CHAPTER 6

WEEDS IN COMPOST APPLIED IN SMALLHOLDER CONSERVATION FARMING

ABSTRACT

The use of composted cattle manure and plant litter to improve soil fertility in conservation farming (CF) may create a weed management problem if poorly composted materials are used. In a study carried out during the 2009/10 cropping season in Wards 12 and 14 of Masvingo District, compost samples were collected during storage in August 2009 and at time of field application in December 2009 from six randomly selected CF farms to determine the effect of composting on weed seedling emergence. The weed spectrum in compost applied to CF fields was also assessed on an additional 10 farms selected randomly from farms that were monitored for weed emergence during the 2008/09 cropping season. Weed seed viability in compost was determined using the weed seedling emergence method. On four out of six farms, composting markedly ($P < 0.05$) reduced weed seedling emergence by at least 60% with an associated decline in density of the most important weed species *Eleusine indica, Cynodon dactylon* and *Amaranthus hybridus*. However, on most farms composting did not completely eliminate viable weed seeds with emergence of between 3 and 142 weed seedlings kg^{-1} of mature compost observed. This translated to potential addition of weed seedlings that ranged from 18 000 to 852 000 ha^{-1} at the current farmer compost application rate of 6 t ha^{-1}. The variation in weed seedling emergence from the composts probably reflected the differences in compost storage on the different farms. Heap stored cattle manure had 57% more ($P < 0.05$) weed seedlings and double the *C. dactylon* density than pit stored compost suggesting that pit storage was more effective than heap storage in reducing weed seed viability. However, it is unlikely that labour constrained households will carry out all the recommended pit composting practices as CF is already associated with high labour requirements for basin preparation and weeding.

Key words: Conservation farming, compost storage, cattle manure, plant litter, weed composition

6. 1 INTRODUCTION

The use of organic nutrient sources is being widely promoted to smallholder farmers practicing conservation farming (CF) in Zimbabwe (Twomlow *et al*., 2008; ZCATF, 2009). Smallholder farmers in southern Africa commonly use animal manure (Materechera, 2010) and partially decomposed tree litter (Mafongoya & Dzowela, 1998) to amend soils. The benefits of using composted manure have been reported widely and include improvement in the soil physical environment, contribution to long-term soil organic matter buildup, supply of nutrients and essential trace elements (Simpson, 1986; Zingore, 2006). However, the use of manure is limited by the severely low quantities available on most smallholder farms and its poor quality characterised by high soil content and low N (Nzuma *et al*., 1999; Murwira *et al*., 2004).

In CF, farmers are encouraged to supplement locally available organic soil amendments with small quantities of inorganic fertilisers (Twomlow *et al*., 2008). This practice is reported by Nyamangara *et al*. (2009) to improve synchonisation of nutrient release and subsequent uptake by crop. Furthermore, both organic and inorganic fertilizers are precision applied into planting basins so as to concentrate nutrients in the root zone of the crop and limit access of weeds to nutrients. However, given that the conservation agriculture manual does not include training on composting (ZCATF, 2009) and that only a small number of smallholder farmers use recommended composting techniques (Murwira *et al*., 2004) there is a strong possibility of increased weed infestation in CF fields through the use of poorly managed composts.

The frequent use of composts to ameliorate soil fertility recommended in CF may, therefore, inadvertently exacerbate smallholder farmers' weeding burden. Svotwa *et al*. (2009) reported that smallholder organic farmers in Zimbabwe cited increased weed infestation in fields where composts were used as one of their main crop production challenges. Sub-optimal composting practices were identified as the main reason for the presence of viable weed seed in composts by Zarborski (2011). The high temperatures of between 50 and 70 ^{0}C that are critical for reducing the number of viable weed seeds in compost (Egley, 1990; Dahlquist *et al*., 2007) may not be attained during the thermophilic stage of active composting under sub-optimal composting conditions. In addition to exposure to high temperature, microbial activity and emission of various chemicals including acetic acid and ammonia in compost can result in high weed seed mortality (Larney & Blackshaw, 2003; Menalled *et al*., 2005). Hence, the composting process should create conditions that are phytotoxic to weed seeds so that there is minimal introduction into field of seed of both old and new weed species that may result in future weed management problems.

The aim of this study was to determine the effect of composting practices used by farmers in Wards 12 and 14 of Masvingo District on weed seedling emergence and to assess the weed spectrum in compost applied in CF fields during the 2009/10 season. In this study, compost refers to any soil amendment obtained from the thermophilic decomposition of locally available organic waste including animal manure, plant litter and household wastes.

6.2 MATERIALS AND METHODS

6.2.1 Sample collection

Availability sampling was used to collect a total of six composts from farms in Wards 12 and 14 of Masvingo District during the dry season in August 2009. The six farmers were part of the 23 farmers whose fields had been monitored for weed emergence during the 2008/09 season (Chapter 5). The compost was collected from heaps either outside the kraal or in fields and pits depending on the farm. Samples were obtained from four random spots in pit or heap at a depth of 50 cm from the surface to give a composite sample of 1 kg. In November 2009, at the beginning of the 2009/10 cropping season, samples of the compost applied to CF fields was obtained from 16 farms including the six from August 2009 and were collected from pits or heaps (Plate 6.1) using the same procedure outlined above. However, due to limited amounts available on some farms composite samples ranged from 0.6 to 1 kg. Information on general field management including application dates and rates of composts were captured in record books given to farmers at the beginning of the 2009/10 season. Semi-structured interviews were carried out for the six farmers with paired compost samples to elicit detailed information on handling and storage of compost used by farmers.

Plate 6.1 Storage of compost with composted cattle manure heaped outside cattle kraal at farm 1(left) and pit stored compost at farm 2 in November 2009 in Ward 12 of Masvingo District

6.2.2 Weed composition determination

The compost samples from each farm were gently hand pulverized and sub-samples of 200 g per farm were each placed in a plastic pot in an uncontrolled greenhouse at Matopos Research Station. A weed seedling emergence trial was set up as a randomized complete block design with 5 replications per site for August 2009 samples and 3 replications for November 2009 samples.

The lower number of replications for November 2009 compost samples was as a result of some samples being less than 1 kg. In addition, 50 g of the applied compost from eight farms including the six farms where samples were collected in both August and November 2009 were sent for analysis for pH (water), total N and P (%), OC (%) and available N (%). The compost samples were watered daily and stirred monthly to encourage weed emergence in the greenhouse. Weed seedlings were identified and counted weekly until there was no further weed emergence. The samples obtained in August 2009 are hereafter referred to as immature compost samples as they were assumed to have been still undergoing composting at time of sampling. The November 2009 samples were sub-samples of compost applied to CF fields by farmers and will be referred to as mature compost.

6.2.3 Statistical analysis

Relative importance values were calculated for all weed species identified in immature and mature compost in order to rank weed species according to importance.

RIV = (Relative frequency + Relative density) / 2 *Equation 1*

All weed species with an RIV of 10 or less were considered rare (Chikoye & Ekeleme, 2001) and dropped from further analyses. Weed seedling data was Log (x + 1) transformed to homogenize variances and was subjected to an Un-balanced design Analysis of Variance (GenStat 9.1). For the six farms with immature and mature compost, the stage of maturity of compost and farm were the treatments. Farm was the treatment factor for the 16 mature composts. In addition, the mature composts were grouped according to type of storage used (heap or pit) and this was used a treatment factor in ANOVA.

6.3 RESULTS AND DISCUSSION

6.3.1 Effect of composting on weeds

6.3.1.1 Weed spectrum

In both the immature and mature composts, the three most important weed species were *Eleusine indica, Cynodon dactylon* and *Amaranthus hybridus* (Table 6.1). More (15) weed species were identified in the immature than mature composts (10 species). Of the important species, *Galinsoga parviflora* and *Gallium asparium* were absent from mature composting suggesting that composting was effective in reducing the seedling density at most farms. However, *E. aspera* was absent in immature samples but was identified as an important weed in mature compost samples (Table 6.1). Interestingly the RIV values of *E. indica, C. dactylon* and *A. hybridus* in mature compost were higher than in immature compost indicating that consistently high weed seedling numbers of these species were recorded in the mature compost across farms. This suggests that the compost used on the six farms during 2009/10 season were potential sources of viable weed propagules of these species. The three weed species were also found to be dominant in heaped manure by Rupende *et al*. (1998) and Munguri *et al*. (1995) in sub-humid Zimbabwe. Makanganise and Mabasa (1999) characterize *E. indica* and *A. hybridus* as weeds associated with manured fields in Zimbabwe.

One of the uses of *E. indica* identified by farmers in the study area was as one of the main grasses used for compost making (Chapter 5). Since the late season weeding was delayed to the dry season when weeds had probably seeded in CF (Chapter 5) addition of weeds such as *E. indica* likely introduced weed seeds to composts. It is recommended that farmers add weeds to compost that have not reached the reproductive stage to minimize introduction of weed seeds to compost. The prevalence in compost of the weed species *E. indica* and *C. dactylon* that were also identified as being among the most difficult to control weed species by farmers in the study area (Chapter 5) may have serious consequences for future weed management. This is because prevention of seed addition to the soil weed seed bank has long been identified as one of the central strategies of sustainable long-term weed management (Dekker, 1999; Swanton & Booth, 2004).

Table 6.1 Relative importance value (%) of weed species occurring in fresh and mature compost obtained from farms in Wards 12 and 14 of Masvingo District during 2009. Weed species are ordered according to abundance in immature compost

Latin name	Growth form	Compost (RIV %)	
		Immature	Mature
Eleusine indica (L.) Gaertn.	Annual monocot	50	66
Cynodon dactylon (L.) Pers.	Perennial monocot	38	43
Amaranthus hybrius L.	Annual dicot	30	48
Galium spurium L. ssp. africanum Verdc	Annual dicot	18	-
Galinsoga parviflora Cav.	Annual dicot	18	-
Cyperus esculentus L.	Perennial monocot	9	9
Dactyloctenium aegptyium	Annual monocot	9	-
Heterophylla hirta	Annual dicot	9	-
Hibiscus meeusei Exell	Annual dicot	9	9
Leucas martinicensis (Jacq.)R.Br.	Annual dicot	9	9
Portulaca oleracea	Annual dicot	9	-
Richardia scabra L.	Annual dicot	9	-
Setaria monophylla	Annual	9	9
Sida alba L.	Perennial dicot	9	-
Digitaria spp.	Annual monocot	1	-
Eragrostis aspera (Jacq.) Nees	Annual monocot	-	17

A '-' indicates that a weed species was absent in a given tillage system.

6.3.1.2 Weed seedling emergence

The number of total, monocot, dicot, *A. hybridus*, *C. dactylon* and *E. indica* weed seedlings significantly ($P < 0.05$) varied between the six farms. There were significant ($P < 0.05$) differences in the density of total, monocot, dicot and the population of the three most important weed species between the immature and mature compost. However, in all cases the farm and maturity factor effects were confounded within the highly significant ($P < 0.001$) farm x compost maturity interaction (Figs 6.1 and 6.2).

Mature compost obtained from four of the six farms had at least 60% ($P < 0.05$) less weed seedlings than immature compost (Fig. 6.1). The greatest reduction in weed seed viability was obtained from farm 1 where the mature composted cattle manure (Plate 6.1) had only a third of the density of weed seedlings found in the immature compost. The cattle manure at farm 1 was removed from the kraal in August 2009 and, thus, the immature compost had been heaped for less than a month at time of sampling (Appendix A). However, storage of the manure in a heap for three months reduced weed seed viability of both monocots and dicots (Fig. 6.1) including *E. indica*, *C. dactylon* and *A. hybridus.* The immature composted kraal manure had high numbers of *A. hybridus* whose seeds according to Costea *et al*. (2004) still maintain viability even after rumen digestion and elimination from the animal. The seeds may have been ingested by cattle and excreted in cow dung which was later used for composting However, heap composting for three months markedly reduced weed seed viability of *A. hybridus* such that no weed seedlings emerged in the mature composted kraal manure.

Pit composting reduced weed seedling emergence of both dicot and monocot weeds that included the species *E. indica* and *C. dactylon* at farms 2, 3 and 4 (Fig. 6.1 and 6.2). The species *A. hybridus* had low density in both immature and mature composts stored in pits probably because low amounts of cattle manure were added to the compost. The immature compost at site 4 had the lowest number of weed seedlings with no weed emergence observed in the mature compost. The level of reduction in weed seedling emergence on composting varied between farms 2, 3 and 4 probably reflecting the differences in composting procedures. Only the farmer at farm 4 received training on composting from a local NGO in 2000 and this probably contributed to production of compost that was largely free of viable weed seeds. The immature compost at farm 4 had been stored in pit for three months when sampling was done and this may explain the low weed emergence observed. The period of composting, size of pits, materials used for composting and management varied between the three farms (Appendix B) and this probably contributed to the differences observed on the effect of composting on weed seedling emergence. A reduction in weed emergence on composting has also been reported by Cudney *et al.* (1992), Rupende *et al*. (1998) and Menalled *et al.* 2005. High temperatures, increased microbial activity, toxic gases and acids produced during composting have been reported to reduce weed seed viability (Egley, 1990; Eghball & Lesoing, 2000; Dahlquist *et al*., 2007).

However, pit composting was associated with high weed seedling emergence in mature relative to immature compost at farms 5 and 6 (Fig. 6.1 and 6.2). Mature compost obtained from farm 6 had at least 2-fold ($P < 0 .05$) the density of total and monocot weeds compared to the immature compost. The seedlings of *E. indica*, *C. dactylon* and *A.hybridus* did not emerge in the immature compost but emerged in high numbers in the mature compost from farm 6 with a similar observation recorded for *C. dactylon* in compost from farm 5 (Fig. 6.2). The composts from farms 5 and 6 received the least management compared to those obtained from farms 2, 3 and 4 (Appendix B). The farmer at farm 6, although trained on composting by a local NGO in 2000, reported that the recommended composting procedure was too labour intensive and had opted to collect partially decomposed forest litter from an anthill in the Lake Mutirikwi Game Reserve and place in a shallow pit for four months until field application. According to the farmer there was no need to dig a deep pit, add water and other compost making aids such as anthill soil or N fertiliser. This low management of compost pit was in contrast to management at farm 4 where the farmer followed most of the recommended composting practices outlined in the AGRITEX/ZFU, (1999) soil fertility management manual. According to Zarborski (2011) improperly assembled and maintained compost piles may not reach the high temperature that is lethal for most weed seeds. Furthermore, temperatures of above 40 ^{0}C but below 50 ^{0}C were observed to promote germination of some weed species (Egley, 1990; Dahlquist *et al*., 2007) and this was attributed to these sub-lethal temperatures breaking seed-coat enhanced dormancy. The compost at farms 5 and 6 may have created conditions that relieved dormancy of weed seeds during composting and this was observed as high weed seedling emergence in the mature compost.

On the overall both heap and pit composting reduced weed seed viability. However, the extent of reduction in weed seedling number in mature compost depends on how the compost was managed.

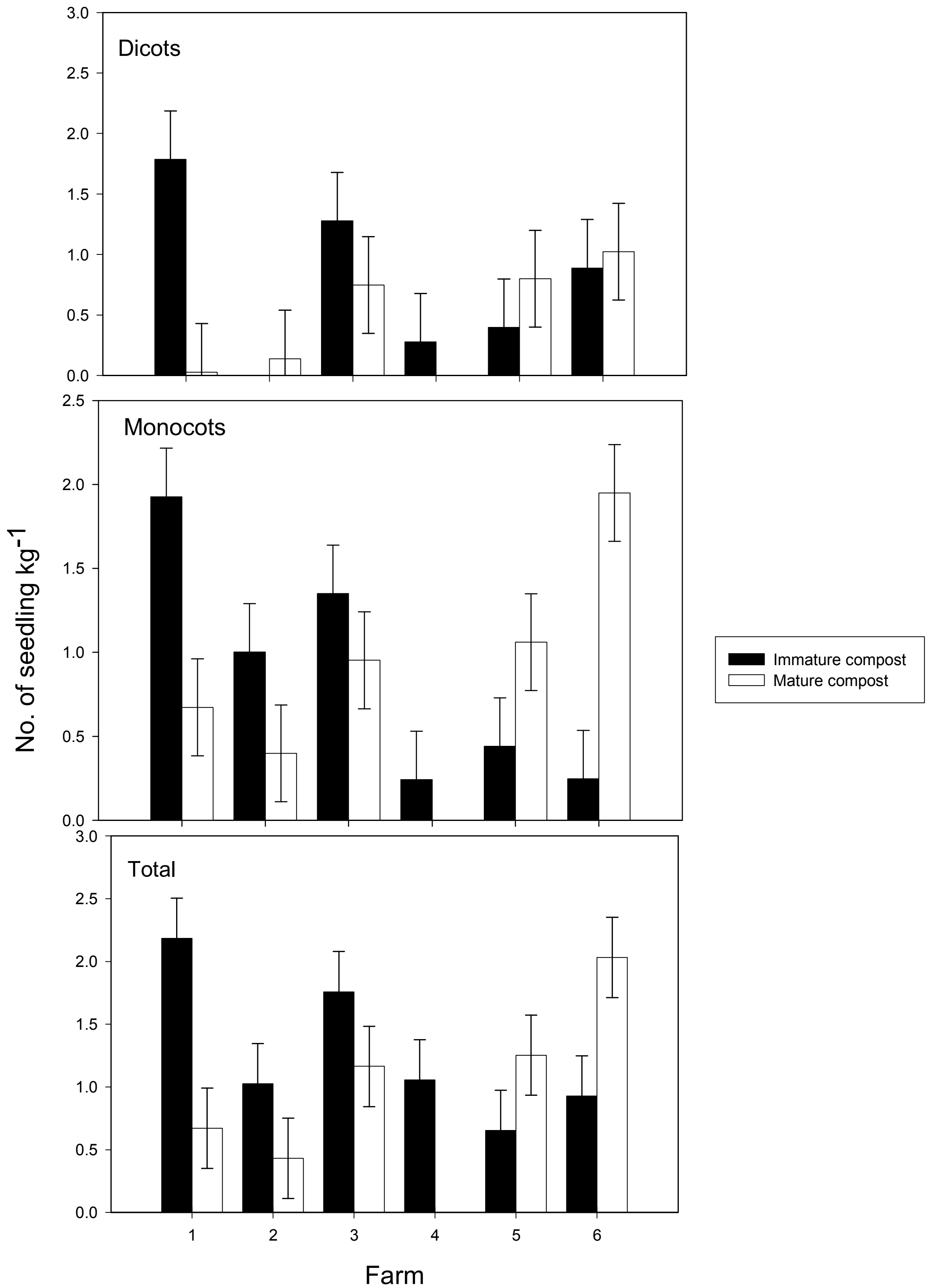

Fig 6.1 Farm x compost maturity interaction on the number of weed seedlings that emerged from composts obtained from farms in Wards 12 and 14 of Masvingo District during 2009/10 season. Narrow bars represent ± SED. Log (*x* + 1) transformed data presented

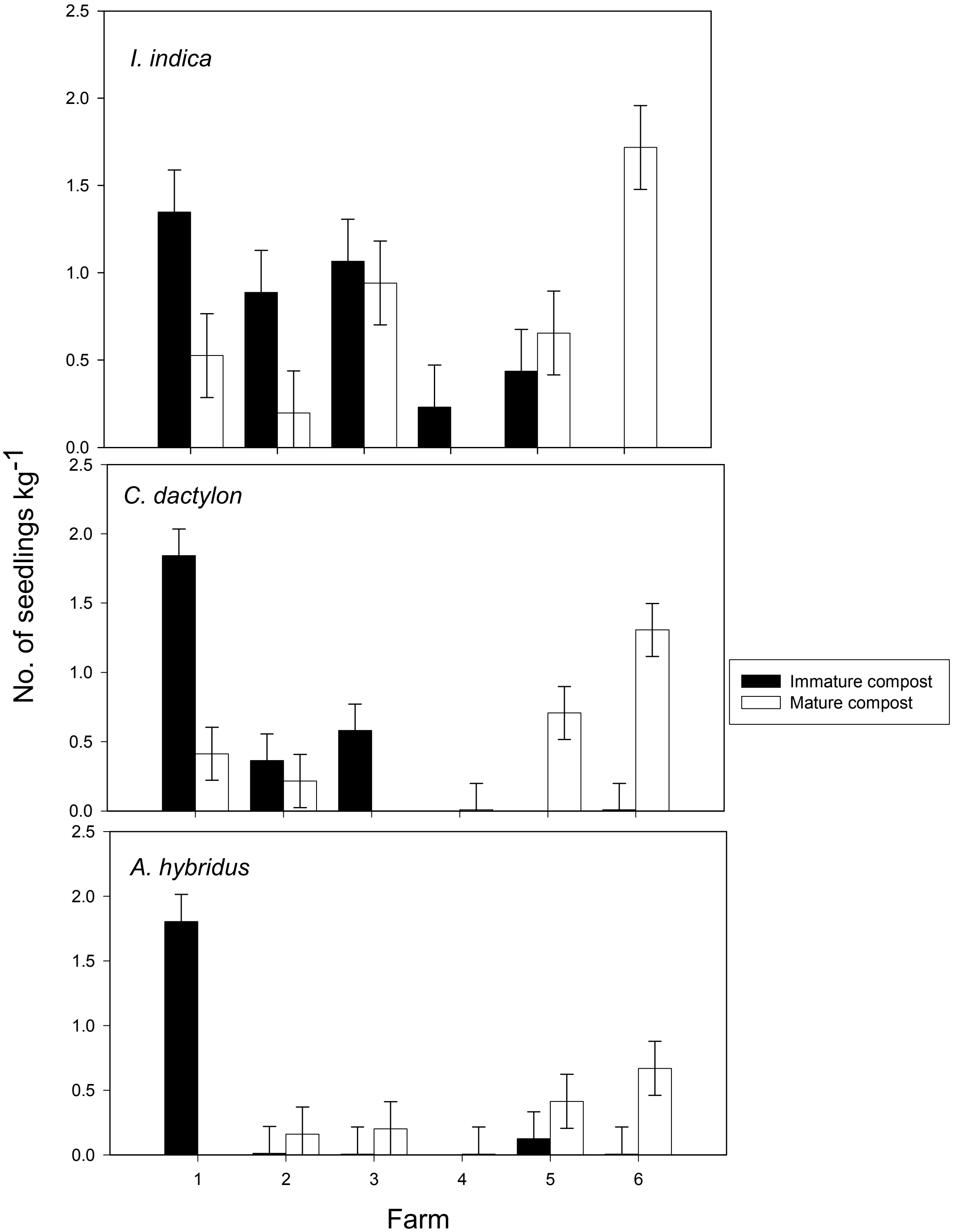

Fig 6.2 Farm x compost maturity interaction on the number of weed seedlings of *E. indica*, *C. dactylon* and *A. hybridus* that emerged from composts obtained from farms in Wards 12 and 14 of Masvingo District during 2009/10 season. Narrow bars represent ± SED. Log (x + 1) transformed data presented

6.3.2 Weeds in applied composts

6.3.2.1 Weed species composition

The most important weed species in composts applied to CF fields during the 2009/10 season were *E. indica*, *C. dactylon* and *A. hybridus* (Table 6.2) reflecting the findings obtained from the smaller sample of farms used to compare immature and mature compost (Table 6.1). Grass species were the prevalent weeds in compost applied in CF fields which may be a result of the widespread use of grass weeds as composting material by farmers. Although there was variation in relative importance values of weed species identified in heap and pit stored compost, the ranking of the four most important weed species remained the same (Table 6.2).

Table 6.2. Relative importance value (%) of weed species occurring in heap and pit stored composts applied on farms in 2009 in Wards 12 and 14 of Masvingo district. Weed species are ordered according to abundance in heap stored compost

Latin name	Growth form[a]	Compost storage (RIV %)	
		Heap	Pit
Eleusine indica	Annual monocot	66	68
Cynodon dactylon	Perennial monocot	65	40
Amaranthus hybridus	Annual dicot	19	33
Cyperus esculentus	Perennial monocot	15	11
Phyllanthus leucanthus	Annual dicot	7	-
Sida alba	Perennial dicot	7	-
Hibiscus meeusei	Annual dicot	-	6
Ipomea plebia	Annual dicot	-	6
Leucas martinicensis	Annual dicot	-	6
Acalypha crenata	Annual dicot	-	6
Corchorus tridens	Annual dicot	-	6
Digitaria spp.	Annual monocot	-	6
Setaria monophylla	Annual	-	6
Citrullus lanatus var. *lanatus*	Annual Dicot	-	6

A '-' indicates that a weed species was absent in a given tillage system

6.3.2.2 Effect of farm

There were significant ($P < 0.05$) differences in the number of total, dicot and monocot weed seedlings that emerged from mature compost obtained from the different farms in 2009 (Fig. 6.3). Mature compost obtained from farms 6, 11 and 12 had the highest ($P < 0.05$) number of weed seedlings whereas those from farms 4, 8 and 13 recorded no weed seedlings emergence. Significantly higher density of *E. indica* and *C. dactylon* emerged from composts obtained from farms 6, 11 and 12 (Fig. 6.4) which translated into the higher monocot weed seedling numbers recorded at these farms (Fig. 6.3) compared to composts obtained from the other farms. This suggests that although compost was also introducing dicot weed species such as *A. hybridus* greater numbers of monocot weed species such as the more difficult to control *E. indica* and *C. dactylon* were introduced in fields.

Compost used at farms 6, 7, 10, 11, 12 and 16 had high weed seedling emergence (Fig. 6.3) indicating that this compost likely introduced weed seeds to fields were it was applied. Since the average manure application rate used by farmers in CF fields in 2009 was 6 t ha^{-1} (equivalent to 2 handfuls of compost $basin^{-1}$), the compost from farm 12 potentially introduced about 852 000 weed seedlings ha^{-1} compared to introduction of no viable weed seeds by composts at farms 4, 8 and 13. These differences may have been as a result of how composts were handled and stored at the different farms.

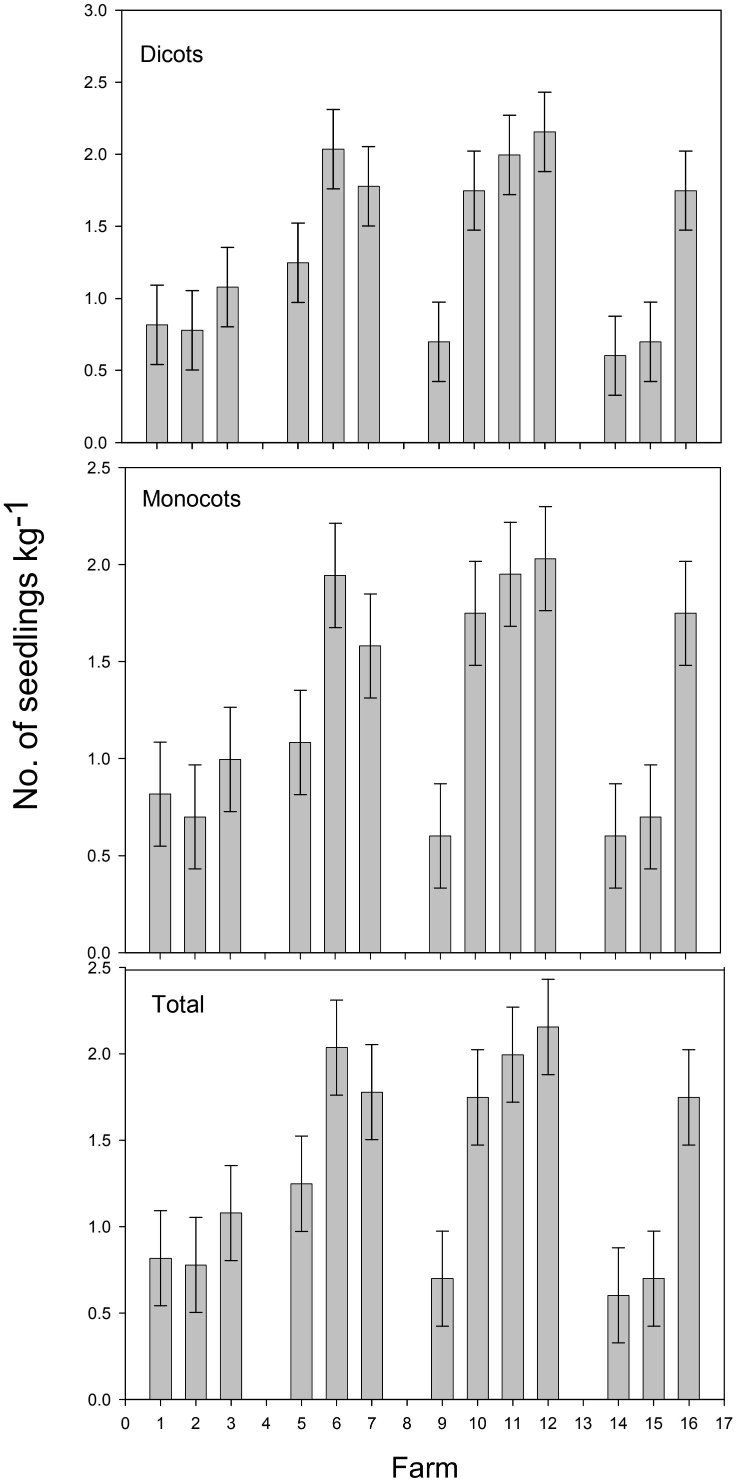

Fig 6.3 Number of total, monocot and dicot weed seedlings that emerged from composts applied to different fields in Wards 12 and 14 of Masvingo District during 2009/10 season. Narrow bars represent ± SED. Log (x + 1) transformed data presented

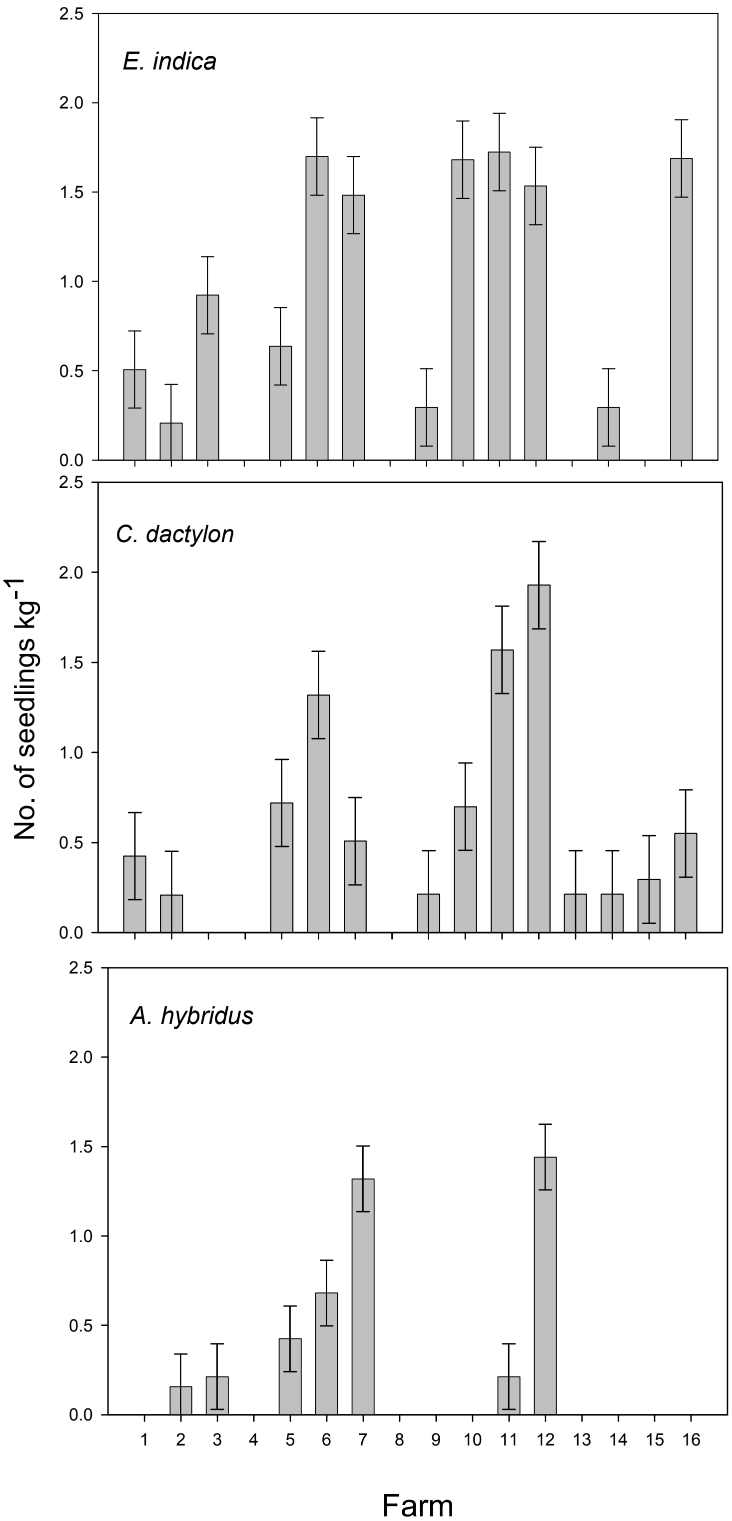

Fig 6.4 The number of weed seedlings of *E. indica*, *C. dactylon* and *A .hybridus* that emerged from composts applied ondifferent farms in Wards 12 and 14 of Masvingo District during 2009/10 season. Narrow bars represent ± SED. Log (x + 1) transformed data presented

6.3.2.3 Effect of storage method

The marked differences in weed seedling emergence from mature composts (Fig. 6.3 and 6.4) used during the 2009/10 season were likely due to handling of composts which varied between farms (Appendix A and B). During the 2009/10 season, the majority (56%) of farmers stored composts in pits while the remainder used heap storage. Where pit storage was used, the composting material comprised mainly forest litter, maize residues and mostly mature weeds to which were added small quantities of anthill soil, cattle manure and sometimes AN fertiliser depending on the farm (Appendix B). This was probably because the majority of CF farmers had limited access to cattle manure due to low livestock ownership as this group was made up of the early adopters of CF in Wards 12 and 14 (PB3+ in Chapter 5). On farms where there was access to cattle manure, harvested maize residues were added to kraal as cattle feed (Plate 6.1 at farm 1). This group comprised mainly late CF adopters (PB3-) and CONV tillage farmers. On four of the six farms, the cow dung mixed with maize residue was removed from kraals beginning from July 2009 and heaped outside kraal for a period of between 3 and 6 months before field application (Appendix A). However, on two farms the deep stall method was used where cattle manure was left in kraal until a month before field application after which it was heaped in field for a month. The differences in composting may have affected weed seed viability in heap and pit stored composts.

Heap stored composted cattle manure had significantly ($P < 0.05$) higher numbers of monocots with double the number of *C. dactylon* seedlings which ultimately translated to 57% more weed seedlings compared to pit stored compost (Table 6.3). There was, however, variation in weed seedling emergence from composted cattle manure obtained from the different farms which may have been due to differences in heaping period and size of heaps. The importance of heaping period in reducing weed seed viability is highlighted by the decline ($P < 0.01$) in weed seedling emergence with heaping period with lowest emergence recorded in composts heaped for three months (Fig. 6.5). The composted cattle manure obtained from farms 11 and 16 where the deep stall method was used was among the composts with high weed seedling emergence (Fig 6.3) probably because heaping for one month may have been insufficient to reduce weed seed viability. The high weed population in manure heaped for more than three months may have been due to dispersal of wind-blown weed seeds into un-protected heap or introduction of mature weeds after the active composting stage was complete. Zarborski (2011) reports that finished compost can be re-contaminated with weed seeds if weeds continue to be added especially after the active composting stage.

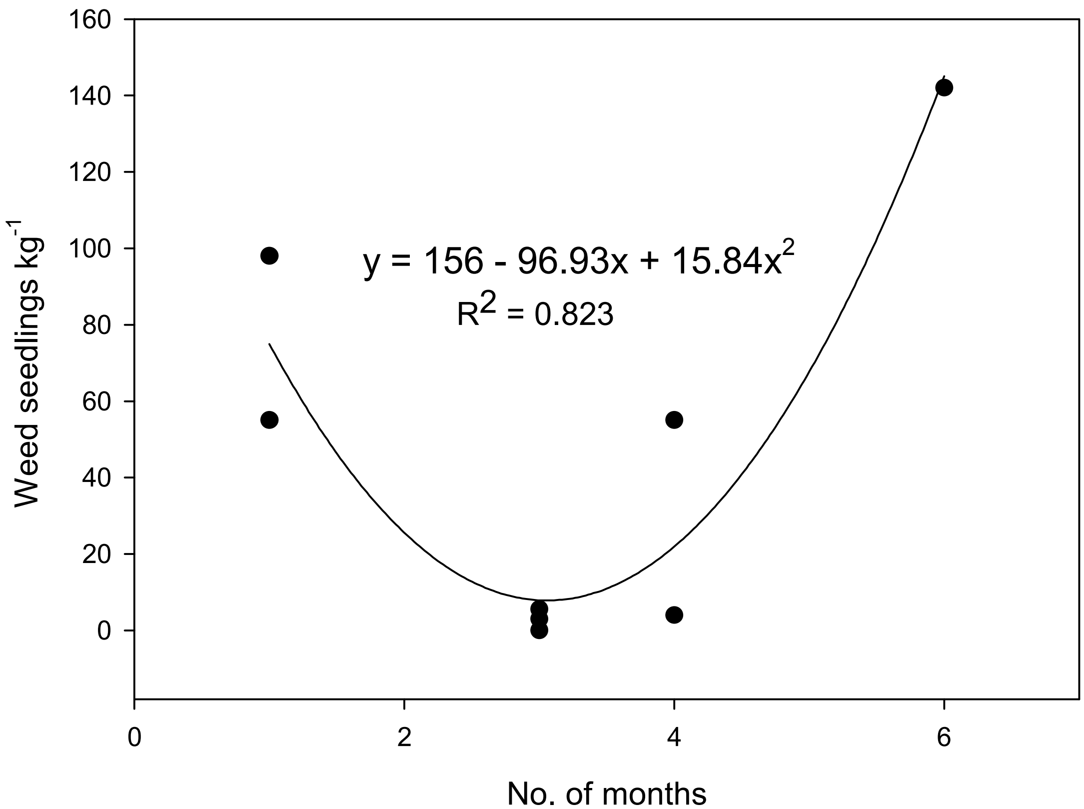

Fig. 6.5 Relationship between period of heaping and weed seedlings in composted cattle manure applied on farms in Wards 12 and 14 of Masvingo District during 2009/10 season

There is, therefore, a need to train farmers on composting cattle manure using heaps as according to N'Dayegamiye and Isfan (1991); and Rupende *et al.* (1998) the size of the heap and period of heaping have an effect on temperatures attained within compost pile and consequently the number of weed seeds that still remain viable in mature compost. The results from this study confirm the observation made by farmers in sub-humid Zimbabwe that heap stored cattle manure was associated with more weeds than compost stored in pits (Mutiro *et al*. 2004). The higher prevalence of *C. dactylon* in compost especially heap stored composted cattle manure (Table 6.3) is of concern in CF as the perennating structures are unlikely to be destroyed by the shallow hoe weeding carried out in these systems. Without access to systemic herbicides perennial grasses are likely to become a serious problem in CF for smallholder farmers.

Although pit stored compost had significantly lower weeds than heap stored compost, on most farms the mature pit stored compost still contained viable weed seeds. The compost stored in pits obtained from farms 6 and 7 had the highest weed seedlings compared to that from other farms (Fig. 6.3 and 6.4). At both farms, forest litter was used as the main plant material and it may be that forest litter required a longer composting period than the 4 months done at both farms. Furthermore, the composts from these farms were the least managed compared to those obtained from the other farms (Appendix B) and the resulting composting process may have allowed weed seeds to remain viable. Therefore, improperly handled compost was potentially a vector of weed seeds in CF fields where composts were applied annually. The compost used at farm 7 may have added over 650 000 weed seedlings ha^{-1} if applied at a rate of 6 t ha^{-1} and the farms whose composts had intermediate emergence may have added between 30 000 and 66 000 weed seedlings ha^{-1} compared to compost from farm 4 where no weed seedlings emerged. This highlights the importance of following recommended composting practices so that compost with low weed seed viability is applied in CF fields.

However, pit composting is labour intensive (Mutiro & Murwira, 2004) and most labor-constrained households are unlikely to be able to carry out all the recommended composting practices. For CF farmers there is likely to be demand for labour during the dry season for composting and basin preparation among other non-farm activities. In addition, farmers also need to decide on how to allocate the scarce crop residue among livestock feeding, mulching and composting. The high labour demands associated with basin preparation, composting and weeding in CF may result in some farmers taking the approach of the farmer from farm 6 who although trained on composting, had for the past three years opted to collect partially decomposed forest litter as this method was less labour demanding than pit composting.

However, the compost produced had high population of viable weed seeds which may have emerged in CF fields and increased the amount of labour required for hoe weeding.

Table 6.3 Weed emergence in heap and pit stored compost applied on farms in Wards 12 and 14 of Masvingo District during 2009/10 season

Compost storage	No. of weed seedlings kg^{-1} fertiliser					
	Total	Monocot	Dicots	*A. hybridus*	*C. dactylon*	*E. indica*
Heap	1.1	1.1	0.4	0.3	0.7	0.5
Pit	0.7	0.6	0.4	0.2	0.3	0.8
LSD (0.05)	0.45	0.43	ns	ns	0.33	ns

Log (x + 1) transformed data presented *Abbreviations:* LSD - least significant difference; ns - not significantly different.

6.3.2.4 Compost quality

Both heap and pit stored compost had an N% of less than 0.6% indicating that the compost used in Wards 12 and 14 was of poor nutrient quality. There was no significant difference in nutrient quality between heap and pit stored composts with levels of P and K being generally low in both. Nutrient loss in composts may have occurred when material was heaped outside pits or in fields without being covered (Appendix A and B). Nitrogen could have been lost through volatilization and leaching when the compost was exposed to hot, dry winds, sun and sometimes rains. The handling and storage of both manure and composts may have contributed to their low nutrient status suggesting the need for further training of farmers on composting.

6.4 CONCLUSION

Composting was effective in reducing ($P < 0.05$) weed seedling emergence by at least 60% in four out of six farms. There was also a significant reduction in the density of the most important weed species *E. indica*, *C. dactylon* and *A. hybridus* at these farms on composting. However, on most farms composting did not eliminate weed seeds and compost application may have potentially resulted in emergence of between 18 000 and 852 000 weed seedlings ha^{-1} at the compost application rate of 6 t ha^{-1} used on most CF fields in the study area. The variation in weed seed viability in compost applied to fields was probably a reflection of different composting practices used at the 16 farms. The majority of CF farmers practiced pit composting of mainly plant litter while farmers with access to cattle manure stored it in heaps. Heap stored composts had 57% more ($P < 0.05$) weed seedling emergence and double the *C. dactylon* density than pit stored compost suggesting that pit storage was more effective at reducing weed seed viability. Therefore, frequent use of compost as recommended in CF may lead to increases in weed infestation and density of the problematic *E. indica* and *C. dactylon* weed species where poorly stored compost is used. There is, therefore, a need to include training on composting in CF programs so as to improve nutrient quality and reduce the number of viable weed seeds.

CHAPTER 7

GENERAL DISCUSSION

7.1 Introduction

The low area under conservation agriculture (CA) on smallholder farms in southern Africa may be due to the need for more intensive weed management in CA compared to conventional tillage. Farmers, agriculture extension and research agents in the region have reported increased weed infestations on fields reported to be under CA relative to mouldboard ploughed fields. However, proponents of CA claim that weeds are only a problem where minimum tillage is adopted without the other CA principles of permanent organic soil cover and diversified crop rotations. Furthermore, they argue that with good management weeds decline within three years of CA adoption leading to more sustainable weed management in the long-term. Research presented in this thesis provides important new information on weed population dynamics under practices recommended by the Zimbabwe Conservation Agriculture Taskforce (2009) and under actual smallholder farmer practice in semi-arid areas of southern Zimbabwe.

7.2 Conservation agriculture

7.2.1 Tillage effect on weed and crop growth

A series of investigations were carried out on a long-term CA experiment to determine the effect of tillage on weed growth (Chapter 3) and weed community composition (Chapter 4). The view that weed infestations decreased within three years under recommended CA practices was not substantiated in this study. The MT systems of planting basins and ripper tine were associated with greater early season weed growth than CONV tillage in both the fifth and sixth years of CA. The weed infestations were observed as high weed emergence (cowpea phase) and growth (sorghum phase) in MT a week before crops were planted (Chapter 3). This would necessitate an early weeding in CA to provide a clean seedbed for the crop that is likely to exacerbate existing labour peaks experienced by farmers at the beginning of the season. The majority of smallholder farmers are likely to postpone weeding until after most fields are planted given the erratic nature of rainfall in semi-arid area. Delayed weeding is reported to be the major cause of loss in maize yield on smallholder farms (Rambakudzibga *et al*., 2002).

The increased weed growth in MT systems was maintained during the first four weeks after planting (WAP) in both cowpea and sorghum (Chapter 3). Corresponding results of high weed growth early in the cropping season in MT were also reported in the maize phase of the rotation in the fourth year of CA in the same study (Mashingaidze *et al*., 2009b). This indicated that conditions conducive for weed emergence and subsequent growth existed under MT systems within the first weeks after planting regardless of the crop grown. Since this period falls within the period in which weed control is required to avert significant crop yield losses for most crops, early and frequent weeding may have been needed in CA even after four years. In fact, MT systems required double the weeding (a week before planting and a week after planting) done in CONV tillage to reduce weed biomass at 4 WAP to levels comparable to CONV tillage. Since weed biomass measures the increase in individual weed size, the high weed biomass under MT indicates high biomass accumulation by weeds and, therefore, increased competition. Larger weeds have a greater impact on crop plants through competition and also have a better chance of achieving reproductive maturity and setting seed (Miyizawa *et al*., 2004). That CA had increased weed infestations early in the cropping season after three dry season weedings leads to questions on the effectiveness of hoe weeding in controlling weeds under MT systems.

The observed proliferation with the first rains of the cropping season of perennial and annual weeds with deep roots such as *Alternanthera repens*, *Boerhavia diffusa* and *Setaria* spp. (Chapter 3) demonstrates that dry season weeding using hand hoes was largely ineffective against these weeds. The high weed biomass observed a week before planting in the sorghum phase of the rotation despite three dry season weeding arose from poor weed control of these weed species. The frequency of weeding carried out in this study especially early in the cropping season is impractical given the labour shortages in smallholder agriculture. The use of herbicides such as glyphosate can reduce the early season weeding burden and more effectively control perennial weeds in CA. Systemic herbicide would be useful for controlling weeds such as *Portulaca oleracea* whose weed density was observed to increase under CA when the maize mulch rate was below 8 t ha^{-1} (Chapter 4). However, issues such herbicide availability, limited capital for purchasing knapsack sprayers, herbicides and protective clothing, and training of both extension agents and farmers on the safe use of herbicides still remain. Research carried out on a low cost weed wipe made in Zambia for use in CA found that weed control was poor especially in the presence of crop residue (Mashingaidze *et al.*, 2009a). There is need to carry out studies that include herbicide application combined with different levels of hoe weeding under CA to investigate the economic feasibility of using herbicides in CA. If herbicide use is profitable then the use of a subsidy scheme between smallholder farmers and agro-dealers can be set up. The use of herbicides for early season weed control would minimise the labour bottlenecks common early in the cropping season. However, there is a need to train both extension workers on weed species identification, the proper handling of herbicides and management of herbicide resistant weeds. This can be done using participatory research approaches including field demonstrations and Farmer Field Schools. The knowledge intensiveness of herbicide use may be an impediment to herbicide use by most of the older farmers. On the other hand, the promotion of herbicides will be inappropriate for the resource-poor farmers who at present have limited cash investment for seed and fertiliser.

However, MT systems were associated with poor crop establishment in both cowpea and sorghum that reduced grain yields (Chapter 3). Cowpea yield was especially low in MT systems and close to the Zimbabwe national yield average of 300 kg ha^{-1}. There is a need to re-visit the CA practice of maintaining the spacing recommended for maize when growing legumes and small grains. The recommended spacing of these crops is usually narrower than that for maize. The crop canopy in cowpea and sorghum developed slowly due to the poor crop stand and afforded weeds a chance to emerge and grow as was observed early in the cropping season. The increased weed growth would necessitate frequent weeding in crops that are largely viewed as minor crops in smallholder farming. Given the markets for these crops it is highly unlikely that smallholder farmers would carry out more than one post-plant weeding let alone consider applying herbicides to control weeds in the crops. From the viewpoint of weed management, the inclusion of crops such as cowpea in CA rotation while diversifying management practices would actually result in high weed seed return as most farmers are likely to weed crop only once after planting. However, in this study the below optimum crop densities probably contributed to the increased weed growth observed under CA. Intercropping of cowpea with maize has been reported to suppress weeds and effectively reduced hoe weeding from thrice to once per season (GART, 2008).

7.2.2 Maize residue mulch effect

Suppression of weed growth is one of the benefits attributed to the retention of crop residue as soil surface mulch in CA. However in this study, maize residue mulching offered only limited weed suppression that was observed only in sorghum early in the cropping season (Chapter 3). Maize residue mulching reduced the density of some weed species including *P. oleracea* and may be useful in reducing the density of this weed early in the cropping season in CA where frequent early season weed control is not possible (Chapter 4). However, this required maize mulch rates of 8 t ha^{-1} which are unlikely to be retained by most smallholder farmers due to problems of crop residue availability in semi-arid areas.

However, during the course of the study maize residue mulching, especially under the intermediate rate of 4 t ha^{-1}, was consistently associated with increased mid- to late- season weed emergence in both cowpea and sorghum crops, and weed biomass accumulation in the sorghum phase of the rotation at the highest maize mulch rate of 8 t ha^{-1} (Chapter 3). The present findings indicate that weeds benefited from the moist conditions and moderate temperatures under the mulch during dry periods of the season. In addition, mulches trapped seeds of wind-dispersed weed species resulting in their increased density under mulch. Weed species such as *Conyza albida, Eleusine indica, Gnaphalium penysvalvicum, Leucas martinicensis, S. pinnata* and *Setaria* spp. were observed to emerge in greater numbers from mulched than un-mulched soil surfaces (Chapter 4). For *L. martinicensis, Setaria* spp., *Urochloa panicoides, S. pinnata* and *B. diffusa* the increased density on mulching was observed only MT systems suggesting that these species will emerge in greater numbers under CA. In both crops, the intermediate maize mulch rate of 4 t ha^{-1} had significantly higher weed density than 8 t ha^{-1}. A number of reasons were responsible for the increased weed infestations under the intermediate mulch rate. The thicker layer at a maize mulch rate of 8 t ha^{-1} may have reduced weed emergence through increased shading. Moisture conservation may have been greater at maize mulch rate of 4 t ha^{-1}

than 8 tha^{-1} as Mupangwa *et al*. (2007) reported that maximum soil water content was observed at the 4 t ha^{-1} maize mulch rate. This increased in density of some weed species under the intermediate maize mulch rate contributed to its reduced weed diversity (Chapter 4). This led to a CA community dominated by the competitive *Setaria* spp. group with difficult to control weeds such as *E. indica* increasing under the 4 t ha^{-1} maize mulch rate.

The findings of this study demonstrated that retention of moderate rates of maize stover increased mid-season weed growth and necessitated late season weed control in CA under semi-arid conditions. Furthermore, mulching was not associated with increased crop yield after four years of CA. In fact, mulching reduced sorghum yield as a result of the increased weed growth under the maize mulch (Chapter 3). However, the many significant interactions of maize mulch rate with factors such as tillage, season and even level of weed management indicate that the effect of mulching on weed and crop growth are complex. This cautions against making generalised statements as is often done in CA as the influence of mulching is season – and management specific.

7.2.3 Hoe weeding intensity

In this study, a high weeding effort was still required in the fifth and sixth years of CA (Chapter 3) demonstrating the need for intensive hoe weeding even after the three years weed pressure and weeding effort were claimed to decline under CA. This was because MT systems had high early season weed infestations and maize residue mulching increased mid- to late- season weed growth (Chapter 3) which necessitated frequent weeding throughout the cropping season to keep CA fields weed-free. The high weeding intensity of four hoe weedings during the season significantly reduced weed density and biomass which translated into improved growth of both cowpea and sorghum. In fact, the significantly greater sorghum grain yield obtained under the high weeding intensity than low weeding intensity highlighted the need for frequent weeding after six years of CA in order to avert crop yield loss. Therefore, even under recommended CA practices a high weeding intensity was required which did not substantiate the claims that weed infestation and weeding effort to control them were high only in the initial years of CA.

Although hoe weeding was less effective at controlling perennial weeds species during the dry season (Chapter 3), it was effective against most weed species found at Matopos Research Station (Chapter 4). Frequent hoe weeding significantly reduced the density of a number of weed species including *Commelina benghalensis, E. indica* and *Setaria s*pp. (Chapter 4). This demonstrated when done early hoe weeding can control weeds such as *C. benghalensis* and *E. indica* that are often identified by smallholder farmers as difficult to control using hoe weeding (Chapter 5). Delayed weeding on smallholder farms probably allows the weed species to form structures such as tubers and deep fibrous root system that make their removal difficult using hoes. Hoe weeding could also be used to reduce the density of the dominant *Setaria* spp. Previous studies also report that when done early, hoe weeding is as effective as any of the mechanical methods of weed control used in smallholder agriculture (Riches *et al*., 1998)

However from the viewpoint of smallholder farmers, the four within cropping season hoe weedings plus at least one dry season weeding done as was done in this study may be too labour demanding for most smallholder farmers. Therefore, the requirement for weeding effort ven after six years of recommended CA practices may ultimately limit the area that can be committed under CA on smallholder farms in Africa. There is, thus, need to explore the used of herbicides to supplement hoe weeding if CA is to be adopted on a wide-scale by smallholder farmers in semi-arid areas.

7.3 Conservation farming

7.3.1 Weeds in conservation farming

The CF farmers in Masvingo District were neither retaining the minimum soil cover of crop residue of 30% at planting nor rotating their maize crop with a legume or other crop in the past four seasons (Chapter 5). During the 2008/09 season, there was no evidence of a decline in weed density with time under CF. Weed density was found not to be significantly different between PBand CONV tillage. However, CF fields were weeded earlier and more frequently (thrice) than CONV tillage systems (twice). The first hoe weeding in PB was done at least 15 days earlier than in CONV tillage with the majority of PB fields weeded within the first week after maize was planted (Chapter 5). This suggested higher weed growth in PB than in CONV tillage. Since the area within the quadrats were weeded at the first weeding (Chapter 5), it is highly possible that the early weeding in PB masked the differences in weed density at 3 WAP between PB and CONV tillage. High levels of weed management have been observed to diminish the differences in weed infestation between tillage systems (Chapter 3; Locke et al., 2002). Observations from PB farmers who had not weeded fields before the first and second weed counts showed PB fields to have more than treble the weed density under CONV tillage.

Hoe weeding was done thrice during the cropping season and once in the dry season translating to four hoe weedings per year in PB compared to only twice in CONV tillage. However, none of the PB farmers carried out a late season weeding prior to or at harvesting. The lack of weeding allowed late season weeds such as *Acanthospermum hispidum* that was observed to increase in PB3- to reproduce and return seed to the soil weed seed bank. The frequency of weeding recorded in PB in this study agrees with findings of Mazvimavi *et al*. (2011) from a survey of CF in Zimbabwe that showed that most fields were weeded between twice and thrice during the cropping season. The higher hoe weeding demand in PB compared to CONV tillage may be the reason for the low area under PB on most farms in Wards 12 and 14 of Masvingo District. During the 2008/09 season less than 50% of the cropped area was under PB on most farms in the study area.

Shortage in inputs such as fertiliser and seed was identified as a more important constraint in PB than labour availability. Most smallholder farmers had under PB an area that was equivalent to the seed and fertiliser that was received from CARE International. Without fertiliser CONV tillage farmers did not adopt CF/PB as they believed that the yield benefits would be minimal. Grabowski (2011) reports that although farmers in Mozambique were aware of the benefits of CA, the majority of farmers had small areas under CA. These smallholder farmers identified lack of inputs as the main reason for the low area under CA. Labour requirements were an additional constraint to the farmers in Masvingo District. However, under the low acreage committed to PB weeds could still be managed with available family labor. Planting basins out-yielded CONV tillage with the higher yields obtained in fields that had been under PB for the longest time (Chapter 5). The increased yields in PB were a result of improvements in soil fertility and weed management. The decrease in maize grain yield with increase in weed density at 3 WAP highlighted the importance of early season weed control in PB. If the yield benefits associated with PB are to be realised over large areas in smallholder agriculture, there is need to improve farmer access to inputs and investigate the use of low cost herbicide options such as banding to facilitate the widespread adoption of CF by labour-constrained smallholder farmers in southern Africa.

Therefore, PB was still associated with earlier and frequent weeding than CONV tillage suggesting that weed pressure may have been high early in the season in MT. Frequent hoe weeding was probably effective in diminishing the high weed infestation in PB. Weed species composition in PB was similar to that in CONV tillage. As weed density and the labor requirements did not decline with time under PB, the use of herbicides may facilitate the wide adoption of PB by labour-limited smallholders. However, weed composition in PB fields was quite variable suggesting that other management practices could have influenced in weed infestations in PB fields.

7.3.2 Influence of management practices

The positive correlation between frequency of manure use and weed density at 3 WAP and the increase in weed density within planting basins suggested that poorly stored compost introduced viable weed seeds to PB fields (Chapter 5). Although both pit and heap composting reduced the number of viable weed seeds in composts, composts applied in PB fields during the 2009/10 cropping season on most farms still contained viable weed seed (Chapter 6). Weed seedling emergence varied between farms from 0 to 142 seedlings kg^{-1} of compost reflecting possibly the differences in how the composts were stored (Appendix A and B). The weeds *E. indica*, *C. dactylon* and *Amaranthus hybridus* that were identified in the soil seed bank and in the above-ground-flora in fields (Chapter 5) were of high relative importance weeds in the applied composts (Chapter 6). This suggests that these species could have been introduced into fields through frequent use of poorly stored compost. A compost application rate of 6 t ha^{-1} would have introduced on average 6 weed viable seeds to each planting basin. This was probably one of the reasons for the increased weed emergence within planting basins observed during the 2008/09 season (Chapter 5).

Weed seedling emergence varied between composts obtained from the different farms probably due to differences in handling and storage. Pit stored compost had a lower weed seedling emergence than heap stored compost suggesting that pit storage was more effective at reducing weed seed viability. However, pit composting is more labour intensive than heap storage. Considering that PB tillage is already associated with high labour demands throughout the year it is unlikely that all the recommended pit composting practices will be followed on the majority of smallholder farms. Most PB farmers were untrained on composting and this may have resulted in the minimal reduction in weed seed viability and poor nutrient status of applied composts.

7.4 Conclusions

This study was the first to characterise weed population dynamics in details under recommended and actual smallholder farmer CA practices in semi-arid southern Africa. The focus of the on-station study were legume (cowpea) and small grain crops (sorghum) that are recommended for rotation with the staple maize crop under CA in semi-arid areas as these crops are drought tolerant. Agronomic or weed research on non-maize crop is limited from southern Africa. Important and new research findings were obtained from the study that will contribute to increased understanding of the behavior of weed species under the different management practices recommended in CA. This information will guide future research in developing low-cost weed management strategies for resource-limited smallholder farmers practicing CA in semi-arid areas in the region.

- Contrary to the widely held belief of CA promoters, weed growth under the recommended CA practices for smallholder farmers in Zimbabwe was higher than in CONV tillage early in the season after more than three years of CA practice. This finding has important implications for weed management as labour bottlenecks are common under smallholder agriculture early in the season and often result in delayed weeding and crop yield loss.

- The MT systems of PB and RT promoted in smallholder CA had poorer cowpea and sorghum grain yield than CONV tillage as a result of the sub-optimal crop populations in these tillage systems.

- Under the three-year maize-cowpea-sorghum rotation, maize residue retention and frequent hoe weedings practices in this study, there was no evidence of a shift to more difficult to control weed species with adoption of CA. However, the weed species *P.oleracea* may be a problem weed under CA when maize residue of 4 t ha^{-1} or lower are retained.

- Maize residue mulching offered limited benefit in CA. Retention of maize residue mulch especially at 8 t ha^{-1} was associated with limited weed suppression early in the season in sorghum. Contrary to expectations based on previous research findings, maize residue mulching and in particular the rate of 4 t ha^{-1} increased mid- to late season weed density and biomass in both cowpea and sorghum. This higher weed growth under mulch decreased sorghum grain yield.

- The effort required to manage weeds under CA was still double that required under CONV tillage on smallholder farms even after three years of recommended CA practice. Early and frequent hoe weeding (four times within the crop growing season) was still required in both the fifth and sixth years of CA to reduce weed growth and improve both cowpea and sorghum grain yields.

- On most smallholder farms, PB was the only CF component practiced by farmers in Wards 12 and 14 of Masvingo District. There was no evidence of a decline in weed density and intensity of hoe weeding with years a field had been under PB. Hoe weeding was done earlier and more frequently in PB relative to CONV tillage suggesting high early season weed infestations in PB.

- Poorly stored composts were identified as one of the recommended CF practices that exacerbated weed infestations in most PB fields through the introduction of viable weed seeds. Pit storage was more effective in reducing weed seed viability in composts.

7.5 Recommendations for future research

- There is need for research on use of herbicides combined with different hoe weeding frequencies to reduce weeding burden early in the cropping season. The economic feasibility of using full cover and band application of herbicides including glyphosate and atrazine should be explored to reduce the cost for resource-poor smallholder farmers. Farmer Field Schools and demonstration plots can be used to train farmers and extension workers on weed identification and proper use of herbicides.

- More research should be done on biology and ecology of weed species as this is not available for most species in southern Africa. Information on weed biology and ecology can assist in making predictions on behavior of individual species or a group of related species when there is a change in management practices.

- Improvements in CA should include the development of appropriate crop spacing for small grain and legume crops in CA as the current wide spacings can compromise yields. The option of intercropping legumes should be explored including identification of suitable varieties, optimum spacing and planting density.

- There is also a need to train CA farmers on composting so as to improve nutrient quality and reduce weed seed viability.

- Detailed research is required to determine the mechanisms behind the effect of crop residue mulching on weed and crop growth on different soil types. There is a need for long-term research on CA to be carried out on contrasting soils and under researcher management and farmer management to more effectively evaluate weed population changes in the long-term.