Weed population dynamics and management in a smallholder farming system in transition from conventional tillage to planting basins in a semi-arid area

By

Zira Mavunganidze

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Supervisor: Dr. Ignacio Casper Madakadze

Co-supervisor: Professor Justice Nyamangara

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DECLARATION

I certify that this dissertation hereby submitted for the PhD degree in Agronomy at the Faculty of Natural and Agricultural Sciences, University of Pretoria except were duly acknowledged has not been submitted by me at another University. I also certify that no plagiarism was committed in writing this dissertation

Signature………………………..

Date………………………..

ABSTRACT

This study was conducted in Kadoma, Zimbabwe in the smallholder sector (SH) during 2009/2010 and 2010/2011 seasons. The overall aim of the study was to understand the changes that occur to weed densities, species diversity and management under Minimum Tillage (MT) system of planting basins which is a component of Conservation Agriculture (CA) being promoted in the SH sector. A survey was carried out to determine the biophysical and socio-economic factors that affect the adoption of CA. The paired plot technique was used to compare weed densities and diversity in planting basins (PB) and Conventional Tillage (CONV) at 3, 6 and 9 weeks after crop emergence (WACE) in clay loam, loamy and sandy soils. Multivariate ordination techniques and a quadratic model were used to describe the relationship of soil properties, socio economic and management variables with weed densities. The effectiveness and economic benefits of chemical weed control were also evaluated.

A Multinomial Logit Model revealed that the choices of the CA components and agronomic practices to be adopted were positively influenced by the farmer's age, formal education, and access to extension services, labour, draft power availability and land size. The empirical results suggest that to promote adoption of a complete package of CA, policies that increase access to formal education and training of CA through extension be enhanced. Extension of CA should make strategic intervention through innovative methods of farmer to farmer extension services.

Planting basins had 57 and 51 percent higher weed densities than CONV during 2009/2010 and 2010/2011 seasons, respectively on loams. The corresponding weed densities on clay loams in PB were 27 and 19 percent higher than CONV, while on sandy loams no significant

effect of tillage was evident. The weed species diversity indices for PB were 58 and 45 percent higher than CONV for clay loams at 3 WACE, during 2009/2010 and 2010/2011 seasons, respectively. At 3 WACE, PB resulted in a 13 and 28 percent higher diversity index for loams during 2009/2010 and 2010/2011 seasons, respectively. A total 13 variables, explained 32 percent of the total variation of the weed species data. The socio-economic and management factors accounted for the greatest variation, more than twice that of soil properties.

The effective control of weeds with pre-emergence herbicides resulted in the highest crop yields of 2136 and 4024 kg ha^{-1} for cotton and maize, respectively. While, higher crop-weed competition in the hoe weeded treatments resulted in the lowest crop yields of 1349 kg ha^{-1} for cotton and 3509 kg ha^{-1} for maize. The gross margin for atrazine + alachlor in maize was US$ 351.00 and US$ 373.00 higher than hoe weeded treatment in PB and CONV, respectively. While the gross margin for cyanazine + alachlor in cotton was US$ 849.00 and US$ 399.00 higher than the hoe treatment, in PB and CONV, respectively. The hoe weeded treatment was affected by worst case scenarios of variations in climate, input and output prices resulting in negative gross margin.

Earlier weeding is recommended in PB than in CONV because of higher weed densities early in the season and atrazine + alachlor in maize and cyanazine + alachlor in cotton can be used to reduce labour costs and time required for weed control in PB. The changes that occur to weeds in PB are an interaction of tillage, soil properties, socio-economic and management factors. To enhance the promotion of PB in the SH sector, there is need to address issues that affect weed management such as training, input and subsidy schemes.

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LIST OF ACRONYMS

WACE	Weeks after crop emergence
Kg	Kilogram
m	metre
mm	millimetre
LSD	Least significance difference
cv	coefficient of variation
PCA	Principal Component Analysis
Mg	milligram
a.i	active ingredient
ha	hectare
g	gram
L	Litre
cm^{-2}	square metre
WACE	weeks after crop emergence
°C	Degrees Celsius
>	Greater than
<	Less than
$^{-1}$	Per
$^{-2}$	Per square metre
%	Percentage
CA	Conservation Agriculture
PB	Planting basins
CT	conservation tillage
CONV	conventional tillage
FAO	United Nations Food and Agricultural Organisation
SED	standard error of the difference of means
ZCATF	Zimbabwe Conservation Agriculture Taskforce
AGRITEX	Zimbabwe Department of Agricultural, Technical and Extension Services
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit GmbH
ANOVA	Analysis of variance
PC-ORD	Principal Co-ordination
pH	pH in water
SAS	Statistical analysis Software
SPSS	Special Package Software for Social
SAT	Sustainable Agriculture Trust
ZFU	Zimbabwe Farmers' Union
NGO	Non Governmental Organisation
AU-NEPAD	African Union-New Partnership for Africa's Development
SH	Smallholder

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Soil degradation is one of the major challenges to sustainable agriculture (Knowler & Bradshaw, 2007). The unabated incidence of land degradation is a threat to food security for the country. Food security is one of the focal themes for Zimbabwe's policy initiatives towards attainment of the Millennium Development Goals (United Nations, 2007). The yields under Conventional Tillage (CONV) for maize (a staple crop) in the SH sector are below one tonne ha^{-1}; which is below the global average of 5.1 t ha^{-1} (Gianessi, 2009). Some pest management practices such as burning of crop residues, especially in cotton, and continuous tillage to prepare a fine tilth seed bed have led to excessive soil erosion (Owenya *et al.*, 2012). In addition, CONV increases soil organic matter mineralisation that leads to a decline in the soil's physical, chemical and biological properties (Wall, 2007; Mupangwa *et al.*, 2012). The effects of tillage on soil structure, decrease water infiltration and increase soil erosion through runoff (Thierfelder & Wall, 2009). The animal drawn mould board plough used for tillage in the SH sector is linked to sheet erosion, a phenomenon that compromises the fertility of the cropped lands (FAO, 2011).

Zimbabwean smallholder (SH) farmers face many challenges in crop production inter alia: erratic rainfall often associated with dry spells (Nyagumbo *et al.*, 2009), lack of appropriate soil fertility management, limited weed management options, shortage of labour and blanket recommendations that ignore resource status of households (Twomlow *et al.*, 2006; Marongwe *et al.*, 2011). The farming systems in the SH sector are mainly characterised by limited organic matter returns to the soils, minimal and unbalanced fertilizer application, limited options for crop rotation and continuous tillage. Consequently, all these factors lead to soil degradation (Baudron *et al*., 2011). However, these undesirable effects of tillage have been addressed in recent years through the development of Conservation Agriculture (CA) (Friedrich & Kassam, 2009; Kassam *et al*., 2011; FAO, 2012).

Conservation Agriculture comprises of any tillage sequence that minimises or reduces the loss of soil and water, while achieving at least 30 percent soil cover using organic residues, in addition to crop rotations (FAO, 2012). The benefits of CA include; timely planting, improved water retention and infiltration, good root development, reduced soil erosion, greater precision in input use and increased crop yields (Thierfielder & Wall, 2009). However all the benefits of CA can only be achieved when the principles of CA are practised simaltenously (Giller *et al*., 2009). Farmers often decide on selecting an entry point to CA after considering the most important benefit to be derived.

Non-Governmental Organizations (NGOs), Research Institutions, the Food and Agriculture Organisation (FAO) and the African Union-New Partnership for Africa's Development (AU-NEPAD), have promoted CA with the aim of improving crop production and food security for the vulnerable households since 2004 in Zimbabwe (Mazvimavi & Twomlow, 2009). The major focus has been promotion of CA practices such as mulching, manual planting basins (PB), jab-planters, ripper tine and animal traction seeding systems (Johansen *et al*., 2012).

Despite many benefits of CA to the vulnerable households in marginal environments in Zimbabwe, this technology has not been widely adopted (Hobbs, 2006, Thierfelder & Wall, 2010). Empirical evidence in southern Africa has shown variation in the farmers' adoption rate of CA. Some farmers have adopted the complete technology, some partially, while others have completely abstained (Hobbs *et al*., 2007; Gowing & Palmer, 2008). Among the farmers who continue to practice CA, many have modified the package and generally adopted some components of the technology while leaving out other recommended practices (Mazvimavi & Twomlow, 2009). There are various socio-economic constraints which have prevented SH sector farmers from adopting CA practices (Wall, 2007). Marongwe *et al.* (2011) noted that there could be a number of socio-economic factors that determine the extent to which SH farmers in Zimbabwe adopt CA.

In Zimbabwe, the widely promoted CA system is based on PB, with permanent soil cover and crop rotations. The PB are dug manually throughout the winter period using hoes and are planted at the onset of the rainy season without incurring time delays (Twomlow *et al*., 2006). Basins support many other good agricultural management practices, for example the timely planting or precision application of manure and fertilizers (ZCATF, 2009). In Zimbabwe, by 2011, about one percent (139 000 ha) of the total arable area in SH sector had been put under PB. This is relatively low considering that various organisations have spent more than 10 years promoting PB (FAO, 2012).

The planting basins have not been widely adopted in Zimbabwe because it is labour intensive (Andersson *et al.,* 2011). In a household survey by Twomlow and Mazvimavi (2009), farmers cited an increase in weed density with adoption of PB in Zimbabwe. In addition, changing from CONV to CA may lead to changes in the suite of weed species and weed ecology (Gonzalez-Andujar *et al*., 2011). A number of studies in the temperate regions also reported increases in weed densities in CA systems (Otto *et al*., 2007; Lègére *et al*., 2011; Gruber *et al*., 2010). The increased weed density is explained by the fact that CA tends to promote higher weed seeds concentration on the soil surface which can easily germinate when adequate moisture is available (Mrabet, 2008).

Conversely, the lower weed densities in CONV when compared to CA might be due to the effect of the plough as it turns the soil and buries more weeds to a depth devoid of the optimal stimuli to promote germination (Douglas & Peltzer, 2004). However, Vasileiadis *et al*. (2012) and Tuesca (2004) observed no effects of tillage system on weed density. Santín-Montanyá *et al.* (2013) reported that minimum tillage reduced stimulation of weed seed germination; however, crops faced competition from weeds that were growing at sowing time including those emerging after crop sowing.

The literature to date has not been consistent as evidenced by contradictions on the effect of tillage on weed density in CA. Wall (2007), reported an increase in weed density in the first few years and a decrease in weed populations with timely weed management which controls weeds before they set seed in Zimbabwe. Controlling weeds before they set seed ensures that no or few weed seeds are added to the weed seed bank which might add to future weed infestations (Chauhan *et al.*, 2006). There is, therefore, a need to ascertain the interactions that occur between tillage and weed composition as farmers adopt CA. It is important to study and quantify the changes that occur to labour requirements and associated costs as farmers adopt CA. Such information is vital in developing effective weed management strategies. It is also important for farmers adopting CA to know the changes to anticipate as they adopt CA and thus help them to proactively prepare the necessary mitigation measures. The increase in weed density in CA is likely to exacerbate the problem of weed control in the SH sector. This necessitates the development of sustainable weed management options that will enable the SH farmers to effectively deal with the increased weed density problems. Increased weed density is likely to put pressure on women and children since they are the main sources of weeding labour in the SH sector (Giller *et al*., 2009). The major reasons attributed to poor weed management in the SH sector are the lack of alternative methods of weed control, shortage of labour due to urban migration and the rising costs for manual labour, and lack of technical knowledge on effective weed control (Mangosho *et al*., 2011).

It is difficult to generalise the effects of tillage on weed density to all farms since there are differences in soil types and household wealth categories both of which affect weed management. The soil types and management factors all have a bearing on weed density and composition (Fried *et al*., 2009). There is a possibility of an interaction of tillage, soil types and management factors which influences the weed density and composition. Information on other factors that influence the growth and distribution of weeds within a field is important in developing weed control measures.

Continued reliance on traditional manual hand hoe weed control would be difficult if SH farmers adopted PB and without residue retention (Wall, 2007; Steiner & Twomlow, 2003). The observed increase in weed density associated with the adoption of PB brings to the fore the need to develop alternative weed management options to supplement the cumbersome hand hoeing method, which is often not effective in wet weather (Makanganise *et al.*, 2002). There are options for better weed management validated in Zimbabwe using ox drawn implements such as mouldboard plough; Tyne cultivator and spike tooth harrow for weeding, but the use of these implements does not align with the principles of CA (Riches *et al.*, 1997). The use of herbicides is also another option for timely weed control but a particular concern associated with the use of herbicides is the development of herbicide resistance of major weed species, particularly if herbicides are not used at appropriate rates (Chauhan, 2012).

Other non-chemical options for integrated weed management in SH cropping systems rely on a holistic understanding of crop and weed ecology (Johansen *et al*., 2012). They include using crop rotations unfavourable to major weed species, use of cover crops, adjusting sowing time and procedure, use of competitive crop genotypes, minimizing contamination of crop seed with weed seeds, and adjusting fertilizer strategy to minimize weed competition (Powles & Yu, 2010). Studies in Eastern Cape, South Africa under maize based irrigation system showed that winter cover crops such as grazing vetch (*Vicia dasycarpa)* and oat (*Avena sativa*) can provide ground cover which can suppress weeds (Murungu *et al*., 2010). Cover crops can suppress weeds by competing for the use of growth resources, such as light and nutrients (Derpsch, 2008). However the use of cover crops can be a challenge in the SH sector with dry winter seasons. The arable fields are also used for communal grazing animals making it difficult to grow crops in the SH sector.

If CA is to be adopted by SH farmers, then it is imperative that integrated weed management strategies be simultaneously adopted. However, the major challenge is the ability to develop integrated weed management strategies that can be used by SH farmers. Although herbicides can be used to suppress weed emergence, access by SH farmers and the knowledge required for their effective and safe usage is very limited in this sector. Priority is thus required in establishing integrated weed management strategies for particular cropping situations, considering all the entire options available: herbicides, mechanical, rotations and weed seed bank management.

1.2 RATIONALE OF THE STUDY

Some of the farmers in 12 districts in southern and northern Zimbabwe cited an increase in weed density in PB during a survey by Mazvimavi and Twomlow (2009). The changes that may occur to weed density and species composition may deter adoption of CA in SH sector considering that weed management has already been a major constraint in crop production in this sector (Marongwe *et al*., 2011). Ellis-Jones *et al*. (2001) reported that each year farmers abandon approximately 20 percent of their fields as a result of failure to cope with high weed infestation. The problem of high weed infestation is worsened by the fact that hand hoe weeding is slow and labour intensive, and frequently farmers fail to adequately weed a proportion of their crops in time to avert sequential yield losses. Labour shortage and the increasing labour cost over the years further compound the problem (Rugare, 2009). To date there is a paucity of literature on the perceived weed density increases reported by the SH farmers in Zimbabwe. Particularly lacking in Zimbabwe is information regarding weed species that farmers should expect to proliferate in PB. Therefore, there is a need to ascertain the changes that occur to weed species by carrying out research on the farmers' fields that are in transition to PB. This information is vital in developing alternative strategies to overcome the increased weed densities if any, as perceived by the SH farmers. The information will also inform the farmers the quantitative weed increases and possible labour and associated costs required for weed control in PB.

Previous research findings on the effect of tillage on weed density are not clear as to whether the changes in weed spectrum and density are solely due to tillage system effects or that other factors contribute. These knowledge gaps make it difficult to predict or make recommendations to farmers in the SH sector practising PB. Hence, this warrants the need to ascertain whether the changes in weed density and species composition are as a result of other factors other than tillage. Due to the heterogeneity in farmers' socio-economic characteristics and the bio-physical conditions, it is probable that the effects of tillage might be differentiated based on these varying farmer circumstances. Research on different socio-economic and biophysical conditions will help in the development of specific weed management options tailored to mitigate specific challenges and will help avoid generalisations and blanket recommendations to farmers practising PB. Identifying socio economic factors affecting uptake of CA will also assist governments, Non-Governmental Organizations (NGOs) and other development partners involved in the development and promotion of CA technologies by providing information which is vital in designing appropriate intervention strategies that will help increase the adoption of CA in Zimbabwe.

1.3 RESEARCH QUESTIONS

1. What are the socio-economic factors that affect the uptake of CA?

2. What are the effects of tillage on weed density and diversity under PB?
3. What are the effects of soil properties and management on weed density and diversity under PB?
4. Can herbicides be used to alleviate labour shortages in weed control under PB?

1.4 HYPOTHESES

The hypotheses of the study were:

1. Farmer socioeconomic factors affect the level of CA uptake and the resultant challenges during the transitional phase from CONV to PB.
2. Weed density and diversity increase during the transitional phase from CONV to PB system in the SH sector.
3. In addition to tillage, soil properties influence weed density and diversity during the transition phase from CONV to PB.
4. The use of herbicides can be a cost effective strategy of weed management for SH farmers in transition from CONV to PB.

1.5 OBJECTIVES

The specific objectives of the study were to:

1. To identify the socio-economic factors that affect the uptake of CA in the SH sector
2. Quantify changes in weed density and diversity on SH farms in transition from CONV to PB.

3. To investigate the effects of soil properties on weed density and diversity on SH farms in transition from conventional tillage to PB
4. Evaluate the effectiveness of herbicides under PB on weed pressure, crop growth and yield.

1.6 OUTLINE OF THESIS

This thesis is presented firstly in the form of a General Introduction (Chapter 1) which focuses on the general background of the study, purpose, research problems, hypothesis and significance of the study. Literature Review (Chapter 2) describes theoretical perspectives and previous research findings on weed dynamics and management in CA. The literature was useful in identifying research gaps and the formulation of the research problems which led to this study. The literature review is followed by Chapter 3 which presents results of a survey done in the study area to identify the bio-physical and socio-economic factors that influence the level of adoption of PB practices by farmers in a cotton-maize based farming system. Chapter 4 tests the hypothesis that there are likely to be changes in weed populations during the transition phase from CONV to PB, which might deter the adoption of PB. Chapter 5 investigates the influence of the soil factors and management variables on distribution of weeds species within arable fields in Kadoma as an entry point towards developing weed management options for perceived increased weed density in PB. Chapter 6 investigates the feasibility of using herbicides in PB to suppress the weeds and increase productivity in SH. An economic analysis of profitability of herbicides is presented in Chapter 7. Chapter 8 is the general discussion that provides a synthesis of the findings of this study and leads to conclusions and recommendations.

CHAPTER 2

LITERATURE REVIEW

2.1 CONSTRAINTS TO CROP PRODUCTION IN THE SMALLHOLDER FARMING SECTOR

A large proportion (80 percent) of the staple crop production comes from the SH sector, however, yields have been declining. For example, in the 1990s, the average yields ranged from 1.0 - 1.5 t ha^{-1} to below 1 t ha^{-1} in 2012 yet maximum expected yields in the large scale commercial can be up to 10 t ha^{-1} (Ministry of Agriculture, 2012). The decline in yields is attributed to poor weed management practises, poor soil fertility (Zingore *et al*., 2008; Marongwe *et al*., 2011), inadequate and unpredictable rainfall (Chimhou, 2009; Mupangwa *et al*., 2012), among other factors. Farmers often abandon part of their fields as they fail to cope with the increased demand for weeding and thus negate all the time and labour invested initially during crop establishment (Ellis-Jones *et al.,* 2001; Mashingaidze, 2004). The use of the hand hoe for weeding is slow, labour intensive and inefficient hence farmers fail to cope with increased demand for weeding (Mangosho *et al*., 2011). Ellis-Jones *et al*. (1993) noted that farmers require 100 to 210 person-hours to weed a hectare of maize. As a result, farmers spend approximately 50 to 70 percent of their labour time weeding (Chikoye *et al*., 2007).

This inefficiency of the hand hoe in weed control method is worsened by the shortage of labour due to migration of young people to urban areas. In the SH sector, the burden usually falls on women and children who in most cases fail to cope with the weed pressure and often end up weeding the crops late. This exposes the crops to weed competition (Giller *et al*., 2009). Weed competition during the first 2 to 3 weeks after crop emergence results in serious yield losses (Gantoli *et al*., 2013). A study from a typical SH sector in Zimbabwe showed that farmers loose at least 79 to 85 percent of their yield due to weed competition (Mavudzi, 2007).

Most of the SH farmers grow crops under the dryland system with major reliance on seasonal rainfall which is erratic (World Bank, 2012). Zimbabwe has experienced devastating climate such as droughts, caused by within and across seasonal rainfall variability (Manatsa *et al.,* 2011). Rockström (2002) noted that inconsistent rainfall has reduced yields every two to four years and has in some areas led to complete crop failure every 10 years. The rain-fed SH areas are characterised by high water loss resulting in only 10 to 30 percent of the rain water being used effectively and up to 50 percent being lost as non productive evaporation (Falkenmark & Rockström, 2009; Nyamadzawo *et al*., 2012). The high water loss from the soil implies low moisture reserves available for the plant to tap from during the dry spells resulting in increased incidence of crop failure (Marongwe *et al*., 2012). Continuous tillage with an ox drawn mould board plough as a basic method of mechanisation has led to high rates of sheet erosion in the SH sector as illustrated (FAO, 2011; Munodawafa, 2012).

Soil losses have been estimated to be more than 76 t ha^{-1} $year^{-1}$ in Zimbabwe (Makwara & Gamira, 2012). The practice by most SH farmers to burn crop residues especially cotton, for the purpose of pest management and in other crops removal from the field of crop residues to store as livestock feed during winter leave the soil without protection, exposing it prone to rain and wind erosion (Mupangwa *et al*., 2012). Continuous mining of nutrients with no replacement has resulted in a decline in essential nutrients such as nitrogen (N) and phosphorus (P) which are important in crop production (Mtambanengwe *et al.*, 2006). The declining soil fertility and low pH as a result of soil erosion has led to low crop yields (Kanonge *et al*., 2009). Other than the climatic risks, poor soil fertility and soil physical degradation are major limitations to food security in Zimbabwe resulting in many families requiring food aid (Nyamadzao *et al*., 2013). The need to arrest the soil degradation, improve soil fertility, increase resilience of the agricultural production systems from the threat of climatic change and address increased demand for food against declining production capacities of arable lands has prompted initiation of Conservation Agriculture (CA) in Zimbabwe (ZCATF, 2009).

2.2 WHAT IS CONSERVATION AGRICULTURE?

The term Conservation Agriculture (CA) was introduced by FAO in 2001. Conservation Agriculture aims to conserve, improve and make more efficient use of natural resources through integrated management of available soil, water and biological resources combined with external inputs. Conservation Agriculture contributes to environmental conservation as well as enhanced and sustained agricultural production. It can be referred to as the resources efficient or resource effective agriculture' (FAO, 2012). Conservation Agriculture is a holistic system that includes the three principles for sustainable crop production which are reduced tillage, use of mulch for ground cover, and crop rotations.

The definition of CA has brought confusion to farmers and agricultural scientists alike, with other terms such as Conservation Tillage (CT) which were already in use in the 1970s before FAO introduced the term CA (Anderson & Giller, 2012). Farmers in America adopted CT after the Dust Bowl of the 1930s in the US Great Plains (Hobbs, 2007). The Dust Bowl resulted from excessive soil erosion caused by wind. It is estimated that at least 91 million hectares of arable land were lost due to soil erosion (Baker & Saxton, 2007). The dust storms that occurred at that time prompted farmers to adopt sustainable agricultural systems. Conservation Tillage is a collective umbrella term commonly given to no tillage, minimum tillage and or ridge tillage to denote practices that have a conservation goal of some nature, usually with retention of at least 30 percent ground cover by residues' (Baker & Saxton, 2007). Conservation Tillage practices can be viewed as transition steps towards Conservation Agriculture' (Barker *et al.,* 2007). It can be deduced from the definition that CT includes a principles of CA that involves minimum soil disturbance. Therefore, CT is a component of CA.

2.3 PRINCIPLES OF CONSERVATION AGRICULTURE

Conservation Agriculture requires the implementation of the three main principles or pillars; upon which the system is based as illustrated in Figure 2.1 (FAO, 2011). The CA principles are applicable to a wide range of crop production systems from low-yielding, rain fed conditions to high-yielding irrigated conditions. However, the success of the implementation of the principles varies with biophysical factors, system management conditions and farmer circumstances (Verhulsta *et al.,* 2010).

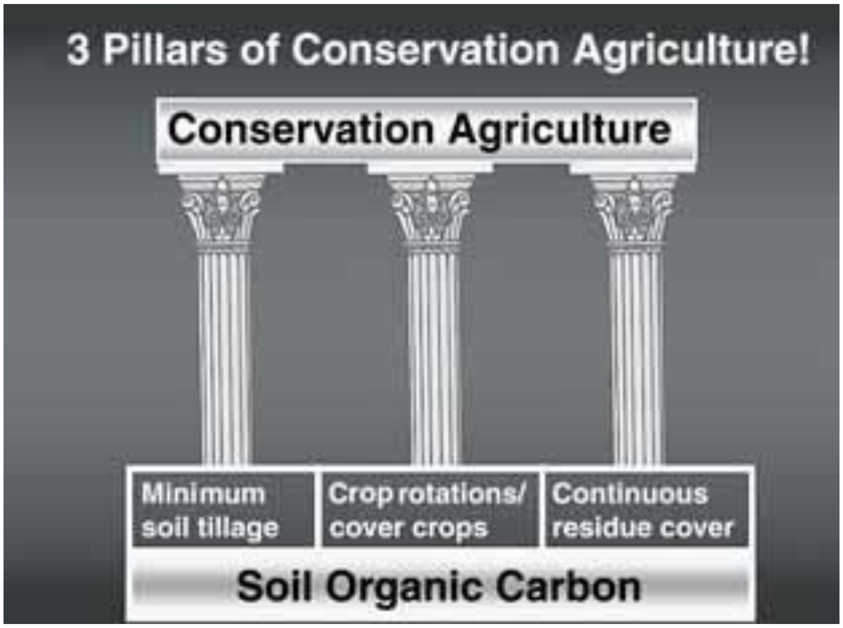

Figure 2.1 Schematic representations of the three pillars of Conservation Agriculture Pillars (Adapted from Reicosky & Saxton, 2006)

2.3.1 Minimum Soil Tillage

The purpose of tillage is to create a fine tilth for crop establishment, incorporate fertilisers, increase infiltration and alleviate soil compaction (FAO, 2012). Continual use of plough discs and harrows for tillage by farmers has led to an increase in soil bulk density, decreased soil water infiltration and retention, increased soil erosion, reduction in soil biodiversity, and decline in soil organic matter due to increased oxidation (Kassam *et al.*, 2009; Kassam *et al.*, 2011). The confounding damaging effects of tillage on the soil structure and properties has spawned the promotion of Minimum Tillage as a sustainable method of farming (IIR & ACT, 2005; FAO, 2011). Initially, in America no implements were used in no tillage farming; seed and fertilisers were placed on the soil surface to avoid disturbing the soil. It, however, proved to be impossible and the system of no tillage was changed to minimum soil disturbance because implements were now used to make planting furrows (Bhan & Bharti, 2008). Though there are many terms used to describe minimum soil disturbance such as Minimum Tillage, direct seeding and zero tillage, the process is basically the same where crops are planted in untilled land by opening slots and furrows to facilitate the placement of seed, fertiliser and pesticides (Barker *et al.*, 2007).

A lot of equipment has been designed to enable farmers to plant in unploughed lands; some of the equipment was originally designed for CONV tillage, but was later modified and adopted for no tillage. In commercial farms, the implements used are tractor drawn disc openers, no till seeders and no tillage drills as illustrated in Figure 2.2 (Barker & Saxton, 2007). No soil disturbance during weeding is achieved by the use of herbicides and tractor mounted weed wipers.

Figure 2.2 Equipment for planting in no-till. (a) inverted-t coulter; (b) Indian no-tillage drill using inverted t; (c) disk type planter; (d) star-wheel punch planter; (e) “happy planter”, which picks up straw and blows it behind the seeder; (f) disk plants straw and blows it behind the seeder (Source: http://www.ecaf.org/index.php)

In southern Africa, the manual system of CA is being promoted in the SH agricultural sector, particularly among farmers without draft power. These farmers use hand hoes to dig PB as developed by Brian Oldreive (1993) in Zimbabwe. The PB are actually a modification of the Zai pit system which was developed in west Africa which make use of pits measuring (0.6 m * 0.6 m * 0.3 m, Width, Length, Height) (Mazvimavi & Twomlow, 2009), though the PB in Zimbabwe measure (15 cm * 15 cm *15 cm, Width, Length, Height) (FAO, 2011b). The row spacing depends on the Natural Farming Region with higher row spacing for Natural Farming Regions III, IV & V as specified in Figure 2.3 (ZCATF, 2009). The five Natural Farming Regions or Agro Ecological Zones of Zimbabwe, are based mainly on the mean annual rainfall (mm year^{-1}) as described in Table 2.1.

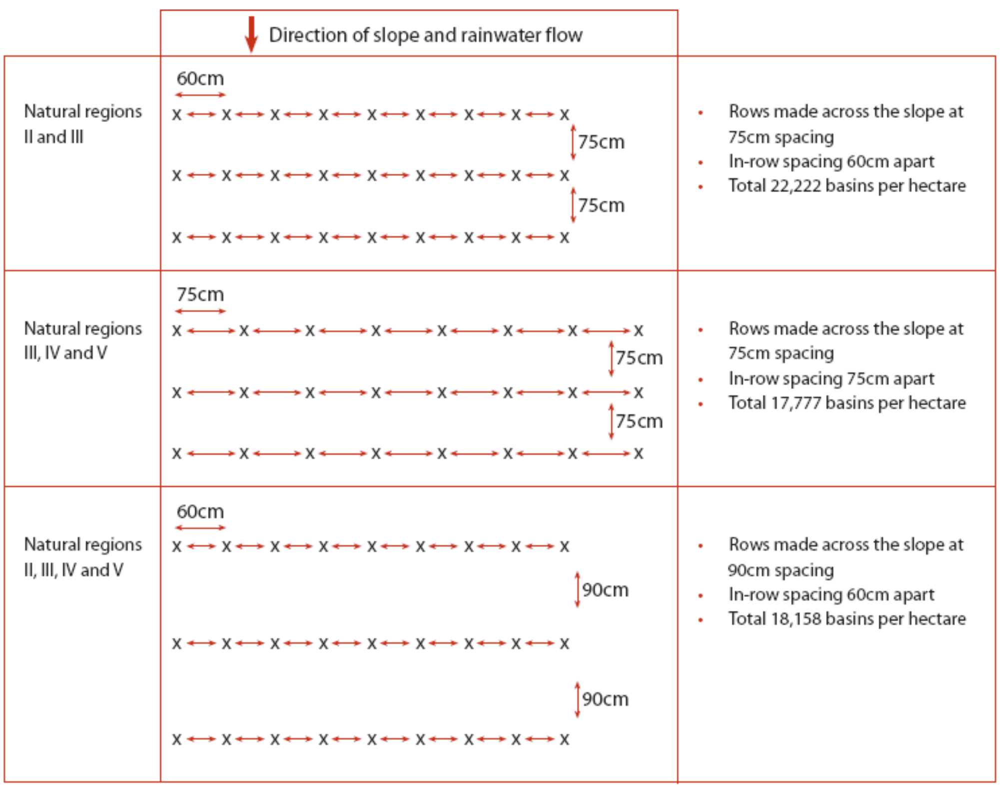

Figure 2.3 Basin spacing for different Natural Regions in Zimbabwe (Adapted from ZCATF, 2009)

Table 2.1 Rainfall characteristics of the Five Agro Ecological Zones of Zimbabwe (Adapted from Vincent & Thomas, 1960)

Natural Region	Annual rainfall(mm)	Rainy season	Number of growing days
I	1000+	Rain in all months of the year, relatively low temperatures	170-200
II	750-1000	Rainfall confined to summer	120-170
III	650-800	Relatively high temperatures and infrequent, heavy falls of rain, and subject to seasonal droughts and severe mid-season dry spells	60-120
IV	450-650	Rainfall subject to frequent seasonal droughts and severe dry spells during the rainy season	60-120
V	<450	Very erratic rainfall. Northern low veldt may have more rain but the topography and soils are poor	>70-135

The basins are prepared before the start of the rainfall season by disturbing about 10percent of the soil (Twomlow *et al*., 2008). This is more beneficial for farmers without animal draught power since they do not have to wait for other farmers to finish planting before they can borrow or hire draft power. Inorganic fertiliser or manure is applied just before planting in the planting basins (Figure 2.4A & B). This allows precise application of fertilisers and increases fertiliser use efficiency by 10 to 15 percent (Hobbs & Gupta, 2004). On the other hand, PB increases water infiltration by capturing rain water, Figure 2.4 (C). Nevertheless, this method has been associated with drudgery and it is estimated that it requires 58 percent more labour than the conventional method of farming in Zimbabwe. As a result, farmers are not able to practice CA with basins on areas greater than one hectare (Haggblade & Tembo, 2003b).

Figure 2.4 (A) An illustration of precise application of fertiliser in planting basin (B) precise application of manure (C) basins capture rainwater, (D) field of planting basins (Adapted from ZCATF, 2009)

Figure 2.5 (A) shows a ripper tine which was developed for farmers with animal draught power for use to open planting furrows, where seed and fertiliser are placed at planting (ZCATF, 2009). Farmers with animal draught power can also use direct seeders which have a caulter that cuts through the residue opening furrows where seed and fertiliser are placed in a single operation as shown in Figure 2.5 (B). The jab planter in Figure 2.5 (C) is used as a Minimum Tillage implement for farmers without draft power. The jab planters were originally developed by Brazilian manufacturers and were imported to Zimbabwe in the 2000s and since then there have been successful efforts to manufacture them in Zimbabwe (Johansen *et al*., 2012). The jab planter has two holes which release seed and fertiliser in the ground. However, it is difficult to use on wet soils as the tips can be clogged with soil (Johansen *et al*., 2012) and it is also difficult to use on hard setting and crusting soils.

Figure 2.5 Figures showing implements for SH sector A) Ripper tine B) Ox drawn planter C) Jab planter (Photograph by Thierfelder in Johansen *et al*., 2012) D) Ripper lines made by a Ripper (Adapted from ZCATF, 2009)

The equipment developed for CA has environment and economical advantages for instance Hobbs & Gupta (2004) reported a US$ 55.00 ha^{-1} decrease in the costs of fuel mainly because the seed drill passes once in CA than in CONV tillage. The decrease in fuel use also reduces the greenhouse gases emitted into the atmosphere which increase global warming (Mukherjee, 2012). In a study conducted in the Zimbabwe SH sector, planting time decreased by more than 50 percent with an ox drawn direct seeder (Sibanda, 2002). The reduction in time for land preparation allows farmers to carry out other farm activities.

2.3.2 Continuous Residue Cover

Conservation Agriculture encourages the maintenance of a permanent soil cover with 30 percent of the soil covered with crop residue or cover crops (FAO, 2011). In contrast, CONV retains less than 10 percent of the soil residues and thus expose large soil areas to soil erosion. Crop residues are important in enhancing organic status and suppress weed growth (Murungu *et al*., 2010). Under CA, it is recommended that farmers retain at least two to three t ha^{-1} of crop residues every year (Derpsch, 2008). However it is difficult for SH farmers to retain crop residues on the soil surface due to multiple uses of the crop residues (Giller *et al*., 2009). The yields are also very low below 1 ton ha^{-1}, therefore making it impossible to retain residues up to 3 ton ha^{-1}.

Studies in Eastern Cape, South Africa under maize based irrigation system showed that winter cover crops such as grazing vetch (*Vicia dasycarpa)* and oat (Avena sativa) can provide ground cover which can suppress weeds (Murungu *et al*., 2010). Cover crops can suppress weeds by competing for the use of growth resources, such as light and nutrients (Derpsch, 2008). However the use of cover crops can be a challenge in the SH sector with dry winter seasons. The arable fields are also used for communal grazing animals making it difficult to grow the crops in the SH sector.

2.3.2.1 Reduced Soil Erosion

Crop residues reduce wind and water erosion and play an important role in increasing water infiltration by reducing surface runoff (Adekalu *et al.*, 2007; Montgomery, 2007). The soil organic matter which is increased by crop residues helps reduce soil erosion by stabilising the surface aggregates through reduced crust formation and surface sealing (Alvear *et al.,* 2005; Kassam *et al*., 2009). Soil aggregation is important in developing and maintaining good soil porosity and hence good root growth and movement of soil water and gases. Stable soil aggregates increase the rate of water infiltration, percolation and decrease soil crusting (Zingore *et al.*, 2005). Crop residues also act as tiny reservoirs that slow down water runoff which creates more time for water to soak into the soil (Castro *et al*., 2006). Conservation Agriculture also increases water use efficiency by 15 to 50 percent due to the effect of the ground cover which reduces the splash effect of raindrops and reduces runoff (Hobbs, 2007). As a result, more water is available to the plant which is important especially in areas that receive low rainfall (Araya & Stroosnijder, 2010).

2.3.2.2 Soil Organic Matter

The reduction of tillage in CA and the use of crop residues increase the accumulation of organic matter in the topsoil layer (0 to 5 cm). This is an important indicator of soil quality. Soil organic matter is valuable for its influence on physical, chemical, and biological properties within the soil system (Riley *et al.*, 2005). The soil organic matter is critical in providing exchange sites for nutrient ions, thereby minimising leaching or sorption of clay minerals through slow release to the soil (Soon & Arshad, 2005).

The higher level of soil organic matter at the soil surface in CA increases soil fauna compared to the CONV system (Rasmussen & Collins, 1991). The soil fauna are divided into three groups namely Micro-organisms, Mesofauna and Macrofauna. The micro-organisms (e.g. bacteria), mycorrhizal fungi, protozoa, Nematoda, Rotaroria and Tardigrada) play a variety of functions in the soil especially recycling of nutrients and also forming the base of the food chain (Wardle, 1995; Lupwayi *et al*., 2001). Mesofauna (e.g. Enchytraeidae, collembola, Acarina, Protura and Diplura) enable nutrient recycling and create micro aggregates that stabilise the soil structure.

One of the abundant groups is the Enchytraeidae (potworms) their abundance depends on levels of soil organic matter. These live in the pore system and feed upon fungi, decomposed plant material and mineral particles (Holland, 2004). Macrofauna (e.g. Gastropoda, Lumbricidae, Arachnida, Isopoda, Myriapoda, Diptera, Lepidoptera, and Coleoptera) reside between the soil micro-aggregates feeding upon the soil substrate, microflora fauna, soil organic matter, surface flora and fauna. They help move the soil which improves soil porosity, water and air flow. Lumbricidae (earthworms) modify the soils physical structure when they create burrows, which penetrate the sub-soil to control infiltration and drainage and this ultimately decrease the risk of soil erosion (Holland & Reynolds, 2003; Rodriguez *et al.*, 2006). In a study by Castellonos-Navarrete *et al.* (2012) earthworm abundance was significantly higher under CA (152 earthworms m^{-2}) compared to CONV (42 earthworms m^{-2}) (Figure 2.6).

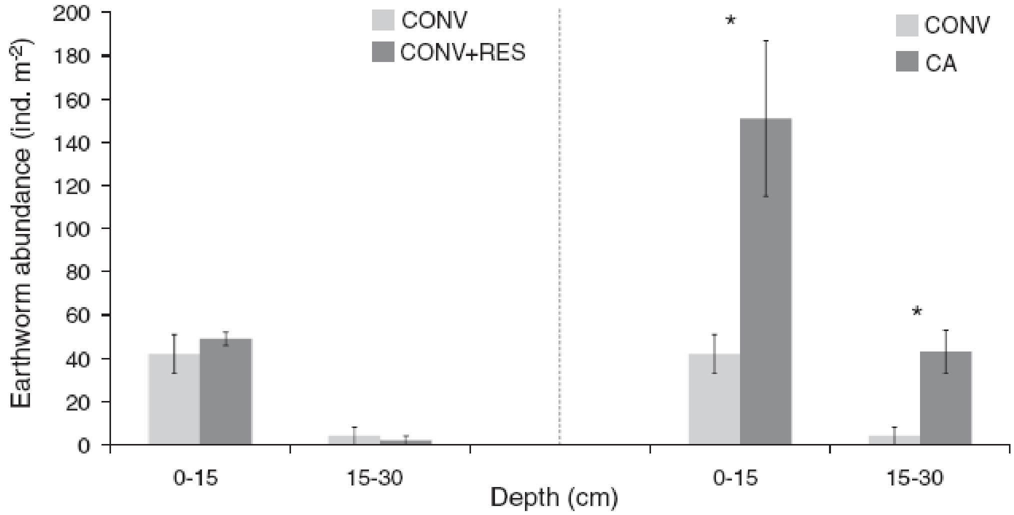

Figure 2.6 Earthworm abundance per depth layer and treatment. CONV = Conventional Tillage; CA = Conservation Agriculture; CONV + RES = Conventional Tillage with residue; (*P<0.05); Error bars indicate the standard error (Adapted from Castellonos-Navarrete *et al*., 2012)

The soil micro-organisms also facilitate weed predation which is beneficial in reducing weed seed bank and is described as an ecological weed management tactic (Menalled *et al*., 2013; Davies *et al*., 2013). There are numerous above ground weed seed predators, the most common include birds, mice, ants, crickets, insect larvae and ground beetles (Holland, 2004). Reicosky & Allmaras (2003) noted that soil organic matter is a principal factor in maintaining a balance between economic and environmental factors and its importance is represented by a central hub of a wagon up wheel.

However, it has been argued that organic matter accumulation is only possible in humid and sub-humid tropics and is not possible in semi arid areas due to insufficient biomass (Erenstein, 2003). In contrast, studies in semi arid areas of Morocco have witnessed an increase in organic matter in CA (Mrabet, 2008).

2.3.2.3 Weed Control

The crop residues on the soil surface have been observed to play a pivotal role in weed control. The mulch controls weeds in a number of ways. Firstly, there is the allelopathic effect of the mulch and cover crops. Some crops residues exude phototoxic allelochemicals into the soil which negatively affect growth of weeds as shown in Table 2.2 (Singh *et al*., 2006). Maize mulch has been observed to release p-hydroxybenzaldehyde, fluro-glucinol, rescinol and caffeic acids which affect negatively weed growth. In recent developments sorgolene, DIMBOA (2, 4 – hydroxy-7-METHOXY-1, 4–BENZOXAZIN-3-one), and quinones have been identified in sorghum (Souza & Alvers, 2004). The issue of allelopathy in cereals is controversial according to Jung *et al*. (2004) there is no evidence of allelopathic properties of cereals residues in inhibiting weed germination. This controversy indicates a need for further research on allelopathy.

Table 2.2 List of crop plants where accessions/varieties have been screened for allelochemicals (Adapted from Singh *et al*., 2006)

Crop plant	Allelochemicals screened	Reference
Avena spp	Scopoletin	Fay & Duke, 1997
Hordeum spp (*H. vulgare*) *H. spontaneum H. agriocrithon)*	Gramine	Lovett & Hoult, 1992
Oryza sativa	Phenolic acids	Jung *et al.*, 2004
Sorghum spp.	Sorgoleone, 5-ethoxysorgoleone, 2.5-dimethoxysorgoleone	Rimando &Weston, 2003
Triticum spp. (*T.speltoides, T.aestivum, T. tauschii*	DIMBOA	Niemeyer, 1998
T.eastivum)	Phenolic acids	Wu *et al.*, 2002
T.speltoides	DIMBOA	Quader *et al.*, 2001

Secondly, in some cases, a decrease in germination of weeds was observed due to the suppressing effects of the mulch. The mulch inhibits weed seed germination by shading and altering the ratio of P_r/P_{fr} required for germination (Collins, 2004; Heschel *et al.*, 2007; Chauhan & Opena, 2012). The mulch also results in low temperatures, which are not favourable for seed germination. However, this depends on the thickness of the mulch as higher quantity than normally found on dryland is required to substantially suppress weed emergence (Chauhan & Johnson, 2009). The recommended mulch application rate of 0.5 to 2 t ha^{-1} is difficult to attain on SH farms (Giller *et al.*, 2009). This is mainly because of low crop production and with the crop residues, especially maize, being used as fodder, fuel, or construction material in a typical farming system as illustrated in Figure 2.7A. Despite the benefit of crop residues in weed control, farmers prefer to collect the crop residues from the fields and store to feed livestock mainly because of the economic importance of livestock in their livelihoods (Figure 2.7B) (Mazvimavi *et al.,* 2008). In addition, SH farmers are not able to realise the benefits of mulching because of their inability to attain the recommended rate.

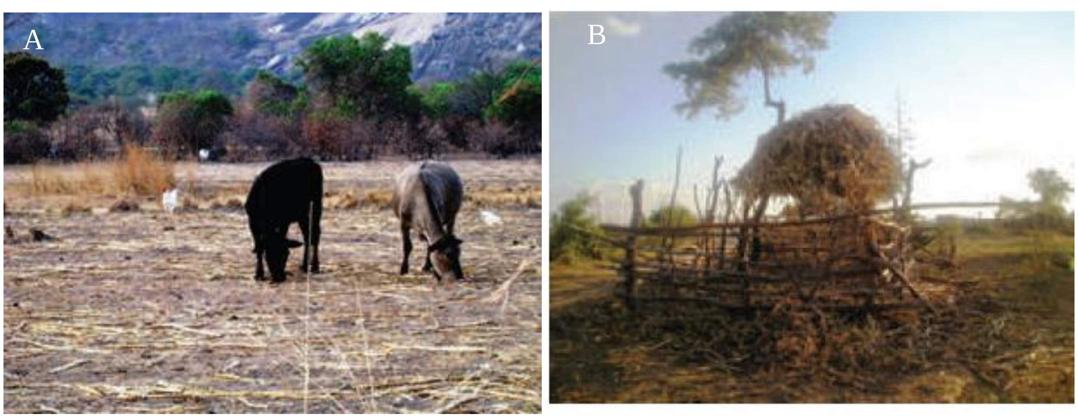

Figure 2.7 (A) Crop residues being eaten by cattle (B) crop residues which were removed from the field to feed the animals during the dry season (Adapted from ZCATF, 2009)

However, the mulch in CA has been associated with negative effects such as disease carryover from one season to another (Baudron *et al.*, 2003). Fungi can survive from one season to another as spores in the mulch with the aid of favourable soil moisture, temperature and nutritional conditions adequate for growth and reproduction. An example is the carryover of *Sclerotium rolfsii*, a pathogen of legume seedlings, which survives in crop residues and infects the subsequent crop (Allen & Lenné, 1998).

2.3.3 Crop Rotation

Crop rotation is a practice of alternating different crops over seasons (Bolliger *et al.*, 2006). Cropping sequences that vary in planting dates, growth periods, are important in weed control practices and in reducing the weed growth (Singh *et al.*, 2006). Improved weed control is realised because certain weeds that are accustomed to certain crops can be suppressed by rotation. This cycle can be broken by rotation of crops that have different morphology and growth patterns. The use of different herbicides with different modes of action in crop rotation also helps to reduce herbicide resistance and effectively control weeds (Vasileiadis *et al.*, 2007). A study that was done in Colorado showed a low weed biomass in rotations of Wheat-Millet-Fallow, Wheat-Corn-Millet-Fallow, and Wheat-Corn-Millet as compared to continuous millet as illustrated in Figure 2.8 (Anderson & Garlinge, 2000). Another positive effect of rotation is that it increases crop yields through reduced weed growth, pest problems and improved soil characteristics (Liebman & Davis, 2000). In a study where cotton, was followed by maize a 10 percent increase in yields as compared to cotton monoculture was observed (Reddy & Norsworthy, 2010).

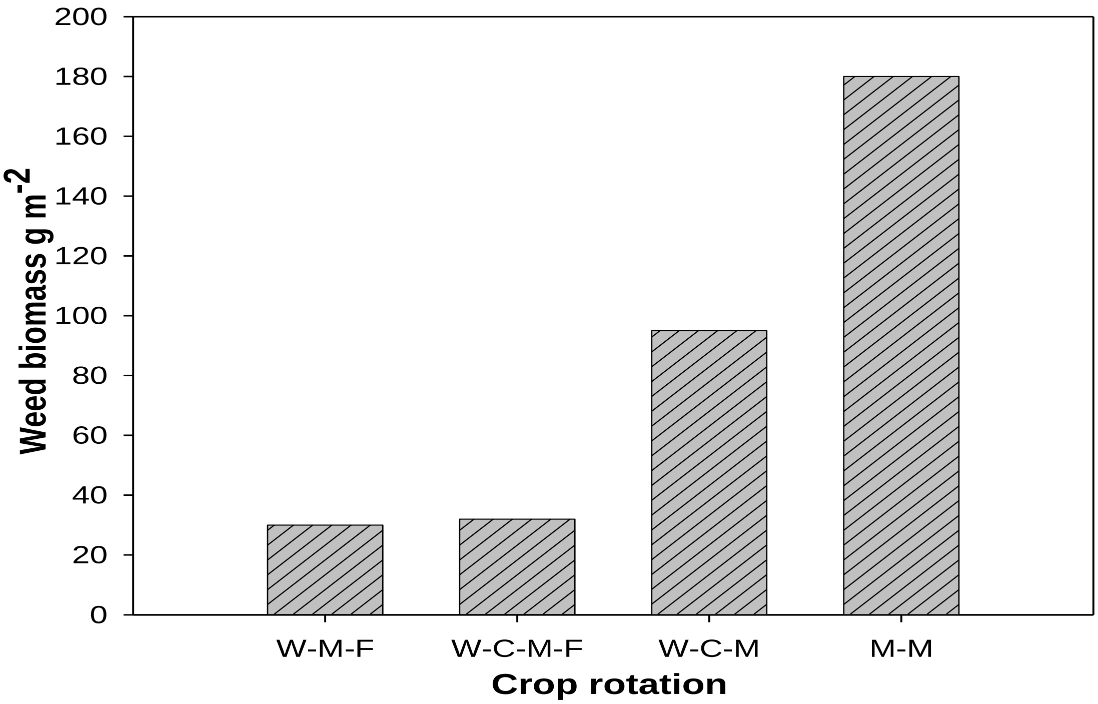

Figure 2.8 Biomass of green foxtail and long spine sandbur in proso millet for four rotations at Akron, Colorado (W = winter wheat, M = Proso millet, C = corn, F = Fallow). Study initiated in 1990, with weed biomass measured in 1997 and 1999. (Adapted from Anderson & Garlinge, 2000)

In Zimbabwe, there is promotion of legume-cereal rotation (ZCATF, 2009). Legumes have the potential to suppress weeds through competition. Inclusion of cereals has also been observed to suppress weed by allelopathic effects (Rimando & Weston, 2003). The effects of rotation on weed density are complex and depend on a variety of factors such as farmer management and climate (Daniel *et al.*, 2008). Rotational options in Zimbabwe are limited because the cereals dominate the farming systems hence no equal proportions of land are allocated to cereals and legumes (Mazvimavi *et al*., 2010a). Farmers prefer not to grow legumes on large areas of their land because of limited markets for legumes (Baudron *et al*., 2011). As a result cereals are largely grown on the same piece of land year after year (Giller *et al*., 2009).

2.4 CURRENT STATUS OF CONSERVATION AGRICULTURE ADOPTION IN THE WORLD

Borlaug (Nobel Prize winner of World Congress of Soil Science, 1994) in his key note address estimated that world grain yields need to be increased by 80 percent by the year 2025 in response to increased food demand. Until now, yield increases around the world have come from increased fertiliser, pesticide use and genetic improvement (Barker & Saxton, 2007). Reynolds & Tuberosa (2008) also noted that despite the availability of improved varieties with increased yield potential, yield increases will not be attained because of poor soil structure. The challenge is for CA to contribute to future global food increases in a sustainable manner. Furthermore, climatic models suggest that climate change will prejudice crop production and there is need for change of existing cropping systems (FA0, 2011).

Conservation Agriculture is now being widely recognised as a sustainable method of crop production worldwide (FAO, 2011; Kassam & Friedrich, 2011). FAO (2012) estimated that CA is being currently practised on approximately 124 795 million hectares across all the continents in the world (FAO, 2011). The area under CA has been increasing at a rate of 6 million ha year^{-1} (Kassam *et al*., 2011). However, most of the increase has been observed in America, Australia and recently in Asia. Approximately 47 percent of the technology is practised in Latin America, 38 percent in the United States of America and Canada, 9 percent in Australia and about 3.7 percent in the rest of the world, including Europe, Africa and Asia. CA practices in the world accounts for five to 10 percent of food production in the world (Derpsch, 2008; FAO, 2011).

2.4.1 Conservation Agriculture in America

The United States of America is the world leader in terms of the percentage of land under no tillage. However, it is interesting to note that CA accounts for 22 percent of the arable land in the country. Paraguay is rated as the leading country in terms of adoption of CA in the world with 85 percent of the cultivated area under CA (FAO, 2012). Argentina had the second largest area under CA in the world by 2009 and the adoption rate has reached an exponential phase with CA being practised on about 60 percent of the cropped lands. No –tillage, *plantio directo*, in Brazil is also rapidly growing and is encouraged by the availability of glyphosate at affordable prices (Kassam *et al*., 2011).

2.4.2 Conservation Agriculture in Europe and Asia

A report from FAO (2012) showed that there is great potential for adoption of CA in Asian countries such as China, Russia, and Kazakhastan, Ukraine (Table 2.4). Adoption of CA is increasing in the Asian countries mainly due to existing favourable institutional and policy conditions, the involvement of machinery manufacturers and national and international research institutions (Harrington & Erenstein, 2005). The countries leading in the area under CA in Europe are Spain, Italy and France with corresponding areas of 5, 1.5 and 1 percent of the cropland, respectively. Countries like the Netherlands are still in the early stages of adoption (Kassam *et al*., 2011).

2.4.3 Conservation Agriculture in Africa

2.4.3.1. Conservation Agriculture in North Africa

Conservation Agriculture is being promoted in the Northern region of Africa with a view to reduce costs of machinery, fuel and time, allow timely sowing, fertiliser application and weed control, increase yields, reduce water and wind erosion, increase nutrient-efficiency and increase water use efficiency in dry areas (Cantero-Martinez *et al.* (2007). Extensive research has been conducted in northern African countries such as Algeria and Morocco (Mrabet, 2008) and more recently there have been series of initiatives in Tunisia (M'Hedhbi *et al*., 2003; Ben-Hammouda *et al*., 2007). Conservation Agriculture is used for winter crops, in rotations with legumes, sunflower and canola, and in field crops under irrigation to help optimize irrigation system management to conserve water, energy, soil quality and to increase fertiliser use efficiency (Kassam *et al.,* 2011). According to the work by ICARDA and CIMMYT, CA systems have increased crop yields, soil organic matter, water use efficiency and net revenue.

Conservation Agriculture also shows the importance of utilising fallow period for cropping and of crop diversification, with legumes and cover crops providing improved productivity, soil quality, N-fertilizer use efficiency and water use efficiency (Pala *et al.,* 2007). In dry-land farming, CA is an important land management technique which results in increased productivity and profitability while conserving and improving the environment (Kassam & Friedrich, 2011). However, CA adaptation in dry-land is constrained by, unreliable rainfall characterised by droughts, low biomass production and acute competition between conflicting uses including soil cover, animal fodder, cooking/heating fuel, raw material for habitat (Giller *et al*., 2009). Poverty and vulnerability of many SH farmers that rely more on livestock than on grain production are other key factors lowering adoption of CA.

2.4.3.2 Conservation Agriculture in Sub-Saharan Africa

In Sub-Saharan Africa, CA is being promoted in 14 countries namely, Burkina Faso, Ghana, Kenya, Lesotho, Madagascar, Malawi, Mozambique, South Africa, Sudan, Swaziland, Tanzania, Uganda, Zambia and Zimbabwe (Kassam & Friedrich, 2011). The organisations promoting CA in Sub-Saharan Africa are Food and Agriculture Organisation (FAO), Centre de Coopération Internationale en Recherche Agronomique pour le Dévelopment (CIRAD), the African Conservation Tillage Network (ACT), International Centre for Agro Forestry (ICRAF), International Maize and Wheat Improvement Center (CIMMYT), International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) and International Institute of Tropical Agriculture (IITA) (Haggblade & Tembo, 2003a; Kaumbutho & Kienzle, 2007; Shetto & Owenya, 2007; Nyende *et al*., 2007; Baudron *et al*., 2007; Boahen *et al*., 2007; Erenstein *et al*., 2008). Other organisations facilitating the promotion of CA, particularly in eastern and southern Africa are New Partnership for Africa's Development (NEPAD), Forum for Agricultural Research in Africa (FARA) and Alliance for a Green Revolution in Africa (AGRA) through their work on soil health. The edge to promote CA in these countries was derived from the desire to curb the continous continual environmental and land degradation, low soil fertility, organic matter and climate changes affecting crop production (Kassam & Friedrich, 2011). The decreased labour costs, time of planting, costs of fertiliser and increased yields were evident with adoption of CA (FAO, 2011).

So far, the area in hectares under CA is still small (368 000), and promotion is mainly among SH farmers. The total number of farmers practising CA are more than 100,000 SH farmers in the southern African region. The areas under CA in the Sub Saharan Africa are still low and are as follows: Ghana 30,000 ha; Kenya 33 100 ha; Morocco 4,000 ha; Mozambique 152 000 ha; Sudan 10,000 ha; Tanzania 25,000 ha; Tunisia 8,000 ha; Zambia 200,000 ha and Zimbabwe 139,500 ha (Tbale 2.3) (FAO, 2012).

While there is evidence of CA adoption in African countries, the adoption rate is slow among SH farmers than large scale farmers and has not entered into the exponential phase (Derpsch *et al*., 2010; Haggblade & Plerholpes, 2010). It has been difficult for SH farmers to adopt all CA components particularly maintaining a permanent crop cover due to the multiple uses of crop residues in the system. In most cases, farmers prefer to feed animals with the crop residues leaving little or no residues in the fields. Unless other cover crops are found or there is an improvement of the current crop residue management practices, it will be difficult to maintain crop cover in the SH sector (Giller *et al*., 2009).

There are numerous production constraints in the SH sector which hinder adoption of CA such as erratic rainfall, limited knowledge, as well as lack of inputs, poor soil fertility leading to low crop production, poor weed management, lack of implements, lack of supporting polices and implementing institutions and high labour requirements for making basins (Kassam & Friedrich, 2011). However, despite the mentioned constraints there is evidence of CA adoption suggesting that CA elements can work for SH farmers in Sub-Saharan Africa. The priority is to focus on research on major constraints to help adoption of CA (Fowler & Rockström, 2001; Haggblade & Tembo, 2003b).

Table 2.3 Overview of Conservation Agriculture by country

Country	Area (ha)	Year of survey	Country	Area (ha)	Year of survey
Argentina	25 553	2009	Mozambique	152	2011
Australia	17 000	2008	Namibia	0.34	2011
Bolivia (Plurinational State of)	706	2007	Netherlands	0.5	2011
Brazil	25 502	2006	New Zealand	162	2008
Canada	13 481	2006	Paraguay	2400	2008
Chile	180	2008	Portugal	32	2011
China	3 100	2011	Republic of Moldova	40	2011
Colombia	127	2011	Russian Federation	4500	2011
Democratic People's Republic of Korea	23	2011	Slovakia	10	2006
Finland	160	2011	South Africa	368	2008
France	200	2008	Spain	650	2008
Germany	5	2011	Sudan and South Sudan	10	2008
Ghana	30	2008	Switzerland	16.3	2011
Hungary	8	2005	Syrian Arab Republic	18	
Ireland	0.1	2005	Tunisia	8	2011
Italy	80	2011	Ukraine	600	2011
Kazakhstan	1600	2011	United Kingdom	150	2011
Kenya	33.1	2011	United Republic of Tanzania	25	2011
Lebanon	1.2	2011	United States of America	26 500	2007
Lesotho	2	2011	Uruguay	655.1	2008
Madagascar	6	2011	Venezuela (Bolivarian Republic of)	300	2005
Malawi	16	2011	Zambia	200	2011
Mexico	41	2011	Zimbabwe	139.3	2011
Morocco	4	2008			
Total (ha)			124 795		

(Source Aquastat http://www.fao.org/ag/ca/6c.html, accessed 10/09/2012).

2.4.3.3 Conservation Agriculture in Zimbabwe

In Zimbabwe, non-tillage can be traced back to the 1920's to the establishment of no-ploughing trials in tobacco. Increased land degradation, decline in soil fertility and increased costs of fuel and spare parts as a result of the sanctions imposed on the northern Rhodesian government promoted the demand for reduced tillage equipment in the large scale commercial sector (Ministry of Agriculture, 1988). The adoption of reduced tillage increased such that by 1980 30 percent of the large scale farmers had adopted reduced tillage (Nyagumbo, 1998). In the late 1980s, CA in the form of conservation farming was promoted in communal areas in northern-eastern Zimbabwe by Brian Oldrieve. The positive aspects of CA such as increased crop yields and reduced soil erosion incited the promotion of all components of CA to the SH and large scale farmers and the dissemination was aided by Conservation Tillage hand books (Oldrieve, 1993).

During the period from 1988/1996 the CT for Sustainable Crop Production Systems known as the Contill Project collaborating with AGRITEX and GTZ introduced and promoted mulch ripping, clean ripping, and tied ridging against the CONV system in northern Zimbabwe (Marongwe *et al.*, 2012). Of the three tillage systems, mulch ripping resulted in higher water use efficiency and proved to be most suitable in semi arid areas of Zimbabwe (Moyo & Hagman, 1994). However, there was no significant uptake of the CT system in the SH sector as observed by various Research Institutes in Zimbabwe which prompted the formation of African Conservation Tillage (ACT) (Benites, 1998). ACT aimed at creating a forum for sharing information among researchers on CA. Since then until 2004 there has not been much work to understand what could have been the factors resulting in low adoption of CA among the SH farmers in Zimbabwe.

In 2004, there were renewed efforts to promote CA in the SH sector by twenty five NGO's focusing on households with difficulties in meeting their basic food requirements (Mazvimavi & Twomlow, 2009). These households were supplied with agricultural inputs and extension support which enabled them to adopt CA resulting in higher yields in CA than in CONV (Table 2.4).

Table 2.4 Maize yield (kg ha^{-1}) from CA plots and non CA plots for three cropping seasons in Zimbabwe (Adapted from Mazvimavi *et al.,* 2010)

District		2006/2007		2007/2008		2008/2009	
		CA	CD Tillage	CA	CD Tillage	CA	CD Tillage
NR II	Bindura	1950	920	1109	510	1490	1208
	Murehwa			2266	897	2132	1412
	Seke					1635	962
NR III	Chirumhanzi	1162	789	1207	840	1428	914
	Masvingo	1735	725	3060	557	2439	1355
	Mount Darwin	1105	701	1011	368	1190	877
NR IV	Gokwe	2056	421	766	285	1433	713
	Insiza			800	247	1646	1105
	Nkayi	1244	789	1175	398	1579	792
	Nyanga	1917	1250	1247	787	1308	874
NR V	Binga			500	250	1384	868
	Chipinge			222	79	1262	1105
	Chivi	1500	910	1061	270	1658	874
	Hwange	1464	385	561	424	1563	713
	Mangwe			614	283	1048	792
Total average yield		1570	765	1114	407	1548	970

CA = Conservation Agriculture; CD = Conventional draught tillage

Maize yielded on average 1 546 kg ha^{-1} on CA and 970 kg ha^{-1} on CONV plots in the 2008/2009 cropping season in all districts in Zimbabwe practising CA (Mazvimavi *et al*., 2010a). On the other hand, other less vulnerable households also adopted the technology without assistance of inputs from NGO'S when they realised the benefits of CA (Mazvimavi *et al.*, 2008). There has been some machinery developed specifically for CA such as Jab planters, rippers, and direct seeders, herbicide sprayers and hoes by HASST Zimbabwe, AGVENTURE, ZIMPLOW, and GROWNET (Marongwe *et al*., 2012). The government of Zimbabwe launched the Conservation Agriculture Promotion Network (CAPNET) in 2008 involving ministries in the Ministry of Environment, Ministry of Education and Zimbabwe Farmers Union which was the CA task force. In 2010, the CA task force convened to review the CA status in Zimbabwe. The workshop identified major challenges in CA implementation as lack of support from the government, limited involvement of the private sector to develop machinery and absence of the National Implementation Framework to guide implementation agencies. However, since CA had been promoted before in the 1920s and 1980s and had not been successful, it would be important to first look at the biophysical and socio-economic factors affecting farmers before implementing CA again. There hasn't been much research to identify the biophysical and a socio-economic factor which is crucial if CA promotion is to continue.

The National CA implementation Task Force has a target of 500 000 farmers practising CA on at least 250 000 ha of land with doubling yields on CA plots in comparison to CONV by 2015 (Ministry of Agriculture, Mechanisation and Irrigation Development, 2012). It is estimated that over 130 000 households adopted CA in the period between 2004 and 2010 (Mazimavi *et al*., 2010). While some farmers were adopting the CA technology, other farmers were dis-adopting the technology. Most of the farmers who adopted CA most of them were not practising all the components of CA (Marongwe *et al*., 2010). It was observed that most of the farmers adopted

Minimum Tillage with digging of planting basins. The CA components such as crop rotation and maintaining a permanent soil cover were not widely adopted by most of the farmers (Mazvimavi & Twomlow, 2009). Additionally, winter weeding was not practised by most farmers since they preferred to do off field activities during winter. If the benefits of CA are to be fully exploited changing tillage is not in itself sufficient, all three principles must be considered and implemented taking into consideration the individual circumstances of the farmers (Derpsch, 2008). When such a situation is achieved consistently, it is called “full Conservation Agriculture” as illustrated by the practices of many farmers in Southern Brazil (do Prado Wildner *et al.,* 2004). There is a need to identify why farmers decide to adopt some components of CA and leave other factors. This information is important for dissemination of CA.

The trends of CA adoption in Zimbabwe have been quite low compared to countries in South and North America despite the fact that most farmers know and can articulate all the components and benefits of CA (FA0, 2011). The area under CA has not increased since most of the farmers practice CA on areas less than a hectare due to labour constraints required for making planting basins. When comparing the SH farmers in Zimbabwe and countries that have high adoption rates of CA, the farmers in Zimbabwe are constrained by lack of implements for use in CA, poor soil fertility and limited weed management option exacerbate the situation. Farmers fail to maintain permanent ground cover due to multiple uses of crop residues resulting in less or no crop residues being left in the field (Giller *et al.*, 2009). Thus there is a need to address the constraints which are hindering the adoption of CA in the SH sector and also provide answers on why CA adoption has remained low despite the fact that it has been promoted for more than a decade.

2.5 WEED DYNAMICS IN CONSERVATION AGRICULTURE

2.5.1 Tillage Effects on Weed Seed Bank

Soil weed seed banks are reserves of viable weed seeds present in the soil and on its surface through seed production and dispersal, while it depletes through germination, predation and decay (Huang *et al.,* 2012; Chauhan & Opena, 2012). The weed seed bank usually consists of new weed seeds recently shed as well as weed seeds that were shed for several years, which are all important for the perpetuation of the weed flora in a particular area (Appleby, 2005). Tillage system can have an influence on the number of weed seeds, composition and weed seed survival in the weed seed bank (Carter & Ivany, 2006). It is expected that with no tillage, the composition and density of weed seeds in the seed bank is likely to be altered (Chauhan *et al*., 2006a). Tillage systems influence the distribution of weed seeds in the soil profile (Cardina *et al*., 2002).

In a study by Swanton *et al*. (2000), the 0 to 5 cm level of the soil profile resulted in 60 to 90 percent of the weed seeds under no tillage while 3 percent was found in the same zone under CONV tillage because most of the weeds were incorporated by tillage. Shrestha (2002) showed that tillage implements have an impact on the distribution of weed seeds in the soil profile. Chisel ploughing resulted in most seeds being concentrated in the 5 to 10 cm zone and for the mouldboard plough most of the weed seeds were concentrated in the 10 to 15 cm zone of the soil profile (Fig 2.9). Seed placement within the soil profile by tillage implements has implications on weed seed germination and survival (Swanton *et al*., 2000).

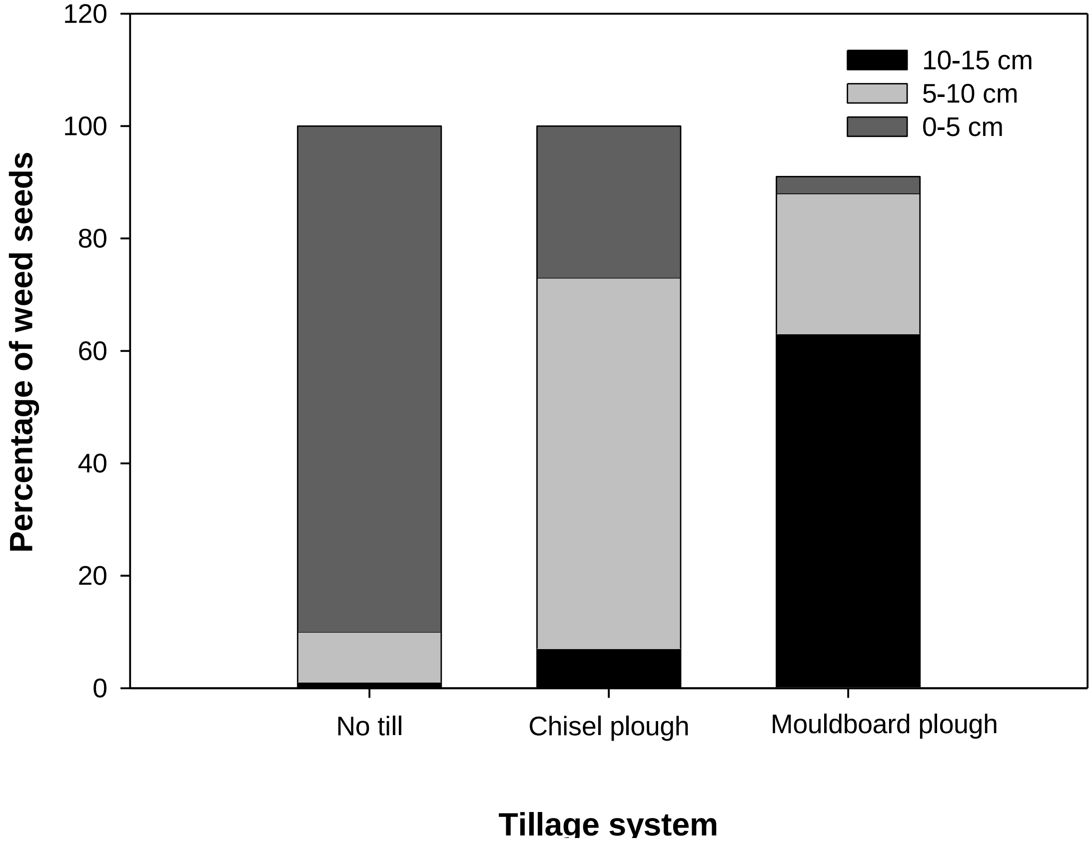

Figure 2.9 The vertical distribution of weed seeds in the profile at depths of 0 to 5 cm, 5 to 10 cm, 10 to 15 cm (Adopted from Shrestha *et al.*, 2008)

It is believed that the weed seed bank decrease with time in CA when there is no incorporation of shed seeds into the soil (Wall, 2007). The weed seeds shed concentrated on the surface may germinate or be eaten by rodents and birds (Chauhan *et al*., 2007; Baraibar *et al*., 2009). The weed seeds buried in the soil which are not brought to the surface and remain dormant and die with time resulting in a decrease of the weed seed bank (Melandor *et al*., 2007). Souza and Alvers (2004) noted a 98 percent decrease in the weed seed bank when weeds are not allowed to set seeds for one year (Figure 2.10). Ruedell (1995) observed a 10-fold reduction in the weed species in soils that were under reduced tillage for 10 years. This also tallies with the findings by Carter & Gregorich (2007) that the weed seed bank decreases with time, as there is no addition of weeds into the weed seed bank. According to Westerman *et al*. (2003), seed predation may be responsible for the larger part of weed seed bank losses. Predation of *Abutilon theophrasti* Medikand *Setaria faberi* Herrm seeds was found in maize-soya bean crop rotations in America (Heggenstaller *et al*., 2006).The reduction of weeds seeds in CA with time makes it possible to manage weed seed bank in CA.

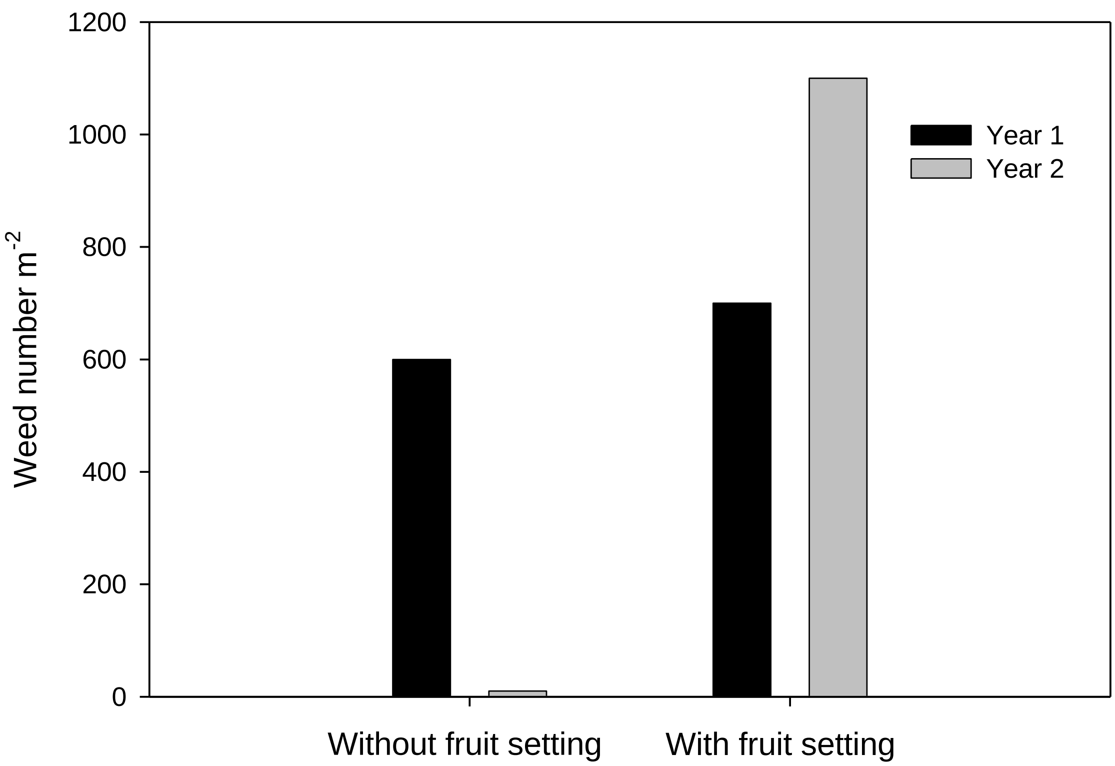

Figure 2.10 Weed densities under oat plant residue managed before and after fruit setting (Adapted from Souza & Alvers, 2004)

There are various studies which have been conducted to elucidate the effect of tillage on the weed seed bank (Barberi LoCascio, 2001; Cardina *et al*., 2002). The results show variation on the effects of tillage on the weed seed bank. For example some studies (Vanasse & Leroux, 2000; Cardina *et al*., 2002) show that the weed seed bank increased by no tillage while others indicate the opposite (Swanton *et al*., 2000) or showed no difference (Bárberi & Lo Cascio, 2001; Derkensen *et al*., 2002). Studies carried out in Saskatchewan over a 12 year period showed variation on the effects of tillage on the weed seed bank (Derkensen *et al.*, 2002).

The variation on the effects of tillage on the weed seed bank observed from various research shows that there are various factors that affect the weed seed bank. Ćiuberkis *et al*. (2008) emphasised that crop rotation, type of crop, cropping and weather patterns can impact on the weed species composition and density. Soil textural conditions can also determine the effects of tillage on the weed seed bank. For example the clay soils which are subject to shrink and swell, could develop cracks through which seeds enter into the soil profile of untilled soil and thus replenish the weed seed bank (Carter & Gregorich, 2007).

2.5.2 Tillage Effects on Weed Germination and Emergence

One of the principal reasons for tilling the soil is to control weeds, for that reason the absence of tillage in CA implies that weed control becomes a huge challenge (Baker & Saxton, 2007). It is reported that weed control in the first year of transition from CONV to CA is difficult and costly (Ekboir, 2003). Weed control requires more intensive weed management in CA than in CONV (Melandor *et al*., 2007). In a study by Thomas *et al.* (1996), CA resulted in higher weed density for all weed species (Table 2.5). The increase in weed density is mainly due to the fact that most of the weed seeds remain on the top 5 cm of the soil which is susceptible to favourable temperature and moisture which facilitate germination of weed seeds on the soil surface (Blackshaw *et al*., 2007). Consequently, the increase in weed populations has an impact on the amount of labour and time required for weeding. In a study by Twomlow *et al.* (2008), CA resulted in a threefold increase in labour requirements and costs.

Table 2.5 Weed density in conventional and Conservation Tillage in Canada (Adapted from Thomas *et al.*, 1996)

	Zero tillage Density m^{-2}	Conventional tillage Density m^{-2}
Dandilion	7	1.0
Perennial saw thistle	2.8	1.8
Canada thistle	12.9	5.3
Quack grass	14.8	6.1
Wild oats	29.8	20.1
Volunteer canola	140.8	63.7
Cleavers	1.9	0.4
Hemp nettle	2.1	1.3
Round leaved marrow	9	0.7

The influence of tillage systems on weed seeds germination and emergence is thought to be mainly due to weed seed burial and distribution in the soil profile by soil implements (Grundy *et al*., 2003; Chauhan & Johnson, 2009). Conventional mouldboard ploughing distributes weed seeds uniformly over the plough depths reducing the germination of fresh shed weed seeds by burying them, but at the same time exposing the previously buried weed seeds to the surface (Chauhan *et al*., 2006). Tillage, therefore, enhances seed emergence by bringing them to the surface where there is enough light required to stimulate germination (Melander *et al*., 2007). Souza and Alvers (2004) noted that weed seeds emergence is expected to be high in CONV because of more soil seed contact that occurs as the seeds are incorporated in the soil by tillage implements than in CA. The movement of tillage implements and soil-particles in CONV also enhances the germination of weed seeds by scarifying seeds to remove dormancy (Chauhan & Johnson, 2009).

It can be argued that weed seedling emergence is often expected to be higher in CA than in CONV because most of the seeds are concentrated near the soil surface where it is easy for seeds to germinate with enough light suitable depth (Chauhan & Johnson, 2008b). This is supported by the work of Chauhan & Johnson (2008b) in which only four percent of the seedlings emerged from a depth of 6 cm while 80 percent was from the seeds on the surface. The weed seeds in deeper depths in the soil profile in CA remain dormant and do not germinate, since the optimum depth for germination of most seeds is below 2 cm and maximum depth is 6 cm (Froud-Williams, 1988; Carter & Ivany, 2006).

Seedlings of *Digitaria ciliaris* (Retz.) Koel (southern crabgrass) did not emerge from a seed burial depth of 6 cm (Chauhan & Johnson, 2008a) in a pot study. The weed seeds which are buried deep in the soil require more energy to emerge. The seeds in CA which are located mostly in 0 to 5 cm zone of the soil profile will emerge easily when compared to seeds buried at depths greater than 5 cm (Chauhan & Johnson, 2009). The weed seeds on the surface germinate in higher densities at the start of the season suggesting that weed seeds could become a potential problem in CA since they germinate and grow earlier than the crop. Weed seedlings, in any system, emerging faster and earlier than the crop or other weed species have the potential to be more competitive than the crop and will likely cause greater yield loss (O'Donovan *et al*., 2000). This suggests that weeds could become a major constraint in CA systems, in this regard; management strategies are needed to mitigate this development.

A large proportion of the weed seeds on the soil surface in no till promote greater emergence of weed species that require light to germinate (Chauhan *et al*., 2006; Singh, 2006) whereas emergence of deep-buried seeds in other weed species has been reported to be contrariwise correlated to seed weight (Benvenuti *et al*., 2003). Greater abundance of wind-dispersed species has been observed under reduced tillage, which might be due to lack of burial by tillage equipment (Derksen *et al*., 1993; Froud-Williams *et al*., 1988). Small-seeded species mainly emerge from the surface layer and not from the deeper depths, probably because they have insufficient nutrient reserves to emerge from such depths (Chauhan *et al*., 2006). A number of perennial weeds were substantially greater in no till compared with CONV systems (Deveikytė *et al*., 2008). The weed seed morphology can influence the germination of buried weed seeds and seeds that have ridges and hairs can be incorporated in the soil easily while soil seed contact is enhanced (Benvenuti *et al.*, 2003). This interaction of the weed seeds with soil aggregation can in turn influence micro climate and consequently aid seed germination (Carter & Ivany, 2006).

In summary the literature on the effects of tillage on weed densities finds mixed results of tillage on the weed emergence and germination. Several studies have indicated an increase in weed seeds germination in CA (Froud-Williams *et al*., 1988; Yenish *et al*., 1992; Grundy *et al*., 2003; Carter & Ivany 2006; Chauhan & Johnson 2009; Skuodiene *et al*., 2013). While in other studies indicated no effect of tillage on weeds dynamics was observed (Derkesen *et al*., 1993, Tuesca, 2004; Carter & Ivany 2006; Mandumbu *et al*., 2011). The mixed results shows the need for further research on the effect of tillage on weed dynamics in CA, particularly in the SH where such research is lacking. More studies are required to elucidate the ecological implications of weed seed characters and their relation to tillage practice.

2.5.3 Tillage Effects on Weed species Composition

In addition to changes in weed density, a shift in weed composition also occurs through adoption of CA which results in an increase of perennial broad-leaved and grass weeds, both of which are difficult to remove with the hand hoes (Giller *et al.,* 2009). The perennial weeds increase in CA because they reproduce from several reproductive structures such as bulbs and rhizomes which are left undisturbed in CA compared to ploughed systems (Vasileiadis *et al.*, 2007; Ćuiberkis, 2008). The reproductive structures remain buried in the soil depths, and will germinate when favourable conditions occur. A survey done in Canada showed an increase in perennial weeds like quack grass (*Agropyron repens* (L) Beauv) and some annual species such as *Avena spp*, *Setaria spp*, volunteer barley, wild mustard, redroot pigweed (*Amaranthus retroflexus* (L)), and common lambs quarters (*Chenopodium album* (L) and *Kochia scoparia* (L) (Carter & Gregorich, 2007).

Over time small seeded weeds, which are wind disseminated, increase in CA, for example *Amaranthus spp* and *Ipomoea spp*, because they germinate easily from the soil surface (Culpeppper, 2005). In another study, Vargas & Wright (2003) noted an increase in small seeded weeds, like morning glory (*Ipomoea spp*.) While weeds tend to increase in CA, during the first few years of adoption, they are expected to decrease with time (Wall, 2007; Hobbs, 2008). Skora & Darolt (1996) noted a 78 percent decrease in weed seeds from the first to the second year of no tillage, while the weeds decreased by 98 percent by the sixth year (Figure 2.11).This is partly due to the incorporation of weed seeds in the weed seed bank, while the weed seed bank is depleted by seeds which germinated and some were eaten by predators.

The shifts in weed populations are a concern because of the resultant increase in time and costs that will be incurred to remove the weeds. There is a need to study the particular shifts that occur in different environments, particularly on the extent and direction of the shifts to guide management options that might be required. Factors such as region, soil type and agronomic practices influence these shifts (Shretsha, 2003). Childs *et al.* (2001) reported that alternating herbicides over seasons has a significant effect on the weed population shifts. Some weeds can become resistant to certain herbicides and tend to proliferate. The mulch in CA reduces light and temperature to emerging weeds hence, weed species that are tolerant to shade and low temperatures e.g. Arrow leaf (*Sida rhombifolia* (L) may increase in reduced tillage. Reports of weed species shift have been inconsistent. For example, Childs *et al*. (2001) associated CONV with an increase in weed density. Shretsha (2003) reported no changes in the weed density with tillage while Shrestha *et al.* (2008), concluded that the changes in the weed spectrum are an interaction of multiple factors such as tillage, environment, crop rotation, crop type and weed management. Very little has been reported in Sub-Saharan African on the effects of tillage on weed seedling density and the findings are not clear as exemplified by the contradictions stated above.

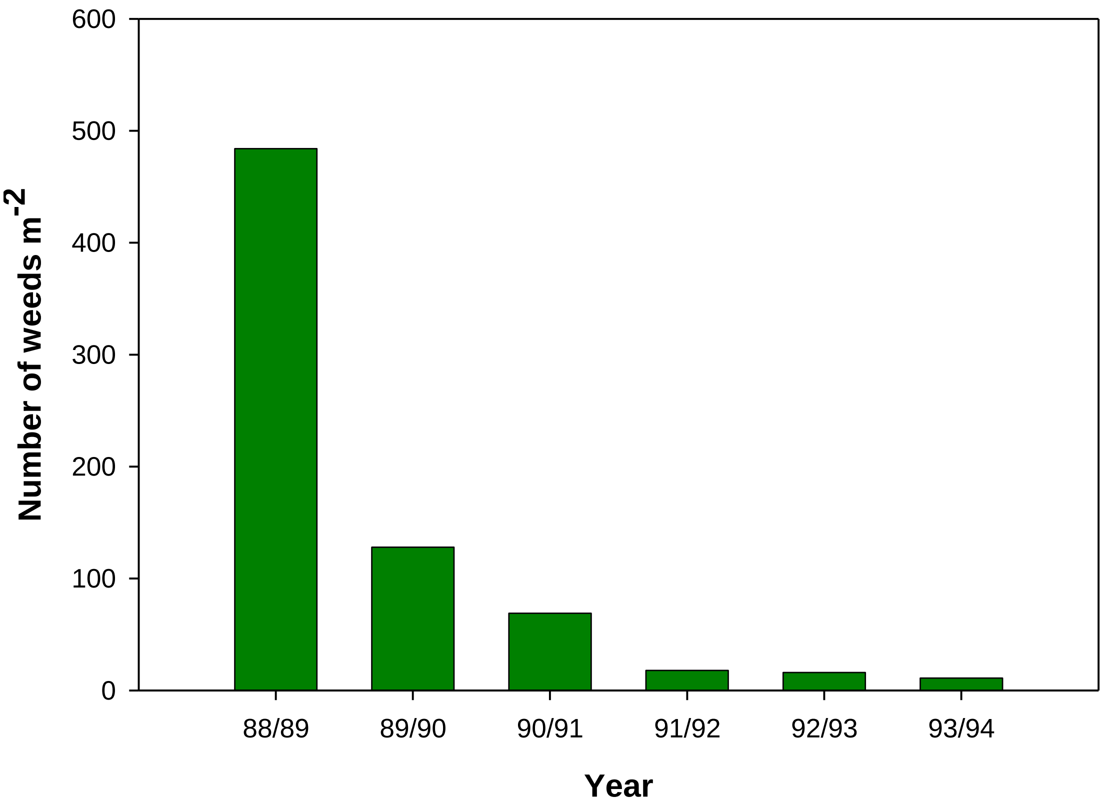

Figure 2.11 Decline in weeds under no-tillage as a result of reduced seed formation (Adapted from Skora Neto & Darolt, 1994)

2.6 MANAGEMENT EFFECTS ON WEEDS

Several studies in Europe identified management factors as more important than environmental factors in influencing weed communities and the type of crop as the main determinant factor (Fried *et al*., 2008; Šilc *et al*., 2008; Andreasen & Skovgaard, 2009; Cimalova´ & Lososová, 2009; Lososová & Cimalová, 2009). In some areas there might be more weed species which are affected by intensive management it therefore implies management determines weed composition in that particular area. Consequently, there is likely to be differences on the effect of management and environment on weed density and composition.

The management history of fields pertaining to plant establishment technique, type and rate of fertiliser used may affect weed composition and density (Wilson & Aebischer, 1995). Application of inorganic fertilizers to increase soil fertility was found to increase the weed density in cereal crops (Arlauskienė Maikštėnienė, 2005). In another study by Banks *et al.* (1976), species such as *Oenotheca laciniata* (Hill) were associated with low soil fertility. Preston & Prowles (2002) observed an effect of herbicides (as a means of weed control) on the ecological shift from broad leaved weeds to annual weeds in direct seeded rice. Hussein *et al.* (2007) also noted that the weed management option used may alter vegetation community and affect micro environmental variables in the ecosystem. The management history of a field may also affect the composition of weeds hence, an understanding of the ecology of the weeds species and management history is pertinent for the developing weed management strategies. There is likely to be variations on weed densities and composition in Zimbabwe considering the heterogeneous agronomic, climatic socio-economic conditions and resource endowments in the SH farming sector. For example, high resource endowed farmers' use more inorganic and organic fertilisers and can afford intensive weed management than poor resource farmers, which has an impact on the weed community (Zingore *et al*., 2008). It is pertinent to identify the effect of management on weed community as an entry point to developing weed management options appropriate for different types of farmers.

2.7 EFFECT OF SOIL PROPERTIES ON WEEDS

Weed flora and the changes in weed composition may be influenced by soil properties (Froud William, 1988) and this may be an indicator of inherent soil characteristics. It has been observed that soil properties and weed populations vary within arable fields (Otto *et al.,* 2007).

Consequently, maps of weed distribution in the fields or in particular areas may be used to develop temporary weed control treatments (Mohammadi, 2002). Hyvonen & Salonen (2002) noted that some weed species were affected by the soil properties such as phosphorus (P), magnesium (Mg) and manganese (Mn) concentration in the soil. Luoto (2000) found out that the amount of P in the soil determines weed species richness. *Mullogo verticilata* (L) and *Lamium amplexicaule* were found in high densities in soils with high P and N. However, Swanton *et al.* (1999) found no effects of N on weed composition over a 9 year period. Soil K has also been found to influence weed density by Tarmi *et al*. (2009), while Andreasen & Skogvard (2009) showed that K does not influence the weed species composition. This could have been due to the effective weed control with herbicides that reduced the weed density.

Pinke *et al*. (2012) showed pH gradient in the fields to determine weed composition resulting in distinct weed communities in basic and acidic soils. In France, Fried *et al*. (2008) determined the soil pH as the most important factor resulting in more growth of weeds in basic than in acidic soils. In Central Europe, Ries (1992), Mucina (1993) and Fried *et al*. (2008) observed that pH gradient co-varied with the gradient of annual rainfall. This resulted in distinct weed communities associated with basic soils which are prevalent in drier areas and different weed communities in acidic soils which are common in precipitation rich areas. The effect of pH on weed density and composition is likely to be evident in Zimbabwe due to the varying pH gradients across the country. In Zimbabwe pH varies across natural regions ranging from strongly acidic (pH <5) to alkaline (pH>7.) with lowest ph in high rainfall areas in natural region II and highest in natural region IV (Nyamangara *et al*., 2001). Furthermore, Nyamangara *et al*. (2013) observed high pH in planting basins in CA indicating that there might be variation on weed density as farmers adopt CA. There is need for research to establish if the pH in planting basins results in variation in weed density.

Soil texture can influence weed seed composition and weed density. In a study by Cardina *et al*. (2002), the effect of tillage on weed density was reduced in a silt loam compared to a silty clay loam which is subject to shrink and swell. Soil aggregation that allows seed placement within aggregates can protect weed seed viability and thereby influence the germination of the weed seeds (Čiuberkis, 2008). Benvenuti, (2003) indicated that sandy soils reduce dormancy compared to clay soils because of reduced physical protection and aggregate entrapment compared to clay textured soils which allows weed seeds to move deeper soils depths greater than 12 cm where weed seeds will not germinate but lie dormant as a result of in conducive conditions.

In the Albrecht & Pilgrim (1997) study, sandy soils increased the density of small seeded plants. In a light loam soil, the number of annual weeds increased in ploughed treatments compared with reduced tillage treatments (Faccini & Vitta, 2005). Clay loam soils, under reduced soil tillage for two years in succession resulted in a decrease in annual weeds and an increase in perennial weeds (Velykis & Satkus, 2003). The latter observations related to soil textural conditions and tillage illustrates that weed seed bank dynamics under tillage regimes could be soil type related. There is need to evaluate soil texture as one of the soil properties that results in variation of the weed seed bank. Such information, which is probably not readily available in Zimbabwe's SH sector, could be critical in developing weed management options. Further, this could better explain the mixed results arising from the effect of tillage on weed dynamics.

2.8 WEED MANAGEMENT IN THE SMALLHOLDER SECTOR IN ZIMBABWE

2.8.1 Weed Management Prior to Conservation Agriculture

The SH farmers use animal-drawn mould-board ploughs twice during the year in winter (after harvesting) and spring (at the start of the rainy season) to prepare weed-free seedbeds for planting and reduce subsequent weed infestations (Sibanda *et al.*, 2002). Weed management has been one of the production constraints in the SH sector prior to CA and is still a major production constraint to increased crop productivity (Mashingaidze, 2004; Mandumbu, 2012). The acute labour shortage and limited weeding options has often resulted in farmers abandoning part of their fields (Ellis-Jones, 2001).

Smallholder farmers use the plough, tyne cultivator, hand hoe or a combination of methods depending upon implement ownership, animal draught power and labour availability (Ellis Jones *et al*., 1993; Sibanda, 2002). If a plough is used, farmers usually remove the body from the plough leaving the share as the operational weeding blade and in some cases they leave the plough ridge attached in an effort to create furrows during weeding. The furrows created with plough during weeding smother weed seedlings and reduce the need for in-row hand weeding (Mbanje *et al*., 2000). The plough reduces labour hours by 30 to 70 hours of hand weeding (Sibanda, 2005). The use of hoes is referred to as manual weeding whereas the use of animal powered implements (ploughs and cultivators) is referred to as mechanical weeding (Mbanje *et al.,* 2000). Mechanical weeding was adopted to reduce the labour on women due to hoe weeding and increase timeliness and precision in operations (Muza *et al.*, 1996). Medium resourced farmers use the entire range of implements such as hand hoe weeding, ox cultivator or plough in combination with hand hoe weeding. Most poor resourced farmers use the hand hoe weeding and cannot afford to hire labour for their weeding. The labour for hand weeding is derived mainly from family members' particularly women and children (Giller *et al*., 2009) and they weed maize crop at least twice and cotton crop at least three times per season (Mavudzi *et al.*, 2001).

Hoe weeding has a number of advantages considering the socio-economic conditions prevailing in the SH sector in southern Africa in that it is simple, does not require investment in expensive equipment nor does it require the farmer to be literate and numerate. Hoe weeding has been reported to be efficient in weed control particularly in removing weeds within the crop rows (Mabasa *et al*., 1998; Mangosho *et al*., 2011). However, the technology has a number of disadvantages as it is not efficient in wet weather reducing its efficacy is limited to hot and dry conditions (Mashingaidze, 2004). Hoe weeding is inefficient and often is inappropriate given the farmer's circumstances of shortage of labour and cash to hire additional labour (Mandumbu *et al*., 2011).

The mechanical weed management options of using ploughs and cultivators in CONV are not applicable in CA because of the need to reduce implements that leads to soil erosion. This leaves SH farmers with only hand hoe weeding as the optimal option and means of weed control. The limited weed management options in CA of the SH coupled with increased weed densities necessitates the need to develop other weed management strategies.

2.8.2 Weed control in Conservation Agriculture

Some of the SH farmers find weed management as a challenge in the first few years of changing from CONV to CA due to increased weed densities (Marongwe *et al.*, 2011). The perceived weed density increase in CA has negative implications on the adoption of the technology. In Zimbabwe, hand hoe weeding is the predominant weed control method available to most farmers and it has not been effective in achieving timely control of weeds in CONV (Gianessi, 2009). The National Task Force on CA in Zimbabwe recommends farmers to weed up to six times using hand hoes during the season in order to control the weeds while they are still small. This helps to avoid a scenario where the weeds may set seed resulting in increased future weed infestations (ZCATF, 2009). Since SH farmers rely on the hand hoe weeding in PB which is slow and requires more labour, it might be difficult to weed up to 6 times, and considering that they have been failing to cope with weed pressure in CONV. The concept recommended by Zimbabwe Conservation Agriculture Task Force (ZCATF) of weeding up to 6 times per season might be difficult to implement in the SH sector and the hope of reducing the weed seed bank might be farfetched.

Early weeding is recommended so that farmers remove weeds before they are in a position to compete with the crop, which results in yield losses. Farmers prefer to finish planting all the fields early in the season in order to take advantage of the moisture (ZCATF, 2009). Thus little labour is devoted to early weeding at the beginning of the season and in most cases farmers fail to cope with the resultant early increase in weeding pressure (Mangosho *et al.*, 2011). In most cases, farmers start weeding after the critical period of weeding has lapsed, that is when the crops have been exposed to excessive competition for nutrients by weeds (Ellis-Jones *et al.*, 2001).

This fact highlights a need for alternative methods of weed control early in the season to aid removal of weeds.

Cover crops such as *Mucuna pruriens* (L) (Velvet beans) *Lablab purpureus* (L) (lablab), and *Crotalaria juncea* (L) (Sunhmep) are recommended to aid in weed control since they have been found to smother weeds and are effective in controlling weeds such as *Cynodon dactylon* (L), *Imperata cylindrica* (L) (GART, 2008). The cover crops are sown between the crop rows six weeks after planting maize to avoid competition and slashed after harvesting to provide mulch which can suppress weed seed emergence (Steiner & Twomlow, 2003). Some cover crops control weeds due to the allelopathic effect, for example Black oats in Brazil (de Lima *et al*., 2012). The inclusion of non-edible cover crops has not been widely adopted by SH. Further, it has been impractical to retain most of the residues of the cover crops on the soil surface during the dry season because the arable lands are also used for communal grazing of animals precluding the use of the cover crops (Giller *et al*., 2009). Given that food security is a priority among many SH farmers, it is not viable for them to invest the scarce labour, land, seed and fertilizer in cover crops that do not result in something to eat or to sell (Kassam & Friedrich, 2011)

Farmers are also being encouraged to practice off season weed control using hand hoes during the dry season which is called winter weeding to control weeds that emerge at the end of the season before they set seed and keep the fields weeds free until planting time (ZCATF, 2009).Winter weeding has been implemented with some difficulty since most SH farmers prefer to do other farm activities such as gardening or take time to rest from field operations during the dry season (FAO, 2011). Traditionally, most farmers believe it is taboo to do operations in the fields during winter (Rugare, 2009). Thus most CA farmers are reluctant to go to the field to avoid embarrassment; hence they leave the weeds in the fields to produce seeds after flowering. These weed seeds are shed onto the soil surface replenishing the weed seed bank (Shrestha *et al*., 2008).

Herbicides are also used for weed control in the SH but are widely used in commercial farms (Mandumbu *et al*., 2011). The use of herbicides in the SH sector has been limited due to problems such as high costs, limited access, and lack of knowledge of herbicide use (Rugare, 2009). In spite of these problems, given the requisite training it may be possible to introduce herbicides in the SH sector for weed control in CA in Zimbabwe. In Brazil, herbicides such as glyphosate facilitated widespread adoption of CA in the SH sector. Similarly, the same technology can also be used to facilitate the adoption of CA in Zimbabwe (Bolliger *et al*., 2006). It is not advisable to try and transfer the way herbicides are used in other countries, without carrying out research to adapt them to the socio-economic, edaphic, climatic and agronomic conditions obtaining in this sector. Hence, there is need for research to evaluate the efficacy of herbicides in CA of the SH in Zimbabwe.

2.9 Herbicides in the Context of the Smallholder Sector

The usage of herbicide in the SH sector has been low due to a number of constraints (Gianessi, 2009). Prominent among these constraints was the lack of knowledge and technical ability to use herbicides, lack of cash to invest in herbicides and application equipment, poor support services and lack of research on herbicide technology directly targeted to the socio-economic conditions in the small holder sector (Makanganise *et al.,* 2002). Despite the observed challenges of using herbicides in the SH sector, herbicides can offer improved yields due to more effective weed control especially early in the crop life, when the critical period for weeding occurs and wet conditions may preclude weed removal by hoe-weeding (Mangosho *et al*., 2011; Mandumbu *et al*., 2012).

The use of herbicides can help to increase the area of cropped land without undue increase in labour, yield loss as a consequence of late weeding or abandonment of portions of the planted crop that are severely weed infested (Steiner & Twomlow, 2003; Gianessi, 2009). The quality of life of the SH farmers can also be improved, particularly for women, who spent approximately 75 percent of their available time hoe weeding during the peak weeding period between December and February in Zimbabwe (Mashingaidze, 2004). While herbicides could help suppress weed emergence, reduce labour requirements and lighten the burden of women and children (Giller *et al*., 2009), it is important not to depend heavily on herbicides as the overuse of herbicides contradicts the Millennium goal number 7 which encourages sustainability and reduction of excessive use of herbicides (Hobbs, 2007). The overuse of herbicides has consequences to the environment as they may contaminate ground water and also leads to herbicide resistance (Chauhan & Opena, 2012). Since it is expected that the weed density will decrease with time in CA the herbicides can be used to help control weeds in the transition phase and herbicide usage may decrease as the weed density decreases (Wall, 2007; Hobbs *et al*,, 2008).

2.10 RESEARCH GAPS

This review shows that CA proves to be an antidote to some of the crop production challenges faced in the SH sector due to the positive experiences observed such as improved soil fertility, reduced soil erosion and increased yields. In spite of this, there have been some apparent challenges associated with the technology which needs to be addressed in order to enhance the positive benefits that have been realised to date. This section highlights knowledge gaps for the success of CA in the SH sector in terms of weed management.

1. CA is comprised of complex and interdependent components that have evolved over many years in response to not only environmental challenges, but to socio-economic factors. If CA is to be successful, it must be developed with an awareness of these interdependencies and constraints. Socio-economic factors may have important implications for the design of successful CA and should therefore be explicitly recognised and incorporated in research.
2. Tillage has been noted to result in changes in weed composition and density. However the research findings to date have been contradicting. There is a need ascertain the changes that occur as farmers adopt PB especially in the SH sector where such research is lacking.
3. While there have been research findings on the effect of tillage on weed density it was not clear whether the changes in weed spectrum and density are solely due to tillage. Soil properties and management factors may also have a direct bearing on the weed distribution and density. This information is important in formulation of weed management options and is lacking particularly in the SH.

The increased weed densities in PB will exacerbate the problem already existent in PB. There is need to explore other affordable methods of weed control e.g. use of herbicides to allow timely weeding and suppress weed emergence in the SH sector in PB.

CHAPTER 3

FACTORS AFFECTING THE CHOICE OF CONSERVATION AGRICULTURE COMPONENTS AND PRACTICES ADOPTED BY SMALLHOLDER FARMERS

3.1 ABSTRACT

The adoption process of Conservation Agriculture (CA) has been slow and has not yet entered into the exponential uptake phase. The aim of the study was to identify factors that influence the level of adoption of CA components and agronomic practices. A Cluster analysis from results of a survey administered to 146 households in Muzvezve II, Kadoma District, Zimbabwe, identified five dominant CA strategies (Clusters) practiced by SH farmers. A multinomial logit model revealed that the choice of CA components and agronomic practices adopted is positively influenced by farmer's age, level of formal education, access to extension services, labour, animal draught power availability and land size. The empirical results suggested that, the government should promote policies that increase access to formal education and farmer to farmer extension services to aid the adoption of a complete package of CA. About 64 and 71 percent of the farmers indicated that CA results in increased weed density and labour requirements respectively. Promotion of long-term and effective CA can only be accomplished through an increase in formal education and extension services. It also critical to address the main factors leading to non and slow adoption of CA that include shortage of labour and increased weed densities among others.

Keywords: Cluster analysis, household survey, multinomial logit, non adoption, sustainable agriculture

3.2 INTRODUCTION

Significant initiatives have been undertaken to improve the livelihoods of smallholder (SH) farmers in southern Africa through Conservation Agriculture (CA) (ZCATF, 2009). These farmers generally encounter problems as a result of non-viable agricultural production which is characterised by low yields, continual land degradation due to soil erosion, soil nutrient depletion and global depression of crop prices, in particular the price of cotton (Marongwe *et al*., 2011). Low production levels have further threatened the livelihood of these farmers compelling them to engage in unsustainable soil and crop management practices (Theodor & Kassam, 2011). For example, in Zimbabwe cotton yields fell from 503 to 243 kg ha^{-1} in 1980 and 2012 (USDA, 2012). The fall in production has been attributed mainly to poor husbandry practices and recurrent droughts (Hassan & Nemachena, 2008). The economic crisis experienced since the year 2000 further affected crop production, thus deepening the livelihood insecurity of SH farmers (FAO, 2012). Many studies have highlighted the potential of CA in addressing these challenges to secure livelihoods, whilst improving soil and water management (Kassam *et al*., 2009; Guto *et al*., 2011).

The Conservation Agriculture package, promoted in Zimbabwe consists of the following three CA principles and five agronomic practices which are deemed good agronomic practices that support CA (as adopted from Protracted Relief Program, 2005):

(a) Digging planting basins: Planting basins are holes dug in a weed-free field into which a crop is planted. The basins re prepared in the dry season from July to October.Winter weeding: This should be done soon after harvesting in May/June. The importance of weeding before land preparation is to ensure that the plot is weed-free at basin preparation, conserve moisture, and also to prevent the dispersal of weed seeds.

(b) Application of crop residues: Crop residues (at least 30 percent soil cover) are applied on the soil surface in the dry season, soon after harvesting.

(c) Crop rotation: Involves alternating crops of different families such as legumes and cereals every season.

(d) Application of manure: The application of organic manure/composts is recommended soon after land preparation.

(e) Application of basal fertilizer: Inorganic basal fertilizer is also applied soon after land preparation before the onset of the rains.

(f) Application of topdressing: Nitrogen fertilizer is applied to crops between 3 and 6 weeks after crop emergence soon after the first weeding.

(g) Timely weeding: Farmers are encouraged to weed in a timely manner (i.e. when the weeds are still small) so as to prevent the weeds from setting seed.

Though CA has the potential to address land degradation and offers many benefits to the vulnerable households in marginal environments in Zimbabwe, this technology has not been widely adopted as a result of various factors (FA0, 2011). Proponents of CA argue that its benefits can be fully realized when the complete set of agronomic management practices are applied simultaneously (Gowing & Palmer, 2008). Evidence in southern Africa has shown variation in the farmers' adoption rate of CA technologies (Mazvimavi *et al*., 2008). Some farmers have adopted the complete package, others only partially, while others have completely dis-adopted (Giller *et al*., 2009). Among the farmers who continue to practice CA, many have modified the package and adopted some components of the technology while leaving out other recommended practices (Mazvimavi & Twomlow, 2009).

The adoption of a technology by farmers goes through various decision making levels. The initial stage is awareness followed by the formation of positive and negative perceptions and finally the farmers will make a decision whether to adopt the technology or not (Prager, 2002). However each stage of adoption is determined by various factors which include; biophysical characteristics (soil type, farming region); Institutional support (training from government and Non Governmental Organisations (NGOs)); community characteristics (access to markets and extension services, infrastructure); socio-economic and political factors (household resources, source of income, policies and legislation); farmer characteristics (education level, attitude and personal values) (Prager & Posthumus, 2010). The factors that influence adoption of CA vary with socio-economic factors, agro-ecological region and the institutional settings in which the farmers operate (Posthumus *et al*., 2010). There are no commonly significant factors that affect CA adoption, though socio-economic factors seem to be the most important determinant (Knowler & Bradshaw, 2007). Marongwe *et al*. (2011) noted that there are a number of socio-economic factors which determine the adoption of CA in Zimbabwe.

Identifying the socio-economic factors that are likely to enhance or impede adoption of CA would perhaps assist policymakers' researchers and farmers in their planning and implementation of comprehensive CA. The overall objective of this study was to determine the socio-economic factors that influence the level of adoption of CA practices and agronomic practices supporting CA by cotton growing farmers in Kadoma District, Zimbabwe. Specific objectives of the study were:

a. To identify the components of CA practices and agronomic practices adopted by SH cotton farmers.
b. To explore the influence of socio-economic variables on the choice of different components of CA practices and agronomic practices.
c. To understand farmer's perceptions and the constraints faced as they adopt CA.

3.3 METHODOLOGY

3.3.1 The Study Area

A survey was conducted in Muzvezve II, Kadoma District which is situated in Mashonaland West Province, Zimbabwe. The geographical coordinates for the study area are 18°31′S; 29°40″E. Climatically, Kadoma District straddles Natural Regions IIa, IIb, and III with the study site being in Natural Region III according to the land classification in Zimbabwe (Vincent & Thomas, 1960). The study site is characterised by semi-intensive farming. The rainfall is erratic and fluctuates from season to season averaging between 650 to 800 mm year^{-1}. The erratic rainfall during the cropping season makes the crops vulnerable to seasonal and mid seasonal droughts, which pose a risk to crop production. The minimum temperatures range from 10 to 14°C, while the maximum temperatures range from 28 to 35° C. The soils in the study area are classified as Usotropept (USDA) or Chromic Luvisol (FAO). In *vlei* areas the soils are heavier, black in colour and relatively more fertile. Cotton (*Gossypium hirstum* L.) and maize (*Zea mays*

L.) are the major cash crops grown while groundnuts (*Arachis hypogaea* L.), cowpeas (*Vigna unguiculata* L.), beans (*Phaseolus vulgaris* L.) and bambara nuts (*Vigna subterranean* L.) are common food crops. The majority of the farmers keep cattle, goats and poultry as a source of livelihood.

3.3.2 Sampling Procedure

A total of 146 households were selected from 13 villages in Muzvezve ward II, Kadoma where Non Governmental Organisations (NGOs) under Food and Agriculture Organisation (FAO) have been dissemination CA since 2005 through the Farmer Field School extension method (Braun *et al*., 2000). The study site was therefore purposively selected because most of the farmers were in transition period from CONV to CA. Additional data on CA adoption levels for each village community based variables such as land use patterns and average proportion of land under these technologies, were obtained from secondary data FAO (Union Project) and key informant interview of different organizations working in the area such as and Ministry of Agriculture, (Department of Research and Extension (AREX); Zimbabwe Farmers Union (ZFU) and Sustainable Agricultural Trust (SAT).

3.3.3 Data Collected

Primary data collected included detailed household socio-economic characteristics, household income, their sources of livelihood, exposure to economic and natural shocks and their mitigation strategies, access to financial physical capital and institutional support. Head of households were also asked about crop and livestock production and where possible retrospective data for 2006/07 season to 2008/09 season were collected. Crop production information included crop area under different agricultural technologies and practices, input quantities and sources, quantity of each crop harvested and marketed. Primary data was complemented with secondary data from the Ministry of Agriculture at District level and from FAO.

3.3.4 DATA ANALYSIS

3.3.4.1 Cluster Analysis

Cluster analysis was used to group households based on similarities in their CA practices through maximising within-group similarities and between-group differences (Kaufman & Rousseeuw, 2009). Clustering can provide information to better target interventions towards households with certain common characteristics, thereby increasing the efficiency of targeted interventions and other incentive structured towards the intended beneficiaries (de Janvry & Sadoulet, 2000). The identification of clusters is empirically based and not guided by theory (Hair *et al*., 1998). The reasoning is that there are some latent common features that enable the agglomeration of individual observations into a smaller number of groups based on the similarity along particular, pre-determined dimensions of individuals in each group. As agglomerative hierarchical Cluster analysis can give rise to misclassification of observations at the boundaries between Clusters (Wishart, 1999), *k*-means Cluster analysis was used in the study. In *k*-means Cluster analysis, observations are initially randomly assigned to each of the *k* Clusters, and then reassigned using an iterative method to minimize within-Cluster variance and maximize between-Cluster variance (Wishart, 1999). The similarity measurement used was the Euclidian distance, and the centroid method of measuring similarity was employed because this method is more robust to outliers than most other hierarchical methods. The outcome of this Cluster analysis was several Clusters of households, with each Cluster displaying a distinct CA choice.

3.3.4.2 Multinomial Logit Model

A multinomial Logit Model (MNL) was specified according to Hausman and McFadden (1984) and estimated to explain a household's choice of CA technologies and agronomic practices. The farmer will choose certain components of CA technology only if the expected utility level of the chosen combination of technologies is greater than the utility obtainable for other available alternatives (Greene, 2003).

The MNL is specified as:

$$\ln (P_j/P_m) = \beta'_i X \qquad j = 1, 2\ldots m\text{-}1 \qquad (2)$$

where ln = natural log, P is the probability that a given household falls into the j^{th} Cluster, P_m is the probability that a household falls in a benchmark Cluster, X is the set of explanatory variables, and β' is the corresponding set of MNL regression coefficients to be estimated. The dependent variables in these equations are the log-odds ratios of being in Cluster j versus being in Cluster m (the benchmark Cluster). A total of (m-1) binary logit equations are estimated simultaneously in the MNL, and the sum of the m predicated probabilities is restricted to 1 (Greene, 2003). The probability of the *ith* household being in Cluster j is computed as

$$Pj = \frac{e^{\beta jx}}{m}$$

$$\frac{1+\Sigma e^{\beta jx}}{j=1} \qquad (3)$$

The i[th] household's probability of inclusion in Cluster *m* is estimated by

$$Pj = \frac{1}{m}$$

$$\frac{1+\Sigma\ e^{\beta jx}}{j=1} \qquad (4)$$

It is hypothesised in the MNL that the choice of a particular CA strategy (Cluster) is a function of the Xs representing household resource endowments, community factors (access to extension, education) and institutional factors (extension services, training and material support through government and local NGOs). The effect of a unit change in any of the X explanatory variables on the probability that the i[th] household will choose a particular CA strategy is given by the marginal effect statistic (Greene, 2003), which is derived as follows:

$$\frac{\Delta P_j}{\Delta X_i} = P_j[\beta j - \sum_{k=1}^{m} Pk\beta k] \qquad (5)$$

3.4 RESULTS AND DISCUSSION

3.4.1 Socio-economic Characteristics of Respondents

The socio-economic characteristics of the respondents are presented in Table 3.1. Approximately 61 percent of the households interviewed were less than 45 years old. Age has been found to be an important factor influencing the adoption of farming technologies (Nwakor *et al*., 2011) although, more recently there has been mixed findings on the effect of age on adoption of CA (Langyintuo & Mungoma, 2008; Mazvimavi & Twomlow, 2009). Adoption theories for labour-intensive and complex technologies such as CA reiterate that for technologies to be successful, young farmers should be the prime target (Defrancesco *et al*., 2008). Young farmers have been found to be more innovative and less risk averse than older farmers (Mazvimavi & Twomlow, 2009).

About two thirds (65.8 percent) of the respondents had secondary education which helped to provide a good opportunity for successful extension campaigns and programs that seek to disseminate and promote adoption of any agricultural innovation, particularly soil and water conservation (Mupangwa *et al*., 2012). More than half of the households had medium sized households and farms, about 4.45 to 6.67 hectares. Family members are the main sources of labour in rural areas of Zimbabwe. Given that some agronomic practices (digging, planting, and timely weeding) are laborious and labour intensive, large families and/or families with animal draught power are expected to be more productive compared to small families or those without animal draught power. In addition, large farms will also make more land available for CA, therefore, the adoption of the technology will not be perceived as a risk to household food security.

Table 3. 1 Socio-economic characteristics of respondents of household survey in Kadoma District, Mashonaland West, Province, Zimbabwe, 2009

Socio economic characteristics	Frequency	Percentage
Age of head of household (Years)		
<25	6	4.1
25-35	23	15.8
36-45	60	41.1
46-55	15	10.3
56-65	37	25.3
>65	5	3.4
Total	146	100
Years of formal education		
No formal Education	1	0.6
Primary education (1-7)	47	32.2
Secondary Education (8-13)	96	65.8
Tertiary Education (>13)	2	1.4
Total	146	100
Average number of people in a household		
≤ 5	24	16.4
6-10	67	45.9
11-15	31	21.2
16 -20	21	14.4
< 20	3	2.1
Total	146	100
Average area of cultivated land (Hectares)		
<0.8	5	3.4
0.8-1.6	63	43.2
1.82-2.4	70	47.9
2.6-3.23	6	4.1
3.4-4	2	1.4
Total	146	100
Mean number of cattle per household		
0	37	25.3
<5	55	37.7
5-10	38	26
11-15	15	10.4
>15	1	0.6
Total	146	100

3.4.2 Components of Conservation Agriculture Practices and Agronomic Practices

Results from the descriptive analysis (Table 3.2) revealed that 63.5; 28 and 56.2 percent of the households practiced winter weeding, planting basin and crop residue application during the 2008/09 season, respectively. Manure application and timely weeding were the most popular agronomic practices. There, has been a decrease of 13.1 percent in farmers applying basal inorganic and top dressing fertilizers from 2007/08 to 2008/9 season. This change was attributed to the decrease in the availability of free inputs both from Non-Governmental Organizations promoting the technology and from the Government of Zimbabwe (Mazvimavi & Twomlow, 2009). The scarcity of inorganic fertilizers and the economic challenges during 2007/08 and 2008/9 seasons further constrained the use of fertilizers in the SH areas. Proponents of CA emphasize that for farmers to fully realise the benefits of this technology, they need to incorporate all the components of the package (Mupangwa *et al*., 2012). Giller *et al.* (2009) noted that adoption of CA in the SH sector is characterised by partial adoption also referred to as 'distorted adoption'. Farmers tend to disentangle technology packages and adopt what they perceive as the most relevant components followed by additional components with time. Heterogeneity in resource endowments, livelihood goals and risk perceptions explained the difference in components of the technologies adopted (Mazvimavi & Twomlow, 2009) (Table 3.2).

Table 3. 2 Components of Conservation Agriculture and Agronomic Practices Practiced in the 2007/2008 and 2008/2009 Agricultural Seasons in Kadoma

	Households practicing components	
Components of Conservation Agriculture	2007/2008 (%) (n=146)	2008/2009 (%) (n=146)
Planting basins	20	28
Application of crop residue	43.0	56.2
Crop rotation	40.5	48.3
Agronomic practices		
Winter weeding	46.7	63.5
Application of manure	68.9	74.5
Application of basal inorganic fertilizers	77.4	64.3
Application of top dressing	79.6	71.7
Timely weeding	92.5	95.9

2007/2008 data represents retrospective data which was collected in 2008/2009 season.

3.4.3 Conservation Agriculture Strategies

The five Clusters or strategy dimensions of CA are presented in Table 3.3. Cluster 1 which consisted of 7.5 percent (11) of the households, had 2 and 0.4 hectares of its land under CONV, and PB as a component of CA, respectively. These farmers only practiced three agronomic practices supporting CA consistently, namely application of basal inorganic, top dressing fertilizers and timely weeding. Cluster 2 had 12 percent of the sampled households practising all the components of CA consistently. Cluster 2 was different from all the other clusters in that it had more land under planting basins and less land under CONV (1.2 hectares). Cluster 3 consisted of 40 percent of the sampled farmers who mainly practiced CONV, with timely weeding; application of basal inorganic and top dressing as agronomic practices supporting CA. Farmers in Cluster 4 practiced all the components of CA except digging of PB. Households in Cluster 5 (18 percent) were unique in that they had only an area of about 0.4 ha under CONV, practiced timely weeding, manure and top dressing application as well as crop rotation consistently. The results of the Cluster analysis also confirmed the findings of Thierfelder & Wall (2011) that, different households tend to conveniently select and adopt different components of CA (Table 3.3).

Table 3. 3 Clusters of Conservation Agriculture strategies practiced by survey households, Kadoma District, Mashonaland West, Province, Zimbabwe, 2009.

Conservation Agriculture components	Cluster 1 N = 11	Cluster 2 N = 18	Cluster 3 N = 57	Cluster 4 N =33	Cluster 5 N = 27
Average area of maize & cotton with planting basins (Hectares)	0.40	1.21	0	0	0
Crop rotation practice	0	1	0	1	1
Agronomic practices					
Average area under conventional agriculture (Hectares)	2	0.40	1.21	0.81	0.40
Application of cattle manure (dummy 1 = Yes, 0= No)	0	1	0	1	1
Application of inorganic basal fertilizers	1	1	1	1	0
Application of top dressing	1	1	1	1	1
Winter weeding	0	1	0	1	0
Timely weeding	1	1	1	1	1

3.4.4 Multinomial Logit Model Determinants of Conservation Agriculture Components Choices

A multinomial logit regression was applied to identify the main determinants of CA component choices and agronomic practices from Cluster analysis. The coefficients for Clusters 1, 3, 4 and 5 were compared to Cluster 2, (those households who had adopted all the eight components of CA package) as the base category. Therefore, the inference from the estimated coefficients for each choice category was made with reference to the base category. The model was tested for the validity of the independence of the irrelevant alternative (IIA) assumptions using the Hausman test for IIA and the SUEST (Seemingly unrelated post-estimation procedure). Both tests failed to reject the null hypothesis of independence of the CA options available to SH farmers. Therefore, the MNL specification was appropriate in modelling CA choices of the SH farmers in rural Kadoma. The likelihood ratio as indicated by the chi-square statistic was highly significant ($P<0.001$) suggesting that the model has a strong explanatory power (Table 3.4).

For Cluster 1 contrast, the coefficients for age of the head of household, average land owned and animal draught power owned were positive and statistically significant ($P<0.001$). This suggested that the odds of being in Cluster 1 relative to Cluster 2 rose for those households with older household heads, more land and animal draught power. The results presented in Table 3.4 showed that an increase in education level of the head of the household, access to extension service, institutional membership and CA experience significantly reduced the likelihood of choosing Cluster 1 relative to Cluster 2. A unit increase in number of years of schooling would result in a 19 percent increase in the probability of being in Cluster 2. These results have important policy implications to CA promoters in that increase in formal education, and access to extension services increase the probability of adopting all the eight components of CA. They also confirm the findings from other studies that increased access to formal education and extension services enhance farmers' understanding and technical capability for CA practices (Teklewold & Köhlin, 2011). For Cluster 3, only age of head of household and animal draught power increased the probability of being in this Cluster relative to Cluster 2 while increase in education level of the head of household decreased the probability of choosing Cluster 3. For Cluster 4, formal educations and extension services had a positive and statistically significant coefficient, whereas land ownership, labour and CA experience had negative statistically significant coefficients. This implies that the probability of the households to be in this Cluster relative to Cluster 2 increased with education and extension contact while an increase in size of land owned, CA experience and labour availability reduced it. Finally, the probability of being in Cluster 5 relative to Cluster 2 decreased with increased education, size of land owned, labour and animal draught power availability. This implied that resource constrained households, particularly physical and human capital were more likely to belong to Cluster 5. The MNL results confirm that adoption of all the eight CA components increased with a unit increase in number of years of education of the head of household except for Cluster 4 were land and labour availability were the major limiting factors.

The marginal values of education were negative for all Clusters relative to Cluster 2 except for Cluster 4. Conversely, all the Clusters had positive marginal values for head of household's age and labour availability except Cluster 4. It can be inferred from the results that households with more educated heads, more land and labour have better chances of adopting a higher proportion of CA components. Education was important in determining the CA components adopted for all Clusters expect for Cluster 4 whilst animal draught power was important for Cluster 5 and labour availability for Clusters 4 and 5.These results are consistent with Bandara and Thiruchelvam (2008) and Mangisoni *et al*. (2011) who assert that choice of CA components is positively influenced by farmer's formal education level, available labour and the land size.

Table 3.4 Multinomial Logit Estimates for the Conservation Agriculture practice choices of Kadoma District rural farmers, Mashonaland West, Province, Zimbabwe, 2009

Variables	Cluster 1 P1/P2			Cluster 3 P3/P2			Cluster 4 P4/P2			Cluster 5 P5/P2		
	Coefficients	Marginal effects	P-values	Coefficients	Marginal effects	P-values	Coefficients	Marginal effects	P-values	Coefficients	Marginal effects	P-values
Education (years)	- 2.756**	- 0.19	0.03	-1.893***	-0.107	0.005	3.549***	0.282	0.004	- 2.469***	- 0.165	0.0001
Age of head of household	1.082***	0.051	0.002	2.694***	0.22	0.001	- 0.972	-0.019	0.612	0.784	0.020	0.76
Average land owned (Hectares)	0.594***	0.037	0.007	0.253	0.001	0.522	- 4.118***	-0.367	0.0001	- 3.098***	- 0.249	0.005
Extension service	- 2.031*	- 0.22	0.069	0.994	0.006	0.23	1.436**	0.254	0.023	- 0.0616	- 0.001	0.92
Institutional Membership	-0.026**	- 0.008	0.041	0.828	0.003	0.48	0.015	0.0007	0.81	- 0.018	-0.0012	0.53
Draught Power	4.382***	0.314	0.005	2.933***	0.182	0.009	0.787	0.004	0.37	- 2.641**	-0.3008	0.033
Labour[1]	0.071	0.005	0.681	0.056	0.011	0.18	-1.629***	- 0.189	0.008	-2.044***	-0.2941	0.0021
Conservation farming experience	-0.421	- 0.013	0.19	-0.744	0.002	0.27	- 0.948**	- 0.071	0.041	0.025	0.0092	0.591

* = P < 0.05; ** =P < 0.01; *** = P < 0.001

Base category – Cluster 2 (households that adopted all the three components of CA and five agronomic practices)

Number of observation 146

LR Chi-square 190.74***

Log likelihood 203.8

Overall percentage of households correctly predicted 61.7 percent

[1] Labour- consists of family labour available for general farm work, hired and exchange.

3.4.5 Perceptions of Conservation Agriculture by Farmers

Higher yields were realised under CA than CONV by most (75 percent) of the farmers (Table 3.5). Increased yields under CA were also realised by farmers in the semi arid areas of Zimbabwe with yield increases ranging from 10 to more than 200 percent (Twomlow *et al*., 2008). However, yield increases under CA depend upon the farming experience of the household and the seasonal rainfall (Mazvimavi & Twomlow, 2009). The increased yields in CA are important for ensuring food security in the SH sectors. The positive understanding of the benefits of CA such as reduced soil erosion is important for adoption of CA and will help to reduce the continual soil erosion in the SH sector. The increased weed densities mentioned by 64 percent of the farmers is likely to deter the adoption of CA since weed management has already been a major crop production constraint the SH sector. The increased labour requirements for weeding are likely to accentuate the labour shortages. However there were mixed perceptions on the changes that occur to weed densities, composition and labour requirements as farmers adopt CA. There could be various factors which determine the changes in weed densities and species composition in CA. The differences in weed densities, soil types and management could explain the differences in the perceptions however there is need to test this hypothesis. The results of the survey showed that there are three issues on weed management that need to be addressed as farmers adopt CA viz; increased weed density, labour requirements and possible weed composition changes.

Table 3.5 Perceptions on Conservation Agriculture by smallholder farmers in Kadoma, Zimbabwe

	Percentage of farmers practising Conservation Agriculture		
Statements	Strongly agree	Somewhat agree	Disagree
1.Results in high yields	75	11	14
2. Helps reduce soil moisture	74	20	6
3.Conserves moisture	84	12	4
4.Increase weed density	64	20	16
5.Increase weed species composition	1	38	61
6.Increase labour requirements	71	14	15

3.5 CONCLUSION

The study revealed that farmers disentangled the CA package and adopted what they perceived to be the most relevant components. The Cluster analysis identified five dominant CA strategies as recommended by extension services. Few farmers practiced all the eight recommended components of CA which are important for them to realise the full benefits of CA. Digging of planting basins and crop residue application as components of CA were practiced by few farmers while winter weeding was the component widely practiced by the farmers. Results from the multinomial logit analysis showed that the choice of CA adopted was positively influenced by farmer's formal education, access to extension services, labour and animal draught power availability, and land size. The farmer's decision to adopt components of CA was also conditioned by age. Most farmers had positive perceptions of CA such as increased yields, reduced soil erosion and increased moisture conservation. The negative perceptions of CA were increased weed densities and labour requirements. The results implied that to promote the adoption of a complete package of CA, increased access to formal education and extension services should be a priority. Promotion of long-term and effective CA can be accomplished through addressing the main factors underlying non-adoption such as labour unavailability. There is also a need to determine under field experimental conditions the changes that occur to weed densities and composition as farmers adopt CA.

CHAPTER 4

TIME AND DENSITY OF WEED EMERGENCE AS AFFECTED BY PLANTING BASIN IN A SMALLHOLDER AGRICULTURAL SECTOR

4.1 ABSTRACT

An on-farm study was conducted to evaluate the effects of tillage on weed density and diversity in the SH farming sector. The paired plot technique was used to compare weed density and diversity in planting basin (PB) and Conventional (CONV) Tillage at three, six, and nine weeks after crop emergence (WACE) on loam, clay loam and sandy loam soils. Yield data was used to predict yield losses as a function of weed density using the hyperbolic model. Planting basins had 57 and 51 percent higher weed density than CONV during 2009/2010 and 2010/2011 seasons, respectively on loamy soils. The corresponding weed densities on clay loam soils in PB were 27 and 19 percent higher than CONV, while on sandy loam soils no significant effect of tillage was evident. Weed emergence in BP peaked from 0 to 3 WACE and 3 to 6 WACE in CONV. On loamy and clay loams at 3 WACE the diversity indices in BP where higher than in CONV. The cotton yield losses represented by parameter *i* from the hyperbolic model were 3.88; 4.74 and 10.12 percent under PB; whereas under CONV were 0.24; 0.49 and 2.50 percent for loamy, sandy loam and clay loams, respectively. Maize yield losses were 5.91; 1.60, and 10.86 percent under PB; the corresponding yield losses under CONV were 2.75; 1.40 and 6.80 percent for loamy, sandy loam and clay loams, respectively. Herbicide supplemented by hand weeding in combination with cultural methods is recommended in PB to suppress weed emergence and avoid yield losses.

Keywords: Planting basins, relative density, tillage systems, weed density, weed diversity

4.2 INTRODUCTION

In traditional agricultural systems, the objective for tillage is to mechanically manipulate the soil and to prepare a seed bed suitable for crop establishment. In addition, tillage ensures that weed seeds were buried to depths which make it difficult for them to emerge (Douglas & Peltzer, 2004; Légère *et al*., 2011). A reduction in tillage posses a serious concern on weed management since tillage has been used to control weeds (Triplett & Dick 2008; Johansen *et al*., 2012). The results from a survey in Chapter 3 which was carried out in Kadoma, Zimbabwe showed that weed densities increase during the transitional period from CONV to CA. One of the major reasons for increased weed densities in the SH observed in Chapter 3 is that most of the farmers are only practising Planting basins (BP) as a form of minimum tillage of CA without crop rotations and have limited crop residues which can help to suppress weeds. Other SH farmers in the arid areas of Zimbabwe practising PB reported an increase in weed density (Mazvimavi & Twomlow, 2009). Similarily, SH farmers in other southern African countries such as Mozambique, Zambia, Lesotho and Malawi also reported increased weed density in CA systems (Baudron, *et al*., 2007; Rockström *et al*., 2009; FAO, 2011).

Despite the expected increase in weed densities reported by SH farmers in Zimbabwe, there is likely to be an increase in influential selective forces on weed species diversity due to the change in tillage (Owen, 2008). Makanganise *et al*. (2002) observed an increase in common perennnial weeds such as *Cynodon dactylon* L. Pers. and *Richardia scabra* L. as farmers adopt PB in Zimbabwe. Similar findings of increased infestations of perennial weeds and low densities of annual weeds after a five year period of reduced tillage in cotton and soyabean rotation were observed (Hanks & Bryson, 2001). In addition, in warm arid conditions a shift on the vertical distribution of weed seeds in the soil with time as farmers adopt CA (Demjanová *et al*., 2009). Time of weed emergence was also observed to be earlier with change in tillage . However, it has been observed to be species dependant in Canada by Bullied *et al.* (2003). The above mentioned changes in weed population densities and spectrum are likely to result in serious weed management problems particulary for SH farmers as they adopt PB. An increase in weed density will consequently result in an increase in labour requirements for hand weeding.

Smallholder farmers in Zimbabwe engage in subsistence mixed farming and have limited resources such as labour and animal draught power (Wall, 2007). The increased weed pressure is likely to increase crop weed competition resulting in reduced crop yields. Yield losses of more than 30 percent due to weed competition have been reported in the SH sector (Rambakudzibga *et al.*, 2002). The results from the survey in Chapter 3 showed that weed management in the SH sector is constrained by the shortage of labour and animal draught power for the cumbersome hand hoe weeding. Labour is mainly supplied by family members and the hand hoe is not efficient in wet weather and when high weed densities prevail (Chikoye *et al*., 2007). Considering that weed management is already a major crop production constraint in the SH sector, adoption of PB will exacerbate the problem.

Reports on weed dynamics in CA have, however, been inconsistent. Streit *et al*. (2003) reported that reduced tillage might favour annual grasses over annual broadleaved weeds partly due to more effective control of broad-leaved weeds with herbicides. There may be a shift within the annual grass weeds to those that are more difficult to control (Peltzer & Matson, 2002; Tuesca & Puricelli, 2007). The findings from a research carried over two successive seasons in Greece showed no significant effect of CA on weed spectrum and density (Vasileiadis *et al*., 2012). Similary, no significant differences in weed densities observed over a four year study and also the changes in weed communities were found to be influenced by environment rather than by tillage (Widderick *et al*., 2004). In contrast, an increase in weed densities in CA in the temperate regions was reported by (Otto *et al*., 2007; Lègére *et al*., 2011; Gruber *et al*., 2010) while similar findings were observed in Zambia, which is located in a tropical region (Baudron *et al*., 2007). In Australia, CA resulted in an increase in wind dispersed species such as *Sonchus oleraceus* L. (Widderick *et al*., 2004). In a study by Bullied *et al*. (2003) tillage systems did not only influence total recruitment, but also affected the periodicity of weed emergence with a promotion of early emergence of *Chenopodium album* L. and *Setaris viridis* (L.) Beauv. However, it has been argued that weed populations in PB sytems will increase for a particular period after which they decrease with good management over time (Wall, 2007). If weed density will decrease with time, abandoning PB in the first few years will result in farmers forfeiting its several advantages. Consequently, there is a need to ascertain the changes that occur to weed density in PB considering the contradicting findings in the SH sector. In this sector, several interacting factors ranging from bio-physical to socio-economic, are likely to influence these changes as farmers adopt PB. The objectives of this study were:

1. To determine the effect of tillage system and soil textural class on weed density, diversity and the time of weed emergence in the SH sector.
2. To compare the yield losses in PB and CONV tillage systems

4.3 MATERIALS AND METHODS

4.3.1 Site Description

The field experiments were conducted during in Kadoma District, Mashonaland West Province, in Zimbabwe. The daily rainfall data during 2009/2010 and 2010/2011 seasons were collected by farmers participating in the study. While the 30 year average climate data was obtained from the Kadoma Meteorological Station, which is located within the accepted 150 km radius according to the meteorological standards (FAO, 1988) The soils varied from silty clay loams to clays classified as Chromic Luvisols and Vertisols (www.fao.org/../en).

4.3.2 Field Procedures

Three different locations were chosen across the study area to capture variation in soil type's main soil types in the study area were loamy, sandy loam and clay loam which were classified by the percentages of sand, silt and clay content. Six farmers were selected from each of the three localities and each locality represented either loamy, sandy loam or clay loams. The corresponding average pH for loamy, sandy loam and clay loams were 7.5; 5.3 and 5.8 respectively. Paired comparison design was used in the study with two plots laid side by side with, each plot measuring 6 * 5.4 m and representing either CT or CONV. The plot size was determined by considering the available labour, area that gives high precision in data collection and costs of inputs. The paired plots were laid out in a randomised complete block design replicated three times at each farm. The plots under PB had also been under no tillage for two years before the beginning of the study. Conventional tillage plots were ploughed with an ox drawn mould board plough twice during the year, in winter and spring. The plough depth ranged between 0.20 to 0.23 m. Planting furrows in CONV were also made with the ox drawn mould board plough to a depth of 0.15 m. Planting basin plots were only disturbed when PB (holes dug with a hand hoe) measuring 0.15 m length * 0.15 m width * 0.15 m depth were being made.

Cotton was planted during the 2009/2010 followed by maize during 2010/2011 season. Tillage systems were maintained in the same plots for the duration of the study. Both crops were planted after 50 mm of rainfall had fallen, being a general guide for the start of the cropping season. In 2009/2010, a medium maturity cotton variety was planted at a spacing of 0.30 m in row and 0.90 m inter-row spacing in both PB and CONV, to give a population of 37 037 plants ha^{-1}. A medium maturity maize variety was planted in 2010/2011 at a spacing of 0.9 m between rows and 0.3 m within rows to give a population of 37 037 plants ha^{-1}. Three seeds were planted per hole and were thinned to one plant per hole at two weeks after crop emergence (WACE) for both crops.

Basal fertiliser for maize (8N:6P:7K) and cotton (5N:8P:8K) was applied at a rate of 200 kg ha^{-1} prior to planting. Nitrogen fertiliser was applied as ammonium nitrate (34.5N) to both cotton and maize in equal splits of 100 kg ha^{-1} at five and nine WACE. Carbaryl, endosulfan and fenverate were used to control insect pests such as Heliothis bollworm (*Helicoverpa armigera*) and red bollworm (*Diparopsis castanea*) in cotton. Dimethoate was used to control aphids in cotton following local standard pest management guidelines. No pest control was done in maize.

The maize grain and cotton lint yields were obtained by harvesting from net plots of four rows, which were four metres long. Maize grain yield was adjusted to 12.5 percent moisture content and cotton lint yield to 14 percent moisture content. Yield per net plot was converted to kg ha^{-1}.

4.3.3 Weed Assessment and Data Analysis

The required number of quadrats for an accurate representation of weed species in the fields was determined by the species area curve (Barbour *et al*., 1987). Cumulative number of weed species was plotted against quadrat number. The asymptote (leveling off or plateau) marked the required 3 quadrats to obtain a representative sample in the experimental plots. Weeds that germinated in each plot were counted by species at 3, 6 and 9 WACE by making use of three 0.50 m* 0.50 m quadrats randomly placed across the plots in each of the 18 fields. All weeds were removed from plots after the counting process; this allowed an assessment of weed species and the densities that germinated at 3, 6 and 9 WACE. The quadrats positions were moved between 3, 6 and 9 WACE. Weed species diversity index was calculated according to Shannon & Weiner (1963).The species diversity refers to the number of different species in the community including both abundant and rare species. The diversity index was calculated for each plot according to the Equation 1.

Diversity index $$H' = \sum_{i=1}^{S} \frac{\mathrm{ni}}{\mathrm{N}} \mathrm{In} \frac{\mathrm{ni}}{\mathrm{N}} \qquad (1)$$

Where, S = number of species; N = average total number of weed density in each plot; ni= number of individuals of the *i*th species of the area.

The quantitative characteristics of the weed community measurements such as relative frequency (RF), relative density (RD), and relative abundance (RA) were calculated on the identified weed species in PB and CONV for both seasons. Relative density was calculated using Equation 2, which was adopted from Hussain and Durrain (2004).

$$\text{RD}=\frac{\text{Number of plants for a given weed species within quadats per plot}}{\text{Total number of weeds within each plot}} \qquad (2)$$

The relative frequency was calculated using the formula adopted from Hussain and Durrain (2004).

$$\text{RF}=\frac{\text{Number of plants for a given weed species within quadats per plot}}{\text{Total frequency of all species}} \qquad (3)$$

The relative abundance of weed species (Equation 4) was adopted from Takim and Fadayomi (2010).

$$\text{RA}=\frac{\text{RD}+\text{RF}}{2} \qquad (4)$$

An examination of the weeds data prior to analysis showed a skewed distribution, which was an indication of variance heterogeneity. To meet the assumptions of parametric analysis, the weed data was square root transformed (x + 0.5) prior to analysis to homogenise variances (Gomez & Gomez, 1984). The square root transformation was appropriate for the weed count data where values less than 10 and zeros were also present. Paired *t*-test was used to compare the weed density and diversity indices in PB and CONV using SAS procedures (SAS, 2010). Standard error of the difference (SED) was used for mean separation where treatments were significantly different at ($P<0.05$).

The relationship between yield loss and weed density was assessed by comparing yield recorded from the net plots in each tillage system and the total cumulative weed density in each of the plots. Regression analysis was performed to relate crop yield loss to weed density. The data was fitted to the hyperbolic model as follows:

$$YL = \frac{iD}{1 + iD / a} \qquad (5)$$

Cousens (1985)

Where YL = yield loss; *D* = weed density; *i* is the percent yield lost to each additional weed when *D* approaches zero and *a* is the asymptote corresponding to the maximum relative yield loss when *D* tends to infinity. The equation and their parameters were estimated using the curve-fitting module of the SAS procedures (SAS, 2010). The differences in yield loss were assessed by comparing the slope of the curves for the two tillage systems.

4.5 RESULTS

4.5.1 Weather Data

Although the 2009/2010 cropping season received 3 percent more rainfall between November and March than the 2010/2011 season, the distribution of rainfall was different between the two seasons (Figure 4.1). The month of January 2009 received 14 percent of the total rainfall from November to March. In contrast, January 2010 had the highest rainfall, receiving 51 percent of the total rainfall for the 2010/2011 season (Figure 4.1A). The rainfall in January 2010 was above average and exceeded the 30-year average by 53.4 percent. There was no rainfall received during February 2010. The minimum and maximum temperatures for

2009/2010 and 2010/2011 were almost similar with very little variation and were comparable to the 30 year average (Figure 4.1B).

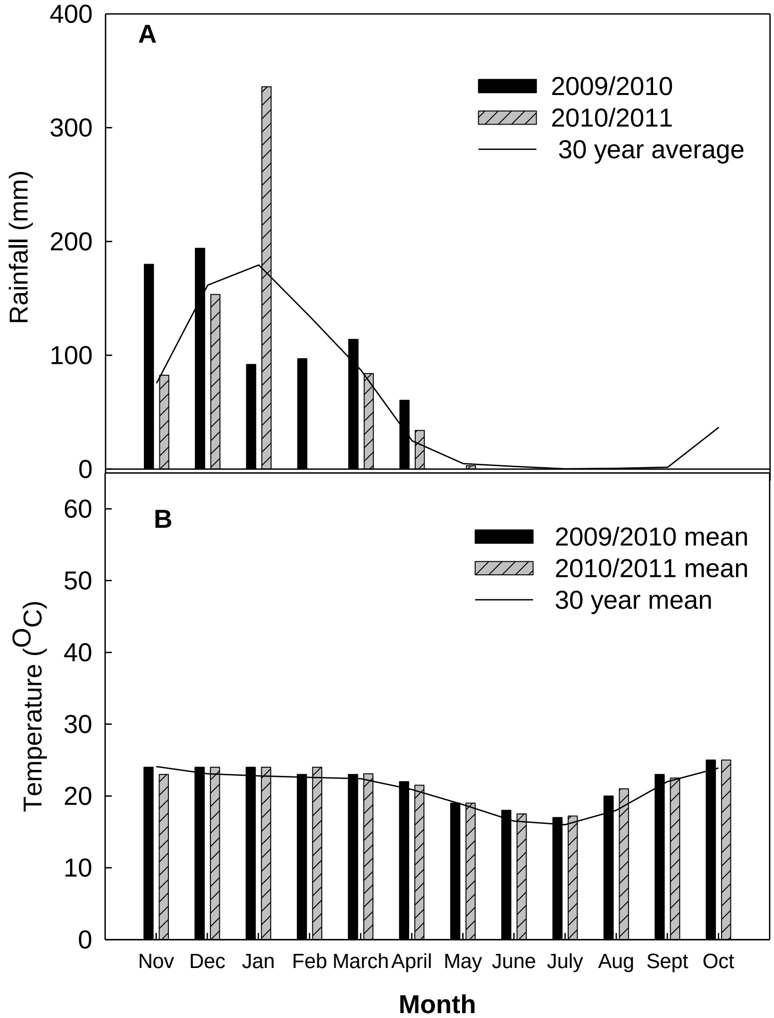

Figure 4. 1 Monthly cumulated rainfall and temperature during the 2009/2010 and 2010/2011seasons and 30-year average in Kadoma, Zimbabwe

4.5.2 Weed Composition in the Study Site

Twenty-eight weed species of varying densities were identified in the three locations on the study site in (Table 4.1). The weed community comprised of 18 broad-leaved weed species, nine grasses and one sedge.

Table 4.1 The relative abundance of weed species identified during 2009/2010 and 2010/2011 seasons in Kadoma, Zimbabwe

Family	Weed species	Life cycle*	Loamy soils	Sandy loam soils	Clay loam soils
Amaranthaceae	*Amaranthus hybridus* L.	A	0.001	0.027	0.006
	Amaranthus retroflexus L.	A	0.001	0.001	-
Asclepiadaceae	*Asclepias syriaca* L.		-	0.002	-
Asteraceae	*Bidens pilosa* L.	A	0.156	0.234	0.086
	Leucas martinicensis (Jacq.)	A	0.176	0.217	0.039
	Acanthospermum hispidum D.C	A	0.019	0.199	0.113
	Tridax procumbens L.	A	0.095	0.094	0.01
	Tagetes minuta L.	A		0.040	
	Galinsoga parviflora Cav.	A	0.033	-	0.006
Boraginaceae	*Trichodesma zeylanicum* (Burm. f.) R. Br.	A	0.004	-	0.010
Convolvulaceae	*Ipomoea plebeia* R.Br	A	0.018	0.098	0.124
Cyperaceae	*Cyperus esculentus* L.	p	-	-	0.001
Euphorbiaceae	*Euphorbia hirta* L.	A	-	0.002	0.002
Fabaceae	*Acacia longifolia (Andrews.)Willd.*	P	0.023	0.015	0.038
Malvaceae	*Corchorus olitorius* L.	A	0.108	0.109	0.023
	Sida alba L.	A	0.020	0.009	0.117
	Hibiscus calyphyllus Cav.	A	-	-	0.013
Poaceae	*Melinis repens* (Willd.) Zizka	A	0.060	0.278	0.096
	Rottboellia cochinchinensis (Lour.) W.D Clayton	A	0.032	0.126	-
	Eragrostis aspera (Jacq.) Nees	A	0.029	0.099	-
	Eleusine indica (L.) Gaertn	A	0.001	0.050	0.008
	Urochloa panicoides P. Beauv.	A	0.033	0.040	-
	Poa compressa L.	A	-	0.024	-
	Dactyloctenium aegyptium (L.) Willd.	A	0.022	-	0.075
	Phleum pratense L.	P	-	-	0.004
	Perotis patens Gand.	P	-	0.02	0.001
Portulacaceae	*Portulaca oleracea* L.	A	-	0.001	0.001
Rubiaceae	*Richardia scabra* L.	A	0.043	0.322	0.283

*Life cycle: A= Annual, P=Perennial

The weed families comprised of the following: 32 percent Poaceae; seven percent Compositae; 11 percent Malvaceae; 21 percent Asteraceae; four percent Portulaceae; four percent Asclepiadaceae; four percent Boragnaceae; four percent Cyperaceae; four percent Euphobiaceae; four percent Rubiaceae; four percent Convolvulaceae and seven percent

Amarathaceae. Twelve of the weed species representing 43 percent of the total were found in all the three soil types, whereas 36 and 21 percent of the total weed species occurred in two soil types (referring to soil texture) and one soil type, respectively. The most dominant weed species in sandy loam soils was *R. scabra* (highest relative abundance values) while *Leucas martinensis* L. was the most dominant weed in clay loam and loam soils.

4.5.3 Tillage Effect on Total Weed Density

The results were presented by soil type because there was a significant ($P<0.05$) tillage * soil type interaction at each of the sampling times for both seasons. Total weed densities under PB and CONV during the 2009/2010 and 2010/2011 seasons at the three assessment dates (3, 6 and 9 WACE) and three field groups following a *t*-test are presented in Table 4.2. There was a significant effect of tillage ($P<0.05$) on total weed density at 3 WACE during both seasons in loamy and clay loam soils. Total weed density for PB was 57 and 51 percent higher than CONV during the 2009/2010 and 2010/2011 seasons respectively for loamy soils as shown in Table 4.2. The total weed density in PB at 3 WACE was 27 and 19 percent higher than CONV in clay loam soils for 2009/2010 and 2010/2011 seasons, respectively. There was no significant effect of tillage system identified in sandy loam at all three weed assessments dates. There were no records at 9 WACE during 2010/2011 season due to a drought experienced during the month of February, which hampered weed emergence after weeding at 6 WACE. As a result, there were no weeds to be counted at 9 WACE. The weed density in PB was lower at 6 compared to 3 WACE in both seasons in loamy and clay loam soils. A different trend was observed in CONV where the weed density peaked at 6 WACE than at 3 WACE for loamy and clay loam soils

Table 4. 2 Mean total weed density (m^{-2}) in cotton (2009/2010) and maize (2010/2011) as affected by tillage system in Kadoma, Zimbabwe

		2009/2010			2010/2011		
Farmer group	Tillage System	3 WACE§	6 WACE	9WACE	3 WACE	6 WACE	9 WACE
Loamy soils	PB	9.72 a (93.98)≠	7.74a (58.87)	4.59a (20.50)	11.19a (124.72)	9.51a (89.94)	-
	CONV	5.52b (29.97)	7.34a (53.38)	3.89a (14.63)	5.71b (32.10)	10.87a (117.66)	-
Sandy loam soils	PB	13.79a (189.66)	13.94a (193.82)	10.82a (116.57)	15.49a (239.44)	14.94a (227.51)	-
	CONV	13.47a (18.94)	13.24a (174.80)	9.97a (98.90)	15.09a (227.20)	15.10a (227.70)	-
Clay loam soils	PB	9.17a (83.59)	7.73a (59.25)	5.64 (31.31	10.22a (104.45)	8.12b (65.54)	
	CONV	6.71b (57.41)	7.98a (63.18)	5.87a (33.96)	7.68b (58.48)	8.23b (67.73)	

Means in a column within the same assessment period and soil type followed by a different letter are significantly differently based on *t*-test ($P<0.05$); ns- not significant.≠ Untransformed data in parenthesis; §WACE=- weeks after crop emergence; PB= Planting basin; CONV= Conventional tillage

4.5.4 Tillage effect on Dominant Weed Species

Small seeded and wind dispersed annual grass species such as *Eragrostis aspera* (Jacq.) Nees, *Melinis repens* (Wild.) Zizka, were significantly ($P<0.05$) affected by tillage resulting in higher weed densities in PB than CONV at 3 and 6 WACE depending on the soil type (Table 4.3, 4.4 and 4.5). The effect of tillage on *E. aspera* differed with soil type with significant effect of treatment noticeable in clay loam and loam soils. The tillage effects on *M. repens* were consistent on all soil types and resulted in a high weed density in PB than CONV. The effect of tillage on *Urochloa panicoides* L. was observed in loamy and clay loam soils resulting in higher weed density in PB than in CONV (Table 4.3 and 4.5). Among the broad leaved weeds the small seeded annual weeds such as *Tridax procumbens* L. and *Ipomoea plebeia* L. had higher densities in PB than CONV (Table 4.3 and 4.5). The effect of tillage on *Bidens pilosa* L. was not consistent on all soil types. On loamy soils, higher weed density in PB than in CONV were only observed during the 2010/2011 season at 3 WACE with high weed density in PB than CONV (Table 4.3). On sandy loam and clay loam soils *B. pilosa*, had higher densities in CONV than in PB at 9 WACE as shown in Table 4.4. The perennial weeds observed in this study, *Cyperus esculentus* L., *Acacia longifolia* (Andrews) Willd and *Asclepias syriaca* L. had low weed densities hence they were not analysed further in the assessment of tillage effects on weed density. *R. scabra* had the highest weed density, this was consistent at three, six and nine WACE, and the weed density was not affected by tillage (Table 4.4).

Table 4. 3 Tillage effects on weed density (plants m^{-2}) of dominant weed species in maize (2009/2010) and cotton (2010/2011) recorded in Kadoma Zimbabwe under loamy soils.

	2009/2010 season						2010/2011 season			
Weed species	3 WACE		6 WACE		9 WACE		3 WACE		**6 WACE**	
	PB	CONV	PB	CONV	PB	CONV	PB	CONV	**PB**	**CONV**
Eragrostis aspera	2.62	1.02*	0.71	0.71	0.71	0.71	3.53	1.90*	0.92	0.71*
Melinis repens	2.31	1.29*	0.81	0.95	0.71	0.86	7.70	2.78*	2.05	3.22*
Rottboellia cochinchinensis	1.68	1.36	0.76	0.78	0.71	0.71	0.71	0.71	1.44	1.59
Urochloa panicoides	1.50	0.71*	1.22	1.18	0.71	0.86	1.27	0.71*	1.09	0.88
Acanthospermum hispidum	0.71	0.71	1.01	1.13	0.71	0.71	0.71	0.71	1.63	1.60
Bidens pilosa	2.27	1.93	3.89	4.16	1.59	0.99	3.82	1.83*	3.40	2.58
Corchorus olitorius	0.80	0.88	0.98	0.88	0.71	0.71	0.76	0.71	0.71	1.07*
Ipomoea plebeia	1.01	0.81	0.76	0.71	0.71	1.15	0.88	1.06	1.05	0.91
Leucas *martinicensis*	1.01	1.06	4.09	6.92*	2.31	1.83	1.38	1.05	2.91	4.17
Richardia scabra	1.09	0.96	1.16	0.95	0.71	0.71	0.81	0.71	1.28	1.48
Tridax procumbens	2.03	1.27*	2.89	1.48*	2.29	0.75*	2.39	1.35*	2.50	2.58

Square root transformed data (x+0.5). Means for weed species followed by a * differ significantly based on *t*-test (P<0.05) within each sampling time. PB = Planting basin; CONV =Conventional tillage; WACE= weeks after crop emergence.

Table 4. 4 Tillage effects on weed density (plants m^{-2}) of dominant weed species in maize (2009/2010) and cotton (2010/2011) recorded in Kadoma, Zimbabwe under sandy loamy soils.

	2009/2010 season						2010/2011 season			
Weed species	3 WACE		6 WACE		9 WACE		3 WACE		**6 WACE**	
	PB	CONV	PB	CONV	PB	CONV	PB	CONV	**PB**	**CONV**
Eragrostis aspera	0.71	0.71	0.71	0.71	0.71	0.71	1.44	0.88	0.92	0.71
Melinis repens	3.48	2.01*	1.94	0.89*	0.71	1.32	2.11	2.41	0.88	1.36
Rottboellia cochinchinensis	2.37	1.69	0.78	0.71	1.00	1.31	8.97	6.46	0.71	1.14
Urochloa panicoides	0.71	0.71	0.71	0.71	0.71	0.71	1.50	1.27	0.76	0.71
Acanthospermum hispidum	0.93	1.26	1.20	1.59	1.73	1.37	1.63	1.60	1.74	2.13
Bidens pilosa	0.71	0.81	1.06	1.52	1.00	2.2*	1.56	1.25	3.67	2.70
Corchorus olitorius	0.78	0.71	1.06	1.07	1.49	0.93	1.28	0.98	1.25	1.43
Ipomoea plebeia	1.71	1.43	1.23	1.33	2.96	1.38*	3.03	3.40	2.86	3.03
Leucas martinicensis	0.78	0.81	1.18	0.82	1.01	0.86	1.04	1.29	1.45	2.25*
Richardia scabra	4.31	4.98	4.82	4.22	3.87	5.06	10.44	11.01	12.11	11.74
Tridax procumbens	0.71	0.71	1.08	1.19	0.86	0.71	2.18	1.67	1.75	1.55

Square root transformed data (x+0.5). Means for weed species followed by * differ significantly based on *t*-test (P<0.05) within each sampling time. PB = Planting basin; CONV= Conventional tillage; WACE= weeks after crop mergence

Table 4. 5 Tillage effects on weed density (plants m^{-2}) of dominant weed species in maize (2009/2010) and cotton (2010/2011) recorded in Kadoma Zimbabwe under clay loam soils.

	2009/2010 season						2010/2011 season			
Weed species	3 WACE		6 WACE		9 WACE		3 WACE		6 WACE	
	PB	CONV	PB	CONV	PB	CONV	PB	CONV	PB	CONV
Eragrostis aspera	3.40	1.72*	0.99	0.82	0.71	0.71	1.44	0.88	0.92	0.71
Melinis repens	3.46	1.06*	3.21	1.62*	1.88	1.29	2.91	0.71*	1.68	1.26
Rottboellia cochinchinensis	3.29	3.26	3.11	3.25	1.21	0.99	2.20	2.27	0.85	1.63*
Urochloa panicoides	0.98	0.92	1.50	0.71*	1.14	0.71	1.50	1.27	0.76	0.71
Acanthospermum hispidum	3.03	2.66	3.78	3.69	2.71	1.01*	1.84	2.13	1.54	1.15
Bidens pilosa	3.11	2.89	3.35	4.65	1.59	2.04*	1.56	1.25	0.93	0.78
Corchorus olitorius	1.71	1.95	2.96	1.96	1.88	1.90	1.28	0.98	0.71	0.71
Ipomoea plebeia	1.92	1.51	2.16	1.79	2.20	3.13	0.88	0.71	0.78	0.90
Leucas martinicensis	2.39	2.10	3.30	4.66	5.24	4.40	1.04	1.29	2.02	1.43
Richardia scabra	3.85	4.05	6.47	5.87	0.86	1.64	5.01	4.05	4.78	3.62
Tridax procumbens	2.11	1.35*	1.79	1.73	1.76	3.04	1.87	0.76*	1.51	1.08

Square root transformed data (x+0.5). Means for weed species followed by * differ significantly based on *t*-test ($P<0.05$) within each sampling time. PB= Planting basin; CONV =Conventional tillage; WACE=weeks after crop emergence

4.5.6 Tillage Effects on Weed Diversity

A significant ($P<0.05$) effect of tillage system on weed diversity indices at 3 WACE was observed for loamy and clay loams during the 2009/2010 and 2010/2011 seasons as shown in Figure 4.2. In PB, the diversity indices were 58 and 45 percent higher than in CONV on loamy soils during 2009/2010 and 2010/2011 seasons, respectively. In clay loams, PB resulted in a 13 and 28 percent higher diversity index at 3 WACE for 2009/2010 and 2010/2011 seasons, respectively. The effect of tillage system on weed density was also significant in clay loams at 9 WACE resulting in 19 percent higher diversity index in PB than in CONV. No significant ($P>0.05$) effects of tillage system were observed on sandy loams during both seasons.

4.5.7 Prediction of Yield Losses

The influence of weed density on maize and cotton yield under PB and CONV is illustrated in Figure 4.3. A wide range of maize grain and cotton lint yields was observed among all the fields. The yield loss parameter *a*, which expresses fraction of yield loss per unit weed density in PB under maize was 3.88; 4.74 and 10.12 percent while that for CONV was 0.24; 0.49, and 2.5 percent on loamy, sandy loamy and clay loams respectively. The yield loss for maize under PB was 5.91; 1.6 and 10.86 percent whereas under CONV it was 2.75; 1.4 and 6.80 percent in loamy, sandy loam and clay loams respectively; whereas overall, all the crops and soil types showed highest yield loss in PB although the clay loam soils resulted in higher yield losses per unit weed density. The yield losses in PB and CONV were almost similar at weed densities less than 90; 110 and 300 m^{-2} on loamy, sandy loam and clay loam soils, respectively. Thereafter, the yield losses in PB were higher than in CONV that increased linearly for loamy and clay loams soils. The r^2 values for 'goodness of fit' for data to the rectangular hyperbola model ranged from 0.80 to 0.98 indicating excellent fit of the data sets.

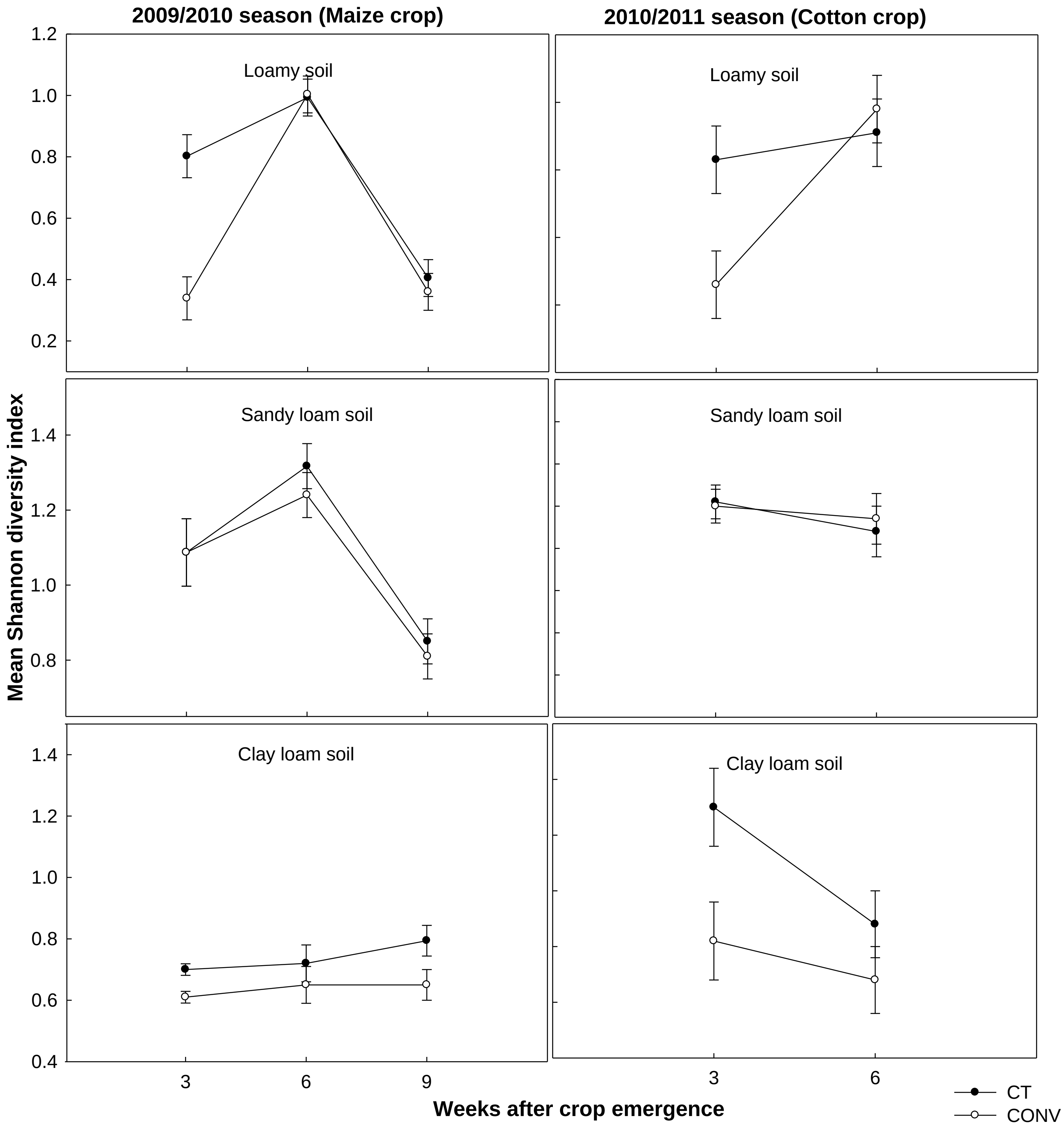

Figure 4.2 Tillage effects on diversity indices during 2009/2010 and 2010/2011 seasons in Kadoma, Zimbabwe. PB=Planting basin; CONV=Conventional tillage. Error bars indicate SED (P<0.05).

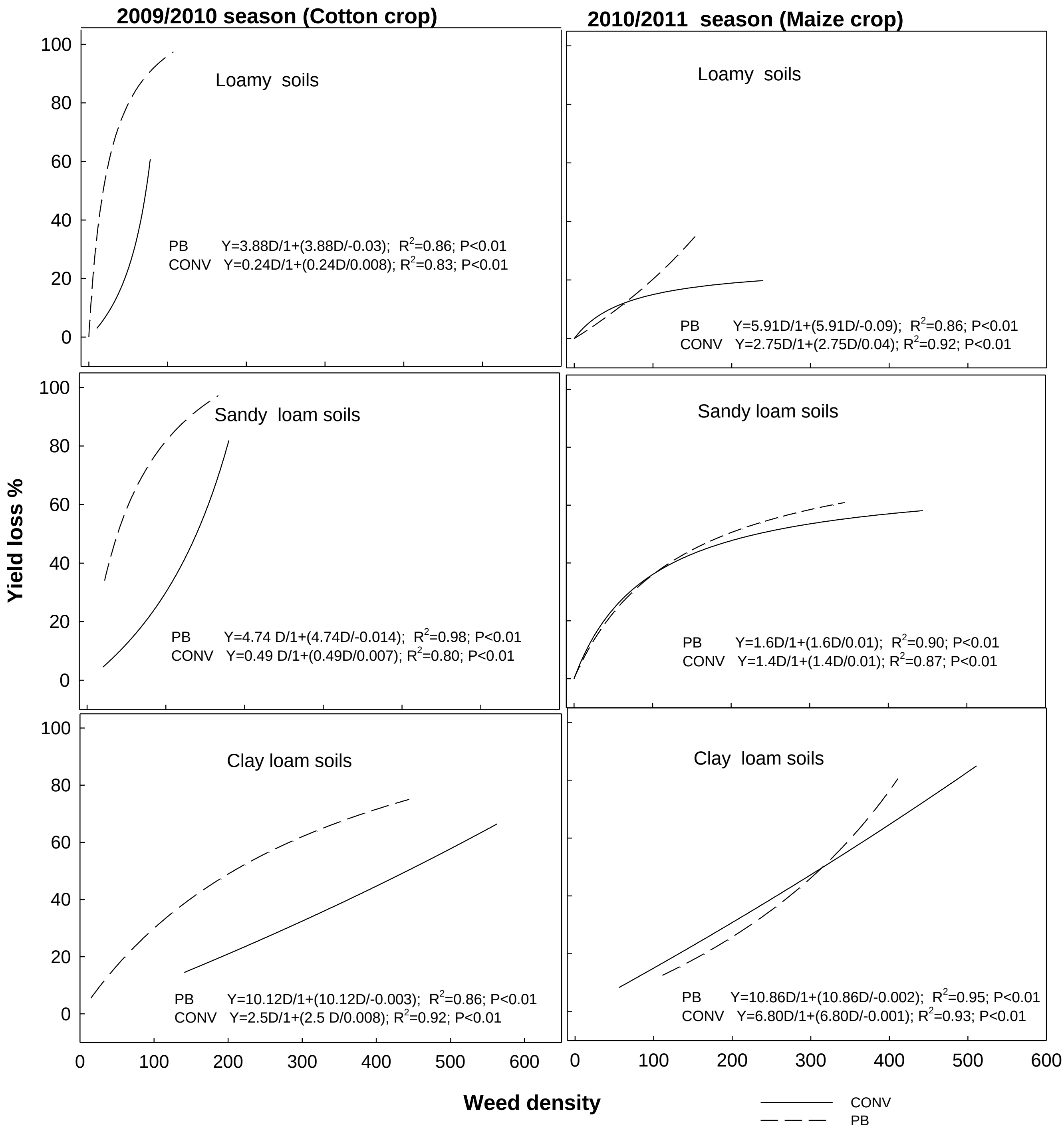

Figure 4. 3 Yield loss resulting from weed competition in conservation and conventional tillage in three soil types during 2009/2010 and 2010/2011 seasons. PB= Planting basin; CONV= Conventional tillage

4.6 DISCUSSION

The higher weed densities observed in PB when compared with CONV in loamy and clay loam soils during both seasons suggested that tillage system affected weed density. These findings concur with several investigations that reported higher weed densities in PB (Demjanova *et al*., 2009; Gruber *et al.*, 2010; Légère *et al*., 2011). The higher weed densities observed in PB might be due to the fact that PB tends to promote higher weed seeds concentration on the soil surface. The weed seeds at the surface therefore require less energy for emergence than deeper layers (Mrabet, 2008). Conversely, the lower weed densities in CONV were attributed to the effect of the plough as it turned the soil and buried more weed seeds to a depth where there are not enough stimuli for germination (Swanton *et al*., 2000; Douglas & Peltzer, 2004). Tillage system did not affect total weed density on sandy loam soils in this study, which also corresponded to findings by Tuesca *et al*. (2001), Shrestha *et al*. (2008) and Vasileiadis *et al*. (2012). This could be attributed to the greater vertical movement of seeds deeper in the soil profile in sandy soils because of their low colloidal activity and aggregate entrapment. The differential effects of tillage on weed density in different soil types showed that soil types also influence the weed density in addition to tillage.

The implication of the increased weed density at 3 WACE in loamy and clay loam soils was that it exacerbated the weed management problems already prevalent in the SH sector. It is, therefore, imperative for farmers to avert yield losses arising from high crop-weed competition in PB, by weeding earlier in PB than in CONV. However, given that labour is a scarce resource, and considering that, farmers tend to concentrate on planting the rest of the fields early in the season in order to take advantage of the moisture, weeding is likely to be delayed. Weeding after the critical period has elapsed leads to serious agronomic consequences, such as yield losses due to high crop weed competition for nutrients (Takim & Fadayomi, 2010; Gantoli *et al*., 2013). The early emerging weeds and those that emerge before the crops have the greatest impact on crop yield (Cerrudo *et al*., 2012; Ayala & Gerhards, 2013). If left uncontrolled, early emerging weeds cause greatest yield losses that can range from 26 to 100 percent (Ishaya *et al*., 2007). In addition, if the early weeds are not effectively controlled, they could produce a higher number of weed seeds than the late emerging ones, which contribute to future weed infestations (Simard & Benoit, 2012).

The majority of weed species, encountered in this study, had their highest emergence between 3 to 6 WACE in CONV and 0 to 3 WACE in PB. This suggests that weed pressure in PB occurs early in the season than in CONV. The other factors, which determine the timing of weed emergence as, noted in this study are moisture and the type of weeds present. It was observed that the high weed density period in both seasons (2009/2010 and 2010/2011) would follow a period of high rainfall. Conversely, low weed density recorded at 9 WACE in loamy and clay loam soils was due to low moisture, which then affected weed emergence. The low weed density at 9 WACE is also attributed to the shading effect of crop canopy on weeds. The crop canopy reduces the photosynthetic far red light (P_{fr}) required for germination of weeds, and as a result, a few shade tolerant weeds will be able to thrive (Shrestha *et al*., 2008).

A fluctuation of weed flora composition observed during the three assessments period might be due to seasonal weather variation since each species has a set of requirements for its emergence and growth. This information is important for proper timing of weed control and is one of the factors limiting manual weed control. An important requirement for any technology to work is that the peak weed emergence must coincide with the critical period of weed control (Ishaya *et al*., 2007). The knowledge of time of weed emergence is important as it can then be integrated in crop models. This could be used to select appropriate weed management options that reduce the competitiveness of weeds (Takim & Fadayomi, 2010).

The use of pre-emergence herbicides can help to suppress weed growth during the critical period of weed control. However, PB can influence the behaviour of soil active herbicides because residues retained under PB intercept a large proportion of the applied herbicides and reduce the amount of herbicide reaching the soil surface (Chauhan & Opena, 2012). Herbicides on the residues can be subject to volatilisation, photo degradation or other losses such as binding to crop residues (Chauhan *et al*., 2006).

The higher weed density for small seeded annual grasses observed in PB, in this study were also reported by Tuesca *et al*. (2001) and El Titi (2003), whereby the grass annuals were more abundant in no till. Small seeded weeds tend to be prevalent in PB because the small seeds germinate easily with adequate light on the soil surface, whereas, the burial of weed seeds in CONV, reduces their chance to germinate (Chauhan *et al.*, 2006). The crop residues in PB may also provide the conditions favourable for grassy annuals (Tuesca *et al.*, 2007). The results suggest that PB increased the emergence of small seeded annual weeds. In this regard new weed management strategies are required to reduce small seeded weeds in PB. There was no increase in perennial weeds in PB and this result was consistent with findings by Tørrensen & Skuterud (2002). Perennial weeds are expected to increase in PB because the underground vegetative reproductive organs are not brought to the surface but remain in the soil and germinate when favourable conditions prevail (Melander *et al*., 2007). However, under CONV, the vegetative reproductive organs are brought to the surface as the tillage implements turn the soil, resulting in their desiccation.

The findings of the study, which show that PB reduced the dominance of a few species but maintained a highly diverse weed community also, agreed with the outcome of the research by Santín-Montanyá *et al*. (2013). The knowledge of weed species composition is important in developing weed control strategies. The more diverse a weed community is, the higher the balance and easier it becomes to implement Integrated Weed Management (Otto *et al*., 2012). However, in other studies, weed species diversity did not vary with tillage (Puricelli & Tuesca 2005; Tuesca & Puricelli, 2007). Robert *et al*. (2009) suggested that the variable and inconsistent reports may be due to edaphic factors or the effects of previous management strategies. These contradicting findings underscore the need to develop specific weed management in PB, which takes into consideration the soil types, and other environmental factors that may affect weed density.

Richardia scabra was the most abundant species in the study site particularly in sandy loam soils, its high seed output might be the reason for its dominance though the shape and size of the seed also plays a role in its survival and germination strategies (Hakim *et al*., 2010). Although *R. scabra* was the most abundant weed in the study area, it was not affected by tillage. The weed density was almost similar at 3, 6 and 9 WACE. The high weed density of *R. scabra* at the end of the cropping season does not significantly result in greater competition with crops. However, if the weeds are not controlled, they may produce seeds that may replenish the weed bank and become a source of future infestation (Puricelli & Tuesca, 2005). Late weeds also have a consequence of depleting soil moisture (Young *et al*., 2010) which necessitates their removal as the cropping season ends.

There was variability on the effects of tillage on yields in the loamy, sandy loam and clay loams indicating that soil type is also important in determining the effect of tillage on yield. The higher weed density during early season in PB than in CONV has consequences of higher yield losses due to the effects of higher crop-weed competition if the weeds are not controlled effectively. In a study by Derksen *et al*. (2002) and Buhler *et al*. (1994), high weed density in PB also resulted in high yield losses. It, therefore, implied that crop weed competition in PB is more detrimental to crops than in CONV. The higher yield loss in clay loam soils may possibly indicate the an inability by the farmers to effectively because of the constraints of labour weed in PB when compared to CONV and thus necessitating a need for an Integrated Weed Management system that incorporates residual herbicides and cultural methods of weed control. In addition, further research that relates to finding the optimal weed management options in PB in the SH sector taking cognisance of the challenges in the sector, would perhaps be is required.

4.7 CONCLUSION

The loam and clay loam soils had higher weed densities and diversity in PB than in CONV from 0 to 3 WACE. The small seeded annual weeds had higher densities in PB than in CONV. The weed emergence peaked from 0 to 3 WACE in PB and from 3 to 6 WACE in CONV. The observed high weed density and diversity on loam and clay loam soil types under PB requires new approaches to weed control. Farmers also need to weed earlier in PB than in CONV in order to keep the weeds below the detrimental economic threshold. However, due to the labour bottlenecks commonly experienced earlier in the season the use of herbicides in combination with cultural methods would be recommended as a means to suppress weed growth early in the season.

CHAPTER 5

INFLUENCE OF SOIL PROPERTIES, SOCIO ECONOMIC AND SOIL MANAGEMENT ON WEED DENSITY AND COMPOSITION UNDER PLANTING BASIN

5.1 ABSTRACT

The study sought to determine the effect of soil properties, socio economic and management factors on the weed density and composition in Kadoma, Zimbabwe under Conservation Agriculture. The study was undertaken during the 2009/2010 and 2010/2011 seasons, wherein weed densities were determined in 18 fields characterised by heterogeneous soil types, socio-economic and management factors. Multivariate ordination techniques and a quadratic model were used to describe the relationship between 11 soil properties, nine socio economic and management variables with weed densities. The gross and net effects of weed densities were calculated for 13 variables selected by stepwise backward variable selection. Soil properties, socio economic and management factors had significant effects on weed densities. The 13 variables explained 32 percent of the total variation in weed species data. The variation was related to soil properties, socio economic or management factors. The socio-economic and management factors accounted for the greatest variation which was more than twice of the variation for soil properties. The study indicated that the weed dynamics in PB cannot be attributed to tillage only, but that tillage interacts with soil properties, socio-economic and management factors. The soil properties, socio-economic, soil management weed relations observed in this study are important in developing weed management strategies that suppress weeds in PB.

Keywords: cluster analysis, planting basins, principal component analysis, weed abundance, soil texture, sustainable agriculture

5.2 INTRODUCTION

Conservation Agriculture (CA) has been promoted since 2004 in Zimbabwe as a sustainable means of crop production in the smallholder (SH) sector which also curbs the declining soil fertility and ultimately increase crop production (FAO, 2012). Jasinskaite *et al*. (2009), however, argued that CA has been associated with shifts in weed composition toward perennial weeds and increased weed densities. This is consistent with the findings of Muoni *et al*. (2013); Gruber *et al*. (2012); and Chauhan & Johnson (2009) who have reported increased weed infestation under CA**.** Some specific examples include reports by Chauhan & Opena, (2012) on Philippines and Mashingaidze *et al*. (2012) on Zimbabwe, which showed higher weed densities in CA compared to conventional tillage (CONV). In Slovakia, total weed density was higher under reduced tillage than CONV (Demjanová *et al*., 2009). On the contrary, no effect of tillage on weed density was observed in several other studies (Perron & Légeré, 2000; Shrestha *et al.*, 2003; Bullied *et al*., 2003; Mandumbu *et al*., 2011).

Manual minimum tillage system, planting basins (PB), have been reported to result in increased weed densities (Mazvimavi &Twomlow, 2009). In the results presented in Chapter 4, there were differential effects of tillage on weed densities on three different soil types resulting in higher weed densities in PB relative to CONV, on clay loam and loamy soils while no effect of tillage was observed in sandy soils. The findings in Chapter 4 suggested that discrepancies in literature on the effect of tillage on weed density under CA and PB may be due to differences in soil properties. However, since there was heterogeneity in management practices of farmers in the study, management practices could also have contributed to the differential effects of tillage on weed density

The varied views arising from the foregoing studies reflect either the complexity of tillage effects on weed density or suggest importance of other factors beyond tillage. Other factors that influence weed densities include soil environment agronomic factors (including methods of weed control and timing of planting) (Lososova´ & Cimalova´, 2009; Vasileiadis *et al*., 2012). Otto *et al*. (2007) argued that any changes that occur to weed density and composition cannot only be attributed to tillage but also to multiple ecological and management factors that affect weed growth. Weed community changes were fluctuational and depended on timing of weeding and soil management (Swanton & Booth, 2004). Management practices on soil fertility and weed control practices can influence the competitive ability of a crop leading to a selection of less competitive weed species (Fried *et al*., 2009). Intensive weed management and the use of herbicides can suppress sensitive weed species (Pinke & Pal, 2005). Other management factors, such as previous crop, crop rotation, and row spacing, significantly reduced weed diversity by eliminating individual species or by selecting resistant biotypes (Stefanic *et al*., 2001). The type of fertilisers used also influenced the weed communities, for example weed densities decreased with an increase in nitrogen fertiliser as a result of increased competitive ability of the crop against weeds (De Cauwer *et al*., 2010). These studies suggest that weed composition and density in arable fields is determined by several anthropogenic factors (Pinke *et al*., 2011).

Soil properties vary among fields and are likely to influence heterogeneity in weed composition and density (Shrestha *et al*., 2003; Otto *et al*., 2007). The, density of *Viola arvensis* L. had a negative correlation with clay content whilst the density of *Lamium purpurem* L. was positively correlated with phosphorus (P) content in the soil (Walter *et al*., 2002). The densities of *Veronica* spp. and *Poa annua* L. were negatively correlated with pH (Otto *et al*., 2007). *Ambrosia artemisiifolia* (L.) was less abundant in fields with soils containing high concentrations of Sodium ions, Potassium and Manganese (Pinke *et al*., 2011). Soil pH and to a lesser extent, soil texture resulted in highly contrasting weed communities on basic clay soils against those on acidic sandy soils (Fried *et al*., 2008). Four soil properties namely soil temperature, soil texture, soil Magnesium and Calcium content, were attributed to the narrow ecological tolerance of *Papaver somniferum* L. (Pinke *et al*., 2011).

There are many factors that affect weed densities and the changes that occur to weed densities in CA may be due to an interaction of tillage, soil properties and management factors. Therefore, as farmers adopt CA, attributing the changes of weed densities to tillage only may be gross generalisation because of the interactions that may occur with environment, soil properties and crop management. Thus the effects of tillage on weed densities can only be described in terms of the interactions between, all factors that determine weed densities. However, interactions of tillage, soil properties and management practices are complex and their effects on weed density have not been well described under PB in the SH sector of Zimbabwe. Evaluation of the factors that affect weed densities is important to our understanding and may help to answer the discrepancies in literature on the effect of tillage on weed densities. This study was carried out to determine:

1. The effects of soil properties, socio-economic and management factors on weed densities and composition in fields under PB.

5.3 MATERIALS AND METHODS

5.3.1 Soil Sampling and Analysis

Soil samples were collected from PB plots on each of the 18 selected farmers' fields (who participated in the previous study discussed in Chapter 4). The selection criterion of farmers in this study is described in section 4.3.2 of Chapter 4. Five samples were taken diagonally from each field with a soil sampler 7 cm in diameter and 20 cm depth and the five samples were combined to make one composite sample for analysis. The soil samples were air dried and passed through a 2 mm sieve to remove plant debris and coarse fragments. Clay and silt content were determined by the hydrometer method with NaP_2O_2 as the dispersing agent (Gee & Bauder, 1986). The sand fraction was determined by wet sieving. Phosphorus (P) content in the soil was determined by the colorimetric method after extraction in Bray I (0.03 M NH_4F + 0.025 M HCI) solution (Carter & Gregorich, 2007). Soil pH was determined by a pH meter with a soil: water ratio of 1:2.5 (McLean, 1982). The mineral nitrogen content (ammonium (NH_4^+) and nitrate (NO_3)) in the soil was determined using Kjedahl digestion and measured with a spectrophotometer (AOAC, 1990). Exchangeable cations, namely calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na), were extracted using a 1.0 M ammonium acetate solution and was determined by atomic absorption (emission for K and Na) spectrophotometry (AOAC, 1990).

5.3.2 Socio-economic, Management Factors and Farmer Grouping

Weed surveys were carried out on the 18 selected farmers' fields. Each farmer was interviewed about his/her management practices on the principal crops grown. The following information on socio-economic and management factors was collected from the interviews with farmers:

- Total area farmed by the household (ha);
- Family labour (number of members working on the farm);
- Capital (income from off farm/non farm activities);
- Total number of cattle (determining the use of manure in the fields);
- Skills in agriculture (any training related to agriculture and use of herbicides);
- Soil fertility (use of inorganic fertilisers);
- Knowledge of herbicide usage.

The total land areas for each farmer, area under crops, labour, number of cattle were coded as actual numbers. Skills in agriculture, usage of inorganic fertilisers and knowledge of herbicides usage were coded as yes or no represented by 1 or 0, respectively in the matrix.

All the farmers were grouped using *k*-means cluster analysis according to similarities in their socio economic and management factors through maximizing within-group similarities and between-group differences (Johnson & Wichern, 1992).

5.3.3 Assessment of Weed Population

An area of 60 * 50 m that was representative of the average area cultivated on each of the 18 fields was selected. Careful attention was given to select areas with homogeneous crop cover and field margins (areas within 2 m from edges of the fields) were avoided because of the spatial variability in soils and management on field margins with field cores large enough to affect weed densities (Zingore *et al*., 2007). A pilot study was conducted to determine weed densities m^{-2} and dispersion pattern of weeds on the selected areas. The number of quadrats required for an accurate representation of weed populations in an area of 3000 m^{-2} was determined by the species area curve as described by Barbour *et al*. (1987). Cumulative weed densities were plotted against quadrat numbers; the asymptote (leveling off or plateau) marked the required 15 quadrats to obtain a representative sample in the experimental plots. A 'W' pattern as described by Hakim *et al*. (2010) was used to systematically sample (2 m * 2 m) quadrats within each field. The quadrats were fixed to remove the problem of environmental heterogeneity and permit the detection of any small changes on weed densities (Lundälv, 1985). Weeds were counted in each of the 15 quadrats per field placed. Weeds were counted and recorded by species three times during the growing season of the crop, at 3, 6 and 9 weeks after crop emergence (WACE) in the fixed quadrats.

5.3.4 Data Analysis

Comparisons of soil properties and weed abundance across the fields were done by descriptive statistics**.** The weed diversity in all the 18 fields was compared using the Simpsons Dominance, Shannon's diversity and Pielou's Equitability indices. The Equations used were:

Simpson's Dominance

$$D=\sum\left(\frac{n_i}{N}\right)^2 \qquad (1)$$

where n_i = numbers of individuals of each species, N = total number of individuals.

Shannon's Diversity

$$H = -\sum\left(\frac{n_i}{N}\right)\times\ln\left(\frac{n_i}{N}\right) \qquad (2)$$

where n_i = numbers of individuals of each species, N = total number of individuals.

Pielou's Equitability

$$E = \left(\frac{H}{\ln S}\right) \qquad (3)$$

where H = Shannon's index and S = species number

Richness index

$$R = \frac{S - 1}{\text{Log}N} \qquad (4)$$

S = species number, N = total number of species

The relative abundance accounts for species density and pattern, hence limits problems arising from weed patchiness (Derkensen *et al*., 1993). The Equation used to calculate relative abundance was as follows:

$$\text{Relative abundance} = \frac{\text{Relative Density} + \text{Relative Frequency}}{2} \qquad (5)$$

where, Relative Density = number of weed species within the quadrats divided by the total number of weeds within all quadrats in each field. Relative Frequency = the proportion of quadrats in which the species was present per field divided by the total frequency of all species.

The relationship between soil properties and relative weed densities was analysed using a partial least squares regression with a second degree polynomial model using SAS Procedures. Before regression analysis the relationship of x (soil properties) predictors and responses y (relative weed density) was improved by normalising the soil properties and relative weed density data using the Equation below:

$$X_n = (x - m_{so})/s_{sd} \tag{6}$$

Where m_{so} is the mean and s_{sd} the standard deviation of the soil properties in the analysis set, x is the value of the soil properties. The Equation for normalising the relative weed density was as follows:

$$Y_{en} = (y - m_{so})/s_{sd} \tag{7}$$

(after Wold *et al*., 1989)

Where y = relative weed density m_{SO} = the mean and s_{SD} = the standard deviation of the relative weed density.

The relative density of weeds Y_N as a result of the effect of soil properties was given by the following quadratic equation:

$$y_n = c1{*}x_n + c2{*}[x^2_n - (1 - 1/u)] \tag{8}$$

Where x = soil properties and x_n = the normalised values, c1 and c2 = regression coefficients of first and second order for the abundance of the species in normalised units. The number of objects in the analysis set was represented by *u;* y_n = the normalised relative density and y the relative density. The relative density of the original unit was then calculated as

$$y = y_n * s_{sp} + m_{sp} \quad (9)$$

where m_{sp} is the mean and s_{sp} the standard deviation of the relative density of the species in the analysis set.

The relationship between socio-economic, management factors and relative weed densities was analysed using Principal Component Analysis (PCA) with the PC-ORD v 6.0 software package (Peck, 2010). The Bartlett's test (Snedecor & Cochran, 1993) was used to determine the homogeneity of variances for the relative weed density data and a larger test statistic than the critical value revealed that the variances were not homogenous. Arcsine Square Root transformation was used to homogenise variances and improve the linearity relationship of the data with ordination Axis in PCA. Data was ordered using a covariance cross product matrix to reduce outliers while allowing full expression of differential gradients in species abundance. The data was also classified with a minimal variance clustering technique using the Eluclidean distance measure and group linkage using Ward's method (McCune & Mefford, 2010).

PCA was also used to determine the relationship of combined effects of soil properties, tillage, socio-economic and management factors on weed densities and determine which of these variables had the greatest effect on weed densities. Initially the number of explanatory variables was reduced by stepwise backward selection using a $P < 0.05$ threshold for type I error. This procedure led to the elimination of the following soil properties (NO_3^-, Mg^+, P and NH_4^+) and management factors (skills (training in crop production) and use of herbicides). Gross and net effects were assessed for each explanatory variable of the reduced model, according to the methodology of Lososova´ *et al*. (2004). The gross effect of a variable was defined as the variation explained by partial PCA (pPCA) containing only one explanatory variable. The net effects, on the other hand, were assessed as the significance of a similar pPCA with the predictor as the only variable and all the other variables were co-variables. The residual variation was analysed and significance was analysed significance and tested with a Monte Carlo permutations test with 999 randomisations (ter Braak, 1988). A rank of importance of the explainable variables soil properties, socio-economic and management factors according to R^2_{adj} values of the pPCA was carried out. A two dimensional ordination diagram was plotted in which the locations of weed species and variables (soil properties, tillage, socio-economic and management practices) were indicated. Weed species located in the direction of the arrow indicated variables had a positive correlation with the weed species. The further an arrow is from the centre of the diagram the greater the confidence that can be placed on the correlation between a species and the variables. The arrows for the variables near the centre had little effect on the densities of weeds.

5.4 RESULTS

5.4.1 Relative Weed Abundance and Diversity of Fields

The total relative weed abundance varied among the sampled fields with averages ranging from 0.06 to 0.13 and the standard deviation ranged from 0.09 to 0.16 (Table 5.1). Field D had the highest mean weed abundance with a value of 0.13 and the field with the least weed abundance was Field E (0.06). Although variation was observed in weed abundance among the fields some fields had similar weed abundance for example Field A, B, H, I and J though unexpectedly there was variation observed in diversity indices for these fields. The Shannon diversity index for all fields ranged from 3 to 11 while the richness indices ranged from 1.00 to 2.37. The evenness and dominance indices also varied among the fields and ranged from 0.85 to 0.99 and 0.61 to 0.90, respectively. Field D had the highest richness (11), Shannon diversity (2.37) evenness (0.99) and Simpson's dominance (0.90) indices. Whilst Field E had the lowest richness (3), Shannon diversity (1) and Simpson's dominance (0.61) indices. Field N had low (0.85) evenness index when compared with fields P and Q which had similar mean relative abundance values.

Table 5. 1 Statistical summary of total weed abundance of the most common weed species in farmers' fields in Kadoma, Zimbabwe during 2009/2010 and 2010/2011 seasons

Field	**Mean**	**Standard deviation**	**Minimum**	**Maximum**	**Diversity indices***			
	Plants (m^{-2})				**R**	**E**	**H**	**D**
A	0.10	0.11	0.00	0.32	8	0.98	2.04	0.87
B	0.10	0.12	0.00	0.38	8	0.97	2.03	0.86
C	0.12	0.12	0.00	0.43	9	0.97	2.12	0.87
D	0.13	0.09	0.00	0.30	11	0.99	2.37	0.90
E	0.06	0.14	0.00	0.44	3	0.92	1.00	0.61
F	0.08	0.14	0.00	0.37	5	0.97	1.56	0.78
G	0.12	0.11	0.00	0.38	10	0.97	2.23	0.88
H	0.10	0.13	0.00	0.38	7	0.94	1.83	0.82
I	0.10	0.12	0.00	0.30	8	0.98	2.03	0.86
J	0.12	0.11	0.00	0.33	10	0.96	2.21	0.88
K	0.11	0.12	0.00	0.35	9	0.97	2.12	0.87
L	0.08	0.14	0.00	0.40	4	0.97	1.34	0.73
M	0.07	0.16	0.00	0.50	3	0.98	1.07	0.65
N	0.09	0.16	0.00	0.62	7	0.85	1.66	0.74
O	0.08	0.13	0.00	0.34	5	0.98	1.58	0.79
P	0.09	0.14	0.00	0.48	6	0.94	1.68	0.79
Q	0.09	0.15	0.00	0.49	5	0.94	1.51	0.76
Average	0.10	0.13	0.00	0.40	6.9	0.96	1.79	0.80

*Diversity indices: R = Richness index; E = Pielou's Equitability; H = Shannon's Diversity; D = Simpson's dominance

5.4.2 Soil Chemical and Physical Properties

Table 5.2 shows the main physico-chemical properties of the soils from the 18 fields in the study area. There were three main soil types identified in the study area clay loam, loamy and sandy loam soils. All the soils had pH >5.5 which is critical for the toxicity of availability of soil nutrients. An analysis of the chemical composition of the soils showed that most of the soils (94 percent) were deficient of major soil nutrients such as P and K with nutrient levels less than the critical levels 7 and 150 coml. kg^{-1} respectively.

Table 5. 2 Summary of the physico-chemical properties of the soil in the farmers' fields in Kadoma, Zimbabwe

		Soil nutrients‡							Soil texture		
Field	pH (H_20)	P	Ca^{2+}	K^+	Mg^{2+} (cmol kg^{-1})	Na^+	NH^+_4	NO_3^-	Clay	Silt (%)	Sand
A	7.8	10.5	3390	138	333	87	8.18	263.09	48.1	28.8	13.8
B	5.4	2.9	1052	67	797	124	9.97	45.47	35.7	30	27.5
C	5.9	3.5	821	54	488	57	5.04	8.18	57.6	22.55	15
D	6.2	2.9	2387	78	1064	109	7.5	38.98	36.9	32.5	22.5
E	7.9	2.8	3707	84	475	125	4.26	55.44	49.5	25	17.5
F	5.7	2	1249	41	747	124	5.82	83.29	37.2	33.1	21.9
G	6	4.1	2041	96	678	126	4.37	15.23	30	6	63.9
H	5.7	3.9	1479	100	775	103	9.18	188.16	31.6	40	20
I	5.7	5.1	833	110	496	97	1.68	111.44	45.5	30.6	16.9
J	5.7	5.1	853	83	643	45	9.18	83.22	41.2	37.5	12.5
K	5.9	5.8	918	56	402	88	35.95	110.88	58.8	23.1	11.9
L	6.6	4.9	1813	119	571	121	7.39	137.76	41.7	38.1	14.2
M	5.7	1.8	2101	97	744	88	3.47	112	27.8	28.1	34.4
N	6	2.5	1578	69	700	49	4.93	91.95	41	25	30
O	6.2	2	2705	73	949	69	6.05	61.82	45.3	22.5	25
P	6.4	4.8	1690	94	553	91	7.62	54.99	44.1	30.6	19.4
Q	6.3	2.6	1474	53	567	102	3.02	31.36	45.4	27.5	20
R	5.8	2.2	2163	92	773	121	2.8	26.88	57.7	13.1	11.9
Mean	6.16	3.86	1791.89	83.56	653.06	95.89	7.58	84.45	43.17	27.45	22.13
SD†	0.68	2.08	850.95	25.10	187.82	26.69	7.48	64.30	9.37	8.41	12.24
Minimum	5.4	1.8	821.00	41.00	333.00	45.00	1.68	8.18	27.80	6	11.90
Maximum	7.9	10.50	3701.00	138.00	1064.00	126.00	35.95	263.09	59.70	40.00	63.90

†(SD) Standard deviation; ‡ Soil nutrients (P) Available phosphorus; (Ca^+) calcium; (K^+)Potassium; (Mg^+) Magnesium; (Na^+) Sodium; (NH_4^+) Ammonium; (NO_3^-) Nitrate

Most (89 percent) of the fields had adequate NO_3^- content while only 11 percent had low NO_3^- . There was a wide variation of the NO_3^- content which ranged from 8 to 263 cmol kg^{-1}. The Ca^{2+} content in the soils ranged from 821 to 3701 cmol kg^{-1} and 24 percent of the fields had Ca^{2+} content below 1000 cmol kg $^{-1}$. The Mg+ content of all fields was adequate and was above 180 cmol kg^{-1}. The Na^{2+} content for the fields ranged from 45 to126 cmol kg^{-1} and was below the optimum level of 640 cmol kg^{-1} (Table 5.2).

5.4.3 Soil Properties Effects on Total and Relative Weed Density

The effect of soil properties on relative weed density and total weed density was analysed by the quadratic model and the results are shown in Figure 5.1 to 5.6. The predictive capacity of the model was good in explaining the relationship for most weed species and soil properties with R^2 values ranging from 0.55 to 0.99. The lowest R^2 value of 0.55 was observed for the relationship of *Urochloa panicoides* and *Melinis repens* with pH, Na, and Ca (Figure 5.5 and 5.6).

5.4.3.1 Total Weed Density

Total weed density increased with increase clay content (Figure 5.1A). Conversely the weed density decreased with an increase in sand and silt content (Figure 5.1A). The highest weed density was associated with low NO_3^- and NH_4^+ whereas weed density increased with an increase in P and K^+ levels (Figure 5.1B). Most of the weeds were associated with slightly acidic pH. The total weeds were also high where Mg levels were above 315 cmol kg^{-1}. It was also observed that Ca^{2+} levels of 940 cmol kg^{-1} associated with high weed densities. High relative weed density was also associated with levels of Na^+ above 122 cmol kg^{-1} (original unnormalised values) (Figure 5.1C).

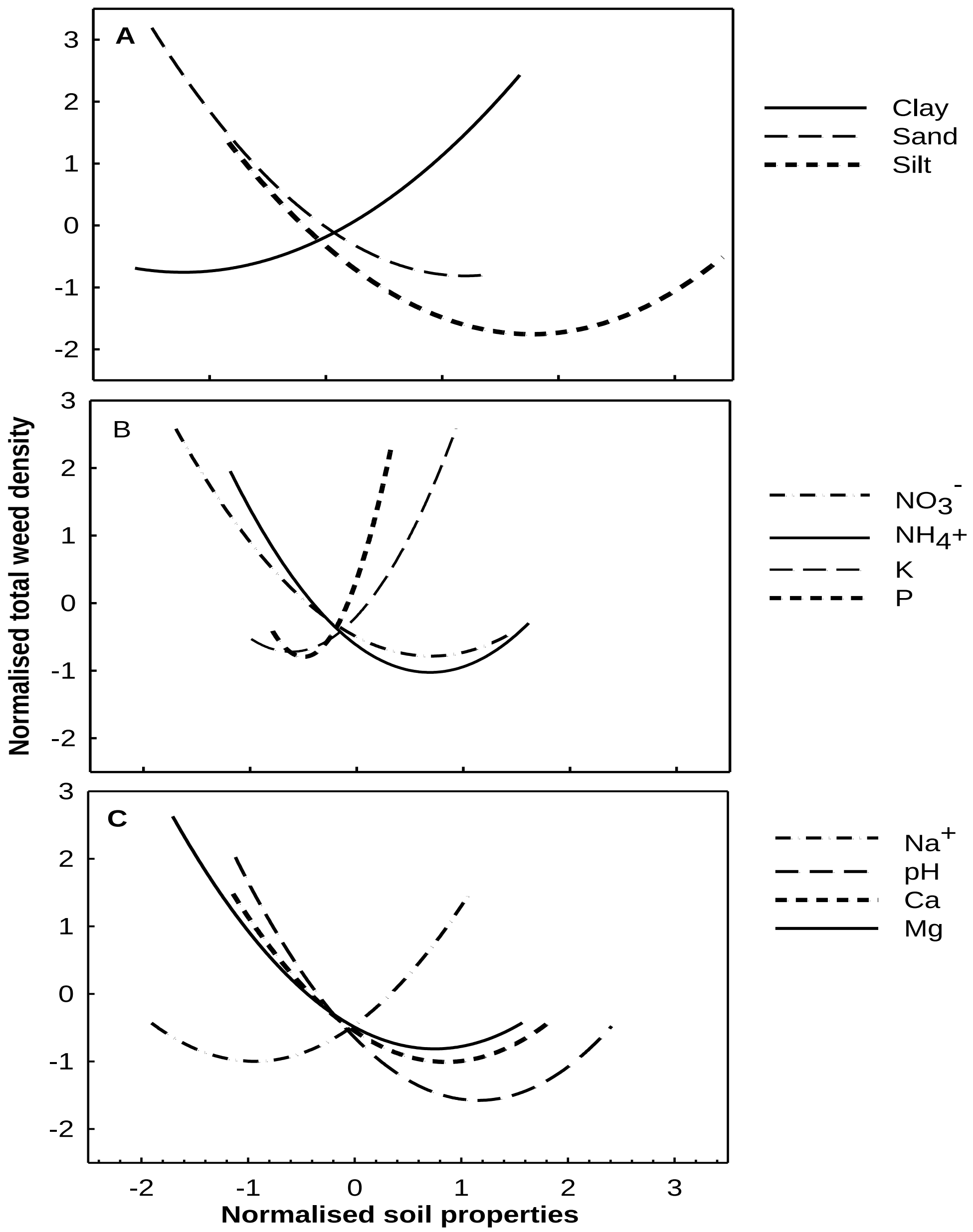

Figure 5. 1 The relationship between soil properties and total weed density in Kadoma, Zimbabwe

5.4.3.2 Diversity and Soil Texture

A relationship of diversity indices with soil texture (percent clay, sand and silt) existed such that all the indices (diversity, evenness, richness and dominances) increased as the clay content in the soil increased (Figure 5.2A, B, C and D). The evenness index had a negative linear relationship with sand content (Figure 5.2C). The richness, diversity and dominance indices decreased with an increase in sand content. Low silt content was associated with high indices for richness, evenness, diversity and dominance and these indices decreased as the proportion of silt increased in the soil.

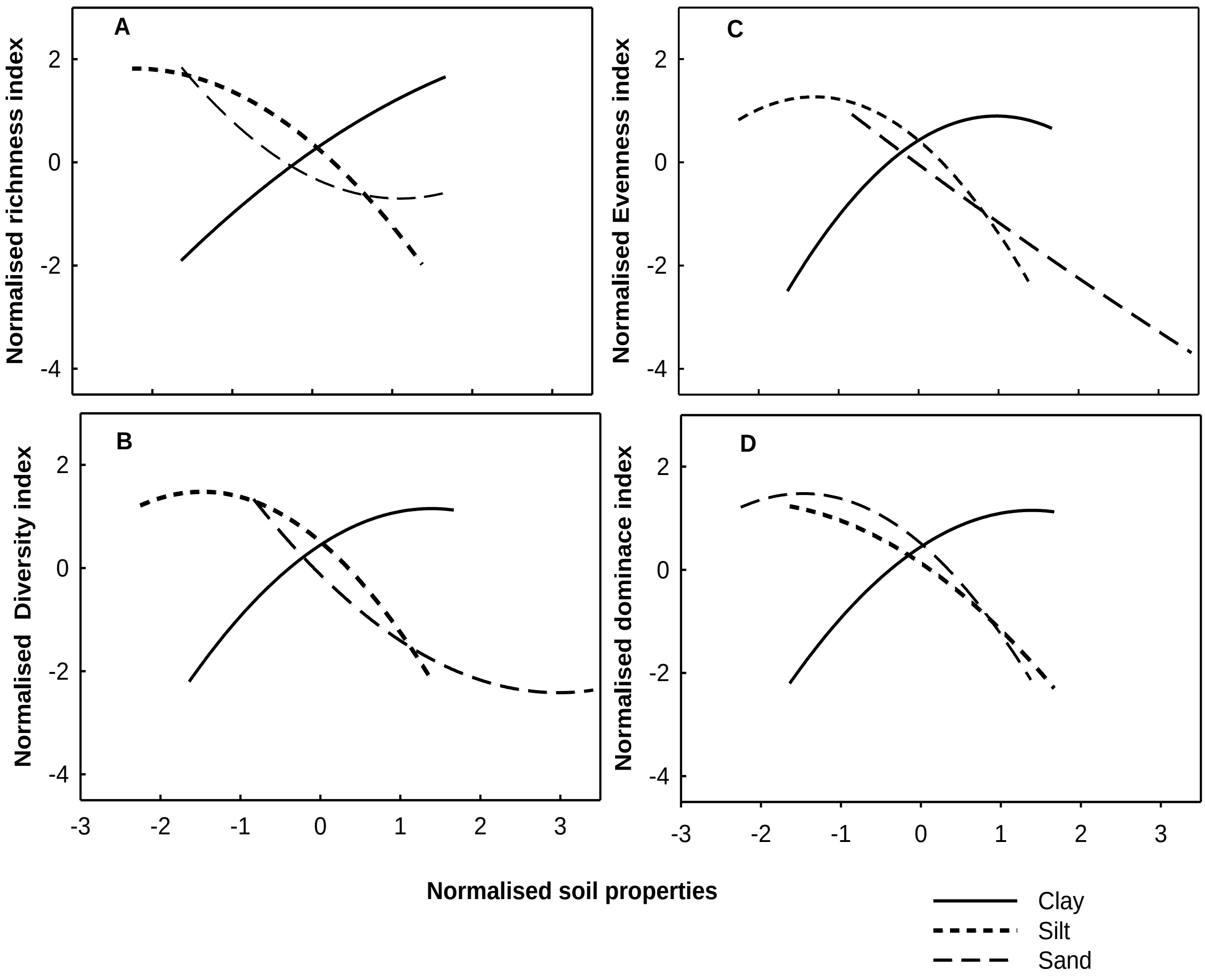

Figure 5. 2 The relationship of soil texture with richness, evenness, and diversity and dominance indices

5.4.3.3 Diversity and Soil Nutrients

The soil nutrients contributed to differentiation of diversity indices as shown in Figure 5.3. A positive linear relationship of NO_3^- with richness index was observed; on the contrary the evenness, diversity and dominance indices had a positive linear relationship (Figure 5.3 A, B, C). High levels of K^+ increased dominance and diversity indices but decreased evenness index (Figure 5.3 B, C, and D). The high richness indices were associated with high P levels in the soil. The relationship between Mg^{2+} and richness was represented by a hyperbola graph indicating that richness index was associated with low and high Mg levels (Figure 5.3E). The increase in Mg^{2+}, Ca^{2+}, pH, increased the evenness, diversity and dominance indices (Figure 5.3F, D, E). The Na^{2+} levels in the soil did not have an effect on the relationship with evenness and the R^2 value was very low (37 percent). Similarly the relationship of Na^{2+} with richness index was poorly explained by the model indicated by very low R^2 value (26 percent) (Figure 5.3E).

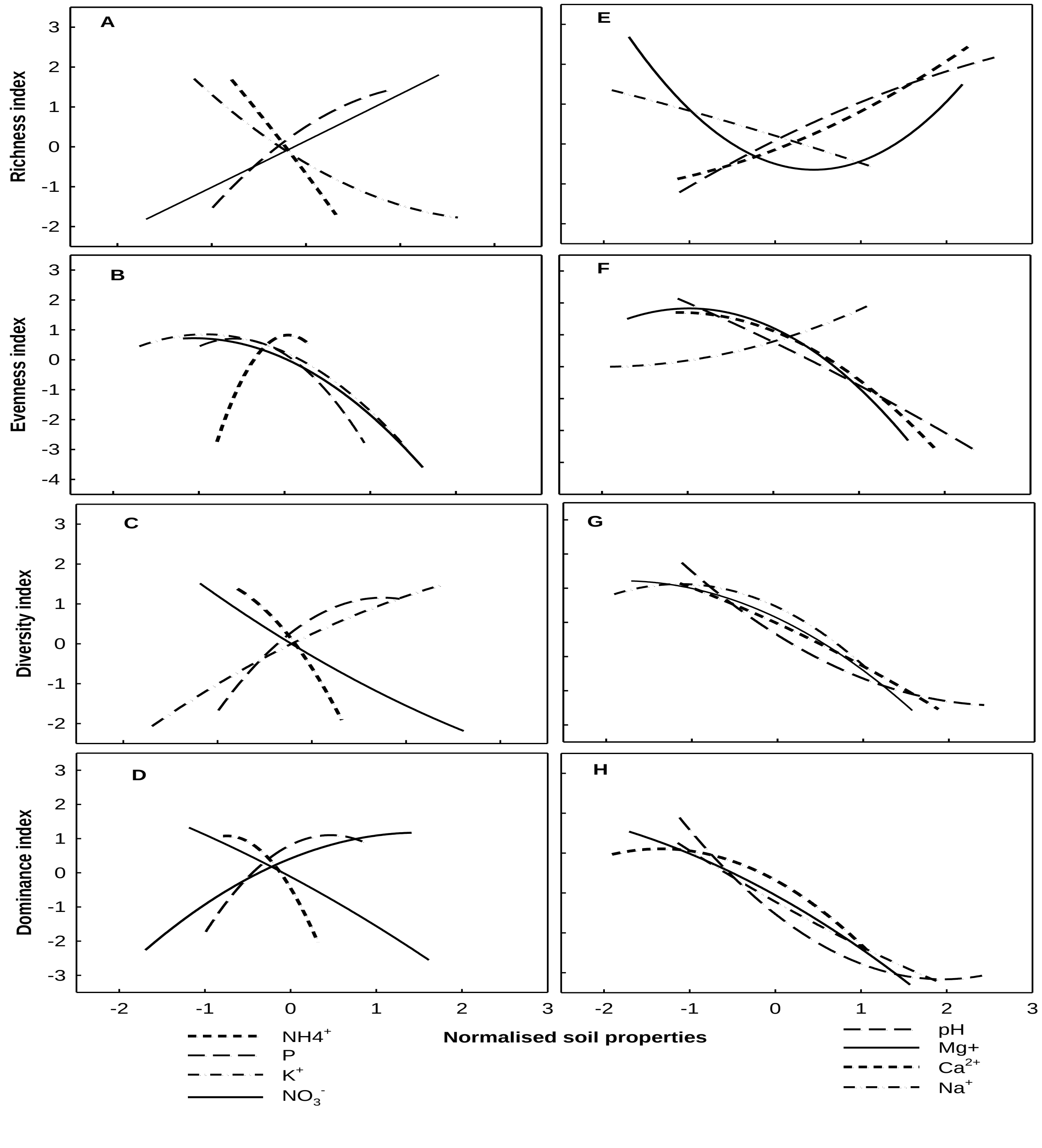

Figure 5. 3 The relationship of soil chemical properties with richness, evenness, and diversity and dominance indices

5.4.3.4 Relative Density

The analysis of the relationship of soil properties and relative weed density was conducted on the first six weed species from the 16 species illustrated in Table 5.1. These species were dominant in the study and they all had mean relative densities =/+ 0.10.

Richardia Scabra L.

Richardia scabra had the highest relative abundance when compared to all the other weeds in the study area. The relationship with soil texture was clear. This species was associated with soils rich in sand and clay but poor in silt (Figure 5.4A). Its density increased as Mg^+ and K^+ levels increased in the soil (Figures 5.4B and 5.4C). *Richardia scabra* density also increased linearly with an increase in NO_3^- content in the soil. In addition the results revealed that low P and NH_4^+ favoured high relative density of *R. scabra* (Figure 5.4B). The abundance of *R. scabra* was associated with soils low in pH, Ca^+, and Na^+ content (Figure 5.4C).

Eragrostis aspera (Jacq.) Nees

Eragrostis aspera density increased with an increase in silt and clay content (Figure 5.4D), whilst, it seemed to be indifferent to sand content. High Na^+ and Mg^+ favoured the abundance of *E. aspera*. The relationship of K^+ and NO_3^- with *E. aspera* abundance was represented by a hyperbola graph where its abundance was associated with low K^+ 58.46 coml kg^{-1} unnormalised value) and NO_3^- 201.15 cmol kg^{-1} (unnormalised value) and further increase up to 88.58 and 97.34 mg kg $^{-1}$ (unormalised values) for K^+ and NO_3^- , respectively, decreased its density (Figure 5.4E). The abundance of *E. aspera* was associated with soils with low in pH, Ca^+, and Na^+ content (Figure 5.4E). *Eragrostis aspera* was also sensitive to NH_4^+ levels in the soil illustrated by a steep decline in abundance with a slight increase in NH_4^+ levels.

The density of *E. aspera* decreased with an increase in pH and Ca^{2+} content in the soil indicating its adaptability to acidic soil conditions The abundance of *E. aspera* was associated with soils with low pH, Ca^{2+}, and Na^{+} content (Figure 5.4F).

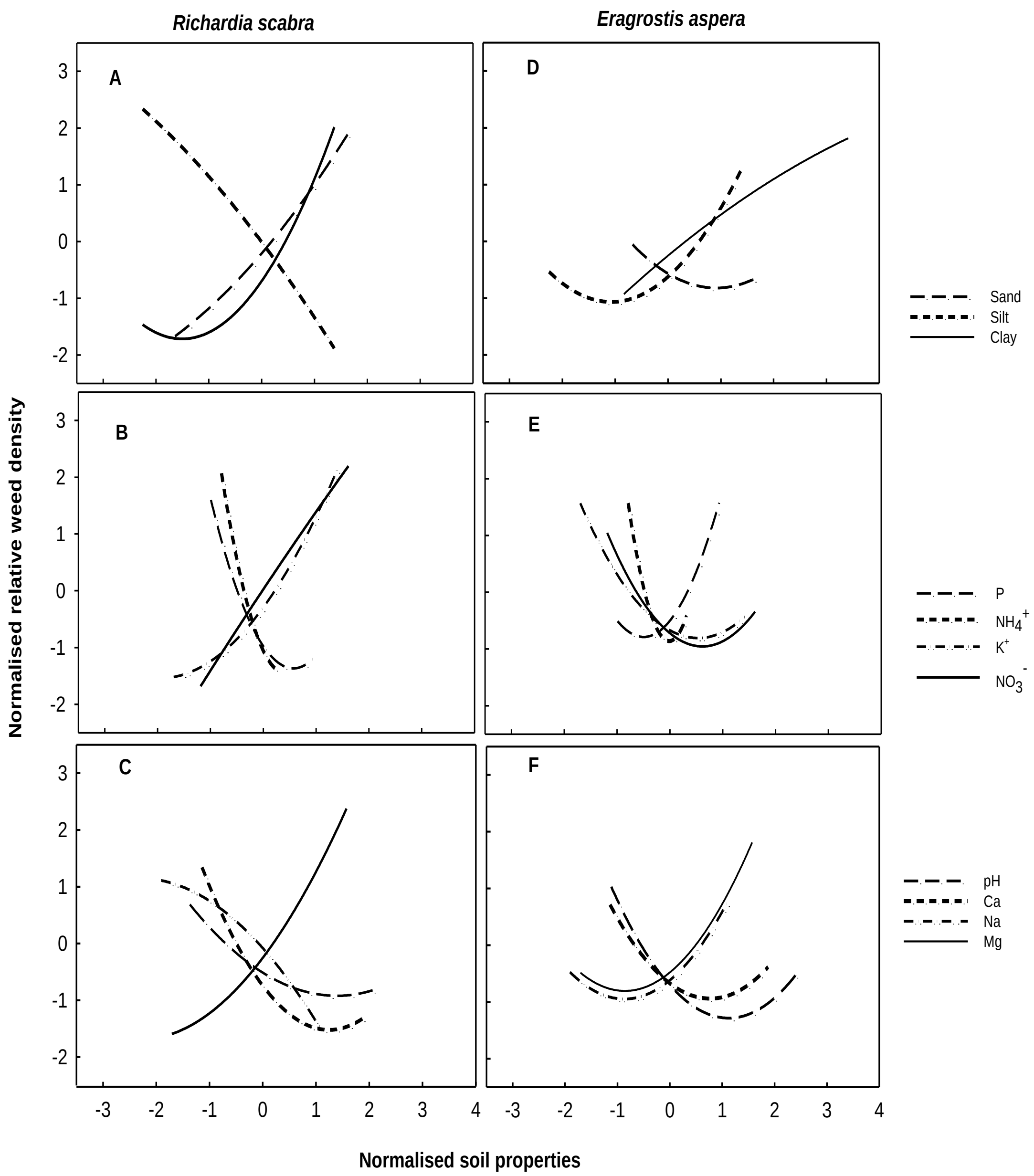

Figure 5.4 Relationship between the relative weed densities of *R. scabra* and *E. aspera* with soil properties in Kadoma Zimbabwe

Tridax procumbens L.

Tridax procumbens abundance was associated with clay soils; low proportion of silt and sand content (Figure 5.5A). High Na^{+} content also favoured its abundance. The data revealed that the abundance of *T. procumbens* was associated with very low NO_3^- <20 cmol kg $^{-1}$ (unnormilised value) content and any further increase in NO_3^- content up to 148 cmol kg^{-1} (unnormilised value) decreased its density. Its abundance also increased with an increase in P, whilst its density seemed to be penalised with a decrease in K^{+} and NH_4^{+} content in the soil (Figure 5.5B). The density of *T. procumbens* increased linearly with an increase in pH indicating its preference for alkaline soil conditions. Interesting to note was the Ca^{2+} which also increased proportionally with an increase in pH and its increase resulted in an increase of *T. procumbens* (Figure 5.5C).

Urochloa panicoides P. Beauv.

The densities of *U. panicoides* increased linearly with an increase in the proportion of clay in the soil (Figure 5.5D). *Urochloa panicoides* is associated with low and high Na^{+} content as shown by the hyperbola graph. The abundance of *U. panicoides* increased with an increase in P and NH_4^{+}. It was also associated with low K and NO_3^- but decreased as K and NO_3^- increased (Figure 5.5E). The density of *U. panicoides* was high in low sand content. Its density also increased with an increase in silt content in the soil. The density of *U. Panicoides* was associated with low pH, Ca^{2+}, Mg^{+} and alkaline conditions as shown by the 3 hyperbolas Figure 5.5F.

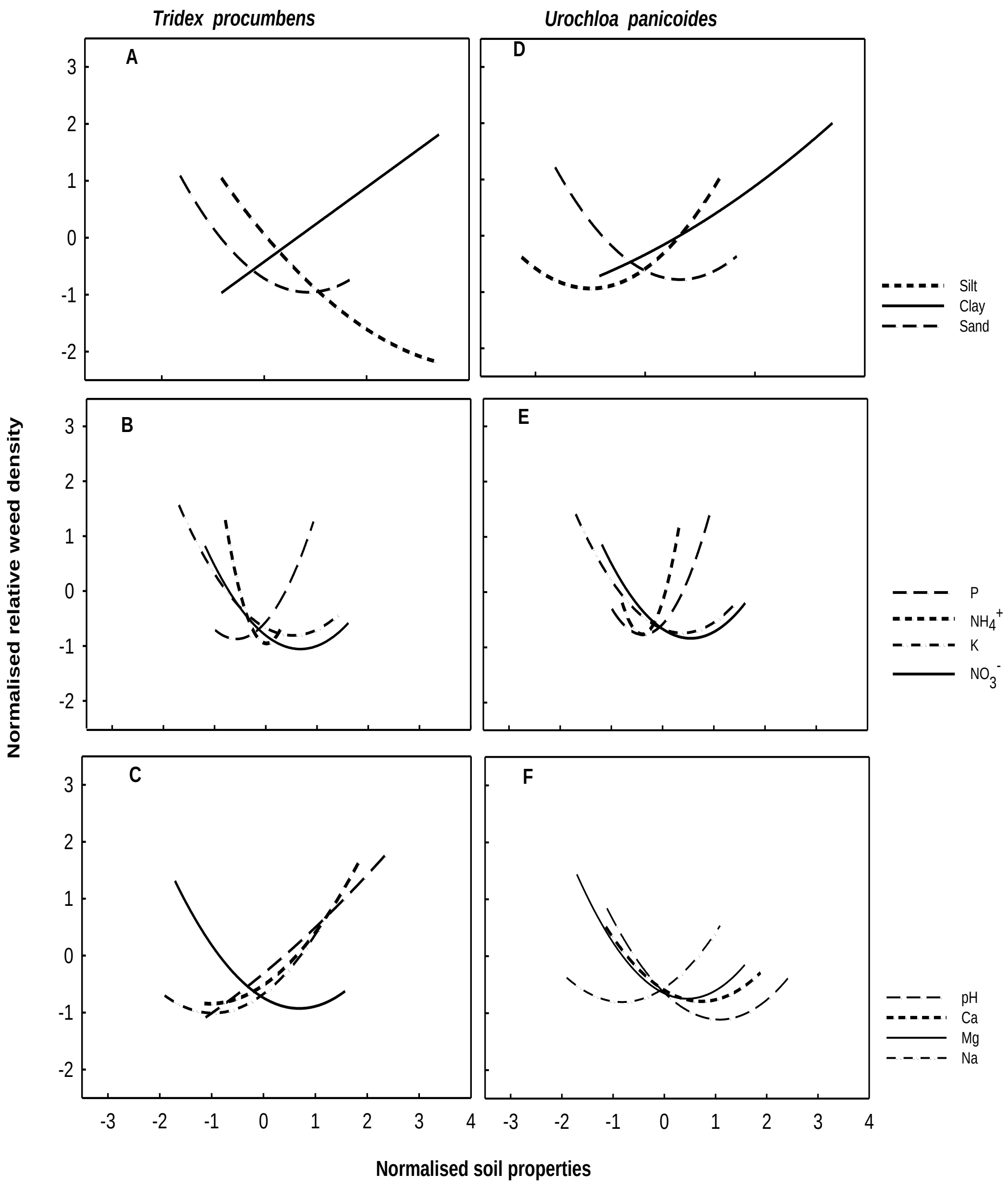

Figure 5.5 Relationship between the densities of *T. procumbens* and *U. panicoides* with soils properties in Kadoma, Zimbabwe

Bidens pilosa

Bidens pilosa was identified in 71 percent of the fields. The abundance of *B. pilosa* was associated with clay soils; however its abundance reached a plateau with clay proportions above 48 percent (Figure 5.6A). There was a negative slope for the relationship of silt and *B. pilosa* indicating that high silt was not favourable for its abundance. Its abundance was favourable in extreme > 149 cmol kg^{-1} and low < 20 cmol kg^{-1} (unnormalised values) NO_3^-, whilst intermediate content between 84.5 to 149 cmol kg^{-1}(unnormalised values) were not favourable for its abundance. The abundance of *B. pilosa* increased with an increase in P, K+ and NH_4^+ (Figure 5.6B).The abundance of *B. pilosa* decreased with an increase in Na^+ content (Figure 5.6C). Alkaline pH favoured the abundance of *B. pilosa*. Low Mg^+ favoured the density of *B. pilosa.*

Melinis repens (Wild.) Zizka

The relationship of the density of *M. repens* and silt content was represented by a negative slope indicating a decrease in weed density in silty soils (Figure 5.6D). *Melinis repens* abundance seemed to be associated with soil with a low proportion of clay and high sand content. The abundance of *M. repens* increased linearly with an increase in Na^+ levels in the soil (Figure 5.6F). High Ca^{2+} favoured high *M. repens* density. The relationship of *M. repens* with pH had a sigmoidal shape and reached a plateau in alkaline conditions. It seemed *M. repens* is not associated with high P content while high NO_3^- favoured its abundance. Its abundance also increased with an increase in NH_4^+ as shown by a straight linear relationship. There was a proportional relationship of Mg^+ and K and both nutrients increased the density of *M. repens* (Figure 5.6E).

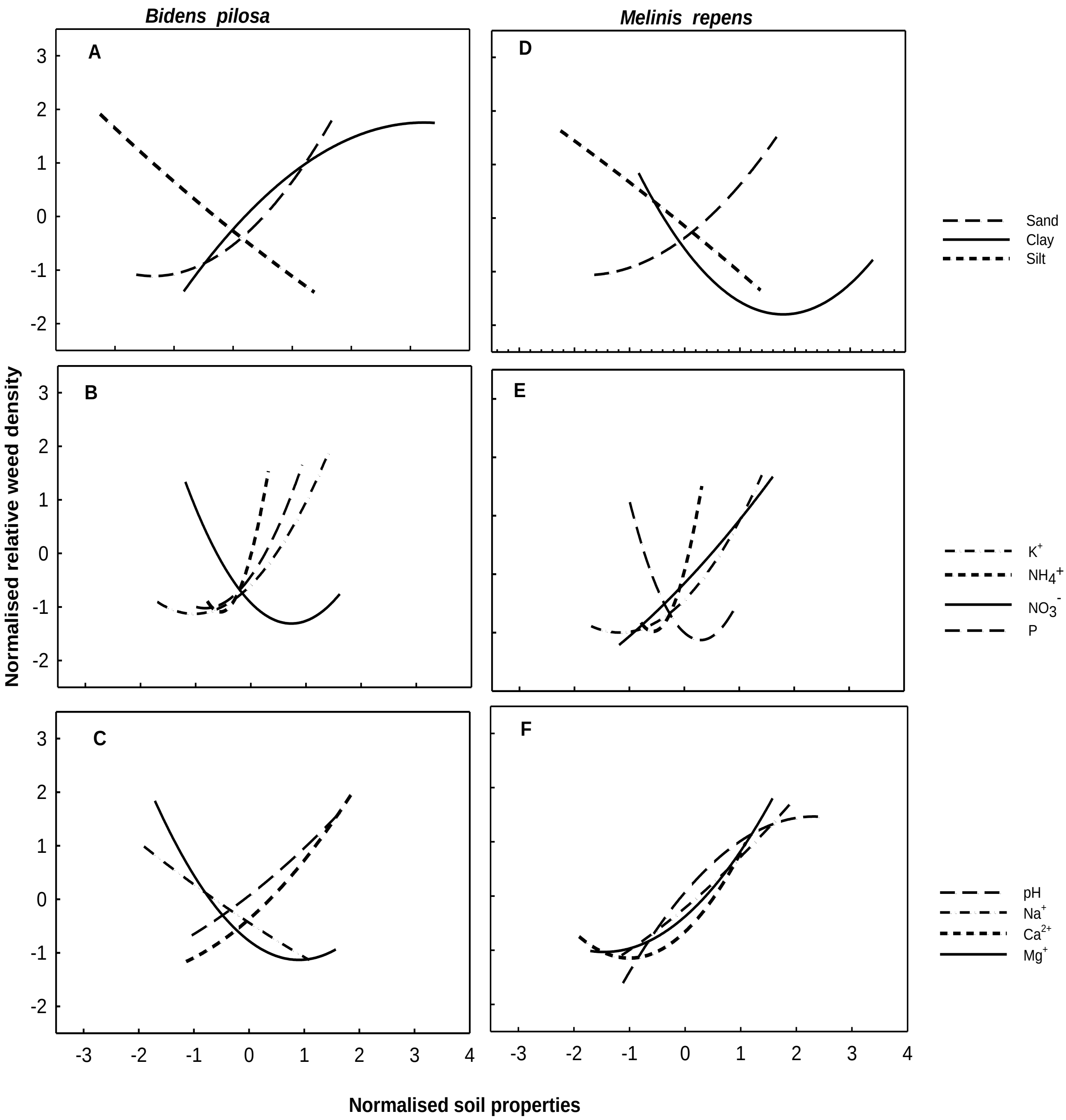

Figure 5.6 Relationship of *M. repens* and *B. pilosa* relative densities with soil properties in Kadoma Zimbabwe

5.4.4 Socio Economic and Management Factors on Weed Density

5.4.4.1 Socio-economic and Management Factors of Farmers

There was variation in the socio economic indicators and management factors on all the 18 selected farmers. Most (67 percent) of the farmers had never received formal training on crop production, while 33 percent had received some formal training on crop production (Table 5.3). Most (67 percent) of the farmers had access to off farm income which was mainly remittances from family members or selling of non farm produce. About 33 percent of the farmers had access to credit to purchase inputs from agro-chemical companies. Cattle ownership varied and ranged from 0 to 12 with an average of 4. Only 22 percent of the farmers had less than two cattle required to make a ploughing team. Most (78 percent) of the farmers had at least one implement for land preparation and the average implement ownership varied from 0 to 2. The area cultivated ranged from 1 to 5 ha with an average of 3 ha. Nearly half of the farmers (44 percent) did not use inorganic fertilisers. A considerable number of the farmers (39 percent) had used herbicides before in their fields. The available labour varied from 2 to 17 people and 39 percent of the households had less than 5 people available to provide labour for the farm operations.

Table 5.2 Socio-economic indicators and management practices for farmers in Kadoma, Zimbabwe recorded during 2009/2010 and 2010/2011 seasons

Field	Socio-economic indicators and management								
	Crop production skills	Capital	Access to credit	No. of cattle	No. of implements	Area cultivated	Use of inorganic fertilisers	Use of herbicides	Available labour
A	0	2	0	0	1	1	0	0	7
B	0	2	0	3	1	3	0	1	15
C	0	2	0	4	1	3	1	0	15
D	0	2	0	3	1	1	1	0	10
E	0	2	0	3	1	4	1	0	6
F	0	2	0	5	1	3	1	0	17
G	1	1	1	4	2	5	1	1	4
H	1	1	1	12	2	5	1	1	3
I	1	1	1	8	1	4	0	1	8
J	1	1	1	4	1	2	1	1	11
K	1	1	1	8	1	3	1	1	10
L	1	1	1	8	1	3	0	1	16
M	0	0	0	0	0	2	0	0	2
N	0	0	0	2	0	2	0	0	2
O	0	0	0	2	0	2	0	0	2
P	0	0	0	3	1	2	1	0	2
Q	0	0	0	1	1	2	0	0	4
R	0	0	0	1	0	2	0	0	2
Mean	0	1	0	4	1	3	1	0	8
Standard Deviation	0	1	0	3	1	1	1	1	5
Minimum	0	0	0	0	0	1	0	0	2
Maximum	1	2	1	12	2	5	1	1	17

5.4.4.2 Socio-economic and Management Factors Effects on Weed Densities and Composition

The relationship between socio-economic, management factors and weed densities is shown in the ordination diagram presented in Figure 5.4. The Eigenvalues of λ=1.05, λ=0.61 and λ= 0.35 were calculated for the first three Axes of PCA (Table 5.3). The 1st, 2nd and 3rd Axes accounted for 12, 8 and 5 percent of the variation extracted from the analysis, respectively (Table 5.4).

Table 5.3 Eigenvalues and variances of Principal Component Analysis of management factors

Axis	Eigenvalue	% Variance	Cumulative % of Variance	P*
1	1.10	12.07	12.07	0.01
2	0.65	8.73	20.80	0.03
3	0.53	5.42	26.22	0.11
4	0.28	8.26	34.48	0.99

* p-value for an axis is (n+1)/ (N+1), where n is the number of randomizations with an eigenvalue for that axis that is equal to or larger than the observed eigenvalue for that axis.

The first and the second Axes were significant at ($p<0.05$) hence the first two Axes were analysed further and were used to explain the variation of the relative weed density among the fields. The relationship between the ordination derived by the PCA and the quantitative variables are displayed by representing the variables as an arrow pointing in the direction of maximum correlation. The longer the arrow, the more highly related the variable is to species composition.

Figure 5.7 illustrates the relationship between socio-economic, management systems and weed communities. The access to social capital which involves income from off farm and non-farm activities had the greatest effect on weed density indicated by the longer arrow. It was also observed in this study that farmers who used inorganic fertilizers had high weed densities and weed species composition. Weeds such as *B. pilosa* and *U. panocoides* were high in fields where inorganic fertilizers were used.

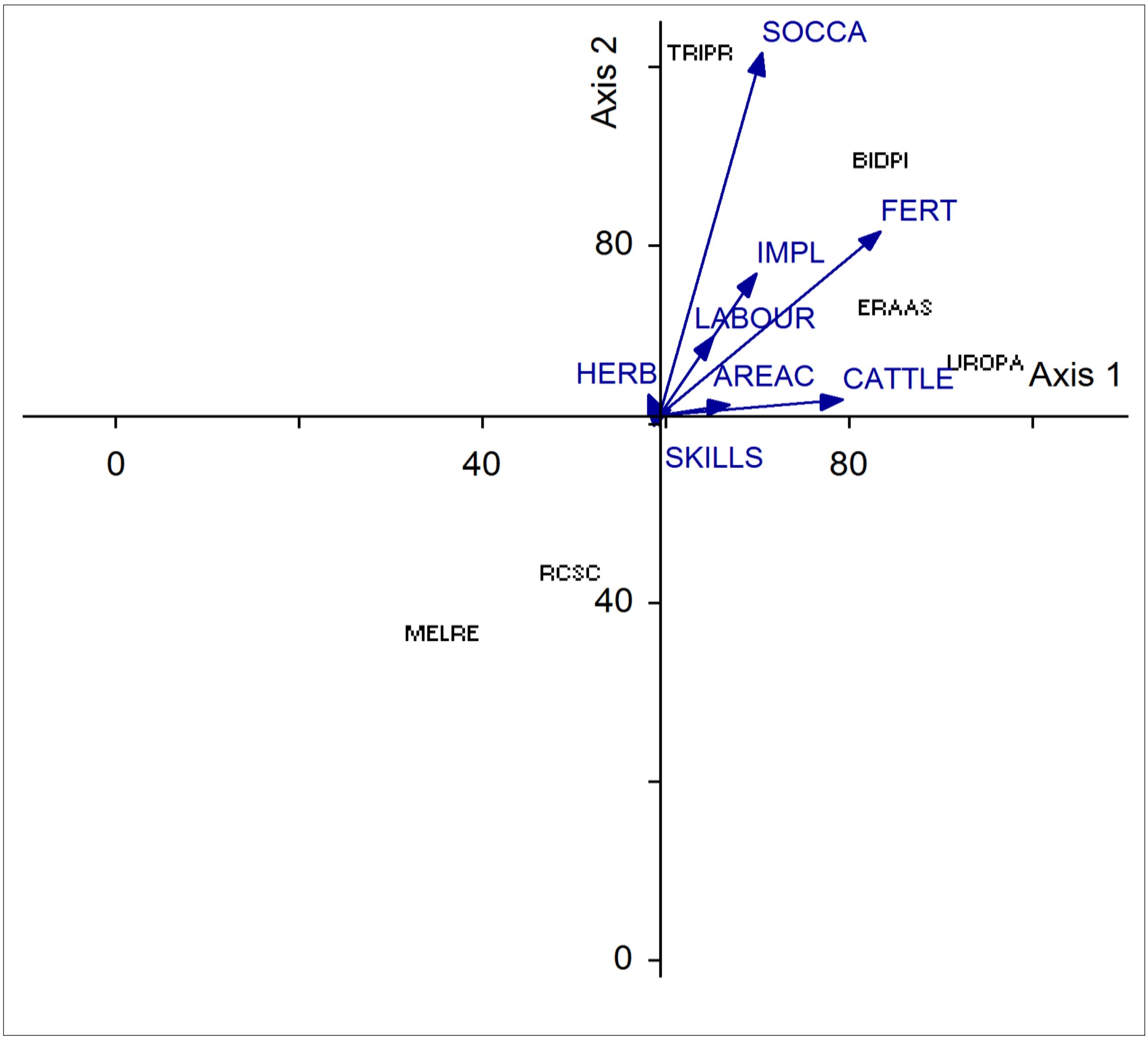

Figure 5.7 Biplot of PCA ordination with Axis 1 and 2 showing associations of weed communities and management factors**. (**IMPL) Implements, (FERT) Fertiliser; (AREAC) Area cultivated; (HERB) Herbicide, (SOCCA) Socio economic factors.

The use of cattle manure correlated with Axis 1 and also exhibited the third most important effect on weed density and distribution of *E.aspera* and *U. panicoides*. The study showed that available labour on the farms determines the density and composition of weeds. It was evident in this study that farmers with a shortage of labour had high weed densities while farmers with adequate labour had low weed densities. The availability of implements such as ox drawn ploughs and cultivators determined the weed composition and density of *B. pilosa* and *T. procumbens* as illustrated in Figure 5.7. The use of herbicides was represented by a short arrow near the centre, indicating a small effect on weed density and composition. The density of *M. repens* and *R. scabra* seemed not to be affected by socio-economic and management factors since all the arrows representing socio-economic and management pointed in opposite directions to the weed species.

5.4.5 Combined Effect of Soil Properties, Socio-economic and Management Factors on Weed Density and Composition.

The relationship of soil properties, socio-economic and management factors with weed species is presented in the 1st and 2nd axes in Figure 5.8 for 13 variables. Some of the variables for soil properties and management factors were eliminated by stepwise backward selection using a ($P < 0.05$) threshold for type I error. The ordination accounted for 32 percent of the total variation in the data set. The remaining variation were due to other factors which were not explained in the analysis. The correlation coefficients for the first 2 axis were 0.25, and 0.3, respectively. The 1st and 2nd axes accounted for 32 percent and 18 percent of variation extracted by the analysis, respectively. However the Monte Carlo simulations indicated that the variation of the relative densities accounted by Axis 1 was significantly related ($P<0.05$) to the soil properties, socioeconomic and management factors.

The most important predictor was capital followed by the use of fertilisers, number of impliments owned, cattle ownership, area cultivated, labour, proportion of (clay, sand, silt) and K^+ (Table 5.5).

Table 5.5 Gross and net effects of socio-economic and managemet factors influencing weed densities and composition in Kadoma, Zimbabwe

		Gross effect		Net effects			
Variable group	Variables	Explained variation	R^2_{adj}	Explained variation	R^2_{adj}	F	P value
S/M	Capital	1.220	0.816	2.094	0.666	0.630	0.020
S/M	Fertiliser	0.396	0.574	0.026	0.330	0.465	0.001
S/M	Implements	4.531	0.543	8.009	0.295	0.443	0.030
S/M	Labour	0.580	0.434	0.268	0.189	0.342	0.005
S/M	Cattle owned	3.137	0.418	8.575	0.174	0.326	0.005
S/M	Area cultivated	5.553	0.349	9.931	0.122	0.238	0.005
S	Sand %	0.534	0.285	1.007	0.081	0.207	0.005
S	Silt %	1.279	0.223	2.405	0.050	0.193	0.005
S	Clay %	0.245	0.201	0.433	0.040	0.178	0.015
S	pH	5.285	0.133	0.291	0.018	0.111	0.010
S	Ca^{2+}	4.266	0.041	3.029	0.002	0.103	0.005
S	K^+	1.977	0.043	4.083	0.002	0.074	0.005

S/M = socio economic and soil management properties; S=soil properties

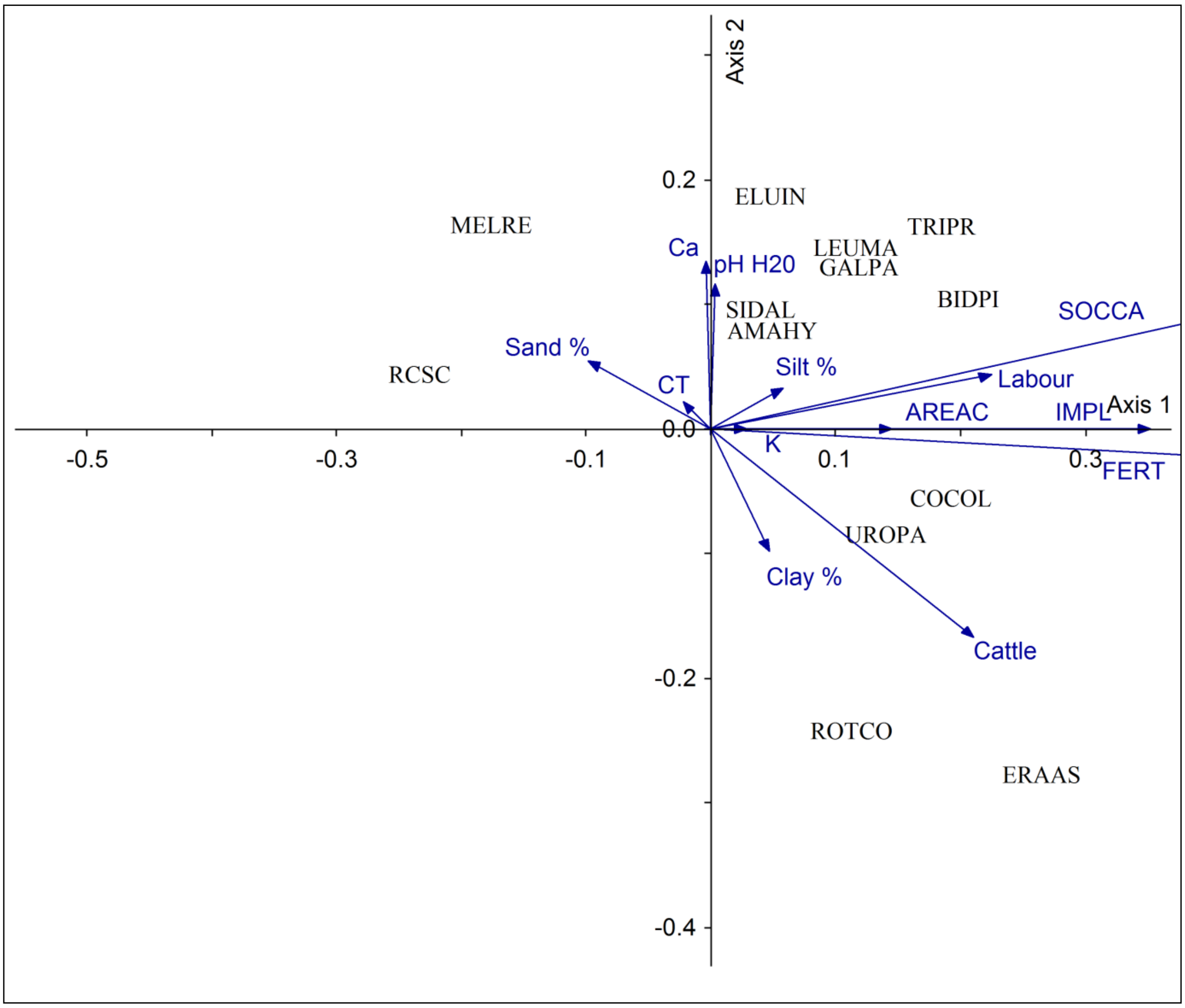

Figure 5. 8 Biplot of PCA ordination with Axis 1 and 2 showing associations of weed communities with soil properties socio economic and management factors. **(**IMPL) Implements, (FERT) Fertiliser; (AREAC) Area cultivated; (HERB) Herbicide.

5.4.6 Cluster Analysis of Fields under Planting Basins

Although heterogeneity in weed abundance was observed, some fields had similar weed densities and species composition which allowed the fields to be grouped according to the average relative abundance and weed species occurrence by cluster analysis. Analysis by hierarchical clustering showed that there were three clusters (groups) based on the weed species that occurred in the fields (Figure 5.9). The clusters were interpreted in relation to soil properties (Table 5.2) and management factors.

Table 5.6 Household categorisation and key socio-economic indicators for the three farm types identified in Kadoma Zimbabwe.

Farm characteristics	Farm type (Groups)				
	1	2	3		
	Well resourced	Medium resourced	Poorly resourced	P value	Significance
Area of fields (ha)	5	5	4	0.002	**
Area cropped (ha)	4.4	2.4	1.9	0.036	*
Training (courses) in agriculture crop production	1	0	0	0.061	NS
Knowledge of using herbicides	yes	yes	no	0.217	NS
Social capital	yes	yes	no	0.003	**
Access to credit facilities	yes	no	no	0.186	NS
Number of cattle	8	5	1	0.001	**
Number of Implements (ploughs)	2	1	1	0.000	***
Available Labour	5	13	3	0.002	**
Use of inorganic fertilisers	1	1	0	>0001	***

Significance * = P < 0.05; ** =P < 0.01; *** = P < 0.001; (ns) not significantly different at P < 0.05; (LSD) Least significant differences of means (5 % level).

Group 1 comprised of fields A, B, and E. The most abundance weed species were *T. procumbens* and *B. pilosa*. Group 1 was also unique in that it had low densities of weeds compared to Groups 2 and 3. The farmers in Group 1 were high resource endowed farmers (Table 5.6) and most of the farmers in this group used inorganic fertilisers, cattle manure, owned more implements and had more labour for weeding. The group is also characterised by farmers who are knowledgeable about use of herbicides and had general training in crop production.

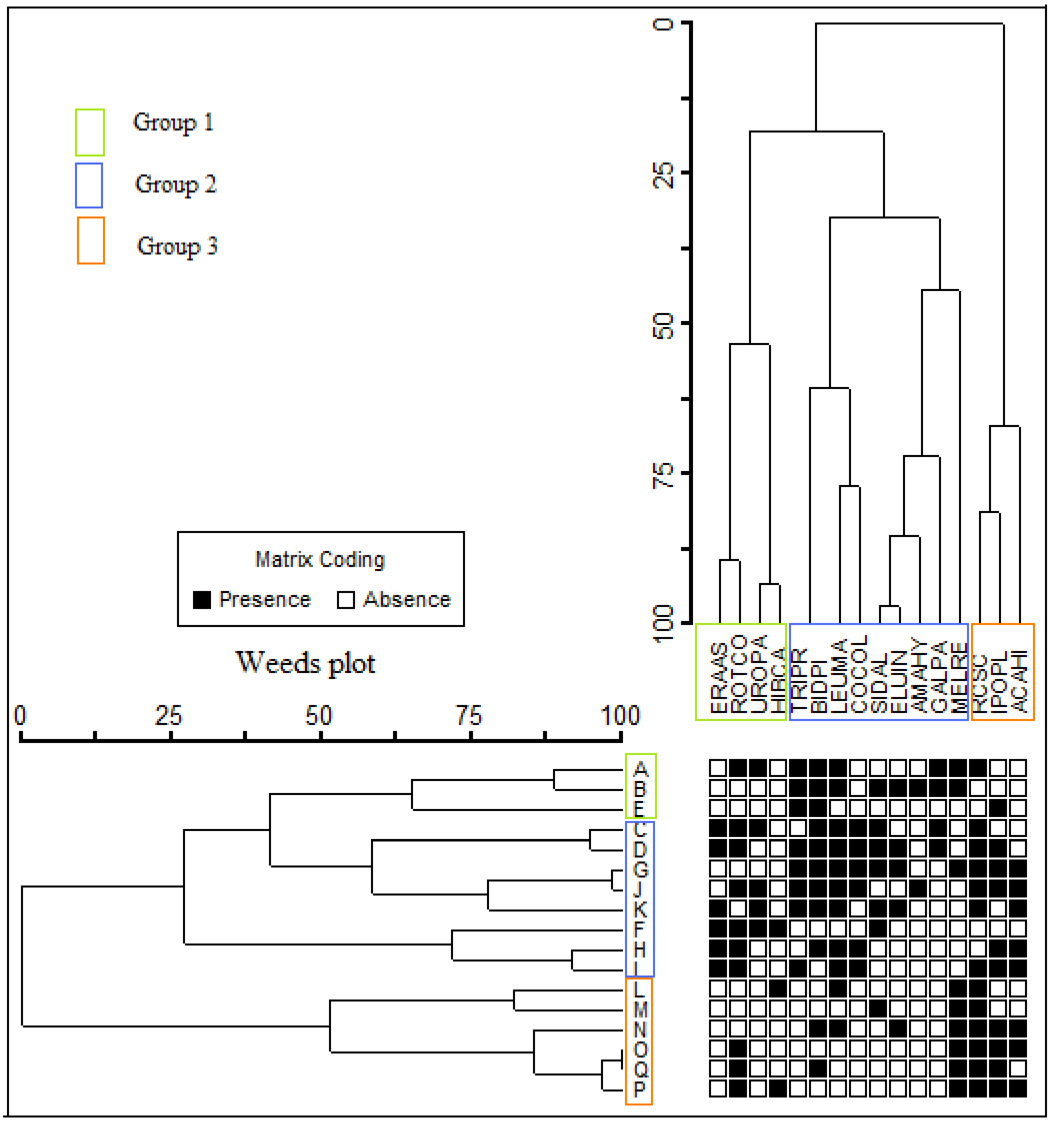

Figure 5.9 Dendrogram of the cluster analysis (Euclidean distance, complete linkage) of the weed species in farmers fields in Kadoma, Zimbabwe.

Group 2 consisted of fields C, D, G, J, K, F, H and I. The most dominant weed species in these fields were *E. aspera* L. and *Rottboellia cochinchinesis* L. The group is comprised of medium resource endowed farmers. The common weeds in Group 2 were also noted in Figure 5.7 to be related to fields where cattle manure and inorganic fertilisers were used particularly fields high in NO^-_3 and NH_4^+. The weed species in Group 2 were more diverse being represented by high species richness values as compared to Group 1 (Table 5.2).

Group 3 included fields L, M, N, O, P and Q. The dominant weeds were *M. repens* and *R. scabra.* All the farmers in Group 3 were poor resource endowed farmers (Table 5.7). Most of the farmers do not own cattle therefore the use of cattle manure was either minimal or absent.

5.5 DISCUSSION

The weed densities and composition across the sampled fields was heterogeneous. Consequently the variation in weed densities was attributed to variations in the soil properties, socio economic and management practices. These findings also concur with the results of Otto *et al*. (2007) that soil properties and management affects the weed distribution pattern and densities.

The soil properties investigated in this study had an influence on weed density. In addition, there seemed to be an interaction among the soil properties in determining the weed densities. Particular trends observed in this study relates to the presence of one soil property which would affect the proportion of other soil properties. For example with regard to an inverse relationship of clay and sand content in the soil, specific trends observed on the effect of soil texture pertain to an increase of the weed densities of *E. aspera*, *T. procumbens*, *B. pilosa* and *U. panicoide*s as the proportion of clay content increased in the soil. In the previous study Chapter 4, soils with higher proportion of clay (clay loams) resulted in higher weed densities in PB relative to CONV. Combining these two phenomenon's implied that the densities of *E. aspera*, *T. procumbens*, *B. pilosa* and *U. panicoide*s could be high under PB than in CONV in soils with higher proportion of clay. The relationship of *M. repens* with soil texture was contrary to *E. aspera*, *T. procumbens*, *B. pilosa* and *U. panicoide*s since its densities increased as the clay content decreased. These trends explain why some weeds were concentrated in specific fields. Some weed species preferred intermediate levels of soil properties. Consequently, the same weed was observed in fields with extreme and low levels of particular soil properties for example *B. pilosa* was associated with low (<20 cmol kg^{-1}) and high (>149 cmol kg^{-1}) levels of NO_3^-. The relationship of *E. aspera, T. procumbens, U. panicoides* and *M. repens* with NO_3^- was not expected as these weeds relative density was high when the levels of NO_3^- were low. This could have been due to the reduced competitive ability of the crop against the weeds in low nitrate levels. De Cauwer *et al.* (2010) also noted that nitrogen fertilisers alter weed species composition and influence weed crop competition.

The study also showed an effect of socio-economic and management practices on weed densities which underlined why some weed species varied in fields with the same soil properties. The first important predictor to explain the variance noted above was the availability of additional sources of capital inter alia remittance and non-farm income. Capital enabled the farmers to compliment the family labour force by hiring extra labour required for timely. Secondly, fields that used inorganic fertilizers to improve soil fertility resulted in high weed densities, relative to those that did not. This phenomenon was also detected by Sibuga and Nzuki (2007) who noted that increasing the fertility status of the soil stimulated weed growth and increased the diversity of weed species. Thirdly, the effect of using of cattle manure increased weed densities indicating that cattle manure may be a source of viable weed seeds. In a study by Svotwa *et al*. (2009) cattle manure contained more than 57 percent of viable weed seeds, hence farmers risked increasing the weed seed bank by applying manure directly to their fields. The fourth important predictor of weed species was availability of implements that determined the time of planting which had a bearing on weed development (Riches *et al*., 2000). The fifth predictor relates to the available labour on the farms, which influenced the timing of cultivation, sowing date, and timing of weeding which all affect the development of weed species (Pinke *et al*., 2011). The accessibility of ample labour for weeding allowed farmers to do timely and effective control of weeds (Leeson *et al*., 2003). Timely removal of weeds also prevented seed set and reduced seed return to the soil seed bank (Melandor *et al*., 2007). Ellis-Jones *et al*. (2001) noted that due to shortage of labour for weeding some SH farmers did not weed their crops.

It was evident in this study that farmers with a shortage of labour had high weed densities while farmers with adequate labour had low weed densities because they could carry out intensive weed management effectively. This is consistent with Pinke & Pal (2005) who posit that weeds are suppressed by intensive weed management. The result of the biplot showed that *R. scabra* and *M. repens* were both not associated with all management factors suggesting that the relative densities of these weeds could be influenced more by soil properties.

Overall the study showed that soil properties, socio economic factors and management practices were significant in influencing the density of weeds. Ranking in order of significance availability of capital, availability of implements followed by number of cattle owned, number of implements owned, use of fertiliser, labour, Ca^+, pH, clay, sand, silt, and K^+, influenced weed densities and composition. The socio-economic and management factors accounted for large proportion more than twice of the explained variation than soil properties and tillage and these findings concur with the findings of Pinke *et al.* (2012). In other studies, soil properties were more important than management factors (Otto *et al*., 2007).

This study showed that the changes of weed densities observed in CA (Muoni *et al*., 2013; Gruber *et al*., 2012; Chauhan & Opena, 2012; Mashingaidze *et al*., 2012; Chauhan & Johnson, 2009) are not only a response to tillage system; but tillage interacts with many other factors to determine weed densities and composition. Although, the distinct trends observed helped to explain the association of weeds with tillage, socio economic, management and soil properties, it was not possible to explain all the variation that existed on the data. The amount of variation in weed species explained by the study was 32 percent which was almost similar to Fried *et al*. (2008) (32.4 percent) and slightly lower than Tarmi *et al*. (2009). There are other sources of variation which were not explained in this study.

5.6 CONCLUSION

Differences in the abundance of weed species in sampled fields were influenced by soil properties, socioeconomic and management practices. The densities of *E. aspera*, *T. procumbens*, *B. pilosa* and *U. panicoide*s increased in response to an increase in proportion of clay in the soil while *M. repens* decreased. *Tridax procumbens* and *B. pilosa* had a positive linear relationship with pH. Overall, socio economic and management practices had greater effect on weed densities soil properties. There is need to explore further other factors which were not explained by data in this study since this information is important in developing weed management strategies in PB.

CHAPTER 6

EVALUATION OF CHEMICAL WEED CONTROL IN THE SMALLHOLDER FIELDS UNDER PLANTING BASINS

6.1 ABSTRACT

Despite the fact that weed management remains a major hindrance to crop production under Conservation Agriculture (CA), southern African countries promote it as a sustainable method of farming. The study evaluated the effects of weeding options on weed emergence, crop growth and yields under planting basins (PB) on 18 farms during 2009/2010 and 2010/2011 seasons. The experiment was set up as a split plot design with three replications on each farm. Tillage was the main plot (PB) compared to Conventional (CONV) and weeding option (hand weeding - compared to cyanazine, atrazine, glyphosate only and mixture of cyanazine + alachlor and atrazine + alachlor) as the sub-plots. The three clusters scaled within the high (Type 1), medium (Type 2) and poorly resourced farmers (Type 3) resource category was formed which used as a covariate on analysis to increase precision. The hand hoe weeded treatments had 49 percent higher weed densities in PB relative to CONV, and was statistically similar to the glyphosate treatment. On average the atrazine or cyanazine alone treatments had similar effects on weed control to cyanazine + alachlor and atrazine + alachlor treatments. The pre-emergence herbicides reduced the diversity indices in both tillage systems when compared to the hand hoe weeded treatment. The effectiveness of all pre-emergence herbicides were not influenced by tillage but were affected by farmers resource endowments. Maximum plant heights of 81.63 and 237.3 cm were recorded for pre-emergence herbicides under PB for cotton and maize, respectively. Minimum heights of 74.7 and 216.9 cm were recorded for the respective hand hoe weeded treatments for Farm Type 1. The hand hoe weeded treatments resulted in average cotton lint yield of 1497 and maize 2018

kg ha^{-1}. The pre-emergence herbicides treatments gave yields of 2138 and 2356 kg ha^{-1} of cotton and maize respectively. The higher weed densities in PB under hand weeded treatments underscored the need for other weeding options. Similarly, a mixture of cyanazine + alachlor in cotton and atrazine + alachlor in maize is recommended for suppressing broad leaf and grass weed populations and enhancing yields in PB systems.

Keywords: conservation tillage, herbicide mixtures, on-farm trial, weeding system

6.2 INTRODUCTION

Conservation Agriculture (CA) is being promoted as a sustainable method of farming that leads to increased yields and reduced soil erosion and labour requirements for land preparation (Govaerts *et al*., 2009). In Zimbabwe, a hand based hoe CA system has been widely promoted in the SH farming communities since 2004 (Marongwe *et al*., 2012). The central component of this package is the planting basin, which is a small hole dug with a hand hoe in which seeds are sown (ZCATF, 2009). The hand based CA system Planting basin (PB) a form of minimum tillage is particularly appropriate to southern Africa because the majority of SH farmers struggle to plant their fields on time due to lack of draught animals (Wall, 2007; Twomlow *et al*., 2008). Planting in basins occurs in November or December after the basins have captured rainwater and then allowed to drain naturally at least once (PRP, 2005; ZCATF, 2009). Smallholder farmers without animal draught power can plant soon after effective rains rather than waiting for draught animals to become available several weeks into the season. In addition, farmers are encouraged to spread crop residues as a surface mulch to cover at least 30 percent of the surface (Kassam *et al*., 2009; FA0, 2012).

Notwithstanding that CA could increase crop production for SH farmers, weed management, particularly in the early years of adoption (Mazvimavi & Twomlow, 2009), has been one of the primary production challenges for SH farmers adopting this system. Traditionally, tillage is used as a means of preparing a weed free seedbed. However, due to the absence of tillage in CA, the density of weeds would be expected to increase particularly early in the season (Johansen *et al*., 2012). Weed management has been one of the major factors that affect crop production in the SH farming sector even before the introduction of PB (Mandumbu *et al*., 2011). Early in the season, farmers often delay weeding to concentrating on planting, because of the limited labour (Makanganise *et al*., 2001). Most of the farmers would rather prefer to continue planting their fields as they take advantage of the moisture. Consequently, the delay in weeding often resulted in increased crop-weed competition for light, water, nutrients, space and some weeds may have some allelopathic effects (Meksawat & Pornprom, 2010). Crop yield losses under un-weeded conditions have been reported to be more than 30 percent in Zimbabwe (Rambakudzibga *et al*., 2002; Mashingaidze, 2004), and in Nigeria, between 55 to 90 percent for maize, and 80 percent for cotton (Ishaya *et al*., 2007). In Chapter 4 the estimated yield losses under PB were higher than CONV being represented by 5.91, 1.60 and 10.86 percent under PB for loamy, sandy loam and clay loam soils; the corresponding yields losses for CONV were 2.75, 1.40 and 6.80 percent under maize crop.

The predominant weed control practice on SH farms under PB is hand hoe weeding. Other methods of weed control, which include the use of ox drawn implements such as ploughs and tine cultivators are discouraged because they increase soil disturbance (Vissoh *et al*., 2004). Hand weeding consists of hand-pulling, hand slashing and hoeing of weeds. However, hand hoe weeding is slow and constitutes 50 to 70 percent of total labour time for SH farmers (Chikoye *et al.*, 2007). Hand hoe weeding is further slowed down in CA because of the higher weed densities (Muoni *et al*., 2013). Under PB, farmers would need to weed up to four times during the cropping season to ensure effective weed control (Mashingaidze *et al*., 2012). The increased weed density and labour requirements in PBexacerbate the labour shortfalls already pervassive in the SH farming sector. Rural-urban migration of young people, including to neighbouring countries, has affected the availability of labour required for hand hoe weeding within the SH farming communities.

Considering the numerous challenges faced by SH farmers on weed management, the use of the hand hoe as the only method of weed control in PB is not adequate to meet increased weed challenges. This underlines the need for other effective weed management options, which take into consideration the increased weed density and diversity in PB. The use of herbicides for weed control in addition to hand hoe weeding, could offer substantial benefits for the SH farming sector. Herbicides can reduce weed pressure and labour costs associated with weed control for the SH farmers. Herbicide usage may increase the capacity of SH farmers to effectively deal with weed pressure, especially during the critical weed free period and in wet conditions. Glyphosate and pre-emergence herbicides such as atrazine, cyanazine and alachlor have been used effectively in conventional tillage (CONV). However, the effectiveness of herbicides in PB in the SH sector has not been determined. The herbicides validated for use in CONV systems may be different in PB systems which have higher weed densities and a very different and diverse weed spectrum.

The objective of this study was to evaluate the effectiveness of herbicides under PB systems through their effect on weed emergence, crop growth and yield.

6.3 MATERIALS AND METHODS

6.3.1 Experimental Procedure

Field trials were conducted during the 2009/2010 and 2010/2011 cropping seasons in Kadoma, Zimbabwe. A cotton crop was planted during 2009/2010 followed by maize in the 2010/2011 season. The study area was described in Chapter 4 section 4.3.3.

The experiment was laid out as a split plot replicated three times at each farm. Tillage system was the main plot encompassing with two levels i.e. conventional (CONV) and PB. Weeding options represented sub plots as follows:

1) Hand hoe weeding at three, six and nine weeks after crop emergence (WACE) for both crops.
2) Cyanazine (2-(4-chloro-6-ethlyamino-1, 3, 5-triazin-2-ylamino)-2-ethlypropionitrile) at 4 kg a.i ha^{-1} for cotton and atrazine [2-chloro-4-(ethylamino) -6- (ospropylamino) s-triazine] for maize at 1.46 kg a.i ha^{-1}applied as pre-emergence herbicide.
3) Glyphosate ((glycin, N- (phosphomethyl)-D) $C_6H_{19}N_5S$) at 0.9 kg a.i ha^{-1} at planting followed by hand hoeing at 6 WACE for both crops.
4) Alachlor (2-chloro-N-(2, 6-diethylyphenyl)-N-(methoxymthyl) acetamide) 0. 960 kg a.i. ha^{-1} tank mixed with cyanazine at 4 kg a.i ha^{-1} applied pre-emergence for cotton and alachlor 0.960 kg a.i. ha^{-1} tank mixed with atrazine at 1.46 kg a.i ha^{-1}applied as pre-emergence herbicides for the maize crop.

The main plot size was 21.6 m * 6 m and the sub plot measured 6 * 5.4 m. A medium maturity cotton variety, Albar SZ 9314 and medium maturity maize variety, PGS61 were planted in all the 18 farmers' fields. The cotton crop was sown in rows 0.90 m apart and 0.3 m spacing within rows to give a population of 37 037 plants $ha^{-1.}$ Maize was sown at a spacing of 0.75 m between rows and 0.6 m within rows to give a population of 44 000 plants ha^{-1}. All farmers applied a basal fertiliser for maize (8N-14P-8K) and cotton (5N-8P-10K), at a rate of 200 kg ha^{-1}. A nitrogen fertiliser (34.5 % N) was split applied to both cotton and maize at a rate of 100 kg ha^{-1} at 6 and 9 WACE. All herbicides were applied with a knapsack sprayer that delivered 15 L spray solution through flat fan nozzles that evenly covered a swath width of 0.3 m. The spray volume was 200 L ha^{-1} and spray pressure was 250 kPa.

Weed seedlings were counted in three 0.35 m^2 quadrats placed diagonally in each sub plot. A method described by Barbour *et al*. (1987) was used to determine the number of quadrats required to obtain a representative sample in each plot. The weed densities were expressed as seedling density per square metre for each weed species. Weed species richness, evenness, and diversity were calculated for each treatment after Magurran, (1988) as shown below, Equation 1-3:

$$\text{Richness index} \quad R = \frac{S-1}{\text{Log N}} \tag{1}$$

$$\text{Eveness index} \quad E = \frac{1/(\lambda-1)}{e^{H-1}} \tag{2}$$

$$\text{Diversity index} \quad H' = \sum_{i=1}^{S} \frac{n_i}{N} \text{In} \frac{n_i}{N} \tag{3}$$

Where, S = total number of species; N = total number of individuals in a given area; n_i = number of individuals of the i^{th} species of the area; λ = the probability that two weed species taken at random from the sample represent the same type of weed species; H measures species diversity through proportional abundance of species, with a higher value signifying a more diverse community.

Yield assessment for cotton and maize were determined by measuring the cotton lint and maize grain weight from four middle rows of each net plot measuring 4 m. Maize grain yield was adjusted to standard moisture of 12.5 percent and cotton lint yield was adjusted to 14 percent moisture content.

6.3.2 Data Analysis

Before statistical analysis was performed on the weeds data, a Bartlett's test (Snedecor & Cochran, 1983) was carried out to determine the homogeneity of variances. A larger test statistic than the critical value indicated a need to transform the data to homogenise variances. Square root (x + 0.5) transformation was deemed appropriate for the data which had values less than 10 and zeros present. All the data was subjected to analysis of variance (ANOVA) using SAS procedures (SAS, 2010). The farmer groups (high, medium and low resourced were denoted as Farm Type 1, 2 and 3, respectively in the results section) that were based on farmer resource heterogeneity identified in Chapter 4 were used as covariates in the ANOVA to improve the precision of treatment comparisons. Standard error of difference (SED) was used for mean separation when treatments were significantly different ($P<0.05$).

6.4 RESULTS

6.4.1 Total Weed Density

6.4.1.1 Weed Density in Cotton

There was a significant ($P<0.05$) effect of weed control treatment and tillage on the total weed density (Figure 6.1). The herbicides effectively suppressed weed density at 3 WACE in PB and the lowest (7.06 weed seedlings m^{-2}) weed density was in the atrazine + alachlor treatment followed by the cyanazine (9.53 weed seedlings m^{-2}) alone treatment (Figure 6.1A). The hand hoe weeded plots in PB resulted in the highest (13.15 weed seedlings m^{-2}) weed density though it was statistically similar ($P>0.05$) to the plots applied with glyphosate only (11.16 weed seedlings m^{-2}). In CONV the hand hoe weeded treatment also resulted in the highest weed density (10.19 weed seedlings m^{-2}) and all the treatments applied with herbicides were statistically similar (P>0.05). When comparing the effect of weeding options under the two tillage systems, the hand hoe and the glyphosate weeding options in PB were less effective in controlling weeds relative to the same treatments in CONV. The effectiveness of cyanazine + alachlor and cyanazine alone treatment in PB were statistically similar (P>0.05).

At 6 WACE in PB, the highest weed density was observed in the hand hoe weeded treatment and it was statistically similar to the glyphosate treatment (Figure 6.1B). The atrazine + alachlor treatment had the lowest weed density followed by the cyanazine treatment. Similar results were observed in CONV where the hand hoe weeded treatment had the highest weed density and lowest weed density in cyanazine + alachlor and cyanazine only treatments. The weed densities in all the weeding options under both PB and CONV were statistically similar (P>0.05) at 9 WACE (Figure 6.1C)

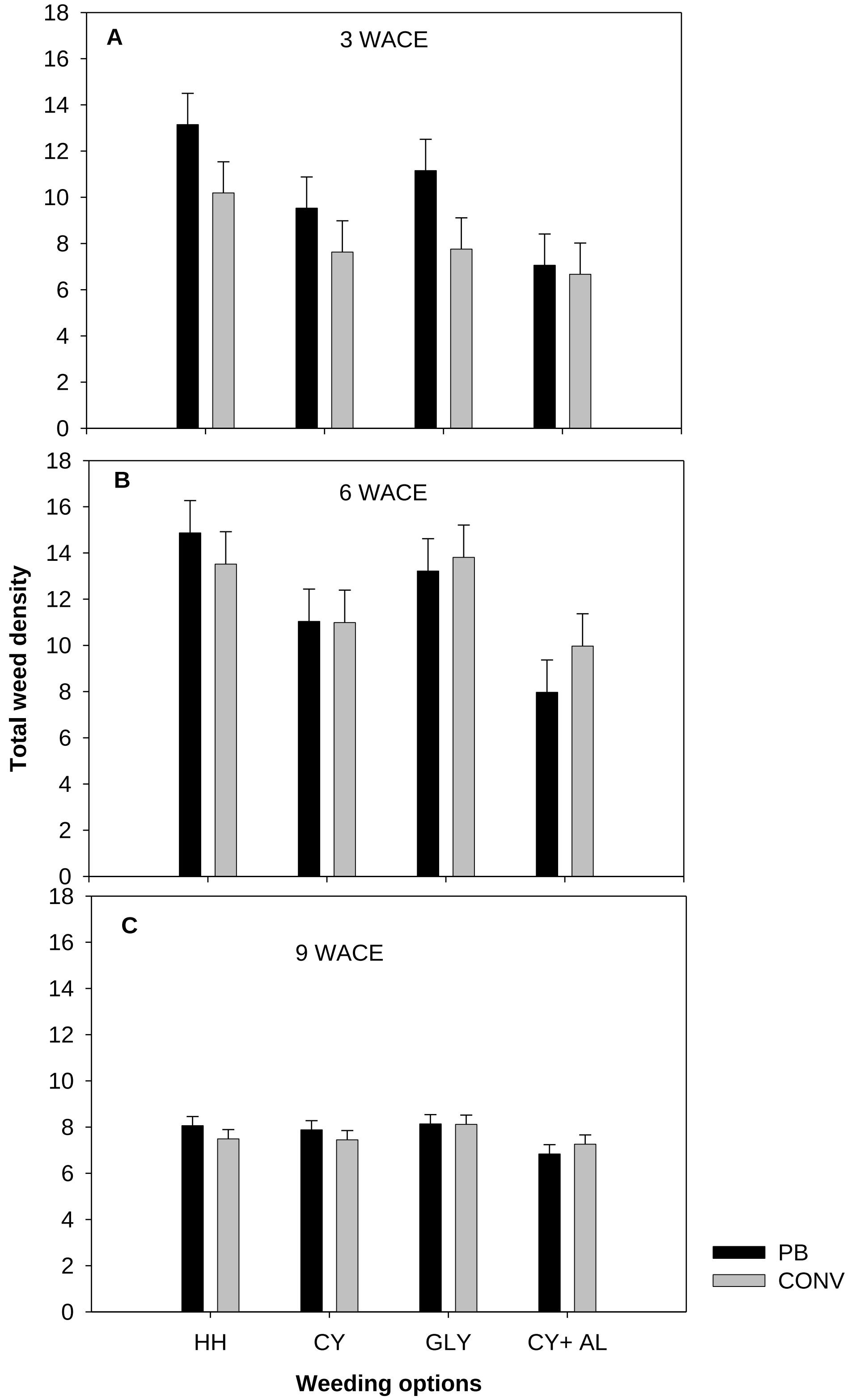

Figure 6. 1 Effect of tillage and weeding treatment on square root (x + 0.5) transformed weed densities data at 3, 6 and 9 weeks after crop emergence (WACE) during 2009/2010 season under cotton. Error bars represent ± SED; PB= Planting basin; CONV= Conventional Tillage; HH= hand hoe; CY=cyanazine; GLY=glyphosate, AL=alachlor; CY +AL = Cyanazine + Alachlor

6.4.1.2 Weed Density in Maize

At 3 WACE for maize under PB the weed densities for the plots, applied pre-emergence herbicides atrazine + alachlor (9.61 weed seedlings m^{-2}) and cyanazine only (8.91 weed seedlings m^{-2}) were statistically similar ($P>0.05$). The weed densities in the hand hoe weeded (12.06 weed seedlings m^{-2}) and the glyphosate treatment (11.93 weed seedlings m^{-2}) was also statistically similar (Figure 6.2A). Similarly, in CONV the pre-emergence herbicide applied treatments had similar effects and the hand hoe and glyphosate treatments were statistically similar ($P>0.05$). The hand hoe weeded treatments had higher weed densities than pre-emergence herbicide applied treatments. The hand hoe weeded treatment in PB had 19 percent higher weed densities than the hand hoe weeded treatment in CONV. The glyphosate treatment in PB had 17 percent higher weed densities relative to CONV. The pre-emergence herbicides had similar effects in both PB and CONV.

At 6 WACE, there was no significant difference on the weed density in PB and CONV for all the treatments (Figure 6.2B). In PB, the hand hoe weeded treatment (12.81 weed seedlings m^{-2}) had the highest weed densities whilst the atrazine + alachlor (8.66 weed seedlings $m^{-2)}$ had the lowest weed densities though it was statistically at par to the atrazine only treatment (10.15 weed seedlings m^{-2}). In CONV at 6 WACE, the hand hoe weeded treatment was statistically similar to the atrazine (10.59 weed seedlings m^{-2}) and the glyphosate treatment (11.34 weed seedlings m^{-2}). The atrazine + alachlor treatment (8.85 weed seedlings m^{-2}) were still effective in suppressing weeds at 6 WACE when compared to the hand hoe (12.10 weed seedlings m^{-2}) weeded plot indicated by the lowest weed density.

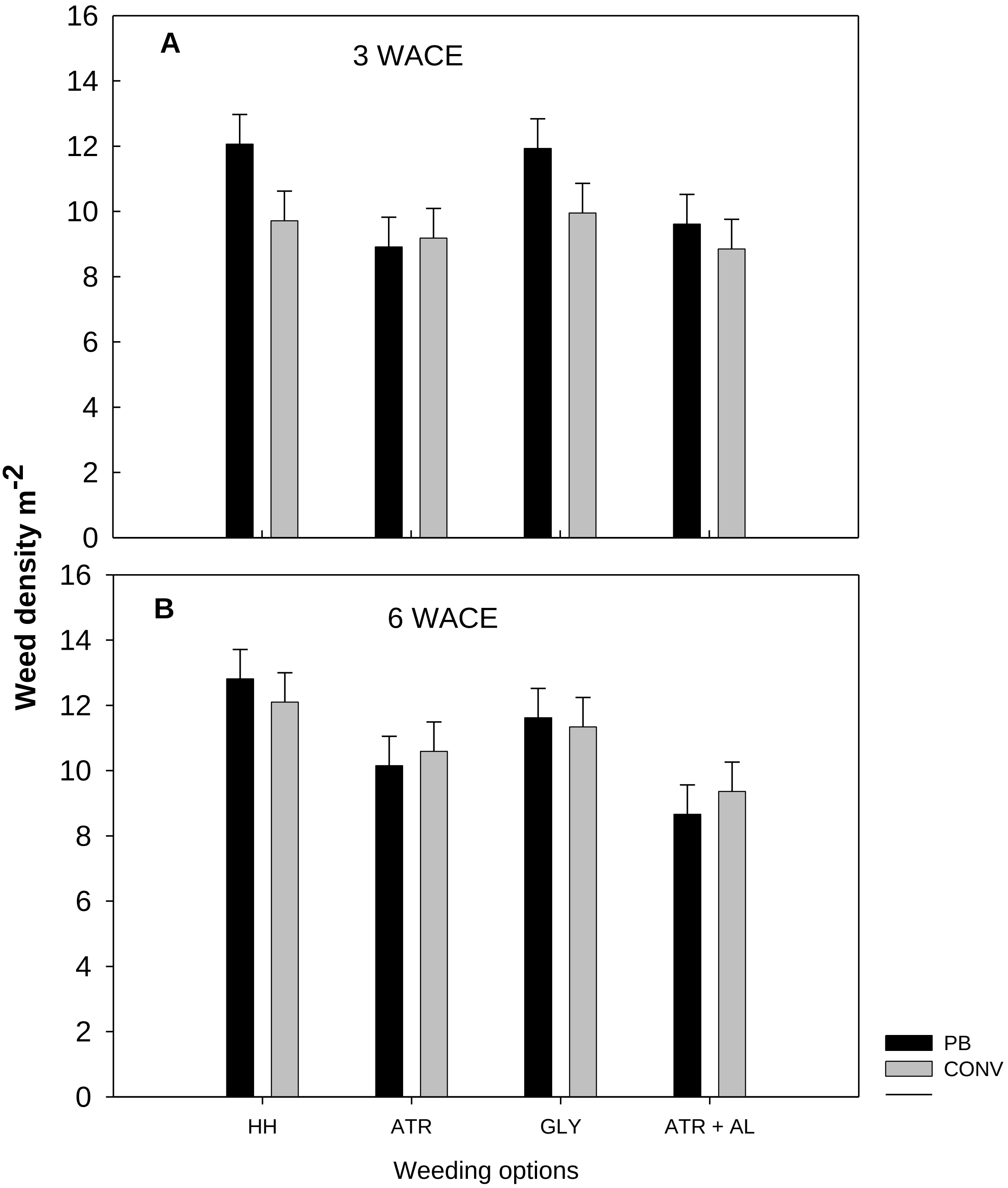

Figure 6. 2 Effect of tillage and weeding treatment on square root (x + 0.5) transformed weed densities data at 3 and 6 weeks after crop emergence (WACE) during 2010/2011 season under maize. Error bars represent ± SED; PB = Planting basin; CONV = Conventional Tillage; HH= hand hoe; ATR=Atrazine; GLY=glyphosate; AL=alachlor; ATR = atrazine; ATR +AL = atrazine + alachlor

6.4.2 Weed Diversity

Cotton

The weed diversity was significantly ($P<0.05$) influenced by weed control treatments (Figure 6.3A). The cyanazine + alachlor treatment reduced the weed diversity indices by 70 and 60 percent when compared to the hand hoe weeded treatments in PB and CONV, respectively. However, the weed diversity for the cyanazine + alachlor treatment did not differ with the cyanazine only treatment indicating that the cyanazine treatment had impact on the weed diversity. The pre-emergence herbicides had similar effects on weed diversity in PB and CONV whilst the hand hoe weeded and glyphosate treatments had higher diversity indices in PB relative to CONV. The evenness index was highest in the hand hoe weeded treatment, though it did not differ from the cyanazine only and the glyphosate treatment in PB. The cyanazine + alachlor treatment had the significantly lower weed diversity when compared to the hand weeded treatment in PB (Figure 6.3B). The response of all weed control options was not influenced by tillage expect for hand hoe weeded treatment which resulted in higher evenness indices in PB than in CONV. In PB, there was no effect of weeding treatment on the richness index while in CONV the cyanazine + alachlor treatment resulted in the lowest richness index (Figure 6.3C). The cyanazine + alachlor treatment in CONV did not allow some species to emerge resulting in the lowest richness index.

Maize

The diversity indices also showed a significant response to herbicide treatment in maize resulting in the lowest diversity indices in the atrazine + alachlor treatment though it was statistically at par with the cyanazine only (0.24) treatment in both tillage systems. The weed diversity index was highest in the hand hoe weeded treatment (0.93) though it was statistically similar ($P>0.05$) to the glyphosate treatment (0.79) (Figure 6.3). The weed diversity index in treatments applied with pre-emergence herbicides i.e. cyanazine + alachlor and cyanazine only did not differ between the tillage systems. The evenness index for the hand hoe weeded treatments was highest though it was statistically ($P<0.05$) similar to the glyphosate treatments in PB and CONV. The evenness indexes for all treatments were higher in PB than in CONV. The atrazine + alachlor treatment reduced the richness index significantly resulting in the lowest index in CONV, while in PB, it was lowest but it was similar to the rest of the treatments. Tillage had no influence on species richness.

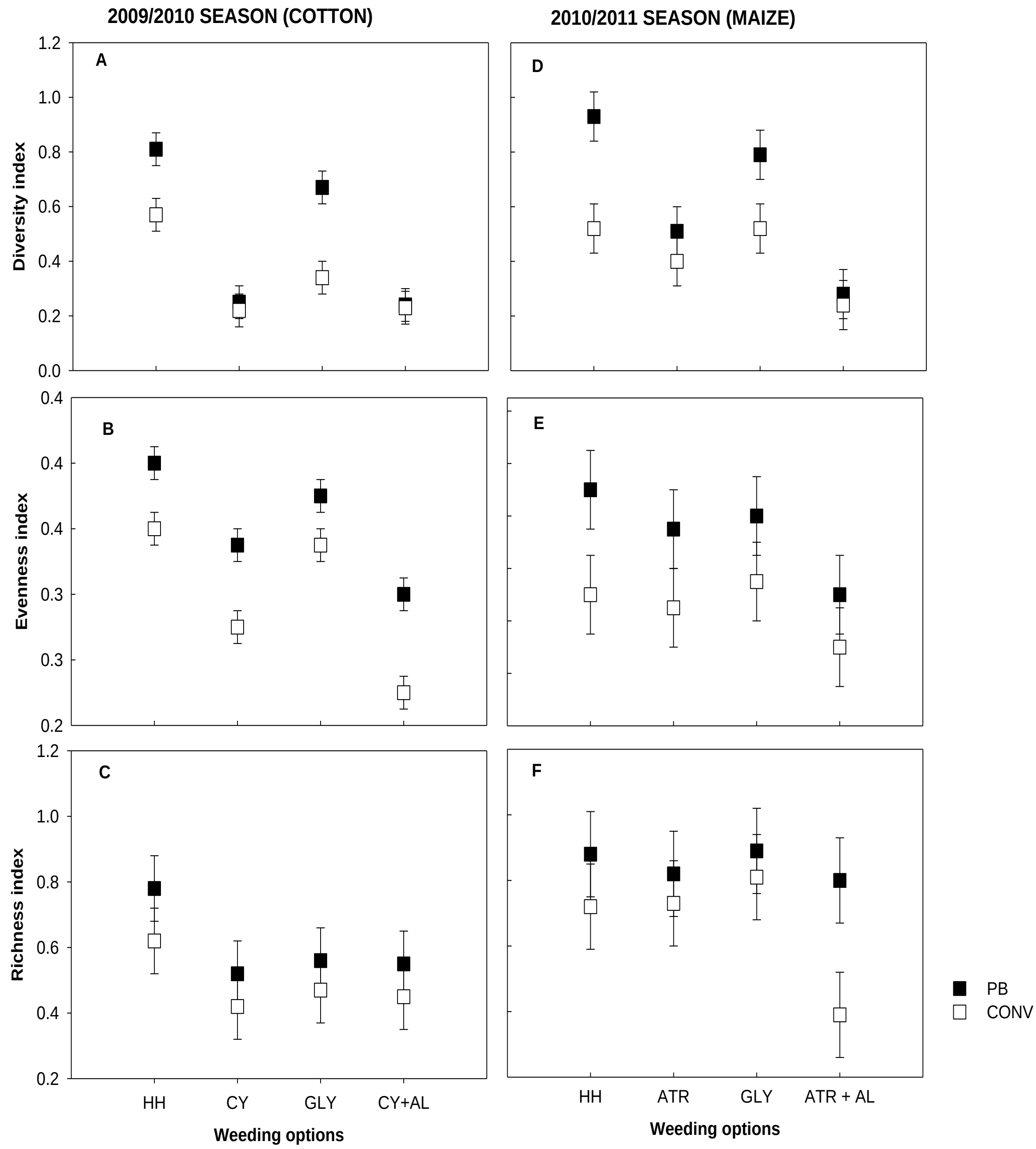

Figure 6.3 Effect of tillage, weeding treatment on diversity, evenness, and richness indices recorded during 2009/2010 and 2010/2011seasons. Error bars represent ± SED; HH= hand hoe; PB=Planting basin; (CONV) Conventional Tillage; CY=cyanazine; GLY=glyphosate; AL=alachlor; CY + AL= cyanazine + alachlor; ATR= atrazine; ATR + AL = atrazine + alachor

6.4.3 Farm Typologies and Weed Densities

6.4.3.1 Cotton

A further analysis of the weed density data with farm typology as a covariate in the ANOVA) revealed a significant ($P<0.05$) effect of the covariate on the weeding options. There were differential effects of weeding treatment on weed density among the farm typologies (Farm Type 1, 2 and 3) (Figure 6.4). More apparent effects of weeding treatment were observed in Farm Type 1 at 3, 6 and 9 WACE (Figure 6.4A, B and C). Under Farm Type 2, the effects of weeding treatments and tillage on weed densities were observed at 3 and 6 WACE (Figure 6.4D and E). Whilst, in Farm Type 3 significant ($P>0.05$) effect of weeding treatment were only observed at 3 WACE (Figure 6.4G).

During the 2009/2010 season, on Farm Type 1 at 3 WACE the cyanazine + alachlor applied treatment (3.94 weed seedlings m^{-2}) suppressed weed densities effectively and had the lowest weed densities though it was statistically similar ($P>0.05$) to the cyanazine applied treatment (3 weed seedlings m^{-2}) in PB (Figure 6.4A). The hand hoe weeded treatment (9.50 weed seedlings m^{-2}) resulted in the highest weed densities and it was statistically similar to the glyphosate treatment (9.04 weed seedlings m^{-2}). In CONV a similar trend was also observed were the glyphosate treatment (6.44 weed seedlings m^{-2}) was statistically similar ($P>0.05$) to hand hoe weeded treatment (5.34 weed seedlings m^{-2}), while cyanazine + alachlor treatment (2 weed seedlings m^{-2}) had similar effects to cyanazine only treatment (2.51 weed seedlings m^{-2}). The weed densities in the hand hoe weeded treatments under PB were 33 percent higher than the densities recorded in the same treatment under CONV. The weed densities under PB in the glyphosate-applied treatment were 39 percent higher than the glyphosate treatment under CONV. There was no significant difference on the weed densities in pre-emergence applied treatments under PB and CONV.

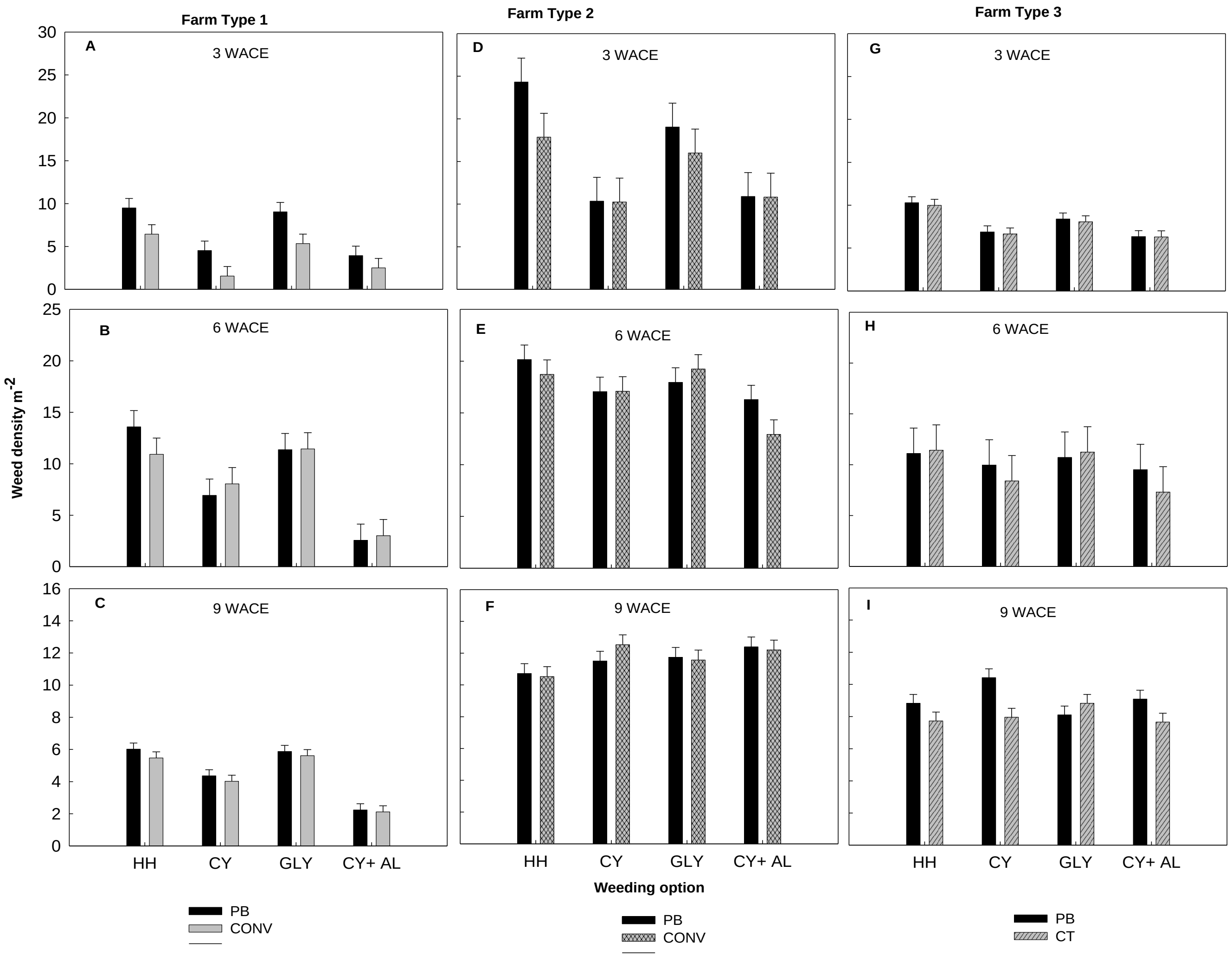

Figure 6. 4 Effect of tillage and weeding treatment on weed densities of square root (x +0.5) transformed data on three farm typologies recorded during 2009/2010 season under cotton. (WACE) = Weeks after crop emergence, Error bars represent ± SED; PB = Planting basin; CONV = Conventional Tillage; HH= hand hoe; CY=cyanazine; GLY=glyphosate; AL=alachlor; CY +AL = cyanazine +alachlor

At 6 WACE the hand hoe weeded treatment was not effective in weed control and resulted in the highest weed densities, secondly followed by glyphosate treatment and both of these treatments were statistically similar (Figure 6.4B). The third in ranking was the cyanazine only treatment and fourthly the lowest densities were recorded in the cyanazine + alachlor treatment (2.56 weed seedlings m^{-2}). In CONV, a similar trend was observed with the highest weed densities in the hand hoe weed treatment while the lowest density was recorded in the cyanazine + alachlor treatment. All the treatments had similar effects in PB and CONV.

The pre-emergence herbicides (cyanazine + alachlor and cyanazine alone) were still effective at 9 WACE in suppressing weeds and resulted in the lowest weed densities and the two treatments were both statistically similar (Figure 6.4C). The weed densities in the hand hoe weeded treatment in PB had similar effects to the same treatment in CONV and consequently resulted in the highest weed densities.

The results for Farm Type 2 during 2009/2010 season also showed higher weed densities at 3 WACE for hand hoe weeded plots in PB which were significantly ($P<0.05$) different from the pre-emergence herbicides applied treatments (Figure 6.4D). Whilst, in CONV at 3 WACE the hand hoe weeded treatment resulted in the highest weed density (17.85 weed seedlings m^{-2}) (Figure 6.4D). At the same time at 3 WACE in CONV the lowest weed density was observed for cyanazine + alachlor (10.83 weed seedlings m^{-2}) which was not significantly ($P>0.05$) different from cyanazine (10.25 weed seedlings m^{-2}) alone application. At 6 WACE, the cyanazine and cyanazine + alachlor treatments were still effective in suppressing weed densities and had the lowest weed densities, whilst there was no significant difference between the hand hoe, cyanazine and glyphosate treatments in both tillage systems (Figure

6.4E). The effectiveness of the herbicides was reduced at 9 WACE and all the treatments were statistically similar (Figure 6.4F).

In Farm Type 3 at 3 WACE the cyanazine + alachlor treatment suppressed weed densities by 38 and 37 percent in PB and CONV when compared to the hand weeded treatment (Figure 6.4G). The cyanazine alone treatment also suppressed weed densities and the weed densities were 34 and 33 percent lower than the hand weeded treatment in PB and CONV, respectively (Figure 6.4G). There was no significant effect of treatment observed at 6 and 9 WACE in Farm Type 3 (Figure 6.4H and I).

6.4.3.2 Maize

The results for 2010/2011 season also showed effective suppression of weed density with pre-emergence herbicides, which was dependant on the farmers' resources (Figure 6.5). On Farm Type 1 under PB the atrazine + alachlor treatments had the lowest weed density which was 69 and 53 percent lower than the hand hoe weeded treatment at 3 and 6 WACE, respectively (Figure 6.5A and B). In CONV, the atrazine + alachlor treatments were 59 and 73 percent lower than the hand hoe weeded treatment. The treatments applied pre-emergence herbicides were statistically similar at 3 and 6 WACE. The hand hoe weeded treatment also had similar effects with the glyphosate treatment at 3 and 6 WACE. There was a significant effect of tillage on the hand hoe weeded treatment where the treatment in PB had 32 percent higher weed density than relative to the CONV treatment 3 WACE. However, in the treatments applied pre-emergence herbicides there was no significant effect of tillage

In Farm Type 2 during 2010/2011 season at 3 WACE the lowest weed density (6.95 m^{-2}; 5.90 m^{-2}) was recorded in pre-emergence tank mixed herbicides (cyanazine + atrazine) in PB and

CONV, respectively (Figure 6.5C and D). On the other hand, the highest weed density was for hand hoe weeded treatment (10.74 and 10.71 m^{-2}) in PB and CONV, respectively (Figure 6.5C and D). The glyphosate treatment had the second highest weed density at 3 WACE and it was statistically similar to the atrazine only treatment in both tillage systems. There was no significant effect of tillage resulting in similar weed densities in PB and CONV at 6 WACE in all treatments.

The atrazine + alachlor treatment in Farm Type 3 during the 2010/2011 season resulted in the lowest weed density at 3 WACE. This was statistically similar to the atrazine only treatment in both tillage systems (Figure 6.5E). The effectiveness of hand hoe weeded and the glyphosate treatment were similar in both tillage systems. At 6 WACE in Farm Type 3, no significant ($P>0.05$) effect of treatment was observed in both tillage systems (Figure 6.5F).

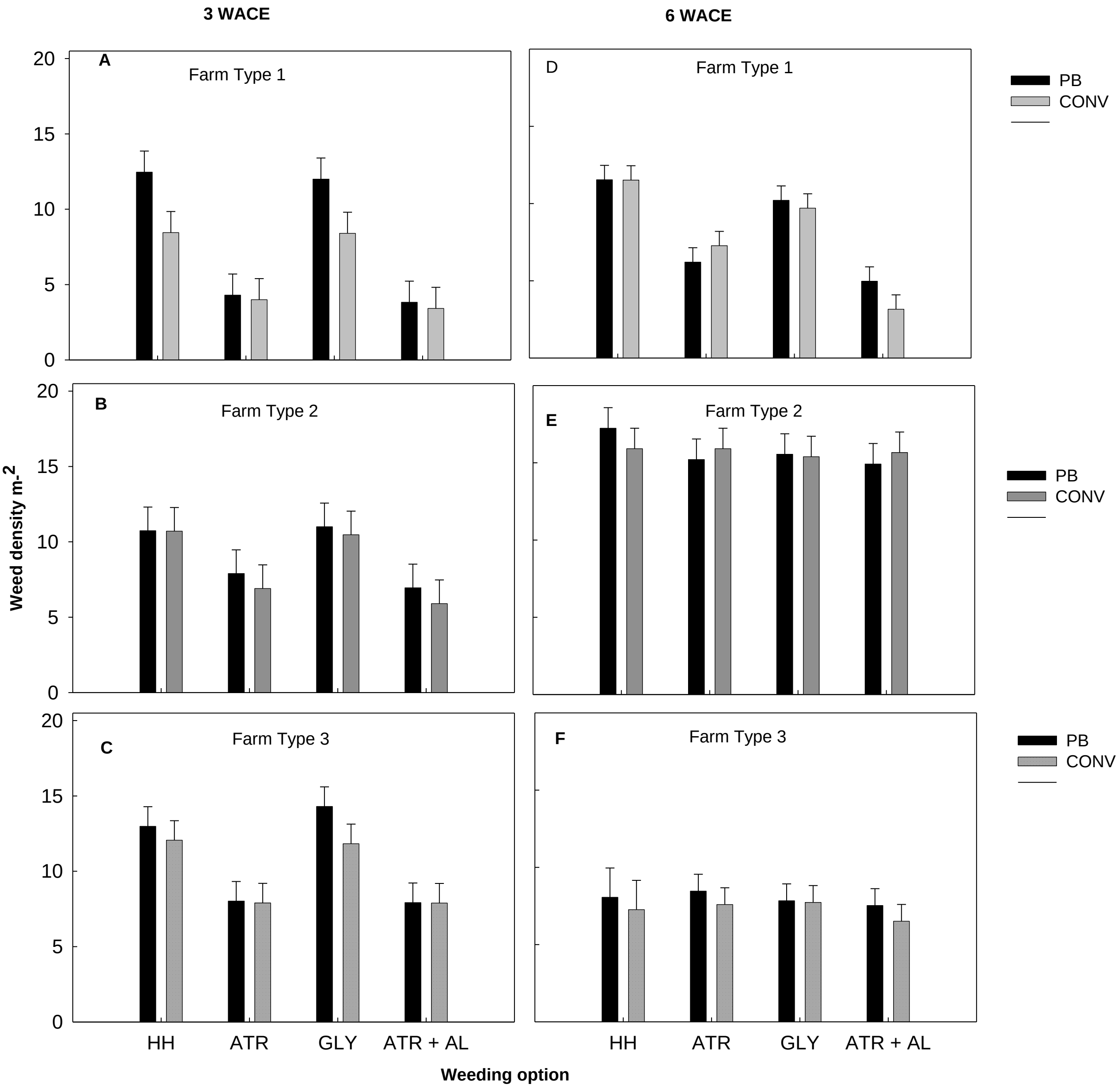

Figure 6. 5 Effect of tillage and weed control treatment on densities of 3 farm typologies during 2010/2011 season under maize. PB= Planting basin; CONV= Conventional Tillage; (WACE) = Weeks after crop emergence, Narrow bars represent ± SED; HH= hand hoe; ATR=atrazine; GLY=glyphosate, AL=alachlor; ATR = atrazine; ATR + AL = atrazine + alachlor

6.4.4 Individual Weed Species Density

Chapter 4 indentified 28 weed species that are common in the study area. However, the effect of tillage and weeding treatment on weed density was presented on six dominant weeds species as shown in Tables 6.1, 6.2, 6.3 and 6.4. The results presented in Table 6.1 and Table

6.2 are for Farm Type 1 at 3 and 6 WACE since apparent effects of treatment were observed in Type 1 Farms.

6.4.4.1 Cotton

The results presented in Table 6.2 are for the main effects because weeding * tillage was only significant (P<0.05) for *T. procumbens* at 3 WACE (Table 6.1). The weeding treatment * tillage interaction for *T. procumbens* at 3 WACE resulting in higher weed densities in the hand hoe weeded treatment under PB. The effectiveness of cyanazine + alachlor was statistically similar in PB and CONV for, *T. procumbens* (Table 6.2).During the 2009/2010 season at 3 WACE the weeding treatment significantly affected the weed densities for all the dominant weed species except for *R. scabra* (Table 6.1). The hand hoe weeded treatment was less effective in weed control evidenced by maximum weed densities when compared to all the other treatments (Table 6.2). In some instances the densities for the hand hoe weeded treatment was statistically similar to glyphosate treatment for example, *E. aspera*, *T. procumbens*, *B. pilosa*, at 3 WACE. The minimum weed densities were observed in cyanazine + alachlor treatments though the weed densities were statistically similar to cyanazine alone application for *E. aspera*, *B. pilosa*, and *T. procumbens* at 3 WACE.

The densities of *E. aspera*, *T. procumbens*, *M. repens* and *U. panicoides* at 3 WACE were significantly (P<0.05) affected by tillage (Table 6.1) and had higher densities weed densities in PB than CONV for hand weeded treatment (Table 6.2). At 6 WACE there was a significant effect of treatment for all the six dominant weeds (Table 6.1) and the highest density of weeds was observed in the hand hoe weeded treatment, which was significantly different from the cyanazine + alachlor treatment (Table 6.2). Tillage significantly affected the densities of *E. aspera, T. procumbens* and *M. repens* resulting in higher weed densities in PB than in CONV.

Table 6. 1 Analysis of Variance for weed densities at 3 weeks after crop emergence during 2009/2010 season under cotton

Source	DF	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Rep	2						
Tillage	1	**	**	ns†	ns	**	**
Residue	2						
Treatment (T)	3	**	***	ns	***	*	*
T* Tillage	3	ns	*	ns	ns	ns	ns
Residue	12						

*Significant at P<0.05; **Significant at P<0.01; ***Significant at P<0.001; †ns non significant

Table 6. 2 Analysis of Variance for weed densities at 6 weeks after crop emergence during 2010/2011 season under maize

Source	DF	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Rep	2						
Tillage	1	**	**	ns†	ns	*	ns
Residue	2						
Treatment (T)	3	*	**	**	*	***	**
T* Tillage	3	ns	ns	ns	ns	ns	ns
Residue	12						

*Significant at P<0.05; **Significant at P<0.01; ***Significant at P<0.001; †ns non significant

Table 6. 3 Effect of tillage systems and weed control treatments on weed density during 2009/2010 season under cotton

			3 weeks after crop emergence			
Weeding treatment	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Hand hoe	2.38a	1.49a	2.99a	2.42a	1.88a	1.01a
Cyanazine	1.85b	1.15b	2.88a	1.76b	1.86a	0.90ab
Glyphosate	2.31a	1.48a	2.70a	2.17a	1.99a	0.94ab
Cyanazine+ Alachlor	1.78b	1.11b	2.64a	1.80b	1.22b	0.84b
P -value	P<0.01	P<0.001	P>0.05	P<0.001	P<0.05	P<0.05
$LSD_{(0.05)}$	0.31	0.18	ns	0.29	0.51	0.12
Tillage						
PB	2.20a	1.40a	2.83a	2.10a	1.92a	0.98a
CONV	1.91b	1.22b	2.77a	1.97a	1.54b	0.86b
P -value	P<0.01	P<0.01	P>0.05	P>0.05	P<0.05	P<0.01
$LSD_{(0.05)}$	0.22	0.13	ns	ns	0.37	0.09
			6 weeks after crop emergence			
Weeding treatment	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Hand hoe	1.82a	1.65a	2.27a	2.09a	1.80a	1.34a
Cyanazine	1.16b	0.96b	2.09a	1.37b	1.05b	0.89b
Glyphosate	1.46ab	1.49a	2.06a	2.03a	2.22a	1.40a
Cyanazine+ Alachlor	1.05b	0.98b	1.04b	1.27b	0.91b	0.83b
P -value	P<0.05	P<0.01	P<0.05	P<0.05	P<0.001	P<0.01
$LSD_{(0.05)}$	0.53	0.41	0.68	0.54	0.57	0.37
Tillage						
PB	1.67a	1.46a	2.04a	1.74a	1.72a	1.23a
CONV	1.06b	1.08b	1.69a	1.64a	1.27b	0.99a
P- value	P<0.05	P<0.01	P>0.05	P>0.05	P<0.05	P>0.05
$LSD_{(0.05)}$	0.38	0.29	ns[†]	ns	0.40	ns

Square root (x + 0.5) transformed data presented; [†]ns: not significant

6.4.4.2 Maize

During 2010/2011 season at 3 WACE, all the dominant weeds were significantly ($P<0.05$) suppressed by pre-emergence herbicides (Table 6.2). The interaction of weeding treatment x tillage was significant for *T. procumbens* and *U. panicoides* at 3 WACE with highest densities of weeds in the hand hoe weeded treatment (Table 6.3). The hand hoe weeded treatment in PB was not effective in suppressing all dominant weeds as indicated by the highest density of weeds (Table 6.4). The atrazine + alachlor treatment resulted in lower weed densities in PB when compared to the hand hoe weeded treatment. The effect of tillage was significant for *B. pilosa* and *U. panicoides* resulting in 24 and 22 percent higher weed densities in PB than in CONV, respectively. The weeding treatment * tillage was significant for *T. procumbens* and *U. panicoides* and the hand hoe weeded treatment had the highest weed densities under PB.

At 6 WACE there was a significant ($P<0.05$) effect of weeding treatment on all the dominant weeds (Table 6.2). The atrazine + alachlor was more effective in weed control when compared to the hand hoe weeded treatment as indicated by lower weed densities in the atrazine + alachlor treatment (Table 6.4). *Eragrostis aspera*, *R. scabra*, *B. pilosa* and M. *repens* were effectively controlled by atrazine + alachlor treatment than the atrazine only as indicated by the lowest weed densities in the atrazine + alachlor treatment. The atrazine + alachlor treatment had similar effect on weed control to atrazine only for *T. procumbens*, *E. aspera* and *U. panicoides*. *Eragrostis aspera* and *M. repens* had 31 percent and 37 percent higher weed densities in PB than in CONV, respectively.

Table 6. 4 Effect of tillage systems and weed control treatments on weed density during 2010/2011 season under maize

			3 weeks after crop emergence			
Weeding treatment	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Hand hoe	1.68a	2.16ab	1.84a	4.03a	0.87a	5.50a
Atrazine	1.18ab	1.57bc	1.59ab	2.24a	0.73b	3.55b
Glyphosate	1.52a	2.54a	1.82a	2.39a	0.77ab	4.61ab
Cyanazine + Alachlor	0.84b	1.28c	1.27b	1.55a	0.71b	2.38c
P -value	P<0.05	P<0.01	P<0.05	P<0.01	P<0.05	P<0.001
$LSD_{(0.05)}$	0.55	0.72	0.35	0.87	0.13	1.14
Tillage						
PB	1.34a	2.04a	1.64a	2.90a	0.79a	4.50a
CONV	1.28a	1.73a	1.62a	2.21b	0.74a	3.52b
P- value	P>0.05	P>0.05	P>0.05	P<0.05	P>0.05	P<0.05
$LSD_{(0.05)}$	ns	ns	ns			0.81
			6 weeks after crop emergence			
Weeding treatment	*Eragrostis aspera*	*Tridax procumbens*	*Richardia scabra*	*Bidens pilosa*	*Melinis repens*	*Urochloa panicoides*
Hand hoe	2.33a	1.38ab	2.27a	2.83a	5.24a	0.97a
Atrazine	1.87ab	1.07bc	2.09a	2.05ab	3.03ab	0.71b
Glyphosate	1.60b	1.47a	2.06a	1.87b	3.80b	0.81ab
Atrazine + Alachlor	1.71ab	0.86c	1.04b	1.62b	2.06c	0.71b
P-value	P<0.05	P<0.05	P<0.05	P<0.05	P<0.001	P<0.05
$LSD_{(0.05)}$	0.62	0.40	0.68	0.79	0.80	0.17
Tillage						
PB	2.19a	1.23a	2.04a	2.34a	4.34a	0.83a
CONV	1.55b	1.16a	1.69a	1.84a	2.74ba	0.76a
P -value	P<0.01	P>0.05	P>0.05	P>0.05	P<0.05	P>0.05
$LSD_{(0.05)}$	0.44	ns[†]	ns	ns	1.14	ns

Square root (x + 0.5) transformed data presented; [†]ns: not significant

6.4.5 Plant Height and Crop Yields

6.4.5.1 Cotton

During the 2009/2010 season the weeding treatment significantly (P<0.05) affected the cotton plant heights (Table 6.5). The interaction of treatment * weeding treatment was not significant P>0.05) on plant heights and therefore the main effects are presented in Table 6.6. The cyanazine + alachlor treatment resulted in the maximum plant heights which were 12 percent higher than those for the hand hoe weeded treatment. The plant heights for the cyanazine treatment were statistically similar (P>0.05) to the cyanazine only treatment. The hand hoe weeded treatment was also statistically similar (P>0.05) to the cyanazine applied treatment. Tillage significantly (P<0.05) influenced the plant heights and resulted in 10 percent higher plants in PB than in CONV.

Table 6. 5 Analysis of variance for plant heights and yields

Source	DF	2009-2010 Plant height	2009-2010 Cotton lint yield	2010-2010 Plant height	2010-2010 Maize grain yield
Rep	2				
Tillage	1	***	ns	***	**
Residual	3				
Treatment	3	***	**	**	**
Tillage * Treatment	3	ns	ns	*	ns
Residual	12				

*Significant at P<0.05; **Significant at P<0.01; ***Significant at P<0.001; †ns non significant
DF= Degrees of freedom

The cotton lint yields were significantly (P<0.05) affected by the weeding treatment Table (6.5). The effective suppression of weeds by cyanazine + alachlor treatment resulted in the highest cotton lint yields which were 26 percent higher than the hand hoe weeded treatment (Table 6.6).

The second highest yields was observed in the cyanazine only treatment though it was statistically similar (P>0.05) to the glyphosate and the hand hoe weeded treatment. The yields obtained for PB and CONV were all statistically similar (P>0.05).

Table 6. 6 Effect of tillage system and weeding treatment on cotton plant heights, and lint yields during 2009/2010 in Kadoma, Zimbabwe

2009/2010 season cotton		
	Plant height (cm)	Cotton lint Yield kg ha^{-1}
Weeding treatment		
Hand weeding	74.76b	1496.60b
Cyanazine	82.63a	1728.7b
Glyphosate	77.53b	1619.7b
Cyanazine +Alachlor	84.63a	2018.50a
P value	P<0.001	P<0.01
$L.S.D_{(0.05)}$	2.2	186.9
Tillage		
PB	84.07a	1716.99a
CONV	75.72b	1714.76a
P value	P<0.001	P>0.05
$L.S.D_{(0.05)}$	3.12	†ns

†ns= not significant

Maize

The plant heights for maize crop were significantly (P<0.05) affected by the weeding treatment*tillage interaction (Table 6.6b). There was a significant (P<0.05) effect tillage for the hand hoe weeded, atrazine and glyphosate treatment which resulted in higher plants in the PB plots. The atrazine + alachlor treatment had statistically similar plant heights in PB and CONV tillage systems Table 6.6b.

Table 6. 7 Effect of tillage system and weeding treatment on maize plant heights during the 2010/2011 season, Kadoma, Zimbabwe

	Plant heights 2010/2011 seasons			
	Weeding treatments			
Tillage	Hand hoe	Atrazine	Glyphosate	Atrazine + Alachlor
PB	252.6a	257.5a	254.6a	252.2a
CONV	246.6b	240.42b	248.4b	255.9a
L.S.D.	4.9			

The average plant heights across all weeding treatments and tillage revealed highest plant height of 319.7 cm for atrazine + alachlor treatment for Farm Type 1 in PB (Table 6.6a). The hand hoe weeded treatment for Farm Type 3 had the lowest plant height (198.47 cm) in PB. The plant heights were higher in plots applied with two pre-emergence tank mixed herbicides 319.67cm and 222.73 cm for Farm 1 and 3, respectively though they were similar to atrazine only treatment 317.07cm and 217.40 cm, respectively. However, in PB there was no significant difference ($P>0.05$) between the plant heights for plots applied with a mixture of pre-emergence herbicides (atrazine + alachlor) and plots applied atrazine only in Farm Type 2. Similar trends were also observed in Farm Type 3 were the lowest plant heights in hand weeded treatments and the treatments applied atrazine + alachlor and atrazine only.

6.4.5.2 Maize

During 2010/2011 season there was a significant effect of weeding treatment on maize grain yield in Farm type 1 (Table 6.6a). In Farm Type 1, the maximum maize grain yield (4024 kg ha^{-1}) was obtained for atrazine + alachlor treatment in PB (Table 6.6). The minimum maize grain yield (3332 kg ha^{-1}) was recorded for the hand hoe weeded treatment in CONV. The yield advantage for the atrazine + alachlor treatment over hand hoe weeded treatment was 13 and 14 percent, in PB and CONV, respectively under Farm Type 1. The effect of weeding treatment was significant ($P<0.05$) in Farm Type 2 and 3 where PB resulted in higher yields particularly in treatments applied pre-emergence herbicides.

Table 6. 7 Effect of tillage system and weeding treatment on maize grain yields during 2010/2011 season in Kadoma, Zimbabwe

	2010/2011 season (maize)
	Maize grain yield kg ha^{-1}
Weeding treatment	
Hand weeding	2138c
Atrazine	2372a
Glyphosate	2251b
Atrazine +Alachlor	2356a
P- value	$P<0.01$
$L.S.D_{(0.05)}$	42
Tillage	
PB	2343a
CONV	2220b
P- value	$P<0.01$
$L.S.D_{(0.05)}$	60

6.5 DISCUSSION

The effective suppression of weeds by pre-emergence herbicides (atrazine, alachlor and cyanazine) during the first 6 WACE helps to reduce labour requirements for weeding early in the season, which is usually scarce in the SH farming sector. These findings are in agreement with the report of Chikoye *et al.* (2007) that pre-emergence herbicides significantly reduced weed densities early in the season. In this study a mixture of alachlor with atrazine or cyanazine, ensured maximum weed suppression. In a study by Mashingaidze (2004), atrazine proved to be the best for controlling weeds compared to other herbicidal treatments when applied as a pre-emergence herbicide in maize. Atrazine and cyanazine mainly control broad-leaved weeds whereas alachlor controls grass weeds and in this study the mixtures and single application of herbicides had similar effects on weed control. The herbicides can be applied as single applications but a mixture of the two herbicides is important in avoiding build up of grass weeds.

The weed density for glyphosate treatment was similar to hand hoe weeded treatment. Glyphosate treatment only controlled existing weeds at planting and the weed cohorts that emerged after crop emergence required subsequent hand hoe weeding. Supplementary glyphosate with pre-emergence herbicides, which suppress weed emergence after planting, could improve the effectiveness of this herbicide.

The differential effects of herbicides on weed density on the farms could be a reflection of factors such as farm management, soil types and pH. The difference in management strategies and soil types can alter weed communities and densities, which in turn, affect the effectiveness of herbicides. High weed densities in Farm Type 2 could have contributed to reduced effective suppression of weed densities than in Type 1 farms. Hence, an increase in the dosage of herbicides could increase the effectiveness of the herbicides in controlling weeds. Farm Type 3 had low weed densities; therefore, the reduced effect of herbicides in these fields could not have been attributed to weed density. The low pH observed in these fields could have reduced the effectiveness of herbicides in weed control. According to Kells & Meggit (2009), low soil pH reduces herbicide efficacy. There could be other factors, which reduced the effectiveness of herbicides in Farm Type 3, for example, the high rainfall received after applying the herbicides could have reduced the effectiveness of the herbicides. Moisture is desirable soon after herbicide application because it enables the herbicides to make contact with the germinating seedlings.

However, high rainfall soon after applying herbicides is not desirable because it washes away herbicides resulting in reduced herbicide effectiveness.

Although many factors can alter herbicide performance, there is no consistent effect of tillage on chemical weed control. Johnson *et al.* (1989) reviewed several studies and found that some studies reported poor herbicidal weed control in CA whilst some studies found comparable weed control with pre-emergence herbicides in both PB and CONV systems. Chauhan & Opena (2012) also made similar conclusions that herbicidal requirements within tillage systems are similar.

In this study, herbicides changed the weed community structure by reducing the weed diversity, evenness and richness indices. It is, therefore, important to note how quickly herbicides can alter the weed communities. The diversity of weed communities determines the strategies required for weed control and the observed higher weed diversity in PB may underscore the need to alter weed management strategies. The higher diversity indices observed in 2010/2011 when compared to 2009/2010 seasons could be a result of high rainfall received and high temperature both of which increase physiological growth of many weed species. The weed diversity in this study appears to be directional rather than random and thus supports the observation by Miyazawa *et al*. (2004) that weed diversity was reduced by herbicides. However, the short duration of this study may make it difficult to authenticate this hypothesis.

The increased plant heights within plots applied with herbicides is in agreement with the findings of Soltani *et al.* (2006) where maximum plant height resulted from the usage of herbicides for weed control. On the contrary, Usman *et al*. (2010) reported that herbicides usage reduced plant heights due to phyto-toxicity of the herbicides. The effects of tillage, weed control treatments, Farm Type and their interactions show that environment and management also have an effect on plant height rather than genetic control only.

The yields were higher in pre-emergence applied treatments due to reduced crop-weed competition, these findings also agree with Chhokar *et al*. (2008) that herbicides reduced crop-weed competition and increased crop yields. These results suggest that the adoption of PB in the SH sector may increase in farmers' yields if effective weed control methods are adopted. The higher yields in PB were a result of enhanced fertilizer and water use efficiency. These results concur with the findings of Erenstein *et al.* (2008) who reported higher productivity for CA over CONV due to early sowing, improved soil fertility level, enhanced water and fertilizer usage efficiency.

The tillage system was not a single over-riding factor in determining the intensity of weed problems within farms. The weed communities were influenced by soil type and a variety of management, practices hence weed management strategies need to consider the differences within farmers' fields.

It is generally, recommended to mix atrazine with other herbicides that are compatible with it to improve their effectiveness on weeds (Williams *et al.*, 2011). There might be a need for follow up weeding with hand hoes after 6 WACE since the effectiveness of herbicides was reduced after 6 WACE. The effectiveness of pre-emergence herbicides in this study is in contrast to the findings of Chauhan & Opena (2012) were herbicides poorly controlled weeds in CA. A possible reason for lower effectiveness of herbicides in PB systems could be due to the presence of crop residues on the soil surface, which could intercept a significant amount of herbicides, and thereby reduce effectiveness (Chauhan & Jonhson, 2008). In this study, there were fewer crop residues on the surface, which could not have intercepted the herbicides.

The findings of this study raise the possibility of inclusion of pre-emergence herbicides in PB in the SH sector. Herbicide reduces labour bottlenecks that are mainly responsible for the inability of SH farmers to control weeds effectively resulting in yield losses at peak weeding times in PB. The effective weed control achieved with herbicides could help farmers to exploit PB without weed management problems, since they are not able to practice crop rotation and permanent soil cover which can be used to suppress weeds. However, there is need for training on usage of herbicides and to determine appropriate herbicide dosage for each farm type.

6.6 CONCLUSION

It can be concluded that the hand hoe weeding option was not effective in controlling weeds in PB The effectiveness of cyanazine + alachlor in cotton and alachlor + atrazine in maize were similar in weed control to the cyanazine and atrazine only treatments. Tillage did not affect the effectiveness of pre-emergence herbicides when compared with CONV tillage. Herbicides controlled weeds to a varying level depending on soil types and significantly affected weed density, diversity, plant height and crop yields. The differential effects of herbicides on the farms shows that the herbicide doses need to be made based on characteristics of the field and blanket recommendations will not be appropriate. The pre-emergence herbicides, which include a combination of cyanazine + alachlor in cotton and atrazine + alachlor, which suppress a broad spectrum of weeds, are recommended to complement hand hoe to suppress weeds in PB. There is a need for further studies to establish appropriate herbicide dosages to control high weed densities. In addition, further studies are required to assess the cost benefit analysis of tillage and herbicides to enable farmers to make informed decisions as they use herbicides in PB

CHAPTER 7

ECONOMIC ANALYSIS OF WEED MANAGEMENT OPTIONS UNDER PLANTING BASINS IN THE SMALLHOLDER SECTOR

7.1 ABSTRACT

A socio-economic model, OLYMPE, was used to evaluate economic benefits of chemical weed control under planting basins (PB). The model was calibrated and validated using primary data from on-farm experiments and discussions with farmers in the study area. The average gross margin for weeding options under different scenarios of climate induced risks and fluctuating farm input and output price were simulated over a 10 year period under well, medium and poorly resourced farmers. Average gross margin for Atrazine + alachlor increased the gross margin by US$ 351.00 and US$ 373.00 in PB and CONV, respectively. While cyanazine + alachlor treatment increased gross margin by US$ 849.00 and US$ 399.00 in PB and CONV, respectively when compared to hand hoe weeding. Gross margin for PB was similar to CONV in pre-emergence herbicide applied treatments, but the hand hoe weeded and glyphosate treatments had higher gross margin in CONV than in PB on average. However, the effect of weeding options on the gross margin varied with farmer resource endowments, with more benefits of using herbicide treatments in well resourced in both tillage systems. Farmers' production was not viable in hand hoe weeded treatment because of high costs of weeding especially in PB and was worsened by worst case scenarios of rainfall, input and output price variations. Alternatively, herbicides can be used to reduce costs associated with weeding thereby increase gross margin.

Key words: farm typology, gross margin analysis, herbicides, OLYMPE, sustainable agriculture,

7.2 INTRODUCTION

The smallholder (SH) farming systems in Sub-Saharan Africa are characterised by continual land degradation, persistent and recurring droughts both resulting in either stagnant or decreasing food production (Friedrich, 2008). Under SH production systems yields of most staple food crops have been less than 1 t ha^{-1} posing a grave threat to family food security (Gowing & Palmer, 2008). There has been concerted effort to promote Conservation Agriculture (CA) in southern Africa with approximately 110,000 and 180,000 farmers adopting CA in Zimbabwe and Zambia, respectively, by the 2009/2010 season (www.prpzim.info (Accessed 09/2012). This is consistent with the drive to promote CA as a sustainable means of crop production in the SH sector in order to increase food production (FAO, 2012). Conservation Agriculture ensures early planting as land preparation can be carried out before the first effective rains (Haggblade & Tembo, 2003a). This may result in more efficient use of rainfall, reducing the risk of crop failure in the event of below-average rainfall and stabilising yields when rains are poorly distributed (Erenstein, 2003). In addition, mulching with crop residues reduces water runoff and increases infiltration and organic matter content in the soil (Thierfelder & Wall, 2009). However, weed management on SH farms in southern Africa is a great challenge, especially under Planting basins (PB), and vitiates efforts to increase food security in the region (Johansen *et al.*, 2012).
Findings from previous chapter 4 indicated that PB systems had higher weed densities than CONV tillage. The increased weed densities under PB have serious weed management implications which have labour shortages and high costs of hand hoe weeding.

Weed management is more costly when compared to other aspects of crop production and has potential to reduce returns from cropping (Baundron *et al.*, 2011). It is now widely accepted that weed management is the principal constraint to crop production under CA in SH systems in sub-Saharan Africa (Giller *et al.*, 2012). Rural - urban migration and HIV/AIDS have exacerbated the already precarious labour shortage in this sector (Mashingaidze *et al*., 2003) Consequently, SH farmers cannot weed their fields timeously and effectively using a single method of weed control (Mandumbu *et al*., 2011). Smallholder farmers use a hand hoe for weed control which is not only laborious but is time-consuming, requiring approximately 400 hours weeding a hectare (Gianessi, 2009). Muoni *et al*. (2013), strongly believes that herbicides could help reduce the labour requirements and increase efficiency and timely weed control. Notwithstanding this, the lack of knowledge on correct handling of herbicides which include: incorrect interpretation of instructions particularly on the dilutions, when to apply herbicides and on which type of crop is pervasive among the SH farmers (Gatsi *et al*., 2001). The shortage of knowledge in the SH possess severe constraints on the effective impact of the herbicides (Makanganise *et al*., 2001). If herbicides are incorrectly handled, water pollution may result and will affect wells and aquatic life in the rivers and will pose great risk to health of both livestock and human beings (Williams *et al*., 2010). In addition, budgetary constraints influence the farmers' ability to buy herbicides (Mashingaidze, 2004). Nevertheless, training SH farmers on the usage of herbicide, could overcome the challenges associated with herbicide usage. This will ensure that the farmers are able to effectively and efficiently use herbicides to compliment hand hoes in CA.

However, for quick uptake by the farmers adapting PB, the use of herbicides should result in a higher rate of return on investment relative to the hand hoe weed control method. In other words, the SH farmers expect the herbicide technology to provide higher returns with low variability. The generally accepted rule of thumb is that, highly rewarding production systems are associated with higher risks. Consequently, a compromise needs to be established between the level of returns desired and the level of risk to be borne. There are risks associated with herbicide usage in crop production such as yield losses due to weed competition resulting from poor herbicide performance. Further, other associated risks relate to crop failure due to climatic risks such as erratic and uneven distribution of rainfall during the growing season (Grave *et al*., 2007), and economic risks such as fluctuating output and input prices which can affect the returns for using herbicides. Therefore, there is a need not only to solely focus on effectiveness of weed control methods, but also on the consistency of net returns over time as farmers adopt the herbicide technology.

A socio economic evaluation of herbicides under the SH sector is of paramount importance considering the positioning of the SH farmers in the lower ranks of the income spectrum which makes their decision making and technology adoption vulnerable to risk considerations. The performance of herbicides with respect to farm profitability is poorly understood. The objective of this study was to evaluate the economic performance of chemical weeding options under PB system.

7.3 MATERIALS AND METHODS

7.3.1 Study Area and Selection of Farmers

The study was carried out in Muzvezve Ward, Kadoma, which is typical of SH area in Zimbabwe. The study area and the weather conditions prevalent during the course of this study are described in Chapter 4, section 4.3.1. The selection of farmers who participated in this study was described in chapter 5. Since the SH agriculture system is diverse the farmer groups described in Chapter 6 high, medium and poorly resourced which were denoted as Farm Type 1, 2 and 3, respectively, in the study were used to assess how the different resource categories influence the returns for weed management options.

7.3.2 OLYMPE Model

Modelling of the maize and cotton production system was carried out using the OLYMPE decision support software for agriculture that facilitates a comprehensive overview of farmer situation and links to technical innovations and practices. It combines a database 'ready to fill' with economic information on prices, productions and households and has an accounting calculator which allows the automatic computation of economic indicators. The overall OLYMPE approach is illustrated in Figure 7.1. The software can also be used as a simulator to test a change in the farming system or to evaluate a farm's resilience to risks such as climatic effect leading to low harvest or price changes (CIRAD *et al.*, 2007).

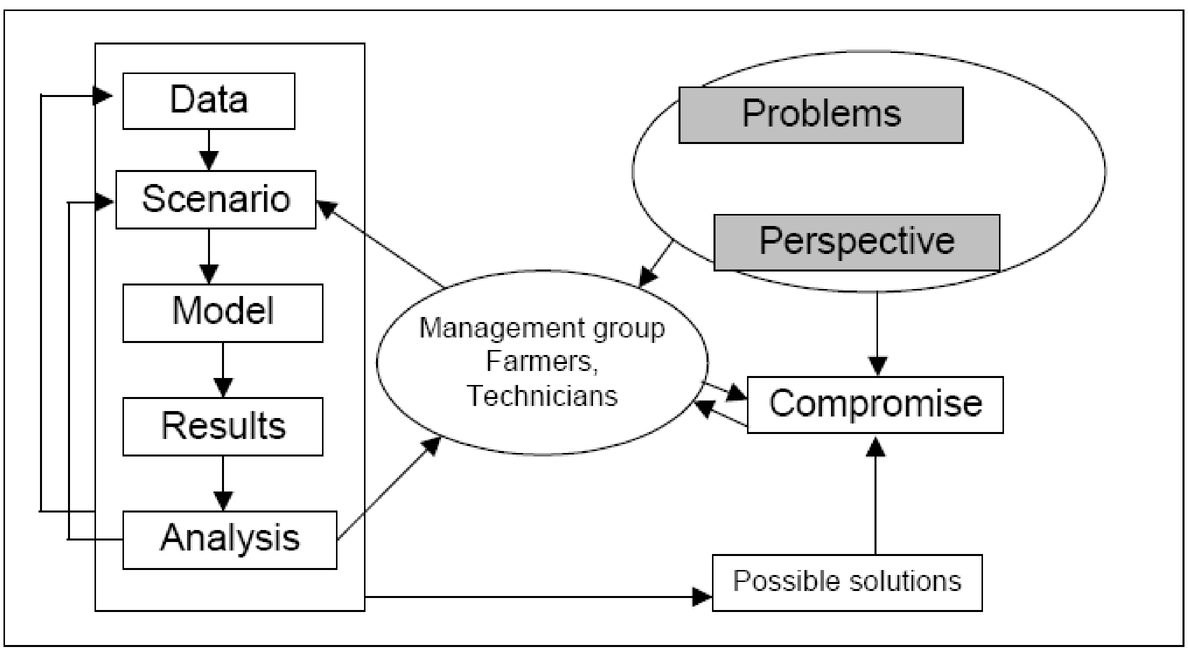

Figure 7. 1 The overall approach behind the use of OLYMPE for farming systems modelling (Grusse *et al.*, 2006).

A comparative analysis of weed management options using economic indicators (returns to labour needs for the whole year) was firstly done. This analysis was extended over to the cotton and maize production systems to reveal the advantages and constraints of the two systems. The input and output data from site trials described in Chapter 6, that were carried out in Kadoma, Zimbabwe during the 2009/2010 and 2010/2011 seasons was used as the basal situation. The labour requirements for land preparation, planting, weeding and harvesting under PB and CONV systems were recorded for each treatment per plot. The input and output data was validated by farmers during group discussions. The prices for input and output data was based on the prevailing prices at the time of planting and harvesting, respectively. The costs of cotton and maize seed were US$ 1.00 kg^{-1} and US$ 0.80 kg^{-1}, respectively. The maize and cotton selling prices were US$ 325.00 and US$ 800.00 ton^{-1}, respectively (RBZ, 2009).

Yields from production functions, prices, costs of production and labour needs were processed in the OLYMPE software and gross margins were calculated in US$ ha^{-1}. The gross margin was calculated using the following Equation:

Gross margin = Gross income - Total variable costs (7.1)

Returns to labour = Gross margin US$ ha^{-1} - costs of labour (US$ $ha-^{1}$)/labour use (7.2)
in (man hour's day^{-1}).

The performance of the weed management practices based on yields and gross margin were evaluated over a 10-year period. Determination of the profitability of different farming systems comprised two steps:

- The costs, returns and gross margins were calculated per season 2009/2010 under cotton and 2010/2011 under maize in PB and CONV under three different farm typologies that were developed in Chapter 6.
- Assessing the profitability of weeding options was done using the following scenarios:
    - ✓ High herbicide price variation
    - ✓ Fertiliser price variation (High and low variations)
    - ✓ Product price variation (High and low variations)
    - ✓ Improved fertility
    - ✓ Worst case scenarios (low crop price, low rainfall, and high herbicide prices)
    - ✓ Combined scenario (Improved fertility and high crop product prices)

The limitation of the model is that it did not account for any damage of the crops by pests and any diseases that may affect leaf area and therefore decrease crop yields over the simulation period. Seasonal decisions by farmers were also not taken into account and these may affect yields.

7.3.2.1 Assumptions on Scenarios

1. It was assumed that the change in maize grain and cotton lint yield was only due to changes in the productivity of the land. The yield changed because of the improved weed management and soil fertility (Mutambanengwe *et al.*, 2006; Mutambanengwe & Mapfumo, 2005).

2. The variations in the prices of cotton and maize and input costs were kept at base year i.e. 2009 season. The types and quantity of fertilisers for the base year 2009 were used for all the years of simulation. The socio economic conditions were assumed to remain constant for the 10 year simulation period.

7.4 RESULTS

7.4.1 Weed Control Treatment and Gross Margin

Cotton

The results showed variations on the gross margin per hectare depending on the weeding treatment and also differed with farmer resource endowment (Figure 7.2). In Farm Type 1 the gross margin for hand hoe weeded (US$ 514.00 ha^{-1}) treatment was the lowest, whilst the cyanazine + alachlor (US$ 1363.00 ha^{-1}) treatment in PB was the highest gross margin though it was statistically similar to cyanazine (US$ 1069.00 ha^{-1}) only treatment (Figure 7.2A). When comparing the effect of tillage on each treatment there was no significant difference ($P>0.05$) on the gross margin in PB and CONV for all the treatments except for the hand hoe weeded treatment were the gross margin in CONV was 38 percent higher than in PB.

In Farm Type 2 the hand hoe weeded treatment (US$ 831.00 ha^{-1}) in PB had the lowest gross margin though it was statistically similar to glyphosate treatment (US$ 802.00 ha^{-1}) in CONV (Figure 7.2B). The highest gross margin was observed in the cyanazine (US$ 665.00, 1149 ha^{-1}) only treatment and it was statistically similar to cyanazine + alachlor treatment (US$ 1018.00, 1069 ha^{-1}) in PB and CONV, respectively. There was a significant effect of tillage between the gross margin for hand hoe, cyanazine and glyphosate treatments where the gross margin in CONV was 65 percent higher than in PB.

A significant (P<0.05) effect of weed treatment on the gross margin was observed in Farm Type 3 (Figure 7.2C). The costs of inputs for the hand hoe and the glyphosate treatments exceeded outputs resulting in negative gross margin in PB. The highest gross margin was in the cyanazine + alachlor treatment (US$ 350 and US$ 261) in PB and CONV, respectively. The cyanazine + alachlor treatment was statistically similar to the cyanazine treatment (US$ 253 and US$ 211) in PB and CONV, respectively.

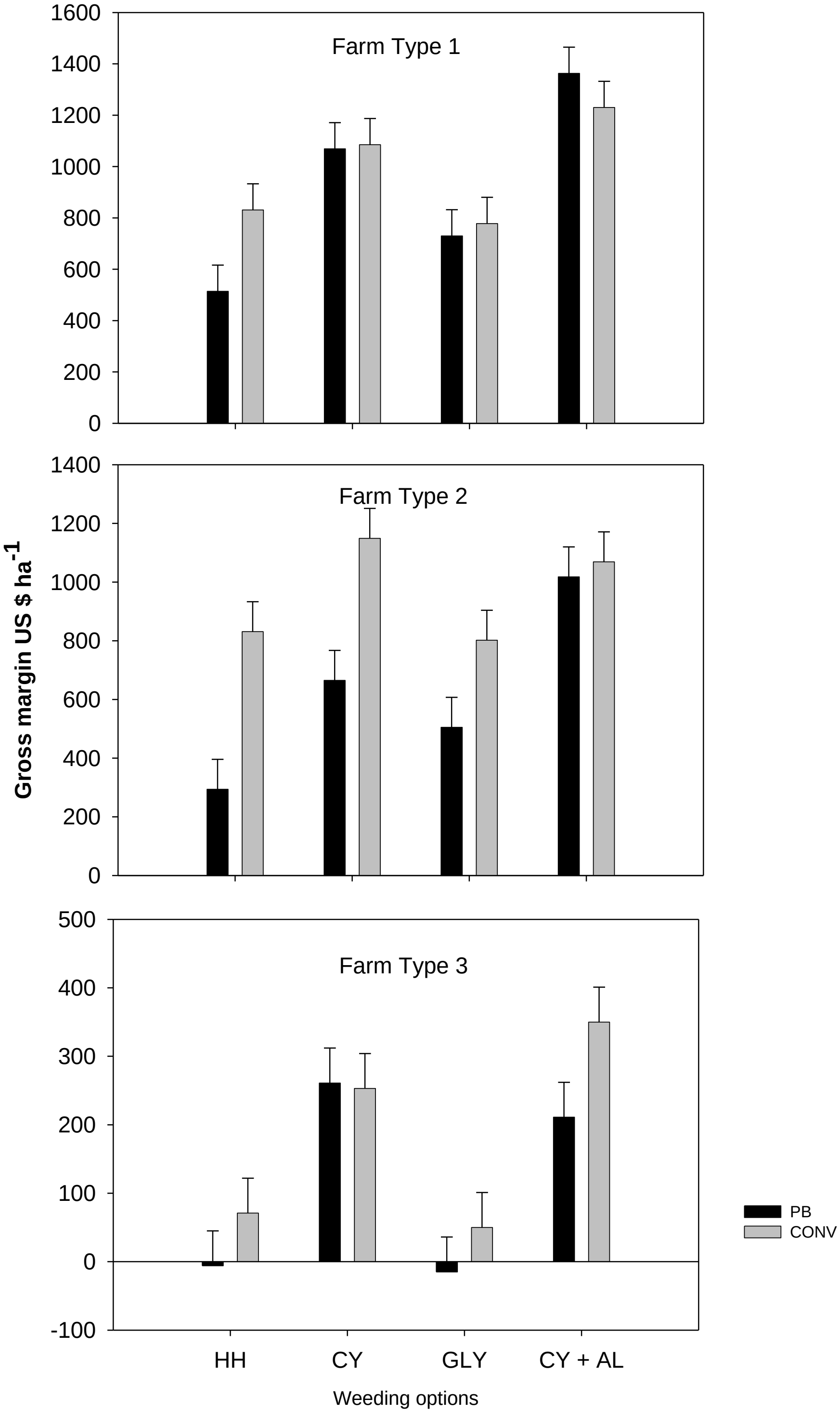

Figure 7. 2 Effect of weeding option on the gross margin obtained during 2009/2010 under cotton, in Kadoma Zimbabwe. PB=Planting basin; CONV= Conventional Tillage; HH=hand hoe weeding; ATR= atrazine; GLY= glyphosate; AL= alachlor; Farm Type 1= Well resourced; Farm Type 2= Medium resourced; Farm Type 3= poorly resourced farmers; Error bars represent SED

Maize

Figure 7.3 shows the gross margin for four weeding options under three Farm Types. The gross margin for atrazine + alachlor treatment under BP and CONV were US$ 1012.00 and US$ 1029.00, respectively and had similar gross margins with the atrazine treatment US $ 975.00 and US$ 954.00 in PB and CONV, respectively (Figure 7.3A). The hand hoe weeded treatment (US $ 661.00 and US$ 656.00) had the lowest gross margin in PB and CONV, respectively though it was statistically similar to glyphosate treatment (US $ 694.00 and US$ 716.00) in CONV. All the treatments had statistically similar gross margin in PB and CONV.

Under Farm Type 2, the lowest gross margin was recorded in glyphosate treatment (US$ -31.00 and US$8.00) and it was statistically similar to the hand hoe (US $ -10.00 US $ 6.00) under PB and CONV, respectively (Figure 7.3B). The highest gross margin for Farm Type 2 was in the atrazine + alachlor treatment which was 95 and 75 percent higher than the hand hoe weeded treatment in PB and CONV, respectively. However, the gross margin in atrazine + alachlor treatment in PB and CONV were US$216.00 and US$ 248.00, respectively. The atrazine + alachlor treatment was statistically similar to the atrazine treatments US $ 224.00 and US$ 223 in both PB and CONV, respectively. There was no significant effect (P>0.05) of tillage on the gross margin for all the treatments.

The gross margin in Farm Type 3 revealed varying gross margin depending on the weed treatment (Figure 7.3C). The hand hoe and the glyphosate treatments were not viable. They are represented by negative gross margin in both PB and CONV. The returns in the atrazine + alachlor pre-emergence herbicides treated plots were 50 percent higher in CONV than in PB in

Farm Type 3. The atrazine only treatment in PB resulted in a negative gross margin CONV was US$180.

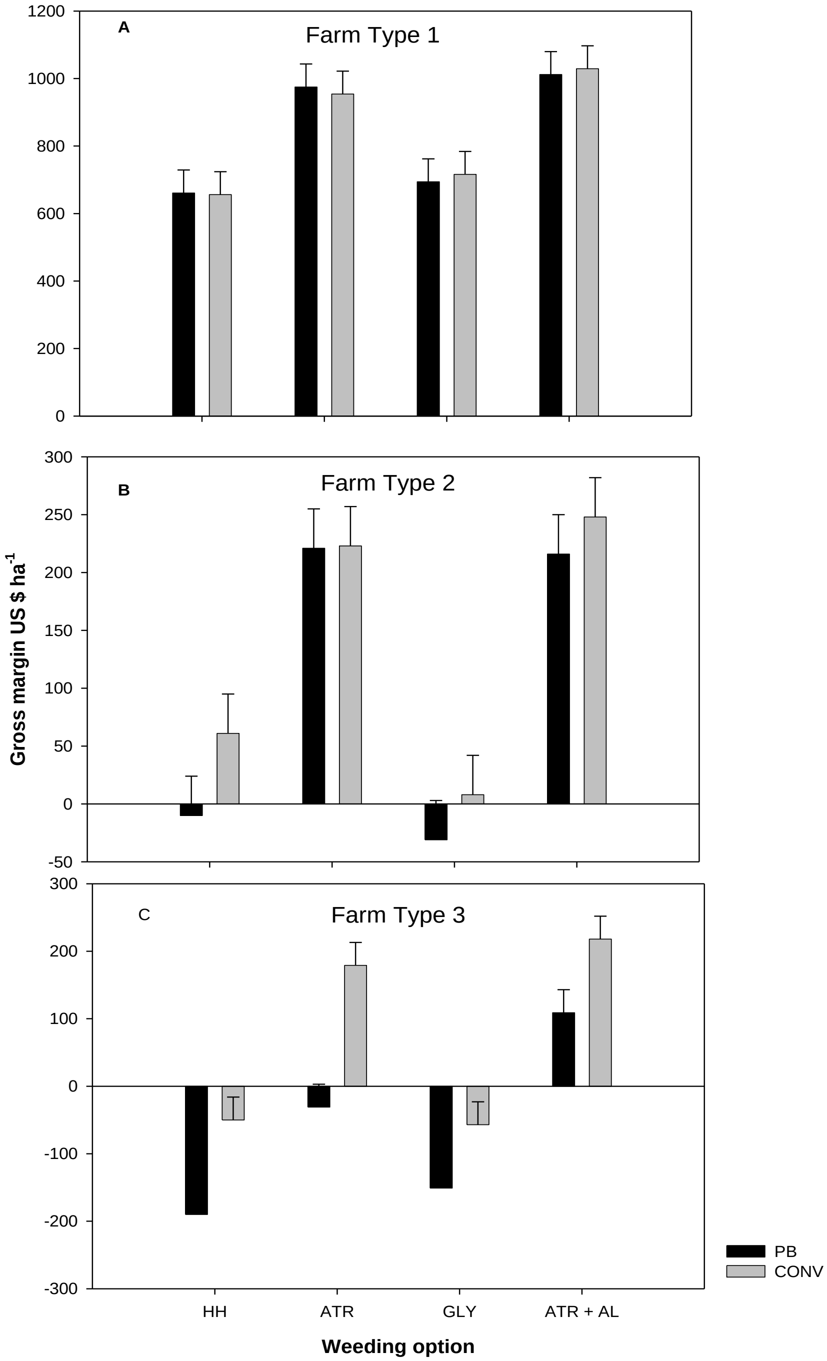

Figure 7. 3 Effect of weeding option and tillage on gross margin obtained during 2009/2010 under maize, in Kadoma Zimbabwe. PB=Planting basin; CONV= Conventional Tillage; HH=hand hoe weeding; ATR= atrazine; GLY= glyphosate; AL= alachlor; Farm Type 1= Well resourced; Farm Type 2= Medium resourced; Farm Type 3= poorly resourced farmers; Error bars represent SED

7.4.2 Simulations of Economic Returns under Maize

7.4.2.1 Low Maize Price Variation

Figure 7.4 shows gross margin for weeding options under low maize prize variation. The effect of the low maize selling price on the gross income, differed with weeding treatment and resource endowment of farmers. Generally across the entire farm the hand hoe weeded treatment had the lowest gross margin while the use of pre-emergence herbicides had the highest gross margin. The gross margin for hand hoe weeded treatment was comparable to the glyphosate treatment with a small difference. For example in the first year of simulation there was only 11 percent difference between the treatments. The gross margin for Farm Type 2 and 3 for hand weeded treatment were negatively affected by the low prizes resulting in negative gross margins in eight and nine years of simulation, respectively. The glyphosate treatment had negative gross margin in all the years of simulation in Farm Type 2 and 3. The pre-emergence herbicides treatments, performed better than the hand hoe weeded treatments and resulted in positive gross margin. In Farm Type 1, the treatments in PB had slightly higher gross margin than in CONV with more differences ranging from 32 to 165 percent between PB and CONV. All the treatments under CONV in Farm Type 2 and 3 had higher gross margin under PB.

7.4.2.2 High Maize Prize Variation

Increasing the maize grain price increased the gross margin for all treatments particularly for pre-emergence herbicides applied treatments represented by high gross margin (Figure 7.5). The gross margin for hand hoe weeded treatment was improved by increasing the price of maize in five and six out of 10 years of simulation, in CONV and PB respectively. In Farm Type 3 the treatments under CONV performed better than under PB. While in Farm Type 1 and 2 the gross margin for PB was slightly higher than the gross margin in CONV expect for the hand hoe weeded treatment under Farm Type 2 were the CONV was slightly higher than PB.

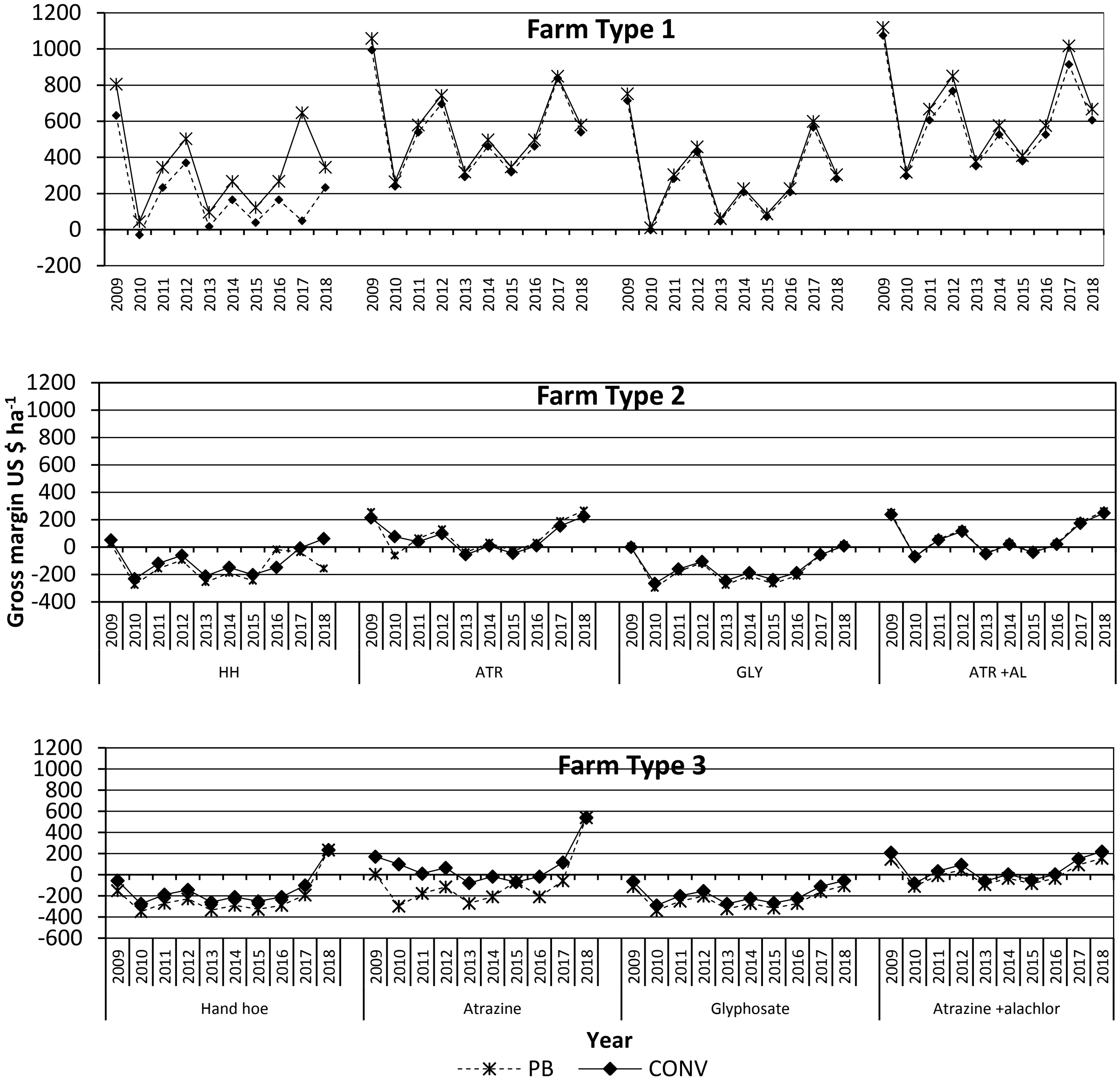

Figure 7. 4 Gross margins for maize crop under different weeding options subjected to low maize price variations in Kadoma, Zimbabwe. PB = Planting basin; CONV = Conventional Tillage; HH= hand hoe; ATR= Atrazine; GLY= Glyphosate; atrazine + alachlor; Farm Type 1= Well resourced; Farm Type 2= Medium resourced; Farm Type 3= poorly resourced farmers

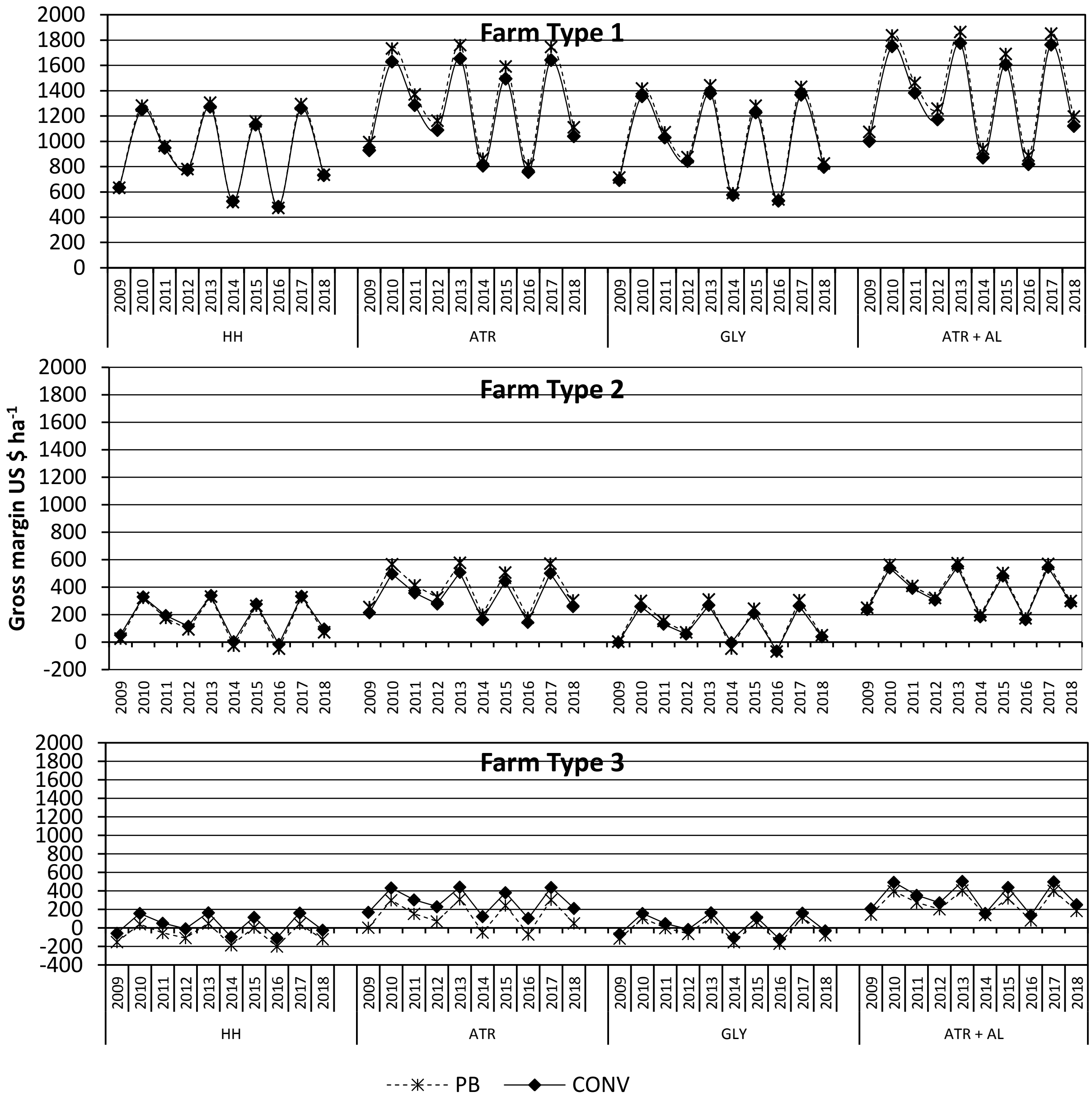

Figure 7.5 Gross margin for maize crop under different weed management options when subjected to high maize price variations in Kadoma Zimbabwe. PB = Planting basin; CONV = Conventional Tillage; HH= hand hoe; ATR = atrazine; GLY= glyphosate; AL=alachlor; Farm Type 1= Well resourced; Farm Type 2= Medium resourced; Farm Type 3= poorly resourced farmers

7.4.2.3 High Herbicide Price Variation

The gross margin for pre-emergence herbicide applied remained higher than the hand hoe weeded treatment even when subjected to high herbicide prices (Figure 7.6). The gross margin for atrazine + alachlor treatments resulted in the highest gross margin while the gross margin for hand hoe weeding was the lowest in both tillage systems. However, the responses of treatments differed with farmers. In Farm Type 1, there was a marginal difference in the gross margin for PB and CONV. In Farm Type 2, atrazine + alachor treatment in PB had higher gross margin than in CONV, while the atrazine treatment in PB was slightly higher than in CONV. In Farm Type 3, the treatments under CONV performed better than in PB, though it was still beneficial to use pre-emergence herbicides even with high prices of herbicides when compared to using hand hoes for weed control.

7.4.2.4 Improved Soil Fertility

The results show opportunities to increase the gross margin with improved soil fertility for all weeding options (Figure 7.7). However, the effects of increasing soil fertility on the weeding options varied with the farmers. In Farm Type 1, the gross margin in PB was slightly higher than CONV for all treatments. Further, the atrazine +alachlor treatments had the highest gross margin but it was comparable to the atrazine only treatment. While the hand hoe weeded treatment had the lowest gross margin. The gross margin for hand hoe weeded treatment under Farm Type 2, increased with an increase in soil fertility though it was still negative in two out of 10 years of simulation. The gross margin for atrazine + alachlor remained higher than the hand hoe weeded treatment. In Farm Type 3, the atrazine + alachlor treatment was unique in that it had a positive gross margin in all years of simulation when compared to hand hoe weeded treatment which had negative gross margin in 5 out of 10 years of simulation. Conventional Tillage was more than PB indicated by higher gross margin in Farm Type 3.

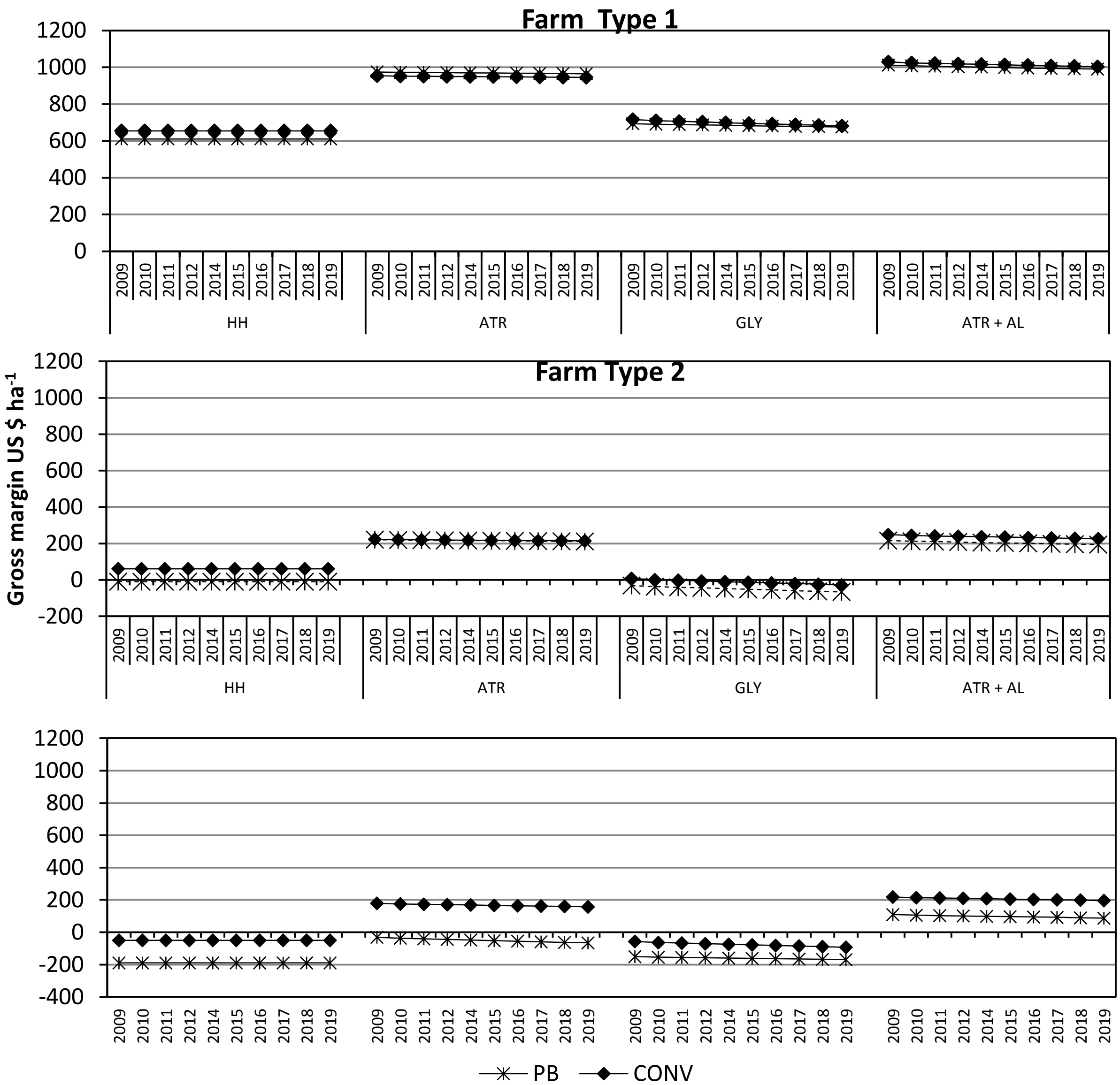

Figure 7. 6 Effect of high herbicide price on the gross margin for weeding options. PB =Planting Basin; CONV = Conventional Tillage; HH = hand hoe; ATR = atrazine; GLY = glyphosate; AL = alachlor; Farm Type 1 = Well resourced; Farm Type 2= Medium resourced; Farm Type 3 = poorly resourced farmers

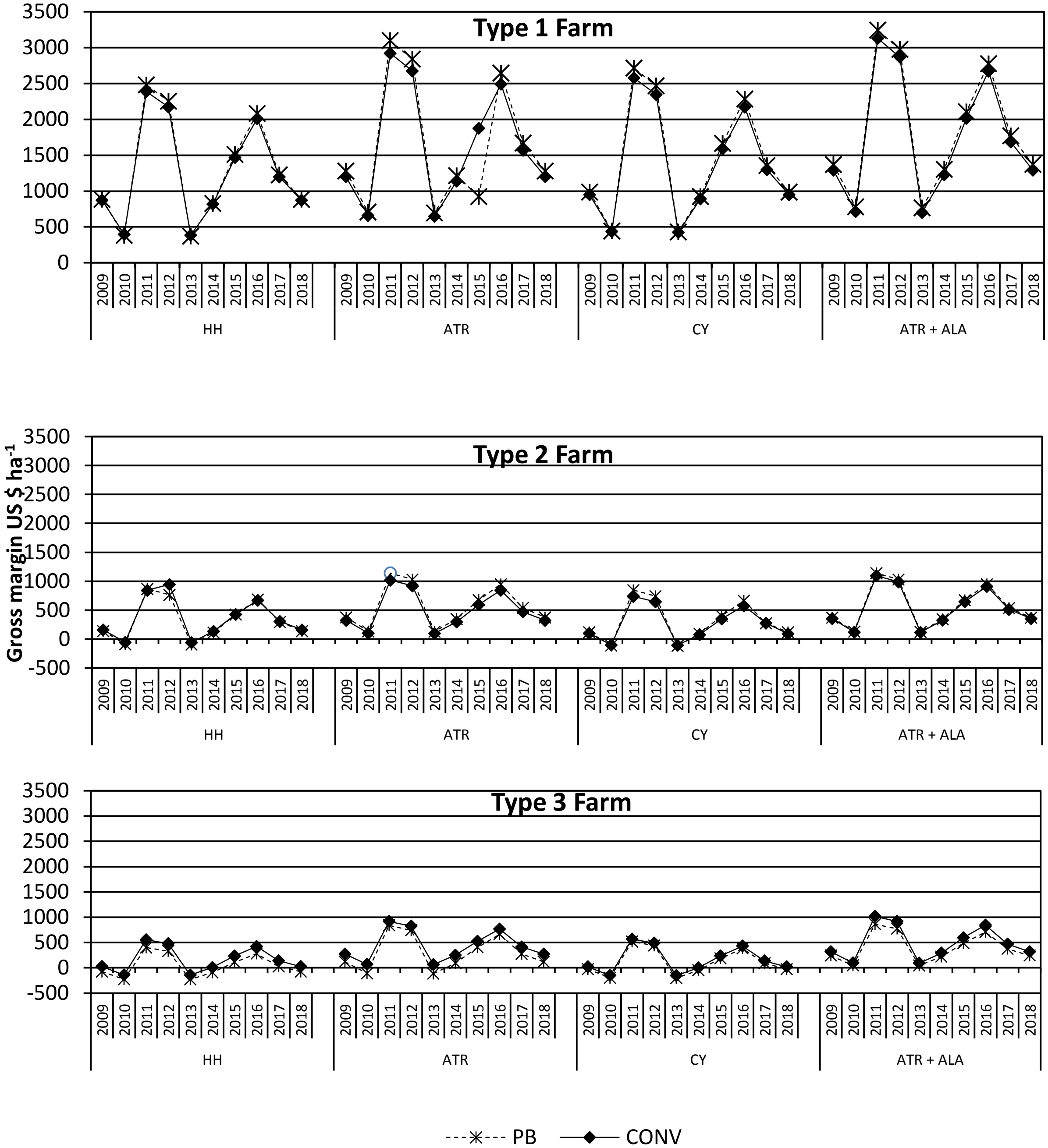

Figure 7.7 Gross margins of weed management options subjected to improved fertility for the maize crop. PB =Planting basin; CONV = Conventional Tillage; HH = hand hoe; ATR = atrazine; GLY = glyphosate; AL =alachlor; Farm Type 1 = Well resourced; Farm Type 2 = Medium resourced; Farm Type 3 = poorly resourced farmers

7.4.2.5 Improved Soil Fertility Combined with High Produce Prices

The combined scenario increased the gross margin for all treatments, however, the gross margin for atrazine + alachlor remained higher than hand hoe weeded treatment and was comparable to atrazine only (Figure 7.8). In most years of simulation, PB had slightly higher gross margin than CONV in Farm Type 1 and 2. In Farm Type 3, the gross margin for PB under all treatments except hand hoe weeded was comparable to CONV unlike in previous scenarios when CONV had higher gross margin than PB.

7.4.2.6 Low Rainfall Scenario

In years characterised by low rainfall, the gross margin decreased for all the treatments and for all farmers. The low yields which were a result of low rainfall reduced the gross margin and in most cases was characterised by negative gross margins as expenses exceeded the income from the crop sales (Figure 7. 9). In years with adequate rainfall, Type 1 farms performed positively. The use of herbicides was advantageous in years of adequate rainfall were represented by higher gross margin. Under Farm Type 2, the gross margin for glyphosate and hand hoe weeded treatments was negative in 7 out 10 years of simulation in both PB and CONV. The treatments of herbicide mixtures (atrazine + alachlor) had the higher gross margin when compared to hand hoe weeded treatment despite the low rainfall received.

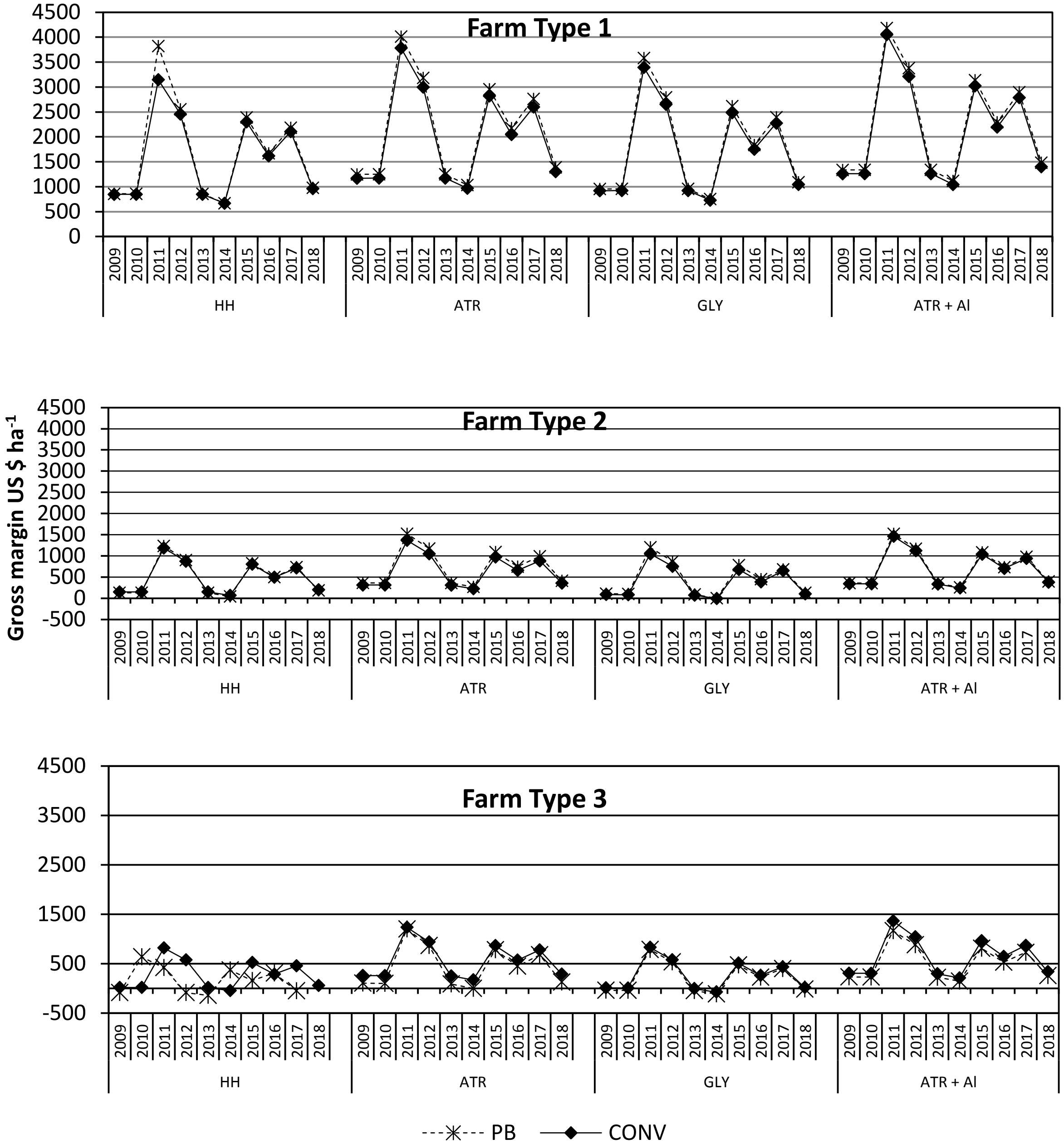

Figure 7.8 Gross margins for weeding management options subjected to improved fertility for the maize crop with high selling prices. PB = Planting basin; CONV = Conventional Tillage; Farm Type 1 = Well resourced; Farm Type 2 = Medium resourced; Farm Type 3 = poorly resourced farmers

7.4.2.7 High Fertiliser Price Variation for Maize Crop

The effect of an increase in price of maize basal fertiliser (8N:14P:8K) and ammonium nitrate (34.5 % N) was analysed based on the (1990/2008) price variation (OECD-FAO, 2008). The prices of the fertilisers ranged from 100 to 260 percent of the 2009 price (US$ 0.60 kg^{-1}). Fertilisers are important in crop production and crop is negatively affected when farmers do not use fertilisers due to high costs. In the study, the high fertiliser variations affected productions for all Farm Types particularly Farm Type 2 and 3 as shown in Figure 7.11. The Farm Type 2 had negative gross margin in eight out of 10 years of simulation for hand hoe weeded treatment. While the atrazine only treatment had negative gross margin in 4 out of 10 years of simulation. The gross margin for Farm Type 1 was not affected by high fertiliser price variations since the gross margin remained positive. In years when the prices for fertilisers increased, the herbicide treatments had positive gross margin in both tillage systems. The performance of Farm Type 3 was the worst with negative gross margin in all years of simulation for the hand hoe weeded treatment, while a positive gross margin was obtained for pre-emergence herbicide treatments in five out of 10 years of simulation.

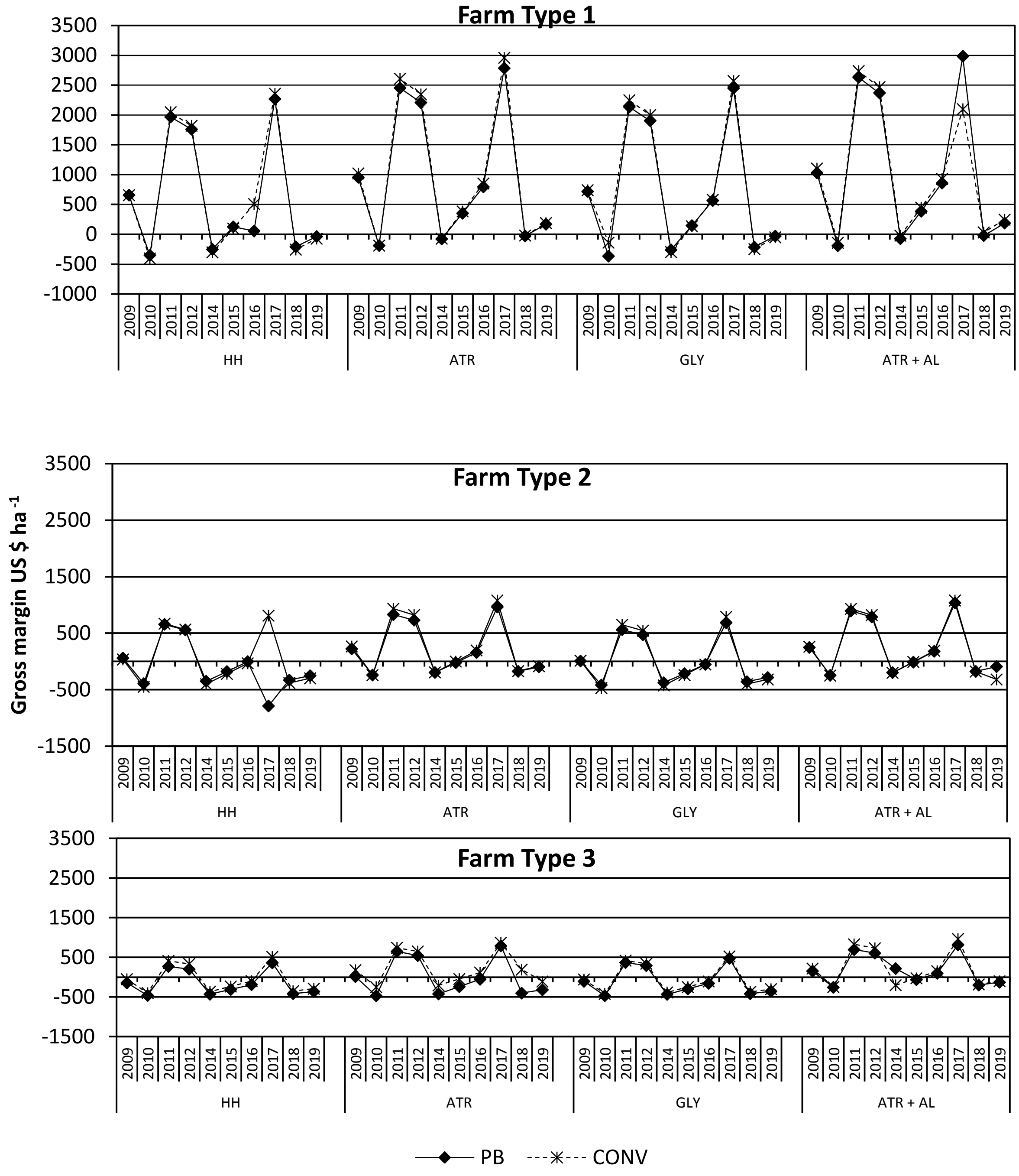

Figure 7. 9 Gross margins for weeding management options subjected to low rainfall variation maize. PB = Planting basin; CONV = Conventional Tillage; HH = hand hoe; ATR=atrazine; GLY = glyphosate; AL =alachlor; Farm Type 1 = Well resourced; Farm Type 2= Medium resourced; Farm Type 3 = poorly resourced farmers.

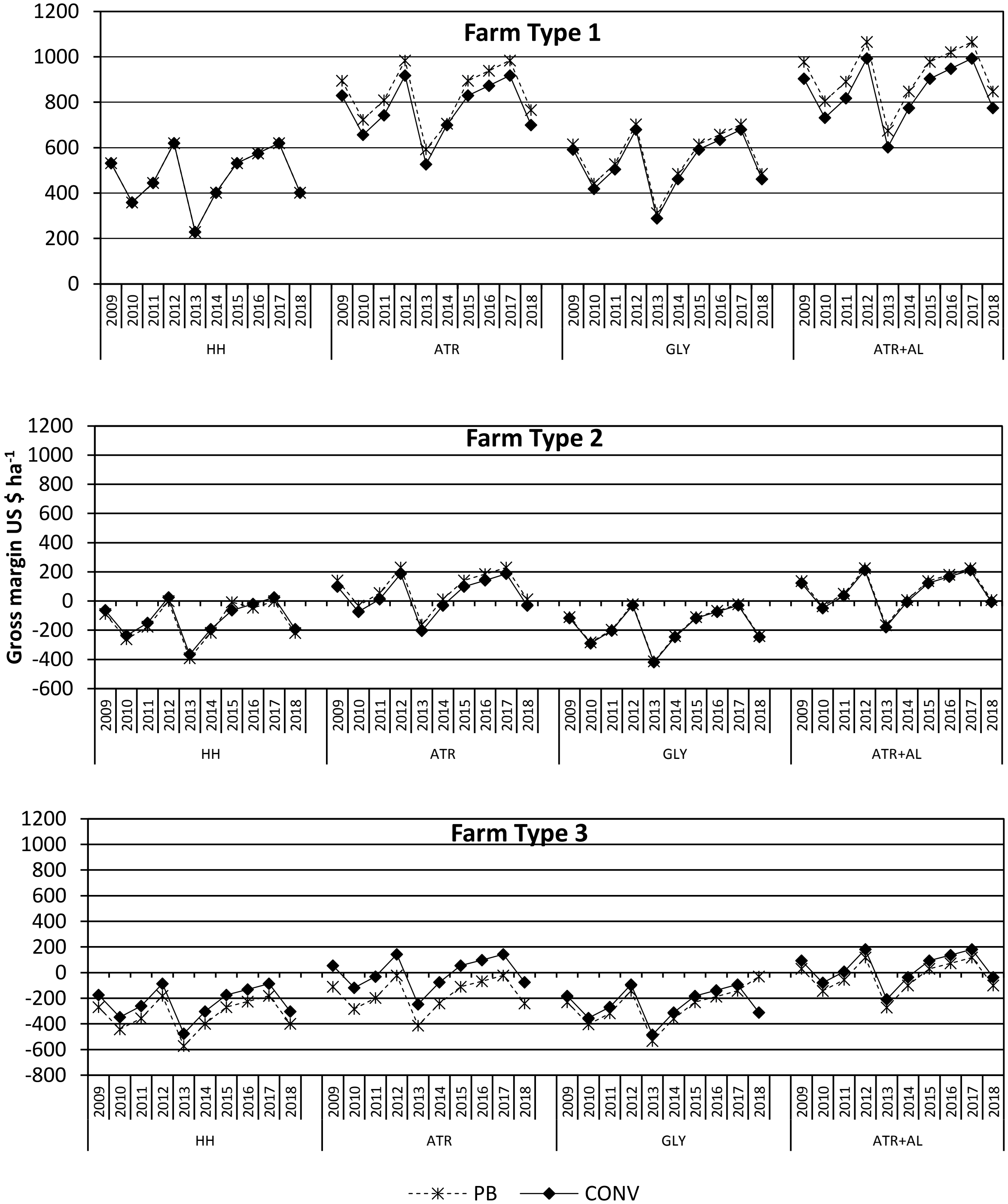

Figure 7.10 Gross margins for weeding options subjected to high fertiliser variation. PB = Planting basin. Tillage; CONV = Conventional Tillage; HH = hand hoe; ATR = atrazine; GLY = glyphosate; AL = alachlor; Farm Type 1 = Well resourced; Farm Type 2= Medium resourced; Farm Type 3 = poorly resourced farmers

7.4.2.8 Average Gross Margin for High Herbicide Prices

The high herbicide prices affected the gross margin for Farm Type 2 and 3 resulting in negative gross margin in both tillage systems (Figure 7.11). The gross margin for Farm Type 1 remained positive for all the four treatments. The highest gross margin was also observed for atrazine + alachlor treatment US$ ha^{-1}100, 204, 97 in CONV and US$ ha^{-1} 1015, 236, 207 in PB for Farm Type 1, 2 and 3, respectively (Figure 7.11). The hand hoe weeded treatment had the lowest gross margin US$ 611,-10, and 190 in PB and in CONV US$ 655, 61, -50 for Farm Type 1, 2 and 3, respectively.

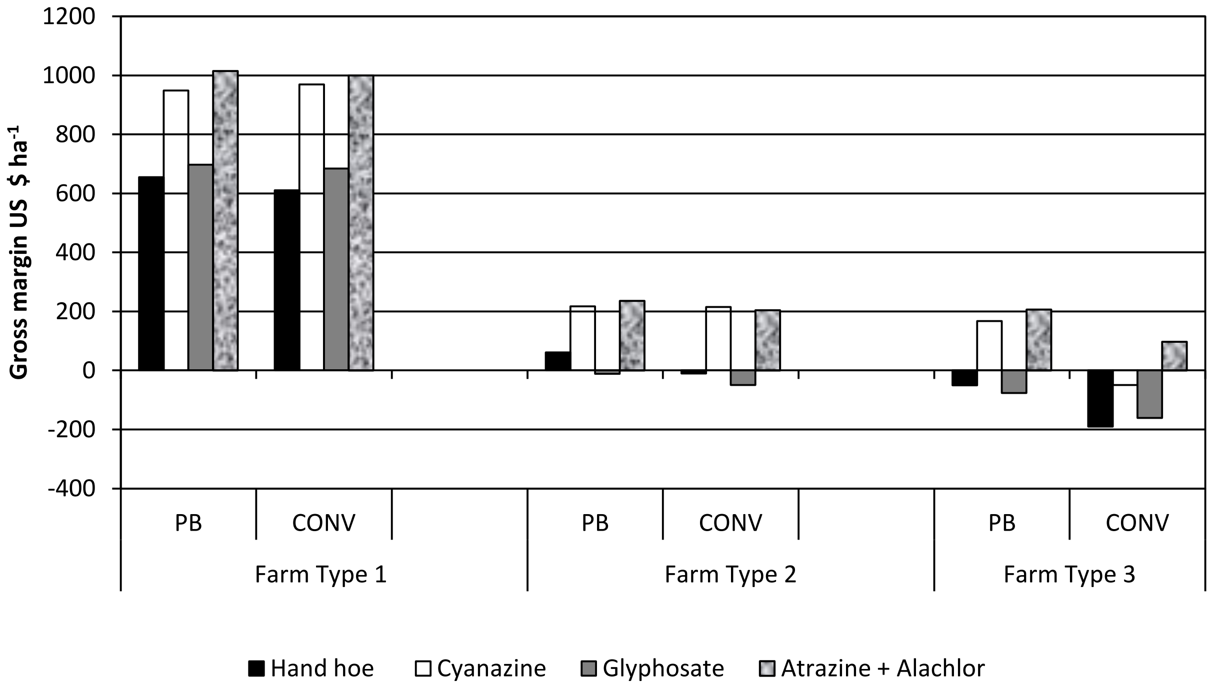

Figure 7.11 Average gross margins for 10 year simulation period of maize crop subjected to high herbicide price variation. PB = Planting basin; CONV = Conventional Tillage; Farm Type 1 = Well resourced; Farm Type 2 = Medium resourced; Farm Type 3 = poorly resourced farmers

7.4.2.9 Worst Case Scenario (Low crop price, high herbicide price, high fertiliser price)

The worst case scenario decreased the gross margin for all the four weed control treatments (Figure 7.12). The most affected treatment was the hand hoe weeded which resulted in negative gross margin in 6 out of 10 years of simulation in Farm Type 1 and 2. In Farm Type 3, there was negative gross margin in 8 out of 10 years of simulation for the hand hoe weeded treatment. The atrazine + alachlor treatment performed better than all the treatments as indicated by larger gross margin. The gross margin in PB was comparable to gross margin in CONV for all treatments.

7.4.2.10 Combined Scenario (Improved Soil Fertility, High Crop Price)

A combined scenario of improved the soil fertility and high crop price improved the gross margin for all treatments (Figure 7.13). The atrazine + alachlor had the highest gross margin in all Farm Types and tillage systems. The hand hoe weeded treatment had the lowest gross margin. The combined scenario improved the gross margin for Farm Type 3 and had positive gross margin in all years of simulation for cyanazine + alachlor treatment while the hand hoe weeded treatment only had negative gross margin during five out of 10 years of simulation. The gross margin in PB was slightly higher than in CONV in some years of simulation in Farm Type 1 and 2. Whilst in Farm Type 3 the gross margin for PB was comparable to CONV.

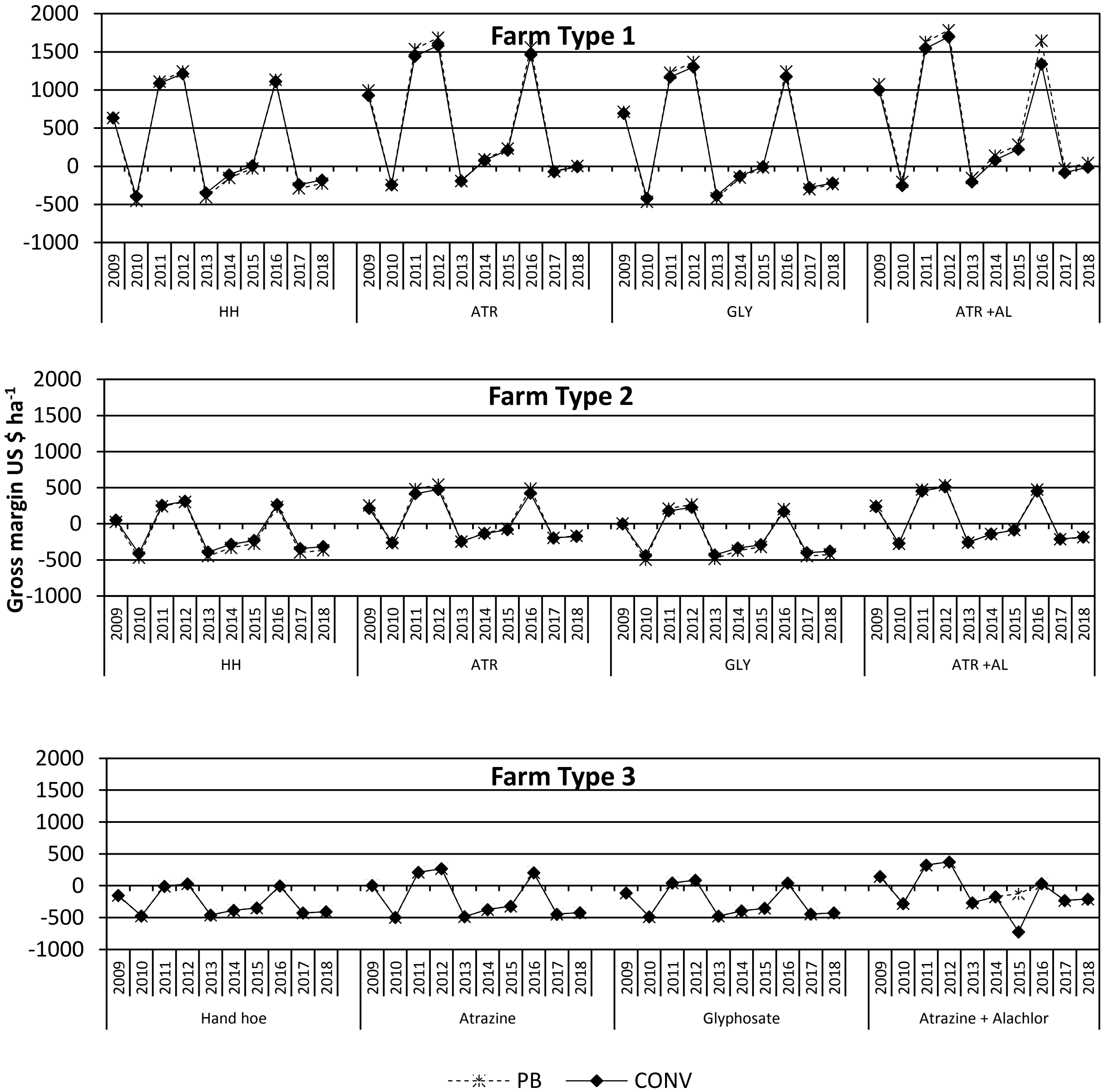

Figure 7.12 Worst case scenario (low rainfall, high herbicide price, low crop price). PB = Planting basin; CONV = Conventional Tillage; HH = hand hoe; ATR = atrazine; GLY = glyphosate; AL = alachlor; Farm Type 1 = Well resourced; Farm Type 2 = Medium resourced; Farm Type 3 = poorly resourced farmers

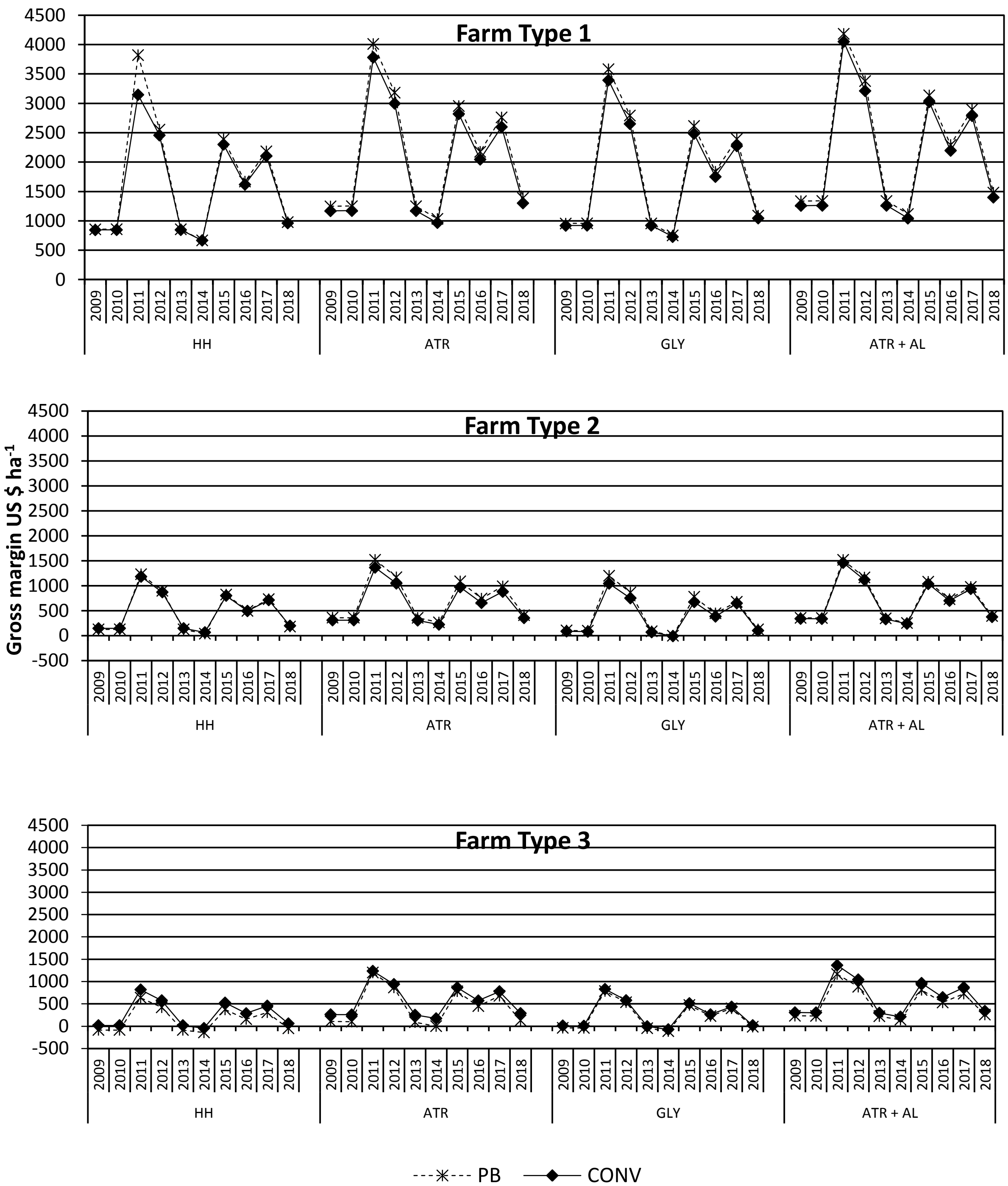

Figure 7.13 Combined scenario of improved fertility and high crop price. PB = Planting basin; CONV = Conventional Tillage; HH = hand hoe; ATR=atrazine; GLY = glyphosate; AL = alachlor; Farm Type 1 = Well resourced; Farm Type 2 = Medium resourced; Farm Type 3 = poorly resourced farmers

7.4.3 Simulations of Economic Returns under cotton

The average gross margins for 10 years of simulation under different weeding options subjected to different scenerios are shown in Table 7.2. The tank mixture of cyanazine + alachlor treatment had the highest gross margin when compared to all weed options under all Farm Types and in CONV and PB. The second highest gross margins were in the cyanazine treatment, while the third and fourth in ranking were the glyphosate and the hand weeded treatment, respectively. In Farm Type 3 the hand weeded and the glyphosate treatments had negative gross margins when subjected to low crop price and high fertiliser price variation under PB and CONV tillage systems. The highest gross margin for all treatments was in the high fertiliser and improved fertility scenario treatment while the increased fertiliser prices resulted in the lowest gross margin under all Farm Types. The gross margins for Farm Type 3 which were the lowest when compared to Farm Type 1 and 2 were increased with improved fertility.

Table 7.1 Average gross margin for 10 simulation years (2009-2018) per Farm Type under cotton for different weeding options.

		Cotton					
		Planting basin			Conventional tillage		
Crop production shocks	Weeding option	Farm type 1	Farm type 2	Farm type 3	Farm type 1	Farm type 2	Farm type 3
High fertiliser & improved fertility	HH	1480	1077	518	1951	1560	542
	CY	2309	1714.7	806	2254	1939	704.
	GLY	1886	1486.6	504	1871	1508	503
	CY +AL	2864	2224.1	713	2528	1811	883
Crop high price variation	HH	804	535.4	166	1099	1129	196
	CY	1431	991.3	439	1395	1474	375
	GLY	1070	799	161	1068	1098	175
	CY +AL	1671	1371.4	381	1664	1377	495
Crop low price variation	HH	159	44.5	-108	344	318	-114
	CY	595	278	108	573	671	74.
	GLY	293	167	-162	303	366	-104
	CY +AL	775	561	71	658	615	136
High fertiliser price variation	HH	375	128	-145	647	647	-113
	CY	896	526	121	901	962	69
	GLY	591	366	-154	694	620	-135
	CY +AL	1223	876	72	1045	885	165
Improved soil fertility	HH	775	512	350	1561	1560	378
	CY	1393	958	635	1846	1946	551
	GLY	1035	769	351	1490	1267	357
	CY +AL	1748	1335	563	2075	1825	706
Rainfall variation	HH	548	331	34	817	818	65
	CY	1100	498	293	1023	1135	248
	GLY	762	539	24	765	789	79
	CY +AL	1390	1049	250	1215	1028	343

HH= Hand hoe weeding; CY= Cyanazine; GLY= Glyphosate; ATR=Atrazine; AL= Alachlor

7.5 DISCUSSION

Smallholder farmers spend between 50 to 70 percent of labour time on weeding (Chikoye *et al*., 2007). Therefore, herbicides have the potential to reduce the labour time required for weeding and ultimately reduce the labour bottlenecks early in the season as reports in a pot study by

Gianessi (2009). Reducing the time required for weeding will allow farmers to devote their time to other farm operations (Muoni *et al*., 2013). The use of herbicides reduces the weeding burden on women and children; hence this allows women to concentrate on other household activities, while children focus more on school.

Reducing the time required for weeding by herbicide usage aids timely weed control. In this study the time required for weed control with tank mixed and single applications of pre-emergence herbicides was statistically similar. The hand weeded treatment in PB required more labour for weeding than in CONV because of the higher weed densities in PB. This implied that hand weeding was not effective and showed the need for other weed management options in PB (Mandumbu *et al*., 2012). The labour required for hand weeding was statistically similar to glyphosate treatment and there was no advantage of glyphosate in terms of saving labour. This was mainly because the glyphosate had no residual effects and only controlled existing weeds at planting and subsequently more labour was required for hand weeding. This, therefore, made pre-mergence more advantageous than glyphosate alone. Alternatively, there is need to apply pre-emergence herbicides after applying glyphosate, however, the costs will be higher.

The pre-emergence herbicides atrazine + alachlor increased the gross margin by US$ 351.00 and US$ 373.00 in PB and CONV, respectively, under Farm Type 1 in maize. The cyanazine + alachlor treatment also increased gross margin by US$ 849.00 and US$ 399.00 in PB and CONV, respectively in cotton. It therefore shows that it is economical to use herbicides for weed control than hand hoes which is consistent with the findings by Muoni *et al*. (2013). The gross margin for cyanazine only and atrazine only treatments were similar to the herbicide. It therefore implied that farmers could only use cyanazine; however, given that cyanazine mainly controls broad leaves, it will be better to apply a mixture of the pre-emergence herbicides. This helps to avoid the build up of grass weeds. The higher gross margins for the hand hoe weeded under CONV than the PB treatments are explained by the higher labour requirements for land preparation and weeding in PB.

The higher margin per hour for PB emanates from higher manual labour requirements for land preparation using hand hoes to make planting basins unlike in CONV, were the ox drawn plough requires less labour (FAO, 2011). The digging of planting basins is laborious (Andersson *et al.*, 2011). Similarly, the time required to make planting basins in this study was noted to be almost two times higher than the labour time required for the CONV method of land preparation. The high labour required for land preparation in PB cited in Zambia resulted in 69 percent more labour than required for CONV method of farming (FAO, 2011). A study by Siegel & Alwang (2005) indicated that 30 to 34 person days per hectare was required for making planting basins. Nevertheless, the time required to make planting basins was expected to decrease with time as the farmers are expected to plant in the same holes in the subsequent seasons (Haggblade & Plerhoples, 2010) with minimal maintenance. However, dry season land preparation was a challenge for SH farmers since they preferred not to do non-farm activities (Umar *et al.*, 2011).

The higher gross margin in Farm Type 3 under CONV indicated that herbicides had more advantage in CONV than PB. The negative gross margin for Farm Type 3 for hand hoe weeding was because of the low yields and the higher costs of weeding. This underscored the need to focus on improving yields by enhancing the fertility of the soils.

The OLYMPE model was useful in assessing the resilience of different farming systems based on the gross margin under climatic, input and output prices variations. Cotton which is considered as a cash crop was more resilient than the staple maize crop. However, the decreasing world market prices for cotton during the past 10 years have deterred cotton production in Zimbabwe. Internationally, the depressed cotton price was due to the United States (US) and to some extent European Union (EU) inputs subsidy schemes on agriculture which has been a subject of debate worldwide (www.seatini.org). Without subsidies similar to their counterparts in the EU or US, Zimbabwean farmers have to bear the costs of production. Diversifying crop production to include cotton in addition to maize safeguards the livelihoods of farmers during years when the maize production is low. This allows the farmers to rely on the sales of cotton to obtain cash to buy food and other household requirements. Cotton is also an important cash crop for the country with approximately 300 million kg of cotton produced annually, out of which 70 percent is exported to the international market, while 30 percent is reserved for domestic consumption. Considering the need to encourage the production of cotton in Zimbabwe by maintaining optimal profitability for the cotton farmers, the government should consider regulating the cotton produce selling price and input costs. Farm Type 1 was more resilient to price variation, high inputs costs, and rainfall variation than Farm Types 2 and 3. Farm Type 1 can be targeted for innovations since farmers are less likely to be at risk to any adverse changes that may occur in agricultural production. Farm Type 3 is at risk to any shocks and it would not be appropriate to target these farmers though they deserve new technologies to improve their production. The negative average gross margin for maize crop for Farm Type 3 is a threat to the production and food security and is exacerbated by low rainfall, high inputs costs of fertilisers, seed and herbicides. Furthermore, the yields obtained by Farm Type 3 are below the minimum requirements of 500 kg ha^{-1} for a family of five persons indicating that this group of farmers are food insecure (Magombeyi & Taigbenu, 2008).

The crop production is threatened by frequent droughts which occur after every two to five years in Zimbabwe (Mupangwa *et al*., 2012). Type 3 farmers have to apply inorganic fertilisers and manure in order to improve soil fertility. Farmers tend to reduce fertiliser usage due to the associated high costs and in most cases apply less than 250-350 kg ha^{-1} (Dar & Twomlow, 2004). There is a need for the Type 3 farmers to improve the soil fertility before they can benefit from the herbicide technology and PB. The negative gross margin for Farm Type 3 therefore shows that the variable production costs exceed the income indicating a need to change the production practices that are associated with weed and soil fertility management.

The gross margin from the weeding options varied with various agronomic and economic scenarios such as price of inputs associated with the risks that farmers can expect when they adopt different weeding options. In all the scenarios the gross margin for pre-emergence herbicides remained high. The most affected was the hand hoe weed treatment largely due to the low yields and the high labour requirements. An increase in herbicides could also influence the gross margin; however, this depends on the resource endowments of the farmers.

Overall this study raises the need to complement hand hoe weeding with pre-emergence herbicides for effective weed control in PB. It was apparent in this study that herbicides reduced labour requirements and costs compared to the hand hoe, hence increased returns. The herbicides have potential to reduce labour bottlenecks currently faced in the SH sector. Overall the herbicides reduced the time and increased the gross margin in cotton and maize however the response differed with the farmer resources. The Farm Type 3 did not benefit from using herbicides because of the low yields. There is a need to improve soil fertility so that farmers can benefit from the herbicides and PB. From the results of this study, it is proposed that pre-emergence herbicides should be integrated with hand hoes.

There is need for the Government to avail loans to farmers to purchase herbicides and fertilisers, considering the relatively high costs that are involved in purchasing these key farming inputs. There is a need to introduce smaller package herbicides in the local markets, which are not only easily accessible to the farmers, but also relatively affordable. There is also need to train the local extension officers in the SH sectors on identification of weeds and the appropriate application of herbicides so that they can improve their level of assistance to local farmers.

The findings of this study have the following policy implications:

1. Availability of herbicides in the local market and schemes to purchase herbicides. There is need for continuous training of extension officers to enhance their knowledge of chemical weed control. This will capacitate them to help farmers in the identification of weeds, selection of appropriate herbicides and correct usage of herbicides in order to avoid environmental pollution in Zimbabwe.
2. There is need for policies that facilitate access to small packaged fertiliser and manure for use by farmers to improve soil fertility and yields. This will likely enhance the farmer's income.
3. There is need for the government to regulate input and producer prices for crops in order to improve the farmers' income from crop sales.

7.6 CONCLUSION

It was evident that there is diversity in agro-ecology and socio-economic farm conditions, such that PB was not applicable to all categories of farmers, particularly the resource-constrained farmers, although they are the most deserving. Different techniques should be promoted to suit different farmers' socio-economic conditions, as blanket recommendations are not sustainable. Hoe weeded treatment resulted in the lowest gross margin. The treatments with tank mixture of alachlor + atrazine, alachlor + cyanazine reduced weeding costs and increased the gross margin when compared to hand hoe weeding. There is a need to develop policies that increase crop production for Farm Type 3, since the low yields are a threat to food security. Weed management should be complemented by practices that enhance crop yield such as manure and fertiliser application. Policy interventions that deal with access to herbicides, and also fertilisers and manure could help deal with both short and long–term fertility problems in resource-constrained farmers. Planting basin system is labour intensive; it generally requires extensive labour for weeding and preparations of basins. Planting basin's high labour requirements for land preparation may force farmers to allocate it smaller areas due to the drudgery of digging basins despite the economic benefit. Therefore, PB should be promoted among farmers with access to large labour pool or introduce low costs equipment for use by the SH farmers. Policy changes that enable the careful use of herbicides would help increase crop productivity and reduce labour in the SH sector, thereby positively impacting the adoption and adaptation of PB without negative consequences to the environment. There is a need for government to increase agricultural subsidies to cushion farmers against global price changes. The results are important for supporting decision making and planning by extension workers and for complimentary efforts by researchers to improve weed management in the SH sector under PB.

CHAPTER 8

GENERAL DISCUSSION

8.1 Introduction

This study which evaluates the socio-economic and crop production constraints that affect the adoption of CA, seeks to contribute to the body of knowledge on the CA with particular reference to Zimbabwe. By so doing, the study also seeks to capacitate policymakers and researchers in their planning and implementation of comprehensive CA strategies. Consistently, the study evaluated the effect of tillage on weed density and diversity on fields in transition from CONV to PB, with the view to proffer advice regarding the development of effective weed management strategies. Furthermore, an evaluation to ascertain the effect of soil properties and management on weed density and diversity in PB was conducted. An exploratory study was carried out to evaluate the effectiveness of chemical weed control in the SH sector to effectively manage weeds in PB. Finally an economic analysis was carried to compute returns for economic analysis of chemical weeding options under different farm typologies using a socio economic farm systems simulation model, OYLMPE. This chapter provides a synopsis of the whole study and puts into perspective how the findings can be used to improve weed management and allow adoption of BP for sustainable crop production.

8.2 Adoption of Conservation Agriculture

The socio-economic factors that determine the adoption of CA that have been identified in this study include inter alia; the farmer's age, level of formal education, access to extension services, availability of labour, draft availability and land size. The adoption of all the three CA components mainly increased with education draft power and labour availability with young and educated farmers adopting all CA components. Most of the farmers adopted minimum tillage (Planting basin) as one of the principle of CA. The lack of adoption of all the three principles of CA (minimum soil disturbance; permanent soil cover and, diversified crop rotations) by most farmers implies that farmers may fail to realise the benefits of CA, such as improved soil fertility, soil water conservation and increased income, which have been reported elsewhere (Baker *et al*., 2007; Kassam, *et al*., 2009). Giller *et al*. (2009) strongly believed that for the benefits of CA to be realised all the foregoing principles should be applied simultaneously. With regards to permanent soil cover it was observed that the mulch needed to cover the soil was not only used as stock feed but also for other household purposes. Consequently, farmers are faced with a dilemma of keeping 30 percent of soil covered or using the mulch for other critical purposes as stock feeds. The benefits of crop residues include restoring of soil organic matter which can lead to water holding capacity, soil structure and soil fertility (Chivenge *et al*., 2007). There is therefore likely to be low soil organic matter levels and nutrient cycling due to continual nutrient mining without replacement.

Considering that mulch can suppress weeds (Murungu *et al*., 2010), in adequate mulch can cause serious weed management problems. The increased weed density and the farmers' over reliance on the hand hoe to curb weed growth, partly explain why farmers failed to adopt CA on fields greater than one hectare. The survey revealed that the adoption of CA was inhibited by increased weed density and incremental labour requirements for weeding among other reasons. By implication, increased weed density in PB would likely exacerbate weed management problems that are prevalent in the SH, thereby curtailing the adoption of CA. With increased weed densities in PB, farmers are not likely to effectively control weeds in time due to labour constraints.

The experiments in Chapter 4 confirmed the survey results that PB resulted in increased weed densities, however, the effects of tillage on weed density depended was soil type dependant. Considering that weed management has already been one of the major constraints to crop production in the SH sector. The increased weed densities will exacerbate weed management problems already prevent. It therefore implies other weed management which are as result of shortage of labour and weeding alternate weeding options. The weed species density and diversity differed from field to field due to the influence of soil type, socio-economic and management factors. This phenomenon was confirmed in Chapter 5, wherein 32 percent variation of the weed densities data was influenced by soil properties, socio-economic and management factors. The socio economic and management factors had the greatest effect on weed densities when compared to soil properties and tillage. Access to extra capital from non farm had the greatest effect on weed densities. Access to capital enabled farmers to hire extra labour which is important for timely weed control. These results help to explain the inconsistent findings on weed dynamics in BP. The heterogeneity in weed composition among farms warrants careful attention in designing weed management strategies. Since the changes to weed density are not solely due to tillage, it is therefore, not appropriate to design weed management options which are specific to PB. Weed management options need to be specific for each field characteristics depending on the soil type and management. There is need to consider the distribution pattern of weeds, density and history of the field when designing weed control options. The findings of this study showed that it could be wrong to generalise that weed management in PB is a challenge, as the effect of tillage on weeds is an interaction of soil properties, socio economic and management factors. However, despite the observed increase in weed densities in PB, the weed species composition in PB and CONV were not significantly different. This contradicts other studies which reported that PB alters weed species composition and results in proliferation of perennial weeds species (Nyagumbo, 2009; Chauhan *et al*., 2012). It might not have been possible to observe the changes of weed species composition in BP in this study because it was a short term study and the changes might be evident over a long period of time.

The high yield losses under PB were as a result of increased competition for nutrients due to high weed densities. Though there was an increase in weed density in PB, a period of learning and adjustment is required during the initial stages of adoption of CA. There may be increased labour requirements in PB but there are opportunities for decreasing weed density in CA with time (Wall, 2007). Nevertheless, this assertion needs to be verified experimentally especially under PB were there are no crop residues and crop rotation.

8.3 Weed Management in Planting Basins

This study showed that weed control strategies had an effect on weed densities. The hand hoe weeding option was not effective in weed control under PB since it resulted in the highest weed densities and lower yields. Pre-emergence herbicides which include single application of atrazine and alachlor as well as the mixtures of atrazine + alachlor and cyanazine + alachlor were effective in weed control and reduced costs of weeding. The herbicides treatments resulted in competitive advantage crops of over weeds which led to increased yields. However, there was differential effectiveness of herbicides among the fields. This showed that blanket recommendation was not effective suggesting a need to consider appropriate rates of herbicides for each field. Though herbicides were effective in weed control, there is need for a holistic approach to weed management in CA which should be focused on the reduction of weed emergence and prevention of the propagule. Herbicides cannot be used in isolation hence the needs for an integrated approach to avoid build up of specific weeds. An integration approach which includes crop rotation, mulching, winter weeding, precision application of fertiliser and intercropping should be incorporated to complement herbicides. Though herbicides effectively control weeds under PB in the SH sector limited knowledge and capacity on how to use the different herbicides currently prevents the farmers from effectively using them. There is therefore a need to offer training and schemes which can aid farmers to purchase herbicides.

8.4 Economic Analysis of Herbicides in the Smallholder Sector

The OLYMPE model was important in accessing the economic performance of herbicides in the SH sector. A combination of qualitative and quantitative data in calibration and validation provided a robust approach and model credence in estimating the impact of crop management, rainfall and market price variations. Pre-emergence herbicides reduced the weeding time thereby compensating for the costs of the herbicides. The gross margin varied with the weeding options. The pre-emergence herbicide treatments had the highest gross margin while the hand hoe weeded treatment had the lowest gross margin. The higher gross margin in the pre-emergence herbicide treatments was a result of high yields achieved. Atrazine + alachlor increased the gross margin by US $ 351 and US$ 373 in PB and CONV, respectively under Farm Type 1. While cyanazine + alachlor treatment increased gross margin by US $ 849 and US $ 399 in PB and CONV, respectively when compared to hand hoe weeding. The gross margin for the pre-emergence herbicide treatments was higher than the hand hoe weeded option even when subjected to worst case scenarios. The gross margin for PB was lower than for CONV in the hand hoe weeded option particularly for the resource poor farmers. This was a result of higher costs of weeding due to higher weed densities in PB coupled with high costs of land preparation and low yields. The economic viability of the PB system can be enhanced by using rippers and jab planters to reduce labour costs as required during land preparation. It became evident that there is need to capacitate the resource poor farmers so that they can increase their yields. The gross margin for Farm Type 3 (poorly resourced) was negative mainly due to low yields. It is also important to be aware of agricultural shocks such as rainfall variation, high crop prices, and inputs costs as they have an impact on the gross margin and had a negative impact particularly on the hand hoe weeding treatment. The limitation of the OLYMPE model was that it could not simulate social human behaviour but it could only simulate the consequences of human decisions. The model also did not account for pest and diseases which may affect crop yields.

8.5 CONCLUSION

- Socio-economic factors which include: the farmer's age, level of formal education, access to extension services, availability of labour, draught availability and land size played a critical role in the adoption of CA.
- In this short term study, PB resulted in increased weed densities, but tillage has shown mixed impact on weed density and diversity. In this regard, increased weed densities in PB was an

interaction of many factors inter alia, soil properties, socio-economic and management factors.

- The high weed densities at 3 WACE had negative impact on crop yields particularly in PB.
- Pre-emergence herbicides effectively controlled weeds and reduced the associated costs of weeding.
- From simulations, climate, input and output price variations had an impact on the gross margin and in all situations the hand hoe weeded treatments had the lowest gross margin.

8.6 RECOMMENDATIONS

1. It is imperative for PB farmers to practice earlier weeding to avert crop yield losses. Alternatively, farmers who can afford herbicides can mix atrazine + alachlor for maize and cyanazine + alachlor for cotton for timely and efficient weed control.
2. There is a need to overcome challenges associated with herbicide usage in the SH sector particularly on knowledge of herbicide usage through training.
3. The weed management strategies should consider field history, management and soil types before recommendations can be made particularly for SH who are often given blanket recommendations.
4. One of the major factors that determined the weed densities was access to capital. There is need for loans or subsidy schemes so that farmers can purchase herbicides.

8.7 ACCEPTANCE/REJECTION OF HYPOTHESIS

1. Hypothesis accepted: Farmer socioeconomic factors affected the level of CA uptake
2. Hypothesis accepted: Weed density and diversity significantly ($P<0.05$) increased but was dependant on soil type.

3. Hypothesis accepted: Soil properties factors affected ($P<0.05$) weed density and diversity
4. Hypothesis accepted: The use of herbicides reduced ($P<0.05$) costs of weeding.

8.8 RECOMMENDATIONS FOR FURTHER RESEARCH

1. Long term studies are required to evaluate the ecology of weeds under PB and observe changes in the weed seed bank in PB in the SH sector. It is also important to determine the long-term fate of seeds that remain in the seed bank due to the absence of tillage that brings buried seeds to the soil surface.
2. There is need for more labour studies on larger farm size plots and where real-time labour input is recorded under CA.
3. Further studies are required to explore other factors that interact with tillage in to determine weed densities in PB.
4. There is need to undertake long-term studies in Zimbabwe's other four Agro-ecological regions. Results from these studies, would provide a comprehensive review of PB in all agro-ecological regions.

8.9 CONTRIBUTION TO KNOWLEDGE

The study contributed the following:

- Identified socio-economic factors such as the farmer's age, one's level of formal education, access to extension services, availability of labour, draught availability and land size that affect the level of CA uptake and the resultant challenges during the transitional phase from CONV to CA.

- Weed densities increase during the transitional phase from CONV to BP in the SH sector in loamy and clay loam soils while no changes were observed in sandy soils.
- Established that in addition to tillage, soil properties, socio-economic and management factors influence weed density and diversity during the transition phase from CONV to PB.
- Demonstrated that herbicides were effective in weed control and economical under PB in the SH sector.

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APPENDIX 1

Kadoma livelihoods, farming systems and weed management survey in Conservation Agriculture.

Enumerator's name……………………….

Date……………………………………

Case number…………………………..

Explain the purpose of the survey, the length of time it will take and request the participation of the designated person. This survey is being carried out to obtain information on the differences that occur between conventional and Conservation Agriculture practice and to understand how farmers make decisions on crop and weed management. This will assist researchers and farmers in identifying better weed management options which farmers can practice to improve their productivity and welfare. The project would be grateful if you could spare an hour of your time to answer the following questions. The information you give will be used in the strictest confidence.

Household details

Q1. Location (to be completed by the enumerator)

……………………………………………

village 10 ☐ *village 11* ☐ *village 12* ☐

village 13 ☐ *village 15* ☐ *village 16* ☐

Q2. Are you the head of the household (tick the appropriate)?

Yes ☐ *No* ☐

Q3. If not what is your relationship with the head of the household?

Wife ☐ *Son* ☐ *Other* ☐ *Husband* ☐

Daughter ☐

Q4. What sex is the head of the household?

Female ☐ *Male* ☐

Q5. What is the marital status of the head of the household?

Single ☐ *Married* ☐ *Widowed* ☐ *Divorced* ☐ *Separated* ☐

Q6. What age is the head of the household?

Less than 25 years ☐ *25-35years* ☐ *36-45 years* ☐ *46-55years* ☐ *56-65 years* ☐ *over 65years* ☐

Q7. What is the highest level of education of the head of the household?

Advanced ☐ *tertiary* ☐ *None* ☐ *secondary* ☐ *Primary* ☐

Q8. Do household members hold any qualifications including short courses?

Yes ☐ *No* ☐

If yes Specify

………………………………………………

………………………………………………

……………………………………

Q9. Do you have any household member who attended an agricultural workshop this growing season (2008/2009)?

Yes ☐ *No* ☐

If yes, what was the purpose of the workshop?

....
....
....

Q10. Where did the head of the household originally come from?

Local ☐ *Mash West* ☐ *Manicaland* ☐

Midlands ☐ *Masvingo* ☐ *Mash Central*
Other ☐ *Midlands* ☐ *Mash East*

Q11. How many people live and work in the household? (Indicate number for each age category in the space provided and includes head of household) P= Live permanently D=Provide daily labour O= Provide occasional labour

	P	D	O
Males over 60	☐	☐	☐
Females over 60	☐	☐	☐
Males 15-60	☐	☐	☐
Females 15-60	☐	☐	☐
Males under15	☐	☐	☐
Females under 15	☐	☐	☐
Males under 5	☐	☐	☐
Females under 5	☐	☐	☐

Q12. Does your household hire labour?

Yes ☐ *No* ☐

Q13. State what is this labour for?

Permanent Labour ☐ *Picking Cotton* ☐ *Cutting stocks* ☐
Weeding ☐ *Ploughing* ☐ *spraying* ☐
Other specify ☐

………………………………………………
………………………………………

Q14. How this is labour paid?

Cash ☐ *Ploughing their land* ☐ *Food* ☐
Other (specify)

……………………………………………………
……………………………………………………
……

Q15. Does anyone in your house work on other people farms?

Yes ☐ *No* ☐

Q16. If yes who is this?

Husband ☐ *Wife* ☐
Children ☐ *Others* ☐
Specify

Q17. If yes how is payment received?

Cash ☐ *Ploughing* ☐
Food ☐ *Other* ☐

Q18. Where do you normally get your agricultural information? Enumerator please indicates the main sources by ticking the boxes.

AREX	☐	*UP*	☐	*Radio*	☐
Agricura	☐	*COTTCO*	☐	*TV*	☐
CARGILL	☐	*NGOs*	☐	*CTC*	☐
UP	☐	*Family*	☐	*Pamphlets*	
Other farmers	☐	*Books*			

If other specify

………………………………………………
……………………………………………

Q19. When did you last receive information on farming (Please indicate the period in months?

……………………………………….…
……………………………………………

Q20. Do you seek extension advice or it is brought to you

…..
....

Q21. How often do you receive technical advice on agriculture?

Never	☐	*Every six month*	☐	*Monthly*	☐
Once a year	☐	*Weekly*	☐	*Every three months*	☐

Q22. Have you ever been trained in cotton production?

Yes ☐ *No* ☐

Q23. If yes what is the training institution?

CTC	☐	*COTTCO*	☐	*NGO*	☐
AREX	☐	*Other*	☐		

Q24. Does anyone in the household belong to any of the following groups or clubs?

None	☐	*Garden*	☐	*Livestock*	☐
ZFU	☐	*Sewing*	☐	*Poultry*	☐
Master Farmer	☐	*Savings club*	☐	*UP*	☐
COTTCO Group	☐	*Master farmer trainee*	☐	*Other*	☐

If other specify………………………………………………
……………………………………………….

Assets-Land

Q25. What is the total area of the land you own (Ha or acres)?

Total area……………………

Q26. When was the land cleared for cultivation?

Less than 3years ago	☐	*6-8 years ago*	☐	*12-15 years ago*	☐
3-5 years ago	☐	*9-11 years ago*	☐	*over 15 years ago*	☐

Q27. What is your main soil type?

Alluvial Black	☐	*Sandy loam*	☐	*Sandy*	☐
Red soil	☐	*clay loam*	☐	*other*	☐

Specify
………………………………………………
………………………………………………
……………………………………….

Q28. What area of crops did you plant last year? (Acres or ha)

Groundnuts ………..

Beans ………..

Pumpkins ………..

Maize ………..

Cotton ………..

Sorghum ………..

Fallow ………..

Bambara nuts ………..

Garden ………..

Other ………..

Specify which crops

Q29. Do you borrow or lease land from others?

Yes ☐ *No*☐

Q30. If yes what is the size of the land

……………………………………………

Q31. How did you acquire the piece of land?

Given by Inherited☐ *Allocated by Chief*☐ *Purchased*☐
Allocated by RDC ☐ *Other* ☐
Unknown

Assets – Cattle and Implements

Q32. How many of the following livestock does the household presently own? (Indicate number)

Bulls ……….

Oxen ………..

Cows/heifers …………

Young cattle/calves …………

Donkeys …………

Goats …………

Sheep ……….

Pigs ………..

Poultry ………..

Q33. Did the household own enough animals to make a ploughing team last season?

Yes ☐ *No*☐

Q34. If not how did you, plough your land

Friend/ Relative helped ☐ *Borrowed animals* ☐ *Hired tractor* ☐
Hired Animals ☐ *other* ☐

Q35. If you hired or borrowed animals how did you pay?

Cash ☐ *Credit* ☐ *Food* ☐ *working* ☐
Give land ☐ *Other* ☐
If other specify

Q36. If you hired or borrowed impliments how did you pay?

Cash ☐ *Credit* ☐ *Food* ☐ *working* ☐

Give land ☐ *Other* ☐
If other specify

Q37. What was the makeup of the ploughing team?

	Oxen	*Cows*	*Young Cattle*	*Donkeys*
Single span 2 animals	☐	☐	☐	☐
double span 4 animals	☐	☐	☐	☐
double span 6 animals	☐	☐	☐	☐

If other specify
……………………………………………………
……………………………………………….

Q38. How many hand tools do you own?

None ☐ *Forks* ☐ *Machete* ☐

Axes ☐ *Shovels* ☐ *Knapsack sprayer* ☐

Wheel-Barrow ☐ *Hoes* ☐ *Other* ☐

Q39. How many animal drawn implements do you own that are in working order

None ……..
Ploughs ………
Cultivators ………
Ridgers ………
Planters ………
Planters ………
Harrows ………
Scotch carts ………
Water carts ………
Other

Specify……………………………………….
……………………………………………….

Farming system

Conventional agriculture
Q40. What was the total area under the conventional agriculture last year …….

Q41. Are you going to increase or decrease the area under conventional agriculture?

Give reasons for your plan
……………………………………………………
……………………………………………………
……………………………………………

Planting
Q42. How do you prepare the land for planting the following crops
Maize…………………………………...
Cotton………………………………….
Other……………………………………

Q43. When do you plant the following crops? Indicate the month
Maize………………………………….
Cotton………………………………….
Other……………………………………

Q44. Do you apply cattle manure?
Yes ☐ *No* ☐

Explain if No…………………………..

Q45. Do you apply inorganic basal fertiliser?
Yes ☐ *No* ☐

Q46. Do you practice crop rotation?
Yes ☐ *No* ☐
Explain…if yes…………………………..

Q47. Do you leave the crop residues for use during the next season?

Yes ☐ *No* ☐

Explain if Yes..…………………………………..
……………………………………………….

Q48. What do you understand about Conventional agriculture?
…………………………………………………
…………………………………………………
…………………………………………………
……………………………………
Q49. How long have you been practicing Conventional Agriculture?
…………………………………………………
…………………………………………………
………………………………………
Q50. What do are the benefits of Conventional Agriculture?
…………………………………………………
…………………………………………………
………………………………………
Q51.What are the disadvantages of Conventional Agriculture?
…………………………………………………
…………………………………………………
…………………………………………………
……………………………………
Q52. How did you obtain information about Conventional Agriculture?
…………………………………………………
…………………………………………………
…………………………………………..
Q53.What were the yields under Conventional Agriculture for cotton and maize
…………………………………………………
…………………………………………………
………………………………………

Conservation Agriculture
Q54. What was the total area under the conventional agriculture last year for cotton and maize
…………………………………………………
…………………………………………

Q55. Do you intend to increase or reduce the area give reason for your answer……………………………………
…………………………………………..

Planting
56. How do you prepare the land for planting the following crops?
Maize……………………………………..
Cotton……………………………………
Other……………………………………

Q57.When do you plant the following crops Indicate the month
Maize………………………………………
Cotton……………………………………….
Other…………………………………………

Q58. Do you apply cattle manure?
Yes ☐ *No*☐

Explain if No……………………

Q59. Do you apply inorganic basal fertilizer?
yes ☐ *No*☐

Q60. Do you practice crop rotation?
yes ☐ *No* ☐
Explain……………………………

Q61. Do you leave the crop residues for use during the next season?

Yes ☐ *No*☐

Explain……………………………………
……………………………………………

Q62. What do you understand about CA?
…………………………………………………
…………………………………………………
…………………………………………………
……………………………………
Q63. How long have you been practicing CA?
…………………………………………………
…………………………………………………
………………………………………
Q64. What do you like about CA?
…………………………………………………

…………………………………………………
……………………………………….
Q65.What are the disadvantages of CA?
…………………………………………………
…………………………………………………
…………………………………………………
……………………………………
Q66. How did you obtain information about CA?
…………………………………………………
…………………………………………………
…………………………………………..
Q67.What were the yields under CA cotton and maize
…………………………………………………
…………………………………………………
……………………………………….

Weed Management in conventional tillage

Weed management
68. When do you start weeding specify for each crop

Maize		*Cotton*	
1ST week	☐	*1st week*	☐
2nd week	☐	*2nd week*	☐
3rd week	☐	*3rd week*	☐

Q69. Which are the common weeds prevalent in your area..5.............
....6............................
....

Q70. Rank the weeds according to the ease of control
...1...
2..3.
....4....
....5.......
....6.........
....

Q71. How many times do you weed the cotton fields?

No weeding ☐
Once ☐ *Twice* ☐ *Thrice* ☐
Four times ☐ *Five* ☐

Q72. In which month did you weed your cotton?

A	S	O	N	D	J	F
☐	☐	☐	☐	☐	☐	☐

Q73. Did you abandon any cotton fields last year?

☐ *Yes* ☐ *No*

If yes what the area

Q74. If yes what was the reason?

Poor Germination ☐ *Bad weeds* ☐ ☐ *Pest problems*

Q75. If yes how many times did you weed before abandoning the field?
…………………………….
Q76. How did you undertake weeding in the maize land fields?

	1st	2st	3st	4st	5st
Hoe only	☐	☐	☐	☐	☐
Herbicide	☐	☐	☐	☐	☐
Plough Only	☐	☐	☐	☐	☐
Cultivator only	☐	☐	☐	☐	☐
Hand Pulling	☐	☐	☐	☐	☐
Cultivator	☐	☐	☐	☐	☐

Q77. If a herbicide is used which one

………………………………….

Q78. Who normally does the weeding on cotton W=Women M=Men C=Children H=Hired labour N=Nhimbe) Tick boxes

	W	M	C	H	N
Hoe	☐	☐	☐	☐	☐
Hand	☐	☐	☐	☐	☐
Pulling	☐	☐	☐	☐	☐
Plough	☐	☐	☐	☐	☐
Cultivator	☐	☐	☐	☐	☐
Herbicide					

Q79. List and rank the problem you are facing in weed control

1……………………………………
2……………………………………
3……………………………………
4……………………………………
5……………………………………

Q80. Do you remove weeds in winter
……………………………………………………
……………………………………………………
……………………………………………………
…………………………………..

Q81. Have you observed any changes on the following issues that pertain to weeds
Weed density……………………………..
Weed species ……………………………..
Labour for weeding……………………….

Q82. What herbicides did you use last year?

None ☐ *Bladex* ☐ *Cottonex* ☐

Prometryn ☐ *Cottco guard* ☐ *Agil* ☐

Metachlor ☐ *Alachlor* ☐ *Atrazine* ☐

Gramoxone ☐ *Glyphosate* ☐ *Other* ☐

Specify

Q83. How big was the area you covered?
Have you ever used herbicides any other time?

Yes ☐ *No* ☐

Q84. If yes why did you stop

Costly ☐ *Not effective* ☐
Caused Crop Injury….. ☐ *Lack of knowledge of application* ☐
Other ☐

Q85. D o you remove weeds in winter
……………………………………………………
……………………………………………………
……………………………………………………
…………………………………..

Weed Management in conventional tillage

Weed management

Q86. When do you start weeding specify for each crop

Maize		*Cotton*	
1^{ST} week	☐	*1^{st} week*	☐
2^{nd} week	☐	*2^{nd} week*	☐
3^{rd} week	☐	*3^{rd} week*	☐

Q87. Which are the common weeds prevalent in ☐ your area?
...1..
2..3.
....4....
....5.......
....6.........
....

Q88. Rank the weeds according to the ease of control
...1..
2..3.
....4....
....5.......
....6.........
....

Q89. How many times do you weed the cotton fields?

No weeding ☐
Once ☐ *Twice* ☐ *Thrice* ☐
☐ ☐

Four times *Five*

Q90. In which month did you weed your cotton?

A S O N D J F

☐ ☐ ☐ ☐ ☐ ☐ ☐

Q91. Did you abandon any cotton fields last year?

☐ *Yes* ☐ *No*

If yes what the area

Q92. If yes what was the reason?

Poor Germination problems ☐ *Bad weeds* ☐ *Pest* ☐

Q93. If yes how many times did you weed before abandoning the field?

…………………………….

Q94. How did you undertake weeding in the cotton fields?

	1st	2st	3st	4st	5st
Hoe only	☐	☐	☐	☐	☐
Herbicide	☐	☐	☐	☐	☐
Plough Only	☐	☐	☐	☐	☐
Cultivator only	☐	☐	☐	☐	☐
Hand Pulling	☐	☐	☐	☐	☐
Cultivator	☐	☐	☐	☐	☐

Q95. If a herbicide is used which one

………………………………….

Q96. Who normally does the weeding on cotton W=Women M=Men C=Children H=Hired labour N=Nhimbe) Tick boxes

	W	M	C	H	N
Hoe	☐	☐	☐	☐	☐
Hand Pulling	☐	☐	☐	☐	☐
Plough	☐	☐	☐	☐	☐
Cultivator	☐	☐	☐	☐	☐
Herbicide					

Q97. List and rank the problem you are facing in weed control

1…………………………………

2…………………………………

3…………………………………

4…………………………………

5…………………………………

Q98. What herbicides did you use last year?

None ☐ *Bladex* ☐ *Cottonex* ☐

Prometryn ☐ *Cottco guard* ☐ *Agil* ☐

Metachlor ☐ *Alachlor* ☐ *Atrazine* ☐

Gramoxone ☐ *Glyphosate* ☐ *Other* ☐

Specify

Q99. How big was the area you covered? Have you ever used herbicides any other time?

Yes ☐ *No* ☐

Q100. If yes why did you stop

Costly ☐ *Not effective* ☐

Caused Crop Injury….. ☐ *Lack of knowledge of application* ☐ *Other* ☐

Q101. D o you remove weeds in winter

……………………………………………

……………………………………………

………………………………………………
…………………………………..

Q102. Have you observed any changes on the following issues that pertain to weeds
Weed density……………………………..
Weed species ……………………………..
Labour for weeding……………………….

Q103. Thank you that is all. Is there anything that you would like to add?

The End

Thank you