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AN EVALUATION OF CONSERVATION AGRICULTURE WEED CONTROL TECHNIQUES IN SUGAR BEAN PRODUCTION AT HATCLIFFE, HARARE, ZIMBABWE

BY

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Abstract

Weed control is considered a major obstacle for Conservation Agriculture (CA) farmers in the smallholder sector of Zimbabwe. In most cases, losses caused by weeds exceed the losses from any category of agricultural pests. The research aims to evaluate different techniques of controlling weeds under CA practises on labour, cost of producing a tone of sugar beans, yield and weed biomass and density. The study was conducted at Hatcliff Institute of Agriculture , Harare which is located $17^{0}42^{'}$ S ad 31^{0} 0n6$^{'}$E and at altitude of about 1500m above sea level. A randomized complete block design was used with four blocks and five treatments. The treatments were replicated four times. The weed control treatments were; were conventional (C), complete herbicides (CH), spot herbicides application plus hand pulling (SHC), spot herbicides application plus, hand pulling (SHHP). The sugar bean variety Kware was used. The trial was set up in January 2020.The weed density and biomass had no significant differences at the first two weeks after crop emergence but they showed significant differences at fourth and sixth week after crop emergence. Results indicated that there were significant differences in weed biomass and density ($p<0.001$), labour required ($p<0.001$) and cost of producing a ton of sugar beans ($p<0.001$). There was no significant difference in yield ($p=0.478$) across all treatments. The yields and production cost were 2.6 t/ha at US$18.62/t, 1.9 t/ha at US$ 12.56/t, 2.5 t/ha at US$38.31/t, 2.3 t/ha at US$64.97 t/ha, 2.2t/ha at US$19.45/t for the respective treatments. Outcomes from this study are that there are significant differences in labour and cost required in weed management of a sugar bean crop between CA and CT practices. These results do suggest that CA weed control techniques are a good basis for promoting CA in small holder farmers. These results show that CA weed control techniques have high efficacy in controlling weeds as they are more economic and provides effective timely weed control. The results imply that widespread adoption of CA weed control strategies will reduce labour requirements, improve timeliness of weed control during crop management which will result in improved yields and reduced production cost. On-farm farmer managed trials are necessary.

Key words: conservation agriculture, weed control strategies, herbicides

Declaration Page

I declare that this dissertation is my original work except where sources have been cited and acknowledged. The work has never been submitted, nor will it ever be submitted to another University for the award of a degree.

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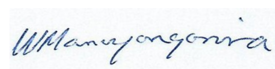
Walter Manyangarirwa  25/04/21

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Dedication

This dissertation is dedicated to my husband Elias Machingura and my children Shingirai, Masimba, Benxaviour and Ngonidzashe who have always been my pillar of strength and saw the potential and determination I have.

List of Acronyms and Abbreviations

AGRITEX	Agricultural, Technical and Extension Services
CA	Conservation agriculture
CT	Convectional tillage
CTA	Technical Centre for Agriculture and Rural Cooperation
DS	Direct seeding
FAO	Food and Agriculture Organisation of the United Nations
FEWSNET	Famine Early Warning Systems Network
WACE	Weeks after crop emergence

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CHAPTER 1 INTRODUCTION

1.1 Introduction

Conservation Agriculture (CA) has been advanced by environmentalists as one of the ways in which agriculture can reduce greenhouse gas emissions by tying organic carbon in the soil (Lugato, Leip & Jones, 2018). It has been argued that weed pressure in conservation agriculture (CA) cropping systems increases as a result of eliminating soil tillage as a management practice to control weeds (Gillet *et al*., 2009; Chauhan *et al*., 2012). Conservation agriculture (CA) is criticized for its reliance on herbicides as compared to tilled systems. Additionally, in many areas targeted by CA, herbicides are unavailable or prohibitively expensive, therefore weed control is a challenge (Ngwira *et al*., 2014). While herbicide use has succeeded in suppressing weed populations of crops under CA, the use of herbicides as a sole control mechanism increases the risk of herbicide-resistant weeds (Norsworthy, 2012). This research reviews the impact of four CA weed control strategies and one conventional practise on labour input, weed biomass and density, yields and the cost of producing a ton of sugar beans. The study aimed at evaluating conservation agriculture weed control techniques in sugar bean production.

In many CA systems, farmers turned almost exclusively to herbicide use to address increases in weed populations due to no-tillage practices, leading to massive weed resistance against potent herbicides such as glyphosate (Kirkegaardet *et al*., 2014).

The sub-Saharan African region is faced with increasing demand for food from the ever-increasing population (FAO, 2000). In Zimbabwe, the annual average production of sugar beans is 0.5 metric tons (Mt) per year which constitutes 0.25 Mt for direct human consumption and the other 0.25 metric tons for canning consumption (Esterhuseizen, 2015).

Soil degradation affects farmers worldwide, including those in Zimbabwe (Tittonell *et al*., 2012). Conservation agriculture (CA) has been proposed as an alternative to conventional tillage practice over the last four decades and has been increasingly tailored to African conditions (Wall *et al*., 2014). Soil degradation from conventional tillage practices emphasizes the importance and need for systems that increase soil organic matter content and improve soil structure (Tittonell *et al*., 2012). The vulnerability of small-holder rain fed farming systems to erratic and reduced rainfall associated with climate change further highlights the need for farming practices that adapt to the impacts of climate change (Thierfelder *et al*., 2018. To avoid soil erosion and degradation and to improve soil health, CA appears to be appropriate good solution. However, to support the adoption of CA, weed management challenges are anticipated and addressed with practical solutions, particularly for small-scale farmers, because they are vulnerable and may quickly get trapped in a vicious weed cycle that goes along with poverty.

Study by (Heijting *et al.*, 2009), showed cultivation following harvest significantly increased weed seed dispersal and work by (Barroso *et al*., 2006) found that weed seeds travelled 2–3 m in the direction of tillage, while in un-tilled soils the distance was negligible. Reducing tillage can therefore reduce the spread of weed seeds both within and across fields. Changing tillage regimes changes the disturbance frequency of the farm field, which results in a shift in weed species (Boscutti *et al*., 2015). Compared to tilled soils, higher weed species diversity has been observed in No till (NT) seed banks (Murphy *et al*., 2006). Studies that report no increase in diversity with NT all found either crop rotation or weather had a larger effect on weed species diversity Ref. While tillage will contribute to community shifts, the weed species present will be an expression of both management and the environment (Plaza *et al*., 2011; Boscutti *et al.*, 2015).

It has been shown that NT combined with residue removal leads to a severe degradation in soil quality (Verhulst *et al*., 2009), but there are few studies that have assessed at the behaviour of weeds in these systems. Often, studies concerning tillage do not include a NT treatment with residue removal or a CT treatment with surface residue, so the interactions between NT and surface residue are unclear. Study study by Anderson (1999) used a sweep plow that tilled to a depth of 5–8 cm but left 90 % of the residue on the surface. In this study they found that sweep-plowed fields had weed densities 35–50 % higher than NT fields, but the study did not include a CT treatment so the weed suppression of residue wasn't estimated. Some work done in Zimbabwe compared CT, NT, and NT + Res, and found similar weed biomass in CT and NT + Res, while NT without surface residue had nearly double the weed biomass (Ngwira *et al*., 2014). The latter study indicates in some NT situations residue provides significant weed control, but more research is needed to clarify the exact mechanisms. There is evidence NT + Res promotes seed predation, increasing predatory seed loss by two to three fold (Menalled *et al*., 2007) compared to CT systems, but again it is not clear if it is due to

NT, residue retention, or their interaction. Allelopathic suppression of weed seed germination via surface residue may be more effective in NT since seeds are concentrated near the soil surface, where allelopathic compounds will be released by the residue.

In Zambia it was found that labour demands increased from 27 person days per ha under conventional tillage to 35, 58, and 81 person days per ha under ripper tillage, hand hoe tillage, and planting basins, respectively (Haggblade & Tembo, 2003). Traditional weed control is done by hand pulling of weeds, by using hand hoewhich can have a short or long handle, and through more mechanical systems such as animal traction cultivators.

Other studies indicate that increased weed pressure in CA systems often results from farmers failing to adhere strictly to no-tillage practices. In fact, tilling the soil, even once, may reduce the benefits of CA (Anderson, 2015). A study in southern Brazil found that soil disturbance from seeding machines may be sufficient to expose weed seeds to the environmental conditions (e.g., light and moisture) necessary for germination, whereas an undisturbed soil surface, in conjunction with crop residue retention, may be sufficient to inhibit weed seed germination (Theisen & Bastiaans, 2015). The same study established that weed pressure was greater within soybean rows where the soil had been disturbed during seeding than in rows seeded using a modified seeder that left crop residue intact and did not disturb the soil. Although the study by Theisen & Bastiaans (2015) addressed soil disturbance during seeding, it is reasonable to assume that soil disturbance during the weeding process may have similar impacts on the weed seed bank. This implies that strictly following no-tillage guidelines may reduce weed pressure for farmers who would have just started CA practices.

Approximately 75 % of smallholder farms in sub-Saharan Africa use hoe-weeding or hand pulling as a weed management strategy; finding supplementary methods to hoe-weeding is therefore essential for easing labor demands in CA systems. Herbicide use, for example, is estimated to reduce labour demands for weeding by 90 % as compared to hoe-weeding (Gianessi *et al*., 2009). Work in Zambia reported that herbicide use had the potential to reduce labor demands from 50–70 to 10–20 person days per ha (Haggblade & Tembo, 2003). Labour reductions provide an additional social benefit as manual weeding in southern Africa is frequently taken on by women and children, and any reduction is beneficial for these household members. Much of the research previously conducted on weed suppression under CA systems focused on large-scale commercial farms in Australia and the Americas or on humid areas of the tropics and subtropics (Flower *et al*., 2012). While several researchers have focused on weed ecology and control under smallholder CA systems in semi-arid areas Africa (Mashingaidze *et al*., 2012; Muoni *et al*., 2014; Nyamangara *et al*., 2013), a comprehensive review and summary of the options available and alternatives to smallholder farmers in southern Africa has been missing. The overall objective of this study was therefore to fill this knowledge gap by generating research results of weed management studies under dryland CA systems and applying them to the context of southern Africa.

1.3 Statement of problem

Weed control remains one of the greatest challenges to the practice of CA on smallholder farms with low inputs (Lee & Thierfelder, 2017). Under CA weed control via tillage is no longer an option, and weed communities and growth dynamics will change compared to conventional tillage systems; the methods of weed control under CA will also need to be adjusted. Information on what CA adopters should expect and effective ways for controlling weeds in CA systems are needed.

The absence of tillage, under conservation agriculture, requires other measures of weed control. One of the ways in which this is realized is through herbicide application (Giller *et al*., 2009; Chauhan *et al*., 2012). However, environmental concerns, herbicide resistance and access to appropriate agro-chemicals on the part of resource-poor farmers, highlight the need for alternative weed control strategies that are effective and accessible to smallholders adopting CA (Norsworthy *et al*., 2012). Farmers in semi-arid regions contend with the additional challenge of low biomass production and, often, competition with livestock enterprises, which limit the potential weed-suppressing benefits of mulch and living cover crops.

There are very few studies that have examined both the direct and interactive effects of the three CA principles on weed dynamics (Chauhan *et al*., 2012). These types of studies are needed so that weed control can be included in cost-benefit analyses concerning the adoption of each practice (Beuchelt *et al*., 2015) and be incorporated into analytical models of weed dynamics.

1.4 Research Objectives

1.4.1 Main objective

The main objective was to evaluate the performance of four different CA weed control techniques and their effects on crop establishment cost in sugar bean production.

1.4.2 Specific objectives were to determine how CA weed control techniques affect:

a) The number of emerged weeds and weed biomass in sugar bean production.

b) Labor requirements in sugar bean production.

c) Grain yield.

d) The cost of producing sugar bean.

1.5 Research questions: Do weed control techniques affect:

a) The number of emerged weeds and the weed biomass for sugar bean production under CT and CA system?.

b) labour requirements for sugar bean production under CT and CA system?.

c) grain yield of sugar beans produced under CT and CA system?.

d) production cost of sugar bean produced under CA and CT system?.

1.6 Significance of the study

There is lack of information on effectiveness and production cost of different CA weed control techniques. Sustainable weed control techniques can be manipulated to produce sugar bean at reduced input cost, making sugar bean viable and eventually reducing price for the retail outlets and affordability of sugar bean by the majority of people. CA practices have not been widely adopted in Zimbabwe despite the proven benefits on reduced soil degradation and soil fertility. This is mainly due to weeds which grow faster in the undisturbed soil, requiring more effort to keep the fields clean. This therefore has led to the need to evaluate different CA weed control techniques and determine impact on effectiveness of each technique and the production costs. The objective is to provide information on the effects of CA weed control techniques on weed biomass, yield, labour, time and cost.

1.7 Delimitation of the Study

The study was conducted at the institute of Agriculture Engineering at Hatcliffe in Harare with the following coordinates $17^{0}42^{'}$ S and $31^{0}06^{'}$E. The site is in natural region II a with red clay soils (Moyo 2000). The study was conducted during the 2019/2020 summer cropping season.

1.8 Limitations to the Study

The rainfall was not constant throughout the growing period during the field research phase.

CHAPTER 2 REVIEW OF RELATED LITERATURE

2.1 Introduction

This chapter is a review of the literature on the conservation agriculture weed control techniques in sugar bean production. The study is based on the conceptual framework based on three principles namely minimum tillage, soil cover and crop rotation. These three aspects have major effects on the germination and growth of weeds in CA. To avoid soil erosion and degradation and to improve soil health through the retention of organic carbon, CA appears to be an appropriate solution (Lugato *et al*, 2018). However, to support the adoption of CA, weed management challenges should be anticipated and addressed with practical solutions, particularly for small-scale farmers.

Work by (Heijting *et al*., 2009) showed that cultivation following harvest significantly increased weed seed dispersal, whereas studies by (Barroso et al., 2006). showed that weed seeds travelled 2–3 m in the direction of tillage, while in un-tilled soils the distance was negligible. Reducing tillage can therefore reduce the spread of weed seed both within and across fields. Conservation agriculture (CA) research was motivated by declining soil fertility, soil erosion, declining crop yields, poor soil moisture retention and non-response to inorganic fertilizers (FAO, 2010). The early studies on CA research started in the late 1980s to 2000 in Zimbabwe (Thiefildier *et al*., 2014). This work focused on improving soil organic carbon, reducing erosion and improving soil physical properties. This was despite the fact that major gains for research and development efforts in the green revolution era focused on enhancing production and productivity (Gupta *et al*., 2005) through the expansion of cultivated area and development of hybrid high yielding crop varieties. Crop production then was based on conventional tillage.

Challenges from conventional tillage are demands that issue of efficient resource utilisation, soil and water conservation receive high priority so that the current gains of reduced soil erosion improved water infiltration and increased productivity in agricultural production can be sustained (Nyagumbo *et al*., 2009. The early work proved that soil degradation and soil loss was evident as a result of overworking the soil from conventional tillage. This was the basis on which intensive studies on CA started from 1988 in Zimbabwe (Thiefider *et al*., 2014). CA is regarded as a sustainable system of reclaiming soil fertility and reducing degradation through reduced soil tillage.

2.2 The Challenge of Weed Management in Conservation Agriculture

Although CA is gaining recognition for its positive effect on soil conservation, it is still not widely known by many farmers around the world. For those who are familiar with the concept, a major challenge lies with weed management. Although, in the long run, some of the challenges reported in the literature for minimum or no-tillage systems, may not be valid for well managed CA crop production systems, they should be considered and anticipated, particularly for the first years, until the soil weed seed bank accumulated during tillage years has been substantially depleted (Streit *et al*., 2007).

In addressing weed control challenges, studies have provided evidence that minimum and no-tillage induces shifts of weed population particularly towards perennial weeds, thus creating a long-lasting weed problem (Thierfelder *et al*., 2018). In general, small-seeded weeds that require light to break dormancy will likely become the dominant weed species in minimum and no-tillage systems, including in the first years of adoption of CA. Thus, effective weed management is considered a critical issue and determines success in minimum and no-tillage based systems and CA (Giller *et al*., 2008). Success with adoption of minimum and no-tillage, as reported in several publications, is attributed to the use of herbicides to control weeds, reduce inherent yield loss and cope with lack of labor in most countries (Fernandez-Cornejo & McBride, 2005). In many cases, minimum and no-tillage, herbicides are considered as alternatives to primary tillage, done in tillage-based systems, for pre-planting weed control (Canon, 2001). Several authors indicate that herbicides have reduced reliance on traditional tillage methods to control weeds and have led to the adoption of minimum and no-tillage practices. Even when cover crops are grown for mulching and weed control, burn-down herbicides are often used to kill the vegetation before planting. The herbicides commonly used for weed control, as a replacement for primary tillage, include 2,4-D, dicamba, diflufenzopyr, fluometuron, glyphosate, glufosinate and paraquat. Alternatives are yet to be identified for some of the herbicides on this list that includes slightly (Class III) or moderately (Class II) hazardous herbicides that can be harmful to human health and the environment (Canon, 2001).

Actually, the challenge of using herbicides for weed control in minimum and no-tillage and CA is further complicated by the fact that mechanical incorporation of herbicides into the soil is not possible with no-tillage or ridge-till systems, which limits herbicide options to only post-emergence. As a consequence of the use of herbicides, resistance of several weed species in minimum and no-tillage systems has been reported, and cases of multiple-resistance of the same weed species to several herbicides have also been documented (Johnson *et al*., 2009). Therefore, alternatives to herbicides should be promoted to support adoption of CA in a farming environment where resistance to herbicides has occurred.

Commercial release of glyphosate resistant crops has simplified weed control and in some regions the adoption of minimum and no-tillage, however, a negative aspect is that multiple applications of the herbicide are now typical, in the absence of other weed management strategies including those before crop emergence and additional in-season treatments to control weeds that emerge after crop planting. Such a huge selection pressure induced by the use of a single herbicide has quickly led to the emergence of glyphosate-resistant weeds (Ruiz *et al*., 2009). CA systems, with their emphasis on crop rotations and associations, will reduce weed pressure; however, there is a challenge for farmers who engage in CA in an environment where resistance to glyphosate has occurred, as this will reduce the applicability of the herbicide. Clearly, unless weed management is sustainably addressed in CA, particularly in the first years, weed pressure, weed resistance and inherent crop yield losses may deter farmers from adopting conservation practices such as direct seeding. Instead, farmers will continue to rely on tillage which contributes to problems such as soil erosion, degradation of soil quality, high carbon footprint and yield reduction in the long run (Sattler & Nagel, 2009).

2.3 Constraints to adopting CA in Zimbabwe

The small holder farming sector in Zimbabwe like any other in the region has not fully adopted CA despite the benefits cited (Mupangwa *et al*., 2016). The major limitations for widespread adoption are residue retention required for mulch. The practice is prevalent in mixed farming system with cropping and livestock production. This is the most common farming system in the small holder sector in Zimbabwe and the region (Mupangwa *et al*., 2013). Free ranging systems in winter leave animals grazing on crop residue. This is mainly attributed to lack of grazing faced by small holder farmers (Thiefilder *et al*., 2012) as sufficient crop residue is required to cover the soil minimum tillage and crop rotation for a practice to be regarded as CA. in addition to the scarcity of mulch, weeds present some major challenge areas to preserve crop residue.

Weed control by the traditional manual way of hoe weeding for both conventional and CA practise is labour intensive. Conventional tillage starts with a clean field from the complete soil inversion while on the other hand CA start with late weeds if no winter weeding was done (Mavungaidze *et al*., 2016). As a result, weed were regarded as a major in the CA practices which increase labour demand for weeding including in winter. Mavunganidze *et al*., (2016) further proposed coming up with options on weed management strategies to address constraints. This is one of the major reasons why farmers opt for CT which starts with a clean field. Risk and uncertainty on practicing CA are major facts that influence the adoption of CA (Pannella, 2014). In addition, economic limitations required interventions that are economically viable for adoption of CA in the small holder sector.

The study was motivated by the desire to evaluate the current available CA weed control techniques options which are currently being promoted in the small holder farming sector of Zimbabwe. The results are envisaged to come up with new evidence on weed control to facilitate widespread adoption of CA. in addition, evidence of short term benefits for stimulation of CA should be provided.

2.4 Mechanical weed control

Convectional tillage techniques involve ploughing to break the soil to greater depth and inverting soil thereby burying organic matter and weeds (Mitchell *et al*., 2010). Follow-up operations are discing or tine harrowing and rolling to break the natural forces binding the soil particles together exposing the soil to erosion at the same time spending time on these operations. Tractor based conventional tillage techniques have been cited as the major drivers of climate change through carbon dioxide emitted from the various operation required to prepare land for crop establishment (FAO, 2014). Methane produced by draught animals during enteric fermentation and release via belches also contributes to climate change (FAO, 2014). The gases are mostly emitted during land preparation for crop establishment. In addition, conventional tillage techniques are widely criticised for land degradation, situation of rivers, dams, formation of gullies and high cost of production and at the same time not increasing productivity (Nyagumbo *et al*., 2009). Earlier studies have established that conventional tillage practices affect soil properties when implemented continuously and in turn affect the way in which crops respond to fertilizer management practices and plant growth (Mafongoya *et al*., 2015)

Conventional tillage is a mechanical method of weed control that can kill live weeds before they reproduce, thus preventing seed production; it is a useful tool for controlling established weed populations. In select CA systems there is still the opportunity for weed control via mechanical soil disturbance, an example being the reshaping of permanently raised beds (Govaerts *et al*., 2007). However in general, once a weed is established in CA fields, options for termination before seed-set are limited to herbicides and hand weeding. The soil structure and environment from which a weed seedling emerges may affect its seed production; however, the effect is likely inconsequential.

In one study Clements *et al*., (1996) found that seed production of common (*Chenopodium album* L.) on a per plant basis was the same across four tillage systems. The number of weeds is likely a more important metric compared to the number of seeds produced per weed. In CA systems, preventing weed establishment may therefore be more crucial in preventing weed seed production than in tilled systems. Seed dispersal and recruitment may be affected by tillage practice. Field traffic and machinery operations such as tillage provide opportunities to introduce or spread weed seed (Buhler *et al.*, 1997). One study showed cultivation following harvest significantly increased weed seed dispersal (Heijting *et al*., 2009), and another found the weed seeds travelled 2–3 m in the direction of tillage, while in un-tilled soils the distance was negligible (Barroso *et al.*, 2006). Reducing tillage can therefore reduce the spread of weed seed both within and across fields.

Changing tillage regimes changes the disturbance frequency of the farm field, which results in a shift in weed species (Boscutti *et al*., 2015). While there is consensus that the weed species composition will shift in response to changes in tillage, whether the diversity of the weed community increases is less clear. Ecologically, highly disturbed environments will tend to be simpler than more stable ones. Compared to tilled soils, higher weed species diversity has been observed in CA seed banks (Murphy *et al.*, 2006). Studies that report no increase in diversity with NT all found either crop rotation or weather had a larger effect on weed species diversity. While tillage will contribute to community shifts, the weed species present will be an expression of both management and the environment, which in many cases may be simply the weather (Boscutti *et al.*, 2015).

The common assumption that NT systems favour perennial weeds may be true in some cases but is by no means universal. The ecological succession theory suggests that perennials will come to dominate undisturbed systems. Indeed high disturbance environments such as CT systems have been shown to favour annual broadleaves, while lower disturbance NT systems favour perennial weeds and species that can successfully germinate on the soil surface such as annual grass (Taa *et al*., 2004). However in a literature review Moyer *et al*., (1994) found there are certain weeds (both annual and perennial) that thrive in NT systems and others which are suppressed. This may be because NT systems still experience periodic disturbance via field activities and depending on the timing, activities that damage or remove above ground material such as harvesting can effectively kill perennials (Mohler, 2001b). In another review of literature, researchers found no consistent trend in long-term tillage studies regarding increases in perennial weeds, and concluded that changes in weed management often associated with crop rotation plays a large role in dictating weed communities (Swanton *et al*., 1993). Reduced tillage may amplify the selection of weed species whose lifecycles and resource demands complement those of the agronomic crop, regardless of annual or perennial classification (Dorado *et al.*, 1999). Indeed there are reports where changing to NT in rotations including two or more crops did not result in an increase in perennial weeds (Tuesca *et al*., 2001).

2.5 Crop residues

Crop residue may be kept in the field in either CT or NT systems (CT + Res and NT + Res, respectively). In CT + Res the residue is incorporated into the soil, with the depth and extent of mixing depending upon type of tillage. Although incorporated residue may affect weeds via altered nutrient dynamics, the effects will be highly dependent on the type of tillage used, the carbon to nitrogen ratio of the residue, the type of soil, and the environment (Liebman & Mohler, 2001). It is therefore difficult to extract useful generalities. This study focused on the effects of surface residues on weeds regardless of tillage regime. Results the effects of residue found were grouped accordingly.

2.6 Germination of weed seeds

Surface residues can affect seed germination via physical and chemical changes in the seed environment. The two main physical effects include a reduction in light and soil surface insulation. Insulation of the soil surface has implications for both soil temperature and moisture. Even under heavy crop residue loads, most seeds on the soil surface receive sufficient light to trigger germination (Teasdale & Mohler, 1993). As such, decreased weed seed germination due to insufficient light-availability is likely not a major advantage of residue retention.

Surface residue decreases the daily maximum soil temperature but has little effect on the daily minimum (Teasdale & Mohler, 1993) resulting in two changes: cooler average soil temperatures and less drastic fluctuations. Most agronomic crops and many weeds require soil temperatures above a certain threshold in order to germinate—lower average soil temperatures would therefore delay germination of both. This delayed germination and resulting shorter growing season of the crop can reduce yield, and it is emphasized that residue amounts should optimize yield rather than weed control (Wicks *et al*., 1994). Some weed species' germination is enhanced by larger temperature fluctuations (Liebman & Mohler, 2001); the buffered soil temperature could therefore reduce germination rates in addition to causing later germination.

In water-limited environments residue may promote weed seed germination while in wetter conditions it may have little effect (Vidal &Bauman, 1996). This is exemplified by studies where residue was less effective in suppressing weeds in drier sites or years (Mashingaidze *et al.*, 2012, Ngwira *et al.*, 2014).

Surface residues change the chemical environment of the weed seed via allelopathy. Allelopathy is the phenomenon in which a plant produces biochemicals that affect the growth of either itself or other organisms. Allelopathic compounds can be released by live plants or when residues decompose. Allelopathic effects from crop residue tend to have more pronounced effects on small seeds (Liebman & Davis, 2000). This may be due to several factors but in general results in preferential suppression of weed growth compared to that of large-seeded crops (Liebman & Mohler, 2001). Greenhouse studies have shown allelopathic compounds can significantly reduce seed germination and may hamper seedling growth (Prati & Bossdorf, 2004). Although identification of allelopathic activity in the laboratory does not always translate to the field and it is difficult to isolate allelopathic effects of residue from associated bio-physical changes (Weston, 2000), in some situations it appears allelopathy reduces weed emergence on a field-scale (Mamolos & Kalburtji, 2001).

2.6.1 Weed seed predation, pathogen attack, and viability

Surface residue may indirectly encourage seed predation by providing foraging and nesting habitat for predators, but may also restrict their mobility. Studies have shown residue effects on predation rates depend on the type of residue, surrounding landscapes, and the type of native predator populations (Liebman, 2001). Some studies report extended season ground cover is correlated with increased predation (Heggenstaller *et al.*, 2006) while others have found no effect (Chauhan *et al.*, 2010).

Modelling studies predict that increasing vegetative cover throughout the season will decrease over-winter seed survival, which will lead to significantly lower weed populations (Davis *et al*., 2009). The plethora of external factors may explain the lack of consensus among studies.

Residue on the soil surface provides an insulated soil-atmosphere boundary that will decrease evaporative losses and maintain humidity. In moisture-limited environments this will protect seeds from desiccation. In environments with sufficient moisture, residue could promote higher rates of seed decay. The increased micro-flora activity and biomass under residue (Govaerts *et al*., 2007, Yang *et al*., 2013) would seem to encourage higher rates of seed losses under residue due to decay (Derksen *et al*., 1996, Kennedy &Kremer, 1996, Chee-Sanford *et al*., 2006). This hypothesis has had little field testing, but one study found no difference in percent seed decay in exposed versus residue protected soil (Gallandt *et al*., 2004), indicating the effects may be more complicated and could involve nutrient status and seed coat characteristics (Davis, 2009).

2.6.2 Growth and establishment of germinated weed seeds

Crop residues provide physical barriers that can prevent both light penetration and seedling emergence. The reduction in available light under surface residue has significant effects on seedling growth; as germinated seeds search for light they exhaust energy reserves and become etiolated, weak, and more susceptible to certain types of herbicide damage (Crutchfield *et al*., 1986). Light filtered through dead biomass does not change in quality, only intensity (Teasdale & Mohler, 1993). While 100% ground cover does not necessarily correspond to 100% light interception, it provides a useful proxy for estimating how much residue is needed to inhibit seedling growth. For example, in a wheat-maize rotation study Crutchfield *et al*., (1986) found that at least 3.4 Mg wheat straw per hectare was needed in order to significantly reduce weed biomass, while in a monoculture maize system in Zimbabwe. Ngwira *et al.*, (2014) found 6 Mg of maize stover per hectare was needed. In general, a linear increase in biomass results in an exponential decay in the percentage of germinated seeds that successfully emerges, although the exact relationship depends heavily on residue characteristics (Teasdale & Mohler, 2009, Ngwira *et al*., 2014). Often CA systems strive to leave at least 30% of the ground covered; while this amount of residue may provide soil quality benefits it may not significantly reduce weed germination and emergence (Liebman & Mohler, 2001). A low light environment will have a more profound effect on small-seeded annual weeds and crops, as they are initially more dependent on light compared to perennials and large-seeded species (Mohler, 1996).

Although crop residue can intercept herbicides, this does not necessarily translate to reduced weed control (Chauhan, 2013, Ngwira *et al*., 2014). Studies have shown that the weed suppression provided by surface residue more than compensates for reduced herbicide contact with weeds (Teasdale *et al*., 2003).

2.6.3 Production, dispersal, and recruitment of weed seed

Crop residues can indirectly reduce weed seed production by limiting weed growth (via light interception, physical barriers, and allelopathy)—smaller weed plants result in lower weed seed production, as the two have a strong linear relationship (Franke *et al.*, 2007). Residue may also trap wind-dispersed weed seeds, leading to higher recruitment of these weeds in systems that retain surface residue as compared to systems that leave the ground bare for large parts of the season (Tuesca *et al*., 2001).

2.7 General considerations

Many weed control methods are not effective when used alone, but when used together can interact to cumulatively reduce weeds. Numerous studies have shown the disproportionate benefits of using several methods in tandem (Westerman *et al*., 2005). Using several methods provides insurance against one method failing, and provides a buffered system of weed control that will be effective in changing and unpredictable environments.

A major criticism of CA is its enhanced reliance on herbicides as compared to tilled systems. In Canada adoption of NT has not increased herbicide use significantly (Derksen *et al*., 1996), and in the US Great Plains NT wheat systems have controlled weeds using cultural tactics and reduced herbicide usage by 50% compared to CT (Anderson, 2005). Additionally, in many areas targeted by CA, herbicides are unavailable or prohibitively expensive, thus weed control must occur through other means (Ngwira *et al*., 2014). When herbicides are utilized, higher rates of use can lead to herbicide resistance, and utilizing different herbicides is crucial to avoid infestations of herbicide resistant (Owen *et al*., 2007)

2.8 Summary

Conservation agriculture weed control techniques involves an integrated approach to the challenge presented by the problem of weed interference and has a role to play in achieving sustainable crop production to feed the growing world population. There is a suite of weed management options, including ecological weed management practices which preclude the use of herbicides. The underlying principle of CA weed management is to prevent the proliferation of weeds rather than to control them when they have appeared and started to cause damage. Also, the aim is not always to eliminate weeds entirely, but to manage populations so that the impact on crop productivity is minimal. Critical to this process is the need for high levels of biodiversity manifested, for example, as crop density, crop rotations and associations with plenty of accommodation of natural weed and weed-seed predators.

CHAPTER 3 METHODOLOGY

3.1 Description of the Study Site

The study was conducted at the Institute of Agriculture Engineering (IAE) in Harare, Zimbabwe. The IAE is located at 17^{0} 42’S and 31^{0} 06’ E and at an altitude of about 1500 m above sea level and is located in Agro-ecological region IIa. The lengths of growing seasons by agro-ecological regions in Zimbabwe are shown in Table 1 and the agro-ecological regions of Zimbabwe are shown in Figure 2.

Table 3.1: The lengths of growing seasons by agro-ecological regions in Zimbabwe.

Agro ecological region	Length of growing season (days)
I	I70-200
IIA	I40-I70
IIB	I20-I50
III	I00-I30
IV	I00-I35
V	70-I00

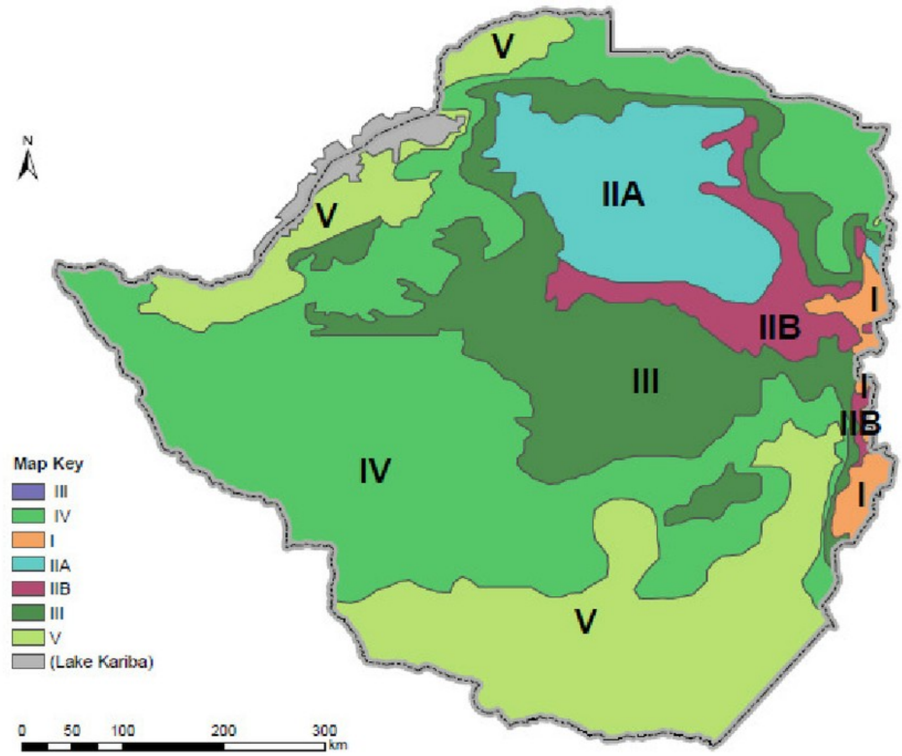

Figure 2: Map of Zimbabwe showing the spatial distribution of the agro-ecological regions (Adapted from Moyo, 2000)

3.3 Field layout of the trial

The trial plots were set up in four blocks with five treatments as shown in Figure 3. The dimensions of each plot are shown in figure 3. The gross plot was 900 m^2 (50 m x l8 m) and the net plot size was 30 m^2 (10 m x 3 m).

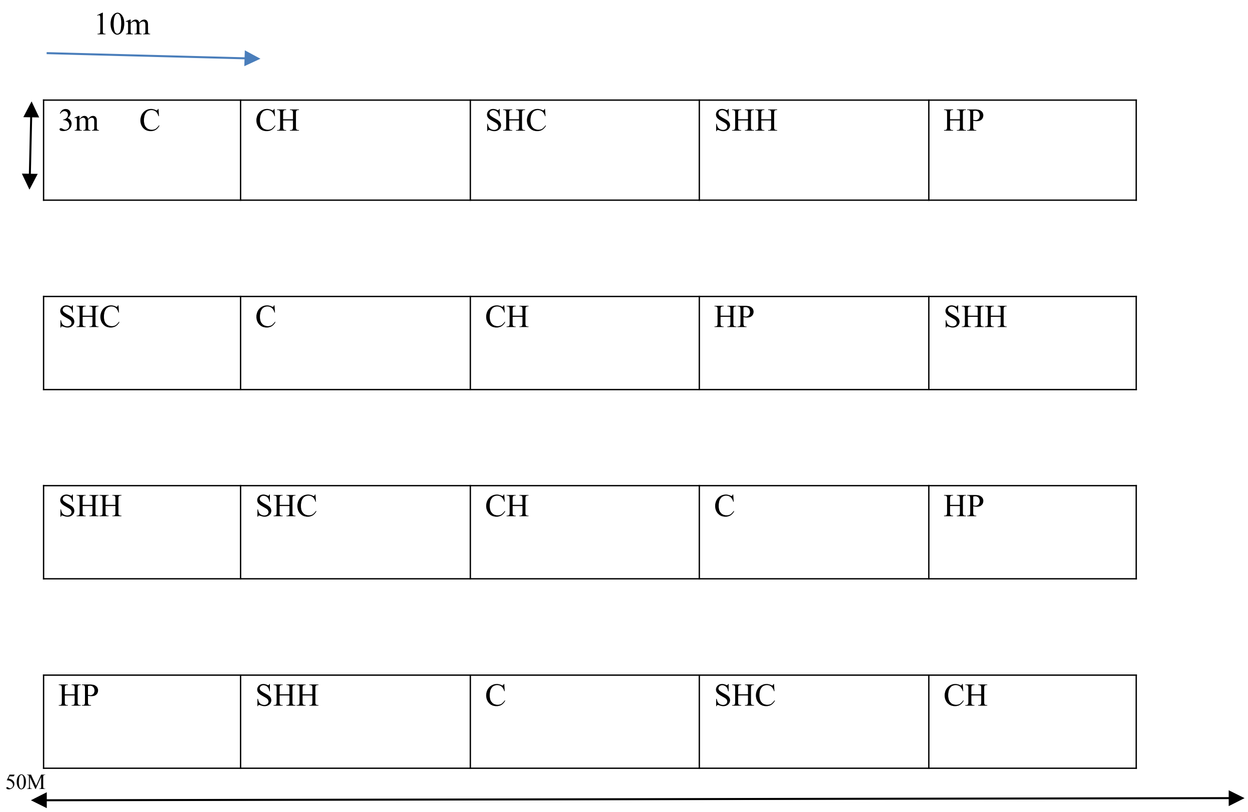

Figure 1: Field layout for the trial plots.

3.3 Descriptions of treatments for the field trial

The descriptions of the treatments used in the field trial are as given in Table 2.

Table 3.1: Descriptions of treatments used in the field trial.

Treatment	Description
1.Conventional (C)	Conventional with hoe weeding at two, four and six WACE
2. Complete herbicides (CH)	Full cover spray herbicide with Basagran at 3.61/ha at two, four and six WACE
3.Spot herbicide	Herbicide basagran application at 3.61/ha on flush weed spots at

plus crop spacing (SHC)	two, four and six WACE plus higher crop spacing
4.Spot herbicide plus hand pulling (SHH)	Herbicide basagran application at 3.61/ha on flush weed spots at two, four and six WACE plus hand pulling
5. Hand pulling (HP)	Hand pulling at two ,four and six WACE

WACE = weeks after crop emergence

3.4 Experimental Procedure

Sugar beans was planted on 1 January 2020 at the IAE. The gross plot was 900 m^2 (50 m x l8 m) and the net plot size was 30 m^2 (10 x 3). Only the conventional plots were ploughed and disked. All the CA plots were sprayed with glyphosate at the rate of 4.1 L/ha. The planting rows were marked using a direct planter at 50 cm x10 cm and 50 cm x 8 cm inter rows and in row spacing respectively. A short season variety, Kware from Klein Karoo Seeds was planted at a depth of 10 cm. Ammonium nitrate (34.5 %) was applied as a top dressing at the rate of 100 kg/ha at 3 WACE. Weed control was done after 2, 4 and 6 WACE.

Figure 4: Before and after application of glyphosate.

Initially the land looked like the first picture (figure 4) before the application of glyphosate herbicide. Thereafter all the grass dried out as is shown in the second picture (figure 5). The burnt grass automatically became the mulch. Addition of the mulch was only done in few areas where there was less existing grass at spraying. The land was then marked for planting using the animal direct planter.

3.5 Single row direct seeding using animal draft (DS)

The type of the planter used was a fitarelli. It was a single unit, planting one row at a time therefore uniformity of inter-row was within the design of the planting yoke (Figure 6). This positioned the planter being pulled at the centre of the yoke. The animals were directed along the previous planted row to maintain a constant inter row of 0.5 m. This eliminated the use of a row marker as inter-row spacing was directed by previous planted row. The planting mechanism was designed to apply seed and fertilizer at a desired rate and specific intra-row and inter-row to achieve the desired plant population and fertilizer application rates. It consisted of a seed hoper, a fertilizer hoper and a seed metering mechanism. The seed metering mechanism comprised of ground wheel for providing drive to the metering mechanism through gears, chains and a seed plate placed at the bottom of the seed hopper with holes to pick the seed and drop at the bottom of the furrow opened by the tine. The speed at which the plate rotates, determines the distance at which the seeds were placed from one another irrespective of the ground speed.

The static calibration (Getnet *et al*., 20I5) was done when the planter was stationary with the drive wheel and tine raised from the ground. This was done to facilitate rotating the planter drive wheel required number of rotations to travel a predetermined distance while collecting seed and fertilizer to verify discharge rates and adjust until the desired discharge was achieved. This was as opposed to the field method which involves pulling the planter along a predetermined distance in the field. The planter dropped seed on the surface and fertilizer was collected in a container to determine the application rates. The static method was chosen because it is quick with the main disadvantage being that the resultant setting did not factor in variations induced by field conditions especially bouncing which affect seed spacing as opposed to field calibration method (Haue *et al*., 20I4). The final setting was at 5 % more application rate to cater for field induced reductions in application rates. This method was also used successfully in testing new CA machinery in Ethiopia (Getnet *et al*., 20I5).

Sugar bean seed comes in different sizes and shapes and if not properly matched with plate holes will not go through the planter plate hole creating gaps along the row. The negative effect is reduced pant population and ultimately reduced yields. Planter plate selection involved placing the planter plates on a flat surface and placed seeds in all the holes of the plates. The plates were then lifted leaving the seed at each hole and the discarded plates had holes not dropping seed because the seed too large for a hole or the dropping more than one seed because the holes were too large for the seed.

Materials and methods mostly should be written in the past tense

Figure 5: Direct planting using animals pulling a direct seeder.

3.6 Conventional tillage using an ox drawn plough

The conventional tillage was characterised by distinct separate intensive land preparation operations to produce a fine seed bed before planting (Figure 7). The ox drawn mouldboard plough was used and set to a depth of 0.25 m at a width of cut of 0.25 m. The technique used two oxen operated by two people one controlling the plough and the other driving the animals. The second operation was planting using an ox drawn conventional planter and two operators. CT involved complete soil inversion and burial of grass leaving the ground bare and clean.

Figure 6: Conventional tillage ploughing operation using animal draft.

The objectives of ploughing were to bury organic matter create a seedbed and loosen the soil to increase water infiltration. The depth of ploughing created helped to produce pore spaces which held most of the rainfall of an average storm before saturation and runoff. The plough had a plough share which cut the soil and transported it to the mouldboard which inverted the soil back into the previous furrow. The share length gave the width of cut and had a side suction to maintain width of cut and had a point inclined downwards to give a pitch which helped penetration. The share and mouldboardwere mounted on the plough beam which werehooked to the animals through a chain and harness. The plough had a land slide to take up side forces and drove the plough straight.

3.7 Records and Data collection

Data collection and measurements for each objective are given following the chronological crop establishment and harvesting operations sequence.

3.7.1 Measurement of labour input

The number of people for each operation was recorded on the field sheets. The time taken to complete each weed control operation in the different plots was recorded and later converted to labour days per hectare. Each Labour Day is equivalent to eight hours. Estimation of labour requirements were as per Agricultural Technical and Extension Service (AGRITEX) labour day of 8 hours (AGRITEX, 2010).

3.7.2 Measurement of weed biomass and density

Weed biomass measurements were taken by placing a 0.5 m x 0.5 m quadrants three times in a plot prior to weed control. Weeds inside the quadrat were counted and recorded according to species. The weeds were then pulled and oven dried at 80 ^{0}C for 48 hours and weighed.

3.7.3 Harvesting and yields

Sugar beans was harvested at 15 % moisture content which was recorded using grain moisture test meter and was air dried and shelled at 12 % moisture content and the yield from herbicide, conventional, hand pulling, spot application plus hand pulling and spot application plus crop spacing treatments were weighed and yields were recorded in tonnes per hectare respectively.

3.7.4 Economic analysis

Economic analysis was done using the method developed by CIMMTY (1988). The method considers how proposed practises and their associated risks may impact profitability. The method involves calculating field net benefits by making partial budgets. This was done by adding all the costs that varies for each treatment as a first step. Secondly, farm gate price was multiplied by the yields to get gross profit. The net benefit for each strategy was obtained by subtracting the total variable cost.

3.8 Statistical Analysis

Data was collected on the following parameters: rainfall, weed density, weed biomass, labour days, yields and cost of production of each treatment. Data analysis was done using Genstat Release 18.1 and mean separation was done using the least significant treatment where analysis of variance (ANOVA) indicate an F test of $P<0.05$ level of significance.

CHAPTER 4 DATA PRESENTATION, ANALYSIS AND INTERPRETATION

4.1Seasonal rainfall

The cropping season was generally dry throughout and this made ox-drawn cultivation and planter penetration very difficult. The season received a total rainfall of 606 mm and the average rainfall is 700 mm per annum. The sowing date of the sugar beans was done in dry period on 1 January 2020. It was easier on the conventional treatment because of the fine tilth created at ploughing. There were no rains from 25 December 2019 to 9 January 2020. The dry period negatively affected the efficacy of the glyphosate which was used as initially clearing in CA treatments. Glyphosate effectively works well when the weed is not dry for better translocation of the chemical. The dosage rate was made slightly high to cater for the dryness. Also, the area was highly infested after receiving the first rains in the first two months of the cropping season.

The first weeding was done on 22/01/2020, second weeding on 5/02/2020. The first weeding was done when it was dry and hand pulling was a bit difficult especially deep-rooted perennial weed. This tended to increase time taken in hand pulling treatment. Pulling the weeds after rain, the soil is easier to move, and the roots will slide out with less resistance.

4.2 The effect of weed control techniques on weed diversity across the five treatments

Table 4.1 shows an inventory of the common weed species which were dominant in the experimental plots. Ten weed species comprising five grasses, two sedges and three broad leaved were found in the experimental plots and they were grouped according to their mode of reproduction.

Table 4.1An inventory of the ten predominant weed species noted in the field trial plots at the IAE Hatcliffe site.

No	Common name	Scientific name	Family	Morphology type
1	Couch grass	*Cynodon dactylon*	Gramineae	Grass
2	Natal red top	*Melinis repens*	Gramineae	Grass
3	Burgrass	*Setaria verticilata*	Gramineae	Grass
4	Annual timothy	*Setaria pumila*	Gramineae	Grass
5	Rapoko grass	*Eleusine indica*	Gramineae	Grass
6	Pig weed	*Amaranthus hybridus*	Amaranthaceae	Broad leaf
7	Gallant soldier	*Galinsoga parviflora*	Asteraceae	Broad leaf
8	Blackjack	*Bidens pilosa*	Compositae	Broad leaf
9	Purple nutsedge	*Cyperus rotundus*	Cyperaceae	Sedge
10	Yellow nutsedge	*Cyperus esculentus*	Cyperaceae	Sedge

The most dominant grass was the couch grass and the *Setaria*. There were other weed species *Acanthospermum hispidum* and *Richardia scabra* but were found in small numbers.

4.3 The effects of weed control techniques on weed density on the second, fourth and sixth WACE (Number of weeds/Ha).

The weed control treatments evaluated did not significantly (P>.001) influence weed density at the 2 weeks after crop emergence (Table 4.2). However, at 4 and 6 weeks after crop emergence the weed control treatments showed significant effects on weed density (Table 4.2). From this study, it can be concluded that all CA weeding treatments showed their superiority over conventional weeding in the production of sugar beans. Among the CA weeding treatments,

Table 4.2: The Effects of weed control techniques on weed density on the second, fourth and sixth WACE (Number of weeds/Ha).

Treatment	**Weed density 2 WACE**	**Weed density 4 WACE**	**Weed density 6 WACE**
Spot application plus pulling	23125	6750^{a}	3000^{b}
Herbicides	21000	1250^{a}	0.0^{a}
Spot application plus spacing	23000	3750^{a}	1375^{b}
Hand pulling	21300	13460^{b}	14000^{c}
Conventional	22875	14875^{b}	12750^{c}
P value	NS	<.001	<.001
cv%	41.2	17.6	26.9

Within column means with different superscripts are significantly different P<0.05

4.4 Effect of weed control techniques on weed biomass at second, fourth and sixth WACE (tonnes/Ha).

There were no significant differences (P>0.05) in weed biomass at 2 WACE (Table 4.3). However, there were significant differences in weed biomass at the fourth and sixth weeks after crop emergence (Table 4.3).

Weed biomass which was collected at first sampling was significantly (p>0.00l) influenced by treatments. However, the weed control methods significantly (p<0.00l) influenced the weed biomass at second and third sampling. Application of the basagran +glyphosate controlled the weeds hence gave no biomass.

Table 4.3: Effect weed control techniques on weed biomass at second, fourth and sixth WACE (tonnes/Ha).

Treatment	Weed biomass 2 WACE	Weed biomass 4 WACE	Weed biomass 6 WACE
Spot application plus pulling	5.3	6.9^{a}	$I.3^{a}$
Herbicides	4.9	0.4^{a}	0.0^{a}
Spot application plus spacing	5.8	2.5^{a}	0.6^{a}
Hand pulling	4.8	5.2a	5.0^{b}
Conventional	4.9	8.1^{b}	4.8^{b}
P value	NS	<.001	<.001
LSD-value	I2.55	6.243	9.49
cv%	33.2	17.6	34.4

Within column means with different superscripts are significantly different P<0.05

In this study there were no significance differences (P>0.05) between treatments on weed biomass at two weeks after crop emergence. This is because weed biomass was sampled before any weed control treatment was done and everything were the same across all treatments up until the different weeding strategies were engaged on the project.

This gave almost uniform biomass in all treatments with full cover spray herbicide and CT having 4.9 kg per ha each, 5.3 kg/ha from hand pulling and 5.0 kg/ha each for spot application plus hand pulling, spot application plus crop spacing. So there was no significant difference and this was expected of all treatments. However, the weed biomass obtained at four and six weeks after crop emergency was influenced by the treatments (p<0.00l).

4.4 Effects of weed control treatments on Labour and Grain Yield

The results indicate that there were no significant differences in yields between CT and CA weed control techniques practises p = 0.478. The highest yield was obtained from spot application plus hand pulling, followed by spot application plus crop spacing, followed by conventional and lowest was on hand pulling. The yields were 2.6 t/ha, 2.5 t/ha, 2.3 t/ha,2.2 t/ha and I.9 t/ha. The weed control treatments did not significantly (p>0.00l) influence sugar bean yield (Table 4.4). The sugar bean yields were not significantly different among the treatments in this study hence the hypothesis that weed control strategy affect yield is rejected. The highest yield was obtained from the spot herbicide plus hand pulling which was l0.5 % higher than conventional. Spot application of herbicides plus crop spacing also performed better than conventional with l.8 % more yield than conventional system.

The yield average of the five treatments was much lower than the potential of the seed variety which is 3 t/ha. This might be due to the insufficient inputs used like there was no use of basal fertilizer and some of the observed pest could not be controlled due to the cost of the chemical. Also the rainfall pattern was not constant enough for the best growth. Weed control results showed that there were significant differences labour between conventional and CA weed control techniques. There were no significance differences ($P>0.05$) in grain yields across all practises. The results indicate that there were significant differences ($P<0.05$) in producing a ton of sugar beans between conventional and CA weed controlling techniques and amongst CA weed techniques practices.

These results show that spot application plus hand pulling produced the highest yield and hand pulling produce the lowest yield. The results also show that spot application and spacing produced a ton of sugar bean at a low cost followed by spot plus hand pulling, herbicide, hand pulling and lastly conventional

The analyses of the results on the effects of CA weed control techniques on labour requirements are presented in Table 4.4 below.

Table 4.4: A comparison of the effect of weed control technique on labour days ha^{-1} and the bean yields obtained in tonnes per hectare.

Treatment	Labour days ha^{-1}	Yield tonnes ha^{-1}
Spot application plus pulling	0.68[a]	2.611
Herbicides	0.36[a]	I.92
Spot application plus spacing	0.60[a]	2.583
Hand pulling	3.16[b]	2.245

Conventional	7.28[c]	2.304
P value	< .001	0.478
Grand mean	2.42	2.332
Lsd	0.975	1.193
Se	0.633	0.775
cv%	26.2	24.7

In column values with different superscripts differ significantly at $P< 0.05$

CA weed control techniques with no significant differences on labour input required for crop establishment. Hand pulling in its own category which is statistically different from conventional and herbicides CA weed control techniques. The animal conventional in its own category which was significantly different from hand pulling and CA herbicides techniques. There were statistically significant differences on labour requirements ha^{-1} p> 001 therefore the null hypothesis was rejected. Conventional had the highest labour input ha^{-1}. Combined CA weed control techniques reduced labour requirements ha^{-1}

Conventional tillage inherently had a high labour demand from several operations required to establish a crop.

While labor demands can decrease by up to90 % as a result of herbicide use (Gianessi *et al.*, 2009),herbicide-resistant weed species and negative environmental impacts from herbicide use (Norsworthy *et al*., 2012) underscore the importance of responsible use of chemical control methods to successfully control weed populations. An integrated weed control approach should guide herbicide use, including proper timing of herbicide applications and appropriate application rates (Norsworthy *et al*., 2012). This helps to come out with combined CA weed control techniques with reduced labour. Arguments which have been brought forward are that there is no single solution to solve challenges of farmers hence need for a holistic approach (Giller *et al*., 2009)

Comparing the yield across the CT and CA weed control techniques, there was no significant differences in yield p 0.478 therefore the null hypothesis is accepted. Spot application plus hand pulling produced the highest yield and herbicides had the lowest yield.

4.6 A comparison of the effect of weed control technique on cost of producing a ton of sugar bean across five treatments.

The analyses of the results further indicate that there are significant differences in cost of producing a ton of sugar beans across the treatments as presented in Table 4.5.

Table 4.5: A comparison of the effect of weed control technique on cost of producing a ton of sugar bean across five treatments.

Treatment	Production cost ton^{-1}(US $)
Spot application plus pulling	18.61[a]
Herbicides	19.45[a]
Spot application plus spacing	12.46[a]
Hand pulling	38.32[b]
Conventional	64.94[c]
P value	0.001
Lsd	11.54
Se	7.49
cv%	24.7

In column values with different superscripts differ significantly at $P < 0.05$

The CA weed control techniques with similar cost of producing a ton of sugar beans. The hand pulling technique classified statistically different on cost of producing a ton of sugar beans across the treatments (p <001) therefore, the null hypothesis is rejected. The conventional weed control technique classified statistically different on cost of producing a ton of sugar beans from CA weed control technique.

4.7 Implications of the effect of weed control technique on cost of producing a ton of sugar beans

The results show that there was weed control technique effect on cost of producing a ton of sugar bean. Therefore, the result from this experiment suggests that weed control technique can be used to reduce production cost in sugar beans. The result indicates that spot application plus crop spacing was the most efficient production cost followed by spot application plus hand pulling. This suggests that combination of techniques helps to reduce cost. Herbicide was the third and hand pulling comes forth on the CA method.

4.8 Effect of weed control techniques on Labour

Herbicide weed control treatment convincingly verified the saving of weeding labour. Zimdahl, (2004) reported that herbicides could save up to 80% of labour normally used of hoeing. However, herbicide alone proved to be less advantageous compared to herbicide combined with other strategy like hand pulling and crop spacing. Herbicides with crop spacing reduce cost of buying more herbicide and applying labour. Herbicides with hand pulling reduce cost of buying herbicide and the adverse effects of the chemical in the soil. Regardless of the advantage of herbicides, farmers in communal areas are not fully willing to adopt this technology citing different reasons which include, insufficient information, lack of capital to purchase herbicides, unavailability of herbicides in local shops and risks involved in herbicides application (Chivinge, 1984). The success of CA systems has largely been attributed to the availability of chemical weed control methods (Swenson &Moore 2009). Obstacles to herbicide access and application, such as local availability, price, and proper and safe handling of chemicals are now being addressed through training by extension agents more market outlets and researchers.The availability of knapsack sprayer has improved in Zimbabwe. The prices of small containers of herbicides (1 litre) ranges US$5-7 (ZFC, 2020) and knapsack sprayers’ price range from US$15-20 (Ag-Venture, 2020).

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CHAPTER 5 DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.1 Introduction

This chapter gives an overview of the discussion, conclusions and recommendations proffered to the farming community on the findings from this research. Suggestions for further research have also been included.

5.2 Discussion

Although the sugar bean yields were not significantly different among the treatments in this study, there are some reports that herbicides in CA gave higher yield in maize crop compared to CT method (Vernon and Parker, 1982).In this study, the yield was not different because all treatments were treated with same level of management. The weed control was done at the right time, at two, four which is the critical time of weed control and the time when yield reduction is great. There results in this study agrees with Ngwiral etal, (2014) who revealed that early stages of sugar beans is very sensitive to weeds competition and if sugar bean growth is checked by weeds in its early stages of growth it never recovers fully, however weeds are controlled subsequently. Weeds infestation should minimized for the first three weeks to maximize yields. Well planted and health sugabr beans will chock and suppress growth of weeds according to Ngwira etal (2014), There was a slight difference in yields in this study. There were no significant a difference in sugar beans yield from the experimental data analysis therefore the null hypothesis is accepted. These results indicate that yield cannot be the basis of evaluating or selecting weed control strategy since there were no significant differences across all treatments

5.2.1 Effects of Weed control technique on weed biomass and density

In this study there were no significance differences between treatments at two weeks. This was because weed biomass and density sampled before any weed treatment. However after those obtained after four and six weeks showed a significance difference and these were influenced by the treatments. The CA treatments and less density and biomass compared to CT treatment. The result showed that CA treatments effectively controlled the weeds hence less weed biomass were obtained. Treatments with combination like spot application plus hand pulling and spot application plus crop spacing effectively controlled the weeds hence less weed biomass were obtained.

5.2.2 Effects of weed control technique on Labour

Weed control by the traditional manual way of hoe and hand weeding for both conventional and CA practise is labour intensive. Conventional tillage starts with a clean field from the complete soil inversion while on the other hand CA start with no weeds after use of herbicide to clear all prevailing weeds (Mavungaidze *et al*., 2016). The Conventional weed control method was the one with highest labour days. The limitation with cultivation is the availability of draft animals. Also unlike in CA, CT needs manual hand hoe weeding which is more labour intensive. Besides CT has a negative effect in soil conservation. The cost of CT is also high because of repeated tillage operation. Hand pulling has higher labour requirement compared to other CA weed control treatments. This might be due to the size of the weeds after two weeks. Weeds need to be of bigger size for easy handling when pulling

5.2.3 Effect of weed control technique on cost of producing a ton of sugar beans

The results show that there were no weed control technique effect on cost of producing a ton of sugar bean. Therefore, the result from this experiment suggests that weed control technique can be used to reduce production cost in sugar beans. The result indicates that spot application plus crop spacing was the most efficient production cost followed by spot application plus hand pulling. This suggests that combination of techniques helps to reduce cost. Herbicide was the third and hand pulling comes forth on the CA method.

Outcomes from this study are that there are significant differences in labour and cost required in weed management of a sugar bean crop between CA and CT practices. These results suggest that CA weed control techniques are a good basis for promoting CA were finance is a constraint. These results also show that CA weed control techniques have high efficacy in controlling weeds as they are more economic and provides effective timely weed control. However, amongst themselves the best are those which are combined together. These alternative techniques especially opportunities offered by combining herbicides with cultural and management practise proved to be more beneficial than herbicides alone. These alternatives help to reduce the challenges presented by herbicides alone which is still considered by many to be the best CA weed control technique.

In contrast hand hoeing which is the main weed control technique under CT has less efficacy as the method is less economic and does not provide effectively timely control of weeds especially were persistent rainfall is experienced. It was concluded that integrated weed management could be the best economic way of mananging weeds in space and time under CA when growing sugar beans. This would reduce the cost of weed control.

CA weed control practises with the exception of hand pulling save labour and improve labour productivity over animal CT. Therefore, weed control technique capacity to cover available cropping area labour, availability and access to source of herbicide are critical in selecting a technique to use for any given situation. The perception of yield losses when practising CA was refuted.

5.3 Conclusions

These studies suggest that CA weed control technique practises does not affect yield in sugar bean production. The assumption in the experiment was that all other parameters which influence yield were uniforms across all the treatments. The results indicate that there were significant differences in the cost of producing a ton of sugar beans across all the treatments therefore the null hypothesis was rejected. Selecting of weed control technique practise on the basis of lower production cost based on the findings of this study will be correct. The results also indicate that increasing productivity reduces production cost per ton. Cost per ton becomes the major competitive issue in sugar bean production. The net effect is reduced prizes of sugar bean products therefore sugar bean products become affordable. Where is the finance economics shown?

5.4 Implications

The results from this study demonstrate that weeds are the major constraint in achieving a good sugar bean yield hence to get optimum yields, farmers should opt for the most effective weed control technique.

It also means researchers and extension workers must thoroughly examine a series of option that can be combined and tailored to smallholder farmers taking into account the resources. Impacts of agricultural practises on weeds must be better understood together with the foundation knowledge in basic weed biology in order to get alternatives to herbicide which is the dominant control strategy being used in CA presently.

5.5 Recommendations

1.It is recommended that application of herbicides in CA should be employed in places where the weeds are concentrated or along the rows whereas hand pulling crop spacing, and other cultural, biological and managerial methods should be done on other parts with less weeds infestation in order to reduce the cost of weed control.

2. Spraying of chemicals as full cover spray in CA could waste the herbicide and since not all the sprayed chemicals are used to control weeds so it's an unnecessary cost to incur. It is necessary only for the desiccation of the weed cover before planting as this will act as soil cover.

3. The extension workers should be trained on these alternatives combining herbicide technologies with other methods of weed control in order for them to be able to help farmers with correct profitable information. It is also recommended that information dissemination to farmers should be improved by provision of this project out come to farmers and helping them to practise these techniques.

4. Extension workers should be provided with internet facilities of quick access of current information and technology. Farmers should be given opportunities to be competitive in weed management that is participatory approach and at the end of competition farmers can be awarded with certificates of competence in best CA weed control technique farmers of the season so as to encourage them to adapt to other methods of weed control strategies since adaption of these strategies is very poor in small hold shoulder sector. The trial can still be carried out in different regions under different climatic conditions

5.The finding that statistically there are no significant differences in yield across all the treatments assuming that all factors were uniform across all the treatments translate to that yield is not recommended as a criteria of assessing or selecting CA weed control techniques

6. The effect on the cost of producing sugar beans in the study (Table 4.7) revealed that there were significant differences in the cost of producing a ton of sugar bean across all the treatments hence production cost can be used for promoting CA weed control technique with reduced production cost.

5.6 Suggestions for Further Research

The study should be continued for another two season to assess the effect of different soil and agro-ecological regions.

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APPENDICES

Appendix 1. Analysis of variance Data output

Variate: labour days ha

Source of variation d.fs.sm.sv.r F pr.

Plot stratum 3 0.3610 0.1203 0.30

Plot. *Units*stratum

Treatment4 138.9009 34.7252 86.77 <.001

Residual12 4.8022 0.4002

Total 19 144.0641

Tables of means

Variate labour days ha

Grand mean 2.42

Treatment Spot application plus pulling Herbicides Spot application plus spacing

0.69 0.35 3.15

Treatment Hand pulling Conventional

0.61 7.28

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	0.447

Least significant differences of means (5% level) Table

Treatment	
rep.	4
d.f.	12
l.s.d	0.975

Stratum standard errors and coefficients of variation

Variate: labour _days_ ha

Stratum	d.fs.ecv%		
Plot	3	0.155	6.4
Plot. *Units*	12	0.633	26.2

2 Analysis of variance

Variate: yieldton ha

Source of variation	d.fs.sm.sv.r		F pr.	
Plot stratum	3	2.0726	0.6242	0.20
Plot. *Units*stratum				
Treatment	4	1.23780.55950.830.478		
Residual	12	6.2006	0.4002	
Total	19	10.6111		

Tables of means

Variate yieldton ha

Grand mean 2.3

Treatment Spot application plus pulling Herbicides Spot application plus spacing

2.61.92.5

Treatment Hand pulling Conventional

2.22.3

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	0.447

Least significant differences of means (5% level) Table

Treatment	
rep.	4
d.f.	12
l.s.d	0.448

Stratum standard errors and coefficients of variation

Table	Treatment
Rep	4
d.f	12
l.s.d	1.193

3 Analysis of variance

Variate: Production -cost- ton

Source of variation d.fs.sm.sv.r F pr.

Plot stratum 3 350.76116.922.08

Plot. *Units*stratum

Treatment 4 7578.471894.6233.74<.001

Residual 12 673.7856.15

Total 19 8603.01

Tables of means

Variate production-cost-ton

Grand mean 2.3

Treatment Spot application plus pulling Herbicides Spot application plus spacing

18.6219.4512.56

Treatment Hand pulling Conventional

38.3164.97

Standard errors of differences of means

Table Treatment

rep. 4

d.f. 12

s.e.d. 5.30

Least significant differences of means (5% level) Table

Treatment

rep. 4

d.f. 12

l.s.d11.54

Stratum standard errors and coefficients of variation

Variate: production cost ton

Stratum	d.fs.ecv%		
plot3	4.84	15.9%	
plot *Units*	12	7.49	24.7

4 Analysis of variance

Variate: Biomass at 2 weeks

Source of variation	d.fs.sm.sv.r	F pr.	
Plot stratum	4508.36	169.43	2.75
Plot. *Units*stratum			
Treatment	4	23.937.970.130.940	
Residual	12	554.39	61.60
Total	19	1086.61	

Tables of means

Variate weed biomass –2 weeks

Grand mean 21.3

Treatment Spot application plus pulling Herbicides Spot application plus spacing

22.021.223.2

Treatment Hand pulling Conventional

19.920.2

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	3.92

Least significant differences of means (5% level) Table

Treatment	
rep.	4
d.f.	12
l.s.d	12.55

Stratum standard errors and coefficients of variation

Variate: production cost ton

Stratum	d.fs.ecv%	
plot	3	6.5130.1%
plot *Units*	12	7.8536.3%

5 Analysis of variance

Variate: Biomass at 4 weeks

Source of variation	d.fs.sm.sv.r			F pr.
Plot stratum	4	508.36	169.43	2.75
Plot. *Units*stratum				
Treatment	4	3458.65	1152.88	75.68 <.001
Residual	12	137.39	15.23	
Total	19	3690.53		

Tables of means

Variate weed biomass – 2 weeks

Grand mean 17.75

Treatment Spot application plus pulling Herbicides Spot application plus spacing

17.750.957.82

Treatment Hand pulling Conventional

23.1539.08

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	2.760

Least significant differences of means (5% level)

rep. 4

d.f. 12

l.s.d6.243

Stratum standard errors and coefficients of variation

Variate: production cost ton

Stratum	d.fs.ecv%	
plot42.81015.8%		
plot *Units*	12	3.90322.0%

6 Analysis of variance

Variate: Biomass at 6 weeks

Source of variation	d.fs.sm.sv.r			F pr.
Plot stratum	4	218.36	72.43	2.07
Plot. *Units*stratum				
Treatment	4	1333.65	444.5512.64<.001	
Residual	12	316.6335.18		
Total	19	3690.53		

Tables of means

Variate weed biomass – 6 weeks

Grand mean 12.3

Treatment Spot application plus pulling Herbicides Spot application plus spacing

9.82 0.09

Treatment Hand pulling Conventional

18.823.0

Standard errors of differences of means

Table	Treatment
rep.	4
d.f.	12
s.e.d.	2.97

Least significant differences of means (5% level)

rep.	4
d.f.	12

l.s.d4.19

Stratum standard errors and coefficients of variation

Variate: production cost ton

Stratum	d.fs.ecv%		
plot	4	4.2734.8%	
plot *Units*	12	5.93	48.4%