CHAPTER 1

GENERAL INTRODUCTION

1.1 Background

The last 10 years has seen an increase in the promotion of conservation agriculture (CA) to smallholder farmers in sub-Saharan Africa by a large number of research and development organisations (Andersson & Giller, 2012). Conservation agriculture is believed to have great potential to sustainably improve crop productivity for smallholder farmers in the region especially those with limited access to draught animal power and external inputs (FAO, 2010). Conservation agriculture comprises the simultaneous application of minimum tillage (MT), provision of permanent soil cover and crop rotation practiced in tandem with good crop management. According to Derpsch & Friedrich (2009) CA is a universal technology from which benefits can be derived across climatic zones and farming systems. On large-scale mechanised farms, benefits associated with CA include savings in fuel, time, labour and improved conservation of soil and water (Kassam *et al*., 2009). Adoption of CA by smallholder farmers is reported to be increasing in South America due to labour and time savings, erosion control, increased crop yield and better incomes (Bolliger *et al*., 2006).

In sub-Saharan Africa, CA offers the potential benefits of early planting for smallholder farmers with limited access to draught animal power (Twomlow *et al*., 2008), labour savings with use of implements like the ripper tine (Baudron *et al*., 2007), yield stabilisation and improvements in soil and water conservation (Thierfelder & Wall, 2009). Grain yield of maize (*Zea mays* L.), teff (*Eragrostis tef* (Zuccagani) Trotter) and wheat (*Triticum aestivum* L.) have been reported to double under CA-based practices compared to conventional farmer practices in Ghana, Ethiopia, Tanzania and Malawi (Ito *et al*., 2007) , Kenya (Rockstrom *et al*., 2009) and Mozambique (Nkala *et al*., 2011; Grabowski, 2011). In southern Africa, CA mainly comprises dry season land preparation using handheld hoes, crop residues retention on fields to provide at least 30% soil cover at planting and three-year rotations of a cereal, legume and cash crop or small grain

(Baudron *et al*., 2007; Mazvimavi & Twomlow, 2009). In semi-arid southern Zambia, this hoe-based CA is reported to have yielded on average an additional 1 694 kg $ha^{-1}$of maize grain on smallholder farmers' fields (GART, 2008). The increased maize yield was attributed mainly to early planting (45%), timely weeding (26%), improvements in soil fertility (20%) and the remainder of yield benefits derived from rainwater harvesting.

However, there is an increasing amount of evidence that suggests that CA may be less compatible with smallholder agriculture compared to large and mechanised farm holdings. Derpsch (2008) reports that adoption of CA by smallholder farmers in South America has been slow compared to that on large and more mechanised farms. The smallholder farmers face challenges in practicing permanent no-tillage and diversified crop rotations as recommended in CA. The no-tillage fields are occasionally tilled in order to control troublesome perennial weeds and combat soil compaction (Ribeiro *et al*., 2005). Furthermore, cover crops with low market demand are excluded from crop rotations resulting in less diversified crop sequences. The suitability of CA for the majority of smallholder farmers in sub-Saharan Africa is also being questioned by a number of researchers (Giller *et al*., 2009; Gowing & Palmer, 2008; Baudron *et al*., 2012a). The majority of smallholder farmers reported to be practicing CA in southern Africa are in fact practicing minimum tillage (Baudron *et al*., 2007; Mazvimavi *et al*., 2011) due to shortages of crop residue for mulching and poorly developed markets for legumes and small grains (Ncube, 2007; Mutsamba *et al*., 2012). In the mixed crop/livestock farming systems common to smallholder agriculture in the region, crop residues are primarily used to feed livestock during the dry season. In much of southern America, additional organic matter is obtained through the growing of cover crops such as black oats (*Avena strigosa* Schreb) and lablab (*Dolichos lablab* L.) either in sequence or association with cash crops in CA (Ribeiro *et al*., 2005). This is, however, not possible in southern Africa where the harsh and long dry season and the use of fields as communal grazing areas after crop harvesting preclude the growing of cover crops in dryland smallholder agriculture.

According to Baudron *et al*. (2012a) most smallholder farmers are unlikely to adopt a technology that requires greater capital and / or labour than their current farming practice. The promotion of CA to smallholder farmers in sub-Saharan Africa was often tied to free or subsidised inputs of seed, fertilisers and to a lesser extent herbicides (Ito *et al*., 2007; Giller *et al*., 2009). This resulted in higher crop yields even where only MT was adopted by farmers than obtained under conventional farmer practice where little or no fertilisers were used (Rusinamhodzi *et al*., 2011). Research findings from on-farm studies in Zimbabwe suggest that without fertiliser, CA or MT systems result in slight or no crop yield increases (Twomlow *et al*., 2009; Rusinamhodzi *et al*. 2011). This requirement for fertilisers may be the reason for the lack of expansion of area committed to MT on smallholder farms in southern Africa despite the reported crop yield increases (Baudron *et al*., 2007; Mazvimavi & Twomlow, 2009, Grabowski, 2011). Furthermore, an increase in hoe weeding frequency that sometimes translated into doubling of labour requirements has been reported under CA as practiced by smallholder farmers (Haggblade & Tembo, 2003). On hoe-based CA farms in Zambia, additional maize grain yield was obtained when weeding was done timeously which in some cases translated to up to six hoe weedings per cropping season (Baudron et al., 2007; GART, 2008). Weed control has long been recognised as a major constraint to the widespread adoption of minimum tillage-based technologies such as conservation tillage and CA. Weeds are viewed by Andersson & Giller (2012) as the ‘Achilles heel of CA’ while Farooq *et al*. (2011) contend that weed management is the fourth principle of CA.

Tillage has long been used as an important method of weed control by farmers. Ploughing minimises weed infestations through burial of fresh weed seeds to depths from which germination and emergence is difficult (Chauhan *et al*., 2006a), buries any existing standing vegetation, disrupts growth of perennial weeds by exposing storage organs to dessication (Locke *et al*., 2002) and in this way prepares a clean seedbed for crops. In contrast, the CA tillage techniques of hand hoe-made planting basins and ripper tine being currently promoted in southern Africa leave over 80% of the soil area undisturbed (Thierfelder & Wall, 2009). Consequently, greater than 50% of fresh weed seeds are maintained near the soil surface where conditions are conducive for germination (Chauhan *et al*., 2006b). Weed infestations may, therefore, be higher under MT systems than conventional tillage. Research carried out in southern Africa reported higher weed biomass (Shumba *et al*., 1992; Vogel, 1994; Mabasa *et al*., 1998; Makanganise *et al*., 2001) and weed scores (Muliokela *et al*. 2001) under MT systems relative to convention mouldboard plough tillage. In addition, Vogel (1994) and Makanganise *et* *al*. (2001) observed the proliferation of perennial weeds such as *Cynodon dactylon* (L.) and annual weeds such as *Richardia scabra* L.in MT systems. The high weed growth associated with MT systems was identified by Nyagumbo (1999) as one of the main reasons for the low adoption of technologies such as no-till tied ridging and ripping by smallholder farmers in Zimbabwe.

However, promoters of CA argue that under the recommended practices weeds are only a problem during the first two years of adoption with weed infestations and labour requirements declining in subsequent years (FAO, 2012a; Thierfelder & Wall, undated). The improved weed management in CA is reported to be a result of the reduction in the soil weed seed bank due to use of practices that minimise weed seed return. Without access to herbicides, smallholder farmers in southern Africa are recommended to weed up to six times during the cropping season and also over the dry season when fields are un-cropped (Baudron *et al*, 2007; ZCATF, 2009) so as to reduce weed seed shed from existing vegetation. In addition, the CA practices of crop residue mulching and crop rotation are reported to aid in weed management. Crop residue mulches have been reported to suppress emergence and growth of weeds (Gill *et al*., 1992; Christoffoleti *et al*., 2007) while crop rotations can lead to greater weed mortalities than monocropping due to greater variability in the type and timing of soil and crop management (Cardina *et al*., 2002; Anderson, 2006). Under recommended CA practices, the cost of herbicides was reduced in sunnhemp (*Crotalaria juncea* L.) grown in a diversified rotation that included short duration green manure cover crops compared to monoculture in Paraguay (Kleuwer *et al*., 1998 cited in Derpsch, 2008). Furthermore, on some CA farms, herbicides were applied only before planting with the low weed infestation during the cropping season managed using only hand hoe weeding.

However, in contrast to the reported improvements in weed management with time under CA mostly observed on large scale farms, Bolliger *et al.* (2006) reports that CA is associated with increased herbicide use more than 20 years after its adoption by smallholder farmers in Brazil. As a result, herbicides are reported to present 11% of production costs in CA compared with between 2 and 5% in conventional tillage systems (Gowing & Palmer, 2008). A consequence of the increased weed pressure and prevalence of some troublesome perennial weed species observed under smallholder CA fields is the occasional ploughing or harrowing carried out in CA in order to effectively control weeds and reduce cost associated with use of herbicides (Ribeiro *et al.*, 2005; Gowing & Palmer, 2008). These findings, therefore, suggest that under sub-optimal CA practices weed management can still be serious issue even after more than 10 years of CA practice.

1.2 Rationale of study

Conservation agriculture is viewed by many to have the potential to sustainably increase crop productivity of smallholder farmers in semi-arid areas of southern Africa. The *in situ* water harvesting, early planting, the judicious use of limited fertiliser inputs and improved management associated with CA address the major constraints to crop production in smallholder agriculture in the region. As a result, CA has received increasing support for dissemination by international agencies, research organisations and has even been incorporated into the agriculture policy of NEPAD, AGRA and national agriculture programs in a number of countries in sub-Saharan Africa (Andersson & Giller, 2012). However, the suitability of CA for the majority of smallholder farmers in Africa is still a contentious among researchers and development practitioners. Practices such as crop residue mulching are incompatible with the prevalent use of crop residue as a livestock fodder during winter. Poor markets for legume seed and products limit the adoption of crop rotation. Due to these challenges, the earliest form of CA adoption by the majority of smallholder farmers in southern Africa has been minimum tillage with improved management. The higher level of management in MT has resulted in crop grain yield increases of over 100% compared to conventional mouldboard plough tillage in the short-term.

However, most smallholder farmers are facing problems in managing weeds with a reported doubling of labour required for hoe weeding. Proponents of CA argue that weeds are only a problem in the first two years and decline with time when MT is practiced with the other CA principles of crop residue mulching and diversified crop rotations (FAO, 2012a). Although a few studies have been carried out on weeds in MT and conservation tillage (CT) systems, no information is available on weed population dynamics under the CA practices currently being promoted to smallholder farmers in southern Africa. There is, thus, no empirical evidence to support the assertion that weed pressure declines from the third year of CA adoption. The studies where weed management improved with time in CA involved the use of herbicides, permanent soil cover and diversified rotations that included cover crops with cropping done in both the winter and summer seasons (Bolliger *et al*., 2006; Derpsch, 2008).

The situation under smallholder agriculture in southern Africa differs quite markedly from that on farms in South America where CA is reported to have led to improved weed management. Most smallholder farmers have limited access to herbicides and rely mainly on manual hoe weeding to control weeds (Gianessi, 2009). Under smallholder CA in southern Africa, permanent soil cover is not possible with the recommended practice being the retention of crop residue as surface mulch to provide at least 30% soil cover at planting. Although crop residue mulching is reported to suppress weed growth (Christofolleti *et al*., 2007) and thus potentially reduce weeding burden in MT systems (Gill *et al*., 1992; FAO, 2010), the mulch thresholds for weed suppression are unknown under smallholder CA practices in southern Africa. Furthermore, the recommendation to use crop residues for mulching in CA conflicts with the traditional use of crop residues as an important feed source for livestock during the long, dry season (Giller *et al*., 2009). According to Mazvimavi *et al*. (2011) more than 80% of farmers practice maize monocropping on fields that are reported to be under CA in Zimbabwe. This partial adoption of CA in smallholder agriculture is likely to result in increased weed pressure and a shift to perennial weed species under MT systems which most smallholder farmers may not be able to cope with using their current weed control strategy of hoe weeding.

The aim of the study was to assess weed infestation, weed species composition and crop yield under recommended CA practices and smallholder farmer management in semi-arid Zimbabwe. Weed growth, weed community composition and crop yields under different maize mulch rates and hoe weeding intensities were studied in the fifth and sixth years of a long-term CA experiment. This experiment explored whether the frequency of hoe weeding and maize mulch rate needed for weed suppression could be reduced without any yield penalty after four years of CA. An observational study was done over one season on farmers' fields to study extent of adoption of CA by smallholder farmers, weed infestation and management in fields that had been under CA for different lengths of time and to determine what farmers viewed as the major constraint to CA adoption. Since other management practices can also influence weed infestations in fields (Swanton & Booth, 2002), cultural practices associated with CA that could potentially reduce or increase weed pressure in fields were also investigated.

The hypotheses to be tested in the study are:

1. Weed and crop growth do not differ among i) tillage systems ii) maize residue mulch rates and iii) levels of hoe weeding intensity after more than four years of CA.
2. There is no difference in the weed community composition under different tillage systems, maize residue rates and intensities of hoe weeding in the fifth and sixth years of CA.
3. Weed infestations and weed management do not differ with number of years field has been under CA on smallholder farms. As a result labour, especially for weed management, is the main production constraint in CA.
4. Weed infestations on CA fields are the result of other cultural practices besides tillage.

1.3 Research questions

This study was designed to determine weed infestation and community composition under recommended CA practices and actual smallholder CA conditions in semi-arid southern Zimbabwe and several issues were investigated.

1. What are the effects of tillage systems, maize residue mulch rates and levels of intensity of hoe weeding on weed and crop growth after more than four years of CA?
2. Does the weed community differ with tillage system, maize mulch rates and level of hoe weeding intensity in the fifth and sixth years of CA?
3. Which of the three principles of CA have been adopted by smallholder farmers in semi-arid Zimbabwe? Do weed infestations differ with number of years a field has been under CA as practiced by these farmers? What is viewed by farmers as the main constraint to widespread CA adoption?

4. Are there any cultural practices that can ameliorate or increase weed infestations in CA under smallholder farming systems?

1.4 Outline of thesis

The thesis is organised into seven chapters beginning with Chapter 1 where the background, rationale, objectives and an outline of the thesis are given. The second chapter consists of a review of literature on CA, its associated benefits and constraints to adoption, weed population responses to tillage, crop residue mulching and crop rotation, and weed management in CA. Chapter 3 is based on a long-term CA field experiment designed to measure weed and crop growth under different maize mulch rates and hoe weeding intensity in the fifth and sixth years. A detailed description of the weed community composition under the long-term CA experiment is presented in Chapter 4. Results from an observational study on weed and maize growth under farmers' fields are given in the fifth chapter. Chapter 6 presents the findings on weed seed viability in composts applied by farmers on CA fields. The seventh chapter is a synthesis of chapters 3 to 6 where overall conclusions and practical recommendations of the entire study are given.