging contributes to yield losses. On the other hand, some scientists suggest that the presence of dry crop residues may actually reduce termite attack on growing crops as they are thought to prefer dry stover as compared to fresh biomass (Nhamo, 2007). The question that then comes to the farmers' mind is, 'At what application rate can termites cease to be pests if the crop residues are applied at the beginning of the season?'

In these highly termite infested areas, the prevalence of termites and resultant crop lodging under conditions of increasing surface applied crop residue amounts in Zimbabwe remains unknown. There is a knowledge gap regarding the changes in termite populations that take place in the soil in CA systems at different soil residue cover levels in Zimbabwe. An improved understanding is therefore required of the effects of crop residues on termite prevalence and subsequently on growing crops in CA systems. This study sought to address this bottleneck to CA systems by establishing the linkage between varying residue amounts applied as surface mulch in cropped fields, termite prevalence and crop lodging. The research hypothesised that termite prevalence in CA systems is significantly influenced by increasing surface crop residue amounts and that increasing surface applied crop residues in CA systems reduces crop damage due to termite attack. This study focuses on two objectives 1) to establish the influence of surface applied crop residues on termite prevalence in CA systems 2) to determine the contribution of crop residues applied as surface mulch in reducing crop damage by termites in CA systems.

5.2 Materials and methods

5.2.1 Site description

The work was carried out on two sites namely Kadoma district in Mashonaland West Province and Chikombedzi in Chiredzi district in the south east (S.E) Lowveld, Masvingo Province. These sites are fully described in chapter 3, Section 3.1.2. Maize (*Zea mays*) is the major cereal crop grown in Kadoma, thus maize residue was used for the experiment at this site while sorghum (*Sorghum bicolour*) is the major cereal crop grown in Chiredzi, hence sorghum residue was used.

Four treatments of surface residue cover amounts of 0, 2, 4 and 6 t ha⁻¹ under CA and a control (conventional mouldboard ploughing system (CMP)) with no mulch were laid out as described in Chapter 3 section 3.2.

5 2.2 Sampling

5.2.2.1Termite numbers

Sampling for termites was carried out in February 2009 and March 2010 in Kadoma and in March 2009 and February 2010 in Chikombedzi at 10-12 weeks after planting in both seasons. A soil monolith measuring 20 cm x 20 cm x 30 cm deep was used to sample in each plot (Anderson and Ingrams, 1993). From the excavated soil samples and using hand sorting, termites were picked and stored in 70 % alcohol for counting and classification in the laboratory (Anderson and Ingram, 1993).

In this study, the term termite abundance was used to refer to the number of termites per square metre of soil.

5.2.2.2 Soil moisture

Samples for soil moisture determination were collected whenever termite sampling was done to a depth of 30 cm (depth of the monolith). Weighed samples were oven dried for 24 hours at 105°C. The gravimetric moisture content was determined as :

 $G_m (w/w \%) = 100 x (M_m - M_d) / M_d$

Where G_m = gravimetric moisture content as a percent (%) M_m = weight of wet sample M_d = weight of dry sample

5.2.2.3 Crop lodging

The number of crops lodged by termites was physically counted in each plot from the 4 replicate plots. The number of lodged plants were expressed as a percentage of the total number of plants (lodged + standing) in the respective plot. The lodging was determined at harvesting.

5.2.2.4 Termite species identification

From the collected termites, a sample was taken from each site (Kadoma and Chikombedzi) and dominant species were identified using a microscope. Termites were identified according to the presence of teeth, shape and presence of mandibles and size/ colour of the head.

5.2.3 Statistical analysis

A *combined analysis of variance* across farmers in each site was conducted using Genstat 11 (2008) statistical package, to analyse for differences between treatment means. The least significant difference (LSD) at P=0.05 was used to differentiate between statistically different means. Simple regression analysis was performed on crop lodging and termite numbers to examine how they are influenced or related to increasing crop residues. A correlation was also established between termite populations and soil moisture.

5.3 Results

5.3.1 Termite abundance/prevalence

In Kadoma, CA with 4 t/ha residue cover had the highest termite numbers in both seasons. In 2008/9 season, conventional mouldboard ploughing (CMP) had the lowest termite abundance and differed significantly from CA treatments with residue cover (Table 5.1). In 2009/10, the

2 t/ha residue cover treatment had the least termite numbers. The differences were significant among CMP, CA 0 and 2 t/ha residue cover and the CA 4 and 6 t/ha residue rates.

In Chikombedzi, CA with 6 t/ha residue cover had the highest termite numbers in both seasons. In the 2008/9 season, CA with no residues had the least termite numbers which significantly differed from CA with residue cover. In the second season, CMP had the least termite numbers which differed significantly from all CA treatments (Table 5.1). Overall, a significant positive linear relationship between maize crop residues under CA and termite numbers was obtained for Kadoma (Fig 5.1). However, in Chikombedzi, a similar but insignificant linear relationship was obtained.

compared to entri in Radoma and entrombedza					
	Kadoma		Chil	Chikombedzi	
	2008/9	2009/10	2008/9	2009/10	
Treatments					
CA- 0t/ha residue cover	300 a	283 a	77 a	2084 b	
CA- 2t/ha residue cover	2100 b	263 a	775 ab	1707 b	
CA -4t/ha residue cover	3050 b	1179 b	780 ab	2064 b	
CA- 6t/ha residue cover	2662 b	1121 b	2320 b	2650 b	
CMP	25 a	358 a	487 a	5 11 a	
LSD	1724	612	1130	956	

Table 5.1: Effects of different residue amounts under CA on termite abundance (termites per m² of soil) compared to CMP in Kadoma and Chikombedzi.

Note: Means followed by the same letters in a column are not significantly different at 5% level, LSD test

With regards to soil moisture, in both Kadoma and Chikombedzi, data collected from the two seasons showed that there was no significant linear relationship between % soil moisture content and termite numbers whenever the termite numbers were sampled



Figure 5. 1 Overall relationship between maize crop residues and termite numbers in Kadoma

The major termite species observed in Kadoma were, in order of abundance, *Macrotermes spp* (53%), *Odontotermes spp* (27%), *Ancistrotermes spp* (12%), *Microtermes spp* (7%) and *Allodontotermes & Pseudocanthotermes* (1%). On the other hand in Chikombedzi, it was *Ancistrotermes spp* (45%), *Odontotermes spp* (33%), *Macrotermes spp* (15%), *Microtermes spp* (5%) and *Allodontotermes* (2%).

5.3.2 Crop residues, termite abundance and crop lodging

By the time the maize crop reached physiological maturity, it was observed that all the initially applied crop residues (Fig 5.2a) in Kadoma had been almost completely eaten by termites and other fauna (Fig 5.2b) at crop maturity. In Chikombedzi, some residues were still observed at the surface of CA plots but in reduced amounts (Fig 5.2c)



Figure 5. 2 Field covered with residues a) Kadoma at the beginning of the rainy season b) in Kadoma end of January and c) in Chikombedzi end of February

With respect to crop lodging, generally CA had more damaged crops by termites compared to CMP in both sites over the two seasons. There was a significant difference between CA with 0, 2, and 6 t/ha residues in Kadoma and CMP in both seasons (Fig 5.3). Increasing crop residue amounts under CA did not reduce crop lodging in Kadoma. In addition, crop lodging in the two seasons at each treatment did not significantly differ from each other (Fig 5.3). During the first season, crop lodging ranged from 30.1% to 47.8% whilst lodging in the second season ranged from 33.9% to 46.4%.

Generally, crop lodging in Chikombedzi was very low during the first season ranging from 0.53-3.53 %. Lodging for CA with 4 t/ha and CMP was significantly lower than the 6 t/ha. In the second season, crop lodging ranged from 8.4% to 25.1%, but the residue amounts under CA had no significant effect on crop damage. CMP had the least lodged crops amongst all treatments with significantly lower lodging compared to CA with 0, 4 and 6 t/ha of residues (Fig 5.4). Overall, results in both Kadoma and Chikombedzi showed that increasing crop residues under CA has no significant effect on reducing crop lodging due to termite attack but rather a shift from CA to CMP showed a decline in crop damage.



Figure 5. 3: Maize crop lodging in Kadoma over the two seasons (2008/9-2009/10)

Note: Error bars =+/- standard error of means and were used to compare treatments means for each season 0 t/ha = CA planting basins + no crop residues added $<math>2 t/ha = CA planting basins + 2 tons ha^{-1} crop residues applied as surface mulch$ $<math>4 t/ha = CA planting basins + 4 tons ha^{-1} crop residues applied as surface mulch$ $<math>6 t/ha = CA planting basins + 4 tons ha^{-1} crop residues applied as surface mulch$ <math>CMP = conventional mouldboard ploughing system



Figure 5. 4: Effects of treatment on crop lodging in Chikombedzi over two seasons (2008/9 to 2009/10)

Note: Error bars =+/- standard error of means and were used to compare treatments means for each season

 $\begin{array}{ll} 0 \ t/ha &= CA \ planting \ basins + no \ crop \ residues \ added \\ 2 \ t/ha &= CA \ planting \ basins + 2 \ tons \ ha^{-1} \ crop \ residues \ applied \ as \ surface \ mulch \\ 4 \ t/ha &= CA \ planting \ basins + 4 \ tons \ ha^{-1} \ crop \ residues \ applied \ as \ surface \ mulch \\ 6 \ t/ha &= CA \ planting \ basins + 4 \ tons \ ha^{-1} \ crop \ residues \ applied \ as \ surface \ mulch \\ CMP &= conventional \ mouldboard \ ploughing \ system \end{array}$

5.4 Discussion

5.4.1 Influence of crop residues and minimum soil disturbance on termite abundance

Results obtained from both seasons in Kadoma and from the second season (2009/10) in Chikombedzi showed that addition of at least 4 t/ha of residues, significantly increases termite numbers compared to CMP. During the first season in Kadoma, results imply that the maize residues (2 to 6 t/ha) attracted more termites compared to where no residues were applied (0 t/ha and CMP) whilst in the second season, 2 t/ha had the least termite numbers which was not significantly different from the CA without residues and CMP treatments. This could have been due to complete removal of residues by termites within the first month, as was observed in the field, thus, when sampling was done at 10-12 weeks after planting, no difference was observed between this treatment and where nothing was applied. The results from Kadoma also confirm the assertion that maize crop residues are a good attractant to termites since results of this study showed that CA with no residues applied (0 t/ha) had no significant difference with CMP with respect to termite numbers. Crop residues act as an energy source, provide a suitable foraging site of soil fauna, and hence influence their activities (Reicosky, 2008, Logan, 1992). These surface residues tend to moderate temperature extremes of the underlying soil surface both through shading against incoming solar radiation and outgoing long wave radiation. Residues also moderate soil temperatures by preventing soil moisture loss through evaporation (Moyo, 2003), hence, protecting more termites.

Lack of significant differences in termite numbers at different CA residue amounts observed in Chikombedzi during second season could mean that sorghum residues may not be a good energy source for termites, thus the residues helped in temperature moderations only rather than food provision. The increase in termite numbers with crop residues under CA in the first season could have been due to the promotion of moderate soil temperatures and moisture content under CA. During the second season, the higher termite numbers obtained under CA compared to CMP could mean that tillage effect had greater influence on termite prevalence compared to the presence of residue applied as surface mulch since the CA treatments were not significantly different.

The higher termite numbers obtained at 4 t/ha residues cover amounts under CA compared to CMP in both Kadoma and Chikombedzi proves that the implementation of the two CA principles (minimal soil disturbance and soil cover), results in more termite prevalence compared to CMP. This concurs Eggleton *et al.*, (2002) who noted that tillage affects trends in termite densities and that there was a negative correlation between degree of disturbance of fauna habitats and species richness.

CA favours soil macrofauna probably because of less soil disturbance and possibly due to high accumulations of SOM compared to conventionally tilled fields (Koga and Tsuji, 2009). During ploughing, termites' nests are destroyed whilst minimal soil disturbance could mean that termites' nesting sites receive less disturbance. (Ayuke, 2010). Nhamo, (2007) also found out that gallery construction by termites was more pronounced under CA treatments than CMP.

5.4.2 Effects of crop residues and tillage systems on crop lodging

Results showed that an increase in crop residues under CA did not necessarily reduce crop damage due to termite attack, as there were no significant differences in lodging at the different residue application rates. In Kadoma, this could be attributed to the fact that by the time of harvesting (physiological maturity), all the residues applied at the onset of the season had been completely eaten by termites. Hence, by the time the maize crop dried up, there was

no extra food reservoir from the CA plots yet the termites were already attracted to the fields due to initial presence of residues. The absence of crop residues by the time of harvest, could then explain the similar crop attack whether the initially applied residue rates were high or low. Sands (1977) and Ayuke (2010) also observed that crops were more seriously damaged towards harvesting than earlier in the season whilst Mitchell (2002) recorded that maize crops are susceptible to termite damage at all growth stages in the absence of dry organic matter. Delay in harvesting could then mean yield losses in crops and termites are thus recognised as important agricultural pests (Logan *et al.*, 1990). Yield loss due to termite attack was estimated at 10-20% in Kenya (Maniania *et al.*, 2001), whilst in Uganda, Semakatte *et al.*, (2003) also recorded a yield loss of between 20 and 28% in maize due to termite attack. Locally, crop lodging in maize fields was about 42% which can translate to similar yield loss if harvesting is delayed.

The lower percentage lodged plants in CMP could also be attributed to the fact that tillage had disturbed termites' channels since this has a bearing on the survival and reproduction of soil fauna (Kladiviko *et al.*, 2008). Since the macrotermes were the major species found in both study sites, the crops were highly susceptible to termite attack. Studies by Cowie (1989), Sands (1998) and Nyeko and Olubayo (2005) all indicate that macrotermes and odontotermes are the most damaging termite species to crops (Ayuke, 2010).

The results from Kadoma showing crop lodging of up to 42% in maize, shows that termites have preference for maize plants. Studies in Zambia by Sileshi *et al.*, (2005) and in Kenya by Malaret and Ngoru (1989) also showed high crop lodging percentages of maize crops whilst in the field. It is suggested that the increased damage of maize crops is because the species lack resistance to African termites (Logan *et al.*, 1990; Wilde, 2006) yet indigenous African crops

are resistant to these as they have co-evolved. The termite damage could also be due to the fact that the usual termite food is depleted due to deforestation and overgrazing, loss of natural enemies and continuous cultivation and overstocking (Eggleton *et al.*, 2002).

In Chikombedzi, results showed low sorghum crop lodging averaging about 9%. This suggests that sorghum is not a good termite attractant and could have repelling ingredients to termites. In some studies, extracts of sorghum have been demonstrated to have some insecticidal properties such as naphthoquinones which may contribute to plant resistance against termites attack (Osbrink *et al.*, 2005). The low sorghum damage by termites could also be due to the fact that the sorghum plant head can dry up earlier whilst the stem and roots are still green (fresh) which also suggests that termites prefer dry residues compared to living and fresh plants (Lavell and Spain, 2001) though some genera can attack live crops. Ayuke (2010) showed that the maize crop has 97 % chances of being attacked by termites compared to sorghum with only a chance of 3 %.

5.4.3 Termite species identified from the study sites

The presence of *Macrotermes, Odontotermes* and *Microtermes* species in both Kadoma and Chikombedzi can be explained by the fact that the Macrotermitinae sub family are known to tolerate semi-arid and even arid conditions (Eggleton, 2000). Macrotermitinae collect up to 60% of grass, woody material and annual leaf fall to construct the fungus gardens in their nests (Lepage *et al.*, 1993). The presence of 53% macrotermes thus explains the high maize crop damage of about 42% in Kadoma. In addition, due to overstocking and deforestation, termites have to feed on whatever material is available (Semakkatte and Okwakol, 2007) thus increasing the pest effects of termites. The low abundance of *Microtermes* in Kadoma is also supported by results in Zambia where farmers rated *Microtermes* spp (Semakkatte and

Okwakol, 2007) as the least dominant termite pests in their fields. The low numbers of *Microtemes* spp across all sites might be explained by their ability to adapt to varying climatic conditions and management practices. Thus, they could have been widely distributed in the fallows and uncultivated land. This could be attributed to their nesting habits and also their ability to utilize a wide variety of food resources which include wood, litter and dung (Mitchell, 2002).

Environmental variables such as temperature and soil moisture were found to contribute 25% in termite abundance in Kenya. Termites were found less abundant in relatively cooler, wetter and more clayey sites (Ayuke, 2010). This could also explain the differences in termite species composition in Kadoma (with 53% *Macrotermes spp*, 27% *Odontotermes spp*, 12% *Ancistrotermes spp* and 7% *Microtermes spp*) and Chikombedzi (with 45% *Ancistrotermes spp*, 33% *Odontotermes spp*, 15% *Macrotermes spp* and 5% *Microtermes spp*). This is so since Kadoma experiences relatively wetter conditions than Chikombezi and the different soils types in the two sites where Kadoma has red fersiallitic soils whilst Chikombedzi has vertisols.

5.5 Conclusion

It could be concluded that mulching fields with maize crop residues at application rates of 4 t/ha and sorghum crop residues at 6 t/ha under CA, in areas with high termite infestation levels increased termite numbers compared to CMP. This, therefore, confirms and provides scientific evidence to the farmers' opinion that addition of crop residues attracts more termites. CA thus suffers from this setback that its use leads to increased crop lodging in fields highly infested with termites of the Macrotermitinae subfamily.

Addition of maize and sorghum crop residues at the beginning of the rainy season under CA in fields with high termite populations does not necessarily reduce crop lodging to an appreciable extent, but rather the shift from CMP to CA results in significant increase in crop lodging. This study therefore disqualifies the general notion that addition of residues minimises crop lodging as termites would prefer to eat dry matter and leave the crop when residues are applied at the beginning of the season. It is therefore recommended that if high amounts of maize crop residues in termite infested areas must be applied as required under CA, there is need for termite control measures and early harvesting so as to minimize crop losses due to lodging.

Chapter 6: The contribution of crop residues to soil organic carbon, soil aggregate stability and crop yield under conservation agriculture

6.1 Introduction

Soil organic matter (SOM) dynamics are affected by land use management practices such as manipulation of the soil environment through tillage (Nyamadzawo, *et al.*, 2007), mulching and application of organic and/or mineral fertilizers (Nyagumbo, 1997, Chivenge *et al.*, 2007). In addition, burning of residues and intensive ploughing results in loss of soil organic carbon hence reduced soil aggregate stability (Yang and Wonder, 1999, Koga and Tsuji, 2009). Conservation Agriculture (CA) has been promoted as a technology which sequesters carbon, thus mitigating global warming (EIA, 2001). Carbon sequestration is a biochemical process by which atmospheric carbon is absorbed by living organisms, including trees, soil micro-organisms and crops, and involving the storage of carbon in soils (carbon sink), with the potential to reduce atmospheric carbon dioxide levels (EIA, 2001). Conservation Agriculture is also seen as one feasible option for enhancing carbon sequestration (Lal and Kimble, 1997) thereby reducing greenhouse gas emissions to the atmosphere that are thought to be the main contributors to global warming (IPCC, 2007).

SOM is a useful indicator of soil quality and plays an important role in aggregate stabilization, although aggregation may also influence SOM storage by lowering microbial attack and loss through erosion (Tisdale and Oades, 1982, Liu *et al.*, 2006). A decline in soil organic carbon leads to poor soil structure, reduced water infiltration (Nyamadzawo, *et al.*, 2007) and storage, hence increased vulnerability of crops to droughts culminating in food insecurity and increasing poverty. Smallholder farmers in the communal areas of Zimbabwe

use cattle manure and other organic inputs such as composts, green manure and crop residues as amendments to increase and maintain the fertility status of their soils (Mugwira and Murwira, 1997, Mtambanengwe, 2006).

Research has been carried out to determine the importance of soil fauna to soil properties such as infiltration, soil organic carbon (SOC) and aggregation (Ayuke, 2010). In Zimbabwe, little is known on the correlation between different residue amounts, SOC and soil aggregate stability in areas with high levels of termite infestation fields under CA. This study thus aimed to determine the contribution of crop residues to soil carbon and soil aggregate stability in crop fields with high termite infestation levels under CA systems.

6.2 Materials and methods

6.2.1 Site description

The study was carried out on two sites namely Kadoma district in Mashonaland West province and Chikombedzi in Chiredzi district in the south east Lowveld, Masvingo province. These sites are described in chapter 3, Section 3.1.2. Maize (*Zea mays*) is the major cereal crop grown in Kadoma while sorghum (*Sorghum bicolour*) is the major cereal crop grown in Chiredzi.

Five treatments of surface residue cover amounts of 0, 2, 4 and 6 t ha⁻¹ under conservation agriculture (CA) and a control (conventional mouldboard ploughing system (CMP)) were laid as described in Chapter 3 section 3.2.

6.2.2 Organic carbon

Soil samples for SOC determination were collected using an auger at the end of the second season from the 0-10 cm depth in all plots. Soil organic carbon was measured using a modified Walkely-Black wet oxidation colorimetric method (Anderson and Ingram, 1993). One gram of soil sieved through a 2 mm sieve was weighed into a conical flask followed by addition of 10 ml 5 % potassium dichromate ($K_2Cr_2O_7$). The resultant mixture was gently swirled until the sample was completely wet. To the mixture, 20 ml of 98 % concentrated sulphuric acid (H_2SO_4) were added and the resultant mixture gently swirled. The mixture was allowed to cool in a fume cupboard followed by addition of 50 ml 0.4 % barium chloride BaCl₂. The mixture was swirled and left to stand overnight, so as to get a clear supernatant solution. A graph of absorbance against sucrose standard concentrations was plotted to determine the concentration for the sample and the blanks. The % organic C in the sample was then calculated as follows:

% organic C= (K x 0.1) / (W x 0.74) where K = sample concentration – mean blank concentration and W =weight of soil

6.2.2.2 Aggregate stability

Soil samples to analyse aggregate stability were taken concurrently with the samples for SOC determination (preceding section 6.2.2.1). Soil samples were collected from the 0-10 cm, 10-20 cm, and 20-30 cm depth using metal cores, with a height of 7.5 cm and a diameter of 5 cm. The samples were air-dried before analysis and sieved through 2 mm sieve. Aggregates retained where used for the aggregate stability test. Water stability of aggregates for Kadoma was determined by the wet sieving method to determine mean weight diameter (mwd) at the Institute of Agricultural Engineering laboratory. However, for uniformity purposes across the

sites, Middleton Dispersion Ratio (MDR) according to Anderson and Ingram, (1993) was used for both samples from Kadoma and Chikombedzi since aggregates in Chikombedzi were not stable in water.

6.2.2.3a Water stable-aggregates determination : Wet sieving Analysis

The stability of aggregates was estimated by the wet-sieving technique as described by Kemper and Rosenau (1986). The tank of the wet sieving apparatus was filled with distilled water to the mark provided (10 mm above the rim of the top sieve). Fifty grams of soil were each placed on top of two nests of sieves of the following apertures, 2, 1, 0.5, 0.2 mm. The two nests of sieves were immersed simultaneously in distilled water in less than 3 seconds and the sieve holders were hooked onto the shaft and left for 10 minutes. The sieving machine was started and sieving was run for ten minutes. The tank was drained to well below the level of the lowest sieve. The two nests of sieves were removed from the tank, separated and placed in an oven for at least 24 hours at 105°C. The sieves were allowed to stand on the metal trays provided to trap any disintegrating aggregates. After drying the material, the aggregates from each sieve were weighed. The weight of the aggregates in each sieve was measured after removal of gravel from the top sieve. Mean weight diameter (MWD) was calculated as the sum of mass of fractions of soil remaining on each sieve after sieving multiplied by mean aperture of adjacent meshes of sieves.

6.2.2.3b Middleton dispersion ratio (MDR) determination: Standard hydrometer method

Samples were air dried and passed through a 2 mm sieve. A volume of 100 ml of Calgon reagent (dispersing agent) was added to the 50 g soil sample + 500 ml distilled water. The solution was allowed to soak. Dispersion was catalysed by placing the mixture on an automatic 52

shaker overnight and then left to stand for 10 minutes. The mixture was transferred into containers and put on an electric mixer and stirred for 5 minutes. The mixture was transferred into a 1 litre measuring cylinder and diluted to the 1 litre mark. Using a plunger, the suspension was thoroughly mixed by moving it up and down for 1 minute. A hydrometer was gently placed into the cylinder, and its reading noted at 5 minutes and 5 hours from commencement of sedimentation. The temperature of the solution was also noted.

The following calculations were done to determine the MDR:

Calculations

5 minutes (corr) = 2(5 mins reading of hydrometer - 5 mins blank reading of hydrometer + T)

5 hr (corr) =2(5hr reading - 5hr blank + T), Where T =Temperature correction:

For every degree which the temperature of the suspension was above 19.4°C, 0.3 units were added to the hydrometer reading. For every degree it was below 19.4°C, 0.3 units were subtracted. (Note: the hydrometer was calibrated at 19.4°C)

The readings at five minutes and five hours (corrected for temperature) were the percentages of silt + clay (< 0.02 mm) and clay (< 0.002 mm) respectively, on the air-dry basis.

Middleton Dispersion Ratio = $\frac{\text{silt} + \text{clay}}{\text{Clay}} \ge 100$

6.2.3 Crop yield determination

The crops were harvested from net plots measuring 4 rows x 4 m in each plot. Grain yields were adjusted to 12.5% moisture content for both maize and sorghum as locally recommended by the Grain Marketing Board in Zimbabwe.

6.2.4 Statistical analysis

Analysis of variance was conducted using Genstat 11 (2008) to analyse differences between treatment means. The least significant difference (LSD) at P<0.05 was used to differentiate between statistically different means. Simple linear regression analysis was performed on soil organic carbon and aggregate stability to examine how they were influenced by increasing crop residues and termites.

6.3 Results

6.3.1 SOC and MDR as influenced by crop residue treatments

In both Kadoma and Chikombedzi, addition of 2-6 t/ha crop residues under CA generally resulted in lower Mmiddleton Dispersion Ratio (MDR) compared to CA with no residues and CMP after two seasons (Table 6.1). There were no obvious trends in MDR with an increase in residue amounts under CA. The results showed that the least MDR was obtained under 6 t/ha treatment in Kadoma and 4 t/ha treatment in Chikombedzi (Table 6.1).

In Kadoma, after the 2 years of implementing CA, there was no significant relationship between increasing crop residue amount and soil aggregate stability (p > 0.05) as explained by mean weight diameter (MWD) and MDR. The MWD for the different CA treatments ranged from 0.34 to 0.47 whilst MDR values were ranging from 8.5 to 10.04% (Table 6.1). In Chikombedzi, the relationship between crop residues and MDR was also insignificant. With respect to MDR in Chikombedzi, an increase in residue amount resulted in an insignificant decrease in dispersion ratio (p > 0.05) and MDR values ranged from 22.4% to 29.9% under CA (Table 6.1). Generally, CMP had greater MDR values compared to CA with crop residues although the differences were not significant.

Treatment	Kadoma (%)	Chikombedzi (%)
CA-0 t/ha	10.0 a	29.9 a
CA-2 t/ha	8.8 a	24.8 a
CA-4 t/ha	8.9 a	22.4 a
CA-6 t/ha	8.5 a	26.9 a
CMP	9.7 a	27.2 a
LSD	6.9	16.7

Table 6. 1 Middleton dispersion ratios of crop residue treatments in Kadoma (red clay soils) and Chikombedzi (vertisols) after two years.

Note: Means followed by the same letters in a column do not significantly differ at 5% level, LSD test

With respect to SOC, CA treatments with 2 to 6 t/ha crop residues had generally more SOC compared to CA with 0 t/ha treatment and CMP. However, in Kadoma, there was no significant linear relationship observed between increasing crop residue amount and SOC over the two seasons. The highest SOC was obtained at CA with 4 t/ha residue amounts in Kadoma. In Chikombedzi, an increase in residue amount, resulted in a significant increase in SOC in Chikombedzi after the two seasons (p < 0.05) (Fig 6.1). The SOC values under CA ranged from 10.91 to 10.96 mg-Cg⁻¹soil with the highest SOC values obtained at CA with 6 t/ha treatment in Chikombedzi.



Figure 6. 1: The linear relationship between residue amount under CA and SOC in Chikombedzi after 2 seasons

6.3.2 Relationships between termites and soil organic carbon and soil aggregate stability

The presence of termites had no effect on SOC and soil aggregate stability in Kadoma after two seasons of implementing CA. There was also no significant relationship (p > 0.05) between termite numbers and both MDR and SOC in Chikombedzi.

6.3.3 Maize and sorghum yields

In Kadoma (2008/9), CA had significantly higher maize grain yield compared to CMP, but the different residue amounts within CA systems had no significant effect on the yield (Table 6.3). In 2009/10, CA at 0 t/ha residue had the least yield (2348 kg/ha) out of all the treatments and CMP had significantly lower yield than CA with 2-6 t/ha residue cover (Table 6.3). In Chikombedzi (2008/9), yield analysis results showed a significant *farmer x treatment* interaction (p < 0.001) hence results are presented separately for each farmer (pooling not justified) (Fig 6.4). In that season (2008/09), CMP had generally lower yields than CA treatments but differences were not significantly higher compared to CMP while a similar pattern was obtained at Zava where CMP yielded significantly lower than all CA treatments (Fig 6.4). At Chavani site, differences were not significant. In 2009/10, the *farmer x treatment x treatment* interaction was not significant and hence results were pooled. Results showed no significant yield differences between CA and CMP (Table 6.3).

•	Kadoma		Chikombedzi	
	2008/09	2009/10	2008/09	2009/10
Treatments	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
CA- 0t/ha	2900 a	2348 a	1281a	7 22 ab
CA- 2t/ha	3055 a	2814 c	1392a	605 a
CA- 4t/ha	3034 a	2693 bc	1471a	871 b
CA- 6t/ha	3348 a	2756 bc	1383a	736 ab
CMP	2117 b	2570 ab	893b	692 ab
LSD	750	222	351	265

 Table 6.2: Crop (maize in Kadoma and sorghum in Chikombedzi) yield under CA with different residue amounts compared to CMP______

Note: Means followed by the same letters in a column do not significantly differ at 5% level, LSD test

0 t/ha = CA planting basins + no crop residues added

2 t/ha = CA planting basins + 2 tons ha^{-1} crop residues applied as surface mulch 4 t/ha = CA planting basins + 4 tons ha^{-1} crop residues applied as surface mulch 6 t/ha = CA planting basins + 4 tons ha^{-1} crop residues applied as surface mulch

C A planting basins + 4 lons na crop restaues applied as surjuce

CMP = *conventional mouldboard ploughing*



Figure 6. 2 Sorghum grain yield under CA and CMP on 3 three sites in Chikombedzi for the season 2008/9 season.

Note: For each farmer, treatments represented by different letters are significantly different using the LSD test (p < 0.05)

In Chikombedzi 2008/9 season, soil moisture was a limiting factor to crop yield at field 1 (Ndawi field). The 3 farmer fields had an average volumetric moisture content of 179, 276

and 323 for field 1, 2 (Chavani) and 3 (Zava) respectively as illustrated in Appendix E. 9. The soil moisture was significantly correlated to crop yield (Fig 6.3).



Figure 6. 3: Correlation of soil moisture and maize yield in the 2008/9 season in Chikombedzi

The samples for soil moisture determination were taken in January and February 2009 With respect to crop yields, an increase in crop residues resulted in an insignificant increase in grain yield (p > 0.05) in both Kadoma and Chikombedzi.

6.4 Discussion

6.4.1 Effects of crop residues on soil organic carbon and aggregate stability

The insignificant effect of crop residues on SOC and aggregate stability in Kadoma could be due to the fact that the experiment was a short term trial, that is, for two agricultural seasons. However, a study by Ibno-Namr, (2004) reported that soil management systems that leave more plant residues on the soil surface generally allow improvements in soil aggregation and aggregate stability after 3 years. Generally, benefits of returning crop residues on SOC and aggregate stability have been observed mostly after at least 5 years of implementation (Filho *et al.*, 2002, Paustian *et al.*, 1998, Liu *et al.*, 2005). It was also found that mean weight diameter was not significantly different within the first 3 years of implementing CA (Hajabassi, 2000). Since crop residues were consumed by termites before crop maturity (chapter 5), it could be that there was little secondary decomposition done within the soil surface layers as the termites carried most of the residues down their channels beyond the sampling depth. Chivenge *et al.*, (2007) also suggested that addition of crop residues has benefits of increasing SOC on sandy soils compared to red clay soils of Zimbabwe while reduced soil disturbance plays a more important role on clay soils. Reduced tillage was also found to result in higher SOC in the top 10 cm depth of soil while crop residues management had no effect on SOC on a silt loam soil (Sparrow *et al.*, 2006).

In Chikombedzi, an increase in residue amount had a significant increase in SOC by 0.4%. Due to the nature of vertisols, that they swell and churn when wet, this characteristic might have contributed to increased soil–residue mixing during dry periods. In addition, the fact that the residues were not completely eaten by termites could have prolonged the release of nutrients from the residues at the surface, hence a significant increase in C as residues increased. The higher SOC in CA systems compared to CMP is supported by Feller and Beare (1997) who reported that minimum and no-tillage practices tend to support higher standing stocks of SOM than conventional ploughing. In another study, reduced tillage and returning residues were also found to increase SOC after 2 years of implementing (Dolan *et al.*, 2006). The results can also be explained by the fact that soil stability improvement with addition of organic residues is not solely dependent on the total amount of organic C present, but it's a function of a number of factors including the chemical composition of the organic materials and employed management system (Dormarr, 1983).

The termite species observed in the sites were mainly fungus-growing termites and studies have reported that fungus-growing termite are less effective in improving structural stability than humivorous termites (Garnier-Sillam and Harry, 1995; Ayuke, 2010). Another study also showed that termites were consequently less important in explaining the variation in aggregation in both the fallow and arable systems where very few soil feeders were found (Garnier-Sillam and Harry, 1995). Very few soil feeder termites were found at these sites, resulting in less of a role of these termites in aggregation.

6.4.2 Tillage effects on SOC and aggregate stability

Generally, CA treatments (reduced tillage) had better SOC and aggregate stability compared to CMP. However, no significant difference was observed due to short term period of experimentation. Although reduced tillage and direct seeding have been reported to maintain or increase organic carbon with concomitant increases in aggregate stability and improved soil structure (Gupta *et al.*, 1994, Martens, 2000), the results of this study shows that it maybe a long term benefit as the measured soil carbon failed to translate to a significant effect on soil aggregate stability. Thanachit *et al.*, (2011) also showed that short term tillage had no clear effect on change of soil properties such as aggregate stability and maize yield grown under tropical savanna climate conditions.

6.4.3 Maize and sorghum yields

Results seem to suggest an inconsistent pattern with regards to the relationship between yield and residue amount. In Kadoma, this could be attributed to the fact that all residues were eaten up by the time of physiological maturity in these sites (chapter 5), so the benefits of residues were only experienced during the first few weeks of the season. Similar results were also obtained at Domboshawa from CIMMYT long term trials (Nyagumbo, personal communication). A two-year study in Zimbabwe also showed that CA treatments with mulching rates of 0, 0.5, 1, 2, 4, 8 and 10 t ha⁻¹ did not have an effect on maize yield (Mupangwa *et al.*, 2007). It was also recorded that zero tillage with full or partial residues retention had similar crop yields in Mexico (Verhulst *et al.*, 2011). In addition to this, short term negative benefits of CA including soil nutrient immobilisation (Giller *et al.*, 1997, Palm *et al.*, 1998), increased weed competition, occurrence of residue-borne diseases and stimulation of crop pests (Giller *et al.*, 2009) might also have played a role in depressing CA yield benefits with respect to increase in crop residues.

The significant difference between all CA treatments and CMP on Zava site and Kadoma (2008/9) could be explained by the fact that CA can also create conditions favourable for crop productivity such as increased infiltration (Nyagumbo, 2002, Mutema, 2009, Thierfelder and Wall, 2009), hence reduced run off. In addition, the short term positive factors determining yield increase under CA including increased soil water availability and reduced soil temperature fluctuations (Vogel, 1994; Chuma and Hagmann, 1995) may have contributed to the results obtained. Results from some of the studies also showed higher yield gains from CA compared to conventional practices (Twomlow *et al.*, 2008).

The significant *farmer x treatment* interaction obtained in the yield analysis for Chikombedzi in 2008/9 could be due to different management systems experienced in on-farm trials such as weeding regimes. Though the Ndawi field was weeded well, it received less rainfall, (about 450 mm) compared to other two fields which received about 924 mm. This site is about 900 m away from the homestead and explanations from farmers confirmed that the area received lower rainfall. The low rainfall received at this field is confirmed by moisture data in

Appendix E which showed that in January, Ndawi field had lower moisture storage of 241 in comparison to Zava (390) and Chavani (344). In March, the Ndawi field also had relatively lower soil moisture storage of 117 in comparison to Zava (255) and Chavani (218). In addition, there was a significant correlation between the soil moisture and the crop yield. For the Chavani field (with average yield of 1181 kg/ha), weeding was done according to blocks and it took about a month for completion of the whole field, hence yield was compromised in two blocks and may have influenced treatment performance. Zava field with an average yield of 2 312 kg/ha received the highest rainfall and weeded the whole field on time hence had the greatest yields. The results from Chikombedzi first season therefore imply that benefits of crop residues on yield are observed when moisture/ rainfall are limiting. This suggests that in terms of crop yields, CA may be more beneficial under low rainfall conditions.

6.5 Conclusion

It can be concluded that there were no observed benefits of maize crop residues on soil aggregate stability and SOC in termite infested red fersiallitic clay soils of Kadoma. In contrast, the addition of more crop residues to vertisols has its benefit to SOC seen within two agricultural seasons but its benefit on aggregate stability was not realized within two seasons. This therefore suggests that the period required to observe meaningful soil quality CA benefits differ with soil type and agro-ecological regions.

Chapter 7: General Discussion, Conclusions and Recommendations

7.1 Effectiveness of identified repellents to grazing livestock

This study identified substances that could be used to repel livestock from grazing crop residues effectively for a period of 3 weeks in areas where there is alternative feed like grass and fodder. The aim of the study was to address one of the major challenges in practicing conservation agriculture (CA), that is, provision of permanent soil cover, since the mulch is often difficult to get for the rainy season due to competition with livestock grazing (Bationo *et al.*, 1999, Mazvimavi and Twomlow, 2009, Mapfumo and Giller, 2001) and veld fires. This study found out that in areas with alternative livestock feed like Hereford, tobacco, chilli, cowdung and goat droppings are potential effective repellents during the non-cropping season. Repellents applied as powder (tobacco scrap and chilli powder) were however easily blown away residues by wind. It was also noted that the repellents were more effective via the choking and smell effect compared to the taste effect.

In some societies in Zimbabwe, the use of repellents might raise social conflicts, where individual farmers do not have exclusive rights to the residues on their land, and attempts to conserve the residues can lead to confrontation (Wall, 2009). Sharing of the information on importance of crop residues as mulch and use of repellents could help to resolve these issues since farmers are allowed to carry, stock and then return residues to their fields without raising conflicts. In Zimbabwe, Wall (2009) reported success with CA farmers through support from a local government councillor who facilitated a by-law barring communal grazing of fields in winter following CA demonstrations implemented in Shamva. The practice of communal grazing has been found to result in net nutrient transfer from fields owned by non-cattle owners to those of cattle owners through regular manure applications in
the fields of the latter (Mtambanengwe, 2006). Local studies in the past have already shown the benefit of cattle manure (Mugwira and Murwira, 1997, Nzuma *et al.*, 1998, Chivenge, 2003, Mtambanengwe, 2006 and) and goat droppings (Masikati, 2006) to replenish soil fertility. Thus, communal grazing occurs at the expense of the poorer farmers who lose their residues to the cattle owners. The findings of this study could thus open a new avenue for livestock management in CA systems.

7.2 Importance of crop residues to termite prevalence and soil properties

This study also showed crop residues attract termites resulting in severe crop damage in maize fields if harvesting is delayed. Fields under CA had generally more termites than conventionally tilled fields (where remaining crop residues are buried and incorporated into the soil during land preparation). In Kenya and Uganda, termites have been reported to result in yield loss (Maniania et al., 2001, Semakatte et al., 2003) since they attack the cob when the maize stalk have fallen down. The results of this study showed a high maize crop damage of about 42% under CA compared to 30.1% under conventional ploughing in Kadoma. The addition of crop residues under CA had no significant effect on crop lodging and CA had higher lodged plants compared to CMP. Thus, the hypothesis that crop damage is reduced by increasing crop residues under CA systems was rejected in Kadoma. The results suggested that crop damage by termites is generally more severe in CA systems compared to CMP. This could have been so, since all initially applied crop residues were consumed by termites by the time the crop reached physiological maturity stage. The higher crop damage under CA compared to CMP could also be attributed to the disturbance of termites' nests and channels under CMP during ploughing (Kladiviko et al., 2008) whilst CA promoted uninterupted movement of termites to the surface. Soil organic carbon and aggregate stability were not significantly correlated to termite prevalence and crop residues in CA systems

In Chikombedzi, even though CA with residues had more termites than CMP, average crop damage due to termites was as low as 7% in CA and 4.6% in CMP. Addition of sorghum residues under CA also had no significant effect on reducing crop lodging. This suggests that sorghum is not a good termite attractant and food source. Some research has shown that sorghum might have insecticidal properties such as naphthoquinones which may contribute to plant resistance against termites attack (Osbrink *et al.*, 2005). However, increasing the sorghum crop residues resulted in a positive but insignificant increase in termite numbers and aggregate stability. In contrast to Kadoma findings, the crop residues resulted in a significant increase could be due to the nature of vertisols, that they swell and churn when wet, this characteristic might have contributed to increased soil–residue mixing during dry periods thereby prolonging decomposition of surface residues into soil organic matter, hence a significant increase in C as residues increased.

In conclusion, the benefits of CA to soil properties are not seen in the short term in Kadoma whilst in Chikombedzi, with respect to SOC, the benefits are short term (experienced after two seasons of implementation). Research has also found that although termites affect aggregation positively in arable systems, they do so only as secondary factors (De Gryze *et al.*, 2007) and the overall aggregate stability produced differs among termite species (Garnier-Sillam and Harry, 1995). The dominant termites observed in the study sites were fungus-growing termites which are reported to be less effective in improving soil aggregation (Garnier-Sillam and Harry, 1995).

7.3 Recommendations to farmers

When farmers grow maize under CA in areas with high level of termite infestation, they should expect higher crop damage by termites compared to CMP. There is thus need for termite control and early harvesting. In areas with high biomass production, farmers can use identified potential repellents (tobacco, cowdung, goat droppings, and chilli) to control livestock from grazing their crop residues in the field. However, their efficiency depends on availability of alternative feed.

7.4 Recommendations for further studies

In addition to the identified potential repellents, there is need to explore more non-poisonous alternative repellents that can be applied at low rates to deter livestock grazing on crop residues during the dry non-cropping season of Zimbabwe.

In most smallholder areas of Zimbabwe, communal grazing during the dry non-cropping season normally starts in May or June up to October or November. Therefore, there is need to further test the effectiveness of repellents when reapplied after at least 3 weeks and observe the behavior of livestock to the treated repellents in areas with high biomass during the non-cropping season. The experiment needs to be done all the way from harvesting till onset of the next rainy season since what an animal eats depends largely on its nutritional needs, past experience and available food resources (Hill, 2002).

There is need to determine crop residues' effect on SOC and aggregate stability in fields cropped for more than 2 years under CA, in areas with high levels of termite infestation.

To determine the effects of CA on SOM, SOC was measured and showed no significant results within two periods. It is therefore recommended that particulate organic matter be measured for short term trials.

Since crop residues are known to enhance soil properties and soil macrofauna abundance, breeding of maize varieties which are non-palatable to local termite species could help in reducing yield loss due to crop damage by termites.

There is also need for frequent sampling (such as fortnightly) after application of residues to determine the trends in termite numbers with increase in crop residue amounts throughout the season.

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Appendices

Appendix A: List of international presentations and publications from this thesis

Mutsamba, **E.F.**, Nyagumbo.I. and Mafongoya (2012). Dry season crop residue management using organic livestock repellents under conservation agriculture in Zimbabwe. *Journal of Organic Systems* 7:5-13

Mutsamba, E. F. Nyagumbo, I. and Mafongoya P.L. (2010). Linkages between crop residues, termite prevalence and crop lodging under conservation agriculture in Zimbabwe. Extended abstract published In *RUFORUM second Biennial Conference Proceedings*, 20-24 September 2010, Entebbe, Uganda.

Mafongoya, P.L. Nyamangara, J., Nyagumbo, I., Sileshi, G., Siziba, S., **Mutsamba, E.,** Chimwene, P., and Mutema, M. (**2011**). Conservation agriculture and soil health. In *Regional Conservation Agriculture symposium Proceedings*, Emperors palace, Johannesburg, South Africa, 8-10 February 2011.

Mutsamba, E. F. Nyagumbo, I. and Mafongoya P.L. **(2011)** Termite prevalence and crop lodging under conservation agriculture in Semi-arid Zimbabwe, Abstract submitted and presented at the 5th World Congress on Conservation Agriculture held in Brisbane, Australia from 26-29 September, 2011

Awards from the thesis data

3rd best oral presentation award at the RUFORUM second Biennial Conference held from

20-24 September 2010, Entebbe, Uganda.



Appendix B: Rainfall received in the study sites

Mean daily rainfall received in Kadoma during 2008/2009 season.

Nov'08 means November 2008 and applies for all the respective month



Mean daily rainfall received in Kadoma during 2009/2010 season.

NB: Nov'09 means November 2009 and applies for all the respective month





Nov'08 means November 2008 and applies for all the respective month



Mean daily rainfall received in Chikombedzi during 2009/2010 season.

NB: Nov'09 means November 2009 and applies for all the respective month

Appendix C: Selected statistical analysis

ANOVA table showing regression analysis of % C as influenced by residue amount under CA in Chikombedzi

Source of variation	d.f.	S.S.	m.s	v.r	Fpr.
Regression	1	0.0729	0.07289	4.42	0.041
Residual	48	0.7925	0.01651		
Total	49	0.8654	0.01766		

ANOVA table showing regression analysis of termites/m² as influenced by residue amount under CA in Kadoma

Source of variation	d.f.	S.S.	m.s	v.r	Fpr.
Regression	1	1947920	1947920	4.18	0.049
Residual	34	15831299	465626		
Total	35	17779219	507978		

ANOVA showing crop yield results at Chikombedzi in 2008/9 season

Source of variation	d.f.	S.S.	m.s	v.r	Fpr.
Farmer.blockstratum					
Farmer	2	37600604	18800302	129.92	<.001
Residual	9	1302349	144705	1.80	
Farmer.block.*Units*stratum					
Treatment	2	2735895	683974	8.51	<.001
Farmer.Treatment	8	2823258	352907	4.39	<.001
Residual	36	2892731	80354		
Total	59	47354837			

Appendix D

Effects of residue amount and time on in-season soil moisture storage in Chikombedzi during the 2008/9 season

		Januar	y 2009	March 2009			
Treatment	Zava	Chavani	Ndawi	Zava	Chavani	Ndawi	
0 t/ha	414.7	333	224.3	248.5	228.3	112.8	
2 t/ha	408.8	358.9	279.2	248.4	224.6	139.4	
4 t/ha	371.5	352.4	266.6	264.5	243.7	113.4	
6 t/ha	380.6	344.6	245.1	277.3	201.4	124.4	
CMP	374.1	332.5	189.5	234.1	192	94.7	
Mean	390	344	241	255	218	117	

Table adapted from Mutema (2009)

Note:

0 t/ha = CA planting basins + no crop residues added 2 t/ha = CA planting basins + 2 tons ha⁻¹ crop residues applied as surface mulch 4 t/ha = CA planting basins + 4 tons ha⁻¹ crop residues applied as surface mulch 6 t/ha = CA planting basins + 4 tons ha⁻¹ crop residues applied as surface mulch CMP = conventional mouldboard ploughing