JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

Evaluation of band application of Atrazine and Metolachlor plus ox drawn cultivation for the control of weeds in maize under smallholder farming conditions in Zimbabwe.

Everton Jaison, Tetiwe Mupakwe , Daiton Mawira, Nathan Sangombe and Benjamin Chirambiwa

Ministry of Lands, Agriculture, Fisheries, Water and Rural Development. (MoLAFWRD).

Zimbabwe

ABSTRACT

Inefficient weed control is one of the main causes of low maize grain yield in A1 resettlement farms where each farmer owns six hectares of land. Farmers rely exclusively on mechanical methods of weed control which need timely implementation and high labor input, which are difficult to meet on these farms. Farmers are encourage to use herbicides for weed control which could be combined with ox-drawn cultivation as a deliberate strategy to reduce the herbicide quantities which are required for weed control also reducing the costs. The objective of this study was to evaluate banded Atrazine at 1.8 l /ha + Metolachlor at 0.5 l /ha applied to 45 cm bands over the crop row pre-ermegence and ox-drawn cultivation, full cover spray Atrazine at 3.6 l / ha + Metolachlor at 1.0 l /ha only and hand hoeing in a high potential farming area in Chinhoyi, located in Zimbabwe. These treatments were replicated twice per site and were arranged in RCBD. The weed control * farm interaction was only significant ($p<0.05$) at the first weed sampling. However, the main effects of weed control and farm were significant ($p<0.05$) at all sampling times. The weed control*farm interaction was not significant ($p>0.05$) on cob count, plant population and maize grain yield. The weed control main effects were significant ($p<0.05$) on cob count and maize grain yield. The farm effects were significant ($p<0.05$) on all maize parameters. In this study it was found that banded Atrazine + Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor had low weed counts compared to hand hoeing. It was concluded that banded or full cover herbicide sprays had good efficacy on weeds compared to hand hoeing. The full cover spray Atrazine had the highest grain yield compared to banded Atrazine + Metolachlor + ox-cultivation and hand hoeing. However, banded Atrazine + Metolachlor had a higher grain yield compared to hand hoeing.

Key words: Band application, Cultivation, Herbicides, Smallholder farming.

1.0 INTRODUCTION

1.1 Background

Maize (*Zea mays* L.) is considered as a major cereal crop grown in the humid tropics and Sub-Saharan Africa among other cereals. It is an important crop and is positioned at number three in the world after wheat and rice production (FAO 2002). Maize as a cereal crop, has a crucial value in Zimbabwe. It is a staple cereal for 99% of Zimbabwe's population (Mashingaidze, 2004). In Zimbabwe, Mashonaland west province is one of the largest maize producing province and the usual method of weed control in the smallholder farming area is hand hoeing at times combined with ox-drawn cultivation.

Maize is produced on large pieces of land in Zimbabwe and mainly consumed as roasted, baked, boiled, fried, pounded or fermented. In developed countries, it is the crucial raw material for industrial products such as maize sugar, maize oil, maize flour, starch, syrup, brewer's grit and alcohol. In terms of production and area covered by the crop, maize is considered to be the major crop in both smallholder farming sector and largescale commercial sector (Gatsi *et al*., 2015). Although there is an increasing pertinence and high demand for maize in Zimbabwe, average yield of as low as 1.0-1.5 tons per hectare are being obtained. The steady decline in maize yields in smallholder farming sector can be attributed to poor weed control methods, poor timing of herbicide application and high herbicide costs and poor agronomic practices such as poor soil nutrient management, no or poor liming methods to correct soil pH, midseason droughts and unequal rainfall distribution in the season (Grant, 1981).

One of the major problems in the smallholder farming areas is the existence of labor bottlenecks in November and December, when there is high demand for labor for planting and weed control in early planted plots (Shumba, 1989). Weed management is a serious problem in the smallholder farming areas, leading to serious crop yield reduction, through competition for water and nutrients (Chivinge, 1986). Some weeds are parasitic to crop plants (Parker, 2002; Rao 2000). Rao (2000) indicated that, weeds account for 45% yield losses, insects 30%, diseases 20% and 5% from other pests each season. Major causes of maize yield reduction is delayed and ineffective weed control (Chivinge, 1986). An increase in weed growth relates to a reduction of crop growth (Rao, 2000). Parker (2002), reported that some common annual weeds consume water and nutrients three times more than the crops to produce the same amount of dry matter. It is important to control weeds in the fields to increase maize grain and yield quality. The only way to increase maize grain yields is through correct timing of weed control and use of sustainable weed control methods.

Resettled smallholder farmers in Zimbabwe, who were given pieces of land by the government during the fast-track programs got at least six to ten hectares of land per household, as indicated by Mbaya (2001) and they generally lack weed management technologies, weeding equipment, and herbicides for effective weed control to attain high crop yields. The major problem faced by these farmers is apparently inability to control weeds. They put large areas under crop and due to lack of resources, only small cropped areas would be weed free. Weed management in crop production was found to be effective through the use of herbicides which contribute more to increased crop yields and crop profitability (Makanganise *et al.*, 1999, Mabasa *et al.* 1999).

Herbicides are hardly used by farmers because of several reasons and high costs could prohibit farmers from using herbicide technology. Herbicide usage in Zimbabwe according to Chivinge (1990), started in the early 1950s in 1955 with the use of 2.4D (2.4-dichlorophen-oxyacetic acid) in large scale commercial farms. In communal farms this technology has been hardly used. Although herbicides are quick and easy to apply, not many smallholder farmers use them because they are expensive and not easily available in local shops (Chivinge, 1990).

Atrazine(2-chloro-ethylamino-6-isopropylamino-1,3,5-trazine), is the most widely used herbicide in Zimbabwe for the control of annual broadleaf and grass weeds in maize (*Zea mays*) and sugarcane (*Sacchurum officinarum*). This herbicide can be applied as pre and post planting as full cover spray or as band application (Meister, 1992). Atrazine provides a seal of approximately 1.5cm when absorbed by the soil particles. Residual effects of Atrazine in the soil, determine the subsequent crops to be planted on the same field. Due to these problems, researchers suggest use reduced doses of Atrazine, in order to avoid residual problems (Donald *et al.*, 2006).

Reduced dose of Atrazine is determined by row spacing and the size of spay width. For effective and economic herbicide band application, Daniel *et al*. (1992) found that the 15.0 cm band width followed by two hoeing sessions would give good results. This indicated that effective band application was obtained with narrow row spacing than wider row spacing (Teasdale, 1995).

Metolachlor, which contains S-metolachlor as the active ingredient, is recommended as a preplant surface applied, preplant incorporated or pre emergence application (Zimbabwe Crop Chemical Handbook, 2008). This herbicide is used to control annual grasses and small seeded broadleaf weeds. It is registered in Zimbabwe to use on a variety of crops such as maize (*Zea Mays*), cotton and soybeans (Zimbabwe Crop Chemical Handbook, 2008).

Makanganise *et al*. (2005) evaluated band herbicide application in combination with the use of ox-drawn cultivation which is available to smallholder farming sectors and reported good weed control in maize. Band herbicide application is when herbicide is applied on prescribed area. In this study, band application was done over the crop row 22.5cm on either side to get a swath of 45cm. Band herbicide application reduces herbicide costs by reducing the quantity of herbicide required per given area compared to conventional broadcast herbicide application. Reducing total herbicide doses required at full cover spray will reduce contamination of surface and ground water. This can be achieved by reducing the area to be treated by herbicides (Donald, 2006).

The effectiveness of banded herbicide application was equal to full cover spray when integrated with timely inter-row cultivation and could lead to 84% herbicide reduction but still achieving the set yield targets (Mulder and Doll 1993; Swanton *et al.,* 2002) also reducing herbicide costs (Swanton and Weise, 1991). Band herbicide application is not a widely adopted system (Loddo *et al.,* 2020). In contrast, full cover spray herbicide application consists of applying herbicide mixture uniformly over the targeted area. For effective results in full cover spray applications, proper calibration of the herbicide and equipment should be done as per manufactures' direction (Kyser *at al.,* 2017).

Ox-drawn cultivators are also used to control weeds in crops planted in rows with the same spacing as the cultivator blades. The method is quicker and easier than by hand. Using an ox-drawn cultivator can take less than one-fifth of the time needed by hand weeding. Ox-drawn cultivation as one of the mechanical weed control methods is an effective method in row crops. It is more economical to use than hand hoeing (Mabasa *et al* 1999). The implement relies on burying and uprooting weeds between crop rows. It can provide effective weed management even when other methods are not possible. There are many positive aspects of ox-drawn cultivation in weed management. However, ox-drawn cultivation has negative effects as well. Its effectiveness is highly dependent on weather and soil condition and it requires skilled labor. Partially uprooted weeds may regain vigor. Repeated operations area required for effective weed control (Mabasa *et al* 1998). Until weed management in maize is improved for the smallholder farmers, maize yields are likely to remain low in smallholder farming areas.

It is important for farmers to combine ox-drawn cultivators with banded herbicide application to reduce on weed control costs, also to reduce the reliance on herbicides at full dose thereby reducing the amount of different herbicides in the environment (Gatsi *et al.,* 2015, Ishaya *et al*., 2008). Tilling between the rows is common in the smallholder farming sector. Periodic cultivation is used between rows to destroy recently germinated weeds. Using cultivators between rows in soils with high clay content creates more air pockets thereby improving soil air circulation (Mulder and Doll, 1993).

1.2 Problem Statement

In Zimbabwe, weeds contribute much to crop losses and famers use most of their time controlling weeds during the crop growth cycle. The quality of life of farmers in smallholder sector is poor, especially for women and children due to time and efforts they spend in the fields battling against weeds. Farmers are forced to pay for expensive and sometimes unavailable hired labor due to weed pressure. Use of hand hoeing method is the most commonly method used in the smallholder sector. The method is associated with some drawbacks which include labor intensive and inefficiency which results in increased weed pressure to the crops. On the other hand, use of full cover herbicide application is not feasible to some farmers due to high costs associated with purchasing of the chemicals. Band reemergence herbicide application accompanied with ox-drawn cultivation, and full cover herbicide application were evaluated to determine their impact on reducing weed pressure in the early crop stages, reducing chemical weed management costs, reducing weeding burden faced by the farmers and their effect on maize grain yield component (Mashingaidze 2004; Makanganise *et al*., 2005).

1.3 Justification

Economically, band herbicide application reduced the quantity and cost of herbicide requirements therefore more attractive for cash-strapped smallholder farmers. Herbicide use in crop production contributes to the contamination of the ecosystem. If band herbicide application is implemented, it will reduce ecosystem contamination (Mashingaidze and Chivinge, 1995). The specification of this study is to provide introspection into the possibilities of controlling weed population and growth, weed competitiveness and reducing weed management costs. Using band herbicide application, integrated with ox-drawn cultivation reduces severe labor bottlenecks and high weed management costs agonized by the smallholder farmers during weed peak periods.

1.4 Aims and objectives of the study

The aim of the study is to develop a low input chemical weed management strategy that can increase maize grain yields while reducing the impact of weeds and can be easily integrated by smallholder farmers in their day to day weed management systems. The study is broadly based on evaluating the feasibility of combining banded preemergence herbicide application and ox-drawn cultivation in a maize crop to control weeds to reduce the impact of weeds in a maize crop during the early growth stages. The study also examines the weed population per area and yield losses due to weed infestation and also costs associated with hand weeding compared to bended chemical method.

1.5 Specific objectives

▪To determine the effect of band application of Atrazine + Metolachlor and ox-cultivation on weed density and maize grain yield under smallholder farming conditions.

1.6 Hypotheses

- Band application of Atrazine + Metolachlor and ox-cultivation will have similar weed densities and similar maize grain yield to the overall application of Atrazine + Metolachlo

2.0 LITERATURE REVIEW

2.1 Weeds

Weeds cause crop yield losses due to their strength in competition with crops for nutrients, water, space, sunlight, and it is more critical when the crop is young. Doll (2003), Indicated that, the critical period of crop-weed competition is between the first one third and the first half period of the crop life cycle. To attain maximum maize yield production, the crop must be kept weed free during the first one third of its life cycle. The most economically important weed species in Zimbabwe include bristly star bur (*Acanthospermum hispidum* DC.), wondering dew (*Commelina banghalensis* L.), Mexican clover (*Richardia scabra* L.), yellow nutsedge (*Cyperus esculentus* L.) purple nutsedge (*Cyperus rotundus* L.) and witchweed (*Striga asiatica* L.) (Chivinge, 1988);

Mupangwa and Thierfelder, 2015). Rapoko grass (*Eleusine indica* L.) and couch grass (*Cynodon dactylon* L.) are the grass weed species of economic importance. Labor requirement and yield reduction due to the effects of rapoko grass and couch grass are quite high, and highly infested areas may be abandoned due to yield reduction which may be up to 50% (Malunga *et al*., 2016). Success on weed management in smallholder farming sector depends on availability of labor (family labor or hired labor), access to herbicides, access to mechanical tools and equipment.

2.3 Hand weeding

Hand weeding is the most practiced weed control method by smallholder farmers and to some extent integrated with animal drawn implements. It is the oldest method of weed management practiced in Africa (Chikonye 2007; Chatizwa 2000). Simuyi (2021) indicated that in Africa there are 500 million smallholder farmers and 200 labor hours are required to weed one hectare which sum up to 100 billion hours, yet yield loss is still between 20-100 percent, so a lot of time and energy are wasted (Chitizwa 2000). Nyanga *et al*. (2012) documented that, in Zambia time spent in weeding during one single cropping season for a maize crop field ranges from 90-120 labor hours and pegged it at 90 labor hours to keep the maize crop free of weeds.

Hand weeding is labor intensive and back breaking with farmers hunching over for long hours. Long term effects of hand weeding include back injuries, sprains, and even physical deformities. Women bear the burden of these health problems as weeding is frequently done by women and their children. Hand weeding is time consuming there by consume time for child caring. Most children are forced to help their parents during weeding peak periods at the expense of their school time. Ishaya *et al.* (2008) indicated that 69% of farm children of between 5-14 years are forced to drop from school joining their parents and guardians in the fields at peak weed period. Socially, most families have quarrels and misunderstandings during this period of farming which destroys love, peace and harmony in the family.

Smallholder farmers spend greater part of their time in weed management and hand weeding is a hard work and it requires more labor of about 250 -780 man hours per hectare as indicated (Chivhinge, 1990; Akobundu, 1987). Using this labor requirement and assuming eight working hours a day at a daily wage of $3 (USD) per person, weeding costs will range from $750-$2340 (USD) per hectare depending on weed infestation, availability of labor and weed peak period. The fact that weeds may regrow easily, could increase the frequency of weeding, therefore, increasing the demand for labor.

Each season farmers spend more labor hours during hand weeding which is equivalent to 35-70 % of their total labor requirement in crop production (Ishaya *et al*.2008). Labor requirement for weeding generally exceeds total labor requirement for all other field operations combined (Chivinge, 1984).

The hoes are designed to suit the user and the crop, when weeds are removed. Some use them while squatting or sitting and slowly moving forward. Those designed with longer handles are used while stooping. Hand

hoeing is a tiresome operation and it requires 200-400 man-hours per hectare (Gilles, 2000). Most smallholder farmers depend on family labor and hired labor when family labor is insufficient. In most cases shortage of labor occurs from November to January when weeding of the early planted crops, heading of livestock and planting of the late crops will be taking place. Severe labor bottlenecks are therefore common (Shumba, 1989).

Hired labor will be unavailable and if available will be very expensive during this period and will result in inefficient weed control. Competition for laborers will usually occur resulting in increased labor charges, long period of weed-crop competition and yield reduction. Heavy textured soils offer prolonged wetness and do not permit efficient hand hoeing. Some weed species are morphologically similar to certain crops which reduces the efficiency of the system for example shamva grass (*Rottboellia cochnchnensis*) at an early stage is morphologically similar to maize and difficult to distinguish. Persistent perennial weeds such as *Cynodon dactylon*, *Cyperus esculentus*, and *Cyperus rotundus*, become a problem as they propagate vegetatively by underground rhizomes, tubers and stolons. They readily (regrow after hand weeding. Weeding frequency depends on the agro ecological region, rainfall pattern and distribution, type of weeds, soil type, efficiency of the weeder, condition of initial land preparation at planting, type of the crop. Anonymous (1973), showed that the frequency of hand weeding in a maize crop is three to four times per season. As indicated by Chivinge (1990), chemical weed control is 20-30 percent more efficient in controlling weeds than hand hoeing. An alternative to reduce the frequency of hand weeding is when hand weeding is combined with mechanical and chemical control methods.

The supply of both family and hired labor has been reduced significantly due to rural urban migration. Hand weeding has been made difficult and unaffordable by smallholder farmers due to shortage of labor and increased labor costs. People in the smallholder farming sector now prefer other jobs like wage employment than hand weeding if they are available. Timeliness is important with hand weeding, in other situations emerged weeds before crop planting need to be removed. Other farmers postpone hand weeding due to labor bottlenecks which force smallholder farmers to plant their crops after weed emergence. If hand weeding is delayed, crop loss due to weed crop competition occurs, especially if weeding is done after critical weeding period. One week delay in hand weeding will result in one third yield loss. If the fields are smothered by weeds farmers usually abandon the crops.

Hand weeding does not provide season-long weed control (Mabasa et al., 1998, Ishaya 2008, Gatsi 2015) indicated that hand weeding efficacy is poor due to continued moist environment during frequent rainfall occurrence. Rejuvenating weeds necessitates several sessions of weeding to keep the crop free from weeds to avoid yield losses (Gianessi, 2009). For perennial weeds such as couch grass (*Cynodon dactylon*), hand weeding alone does not provide adequate weed control. Perennial weeds are capable of regrowth from rhizomes (Akobundu, 1987).

As the smallholder farmers will be trying to control weeds in all their planted crops, weeds will regrow and weeding will be required again and again until the crop canopy is established. Weeds still cause a significant yield loss in maize because most weeding operations are done well after the crops have suffered a competition damage from weeds. Farmers are forced to abandon some of their land due to weed pressure. The abandoned crop may produce low or no grain yields (Mashingaidze and Chivhinge, 1998). Farmers cannot also expand their area of production due to high labor required during weeding and the inefficiency of hand weeding method.

2.4 Herbicide

The use of herbicides by smallholders and its adoption as a substitute to hand weeding depends on how it is introduced to the farmers (Ban and Hawkins, 1988). Only a low population of about 5% of smallholder farming sector in Africa use herbicides to control weeds due to lack of awareness training (Loddo *et al*., 2020). Farmers lack adequate knowledge and an insight to think possible solutions to relieve them from hand weeding. Information on herbicide use by smallholder farmers may be centered on incorrect information due to lack of experience, upbringing, social and cultural factors. Some farmers base their beliefs on past experience of other farmers who once used herbicides and destroyed their crops through herbicide toxicity due to poor herbicide calibration and used wrong herbicides on their crops. Some farmers have the notion that, herbicides are expensive, they also fear that herbicides destroy soil structure and are difficult to use (Mabasa *et al*., 1999).

Herbicides are specific chemicals hence their marketing is done by specific organizations, and they are not readily available to smallholder farmers (Loddo *et al*., 2020). Although smallholder farmers play a major role in food production to enhance food security, family income sustainability, balanced nutrition, and reduced importation of food staff, agriculture information does not reach them due to their inability to read and interpret information on herbicide labels. The dangers caused by improper use of herbicides are due to failure by smallholder farmers and other users to read and understand the manufacturer's guide lines and precaution measures on the herbicide information labels (Loddo, 2020). Smallholder farmers use knapsack sprayers which are cheaper to purchase and use. On the other hand, smallholder farmers do not maintain their sprayers which often give problems during spraying operations as a result some farmers tend to abandon the use of herbicides. Subserviced sprayers are less efficient, leaked chemical may cause health problems to the operator. Repair workshops usually do not exist in smallholder farming sector hence inconsistent use of herbicides.

2.5 Disadvantages of herbicides

Atrazine, herbicide which is widely used in maize production as preemergence and post emergence herbicide, is banned for use in Switzerland where it is believed to interfere with hormonal activity in animals and humans (Dramola *et al*., 2020). Herbicide resistance is also increasing at an exponential rate. Herbicides have detrimental effects on non-target elements (Njirani *et al.*, 2021). Farmers are encouraged to use a wide range of herbicides in rotation to reduce the occurrence of herbicide resistance. Over 270 weed species in the world have already developed resistance to some herbicides (Dramola *et al*., 2020). Flat jet even spray nozzles are used for banded herbicide application.

In Zimbabwe, Agriculture Extension Officers through the Ministry of Agriculture are being used to reach the smallholder farmers to introduce the herbicide technology. Extension involves creating awareness, educating farmers, conducting field demonstrations on herbicide calibration and knapsack sprayer calibration. Farmers are educated on proper handling of the herbicides to protect the environment from pollution, protect animals and human life from detrimental effects of herbicides.

2.6 Ox drawn cultivation

Oxen is one of the most important power source although it is overlooked, (FAO, 2008). Majority of smallholder livestock, particularly cattle is considered to be of great importance economically and also socially as personal value (Magos *et al.*, 2010). Using oxen for draught purpose requires people who are committed to using oxen. It requires strong education, moral and technical support. Farmers who are not familiar with cattle fail to train and use them. Cattle need close management that include supplementation of feed, watering, vaccination, treatment against diseases and proper housing. Loss of one beast to disease and or theft is great economic loss. Magos *et al.* (2010) indicated that cattle are important to smallholder farmers in reducing poverty and creating economic value by allowing farmers to quickly prepare their land, plant their crops and weeding than hand or manual operations while reducing the burden on women and children on time and efforts required in hand weeding (FAO, 2008).

John *et al*., (2000) reported that ox drawn cultivators can play an important role in improving agriculture productivity and alleviate the labor shortages experienced by smallholder farmers Weeding with ox drawn cultivators is much faster and less labor intensive compared to hand weeding. It allows farmers to weed their crops more often and can weed over a wider area increasing area under production, saving time and labor. This can improve timeliness of weeding which can lead to better crop yields, better crop quality and reduced harvesting costs (Simalenga *et al.* 1994). The field should be well ploughed, free from clods, stones and trash to allow smooth operation of the implement. Appropriate yokes must be selected. As a rule of thumb, Kwalimba (1992) indicated that the yoke should be twice in length the width of inter row spacing. The cultivator width and depth should be adjusted to avoid the incidence of damaging the crop roots. Tines should be set to overlap on the line of travel. Setting depth of cut is done by setting the support wheel by raising the hitch point and steepening the angle of cut of tines for a deeper cut. Tines should work the soil down to 2-3 cm soil depth and forward speed should not result in excessive crop covering with soil (Kwaligwa, 1992). One or two rows per run can be implemented depending on weed infestation. Dry and sunny weather following cultivation usually help to improve weeding effectiveness. Ox drawn cultivation provide minimum soil tillage effects which loosen the soil by breaking the soil cap allowing good aeration and improved water infiltration. In Tanzania, trials indicated that ox drawn cultivation requires 50 labor hours per hectare compared to 230 labor hours when using hand weeding (Simalenga, 1994). In Zimbabwe, it took between 60 and 130 labor hours to weed one hectare (Chitizwa and Nazare, 2000). It is recommended that when using ox drawn cultivators, crops should be planted in parallel rows of at least 45 cm wide. The idea is to weed the maize crop two to three times during its growing stages depending largely on weed infestation and rainfall pattern. Ox drawn cultivation perform better when the weeds are still young and tender, when the soil is not too wet and when the weather is clear to allow weed desiccation. If the soil is too wet, the uprooted weeds tend to clog the tines and weeding efficiency will reduce as it will be difficult to operate the implement and reduced tine soil penetration. When cultivation is done on wet soils, the uprooted weeds tend to rejuvenate. Ox drawn cultivation is done when the maize crop is at the height of 5-10 cm and at 45 cm and thereafter if there is need but care should be taken not to damage the crop. The majority of the weeds should not have developed more than three to four true leaves at the time of operation. Animals should be adequately trained to make them walk in straight line without destroying the crop (Kwilimba, 1992). John *et al.*, (2000) stated that weeding with ox drawn cultivators requires about 50 working hours per hectare.

3.0 MATERIALS AND METHODS

3.1 Study site, weather and rainfall.

Weed control experiments were conducted at 15 sites in Mashonaland West Makonde district, which is in natural region IIb receiving a minimum of 700 mm per season. The temperature ranges between 18-32 °C. The areas receive good rainfall but sometimes experiences mid-season dry spells. Rainfall data was collected at Mhangura GMB deport (Table 3.1).

Table 3.1 Rainfall received at the study site in the 2020/21 cropping season

Month	Total amount (mm)
October	23
November	175
December	210
January	186
February	165
March	88
April	25
May	0
Total	**872**

3.2 Experimental Design and Agronomic practices

In 2020/2021, Pan 7M81 maize variety was planted in the second week of January 2021 in rows which were spaced at 90 cm and in row spacing was 30 cm, on conventionally ploughed plots. Pan 7M81 is the mostly commonly used variety by farmers in Mhangura farming area. Two maize pips were planted per station. Fertilizer rate for compound D (N 7%, P 14%, K 7%) was 300 kg per hectare for basal application and Ammonium Nitrate (34.5% N) for top dressing was done at 250 kg per hectare applied at six weeks crop stage. Three weed control treatments, namely, band Atrazine at 1.8 l / ha + Metolachlor at 0.5 l / ha applied to 45 cm bands over the crop row preemergence and ox-cultivation, full cover spray Atrazine at 3.6 l / ha + Metolachlor 1.0 l ha only and hand hoeing were replicated two times per farm at fifteen sites at Cotswold farm, which is 80 km North East of Chinhoyi town. The weed control treatments were allocated at random in each replication and formed a randomized complete block design at each site. Cotswold farm was divided into A1 smallholder farmers each having 6 ha. The gross plots were measuring 8 m × 4.5 m and net plots were measuring 5.2 m × 2.7 m.

The ox drawn cultivator width and depth were adjusted, to avoid the incidence of disturbing the herbicide seal to suit the width of 45 cm. Yoke lengths were made at 180 cm double the row spacing width. The tines of the cultivator were adjusted to overlap on the line of travel. Depth of cut was set by raising the hitch point and steepening the angle of attack of the tines for a deeper cut. Even flat fan nozzles were used for herbicide application. Plastic shields were used to direct the herbicide on a 45 cm swath. When between row cultivation treatments were imposed, the preemergence treated zone was weed free. All treatment plots were cultivated twice at two weeks interval. Hand hoeing treatment plots were weeded twice, first at two weeks after crop emergence and then two weeks later. Full cover spray herbicide treatment plots were treated with preemergence herbicide full dose 2-3 days after planting.

3.3 Data collection

Maize planting, crop emergence and herbicide application dates were recorded for each plot. Crop stand (plant population) was done physically by counting plants in each row for each plot. Tasseling and silking dates were recorded when 50% of the crop had attained the growth stage. Cob count was done physically, counting cobs from each plant in each row in each plot. This was done when the maize crop had reached physiological maturity. Grain yield was measured from each net plot. The cobs were harvested manually and shelled by hand. The grain weight was measured using a digital scale for each treatment plot. Maize yield was calculated using the plants within the net plot (5.2 m × 2.7 m) for all plots. Cobs were air dried to attain a moisture content of 12.5 % and shelled. The Dickey Jon moisture meter was used. Weed species for each plot were counted and recorded. A 45 cm × 45 cm quadrant was used. Three quadrant sites thrown randomly in each plot were used as counting sites for different weed species.

3.4 Statistical analysis

The data on weed counts, maize cob count, maize plant population and maize grain yield was pooled from 15 sites. Weed count and grain yield were subjected to Analysis of variance using statistical software. Maize grain yield data was standardized to 12.5 % moisture content. Means were separated by Fisher's protected LSD test at $P = 0.05$. A partial budget analysis was done using grain yields and labor data.

4.0 RESULTS

4.1 Weed spectrum across Chinhoyi farming area in the 2020/21 cropping season

In this study, banded Atrazine + Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor were evaluated at 15 sites in A1 farming areas around Chinhoyi. It was noted that 11 broadleaf weeds and grasses emerged across the sites (Table 4.1). It was also noted that *Cynodon dactylon*, a perennial grass was common at most of the sites.

Table 4.1 Weed species that emerged across the sites in Chinhoyi farming area

Weed species	Classification
Cynodon dactylon	Perennial grass
Sorghum halipense	Annual grass
Dactylectenium aegyptium	Annual grass
Amaranthus hybridus	Annual broadleaf
Chenopodium album	Annual broadleaf
Cleome monophyla	Annual broadleaf
Commelina benghalensis	Annual broadleaf
Conyza sumatrensis	Annual broadleaf
Hibiscus meusei	Annual broadleaf
Leucas martinicensis	Annual broadleaf
Bidens Pilosa	Annual broadleaf
Tagetes minuta	Annual broadleaf
Acanthospermum hispidum	Annual broadleaf
Eleusine indica	Annual grass
Millenis repens	Annual grass
Nicandra physaloides	Annual grass
Galinsoga parviflora	Annual broadleaf

4.2 Effect of weed control treatments on weed seedling emergence across the sites

The weed control*farm interaction was only significant ($p<0.05$) at the first weed sampling (Fig. 4.2). The main effects of weed control and farm were significant ($p<0.05$) at all sampling times (Table 4.2). The weed control effects are shown in Fig. 4.1. At the first sampling it was generally noted that hand hoeing had the highest number of emerged weeds compared to banded Atrazine +Metolachlor + ox-cultivation and full cover spray Atrazine +Metolachlor at most of the farm sites (Table 4.3). In contrast at six sites, namely, Muchemwa, Chivasa, Mupatsi, Mureza, Taenzana and Mandundu, all the weed control treatments had similar weed counts. It was clear that banded Atrazine +Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor significantly ($p<0.05$) reduced weed counts compared to hand hoeing at the second and third sampling times (Table 4.4). It appeared that Chakwana and Gonondo sites supported the highest weed counts, whereas Garatiya and Nhidza had low weed counts. Therefore, the weed counts varied across the sites.

Table 4.2 F probability values of the 1st weed sampling, 2nd weed sampling and 3rd weed sampling

Source of variation	1st weed sampling	2nd weed sampling	3rd weed sampling
Weed control	<0.001***	<0.001***	<0.001***
Farm	<0.001***	0.020*	<0.001***
Weed control*Farm	<0.001***	0.372ns	0.235ns
CV%	45.3	64.9	56.9

Key: ***, * and ns = significant at 0.1 %, significant at 5% and not significant at 5 % respectively.

Band Atrazine + Metolachlor **Figure 1**	Full cover spray Atrazine + Metolachlor **Figure 2**

Hand hoeing
Figure 3

Fig. 4.1. The effects of weed control methods on maize and weeds in smallholder farms near Chinhoyi in the 2020/21 cropping season.

Table 4.3 Effect of weed control on weed counts / m2 at 1st sampling across the sites in Chinhoyi farming area in the 2020/21 cropping season.

Farm	Banded Atrazine	Full cover spray Atrazine	Hand hoeing
Chakwana	9.50a	10.00a	27.00b
Gorondo	9.00a	12.50a	58.00b
Muchemwa	8.00a	8.00a	16.50a
Rayman	4.00a	9.00a	28.50b
Chivasa	3.50a	3.00a	13.00a
Govera	5.50a	4.00a	15.50b
Mupatsi	6.00a	7.50a	13.00a
Rwere	9.00b	4.50a	17.00b
Mbengo	17.50b	6.00a	18.50b
Guzha	11.00a	10.50a	36.50b
Mureza	6.00a	6.00a	10.50a
Taenzana	10.50a	9.00a	19.50a
Garatiya	2.00a	6.00b	13.50b
Mandundu	6.50a	14.50a	14.00a
Nhidza	0.50a	0.00a	22.00b
F test	p<0.001		
LSD (5%)	10.987		
CV%	45.3		

Means sharing different letters at each farm are significantly different at 5%.

Table 4.4 Effect of weed control on weed counts / m2 at 2nd and 3rd sampling across the sites in Chinhoyi farming area in the 2020/21 cropping season.

Weed control treatment	2nd Sampling	3rd Sampling
Banded Atrazine +Metolachlor +ox-cultivation	6.17a	5.20a
Full cover spray Atrazine+ Metolachlor	5.23a	4.03a
Hand hoeing	16.00b	12.97b
F test	p<0.001***	p<0.001***

LSD (5%)	3.084	2.188
CV %	64.9	56.8

*** = significant at 0.1%. Means with different letters in the same column are significantly different at 5%.

4.3 Effect of weed control methods and farms on maize parameters

The weed control*farm interaction was not significant (p>0.05) on cob count, plant population and maize grain yield (Table 4.6). The weed control effects were significant (p<0.05) on cob count and maize grain yield. However, these effects were not significant (p>0.05) on plant population. The farm effects were significant (p<0.05) on all maize parameters. Banded Atrazine + Metolachlor + ox-cultivation and full spray Atrazine + Metolachlor had significantly higher cob count compared to hand hoeing (Table 4.7). Banded Atrazine + Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor produced similar cob counts. All the weed control treatments had similar plant populations. The full cover spray Atrazine produced significantly (p<0.05) the highest maize grain yield compared to banded Atrazine + Metolachlor + ox-cultivation and hand hoeing. It was also noted that banded Atrazine significantly (p<0.05) produced significantly higher maize grain yield than hand hoeing.

The maize parameters varied across the sites (Table 4.8). The highest cob count was obtained at Nhidza and the lowest cob count at Mureza. Rwere farm had the highest plant population, whereas Mureza had the lowest plant population. The highest maize grain yields were obtained at Garatiya and Mupatsi and on the other hand Mureza had the lowest grain yield.

Table 4.5 Effect of farm site on weed counts / m2 at second and third sampling across the sites in Chinhoyi farming area in the 2020/21 cropping season.

Farm	2nd Sampling	3rd Sampling
Chakwana	16.00	12.00
Chivasa	5.67	4.83
Mbengo	6.50	2.83
Garatiya	4.33	7.17
Gorononondo	16.00	13.83
Govera	9.67	6.17
Guzha	11.50	9.50
Mandundu	6.17	5.33
Muchemwa	9.83	6.17
Mupatsi	5.83	7.00
Mureza	9.17	10.50
Nhidza	5.17	2.00
Rayman	11.50	8.17
Rwere	9.17	4.83
Taenzana	10.50	10.67
F test	p=0.020	P<0.001
LSD (5%)	6.896	4.893
CV %	64.9	56.8

Table 4.6 F probability values of the cob count, plant population and grain yield.

Source of variation	Cob count	Plant population	Grain yield
Weed control	0.028*	0.203ns	<0.001***
Farm	<0.001***	<0.001***	<0.001***
Weed control*Farm	0.328ns	0.402ns	0.192ns
CV%	8.6	5.0	56.9

***, * and ns = significant at 0.1 %, significant at 5% and not significant at 5 % respectively.

Table 4.7 Effect of weed control on cob count, plant population and grain yield across the sites in Chinhoyi farming area in the 2020/21 cropping season.

Weed control treatment	Cob count / ha	Plant population/ha	Grain yield (t/ha)
Banded Atrazine+ metolachlor	36776a	35694a	7.46b
Full cover spray Atrazine + metolachlor	36752a	36537a	8.11c
Hand hoeing	34829b	36194a	5.98a
F test	P= 0.028*	p=0.203ns	p<0.001
LSD (5%)	1616.7	-	0.552
CV %	8.6	5.0	

*** = significant at 0.1 % . Means with different letters in the same column are significantly different at 5%.

Table 4.8 Effect of farm site on cob count, plant population and grain yield across the sites in Chinhoyi farming area in the 2020/21 cropping season.

Farm	Cob count / ha	Plant population/ha	Grain yield (t/ha)
Chakwana	34663	36528	6.65
Chivasa	38224	37639	6.66
Mbengo	35256	37222	6.96
Garatiya	36325.	37593	8.17
Gorononondo	36800.	33056	7.53
Govera	34900	35787	7.57
Guzha	38343	35787	7.35
Mandundu	37156	35602	7.78
Muchemwa	36800	38472	7.67
Mupatsi	40005	38519.	8.81
Mureza	26472	28009.	3.92
Nhidza	40123	38380	7.62
Rayman	38936	35972	7.68
Rwere	37987	38796	7.34
Taenzana	29796.	85470	6.03
F test	p<.001	p<.001	p<.001
LSD (5%)	3615.0	5384.4	1.234
CV %	8.6	5.0	14.8

4.4 Partial budget analysis of the weed control treatments

The partial budget analysis showed that the full cover spray of herbicides had the highest net benefits followed by band application of the herbicides. Hand hoeing had the least net benefits.

Table 4.9 Herbicide treatments Partial Budget (2020-2021 season)

Item	**Full cover spray treatment**	**Band application treatment**	**Hand hoeing treatment**
Average yield kg/ha	8110	7460	5382
Adjusted yield kg/ha (-10%)	7299	6714	5382
Monitory variable costs (USD)			
Herbicide rate /ha			
Atrazine (L)	3	1.5	0
Metolachlor (L)	1.5	0.75	0
Herbicide cost/unit			
Atrazine	9.64	9.64	0
Metolachlor	32.10	32.10	0
Herbicide cost/ha			
Atrazine	28.92	14.46	0
Metolachlor	46.65	23.325	0
Other costs	0	0	0
Total monetary variable costs	75.27	37.635	0
Opportunity variable costs			
Labour hours/ha			
Ox-drawn cultivation labour hours /ha	0	50	0
Ox-drawn cultivation labour hours cost per unit	0	0.50	0
Ox-drawn cultivation labour hours cost/ha	0	25	0
Hand hoeing labour hours/ha	0	0	400
Hand hoeing labour hours cost per unit	0	0	0.75

Hand hoeing labour hours cost/ha	0	0	300
Herbicide application labour hours/ha	5	2.5	0
Herbicide application labour hours cost per unit	1	1	0
Herbicide application labour hours cost/ha	5	2.5	0
Total opportunity variable costs	5	2.5	300
Total variable costs	**80.27**	**65.135**	**300**
Net Benefits	**(2335.68-80.27) 2255.41**	**(2148.48-65.135) 2083.345**	**(1722.24-300) 1422.24**

5.0 DISCUSSION

5.1 Introduction

In this study, the objective was to determine the effects of Atrazine + Metolachlor applied either as banded or full cover spray on weed control efficacy and maize grain yields. It was found that banded Atrazine + Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor had low weed count compared to hand hoeing. The full cover spray Atrazine had the highest grain yield compared to banded Atrazine + Metolachlor + ox-cultivation and hand hoeing. However, banded Atrazine + Metolachlor had a higher grain yield compared to hand hoeing. Weed counts and maize grain yield varied across the farm sites. It was also found that the full cover spray of the herbicides had the highest net benefits, followed by banded spray, whereas hand hoeing had the least net benefits.

5.2 Weed control and site effects on weed counts

It was clear that full cover spray of the herbicides and banded spray of herbicides gave a similar weed control efficacy, although this sometimes varied with sites. In this study the application of the herbicides outperformed the hand hoed plots. As far as herbicide efficacy is concerned this agrees with the results of other research workers (Donald, 2006; Loddo *et al*., 2019). Using banded Atrazine without Metolachlor, Makanganise *et al*. (2001) reported that the herbicide efficacy was similar to the farmer's weed control practice with the exception of one site where Atrazine outperformed the farmer's weed control practice. Edie *et al*. (1992) reported that at two out of three sites, one cultivation combined with herbicide applied as band was sufficient to control weeds. It was also reported that herbicides applied in bands resulted in poor weed control at 8 % of the locations where the studies were done (Hartzber *et al*., 1993). Although banded Atrazine had good efficacy on weeds in general across varied sites in Zimbabwe, sometimes Atrazine efficacy is lost on soils with low pH and when weed plants are drought stressed (Mabasa *et al*., 1991). In the current study the Atrazine + Metolachlor had an outstanding performance in terms of weed control because of mainly four reasons. First, the combination of Atrazine + Metalochlor, rather than Atrazine on its own as was used in Makanganise *et al*., (2001) and (Mabasa *et al*., 1991), could have had an advantage in increasing weed control efficacy across many sites. Second, the absence of sites with low pH could have boosted the efficacy of the Atrazine + Metalochlor combination. Third, the high rainfall received at the sites could have promoted the efficacy of these herbicides. Fourth, the presence of *Cynodon dactylon* at some of the sites were probably not sufficient enough, to pause serious competition to the maize crop. Indeed, *Cynodon dacty*lon is not controlled by the Atrazine + Metolachlor combinations. Although Atrazine + Metolachlor gave good weed control, it should be noted that there are some sites were *Cynodon dactylon* could challenge this chemical weed control strategy.

5.3 Weed control and site effects on maize grain yield

This study showed that the full cover spray produced the highest grain yields followed by banded herbicide and the hand hoe weeding had the lowest grain yields. These results are not in agreement to what was reported by other workers (Mabasa *et al*., 1991; Makanganise *et al*., 2001; Eadie *et al*., 1992). Makanganise *et al*. (2001) reported that band spraying Atrazine without Metolachlor produced similar grain yields to the traditional farmer's weed control practices across many sites in Zimbabwe. The weed control methods which included banded Atrazine gave similar grain yields to the mechanical weed control methods across many sites in Zimbabwe (Mabasa *et al*., 1991). In some studies, the herbicides applied in bands caused maize to be reduced at 1 % of the sites (Hartzber *et al*., 1993). It is possible that the high rainfall of which was received during the current study could have influenced the performance of the weed control methods. The high moisture conditions created by high rainfall is most likely to have increased the efficacy of the overall spray of the herbicides. In this case there were the weed density which occurred in the overall herbicide sprayed plots had either no weeds or had a weed density which was not sufficient to cause serious weed competition. The other possibility is that the weeds sampled in the plots emerged well after the critical period for weed control and therefore could not affect the growth of the maize crop. It is possible that the grain yield reductions associated with band herbicide sprays and hand hoe weeding could be due to weed competition associated with these treatments. It has to be noted here that the band herbicide sprays had higher maize yields compared to hand hoeing. The differences in these treatments could accounted for by the differences in intensity of weed competition. In fact high weed densities were recorded in the hand hoed treatments. During a very wet season, mechanical methods may fail to sufficiently kill the weeds, which have a chance to regrow and challenge the crops. The maize grain yields varied across the sites. Probably this could have been the result of different weed control efficiency which also seemed to vary with sites.

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

In this study it was found that banded Atrazine + Metolachlor + ox-cultivation and full cover spray Atrazine + Metolachlor had low weed counts compared to hand hoeing. It was concluded that banded or full cover herbicide sprays had good efficacy on weeds compared to hand hoeing. The full cover spray Atrazine had the highest grain yield compared to banded Atrazine + Metolachlor + ox-cultivation and hand hoeing. However, banded Atrazine + Metolachlor had a higher grain yield compared to hand hoeing. Weed counts and maize grain yield varied across the farm sites. It was also found that the full cover spray of the herbicides had the highest net benefits, followed by banded spray, whereas hand hoeing had the least net benefits.

6.2 Recommendations

There will be need to do follow up studies at the sites where these trials were carried out with the farmers. It would be interesting to determine whether some farmers are continuing with herbicide technology and other farmers who did not participate in the trials have also adopted the technology. This study could be in the form of a survey which will capture any challenges with the use of herbicide technology under the smallholder farmers who own more than 6 ha of land. The information could be used to do further research or to improve the delivery of herbicide technology in areas with a very high cropping potential

REFERENCES

Adesian, A.A., Johnson, D.E., and Heinrichs, E.A. (1994). Rice pests in the Ivory Coast, West Africa Farmers Perceptions and Management Strategies. Internationl. Jornal. Pest Management. 40: 293-299.

Akobundu, I. O., and Agyakwa, I. (1998). A Handbook of West African Weeds (564p). International Institute of Tropical Agriculture.

Chatizwa, R. (2020). Research on Weed Control Using Animal Power Undertaken by the Institute of Agriculture Engineering, Zimbabwe. Agritex Institute of Agricultural Engineering, Harare, Zimbabwe

Chikobvu, S. (2008) Farm Management Handbook, Crop Production. Agribusiness and Marketing.

Daniel, H., Edward, C.P. and Toller. (1992). Cost Effective Weed Control in Soybean with Cultivation and Band Herbicide Applications Weed Technology, 6: 990-995.

Daramola, O. S., Adigun, J. A., Olorunmaiye, P. M. (2020). Challenges of Weed Management in Rice for Food Security in Africa. A Review. Africa Rice Center, Department of Physiology, Nigeria.

Delgado, L. and MacIntire. (1982). Constrains in the Sahel. American Journal of Agricultural Economics. Vol.64, No.2 pp 188-196. Oxyford University Press.

Donald, W. W. (2006). Preemergence Banded Herbicides Followed by Only One Between-row Mowing Controls Weeds in Corn. Weed Technology Volume 20: 143-149.

FAO (1990). Agricultural Engineering in Development: Selection of Mechanisation Inputs, FAO Agricultural Service Bulletin No. 84.FAO, Rome, Italy.

FAO (2005). FAO Production Year Book FAO, Rome, Italy.pp280

Food and Agriculture Organisation Save and Grow Practice: Maize, Rice and Wheat. A guide to Sustainable Cereal Production. Food and Agriculture Organisation of the United Nations: Rome, Italy, 2016; pp.40-43.

Gatsi, T., Mabasa, S., Kanyungwe, K., Makanaganise, A. (2015). Economics of Integrated Tillage and Weed Control Practices on Maize-based Systems in the Smallholder Farming Sector of Zimbabwe.

Gianessi, L. (2009). Solving Africa's weed problem: increasing crop production and improving the Lives of Women. Crop Life Foundation.

Gill, H. S. (1982) the role of hand and mechanical weeding in weed management in in the advanced countries, in improving weed management: proceedings of FAO/IWSS consultation on improving weed management in a developing countries (Rome, Food and Agriculture Organisation) 17-22

Gilles, D. L. and Tessier, C. M. (2000). Banded Herbicide Application. Implementation, Benefits, Condition for Success.

Grant, (1981). Evaluation of a Pre-formulated Post Emergence Herbicide Mixture of Topramezone and Dicamba on Annual Weeds and Bermuda Grass in Maize sub-tropical agro-ecology.Guykyser, J., Rob, W. (2017) Chemical Application Methods for Herbaceous Weeds.Indirect Selection in Weed Free

Environments. Crop Science 46:372-380.

Ishaya, D.B., Tunku, P., and Kuchinda N.C. (2008). Evaluation of Some Weed Control Treatments for Long Season Weed Control in Maize (Zea mays L.) Under Zero and Minimum Tillage at Samaru in Nigeria. Crop Protection. 27, 1047-1051

John, P. O., Barton, D., Agobe, F., Dave, O. (2000). The Impact of Ox-weeding on the Livelihoods of Poor Smallholder Farmers in the Farming Systems.

Kwilimba, E.M., Shetto, R., and Haule, S. (1992). Experiments on Weed Management Techniques Based on Animal Drawn Cultivators for Control of Weeds in Maize in Southern Highlands in Tanzania. Uyole Agricultural Center, Mbeya, Tanzania.

Loddo, D., Scarabel, L., Sattin, M., Pederzoli, A., Morsiani, C., Canestrale, R., and Tommasini, M.G. (2020). Combination of Herbicide Band Application and Inter-row Cultivation Provides Sustainable Weed Control in Maize. Agronomy 2020, 10(1), 20.

Mabasa, S. and Rambakudzibga, (1993). Periodicity of weed seedling emergence and the effect of weeding frequency on maize and sorghum. Zimbabwe Journal of Agric Research 31:27-41

Mabasa, S., Makanganise, A., Mphisa, P. (1999). Use of Herbicides in the Smallholder Sector. Wood Research Team, Henderson Research Station, Agronomy Institute. Harare Zimbabwe.

Mabasa, S., Riches C.R., Nyahunzvi, S., Twomlow, S.J., Dhliwayo,H.H., and Chatizwa, I. (1998). Tillage and Weed Control Responses on a Semi-arid Granitic Catena ii Weed responses. Paper Presented at CIMMYT 6th Regional Maize Conference for Eastern and Southern Africa. Addis Ababa, September 21-25, 1998.

Mabasa, S., Shamhudzarira, Z., Makanganise, A., Bwakaya, F., Sithole, T. (1998). Weed Management under Different Tillage Systems in Smallholder Farming Areas of Zimbabwe. Weed Research Team, Agronomy Institute, Henderson Research Station. Mazoe, Harare, Zimbabwe.

Magos, Y. T. and Conroy, A. (2010). The Economic Importance of Draught Oxen on Small Farms in Namibia’s Eastern Caprivi region.

Makanganise, A., Mabasa, S., Jasi, L., Gatsi, T. (2001). Verification Trials and Farmer-managed Demonstrations in Integrated Weed Management under Different Systems and Fertility Levels in Smallholder Farming Areas of Zimbabwe. Ministry of Lands and Rural Resettlement, Department of Research and Extension. Agronomy Institute, Harare, Zimbabwe.

Makanganise, A., Mabasa, S., Jasi, L., Mangosho, E. (1999). Farmer Participation and Evaluation on Integrated Weed Control Methods with Specific References to Herbicide Technology in Communal Areas of Zimbabwe. Weed Research, Team Agronomy Institute, Harare Zimbabwe.

Mandumbu. R. Karavina. C. Tibugari. H. (2011). Integrated weed management in Zimbabwe's smallholder sector. Where are we? Morden applied science.

Mashingaidze AB, (2004). Crop and Weed Ecology. PE and RC

Mhlanga, B., 2015a. Weed management in Zimbabwe Smallholder Conservation agriculture farming sector.

Mothander, B., Kjaerby, F., Harvnevik K. (1989). Farm Implements for Small-scale farmers. Tanzania. Scandinavian Institute of Africa Studios Uppsala.

Mulder, TA and J.D Doll (1993). Integrating reduced herbicide use with mechanical weeding in corn (Zea mays) weed technical, 7:382-389

Niazmand, M. A.R., Shaker, M., and Zakerin (2008). Evaluation of Different Herbicide Application Methods and Cultivation Effect on Yield and Weed Control of Corn (Zea mays) Journal of Agronomy 7:314-320. DOI: 10:3923/ja.2008 314-320

Njirani, J. (2021). Gaining Momentum: Herbicides on the Rise in Africa. Agribusiness Global Direct.

Nyakanda, C., A.B Mashingaidze and G. Kurambwa, 1995. Effect of maize/groundnut intra- and inter-row spatial arrangements on yield and weed pressure. Transaction of Zimbabwe scientific association. 69:20-23

Nyamangara J., Mashingaidze N., Masvaya EN., Nyengera K., Kunzekweguta., Tirivavi R., and Mazvimavi K. (2014). Agriculture Ecosystems and Environment 187 pp. pp -9 ISSN 0167-8809

Nyanga, J. and Kalinda. (2012). Gender and Conservation Agriculture in Sub-Saharan Africa.

Rao, A.N. and Matsumoto, H. (2000). Weed managenet in Rice in the Asian-Pacific Region. Asian Science Society of Japan, Indian Society of Weed Science.

Rodernburg, J. and Johnson D.E. (2009). Weed Mangement in Rice-based Cropping Systems in Africa. Crop, Soil and Water Sciences Division International Rice Research Institute (IRRI), Metro Manila, Phillppines.

Ronald F, Krausz, George Kapusta, Joseph L. Metthews (1995). Evaluation of Band Application Versas Broadcasting Herbicide Application in Corn and Soybean

Shumba, E.M., Waddington S.R. and Rukuni, M. (1989). Delayed Maize Planting on a Smallholder Farming Area of Zimbabwe: Problem Diagnosis. Zimbabwe Journal of Agricultural Research 17: 103-122.

Simalenga, T.E. and Shetto, R.M. (1994). Animal Power for Weed Control: Experience and Challenges.

Simiyu, N. (2021). Herbicide Weeding in Africa. Fact Sheet.

Swanton C.J., A. Shrestha, D.R., Clements, B.D. Booth and K. Chandler, (2002). Evaluation of Alternative Weed Management Systems in a Modified No-tillage Maize – Soya Winter Wheat Rotation: Weed Densities, Crop Yield, Economics Weed Science, 50: 504-511.

Teasdale, J.R. (1995). Influence of Narrow row/high Population Corn (*Zea Mays*) on Weed Control and Light Transmittance. Weed Technology, 9: 113-118

Tessier, M.C., Leprous, G.D. (2000). Banded Herbicide application Implementation Benefits Condition for Success.

Theirfielder, C., Nicole, L. (2017). Weed Control under Conservation Agriculture in Dryland Smallholder Farming System of Southern Africa. A Review.

Thembani. P. (2002). Effect of intercropping leaf, leaf stripping, detasseling and weeding regime on radiant environment, weed dynamics and productivity of components. A thesis submitted in partial fulfilment of the requirements of the degree of MSc, Crop Science Department, Faculty of Agriculture University of Zimbabwe.

Thielfelder, C., Mombeyarara, T. Mango, N. and Rusinamhodzi, L. (2013). Integration of Conservation Agriculture in Smallholder Farming Systems of Southern Africa: identification of key entry point. Int. J. Agric. Sustain... DOI:10.1080/14735903.2013.764222.

Van der Weide. (2008). Innovation in Mechanical Weed Control in Row Crops. Applied Plant research, Wageningen University and Research Center, Netheerlands.

Zhoa, D.L., Atlin, D.N., Bastiaans, L., Spiertz, J.H.J. (2006). Cultivar Weed Competitiveness in Aerobic Rice: Heritability, Correlated Traits, and the Potential for Indirect Selection in Weed Free Environments. Crop Science 46: 372-380.