1. INTRODUCTION

1.1 Background

1.1.1 Zimbabwean agriculture

The Zimbabwean economy is heavily dependent on agriculture, which accounts for 18% of the Gross Domestic Product (ZFSPS, 2002). Because of this agriculture is considered as the backbone of the Zimbabwean economy being the second highest foreign currency earner. Among the crops that bring foreign currency to the country, is cotton, which is the second highest next to tobacco (Cotton Research Institute, 1997-1998). Cotton continues to be the most important cash crop for the SH farming sector, which in 1998/99 season produced 80% (300 000t) of total cotton produced (MoLARR, 1999). Cotton production involves 150 000 rural households in the drier parts of the country with over one million people involved in its production (CCGA, 1998; Sibanda *et al.*, 2001).

At the time of writing the proposal, agriculture in Zimbabwe was broadly divided into four farming sectors, communal, resettlement, small-scale and large-scale commercial. Prior to the land reform, individuals owned the large- and small-scale commercial farms while communal land was owned by the community (Mpande, 1992). The average size of a large-scale commercial farm was 1669 ha while that of a communal area was about 2.5 ha (Muchena, 1988). The livelihood of a communal farmer is usually sustained on this small piece of land only. The resettlement schemes were part of the government's land redistribution efforts, and settlers have use rights to the land. Zimbabwe's population is estimated at 12.5 million (ZFSPS, 2002) and a big percentage of this population lives in the four categories of the farming sectors mentioned above.

The government has since embarked on a land reform programme, which has resulted in the acquisition of land from the formerly white owned commercial farms for redistribution to the landless indigenous people. This has resulted in settlement of 127 192 households on 4 231080 ha under the A1 model and 7 260 households on 2 198 814 ha under the A2 model (Utete, 2003). Under the A1 model farmers were allotted land holdings of 4 – 8 ha by the District Administrator through a land permit. In this model grazing pastures are communally owned and there is a planned residential area for farmers. The A2 model is self contained, with each land holding having grazing, residential and a cropping area. The size of the farms vary from 15 ha to 400 ha depending agro-ecological region. Each farmer has a 99 year lease offered by the Ministry of Lands and Rural Resettlement (Chirapa[1], 2005).

An estimated 77% of the Zimbabwean population lives in the rural areas and 56% of this population is living in communal areas while 21% are in the commercial farming areas. Seventy percent of each category is women and children. In the rural areas female-headed households constitute 31%. Also, women constitute 70% of the agricultural labour force (ZFSPS, 2002) as most men are in urban employment. These figures then imply that most of the work in agriculture is carried out by women as men are in alternative employment. The majorities of communal farmers live in areas where mean annual rainfall is below 800mm (Tembo, 1989) and are only suitable for drought tolerant crops (ZFSPS, 2002).

Zimbabwe is classified into five agro-ecological regions, based on soil type, rainfall and other climatic factors. Classification is in the order of decreasing agricultural potential. Over 75% of the communal farms are located in the marginal rainfall regions IV and V, which receive rainfall below 600mm per annum. In these regions the soil is typically loose and infertile (Grant, 1981; Mashiringwani, 1983; Mataruka, 1985) and erratic rainfall patterns make rain-fed cropping a risky undertaking (Moyo, 1995; Nyagumbo, 2002). Under these conditions farmers are only limited to drought tolerant crops or have to diversify to ranching otherwise they need to employ farming techniques that will boost production.

Farmers therefore require an intense management system involving good planting techniques, and good weed and soil moisture control to sustain crop production. The only option is to consider irrigation, which is fairly expensive implying that crop production in most sectors, will continue to depend on limited rainfall. Success in crop production is then likely to depend on application of land management techniques, which conserve and increase the total soil water available to crops (Nehanda, 2000). It is against this background that animal traction to till, conserve moisture in the soil and weed becomes crucial to most of the country's population.

1.1.2 Draft power and weed management.

The use of animal traction can increase crop yields through either intensification or extensification of land use systems. Draft animal power (DAP) enables farmers to work faster

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and undertake additional agronomic practices such as, deeper ridging, mulching, application of fertilisers and better weed control, all of which considerably improve agricultural productivity (Norman *et al*, 1981). Improving weed control within the context of animal traction generally implies using animal-powered weeding implements instead of a hand hoe (Stevens, 1992). Reducing weed infestations plays a role in farmers' decisions almost the whole year round, starting with land preparation. Therefore, animal traction can help control excessive growth of weeds, which is among the leading factors that limit and reduce crop production in communal areas (Chivinge, 1990), at the same time reducing the burden on women.

Communal farmers suffer from a critical shortage of draft power and as a result most farmers are not able to perform their operations on time. Ellis Jones *et al*., (2001a) found that close to 50% of the farmers in Muzarabani district have inadequate draft power (0-3 cattle). This means they cannot effectively plough at the beginning of the season, and plant at the earliest planting opportunity, weed on time and maximise yields. The problem is compounded for farmers with fewer assets as they lack access to labour, draft animals and implements (Ellis-Jones *et al*., 2001a). The poor resourced farmers are forced to delay planting when they wait for well-endowed farmers to complete tillage operations before they can hire tillage units to come to their fields. These farmers are therefore effectively locked up in a vicious poverty cycle. Lack of draft power means that they plant late and their weeding is prolonged. On top of DAP shortages, most farmers' implements are generally in a poor condition as they are not well maintained and most farmers lack the knowledge in the proper setting and correct use of ploughs and cultivators (Koza *et al*., 2000b).

Weed management is one of the important elements of agricultural production systems in the world over (Kropff and Lotz, 1992). In the Muzarabani district of the Zambezi valley in Zimbabwe, farmers claim to begin weeding within one week of crop emergence and may weed cotton 4 to 6 times per season (Twomlow and Chatizwa, 1998; Sibanda *et al.,* 2001). Twomlow and Chatizwa (1998) reported that farmers in Muzarabani ranked weeding as the most labour intensive activity of the cotton crop cycle and indicated that alleviation of the constraints of weeds and weed control is a research priority. Ellis-Jones *et al*., (2001a) alluded to the same sentiments and further elucidated that weed management was a problem to all resource categories of farmers in Muzarabani. Because of shortage of draft power as mentioned earlier, farmers rely on hand weeding which consequently results in low yields and low income from crop production. In Muzarabani 90% of the income comes from cotton.

Further, low cotton yields for 50% of the farmers was shown to result in these farmers earning only 12.5-30 % of the yearly income of the well- resourced farmers (Ellis Jones *et al*., 2001a).

1.2 Justification

Recent work in Zimbabwe (Ellis-Jones *et al*., 1998; Riches *et al*., 1997; Twomlow *et al*, 1997a) has indicated the importance of studying tillage/crop establishment and the development of appropriate practices within an Integrated Crop Management context. The intensity of weed growth among crops is a reflection of the level of land preparation, tillage and planting practices. Soil moisture available to the crop can be enhanced by careful manipulation of tillage and at the same time be conserved by timely weeding (Mashavira *et al*., 1997; Twomlow *et al*, 1997b, Twomlow *et al*, 1998). Prior work has shown the advantages of establishing a crop within either a rip line (Shumba *et al*., 1992) or open plough furrow (Mashavira *et al*., 1995; Twomlow *et al*., 1995), but the two systems have not been compared before in Zimbabwe (Mashavira *et al*., 1997). If combined with weeding using a mould board plough with body attached, early planting, soil and water conservation, weed control and labour reduction could be achieved.

Much of the work has been targeted towards the mould board plough as a primary tillage implement (and not secondary tillage) and this has seen importation of the implement from other countries in the region with subsequent testing, development and fabrication. Testing has been done to determine suitability of the plough as a primary tillage implement to the soil conditions in the country. Information is not available revealing that a lot of extension has been done to introduce these implements to farmers. Work needs to be done to determine whether farmers understand how to use their implements. Koza *et al.,* (2000b) concluded that a detailed formal survey was required in Muzarabani. The emphasis being on the assessment of implements owned by farmers and obtaining a good understanding of the different circumstances faced by farmers that influence how they use and maintain them. Chatizwa and Ellis-Jones (1997) shared the same sentiments in a rapid rural appraisal in the 4 areas in NR II, III, IV and V.

Considerable research has been focused on crops, yet shortages and mismatches in draft animal power (DAP) implements have been ignored (Mupeta *et al*., 1990; Francis *et al*., 1992; Prasad *et al*., 1992; Francis, 1996). Very little research has been done to match implements and draft animals as farmers concede that their animals are increasingly becoming smaller in size, mainly due to poor nutrition (Tembo, 1989; Francis, 1993) resulting in reduced draft capabilities (Howard, 1980). This trend has not been correspondingly matched by research thrusts seeking to develop weeding implements suited to weaker and smaller animals, which are currently used by farmers. The challenge therefore for agricultural research is to develop and promote technologies that will improve crop productivity and reduce energy requirements for land preparation, whilst conserving the resource base in a sustainable manner (Nehanda, 2000). Furthermore farmers recognise the need to reduce weed competition and to keep a receptive soil surface to capture available rainwater and hence the need to weed 4 to 6 times (Twomlow and Chatizwa, 1998).

While cotton is the cash crop in Muzarabani, maize is also important for food security, but is often weeded just once because labour and DAP are allocated to the cotton crop. This leaves limited time to manage the maize crop (their staple grain) resulting in low yields averaging 0.7 tonnes/ha (Agritex, 1999). Most of the farmers will therefore, need to use money obtained from the sale of cotton to purchase maize. Alleviating the weeding constraint in cotton should facilitate improved management of maize, if labour and draft are released (Twomlow and Chatizwa, 1998). Possibilities include use of herbicides integrated with conservation cultivation through mechanical weeding methods that will conserve moisture in this low rainfall area where 400 - 600 mm is the annual average. Eighty percent of SH farmers from cotton production areas grow cotton and have a long experience in using knapsack sprayers and applying pesticides. As a result of their experience the use of herbicides can be applicable to SH farmers in Muzarabani. These farmers have the means (and only lack technical ability) to use chemical weed control combined with traditional hand hoeing and mechanical weeding (Mashingaidze and Chivinge, 1995).

Little consideration has, however, been given to the long-term effects of these technologies on productivity, draft power and labour requirements and the economics of the system (Ellis-Jones, 1997). There is, therefore, a need to further ascertain whether the introduction of herbicides will not introduce an extra cost that is not offset by the benefits derived from their use. Many farmers in Muzarabani believe that herbicide use is expensive compared to hand hoe and mechanical weeding methods (Chatizwa, *et al*, 2000).

From the parameters envisaged in the preceding paragraphs it was determined that farmers needed to introduce herbicides to reduce labour requirements for weeding and researchers needed to assess the effectiveness of each weeding system and also ascertain the draft power requirements of implements.

The work reported here, was part of a series of on-station and on-farm trials carried out to assess the performance of animal powered implements available in Zimbabwe for land preparation, crop establishment and mechanical weeding. The study concentrated on the soil moisture conservation techniques, soil penetration resistance, draft force characteristics, field efficiencies, weeding efficiency and yield responses to three animal powered mechanical weeding methods that are available to SH farmers in Zimbabwe. The thesis also investigated the economic benefits of using an integrated approach of mechanical weeding and pre-emergence band application of herbicides.

The study was undertaken as part of and contributed to a larger project " Weed management options for cotton based systems in the Zambezi valley", simply referred to as the Cotton Weeds Project. The project based in Lower Muzarabani district, was jointly managed and implemented by the Institute of Agricultural Engineering (IAE) (Ministry of Lands, Agriculture and Rural Resettlement) and the Crop Science Department (Faculty of Agriculture, University of Zimbabwe).

This study compliments the work done by two MPhil students under the project "Draft power performance and production management" which was a sister project to the Cotton Weeds Project. One component of this sister project was carried out at IAE, Harare, and Domboshawa Training Centre, Mashonaland East Province. The other component was carried out in Masvingo Province. This project sought to provide stakeholders with improved knowledge of animal-implement systems and best practice guidelines on implement and animal use for existing and innovative crop production methods. It also sought to assess the performance of a range of DAP implements available in Zimbabwe for crop establishment and mechanical weeding.

1.3 Hypothesis

1. The condition of implements in Muzarabani is poor, and a significant number of farmers do not know how to set their implements.
2. There are significant differences in draft force requirements, work rates and field efficiencies of the BS41 5- tine cultivator, the plough with the mould board both attached and removed when used as weeding implements.
3. The BS41 5- tine cultivator, the plough with the mould board both attached and removed significantly affect soil moisture conservation and penetration resistance of the soil when used as weeding implements.

4. The use of chemical and mechanical methods for weeding significantly improves weeding efficiency, crop characteristics and crop yields compared to mechanical weeding.
5. The use of chemical and mechanical weeding methods is significantly cheaper than mechanical weeding.

1.4 Objectives

The broad objective of this study is to evaluate weeding implements in the cotton cropping systems of the Zambezi Valley through use of different land preparation, crop establishment and weed control methods. The focus is to introduce methods of weed control and water conservation techniques and assess the performance of animal powered weeding implements used in Muzarabani. The specific objectives are as follows:

1. To assess the condition of implements and the knowledge of farmers on the use, repair and maintenance of draft animal power implements in Muzarabani district.
2. To compare the draft power requirements, work rates and field efficiencies of the BS41 5 –tine cultivator, the plough with the mould board both attached and removed as weeding implements.
3. To compare the soil moisture conservation effectiveness and penetration resistance attained as a result of the use of BS41 5 –tine cultivator, the plough with the mould board both attached and removed, as weeding implements.
4. To compare the weeding efficiency, crop characteristics and yield responses of the three mechanical weeding methods with/without the use of pre-emergence banded herbicide.
5. To assess the economic merits of three mechanical weeding methods with the use of pre-emergence banded herbicide with those of mechanical weeding.

2. LITERATURE REVIEW

2.1 Farming in Muzarabani district

Muzarabani covers an area of 412 500 ha. There are three distinct farming sectors; communal, resettlement and the large scale commercial (LSC) (Agritex, 1999) as shown on table 2.1.

Table 2.1: Information on three major farming sectors of Muzarabani District.

Sector	**Households**	**Natural region**	**Area (ha)**
Communal	2 600	IIa	15 250
	7 700	IV	216 000
Resettlement	441	IIa	11 566
LSC	95	IIa	133 184
Total	10 836		376 000

Source: Agritex, 1999.

An area of around 36 500 ha (about 9% of the district) is covered by the Mavhuradonha range of mountains. It is a wilderness area of virtually no agricultural value. Farming is limited to Upper Muzarabani (wholly NR IIa with all the three farming sectors) and Lower Muzarabani (wholly NR IV with the communal farming sector only). The main crops grown in Muzarabani are cotton, maize, groundnuts, sunflower, flue-cured and burley tobacco. The first five are the most important to the small holder (SH) farmers. Table 2.2 gives hectarages of the major crops grown in the district in the 1998/99 season.

Table 2.2: Hectarages of major crops grown in Muzarabani district in the 1998/99 season.

Crop	Communal	Resettlement	LSC
Cotton	13 500	100	-
Maize	9 900	1 900	2 500
Groundnuts	800	100	-
Flue cured tobacco	4	400	3 500
Burley tobacco	500	600	800
Sunflower	70	8	-

Source: Agritex, 1999.

2.1.1 Baseline information on livelihood analysis in Muzarabani district

Ellis- Jones *et al.,* (2001a), undertook a household survey*,* in the communal farming areas of Muzarabani District, in the Zambezi valley, to provide baseline information on livelihoods, farming systems and weed management. In this survey farmers were categorised according to their resource availability based on participatory wealth ranking (Chatizwa *et al*., 2000). Four separate resource categories (RGs) were identified, where RG1 was the richest and RG4 the poorest. These were based on livestock and implement ownership; use of crop inputs; yields achieved; type of homestead; education level of the head of household and sources of income. The main characteristics of each resource group are shown in appendix 1.

The average household size was 9 people ranging from 11 for RG1 to 6 for RG4. Poorer households had smaller families and fewer members working outside with potential for sending back remittances from off-farm employment. Overall the most important source of income was from cotton with maize, groundnuts, gardens and livestock all being important. The average area cultivated including land in fallow was 4.4 ha ranging from 6.1 ha for RG1 to 2.9 ha for RG4. From this acreage cotton was the most important crop in terms of area cropped for all resource categories, occupying 40-55 % of the area. In each case lower RGs cultivated smaller areas of each crop.

2.2 Weeds and their economic importance

Weeds are unwanted and undesirable plants which interfere with the utilisation of land and water resources, adversely affecting human welfare (Rao, 1983). Their vegetative habits and demand for resources are usually similar to those of the desirable crop, and so there is competition for nutrients, water, space and sunlight. There is also growing evidence for allelopathic effects of some weeds, which exude chemical compounds harmful to crops, human beings and livestock (Rice, 1984).

The overall effect of weeds is reduced crop yields of desirable plants. Estimates of yield losses due to weeds vary greatly depending on the magnitude of the weed population, the weed species and the fertility of the soil (Kwiligwa, *et al*, 1992). It is generally accepted that about 20 -30% loss of agricultural production in the world can be attributed to the competitive effect of weeds (Sing *et al*., 1996).

In Muzarabani weeding was ranked as the most labour intensive activity for farmers and because of weed infestation, some farmers fail to control the weeds and end up abandoning some portions of their fields (Ellis Jones *et al*, 2001a). Appendix 2 shows the main problematic weeds in Muzarabani as identified by Mavhudzi *et al.*, (2001).

In a focus group discussion in Muzarabani conducted by Ellis-Jones *et al*, (2001b), they concluded that:

- Weeds were a major problem in Muzarabani.
- There has been very little experience with the use of herbicides, largely by better-resourced farmers, who have discontinued use due to problems of high cost and some crop damage.
- Most farmers were willing to try herbicides in conjunction with on-going methods of weed control to improve their weed management.
- There is need to focus on developing alternative weed management options appropriate to the resources available in the different farmer categories.

Cotton is particularly sensitive to weed competition due to slow growth. Full ground cover is only achieved after 6 to 8 weeks. Cotton and weed competition studies in Zimbabwe have shown that the critical period for weed competition is 6 to 8 weeks after germination but in the 'drier seasons', yield loss is significant when weeds are left uncontrolled between 2 to 4 weeks (Schwerzel and Thomas, 1971). Research recommends that cotton must be kept weed free for the first ten weeks (Cotton Hand Book, 1997) but no real suggestions as to which techniques are the most efficient has been given. Further, the recommendation takes no account of the resources available to the communal farmer to achieve this.

From a study, in the southern highlands in Tanzania, Shetto and Kwiligwa (1989) describe the decisive impact that proper weed control has on crop yields and total production and state that the answer to the weeding problem of many households is an increase in productive capacity of available labour. This can be achieved by using draft animals. Riches *et al.,* (1997) in their work with SH farmers in Masvingo Province showed that inter-household variability in access to both draft animal power and labour are key determinants of the ability to weed on time. They also noted that 35 % of the community members neither have access to adequate levels of these resources, nor sufficient cash to hire labour.

Working with communities in Masvingo and Midlands Provinces has also shown how farmers have a deep understanding of the issues, which need to be integrated for them to achieve acceptable maize stands, and to grow a weed-free crop synchronised with available soil moisture (Ellis-Jones *et al*, 1994). Similarly in the Zambezi Valley, the farmer's burden is twofold, the growing season is too short and there is heavy weed infestation or growth as soon as it rains due to high temperatures (Twomlow and Chatizwa, 1998). The success with which the crop production system can be managed depends on household assets and access to resources (Ellis-Jones and Mudhara, 1997). Understanding of this has provided the background for studying the processes involved, and strengths and weaknesses of a range of tillage/weed control practices as potential options for farmer adoption. Open plough furrow planting, ripping and post emergence ridging, have been evaluated with cotton farmers in Sanyati and Gokwe districts with the aim of enhancing moisture conservation (Twomlow *et al*., 1994; Mashavira *et al*., 1995). These systems can be extended to the Zambezi valley to establish an early crop, control weeds and enhance soil moisture conservation.

2.3 Animal traction

Animal draft power will continue to play an important role among small-scale communal farmers in sub-Saharan Africa for many years to come and so will the associated implements. In work done by Francis (1988) in northern Zambia and Sumberg and Gilbert (1992) in Gambia they state that in areas where arable land is abundant, animal traction is often used to expand the cultivated area. This implies that there is a positive correlation between the land area cultivated by a household and the use of draft animal power (DAP) (Barett *et al*, 1982). That not withstanding, it is inappropriate to attribute the increased area totally to the use of DAP; in many cases households which use DAP have a large labour force than households which do not (Panin, 1987; Sumberg and Gilbert, 1992).

Draft animals are part of animal production systems in which work is an indispensable product. They include cattle, buffaloes, horses, camels, elephants, donkeys and others (Upadhyay, 1990). Two billion people throughout the world use almost 400 million draft animals to cultivate 50 percent of the land (Mrema, 1991). Three quarters of these animals are found in Asia and the Pacific and they comprise mainly cattle and buffaloes. Another 5 percent of the world population of draft animals is found in Africa.

Draft animals and human labour provide most of the farm power used in developing countries. Draft animals constitute almost 80 percent of total power used on farms in the world (Ndlovu and Francis, 1997). According to Ndlovu and Francis (1997), compared with other regions of the world, human power is the most common in Sub-Saharan Africa (Table

2.4). DAP and tractor utilisations account for smaller percentages and are limited. This implies that there is potential for improving animal power utilisation in the region.

Table 2.3: Proportion (%) of total power used in developing countries.

Area	Human Power	Animal Power	Tractor Power
North Africa	69	17	14
Sub-Saharan Africa	89	10	1
Asia (excluding China)	68	28	4
Latin America	59	19	22
TOTAL	71	23	6

Source: FAO (1987) cited by Panin and Ellis-Jones (1992).

About 15-20 percent of Africa's arable land is cultivated using DAP (ILCA, 1987). In sub-Saharan Africa, 10-15 million indigenous draft animals are regularly used to cultivate about 5-10 percent of the arable land area that is cropped (Ndlovu and Francis, 1997). Although there are wide regional variations, use of animal traction is increasing in the whole Sub-Saharan Africa (Sindazi, 1988).

Oxen constitute the highest number of work animals. Donkeys, mules, horses and camels are also used where they are available. Cows, though numerically superior to oxen, are seldomly used for work. Use of draft animals is common for ploughing but limited for secondary cultivation such as planting, weeding and harvesting (Ndlovu and Francis, 1997). Intensity of use of animal draft power is highest in East Africa, followed by Southern Africa (Jahnke, 1982). Proportions of cattle and donkey use in selected sub-Saharan African countries are presented in appendix 3. Ethiopia has the highest number of draft animals in East Africa. In Southern Africa, most draft animals are used in Zimbabwe (Goe, 1989; Prasad *et al*, 1991). To reduce use of human power and increase animal traction there is a need to promote DAP mechanical weeding together with associated animal powered weeders.

Animal- powered weeders are available in most African countries, but only 5% of farmers who use animal traction for ploughing also use weeders on row crops (Starkey, 1986; 1988). The figures vary from almost zero in Botswana, Mozambique, Tanzania, Uganda and Zambia to between 10 and 20% in Cameroon and Mali and to as much as 40% in South Africa and

Zimbabwe (Kjaerby, 1983; ILO, 1987). Rain (1984) identified the lack of good animal powered weeders as the main constraint to crop production by those farmers who ploughed with animals.

2.4 Availability of and solutions to DAP shortage in Zimbabwe

In the communal areas of Zimbabwe, DAP is more commonly used than tractor power. Oxen are the main form of DAP, although donkeys are more popular in the arid areas. However, up to 65% of communal farmers do not own any cattle (Mudimu, 1983; Bratton, 1984; Shumba, 1984 a, b; Gesellschaft Fu Agrarprokekte, (1987)). In Zimbabwe animals provide close to 90% of the draft power requirements (Zimbabwe's Agricultural Policy Framework: 1995-2020) and cattle are the preferred draft animals (Mbanje, 1997). Prior to the drought of 1992 in Zimbabwe, DAP availability was a concern in some areas, but with up to 75% of cattle perishing, shortage of DAP became an issue in all areas (Muvirimi, 1997). Table 2.4 shows animal ownership patterns in relation to the farmer recommendation domains in three semi-arid areas of Zimbabwe. The areas are Sebukwe in Matabeleland South, Sebungwe in Matabeleland North and Chikwanda in Masvingo.

Table 2.4: Ownership of draft animals in three semi-arid areas in Zimbabwe

		% of farmers,	(n=247)
No DAP	No access	7	
	Some access	25	32
Inadequate DAP	Donkeys only	12	
	Cattle and donkeys	4	
	Cattle only	4	20
Adequate DAP	Donkeys only	2	
	Cattle and donkeys	14	48
	Cattle only	32	

Source: Muvirimi, 1997

In Muzarabani it is reported that 89% of the farmers use draft animals for land preparation, 6% use tractors and 6% use both (Ellis-Jones, *et al*, 2001a). Ploughing is regarded as the most critical and power requiring DAP operation in Zimbabwe. When there are sufficient oxen, DAP is supplied by oxen, but as numbers have decreased, the burden of DAP is now shared between oxen, cows and donkeys (Ellis-Jones, 1997). A large number of farmers (52%) (Muchena, 1997; Muvirimi, 1997) do not have adequate animals and therefore have to rely on alternative sources. According to Ellis-Jones, *et al*, (2001a) in Muzarabani the richest category of farmers, constituting 26% of the farmers in the area, owned on average 19 cattle, 2 or more ploughs, 2 or more cultivators and one cart. The poorest category making up 22% of the farmers did not have any livestock and did not own any farming implements. The two intermediate wealth ranking categories making up 52% of the population of farmers owned between 3-8 cattle, with the rich half of this group owning, on average eight cattle, a plough, a cultivator and cart while the poorer half of them owned three cattle and a plough.

The shortage of DAP is considered one of the major constraints (after water and soil fertility) to increasing the crop productivity of SH farmers in Zimbabwe and other countries in the Sub-Saharan Africa (Mbanje & O'Neill, 1997). The recurrent droughts, especially the severe drought of 1992, caused the national draft animal herd, particularly cattle, to decrease significantly. As a result of deaths of mature and larger animals there was a decline in older cows and oxen relative to younger and smaller animals (Ellis-Jones, 1997; Francis, 1996). Communal farmers are left with no option but to use lightweight cattle and donkeys, which have lower draft capability than the oxen traditionally used (Mbanje & O'Neill, 1997). The characteristics (breeds and types) of draft cattle available in the SH sector have been studied (Mupeta, *et al*., 1990). Indications are that oxen used up to the 1970s had live weights of at least 500 kg (Howard, 1980) whilst today most have live-weights of around 300 to 400 kg (Hagman and Prasad, 1995). A decrease in size would reduce draft capability of the cattle available for work. The Ministry of Agriculture recognises that some implements used in the communal areas do not match the draft power resulting in either straining or under utilising the animals involved (Zimbabwe Agricultural Policy Framework, 1995-2020).

In Zimbabwe, most animal powered, primary and secondary tillage implements have high draft power requirements and hence are suitable for large draft animals (Mbanje & O'Neill, 1997). The current situation calls for the use of low draft implements, which will be matched to the available smaller animals. In work done by Mbanje *et al* (1997) on the selection and evaluation of a number of implements designed to be used by animals of limited draft capability, they concluded that low draft implements generally take longer to undertake the same work as higher draft implements, when matched to the appropriate draft animals. They further said using higher draft implements with animals of limited capability would take longer with considerable loss of efficiency. When animals are correctly matched to the implement they are able to work for 5-6 hours for ploughing and longer for weeding. It is operator fatigue that often limits the duration of the operation.

2.5 Draft animals and tillage operations

Tillage operations in the semi-arid areas of Zimbabwe coincide with the end of the dry season (October-November) during this period most animals are in bad condition due to inadequate and poor grazing. Draft animals, therefore, cannot provide enough draft power commensurate with their sizes**.** SH farmers are then frequently forced to wait for animals to pick up sufficient condition from the new flush of grass stimulated to grow by the first rains, before ploughing the land to begin planting. This inevitably causes delays in planting with the concomitant yield losses (Shumba *et al*., 1992; Grant, 1981). Delays in planting causes bottlenecks during weeding as in Muzarabani the first weeding should be carried out at three weeks after crop emergence (wace) when most farmers are still busy ploughing and planting.

The options available to farmers to alleviate the draft constraints are to either increase herd size or use cultivation techniques that require lower draft force. Increasing herd size cannot be sustained, as there is limited grazing area. The only sustainable option will be to use appropriate tillage techniques such as winter ploughing, when the animals are stronger and soils are not so hard to till (Tsimba, 2000). It is common practice in the SH sector to plough at the end of the rainy season when the soil is still soft and moist in April and May (winter ploughing). Despite this advantage most farmers are forced to till their lands at the beginning of the season in October and November (spring ploughing) with farmers in Muzarabani undertaking their land preparation from August through to December. Most crops are planted in November and December usually at the time of land preparation. In Muzarabani, most land is spring ploughed (42%) usually after the first rain, 36% is winter ploughed, 8% is both winter and spring ploughed, 9% is directly planted without ploughing because of shortage of DAP (not because reduced tillage is seen as a benefit), 1% spring disc only and 4% winter and spring harrowing (Elli-Jones, *et al*, 2001a). According to CARE (1999), in Masvingo the richest farmers (46%) performed winter ploughing while very few poor farmers did. Farmers perform both winter and spring ploughing to first conserve residual moisture from the previous season and then to eliminate weeds before planting (Mashavira, *et al*., 1997).

The most common time for ploughing for up to 90% of these farmers was after the first rains i.e. spring ploughing. Richer farmers (33%) practised ploughing twice (winter and spring) while only 11% of poorer farmers practised this.

Time of ploughing is important for moisture conservation, with Agritex recommending that ploughing should take place soon after harvesting i.e. winter ploughing (Ellis-Jones, 2000). Once winter ploughing has been practised, reduced tillage planting can be implemented. This involves shallow ploughing once rains fall during the rainy season (spring ploughing), or simple open the planting lines by the use of a ripper tine or use of a mould board plough with the mould board removed (OP-D) (Mbanje *et al.,* 2000; Shumba, 1989). Shallow spring ploughing after winter ploughing is done to remove any weeds that would have germinated before planting. Winter followed by shallow spring ploughing not only curtails the draft power shortage but also ensures early planting. Open furrow planting using the mould board plough can be used as a form of reduced tillage (Twomlow *et al*, 1998).

Howard (1980) reported that two oxen in good condition, with a combined mass of 1360 kg were able to exert a draft force of over 2.5 kN (pulling a cart) for 4 hours a day over three consecutive days. In this example, at least, the beast and burden were well matched, although the oxen developing a draft effort exceeding 18% of their body weight, which Howard acknowledged is generally taken to be 10%, achieved it. Recent information on typical weights of communal farmers' oxen suggests that they have live weights of around 300 to 400 kg. In the study by Hagman and Prasad (1995), twelve Mashona oxen were used as being typical of those in the communal areas and they had an average live weight of 367 kg.

If the live weights of oxen are between 300 and 400 kg a typical communal area ox is 350 kg (Elliot, 1989). In similar work to that done by Howard (1980), Goe (1983) states that using standard figures of sustainable pull of 10 to 14 % of combined weight, four typical oxen can exert a sustained draft force of about 1.4 to 2 kN for a four to six hour working day. Using the typical weight of 367kg, two oxen are expected to till farmers' field in winter and shallow ploughing after the first rains and perform any subsequent mechanical weeding operations without straining them (despite their poor condition during the early part of the rainy season).

2.6 Issues related to draft force

Draft force is the resistance an implement offers to forward movement and determines the tractive force animals should apply through a yoke or harness. The standard international (s.i) unit of measure of draft force is the Newton (N). This force is realised in the draft chain or draw pole, which in turn applies a force to the attached object. This is the major factor considered when determining the draft power requirement of an implement. Animal draft power is a function of animal size; the larger the draft animal, the greater the draft power output (see equation 5.3).

Draft force is affected by the material used to make an implement, working width and depth of the implement, type and composition of soil, soil tillage history, sinkage and tillage strength (Bansal and Thierstein, 1990). It is also affected by the quantity and type of living plants growing in the soil, presence of roots, stones or stumps and slopes of land.

The draft force (H) of an implement is a function of the angle of pull (α) and the pull in the chain (P) on the implement. α, the angle of pull is the angle between the direction of pull of the chain and the direction of movement of the implement. The relationship is: $H = P \cos \alpha$ (Mbanje, 1997) as shown in figure 2.1. H is the useful draft force and is the horizontal component of pull P. The height above ground to the yoke depends on the size of animals. The angle of pull is dependent on the height at the yoke and the length of the trek chain. The length of the trek chain can be appropriately adjusted to hitch the implement. A short chain increases the angle of pull and cos α becomes smaller than when a long chain is used (Koza, 2004). Lengthening the trek chain can increase the horizontal component of pull and more useful draft will be achieved. Better stability and control of the plough is achieved by using a longer chain than a shorter one.

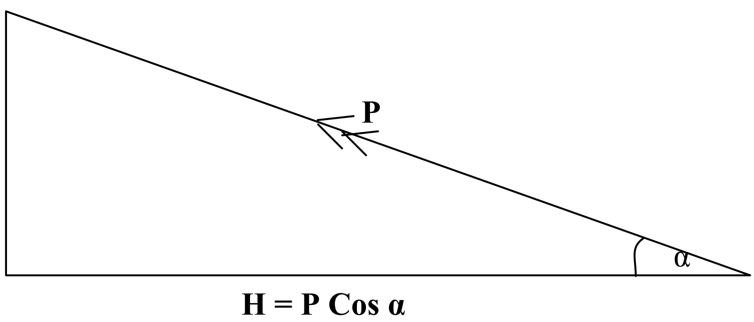

Fig 2.1: Draft force system acting on an implement

2.7 Soil and water conservation

The overall goal of tillage is to increase crop production, whilst conserving resources (water and soil) and protecting the environment (Nehanda, 2000). One of the most critical factors associated with conservation tillage systems in the warmer climates of the world is moisture conservation. The phenomenon of improved moisture conservation tillage systems has been linked to improved soil structural conditions, reduction of evaporation and retention of precipitation (Nehanda, 2000). It is estimated that less than 1% of SH farmers in Zimbabwe practise conservation tillage techniques (Nyagumbo, 1998) and this proportion will not increase significantly until the benefits are clearly demonstrated to the farmers and are fully evaluated. In Muzarabani 32% of households indicated that they use some form of soil and water conservation methods in their lands (Ellis-Jones, *et al*, 2001a), the main ones being ridges (13%), contours (6%), potholes (5%) and tied ridges (4%). As a result of the low level of conservation in an area that experiences particularly erosive rainfall, soil erosion is a widespread problem. Cotton fields with erosion signs were frequently seen during fieldwork in the area.

Any form of soil disturbance after planting will increase infiltration of the water in the soil. Mechanical weeding using a cultivator or plough achieves better water infiltration than when hand hoe weeding is practised. One way of practicing water conservation is through post emergence ridging. When the mould board is attached to the plough during weeding operations ridge and furrow landforms are formed, and these have potential to enhance water retention. (Ellis-Jones *et al*, 1993). The furrows created between crop rows can be easily tied to conserve any precipitation or broken in the event of excessive rains. Research done in Burkina Faso and Mali showed that ridging and tied ridging significantly increased cereal crop yields (Stroosnijder and Hoogmoed, 1984) while in Nigeria sorghum yields significantly increased also (Van der Ploeg and Reddy, 1988) as a result of moisture conservation.

There is a different school of thought though, that views conservation tillage which it defines as all crop production systems in which at least 30% of the soil surface is covered by plant (Parr *et al.*, 1990) as better than winter ploughing and post emergence ridging. This definition is, therefore synonymous with such tillage systems as no-tillage, minimum/reduced tillage and mulch ripping tillage (Nehanda, 2000). (However conservation tillage is known to include also tied ridging). In this definition conservation tillage is viewed to give such advantages as reduced runoff, increased water infiltration, increased water storage for plant growth, reduced soil erosion and reduced fertility losses through soil erosion.

Nehanda, (2000) argues that in spite of the advantages arising from conservation tillage systems (as listed above), these systems have not produced desired out put of increased crop production, as expected under trial conditions. Yields have generally been lower than those of the conventional tillage treatments, with exception of the cotton crop, and a few odd dry seasons for the maize crop. Furthermore in the absence of effective weed control strategies, increased competition for nutrients and water reduce yields.

2.8 Socio-economic issues

Socio-economic studies carried out in Zimbabwe have indicated a wide spread understanding amongst local farmers of the need for timely land preparation, planting and inter-row cultivation for both weed control and for keeping a rough soil surface which can retain subsequent rainfall (Ellis-Jones and Riches, 1992; Mudhara and Ellis-Jones, 1993). Despite this realisation of timeliness of operations there are major socio-cultural constraints that are hampering time management in the fields, e.g., high death rates in the country mainly due to the AIDS epidemic.

The HIV/AIDS pandemic has put Zimbabwe's health system under a lot of pressure in recent years in the face of budgetary constraints. Between 1984 and 1999, 10 to 20 percent of the adult population (15-19) years were effected with HIV/AIDS. Life expectancy at birth has fallen from an expected 64.9 years (at independence in 1980) to 39.2 years as of 2001 (ZFSPS, 2002). Most farmers are spending disproportionate amount of time attending funerals with some farmers claiming that they spend more than 30% of their time attending funerals (Nyagumbo, 1997). Attendance to funerals is expected by local customs and some of these funerals occur during peak periods of crop production. Culturally it is a taboo to work in the fields when there is a funeral within the village/kraal. While the farmers are attending funerals, the fields are unattended and weeds grow unabated. The only way to salvage the situation is through encouraging farmers to use animal traction, as this will improve timeliness of the weeding operation. The other option is the introduction of herbicides to control weeds since once they are applied they do not require any human intervention for their effectiveness.

2.9 Methods of weed control

A plough, cultivator, hand hoe or a combination of methods (depending upon implement ownership, draft power and labour availability) is used in Zimbabwe for weeding (AETC AP 3, 1987). If a plough is used, farmers usually remove the mouldboard leaving the share as the operational weeding blade. Farmers remove the mould board during a weeding operation as it has a tendency to bury young crops and in some in stances damage them (Stevens, 1992). The use of hoes is referred to as manual weeding while use of animal powered implements (ploughs and cultivators) is mechanical weeding. Mechanical weeding was adopted to reduce the drudgery on women due to hoe weeding and increase timeliness and precision in operations (Akoubundu, 1987). In Masvingo province the well-resourced farmers use ox ploughs or cultivators combined with hand hoeing. Some of these farmers can afford to buy herbicides for weed control (CARE, 1999). Medium resource farmers are equally split between hand hoe weeding only and ox cultivator or plough plus hand weeding. Most poorly resourced farmers opt for hand hoe weeding and cannot afford to hire labour for their weeding.

2.9.1 Manual weed control

In some societies, women have the primary responsibility for weeding operations. In Zimbabwe, women view hoe weeding as the most punishing exercise they ever carry out (Chatizwa, 1997). To reduce this drudgery on women, there is need to provide methods that are easier for them to use, such as the use of animal traction and animal drawn weeders operated by men (Starkey, 1992). This not withstanding, the extensification associated with animal traction could increase the workload of women.

Weeding with a hand hoe involves scraping the soil to cut the roots of weeds just below the soil surface and shaking the soil off the roots to prevent re-growth (Kayumbo, 1992). When hand weeding a crop that has been placed on ridges, the ridges need to be rebuilt at the same time, by scarping the soil upward from the furrows. In both cases the process is slow and tedious.

Hoe weeding has a number of advantages when the socio-economic conditions prevailing in the SH sector in Southern Africa are considered. It is simple, does not require investment in expensive equipment or periodic purchases of inputs like herbicides nor does it require the farmer to be literate and numerate. Hoe weeding has been reported to be efficient in weed control particularly within the crop row (Mabasa, 1992). However, the technology also has a number of disadvantages and its efficacy is limited to hot dry conditions. Hoe weeding is often inappropriate given the farmer's circumstances of shortage of labour and cash to hire labour. It is labour intensive and inefficient (Gill, 1982) especially under continuously wet conditions obtaining in the early part of the rainy season in sub-tropical conditions such as Southern Africa (Mashingaidze and Chivinge, 1995; Chivinge, 1990; Akoubundu, 1987). SH farmers therefore spend a disproportionate amount of time during the cropping season battling to control weeds and at the end of the season show very little for the misery and toil (Chivinge, 1990; Akoubundu, 1987).

Akoubundu, (1987) reports that weed control using hoe weeding is the most labour demanding pre-harvest activity in crop production and yet it remains the most common weeding method in Africa. Riches *et al*. (1997) reported that weeding accounts for up to 60% of the labour used in maize production in semi-arid Zimbabwe. Weeding operations utilise 20% of the total human energy in crop production (Gite and Yadav, 1990) and more than 25% of the total labour requirement (900 - 1 200 labour-hours/hectare) during a cultivation season (Nagg and Dutt, 1979). Women and children provide the greater part of this labour (Mortiner, 1994). Furthermore, most children used under these circumstances will not go to school regularly (Labrada and Parker, 1994). The use of hand hoe weeding is common in Muzarabani with 22-26% of farmers using it in cotton, 31-44% in maize, while in ground nuts it is widely used with up to 84% of the farmers (Ellis-Jones *et al*, 2001a).

Observations in Zimbabwe's SH farming community indicate that: -

◊ Use of hand hoe for primary cultivation and weeding imposes strict limitations on production. There is therefore, little or no chance of SH farmers rising above subsistence level while the hoe remains the prime tool for cultivation and weeding. The use of traction implements is therefore encouraged to reduce drudgery particularly for women.

◊ Many implements, especially ox-cultivators are too heavy for women to use. This is because there has been very little consultation, if any between manufacturers and blacksmiths, and their women clients to enable the design of suitable implements.

◊ Animal traction is seen as a possible technology that can alleviate the crop establishment and weed control problems (Chatizwa, 1997).

2.9.2 Mechanical weed control

The main implements used for cultivation purposes in Zimbabwe are cultivators, mould board ploughs and a plough without mouldboard (Chatizwa and Ellis – Jones, 1997). Cultivation using ox-drawn implements is faster and effective, reducing the time from 30 - 70 hours per weeding (using hand hoes) per hectare to 10 –20 hours for animal powered weeding. The labour requirements are reduced by 50 - 70 % when implements are used versus complete hand weeding (Chatizwa, 1993). For ox drawn cultivation implements to be effective, they are used in conjunction with hoe weeding to control weeds within the crop rows (Vernon, 1984). Akoubundu (1987) reported that animal powered weeders are more effective where rainfall is high and uprooted weeds have a chance to dry in sunlight. More than 50% of the farmers in Muzarabani use the cultivator for weeding while 7-11% of farmers use the plough (in combination with the hand hoe) (Ellis-Jones *et al*, 2001a). The use of ox-drawn cultivators and mould board ploughs has added advantages of creating ridges, furrows and small holes on the soil surface therefore increasing moisture retention (Willocks and Twomlow, 1993). However, studies by Ellis-Jones *et al*., (1993), showed that there is 5% crop damage, particularly due to weeding implements as they pass through the land.

2.9.3 Chemical weed control

Delayed weeding by SH farmers in Zimbabwe is attributed to insufficient labour for weeding at the critical early stages of crop growth (Mabasa, 1992). Under such conditions herbicides could be used since they improve timeliness of weeding and allow labour to be released for other farm operations. Parker and Vernon (1982) reported that herbicides could save up to 80% of the labour normally used for hand hoeing. In Zambia, herbicides have been found to increase maize yields by 11% (Parker and Vernon, 1982) and 13% in cotton (Lange *et al*, 1978). In Zimbabwe (Chivinge, 1984; 1990) reported that an indirect increase in yields by use of herbicides might also occur by releasing labour from one crop in which herbicides have been used for timely planting or improved care of another crop.

Herbicide use can also be advantageous in that dormant seeds are not stimulated to germinate as in the case of hand or mechanical weeding. In addition herbicides can be applied under wet conditions whereas other methods of weed control cannot, except slashing. Moreover there is reduced soil compaction and less loss of soil structure (Chivinge, 1984). The use of herbicides has some potential in SH farmers in Zimbabwe where 80% of SH farmers from cotton production areas now produce cotton, and have a long experience in using knapsack sprayers for applying insecticides. These farmers only lack the means and the technical ability to use chemical weed control combined with traditional hand hoeing and other cultural weed control methods (Mashingaidze and Chivinge, 1995). As a result only 6% of farmers in Muzarabani use herbicides (Ellis-Jones *et al*, 2001a). The biggest challenges to herbicide use is the belief that they are not effective and have after season effects, which might be due to improper use of herbicides. Farmers generally consider herbicides to be expensive and would therefore prefer the traditional practice of weed control (Chatizwa *et al*., 1998). Another hindrance is that farmers practice mixed farming and use of herbicides is therefore not appreciated.

2.9.4 Mechanical and chemical weed control

Adoption of herbicides has been very low because of lack of knowledge, technical ability and high costs (Chivinge, 1984; 1990). Although the reduction of herbicides dosage rates by a third or a half reduce weed control efficiency, yield levels were often similar to those obtained under maximum weed management levels (Chivinge and Schweppenhauser, 1994). Besides reducing herbicides dosage rates, a possible further technological intervention to bring herbicide use within the reach of farmers would be to apply herbicides only on intra - row space removing the inter - row weeds by hand hoeing or mechanical weeding afterwards. Applying herbicides on a 30cm band can reduce herbicide cost by 50% (Chivinge and Schweppenhauser, 1994).

2.10 Weeding implements

2.10.1 Ox cultivator

There are five main types of tines for cultivators available in Zimbabwe and these vary in penetration, cutting and soil moving ability. These are; reversible, duck-foot sweep, standard sweep, hiller and shovel. The ox-drawn cultivator used by SH farmers has five tines and is a one-row implement. The cultivator has handles, which allow the operator to keep it in an upright position or to lift it and move it sideways. The width of the cultivator can be changed by pulling (decreasing the width) or pushing (increasing the width) a lever fixing the desired width by securing the lever into a sprocket. At least 31% of farmers in Zimbabwe own one or more cultivators (Mabasa *et al*., 1995; Muvirimi 19[illegible] From a survey in Muzarabani, ownership of cultivators varied with RG, from two cultivators for the richest farmers to zero for the poorest (Ellis-Jones, *et al.,* 2001a).

The use of cultivators for weeding is most appropriate for early weed control (Chivinge, 1990) on smooth, clean fields. Weeding with cultivators becomes troublesome on land heavily infested with weeds, particularly when the implement has many short tine shanks. The ox-drawn cultivator is very efficient at removing weeds between crop rows particularly when they are less than 15 cm in height. Its main disadvantage is that it is believed to be heavy for draft animals (Chivinge, 1990) and hence the reason why some farmers remove some of the tines (Koza *et al*, 2000b). Most farmers complain that the ox cultivator (OC) is too heavy to lift or pull at headlands especially by women (Koza *et al*, 2000b). Clods of soil and uprooted weeds get stuck between the tines and the cultivator starts acting like a rake, not penetrating the soil anymore. It merely sweeps the gathered ball of soil and weed mass forward (Stevens, 1992). The same problem occurs in fields with high levels of crop residues (which are desirable in conservation tillage systems). Another problem with the OCs is rather the complex design, as compared to ridgers and ploughs. In practice this results in the bulky tools, which are often poorly assembled, and which generally cannot be set as specified (Stevens, 1992).

2.10.2 Ox-Drawn plough as a weeding implement.

The idea of using an ox drawn plough with the mould board attached (OP + D) for weed control was suggested by Muza *et al*, (1996) as a viable cropping system for small holder farmers with limited access to draft power and labour. Mabasa *et al*, (1995) noted that there were farmers who were substituting ox-cultivation with inter-row ploughing. At least 90% of SH farmers own ploughs in Zimbabwe (Mabasa *et al*, 1995; Muvirimi, 1997). About 10% of farmers in Muzarabani use this method and ownership of mould board ploughs varies with RG, from an average of two ploughs for the richest farmers to an average of half for the poorest (Ellis-Jones, *et al.,* 2001a). Farmers plough the inter-row area in opposite directions. The plough in the inter-row area directly removes weeds while those along the crop row are buried by the soil thrown in the direction of the crop by the mould board of the plough. Ellis-Jones *et al*, (1993) found that no additional weeding to remove weeds within the crop row was required when this system was used. A ridge is built on the crop row and a channel is opened in the middle of the inter-row area, which can be 'tied' to form a tied ridge system, which can increase water capture and retention. Ridging, and especially tie-ridging, has good potential for soil and water management, particularly in sub-humid regions and on heavier soils in semi-arid areas. Ridges reduce water logging and soil loss and facilitate drought survival.

Ridging is a fast and simple weeding method, which, like ploughing, can cope with crop residues, big weeds and relatively high weed densities. Ploughs are reasonably easy to use on fields with tree stumps and shrub remains. Ridging covers weeds within the crop rows, but ridging early in the season runs the risk of covering seedlings as well as weeds (Stevens, 1992). It would require good management to use a plough effectively for first weeding on flat land; weeding must be done early enough to prevent unacceptable yield reduction and build-up of weeds, but not so early that the crop may be damaged. When the crop is planted on ridges this might be less of a problem. Hence ridging is particularly recommended as a technique for the second weeding (Stevens, 1992).

Some farmers say the mould board plough is versatile, as it can be used for both primary tillage and weeding. Because some farmers do not own anything more than a plough they are left with no option but to use it for both primary tillage and weeding purposes. The advantage it has is that deeper cultivation increases moisture retention of the soil. Its major disadvantages are the number of runs made between the rows compared to the cultivator and that it is also difficult to maintain the depth of penetration (Koza, *et al*, 2000a). It is difficult to maintain a weeding depth of 7 - 8cm as recommended by Mbanje & O'Neill (1997) and the plough has a tendency to go deeper.

2.10.3 Ox-Drawn plough without mould board as a weeding implement.

The other method of weeding involves the use of the plough without the mould board (OP-D) and the ploughshare only is used as the operational weeding blade. It is the more commonly practised method of using the plough for weed control in the communal areas. The width of cut for OP – D is 20 – 25 cm while that for OP + D is 22 – 28 cm. As a result three passes are required per inter-row area for OP – D in a crop with a inter row spacing of 90cm compared to two passes for OP + D. Weeds in the row have to be removed by hand weeding. As a result this method requires more labour input than using the OP + D or the OC (Ellis-Jones *et al*., 1993). Farmers believe that the OP – D is effective though the labour-requirements are highest (Sibanda *et al*, 2001). The basis of the belief is explained by Ellis-Jones, *et al*., (2001b) in focused group discussions in Muzarabani where farmers' claimed that weeding using OP - D required less draft force and created smaller furrows that encouraged aeration and moisture infiltration with less resultant soil erosion compared to OP+D.

2.11 Economics of weeding technologies

Excessive weed growth has been identified as one of the major constraints that are limiting adoption of tillage systems (Shumba *et al*., 1992) and crop production (Chivinge, 1984) in the SH sector in Zimbabwe. Weed management is, therefore, a key element for the success of tillage systems as it reduces competition for nutrients and light between the crop and the weeds. It also influences the availability of moisture (Riches *et al*., 1997). Herbicides could be used for weed control but the high costs have made the adoption of this technology by SH farmers disappointing (Nehanda, 2000). Riches *et al*. (1997) suggests that the problem could be overcome by weeding with the readily available animal-drawn plough with or without the mould board. Overall, the weeding studies indicate that innovative and affordable methods of weed control are required to help farmers curtail the problem of weeds (Nehanda, 2000).

In the bid to come up with innovative methods of weed control, soil moisture retention, lower draft and labour requirements and higher crop yields, there is a tendency to ignore economic evaluation of the systems. It is imperative to realise that merits and demerits associated with technological change influence farmers' decision to adopt or not. The lack of this information is then likely to negatively impact on technology adoption (Nehanda, 2000). The ability of farmers to adopt new technologies is a function of the asset base and constraints faced by the farmers (Muzenda, 2000). A comparative analysis of adoption decisions and farming practices of different farmer resource categories is necessary to explore how the differences in the farmer's circumstances affect their agricultural performance and livelihood. This is important as the household is considered as a decision-making unit allocating different resources among activities under prevailing socio-economic conditions (Singh *et al*., 1984)

There is, therefore, a need for a comprehensive economic analysis of the integrated mechanical and chemical weed control methods to ascertain whether they provide economic relief to the small holder farmers (Muzenda and Ellis-Jones, 2000).

2.12 Summary of literature review

This literature review has revealed that weeds are a serious problem in Muzarabani district and most farmers are spending disproportionate times weeding or end up abandoning some portion of their fields as they are overwhelmed. SH farmers in Muzarabani ranked weeding as the most labour intensive activity they ever carry out in the crop growth cycle. They further alluded to the fact that alleviation of the weed burden was a research priority. Part of the problem could be solved by introduction of mechanical weeding using draft animals. Access to draft animals is a key determinant of the ability to weed on time. As a result of previous droughts the draft animal herd has dwindled and recent studies indicate that the animals being used are now smaller in size. Since the implement size has remained constant there are now mismatches between the animals and the implements. Work has been done on these implements yet there still remains a gap in determining their draft force requirements visa viz. the size of draft animals.

The major draw back to use of animal traction in weed control is the farmers' lack of knowledge on the correct use, repair and maintenance of animal drawn implements. The limited draft power resource is wasted due to improper implement setting, removal of implement parts and by using implements in poor working condition. There is, therefore, a great need to assess the state of implements to ascertain whether they are in good condition for land preparation and weeding purposes and also determine whether farmers know how to use and set them correctly

The introduction of herbicides helps in improving timeliness of weeding and allows labour to be released from important crops to other crops or off farm activities. Once herbicides are introduced there is a need to determine their effectiveness in weed control. Assessment of the merits and demerits of the introduction of herbicides is essential, as this will influence farmers' decisions in choosing them. Another option available to farmers for weed control is the integration of herbicides and mechanical weeding. Overall, a comparison of mechanical weeding alone and an integration of herbicides and mechanical weeding are then proposed.

Soil moisture available to crops is a crucial issue and great care is needed to ensure that any primary or secondary cultivation will retain as much soil moisture as is possible. Winter ploughing immediately after harvest helps in conserving residual moisture and this can be supplemented by shallow ploughing in spring after the first rains. Shallow ploughing in spring is important, as the condition of animals will be poor. The practice of double ploughing is expected to reduce the power requirements at weeding. Therefore, the aspects of land preparation, crop establishment and weed management options need to be addressed if farmers are to realise maximum benefit from their crops.

3. MATERIALS AND METHODS

This chapter presents general materials and methods used in the study. Procedures unique to each experiment and relating to specific objectives are presented in the relevant sections in chapters 4, 5, 6, 7 and 8. The field trials were conducted in Lower Muzarabani during the 2000/2001 and 2001/2002 seasons.

3.1 Site location

3.1.1 Agroecological environment

The study was carried out in Lower Muzarabani, which is located at the foot of the escarpment on the edge of the Zambezi Valley (16^0 20' S, 30^0 and 31^0 30' E: 400m above sea level, appendix 4a). It has a unimodal rainfall season. The rainfall season is normally short, beginning in late November and ending in February. The bulk of the rain falls as sporadic heavy conventional storms between this period. The annual rainfall is 450 - 650mm and the area is designated as Natural Region IV (Vincent and Thomas, 1960). Lower Muzarabani is characterised by high mean summer temperatures, which are in excess of 40^oC.

The soils are variable in detail over short distances but usually conform to the general description of well-drained, moderately shallow to deep (Anderson *et al*., 1993). Typical profiles are in excess of 1m depth (see appendix 4b) with approximately 100mm of crop water available when the soils have been brought to field capacity. The soils are fine-grained loamy sands and sandy loams over brown to yellowish red sandy loams and sandy clay loams, which are usually calcareous. They are largely derived from sand stones and quartzites. Depositional characteristics such as stratification are not present probably through homogenising activities of soil fauna and pedogeneic processes. The soils in Muzarabani are locally classified under the Zimbabwean Classification System as Alluvial soils, 4U or 4C (Thompson and Purves, 1978) or Cambisols or Luvisols under the FAO classification (Nyamapfene, 1991). When the soils are ploughed they produce large clods, which rapidly slake at the first rains and set to form a cap that can impede crop establishment early in the season and encourage runoff.

Little, if any fertiliser is used by the farmers (50 to 100kg per ha once every two to three seasons), as they feel the soils are fertile. Yields have been observed to decline following long periods of cultivation (first lands opened in 1972, next major resettlement in 1986) as reported by Agritex (1999). Many of the soils are now low in organic matter and potassium, although phosphate levels are still quite reasonable. Despite these soil fertility issues the high temperatures experienced in the rainy season result in rapid plant growth.

3.2 Implements and experimental design

The trials involved the use, in cotton, of three animal powered mechanical weeding implements, the BS 41- 5-tine cultivator (OC), the mould board plough with the mould board attached (OP + D), and the mould board plough with the mould board removed (OP-D). Two trial categories were undertaken. These were a "mother trial", established on land at Mfudzi Primary School and a series of "baby trial plots" planted on farmers' field in three villages of Mfudzi, Muringazuva and Gutsa.

3.3 Mother trial experimental design

The mother trial was researcher managed. It provided a site for comparison of soil and weed management methods where detailed measurements of implement performance were made.

The design layout consisted of a split plot design. Primary land preparation as the main strip factor, mechanical weed control as the sub-strip factor, method of crop establishment as sub-plot factor and use or no use of pre-emergent herbicide (±H) as the sub-sub plot factor was used for the mother trial at Mfudzi primary school (table 3.1).

Table 3.1: Summary of the Mother trial experimental design at Mfudzi Primary School.

Factor	**Levels**	**Description**	**Options**
Main strip	2	Primary land preparation	Winter + Spring or Spring plough only
Sub-strip	3	Mechanical weed control	OC, OP + D, OP – D
Sub-plot	2	Method of crop establishment	Open furrow planting or ripping
Sub-sub-plot	2	Additional weeding method	± Pre-emergent banded herbicide

Replicated over three blocks.

The primary land preparation methods used were either winter followed by spring ploughing (wp + sp) or spring ploughing (sp) only. The crop establishment methods used were either open plough furrow planting (OPFP), used by 95% of farmers in Muzarabani (Ellis Jones *et al*., 2001a) or Ripping. In OPFP seed was planted into furrows opened with a single pass of a mould board plough at the desired inter-row spacing, and subsequently covered with a hand hoe. Ripping involved planting into a rip line (RIP) created by a ripper tine mounted on a standard plough beam. The mother trial consisted of 3 blocks. Each block consisted of 2 tillage strips of primary land preparation of either wp + sp or sp only. In each strip there were 3 sub-strips of mechanical weeding method i.e. (OC, OP + D, OP - D). Each sub-strip had 2 sub-sub strips with 2 plot crop establishment factors of open plough furrow planting or ripping. Each plot crop establishment factor had 2 sub plot factors of ± pre-emergence herbicide use (as shown in Figure 3.1). A 5-m discard area (headland) was left at the end of each plot to facilitate turning by the traction animals. Therefore, in each block there were 24 plots (2 Tillage strips x 3 mechanical weeding methods x 2 crop establishment methods x 2 ± pre-emergence herbicide use). Each plot was 15m long by 6-cotton rows 0.9 m wide.

OC, OPFP – H	OP+D, RIP – H
OC, OPFP + H	OP+D, RIP + H
OC, RIP – H	OP+D, OPFP + H
OC, RIP + H	OP+D, OPFP – H
OP+D, RIP + H	OP-D, OPFP – H
OP+D, RIP – H	OP-D, OPFP + H
OP+D, OPFP + H	OP-D, RIP+ H
OP+D, OPFP – H	OP-D, RIP – H
OP-D, OPFP – H	OC, RIP + H
OP-D, OPFP + H	OC, RIP – H
OP-D, RIP+ H	OC, OPFP + H
OP-D, RIP – H	OC, OPFP – H

Key: +H: use of pre-emergence herbicide. -H: No use of pre-emergence herbicide
OPFP: Open Plough Furrow Planting RIP: Planting using a ripper tine
Shaded area: winter + spring ploughing Unshaded area: spring ploughing only.

Figure 3.1 Layout of one block of the mother trial at Mfudzi primary school in Mfudzi village, Muzarabani.

3.4 Baby trial experimental design

The baby trial was managed and implemented by farmers in the three villages of Mfudzi, Muringazuva and Gutsa of Muzarabani. Three farmers were chosen in each village to hold the trials to give a total of nine trial areas. All the operations were done using the farmer practice. Dates were agreed between the farmers and the researchers to facilitate measurements. The three methods of weeding chosen were the most commonly used by farmers in the area i.e. the OC, OP + D, OP - D.

The experiments were set up as a single strip plot design with a strip of each treatment measuring approximately 30 m x 10.8 m (12 rows) being planted at each of the 9 sites. The actual length of plots varied depending on the available land. All the plots were spring ploughed immediately after the first rains using a mould board plough as this is the most common method of land preparation in Muzarabani. For crop establishment cotton planting furrows were opened using OP-D. The treatments were split into 3 methods of mechanical weeding and each further split into 2 plots one with ±H (see Figure 3.2). This gave, 3 mechanical weeding methods x 2 ± H = 6 plots. The treatments were blocked over 9 farmers.

Summary of treatments

1. Ox cultivation at 3 and 6 wace with supplementary hoe weeding, (OC, HH).
2. Ox plough (with mould board) post plant ridging at 3 and 6 wace with supplementary hoe weeding along the row, (OP+D, HH).
3. Ox plough with no mould board weeding at 3 and 6 wace with supplementary hoe weeding along the row, (OP-D, HH).
4. Pre-emergence banding of Cynanzine plus Alachlor 30 cm banding along the row followed by post ridging at 3 and 6 wace, with supplementary hoe weeding along the row, (Hca, OP+D, HH).
5. Pre-emergence banding of Cynanzine plus Alachlor 30 cm banding along the row followed by weeding with Ox plough with no mould board plus supplementary hoe weeding along the row, (Hca, OP - D, HH).
6. Pre-emergence banding of Cynanzine plus Alachlor 30 cm banding along the row followed by ox-cultivator at 3 and 6 wace, plus supplementary hoe weeding along the row, (Hca, OC, HH).

Mechanical weeding strips 10 rows x 30 m - split in half for herbicide treatment	
OP+D, HH	Hca, OP+D, HH
OP-D, HH	Hca, OP-D, HH
OC, HH	Hca, OC, HH

Figure 3.2: Layout of one block of baby trials at farmers' field in Muzarabani district.

3.5 Field operations details

3.5.1 Land preparation

The mother trial was winter ploughed using OP+D in end of May of each research year and then spring ploughed immediately after the onset of rains in November. For the baby trials, all plots were ploughed in November after the first rains. The price for winter ploughing for each year was recorded.

3.5.2 Planting, fertiliser and herbicide application

Crops for the mother trial were planted into either furrows opened by OP – D or by a ripper tine while for the baby trials all the planting lines were opened by OP – D. Compound L (5% N, 18% P, 10% K_20) was applied as a basal fertilizer before seed placement at a rate of 150 kg ha^{-1}. The cotton hybrid seed SQ 4314 was planted in 0.9-m rows and covered with about 1cm layer of soil. Where applicable a 30cm band of pre-emergence herbicide was applied as a tank mix of 0.55 kg a.i. ha^{-1} of cyanazine and 0.96 kg a.i. ha^{-1} alachlor. Thinning of cotton to an in-row spacing of 0.40 m was done 3 weeks after crop emergence (wace). Top dressing for all treatments was applied at a rate of 100 kg ha^{-1} of Ammonium Nitrate (34.5 % N), 6 wace.

3.5.3 Weeding

Mechanical weeding options used were a 5-tine ox-cultivator, or a plough with either the mould board retained or removed. All plots were mechanically weeded at 3 and 6 wace with supplementary hoe weeding where necessary. For the third weeding all plots were hand-hoe weeded at 9 wace as the crop had grown and canopied. The cost of mechanical and supplementary weeding with each option/ treatment for each year was recorded. Times for mechanical and supplementary weeding each treatment were recorded.

3.6 Data collection

A questionnaire (appendix 5) was designed to collect information on the condition of implements in Muzarabani district. Measurements were made of implement performance, soil physical characteristics, cotton performance and weeding efficiency. Full description of the methods used to determine these parameters are provided in chapter 4, 5, 6, 7 and 8. During the first, second and third weeding i.e. at 3, 6 and 9 wace the following measurements were made: -

3.6.1 Implement performance

The depth of cut for each weeding implement was measured in cm using a 30-cm rule by inserting the rule through the soft soil until hitting the unploughed soil. Three measurements were taken at random per plot. The operational width of cut was also measured using a 100cm rule and three measurements were randomly taken per plot. Twelve readings of draft force per run were measured for a total of 6 runs for the mother trial and 15 readings per run for a total of 12 runs for the baby trials were taken using a load cell and meter. Effective working time per run, turning time and total time spent on each plot was measured (in seconds) using a stopwatch. This was used to determine field efficiencies and work rates.

3.6.2 Soil physical characteristics

Theta probe readings and soil core cylinder masses were taken at levels from 0-5 cm at 5cm intervals up to 35cm per station, three readings per plot just before weeding at 3, 6 and 9 wace. The three sets of readings were taken and used to determine soil moisture content (see chapter 6). Penetro-meter readings were taken at levels from 3.5 cm at 3.5-cm intervals up to 35.0-cm soil depth. The readings were used to calculate shear strength of the soil.

3.6.3 Implement weeding efficiency and cotton performance

Three weed counts were done using 30-cm square quadrants (three random readings per plot) just before each weeding operation and weed density was recorded. Plant characteristics were measured i.e. number of rotten cotton balls, number of healthy cotton balls and number of split cotton balls to determine the percentage yield loss due to ball rot. Cotton plant population was recorded at harvest. A net plot was determined, eight middle cotton rows for the baby trials and four middle rows of cotton for the mother trial. The cotton in the net plots was harvested and immediately weighed (in kg). A series of harvests were done from mid April to end of June of each season and a summation of the weights of cotton obtained in each plot was done.

3.7 Statistical analysis

Snap 5 (a statistical package) was used to analyse the data from the survey on the state of implement condition carried out in Muzarabani district. The Genstat procedure was used to conduct statistical analysis for the rest of the data that was collated. Analysis of variance was used to test for any significant difference in draft force requirements, work rates, field efficiency, soil moisture content retention levels, soil penetration resistance, weed density and yield levels, of the three weeding implements. The field efficiencies had variations greater than 40%. According to Little & Hills (1978) the data had to be angular transformed by arcsine of the square root of the actual ratio of Effective Field Capacity (EFC) to Theoretical Field Capacity (TFC) to achieve binomial distribution. The weed counts data was transformed by finding the square root [weed counts, in numbers + 0.5] to achieve normal distribution and homogeneity of variances.

3.7.1 Treatment structure for the mother trial

The treatment analysis of variance for the mother trial was carried out as:

"Split-Plot Design"

Block Structure: Block/Land preparation/Mechanical weeding method

Treatment Structure: Land preparation* Mechanical weeding method * Crop establishment * ± Pre-emergence herbicide use.

The treatment interaction for the analysis were as follows:

Interactions

Land preparation

Mechanical Weeding Method

Crop Establishment

± Pre-emergence Herbicide

Land preparation * Mechanical Weeding Method

Land preparation * Crop Establishment

Mechanical Weeding Method * Crop Establishment

Land preparation * ± Pre-emergence Herbicide

Mechanical Weeding Method * ± Pre-emergence Herbicide

Crop Establishment * ± Pre-emergence Herbicide

Land preparation * Mechanical Weeding Method * Crop Establishment

Land preparation * Weeding * ± Pre-emergence herbicide

Land preparation * Crop Establishment * ± Pre-emergence Herbicide

Mechanical Weeding method * Crop Establishment * ± Pre-emergence Herbicide

Land preparation * Mechanical Weeding Method* Crop Establishment * Herbicide

3.7.2 Treatment structure for the baby trial

The treatment analysis of variance for the baby trials was carried out as:

"General Analysis of Variance"

Block Structure: Block (or farmers)

Treatment Structure: Mechanical Weeding Method * ± Pre-emergence Herbicide

4. ASSESSMENT OF THE CONDITION AND USE OF IMPLEMENTS IN MUZARABANI DISTRICT.

4.1 INTRODUCTION

In the communal areas of Zimbabwe most farmers use their ploughs without regulators and other important components. Implement parts worn out are rarely replaced, due to financial resource constraints, and non-availability of parts in local stores or dealers (Koza *et al,* 2000a). The poor state and lack of proper adjustment of implement results in inefficient operation and poor quality of tillage and mechanical weed control. Koza *et al* (2000b) alluded in an informal survey that a detailed survey needed to be carried out in Muzarabani to ascertain the condition of draft implements.

Koza *et al*, (2000a) reported that improved maintenance and use of implements in good condition can increase agricultural productivity. Improved timeliness, more efficient use of existing draft power, enhanced moisture conservation and tillage, better burying of crop residues and other trash results in increased productivity. The Animal Draft Power Research and Development Programme in Zambia has demonstrated that "proper" ploughing (ploughing with a well-set plough and maintained or new plough rather than a worn out one) results in greater ploughing depth and cutting width (Meijer *et al*, 1990). Greater ploughing depth and cutting width lead to higher crop yields and fewer weeds. It has been shown that farmers (i.e. plough operators) lose a lot of energy in land preparation due to low soil moisture content; poor implement state or improperly set implements (Chatizwa and Ellis-Jones, 1997).

To date the majority of projects developing innovative methods of soil management (conservation tillage, improved weeding, mulching, green manures) have assumed a level of draft power availability and management skill that does not currently exist at SH level. In recent work, the poor performance of the improved draft animal weeding methods was attributed mainly to the poor condition of the implements and the farmers' lack of knowledge about their efficient use and maintenance (Chatizwa *et al*, 1998). Although this was partly addressed by providing training to participating farmers in setting and maintenance of their implements for correct use, most farmers and rural artisans still require better knowledge of implement design, use and maintenance than is the case at present for new technologies to be adopted. The poor condition of implements is compounded by the fact that most implements are sold without operators' manual (Koza, 2004), and this contributes to improper use and maintenance of implements by SH farmers.

4.2 Hypothesis

The condition of implements in Muzarabani district is poor, and a significant number of farmers do not know how to set their implements.

4.3 Objectives

The broad objective was to assess the condition, use and knowledge of draft animal power in Muzarabani district. The specific objectives were as follows:

1. Assess the condition of animal drawn weeding implements used in cotton production systems in Muzarabani district.
2. Assess farmers' knowledge in the use and maintenance of weeding implements.
3. To determine information flow to farmers on the use and maintenance of implements.

4.4 Methodology

A survey was conducted to assess the condition of mould board ploughs and cultivators owned by SH farmers in three villages in Muzarabani district, namely, Mfudzi, Gutsa and Muringazuva, in the Zambezi Valley. The mould board ploughs and cultivators were assessed as weeding implements. A total of eighty-three households were randomly visited to assess the condition of animal drawn weeding implements. A questionnaire (appendix 5) was used to obtain information from farmers about their farming systems, the use and maintenance of their weeding implements and how they carried out their implement setting. At each household, physical inspections were made to determine the condition of weeding implements. Faults, worn out parts and missing components were noted on each weeding implement. The ages of the weeding implement owned were recorded. The weeding implements were categorized under three conditions good, average and poor as shown in table 4.1.

Table 4.1: The parameters used to determine the weeding implements' conditions.

Implement	Condition of weeding implements		
	Good	**Average**	**Poor**
Plough	Intact bolts on all parts including the king bolt. No wear and tear in all parts.	Intact bolts on mould board, frog & kingbolt. Stays removed	King bolt loose, missing regulator hake, wheel & axle, wheel arms. Worn out share and landside
Cultivator	Intact bolts on all parts. No wear and tear in all parts.	Intact bolts on all parts. One side of tines worn out.	Missing or worn out wheel & axle, wheel arms tines & sweep tine.

The head of household was asked to explain the operation, repair and maintenance of his/her implements in order to assess farmers' knowledge and skills in the correct use of equipment. Farmers were further requested to explain how they set their implements for use under different soil and weed density conditions in the fields. Problems associated with equipment use were also noted at each household. Farmers were asked to give reasons why some implement parts were usually removed (e.g. the drawbar hitch assembly). SNAP 5, a survey computer package was used for design and analysis of the survey. Information on tables and figures in this chapter were obtained from analysis of the questionnaire.

4.5 Results

Of the 83 farmers visited a total of 80 (96.4%) owned mould board ploughs while 65 (78.3%) owned cultivators.

4.5.1 The condition, use and repair of ploughs in Muzarabani District

Eighty-three ploughs were assessed and the ploughs condition, the rate at which different parts are replaced, how farmers regulate the width and depth of cut and where they obtain information on their correct use and maintenance are herewith presented.

4.5.1.1 Condition of ploughs in Muzarabani

Figure 4.1 shows the condition of ploughs in Muzarabani whether they were good, average or poor.

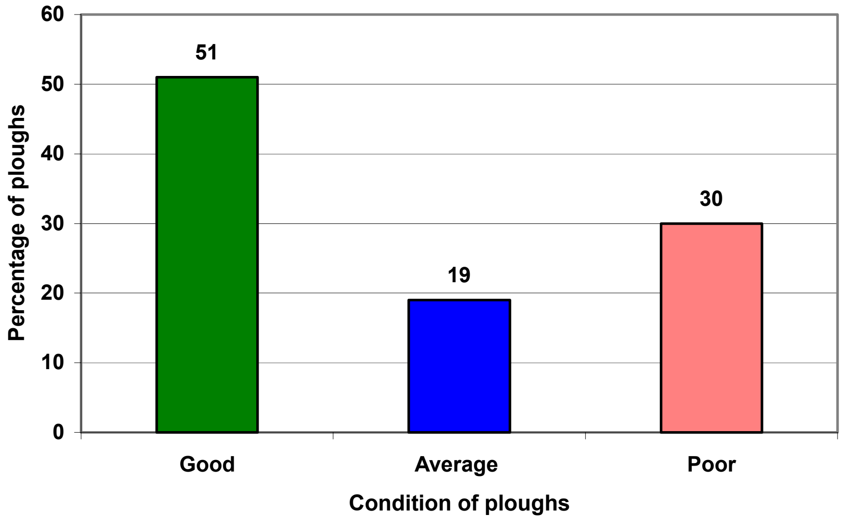

Figure 4.1: The condition of ploughs in Muzarabani district

4.5.1.2 Condition of individual plough parts and their rate of replacement

Table 4.2 shows the percentage of plough parts conditions and the rate at which farmers replace them. Table 4.3 shows how farmers regulate the width and depth of cut of ploughs.

Table 4.2: Condition of mouldboard plough parts in Muzarabani district.

Problem	**% in poor condition**	**% in average condition**	**% in good** condition	**% of parts that are removed**	**Rate of replacement**				
					>3xpa*	1-2 pa*	1 in 2yrs	1 in 3yrs	Rarely
Share	41.3	15.9	42.8	5.0	17.9	66.7	9.0	1.3	5.1
Landside	43.0	15.4	41.6	1.3	1.3	18.2	23.4	16.9	40.3
Frog	14.1	23.2	62.7	0	0.0	0.0	0.0	2.6	97.4
Drawbar hitch assembly	2.6	26.4	71.0	53.8	0.0	0.0	0.0	0.0	100.0
Regulator hake	26.6	19.9	53.5	39.2	0.0	0.0	0.0	1.6	98.4
Wheel	41.3	15.9	42.8	8.8	1.3	50.6	15.6	15.6	6.9
Axle	39.2	16.5	44.3	5.1	2.6	50.0	17.9	14.1	15.4
Wheel arms	25.0	20.3	54.7	6.3	0.0	6.4	12.8	7.7	73.1
U-piece & Screw	6.5	25.3	68.2	37.7	0.0	7.1	1.4	4.3	87.1
U-clamp	6.5	25.3	68.2	9.1	0.0	3.8	9.0	5.1	82.1
King bolt	16.5	22.6	60.9	0.0	1.3	15.4	19.2	3.8	60.3
Handles	10.1	24.3	65.6	0.0	0.0	0.0	0.0	0.0	100.0
Stays	8	24.9	67.1	24	0.0	0.0	0.0	0.0	100.0

* pa - per annum, >3 - more than 3 times

Plough setting

Table 4.3: Percentages of farmers that use different methods of depth and width control of a mould board plough during a ploughing or weeding operation in Muzarabani.

Depth Control		Width Control	
Method	%	Method	%
Using the wheel	67.1	Width regulator	65.5
Using the regulator	31.6	Widening frog	21.8
No Control*	0	Increasing the size of the share	0
Other	1.3	Other	12.7

No control* - means that farmers did not adjust for depth control.

4.5.1.3 Source of information on use, setting and maintenance of ploughs

Figure 4.2 shows where farmers obtain information on the use and maintenance of ploughs.

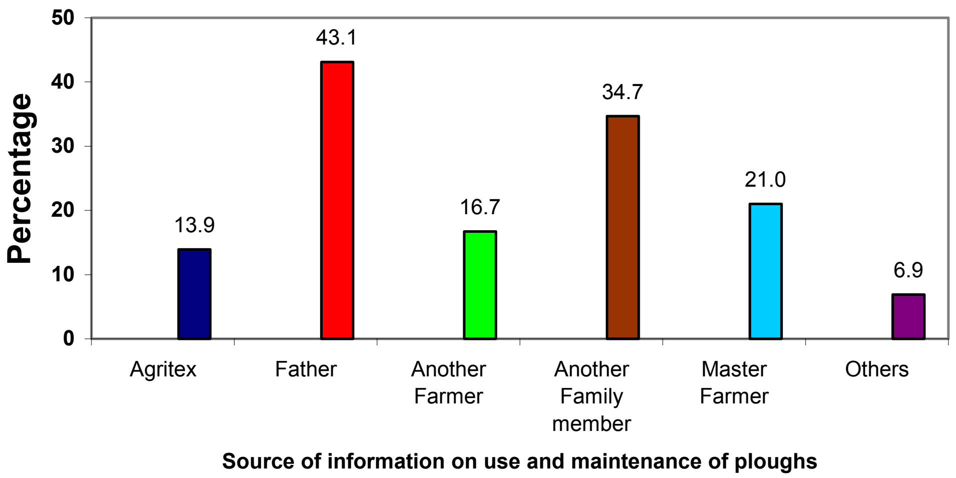

Figure 4.2: Source of information on where farmers obtain knowledge on the use and maintenance of ploughs in Muzarabani district.

The age of ploughs ranged between 1 and 20 years with an average age of 5.4 years. Seventy percentage of the ploughs were in an average to good condition while 30% were in a poor condition. Farmers owned an average of one plough per household. Two farmers did not own ploughs whilst one farmer owned three ploughs.

Most plough parts were in good to average condition and these included frogs, drawbar hitch assembly, u-piece and screw, u-clamp, handles and stays. Parts in poor condition were shares, landsides, wheels and wheel axles. The main parts, which were removed from ploughs by farmers, were draw bar hitch assembly, regulator hake, u-piece and screw.

The plough parts regularly replaced (once or twice a year) by farmers' were shares, wheels and wheel axles. Only 23.4% of the farmers replaced worn out landsides once in two years while 40.3% rarely replaced them. Most farmers rarely replaced their frog, draw bar hitch assembly, regulator hake, wheel arms, u-piece and screw, u-clamp, king bolts, plough handles and stays.

Figure 4.2 depicts that farmers obtained knowledge on the correct use, setting, and maintenance of ploughs from a number of sources. Most of the information was passed from father to child (43.1%) or family member to family member (34.7%). The most represented government extension wing AREX contributed only 13.9% while a further 6.9% of farmers received their information from Cotton Company of Zimbabwe and Zimbabwe Farmers' Union (i.e. others). Only 21% of the farmers from the survey had received formal training on the correct use, setting and maintenance of ploughs through master farmer training.

More than two thirds of the farmers controlled depth of ploughing using the wheel, while about a third used the depth regulator (table 4.3). The percentage of farmers that controlled depth properly is attributed to the master farmers (21%) and those that received training through interaction with Agritex (13.9%). About two thirds of the farmers used the regulator hake for width control while just over twenty percent widened the frog to increase the width of cut. About one percent of the farmers claimed that they increased the size of the share (referred to as other in table 4.3) to increase the width of cut.

4.5.2 The condition, use and repair of cultivators in Muzarabani District

During the survey 65 cultivators were assessed and the condition, the rate at which different parts are replaced, how farmers regulate the width and depth of cut and where they obtain information on their correct use and maintenance are herewith presented.

4.5.2.1 Condition of cultivators in Muzarabani

Figure 4.3 shows the condition of cultivators in Muzarabani whether they were good, average or poor.

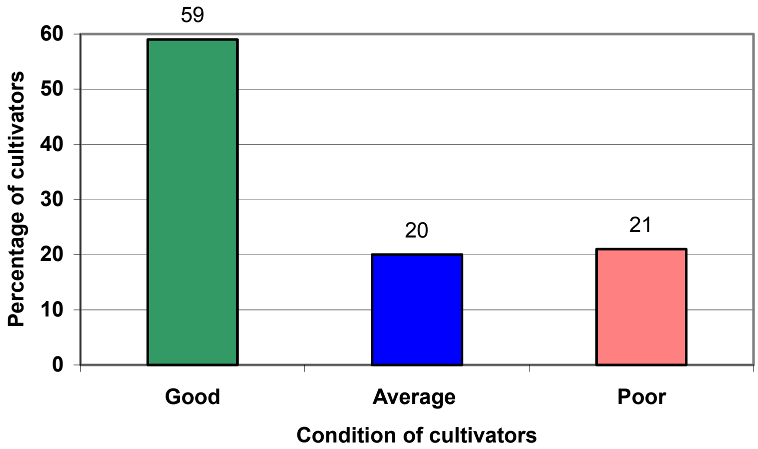

Figure 4.3: The condition of cultivators in Muzarabani

4.5.2.2 Condition of individual cultivator parts and their rate of replacement

Table 4.4 shows the percentage of cultivators with various conditions of parts and the rate at which farmers replace them. Table 4.5 shows how farmers regulate the width and depth of cut of cultivators.

Table 4.4: Condition of cultivators' parts in Muzarabani district.

Problem	**% in poor condition**	**% in average condition**	**% in good condition**	**% of parts Removed**	**Rate of replacement (%)**				
					>3x pa*	1-2 pa*	1 in 2yrs	1 in 3yrs	rarely
Lever adjusting assembly	22.0	19.7	58.3	0.0	0.0	1.6	1.6	1.6	95.1
Rack for adjusting lever	12.3	22.2	65.6	0.0	0.0	0.0	1.6	1.6	96.7
Expanding Beam	18.0	20.7	61.3	0.0	0.0	0.0	0.0	3.2	96.8
Wheel axle	43.8	14.2	42.0	7.8	0.0	12.9	11.3	16.1	59.7
Wheel	32.8	17.0	50.2	7.8	0.0	16.1	12.9	19.4	51.6
Wheel arms	15.6	21.4	63.0	3.1	0.0	1.6	3.2	9.7	85.5
Tines	20.6	20.1	59.3	28.6	1.6	16.1	16.1	22.6	43.5
Sweep tines	28.6	18.1	53.3	52.4	0.0	0.0	9.1	0.0	90.9

* pa - per annum, > more than

Table 4.5: Percentages of farmers that use different methods of depth and width control of an ox cultivator during a weeding operation in Muzarabani district.

Depth Control		**Width Control**	
Method	%	Method	%
Using wheel & chains	27.3	Using Lever	92.2
No Control*	62.9	No Control*	6.2
Other	9.8	Other**	1.6

No control** - means that farmers did not adjust for depth/width control.

Other* modify cultivator by adding a depth control rack and use of different tine holes

4.5.2.3 Source of information on use, setting and maintenance of cultivators

Figure 4.4 shows where farmers obtain information on the use and maintenance of cultivators.

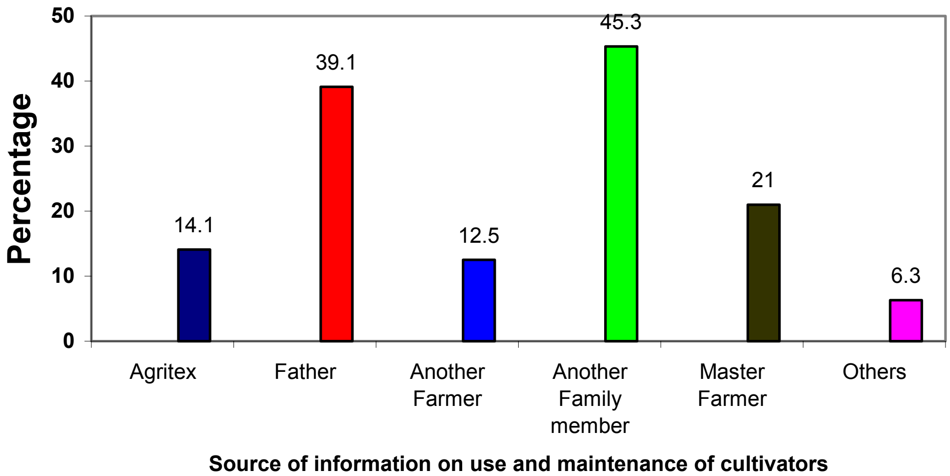

Figure 4.4: Source of information on where farmers obtain knowledge on the use and maintenance of cultivators in Muzarabani district.

The condition of most cultivators was average to good. The average age of cultivators was six years. Eighty percent of farmers interviewed owned at least one cultivator. Sixty farmers owned a cultivator each; one farmer owned three the other owned two while 21 farmers did not own cultivators.

Most parts of the cultivators were in a good condition, excessive wear was only observed with the wheel axle and wheels in 43.8% and 32.8%, respectively, of cultivators. Over half of the farmers assessed removed the two front tines of cultivators. Farmers rarely replaced most parts of their cultivators, except for wheel axles, wheels and tines where 40 - 52% claimed that they replaced these parts at least once in three years.

From figure 4.4 only 21% of the farmers from the survey had received formal training on the correct use, setting and maintenance of cultivators through master farmer training. Only 14.1% of farmers claimed that they received their knowledge on the use and maintenance of cultivators from AREX while a further 6.3% received their information from Cotton Company of Zimbabwe and Zimbabwe Farmers' Union (i.e. others). Most of the information was passed from father to child (39.1%) or family member to family member (45.3%). About 6% of the farmers claimed that they had never adjusted their cultivators to regulate the width of cut. They were still using the settings that were done by the manufacturer. Just over 1% of farmers modified the cultivator by adding a depth control rack while others used the different tine holes for depth adjustment (referred to as other in table 4.5).

Most farmers (63%) were not aware of the depth of cut adjustment options like positioning the wheel arms and adjusting the length of the chain. As observed in ploughs, the percentage of farmers that controlled depth properly (37%) is attributed to the master farmers (21%) and those that received training through interaction with AREX (14.1%). Most farmers knew how to adjust the width of cut of cultivators.

4.6 Discussions

4.6.1 The condition, use and repair of ploughs in Muzarabani District

The condition of ploughs was average to good (70%) as most were relatively new with an average of 5.4 years. Since the ploughs were new, parts that were rarely replaced like frogs, drawbar hitch assembly, u-piece and screw, u-clamp, handles and stays were found to be in a good condition. Koza (2004) made similar observations in a survey in Masvingo.

Farmers remove the drawbar hitch assembly, the u-piece and set screw and the regulator hake. Farmers confirmed that they remove the draw bar hitch assemblies from newly bought ploughs. These parts are removed because the plough is regarded as too heavy for animals and operators (especially women). Without the weight of these assemblies, the plough is said to be easier to handle at headlands. The farmers' lack of knowledge on how to make adjustments as well as on the function/purpose of the draw bar hitch assembly also contributes to its removal. The adjustment of the hitch assembly is also a nightmare to most farmers as the threading of the u piece and screw wears out very fast making tightening a problem. These parts are not easy to replace as the local dealers do not sell them and farmers can only buy them from major towns.

The hitch assembly is connected to the width and depth of cut regulator and once removed, farmers use the wheel assembly to regulate depth of cut and then widen the frog to regulate width of cut. This result in the wheel carrying the weight of the plough and consequently the wheel and axle wear rapidly. Ergonomic observations made at the Institute of Agricultural Engineering in Zimbabwe have indicated that up to about 10% more energy is spent when a plough is used in this condition (Chatizwa and Khumalo, 1996).

The sides of the regulator hakes were worn because of the transport position of the plough. Farmers usually drop the plough on the ground to lie on its side while moving it from one point to another thus wearing out the regulator hake sides. Because of this the combined percentage of worn and removed regulator hakes is about two thirds. The ploughs that had loose kingbolts were 16.5% (rendering the whole plough loose); the percentage is low as most ploughs were fairly new. Loose king bolts contribute to the instability of ploughs. Most stay beams were intact, but in older ploughs these had been removed, as most farmers did not understand their functions.

Hans Helsloot (1992), in a survey in the eastern province in Zambia reports that none of the farmers visited used the regulator hake as it was either dismantled, or broken and repaired. Instead, the farmers used wheel as a depth regulator, to push the plough out of the ground to the desired working depth. He further states that farmers do not replace the regulator hake once it was worn out or simply remove it while it is still new, as they do not understand its function. They hitch the chain direct to the beam because they think that depth adjustment should be done with the wheel. Chatizwa and Ellis-Jones (1997, and Koza (2004) concluded that farmers did not understand the functions of different plough components and that most removed the regulator hakes.

Most of the information flowed from father to child or family member to family member. Since most farmers (about 80%) had not received training they passed on to others information they believed was correct without verification. This included removal of the hitch assembly and adjusting depth using the wheel and wheel arms. However, should AREX intensify its training on farm mechanisation there is scope for an increase in farmer knowledge on the use, setting and maintenance of ploughs. This is evidenced by the fact that about 35% of farmers received either formal or informal training resulting in a third of them setting their ploughs properly.

4.6.2 The condition, use and repair of cultivators in Muzarabani District

The condition of cultivators was average to good (79%) as most were relatively new with an average of six years. Farmers rarely replaced most cultivator parts. Koza (2004) obtained similar results in his work in Masvingo. Since the cultivators were new, parts that are rarely replaced were found to be in a good condition. Excessive wear was only observed with the wheel axle and wheels as a result of friction between the two and the soil.

Over half of the farmers interviewed removed the two front tines of cultivators. Farmers perceive that removing the two front tines reduces the pulling effort of animals as this reduces the amount of trash accumulating on the tines during weeding.

Farmers knew how to adjust the width of cut for cultivators as they need to negotiate their way between crop rows as width vary depending on the width of the yoke when opening planting furrows. They also need to adjust width of cut for different crop growth stages. But farmers were not aware of the depth control measure and most were set half to cater for all weed density and height. Similar results were obtained by Koza (2004). Chatizwa and Ellis-Jones (1997) concluded that farmers did not know that cultivators needed to be set in order to meet the different soil and weed conditions. Discussion with farmers revealed that most cultivators wear out completely without having been adjusted since they were purchased. Depth regulators are never adjusted, and the spare sets of hillers normally bought attached to the frame are also never used.

The situation is not likely to change much as there has not been a big thrust within the extension wing in Muzarabani district to train and avail information to farmers on the correct use, setting and maintenance of cultivators as evidenced by information flow (figure 4.2). However, should AREX intensify it's training on farm mechanisation there is scope for an increase in farmer knowledge on the use, setting and maintenance of cultivators. This is evidenced by the fact that about 35% of farmers received either formal or informal training resulting in 27% of them setting their cultivators properly.

4.7 Conclusions

Most ploughs and cultivators were in an average to good condition as they were relatively new, less than six years on average. Most smallholder farmers did not understand the functions of some plough parts, like regulator hakes (hitch assembly), which were removed to make the plough lighter. When this happens, the operator tilts the plough towards the furrow in order to avoid leaving a bank of un-ploughed land. The operator struggles with the plough, often in a twisted posture in order to maintain control. According to Chatizwa and Ellis-Jones (1997) improperly adjusted regulator hakes are the main sources of excessive wheel and axle wear and unnecessary tiring of animals when the wheel sinks in the soil increasing the plough draft requirements and fatigue on the operator. The removal of regulator hakes shows that most farmers are not setting their ploughs properly.

The same scenario is also observed with cultivators. Farmers do not know that cultivators need to be set in order to meet the different soil and weed conditions. From the survey and discussion with farmers, it was revealed that most cultivators wear out competely without having been adjusted since procurement. Depth regulators are never adjusted, and the spare part set of hillers normally bought attached to the frame is also never used.

The removal of these parts indicates a lack of knowledge by farmers on the depth and width control (setting of ploughs) and corrects use or operation of the mould board plough. It is deduced that most information on the correct use, maintenance and repair of ploughs is passed on from farmer to farmer either through father to son (or daughter) between siblings (or any family member.

The situation is not likely to change much as there has not been a big thrust within the extension wing in Muzarabani district to train and avail information to farmers on use and maintenance of draft power implements. Most of the information flows from father to child or family member to family member. For the situation to improve AREX has to re-introduce on a larger scale the master farmer training courses. The courses are to include the use, setting and maintenance of ploughs and cultivators. Farmers’ access to information can be increased by production of pictorial materials, which show how implements are set, maintained and stored, as not all farmers are literate. Manufacturers and general dealers should also provide operators’ manual once a farmer purchases an implement.

5. DETERMINATION OF DRAFT FORCE REQUIREMENTS, WORK RATES AND FIELD EFFICIENCIES FOR THREE ANIMAL POWERED WEEDING IMPLEMENTS.

5.1 INTRODUCTION

A major thrust of research into reducing the draft power shortage in Zimbabwe is the study of tillage systems, which minimise draft energy requirements. In addition to this, the time required to carry out the tillage operation is also a critical feature of the studies as the lack of timeliness of operations is one of the major factors leading to depressed yields (Tembo & Elliot, 1987). Researchers should consider draft animal sizes and numbers and try and link them to the operations to be done. At the same time the relationship between the draft power requirements of the implements and the animals' sizes has to be known.

Due to limited draft animal numbers and smaller size of cattle available to farmers currently (Hagman and Prasad, 1995), animals are often used for tasks exceeding their capabilities. Also the use of mixed spans of cattle and donkeys is becoming common. This is further compounded by poor use and maintenance of implements (Chatizwa and Ellis-Jones, 1997) and use on donkeys of implements designed for oxen. Following these problems a need to characterise draft implements and relate them to the draft animals was identified in Muzarabani by Twomlow and Chatizwa (1998). To overcome weed infestation, it was proposed in this research work that an integrated approach (of mechanical weeding and banded pre-emergence herbicide application) including good land preparation is needed. The factors considered are draft force characteristics, field efficiencies, work rates, supplementary hand weeding, of three animal drawn mechanical weeding implements that are used by smallholder (SH) farmers in Muzarabani district.

5.2 Hypothesis

There are significant differences in draft force requirements, work rates and field efficiencies of the BS41 5- tine cultivator, the plough with the mould board both attached and removed when used as weeding implements.

5.3 Objectives

The broad objective is to compare the draft force requirements, work rates and field efficiencies of the BS41 5 –tine cultivator, the plough with the mould board both attached and removed as weeding implements. The specific objectives were as follows:

1. To compare the draft force requirements, work rates and field efficiencies of the three weeding implements on a winter followed by spring ploughed area to a spring ploughed only area.
2. To compare the draft force requirements, work rates and field efficiencies of the three weeding implements on an area where the crop is established by open plough furrow planting compared to one where crop establishment is by ripping.
3. To compare the draft force requirements, work rates and field efficiencies of the three weeding implements on an area where a 30cm banded pre-emergence herbicide has been applied along the crop row to one where none is applied.

5.4 Methodology

5.4.1 Draft force

Draft force was measured using a calibrated traction Tedea Huntleigh-No 16 tension/compression load cell that was connected in series with the implement and draft (check) chain as explained by Goe and McDowell (1980) and Francis and Ndlovu (1993b). The load cell was connected to the yoke and plough shaft such that all the force exerted passed through it in a straight line (Pearson, *et al,* 1989). An electronic load cell transducer read out meter was connected to the load cell to determine the force exerted.

Tension in the draft chain changes constantly due to irregularities in the animal's pull and frictional resistance, which are both compounded by elastic properties of the chain. Rapid and continuous sampling of the draft force was needed in order to capture the frequent changes (Lawrence and Pearson, 1985). According to Lawrence (1987) and Pearson (1993), at least 10-20 measurements would have to be taken during every change in the draft force. This was found to be impractical if manual recording was to be used. The compromise solution which was done during measurements was to take draft force readings (P) every 2m or so and average them over the whole ploughing area. For every length of run 15 readings were taken. For the mother trial there were 6 runs and 12 runs for the baby trials per plot. The reading obtained from the dynamometer P was the actual tension along the draft chain. The angle of pull α, which is the angle between the direction of pull of the chain and the direction of movement of the implement, was also measured. The angle of pull α, was obtained by measuring:

L = length of draft chain between the hitch assembly and the yoke;

S = height of attachment to the yoke;

s = working height of the load (height from ground to the yoke)

$$\cos \alpha = \frac{(L^2 - (S - s)^2)^{0.5}}{L}$$

Draft force H = P cos **α** . .. **5.1**

5.4.2 Distance, speed and time measurements

The distance covered by a team of animals during field operations was monitored continuously by measuring the length of each pass (using a 50-m measuring tape) made and summing up lengths of all passes to obtain the total distance traveled. The time taken to complete each length of pass was recorded using a stopwatch (LR 41,Quartz timer), and the total time spent in each plot was obtained by summing up times for each pass.

To obtain speed of work, the total distance traveled was divided by working time, (since the time taken to complete each pass was recorded).

$$\text{Speed of work} = \frac{\text{distance traveled by the span of oxen (m)}}{\text{Time taken to travel the same distance (s)}} \quad .. \textbf{5.2}$$

The speed of work was measured in ms^{-1}.

The total worked area was determined from the relationship between working width, the length and number of runs i.e.: -

Total worked area = working width (m) x length of run (m) x number of runs. ..**5.3**

Total working time was calculated from measuring the time between commencement and completion of work. This time included the time taken for turning at the end of rows, rests and any adjustments or breakdowns. This time was recorded by summing the total time taken in all passes plus the time spent at headlands and the stoppage time.

5.4.3 Draft capacity

Since the draft capacity of an ox is mainly a function of its mass, provided that the mass consists of muscle and not fat the following equation by Howard (1980), was used.

$$\text{Draft capacity (\%)} = \frac{\text{draft force (N)} \times 100}{\text{n} \times \text{LW (kg)}} \qquad ..\mathbf{5.4}$$

Where, n = number of animals in a working team

LW= animal live weight (kg)

The draft force, H, is the horizontal component of the pull. The draft animal live weights were estimated from each animal's girth (G) and length (L) dimensions measured in metres. Animal live mass in kilograms (kg) was estimated using the formula below by Smith, *et al*., (1994):

$$\text{Live mass (kg)} = G^2 \times L \times 92.46 \qquad ..\ \mathbf{5.5}$$

92.46 is a constant that converts the product of the girth and length dimensions to live mass in kilograms.

This formula assumes that draft force is shared equally between or among the working animals. This is not strictly true for ploughing animals because oxen working on the furrow side can expend 20-25 percent more energy than their work mates on the unploughed land side (Dijkman, 1991). Health and well-fed oxen can pull 10-12% of their live weight continuously over a working day (Goe, 1983).

5.4.4 Working depth and width

Three readings (per plot) of working depth and width were measured using a graduated ruler at random during the working period and the parameters were maintained as constant as possible. The working depth was maintained at 7-8 cm as recommended by Mbanje and O'Neill (1997) for the three weeding implements. The working width of the ox cultivator was maintained at 60 cm. The working widths for the mould board plough with and without the mould board was maintained at 25 – 28 cm and 20 – 25 cm respectively. As a result the two plough options required two passes between the cotton rows while the ox cultivator required a single pass. This was done in order to reduce, as much as possible, the considerable variation in these parameters during work. Working depth and width determine the quality of cultivation, especially weed control and conditions for effective development of roots of most crops and draft force requirements (Ndlovu and Francis, 1997).

5.4.5 Effective field capacity, theoretical field capacity and field efficiency

Effective field capacity (EFC) was calculated from the following equation: -

$$EFC = \frac{\text{Total Area Worked (ha)}}{\text{Total Working Time (hr)}} \quad \textbf{5.6}$$

EFC is a useful parameter for a farmer based in an area where rainfall is erratic and primary tillage should be speedily completed to ensure timely planting (Ndlovu & Francis, 1997).

Theoretical Field Capacity (TFC) assumes that work progresses continuously with no time lost in turning, resting or adjusting implements. It is based on the design specifications of the implement such as the width of cut at a recommended depth and the possible speed of operation relative to the maximum recommended speed of operation. This does not take into account losses associated with field conditions such as turning time and operation and unforeseen stoppages as well as implement width overlap on subsequent runs.

$$TFC\ (ha\ hr^{-1}) = \text{mean working width (m)} \times \text{mean speed } (ms^{-1}) \times 0.36. \quad ..\textbf{5.7}$$

Field efficiency (%) gives an indication of the time lost in the field and the inability to utilise the full working width of the implement. It was calculated as follows:

$$FE\ (\%) = \frac{EFC\ (ha\ hr^{-1}) \times 100}{TFC\ (ha\ hr^{-1})} \quad ..\textbf{5.8}$$

Factors affecting FE include, among others, moisture content of the soil, depth of ploughing and the operator's skill. FE changes with working width and depth, but for the purpose of the studies these parameters were kept constant. A standard yoke of length 1.8m was maintained in all spans. All the spans of oxen that were used at the school and farmers' fields had been in use for at least three years. For analyses because the variations of the FE were greater than 40% the data was angular transformed by $\sin^{-1}$ (√ (ratio of EFC to TFC)) according to Little & Thomas (1978).

5.5 RESULTS

In table 5.1 comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. In table 5.2 comparisons are being done separately between methods of mechanical weeding, use/no use of herbicides and the interaction of mechanical weeding and use/no use of herbicides.

5.5.1 Draft force

Table 5.1 summarises the key draft performance characteristics of each land preparation/implement/crop establishment practice for the mother trial for the 2 seasons.

Table 5.1: Draft force (kN) required when weeding, as affected by land preparation, crop establishment, weeding implement and pre-emergence herbicide use in a cotton crop for the mother trial for the 2 seasons.

PLOT	**Draft force (kN)**			
FACTOR	00/01 @ 3 wace	01/02 @ 3 wace	00/01 @ 6 wace	01/02 @ 6 wace
Land preparation				
Winter +spring	0.524a *	0.524a*	0.513a*	0.526a*
Spring only	0.619b *	0.647b*	0.596b*	0.624b*
Crop Establishment				
Open Furrow Planting	0.574 (ns)	0.576(ns)	0.547a***	0.575 (ns)
Ripping	0.570 (ns)	0.596(ns)	0.563b***	0.576 (ns)
Mechanical Weeding				
OC	0.705a*	0.725a***	0.687a***	0.720a***
OP + D	0.527b*	0.547b***	0.516b***	0.537b***
Op - D	0.483b*	0.486c***	0.462c***	0.469c***
Herbicide use				
No	0.572(ns)	0.586 (ns)	0.556(ns)	0.574 (ns)
Yes	0.571(ns)	0.586 (ns)	0.554(ns)	0.576 (ns)
SEDs				
Land preparation	*0.02237*	0.01616	*0.01724*	*0.00905*
Crop Establishment	*0.00494*	0.00509	*0.00484*	*0.00538*
Weeding implement	*0.06425*	*0.02835*	*0.02576*	*0.01578*
Herbicide	0.00494	0.00509	*0.00484*	*0.00538*
% CV	29.8	*31.3*	*31.4*	*33.7*

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 5.2 summarises the key draft performance characteristics of each weeding treatment of the baby trials for the two seasons.

Table 5.2: Effect of implement treatments on draft force requirements (kN) in subsequent weeding operations for the baby trials for the 2000/ 01 and 2001/02 seasons.

	Draft Force (kN)			
Treatment	**3 wace**		**6 wace**	
	00/01	**01/02**	**00/01**	**01/02**
Mechanical weeding method				
OC	0.799a***	0.706a***	0.776a***	0.819a***
OP + D	0.628b***	0.601b***	0.608b***	0.612b***
OP – D	0.536c***	0.484c***	0.503c***	0.473c***
Herbicide Use				
No	0.664a***	0.600 (ns)	0.630 (ns)	0.641a***
Yes	0.645b***	0.593 (ns)	0.628 (ns)	0.629b***
Mechanical Weeding * Herbicide use				
OC, HH	0.808a	0.710a	0.777a	0.815a
OP+D, HH	0.641b	0.621b	0.611b	0.612b
OP-D, HH	0.543c	0.471c	0.503c	0.495c
Hca, OC, HH	0.790d	0.703a	0.775a	0.823a
Hca, OP+D, HH	0.615e	0.580b	0.606b	0.613b
Hca, OP-D, HH	0.529f	0.496c	0.503c	0.452c
SEDs				
Weeding	0.00376	0.00483	0.00360	0.00377
Herbicide	0.00307	0.00394	0.00294	0.00307
Weeding * Herbicide	0.00532	0.00683	0.00509	0.00532
CV %	22.2	31.2	22.0	22.9

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05.

5.5.1.1 Land preparation

From Table 5.1, land preparation significantly affected draft force (P<0.05) in subsequent weeding operations for the two seasons with wp + sp requiring less draft force than sp only. On average about 20% more draft force was required in weeding using any of the three mechanical weeding methods when sp was done. There was about 20% reduction in force requirements in subsequent weeding operation on wp + sp plots compared to sp only.

5.5.1.2 Crop establishment

Crop establishment did not significantly affect draft force requirements in subsequent weeding operations for the two seasons (except at 6 wace for the second season where establishment by use of a ripper resulted in greater draft force required ($P<0.001$) than the use of the OPFP). The draft force averaged over the three implements for OPFP was 0.568 kN and for ripping it was 0.577 kN.

5.5.1.3 Mechanical weeding method

There were significant differences in the draft force requirements ($P<0.001$) of the three implements at 3 and 6 wace weeding operations for the two seasons (tables 5.1 and 5.2). The OC required more draft force than the OP+D or OP-D. The OC required about 0.74kN while the OP+D and OP-D required 0.57kN and 0.49kN respectively on average in subsequent weeding operations over two seasons.

5.5.1.4 Use/no use of pre-emergence herbicides

There was no significant variation in draft force requirements for plots with or without the banded pre-emergence herbicide. The draft force for portions with the pre-emergence herbicide and those without were 0.573kN and 0.572kN respectively average over the three weeding implements.

5.5.1.5 Interactions of land preparation/implement

Interactions of land preparation/implement significantly affected ($P<0.05$) draft force requirements in subsequent weeding operations for the two seasons. Results of interactions of land preparation/implement on draft force requirements are shown in table 5.3.

Table 5.3: Average draft force requirements of land preparation/implement interactions for the 2000/01 and 2001/02 seasons.

Implement used for weeding	00/01 draft force requirements (kN)		01/02 draft force requirements (kN)	
	Winter + spring	Spring only	Winter + spring	Spring only
OC	0.641a	0.752a	0.670a	0.774a
OP + D	0.484b	0.559b	0.483b	0.602b
OP – D	0.432c	0.513c	0.427c	0.532c
SEDs	0.023	0.021	0.024	0.025
Significance	P<0.01	P<0.01	P<0.01	P<0.01

Means followed by the same letter in a column are not significantly different

The least amount of draft force required was for OP-D at 0.43kN under wp + sp while the highest draft force requirements were for OC at 0.76kN under sp only.

5.5.2 Work rates and field efficiency

Tables 5.4 summarise the work rates and field efficiency (FE) of each land preparation/implement/crop establishment practice. The work rates and FEs of mechanical weeding at 3 and 6 wace for the mother trial are shown in table 5.4 and the baby trials in 5.5.

In table 5.4, comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. Means followed by the same letter in a column are not significantly different. In table 5.5, comparisons are being done separately between methods of mechanical weeding, use/no use of herbicides and the interaction of mechanical weeding and use/no use of herbicides.

Table 5.4: Work rates and field efficiency when weeding, as affected by land preparation, crop establishment, weeding implement and pre-emergence herbicide use in a cotton crop for the mother trial for the 2000/01 and 2001/02 seasons.

	Work rates (hr ha^{-1})				***Field Efficiency***			
PLOT	00/01	01/02	00/01	01/02	*00/01*	*01/02*	*00/01*	*01/02*
FACTOR	@3 wace	@3 wace	@6 wace	@ 6 wace	*@3 wace*	*@3 wace*	*@6 wace*	*@ 6 wace*
Land preparation								
Winter + spring	10.04a*	9.78a*	9.84(ns)	10.06(ns)	0.850a*	0.795a*	0.850 (ns)	0.789 (ns)
Spring only	11.93b*	11.63b*	10.11(ns)	10.11(ns)	*0.635b**	*0.773b**	*0.816 (ns)*	*0.783 (ns)*
Crop Establishment								
Open Furrow Planting	10.91 (ns)	10.72 (ns)	9.94(ns)	10.00(ns)	*0.749 (ns)*	*0.791(ns)*	*0.836 (ns)*	*0.800 (ns)*
Ripping	11.06 (ns)	10.69 (ns)	10.01(ns)	10.17(ns)	*0.736 (ns)*	*0.777(ns)*	*0.829 (ns)*	*0.773 (ns)*
Mechanical Weeding								
OC	7.06a***	6.98a***	6.31a***	6.57a***	*0.939a****	*0.995a****	*0.982a****	*0.941a****
OP + D	13.84b***	13.39b***	12.64b***	12.60b***	*0.590b****	*0.659b****	*0.663b****	*0.662b****
OP – D	12.05c***	11.75c***	10.98c***	11.08c***	*0.699c****	*0.688c****	*0.752c****	*0.685b****
Herbicide use								
No	10.97 (ns)	10.77 (ns)	9.96(ns)	10.01(ns)	*0.740 (ns)*	*0.788 (ns)*	*0.832 (ns)*	*0.795 9ns)*
Yes	11.00(ns)	10.65 (ns)	10.00(ns)	10.16(ns)	*0.745 (ns)*	*0.781 9ns)*	*0.834 (ns)*	*0.777 (ns)*
SEDs								
Land preparation	0.2138	0.398	0.2540	0.0.2421	*0.02379*	*0.00350*	*0.03624*	*0.00179*
Crop Establishment	0.1902	0.331	0.1361	0.1894	*0.01721*	*0.01385*	*0.01992*	*0.01434*
Weeding implement	0.2373	0.399	0.2554	0.2452	*0.01549*	*0.02267*	*0.02283*	*0.02473*
Herbicide	0.1902	0.331	0.1361	0.1894	*0.01721*	*0.01385*	*0.01992*	*0.01434*
% CV	7.3	13.1	5.8	8.0	*9.8*	*7.5*	*10.1*	*7.7*

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 5.5: Effect of implement treatments on work rates and field efficiency in subsequent weeding operations for baby trials for the 2000/01 and 2001/02 seasons.

	Work rates (hr/ha)				***Field Efficiency***			
PLOT FACTOR	00/01 @3 wace	01/02 @3 wace	00/01 @6 wace	01/02 @ 6 wace	*00/01 @3 wace*	*01/02 @3 wace*	*00/01 @6 wace*	*01/02 @ 6 wace*
Weeding								
OC	4.96a***	5.04a***	4.72a***	4.28a***	*0.934a****	*0.948a****	*0.872a****	*0.932a****
OP + D	10.07b***	10.06b***	9.84b***	9.38b***	*0.604b****	*0.608b****	*0.576b****	*0.608b****
OP – D	9.83b***	9.34c***	9.50b***	9.03c***	*0.606b****	*0.610b****	*0.578b****	*0.606b****
Herbicide use								
No	8.37 (ns)	8.15(ns)	7.91(ns)	7.60(ns)	*0.713 (ns)*	*0.723 (ns)*	*0.680**	*0.716 (ns)*
Yes	8.20(ns)	8.14(ns)	8.14(ns)	7.53(ns)	*0.716 (ns)*	*0.721 (ns)*	*0.671**	*0.715 (ns)*
Weeding * Herbicide								
OC, HH	5.02a	5.13a	4.51a	4.37a	*0.928a*	*0.949a*	*0.879a*	*0.933a*
OP+D, HH	10.14b	10.00b	9.92b	9.31b	*0.606b*	*0.608b*	*0.576b*	*0.609b*
OP-D, HH	9.95b	9.32b	9.28b	9.12b	*0.607b*	*0.611b*	*0.584b*	*0.605b*
Hca, OC, HH	4.91a	4.95a	4.94a	4.20a	*0.940a*	*0.947a*	*0.864a*	*0.930a*
Hca, OP+D, HH	9.98b	10.12b	9.76b	9.45b	*0.603b*	*0.607b*	*0.576b*	*0.607b*
Hca, OP-D, HH	9.71b	9.35b	9.72b	8.95b	*0.604b*	*0.609b*	*0.572a*	*0.608b*
SEDs								
Weeding	0.1943	0.1103	0.1829	0.0735	*0.00406*	*0.00411*	*0.00367*	*0.00519*
Herbicide	0.1587	0.0901	0.1493	0.0600	*0.00406*	*0.00336*	*0.00299*	*0.00424*
Weeding * Herbicide	0.2749	0.1560	0.2586	0.1040	*0.00572*	*0.00581*	*0.00519*	*0.00734*
CV %	7.0	4.1	12.3	2.9	*1.6*	*1.7*	*1.5*	*2.3*

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05.

5.5.2.1 Land preparation

From table 5.4, land preparation significantly affected ($P<0.05$) work rates and FE at 3 wace weeding operation (while it did not, at 6 wace) for the two seasons. About 21% time was saved in weeding (at 3 wace) operation and FE increased by 17% using any of the three mechanical weeding methods when wp + sp was done compared to sp only.

5.5.2.2 Crop establishment

There was no significant effect of crop establishment on work rates and field efficiency at 3 and 6 wace in subsequent weeding operations for the two seasons. The work rates for portions under open plough furrow planting and under ripping were 9.89 hr ha^{-1} and 10.48 hr ha^{-1} respectively average over the three weeding implements. At the same the time the FEs for the area under open plough furrow planting and ripper planting were 0.759 and 0.778 respectively.

5.5.2.3 Mechanical weeding method

The use of different weeding implements significantly affected work rates and FE ($P<0.001$) with the OC requiring the least time to complete the weeding operation and giving the highest efficiency (Tables 5.4 and 5.5). OC gave the highest FE of more than 90% compared to OP+D and OP-D of less than 70%. There were no significant variation in FEs between OP+D and OP-D. When the OC was used it took about 5.8 hrs ha^{-1} compared to 11.5 hrs ha^{-1} and 10.4 hrs ha^{-1} taken by OP+D and OP-D respectively.

5.5.2.4 Use/no use of pre-emergence herbicide

The use of herbicides did not affect work rates and field efficiency significantly in subsequent weeding operations for the two seasons. The work rates for portions with the pre-emergence herbicide and those without were 10.43 hr ha^{-1} and 10.45 hr ha^{-1}, respectively averaged over the three weeding implements. At the same time the FEs for portions with the pre-emergence herbicide and those without were 0.789 and 0.784 respectively.

5.5.2.5 Interactions of land preparation/weeding implement

Interactions of land preparation/weeding method significantly affected ($P<0.001$) work rates and FE at 3 and 6 wace weeding operations for the two seasons. The Ox cultivated area from wp + sp had the highest FE (0.97) and required the least time (< 7 hrs ha^{-1}) to mechanically weed between the cotton row while the area weeded by the OP+D from sp only areas had the lowest FE (0.64) and required the longest time of an average of 13 hours ha^{-1} as shown in table 5.6.

Table 5.6: Average work rates and field efficiency of land preparation/implement interactions for the 2000/01 and 2001/02 seasons.

Implement used for weeding	Work rates (hr ha^{-1})				Field efficiency			
	Winter + Spring		Spring only		Winter + Spring		Spring only	
	00/01	01/02	00/01	01/02	00/01	01/02	00/01	01/02
OC	6.32a	6.50a	7.05a	7.06a	0.974a	-[1]	0.877a	-[1]
OP+D	12.62b	12.38b	13.87b	12.47b	0.653b	-	0.643b	-
OP-D	10.89c	10.89c	12.15c	12.10c	0.699c	-	0.653b	-
SEDs	0.237	0.399	0.255	0.245	0.015	-	0.023	-
Significance	P<0.01	P<0.01	P<0.01	P<0.01	P<0.01	-	P<0.01	-

[1] Data not collected because of political disturbance during presidential elections. Means followed by the same letter in a column are not significantly different.

5.5.3 Supplementary hand hoe weeding

Tables 5.7 summarise the supplementary hand weeding requirements of each land preparation/implement/crop establishment practice. The supplementary hand weeding requirements at 3, 6 and 9 wace for the mother trial are shown in table 5.7 and the baby trials in 5.8.

In table 5.7, comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. Means followed by the same letter in a column are not significantly different. In table 5.8, comparisons are being done separately between methods of mechanical weeding, use/no use of herbicides and the interaction of mechanical weeding and use/no use of herbicides.

Table 5.7: Labour (hrs ha^{-1}) for hoe weeding, as affected by land preparation, crop establishment method, weeding implement & pre-emergence herbicide use in a cotton crop for mother trial for 2 seasons.

	Labour-hrs ha^{-1} @ 3 wace		Labour-hrs ha^{-1} @ 6 wace		Labour-hrs ha^{-1} @ 9 wace	
	00/01	01/ 02	00/01	01/ 02	00/01	01/ 02
Land preparation						
Winter + spring	28.92a**	20.29a *	32.41a*	28.35a*	62.24(ns)	56.07(ns)
Spring only	42.92b**	31.35b *	41.44b*	40.81b*	67.73(ns)	57.33(ns)
Crop Establishment						
Open Furrow	35.38 (ns)	25.95 (ns)	36.64(ns)	34.87 (ns)	65.33 (ns)	56.41(ns)
Ripping	36.47 (ns)	25.49 (ns)	37.21(ns)	34.29 (ns)	64.64 (ns)	56.99(ns)
Weeding Implement						
OC	36.61(ns)	26.06 (ns)	40.21***	37.38a ***	67.90a***	60.01a***
OP+D	35.41(ns)	24.69 (ns)	31.38***	27.95b ***	58.39b***	50.76b***
OP-D	35.75(ns)	26.41 (ns)	39.18***	38.41a ***	68.67a***	59.33a***
Herbicide						
No	59.44a***	57.55a***	59.50a***	52.70a***	65.44 (ns)	56.87(ns)
Yes	12.40b***	13.89b***	14.35b***	16.46b***	64.53(ns)	56.53(ns)
SEDs						
Land preparation	1.307	*2.305*	*1.261*	*1.831*	*2.268*	*1.373*
Crop Establishment	*0.780*	*0.965*	*0.803*	*1.179*	*0.902*	*0.898*
Weeding implement	*2.053*	*2.388*	*1.633*	*1.642*	*1.203*	*2.141*
Herbicide	*0.780*	*0.965*	*0.803*	*1.179*	*0.902*	*0.898*
% CV	9.2	17.6	9.2	14.5	5.9	6.7

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 5.8: Effect of implement treatments on supplementary hand weeding in subsequent weeding operations for the baby trials for 2000/01 and 2001/02 seasons.

Supplementary hand weeding in hrs ha^{-1}						
Treatment	**3 wace**		**6 wace**		**9 wace**	
Weeding						
OC	47.73(ns)	44.61(ns)	49.64a***	69.39a***	57.90a***	58.01a***
OP + D	47.50(ns)	43.78(ns)	40.09b***	49.01b***	43.78b***	44.98b***
OP – D	47.38(ns)	44.67(ns)	50.87c***	60.10c***	57.56a***	58.78a***
Herbicide use						
No	67.67a***	61.73a***	67.41a***	84.65a***	53.21(ns)	54.439(ns)
Yes	27.40b***	26.98b***	26.33b***	28.35b***	52.95(ns)	53.47(ns)
Weeding * Herbicide						
OC, HH	68.07(ns)	61.73 (ns)	69.96a*	89.34a*	58.24(ns)	58.76(ns)
OP+D, HH	67.56 (ns)	60.64 (ns)	58.30b*	76.42b*	43.72 (ns)	45.21(ns)
OP-D, HH	67.39 (ns)	62.82 (ns)	73.96c*	88.19a*	57.67 (ns)	59.33(ns)
Hca, OC, HH	27.38 (ns)	27.49 (ns)	29.32d*	31.44c*	57.56(ns)	57.27(ns)
Hca, OP+D, HH	27.44 (ns)	26.92 (ns)	21.89e*	21.61d*	43.84(ns)	44.75(ns)
Hca, OP-D, HH	27.38 (ns)	26.52 (ns)	27.78d*	32.01c*	57.44(ns)	58.24(ns)
SEDs						
Weeding	1.509	0.902	1.001	2.279	1.095	0.928
Herbicide	1.232	0.737	0.818	1.861	0.894	0.758
Weeding * Herbicide						
	2.134	1.276	1.416	3.223	1.548	1.313
CV %	9.5	6.1	6.4	12.1	6.2	5.2

Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant ***P<0.001 *P<0.05..

5.5.3.1 Land preparation

From table 5.7, land preparation significantly affected (P<0.05) the labour hours for hand weeding at 3 and 6 wace weeding operations for the two seasons with the wp + sp portion requiring less time for hand hoe weeding than sp portion. About 30% time was saved in supplementary hand hoe weeding (at 3 and 6 wace) when wp + sp was done compared to sp only. It required an average of 27 hrs ha^{-1} compared to sp only where an average of about 40 hrs ha^{-1} were required for the two seasons.

5.5.3.2 Crop establishment

There were no significant differences in labour hours ha^{-1} for weeding as affected by crop establishment method in subsequent weeding operations for the two seasons. The supplementary handing weeding requirements for portions under open plough furrow planting and under ripping were 62.43 hr ha^{-1} and 42.51 hr ha^{-1} (table 5.7) respectively averaged over the three weeding implements.

5.5.3.3 Mechanical weeding implement

The method of mechanical weeding significantly affected ($P<0.001$) supplementary hand weeding at 6 and 9 wace weeding operations for the two seasons (from tables 5.7 and 5.8). Less time (about 75%) was spent in supplementary hand hoe weeding when the OP+D was used for mechanical weeding while the OC required the longest time. When the OP+D was used the time required for supplementary hand weeding one hectare was on average 43.3 hours ha^{-1} compared to 55.6 hours ha^{-1} and 54.1 hours ha^{-1} (table 5.7) required for OC and OP-D respectively.

5.5.3.4 Use/no use of pre-emergence herbicides

Use of pre-emergence herbicides significantly affected ($P<0.001$) labour hours for hand weeding at 3 and 6 wace weeding operations for the two seasons, while it did not at 9 wace. The time-spent hand weeding along the crop row was reduced to about 33% of that spent weeding areas without the herbicides when herbicides were applied, in the earlier part of the season. Averaging over the three implements, about 64 hrs ha^{-1} were required to weed portions without the herbicide compared with 21 hrs ha^{-1} for portions where the banded pre-emergence herbicides were applied.

5.5.3.5 Interactions of weeding method / pre-emergence herbicide

Interactions of weeding method and pre-emergence herbicide use significantly effected ($P<0.05$) labour hours for hand weeding at 6 wace for the two seasons (tables 5.9). The combination of OP + D and herbicide required the least time to hand hoe weed along the cotton row while, the OC and OP-D, without use of herbicide required longer times in subsequent weeding operations. Table 5.9 shows the amount of supplementary hand weeding required after mechanically weeding with any of the implements with or without pre-emergence banded herbicide.

Table 5.9: Supplementary hand hoe weeding required for different implement/herbicide interactions for 3, 6 and 9 wace for the 2000-01 and 2001-02 seasons.

Treatment	Supplementary weeding in hrs ha^{-1}					
	@ 3 wace		@ 6 wace		@ 9 wace	
	00/01	01/02	00/01	01/02	00/01	01/02
OC,HH	60.2	38.2	64.5a	56.6a	68.4	60.5
OP + D, HH	58.9	36.4	51.4b	43.9b	59.0	50.6
OP - D, HH	59.2	38.1	62.6a	57.6a	68.9	59.5
Hca, OC, HH	13.0	13.9	16.0c	18.2c	67.4	59.5
Hca, OP + D, HH	11.8	13.0	11.3d	12.0d	57.8	50.9
Hca, OP - D, HH	12.9	14.8	15.8c	19.2c	68.4	59.2
Significance	ns	ns	*	*	ns	ns

ns not significant ,*P<0.05. Means followed by the same letter in a column are not significantly different.

5.5.4 Draft capacity

Equation 5.4, which was presented earlier on, was used to determine draft capacity. From weights, which were obtained in the working oxen span in Muzarabani district using equation 5.5, it was determined that the average is 285kg (see appendix 6). Table 5.10 summarises the draft force requirements obtained when using the three weeding implements from the "mother trial and baby trials".

Table 5.10: Summary of the draft force requirements and percentage draft capacities of the 3 mechanical weeding implements.

Implement used for weeding	Mother Trial				Baby Trial	
	Winter + spring		Spring only			
	Draft (N)	%draft capacity	Draft (N)	%draft capacity	Draft (N)	%draft capacity
OC	660	11.6	770	13.5	775	13.6
OP+D	480	8.4	600	10.5	610	10.7
OP-D	430	7.5	530	9.3	499	8.8

From table 5.10 it is shown that the draft capacity of an OC in an area sp only is higher than 12% when using a span of oxen with an average body weight of 285kg per draft animal. In all cases considered the OP+D and OP-D had draft capacities of less than 11%.

5.6 Discussions

5.6.1 Draft force

5.6.1.1 Land preparation

Wp + sp affect residual moisture and removes weeds that would otherwise draw moisture from the soil and lose it through evapotranspiration. Wp + sp has been found to suffice in loosening the soil so that it can retain more moisture compared to sp only and thus requiring lower draft force compared to sp only (Sibanda *et al*., 2001).

By carrying out wp earlier on, less draft force was required during subsequent weeding operations for the two seasons, as the soil tended to be loose and moist. Because of the 20% reduction in draft force requirements it means that the draft capacity is lower and draft animals will find it easier to work on the wp + sp area than the sp. This is an important fact as animals are usually in a poor state of condition at the beginning of the season and operations with lower draft force requirements are more appropriate.

5.6.1.2 Crop establishment

It was generally expected that ripper planting would achieve deeper depth of cut and, therefore, looser soil tilth that would encourage water infiltration and this should have resulted in lower draft force requirements. On the contrary the use of the OPFP achieved a wider width of cut than the ripper thus disturbing a reasonable amount of soil to cause lower draft force requirements. Consequently the other offset the advantages and disadvantages of the width and depth of cut of each crop establishment method.

5.6.1.3 Mechanical weeding method

The average draft force for OC was 0.74kN and this is comparable to results obtained in Masvingo province where average draft force requirements were 0.66kN for OC (Koza, 2004). The draft force requirement for OC obtained in Muzarabani was higher than that obtained in Masvingo by Koza (2004) of 0.66kN, as soils in Muzarabani are heavy textured while in the later are light textured. The OC required a very high draft force, as its operational width is 60cm in this instance compared to OP+D and OP-D with operational widths of 22 - 28 cm. The five tines of the OC have also a tendency to hook any trash in the field and usually get hooked to weeds, stones and stumps and thus increasing the draft force requirements as alluded to by Bansal & Theirstein (1990). On the other hand the two plough options cut into the soil with a small width of cut, but for the OP+D more force is required to cut and invert the soil. A smaller volume of soil is moved by these two plough options as a result of the smaller width of cut which then requires less draft force compared to OC. A span of two oxen of average weight of 285kg when pulling the OC gave draft capabilities of more than 12%. According to Goe (1983) the animals should find pulling the OC heavy while it should be comfortable to pull OP+D and OP-D.

5.6.1.4 Use/no use of pre-emergence herbicide

The pre-emergence herbicide was applied as a 30cm band and did not interfere with the area to be mechanically weeded and therefore did not influence draft force requirements. Mechanical weeding was only done in the remaining 60cm between the two cotton rows. In both plots with/without the herbicide the 60cm inter rows was not applied with herbicides.

5.6.1.5 Interactions of land preparation/implement

The lowest draft force requirements of 0.43kN were achieved by OP-D under wp + sp. The use of OP-D results in a smaller width of cut and it also does not invert the soil. Wp + sp at an average depth of 18cm loosens the soils making it easier to work resulting in lower draft force requirements during the weeding operation. These two factors resulted in lower draft force for OP-D. The converse is true for OC that the wider width of cut of 60cm and the fact that the soil tilth was harder as sp only had been done resulted in higher draft force requirements than the two plough options.

5.6.2 Work rates and field efficiency

5.6.2.1 Land preparation

Carrying out wp + sp resulted in 20% reduction in draft force requirements during mechanical weeding using any of the implements compared to sp. The soil tilth is loose and easy to work under winter plus spring ploughing. Weed density is also reduced under the practice of wp + sp. Consequently the loose soil tilth coupled with lower weed densities resulted in lower draft force requirements. The lower draft force requirements culminated in higher work rates that gave higher FEs under wp + sp than sp. This means that a span of oxen would finish a plot under wp + sp faster than under sp and avail the farmer and his span opportunity to do other operations.

5.6.2.2 Crop establishment

Crop establishment did not affect draft force requirements and weed density. Work rates and FE relate to the rate at which a span of oxen does work. The rate of mechanical weeding in the field did not therefore, depend on the method of crop establishment; hence farmers are in this instance, free to choose whatever option is available to them. Choice of the method is then likely to depend on the depth of cut required for planting and how these two methods influence the germination rate. Since the method of crop establishment did not affect the work rate of the span of draft animals, it also did not influence FE.

5.6.2.3 Mechanical weeding method

The OC took approximately half the time (5.8 hrs ha^{-1}) required by the other two implements to weed the same area, as they needed twice the number of runs, as their operation widths are narrower. OP+D required 11.5 hrs ha^{-1} while OP-D required 10.4 hrs ha^{-1}. Ellis Jones, *et al*., (1993), in Masvingo obtained comparable results, the OC had the highest work rate of 8.1 hrs ha^{-1} while OP+D required 14.2 hrs ha^{-1} and OP-D required 13.5 hrs ha^{-1} (for 2 passes). These results excluded manual weeding that might be needed. In comparison Koza (2004) obtained work rates of 5 hrs ha^{-1} for the OC. His results are slightly lower as larger oxen of about 400 kg each, which offer higher draft capabilities, were used.

The operation width of OC was 60cm compared to 22-28cm for the two plough options. As a result OC required a single pass between two rows of cotton while OP+D and OP-D required two passes. The high work rate from OC resulted in higher FE of more than 90% compared to the two plough options of less than 70%. Koza (2004) obtained FEs of 83% for OC in Masvingo, which is comparable to the figure obtained in this research. His results are slightly higher as larger oxen of about 400 kg each, which offer higher draft capabilities, were used.

5.6.2.4 Use/no use of pre-emergence herbicide

The pre-emergence herbicide was applied as a 30cm band and did not interfere with the area to be mechanical weeded. Weed density between rows only depended on the efficiency of the weeding implement. Therefore the use/no use of pre-emergence herbicide did not affect work rates and FE. Work rates and FE relate to the rate at which a span of oxen does work. Mechanical weeding was done between the rows and weed density in this area only depended on the effectiveness of each implement in uprooting weeds.

5.6.2.5 Interaction of land preparation/implement

The highest work rates were attained from the use of OC under wp + sp as a result of the combination of the high work rate of OC and the easy with which the soil can be tilled under double ploughing. The highest work rate resulted in the highest FE for OC under wp + sp.

5.6.3 Supplementary hand hoe weeding

5.6.3.1 Land preparation

Ploughing in winter (in April/May) especially after a maize/ground nut crop removes all weeds that germinate between the period of the last weeding and harvesting. This ensues that the fields are clean of weeds during the off-season. Once in spring and rains fall fields can then be immediately ploughed to remove any weeds that germinate before planting. Therefore, the practice of wp + sp reduces weed density. When sp only is practised the weeds overwhelm the field as the land preparation process takes up to a month in Muzarabani (Twomlow and Chatizwa, 1998), by this time the weeds are dense and very tall.

5.6.3.2 Crop establishment

The method of crop establishment does not affect times required for supplementary hand weeding. Land preparation ensured that established weeds were uprooted so that crop establishment was done on a clean field. Therefore, farmers are free to choose any of the two methods depending on availability.

5.6.3.3 Mechanical weeding method

The use of OP +D as weeding implement results in the soil inverted and thrown over the crop row, this soil then covers and smothers weeds resulting in lower weed density and hence lesser time is required in supplementary hand weeding. OP+D required 43.3 hours ha^{-1} compared to 55.6 hours ha^{-1} and 54.1 hours ha^{-1} required for OC and OP-D respectively for supplementary hand weeding. Kwiligwa *et al* (1992) obtained comparable results for OC of 60 hrs ha^{-1} in their research on the weeding systems of maize in southern Tanzania.

5.6.3.4 Use/no use of pre –emergence herbicide

Times spent weeding plots with pre-emergence herbicides were low as a result of low weed densities as a result of the effect of the herbicide. Plots, which were applied with pre-emergence herbicide, required 30% of the required time to weed plots that had no herbicide. At 9 wace there were no significant variation in supplementary hand weeding for plots with/without herbicides since by 9 weeks the herbicide will have disintegrated in soil. The half-life of the cynazine/alachlor mix is 6 -8 weeks. The times required for hand hoe weeding were very high at 9 wace as no mechanical weeding was done between the rows of cotton. At this stage the cotton will have spread and canopied in such a manner that implements can not move in between the rows without damaging the plants.

5.6.3.5 Interactions of implement/herbicide

The combination of OP + D and use of pre-emergence herbicide had the lowest supplementary hand hoe weeding times (i.e. it was more efficient in weed control) as a result of: -

(i) The ability of OP + D to cut and invert the soil throwing it over the weeds (and in some instances over the cotton crop and thus damaging it especially during the first weeding at 3 wace) on the crop row and hence smothering them.

(ii) The use of pre-emergence herbicide suppresses weed germination thus reducing weed density and subsequently weeding time.

5.6.4 Draft capacity

The draft force requirements for pulling an OC in an area sp only was greater than 12% of the combined weight of the oxen. The oxen capability according to Goe (1983) should be 10-12% of its live weight. The live weight of 285 kg is an average, and for farmers with a span of cows only of average live weight of 225kg the draft capacity will be as high as 17%. For a farmer to comfortably use his span of oxen to pull a BS 41 OC without straining them he might need to consider wp + sp. In all cases considered the OP+D and OP-D had draft force requirements within the capabilities of an average span of oxen. This is as a result of their narrower width of cut compared to that of an OC, which was 60cm.

5.7 Conclusions

Farmers can consider winter ploughing for cotton in April or May (especially after a maize or ground nut crop) followed by sp after the first rains as this loosens the soil further resulting in lower draft requirements at subsequent weeding operations. Draft force requirements were reduced by 20% when this was practised and this then enables deeper ploughing. In this instance deeper ploughing of 15-20cm can be achieved in early winter when the ground is still wet and the animals are still in good condition. Shallow ploughing of 10-15 cm in spring after the first rains can follow this to remove any weeds that would have germinated before planting, as the condition of the animals will be poor. The limitation to this practice is the number of times the soil is cut, inverted and turned over, that might end up encouraging erosion. The practice of wp can be followed by minimum tillage of simple opening the planting furrow using either a plough or ripper tine; this saves on time and would require lower draft force. This though, needs further investigation to determine whether it would not result in higher weed infestation.

The practice of wp + sp also results in lower draft capacities and in the work done in Muzarabani it can be concluded that with an average span of two oxen with weights of 285kg all the three implements could be comfortably used for weeding without straining the animals. Results also depict that work rates were increased by 20% while FEs increased by more than 15%, during subsequent weeding operations when wp + sp operations were performed thereby enabling the weeding operations to be completed in a shorter period. One major limitation to cotton production is the disproportionate times spent in hand weeding, this is reduced by 30% when wp + sp practised (this is because of lower weed infestation).

As there was no significant variation in the method of crop establishment, i.e., between open plough furrow planting and ripping, farmers are free to choose any of the methods. However, the use of a ripper tine might require lower draft force and achieve a deeper depth of planting (useful for other crops and not cotton). But this needs further investigation.

However, the main limitation with winter ploughing is that it is only appropriate following maize or groundnut crop rather than a cotton crop, since harvests of the latter are usually not completed until June/July. (In Muzarabani, 40% -55% of land is dedicated to cotton). By this time, the animals will be in a poorer condition and the soils will be drier, therefore it is difficult for animals to carry out any ploughing operations, therefore sp may be the only option available for at most half the arable land in Muzarabani.

The use of the OC requires draft force in excess of 0.7kN. When a span of oxen with an average body weight of 285kg pulls an OC with this level of draft force requirements it results in draft capabilities higher than 12%. This is too heavy for an average span of oxen in Muzarabani. However, despite being heavy for animals the use of OC results in higher FEs of over 90%, as it requires a single pass. Consequently the use of OC is more cost effective where sufficient draft is available.

For farmers without an OC, the OP+D or OP-D can be just as efficient. They require significantly less draft force than OC which are less than 0.6 kN that is less than 12% which is within the draft capabilities of DAP animals found in Muzarabani. Another benefit derived from use of OP + D is the reduced times required for supplementary hand weeding as its operation tends to throw soil over the weeds and thus smothering them. Their limitations are the number of runs made between rows, which give them lower work rates of 12 hrs ha^{-1}, and lower FEs of about 60%.

Herbicides used in conjunction with mechanical weeding provide a viable alternative that reduces the labour constraint. The banded pre-emergence herbicide applied along the crop row suppresses weeds for 6-8 weeks, thus drastically reducing times needed for supplementary hand weeding along the crop row. Time saved in weeding can be used for other purposes that might better the lives of farmers.

6. DETERMINATION OF THE EFFECTS OF THE THREE MECHANICAL WEEDING IMPLEMENTS ON SOIL CHARACTERISTICS.

6.1 INTRODUCTION

Water is the major factor limiting crop production in semi-arid areas of Zimbabwe. Effective weed control is an essential component of any tillage system, which aims to enhance water retention (Ellis-Jones, *et al*, 1993). In order to provide a framework for tillage/weed control research, a rapid rural appraisal and baseline survey were undertaken in two areas in Zimbabwe. The work indicated a wide spread understanding amongst local farmers of the need for timely inter-row mechanical cultivation, both for weed control and for keeping a rough soil surface which can capture subsequent rainfall. Some on-station trials demonstrated that conservation tillage involving ridge and furrows might be made when using existing animal draft equipment (Ellis-Jones, *et al*, 1993). Enhancement of water retention is of paramount importance in Muzarabani as the area receives low annual rainfall of about 450-600mm at the same time experiencing higher summer temperatures in excess of 40^{o}C.

In Zimbabwe approximately 90% of the SH farmers are located in areas where annual rainfall is low (<800mm) and erratic (Moyo, 1995) and soils tend to be infertile sands to sandy loams (Grant, 1981). All crop production is rain-fed and the SH farmers rely on draft animal power (DAP) and the mould board plough for primary tillage operations. These factors are further exacerbated by unreliable rainfall early in the season as well as residual effects of the previous droughts. As a result all primary and secondary tillage operations should endeavour to retain as much rainwater in the soil as is possible.

SH households experience DAP shortages early in the season when the timely establishment and weeding of crops are essential. If optimum yields are to be achieved, conservation agriculture needs to be practised. Conventional practices of winter ploughing followed by spring ploughing after the rains to eliminate weeds become important (Mashavira *et al*, 1997). Therefore, it is essential that conservation tillage practices are developed that conserve water, reduce DAP inputs, encourage timely crop establishment and timely weed control systems that take into account the resourcefulness of SH farmers (Norton, 1995).

Recent work in Zimbabwe has focused on developing weed control strategies that complement primary tillage techniques for communal area farmers who cannot afford chemical methods of weed control. Riches *et al*., (1997) reported that the use of the mould board plough with the body attached during weeding allows the creation and maintenance of a ridge and furrow landform that enhances soil water retention. A number of techniques open plough furrow planting, ripping and post emergent ridging, have been evaluated with cotton farmers in Sanyati and Gokwe districts with the aim of enhancing moisture conservation (Twomlow *et al*., 1994). This work has been now extended to Muzarabani district.

6.2 Hypothesis

The BS41 5- tine cultivator, the plough with the mould board both attached and removed significantly affect soil moisture conservation and penetration resistance of the soil when used as weeding implements.

6.3 Objectives

The broad objective is to compare the soil moisture conservation effectiveness and penetration resistance attained as a result of the use of BS41 5 –tine cultivator, the plough with the mould board both attached and removed, as weeding implements. The specific objectives were as follows:

1. To compare the soil moisture conservation effectiveness and penetration resistance of the three weeding implements attained on winter followed by spring ploughed area to a spring ploughed area only.
2. To compare the soil moisture conservation effectiveness and penetration resistance of the three weeding implements attained on an area where the crop is established by open plough furrow planting compared to one where crop establishment is by ripping.
3. To compare the soil moisture conservation effectiveness and penetration resistance of the three weeding implements attained on an area where a 30cm banded pre-emergence herbicide has been applied along the crop row to one where none is applied.

6.4 Methodology

Rain gauges were installed at every farmer's field and at Mfudzi primary school (mother trial) and readings were taken at 0800hrs whenever there was a storm. Readings were taken from the 1st of November to 30th of April of each of the two seasons. The rainfall data were used to interpret the soil moisture and penetration resistance of the soil.

In every plot, in the mother and baby trials, three stations were chosen randomly and a Delta-T ML-1 theta probe (T_r), measuring in m^3/m^3, and an Eijkelkamp core cylinder of mass M_c, measuring in m^3 was used. For the off season measurements twelve readings were taken in the mother trial at the end of May in the portions that were going to be winter and spring ploughed and the area where spring ploughing only was going to be done. The readings were taken just before winter planting at the end of the 1999/2000 and the 2000/2001 seasons. The data was used to determine the effects of the two different land preparation methods to the soil moisture content levels of the following season. For the during the season measurements three sets of readings were taken just before weeding at 3, 6 and 9 wace for each individual plot.

The theta probe was inserted into the ground and a reading taken. After which the core cylinder was then inserted on the station and pushed through the soil to a depth of 50mm or 0-50 mm level. The core cylinder was then dug out and the contents (M_t) were immediately weighed using an EKS 1002 digital electronic scale. The procedure was repeated with the theta probe and core cylinders for the levels, 50-100mm, 100-150mm, 150-200mm, 200-250mm, 250-300mm and 300-350mm depth. Measurements could not be taken beyond the 300-350mm as digging and removal of soil was disturbing cotton plant growth. Measurements at 9 wace showed that the cotton root depth was 300mm – 400mm. The rate of growth of roots varies with available soil moisture content. In a drought season they grow very deep up to 1m. The volume of the core cylinder, theta probe readings and the mass of soil were used to determine the volumetric moisture content of the soil.

6.4.1 Soil moisture content

The following equation (full derivation in appendix 7) was used to determine percentage volumetric soil moisture content.

$$\% \text{ Volumetric soil moisture content} = \frac{(M_w - M_d) * 100}{M_d} \quad .. \mathbf{6.1}$$

Where, M_w = Mass of wet soil. M_d = Mass of dry soil

6.4.2 Soil penetration resistance

In every plot, in the mother and baby trials, three stations were chosen randomly and soil penetration resistance measurements were done before the weeding operations at 3, 6 and 9 wace. Soil penetration resistance was measured using a 12.83mm diameter cone to a depth of 35cm. The penetrometer measures the penetration resistance of the soil in KgF. Penetration resistance of the soil was translated to shear strength, which is a force per m^2 using the following equation:

Shear strength (kNm^{-2}) = penetrometer reading * 75.87; ..**6.3**

75.87 is a conversion factor (see appendix 8)

6.5 RESULTS

6.5.1 Rainfall data

The rainfall data was higher for all months (except December and January) in the first season than the second. There were however relatively smaller variations in the total amounts of rain that fell in November, December, and January. The rest of the months gave bigger variation in the total amount of rainfall as shown in figure 6.1. Figure 6.1 shows the monthly average rainfall data for the 2000/01 and 2001/02 seasons for 3 villages (Gutsa, Muringazuva and Mfudzi) in Muzarabani for the period November to April.

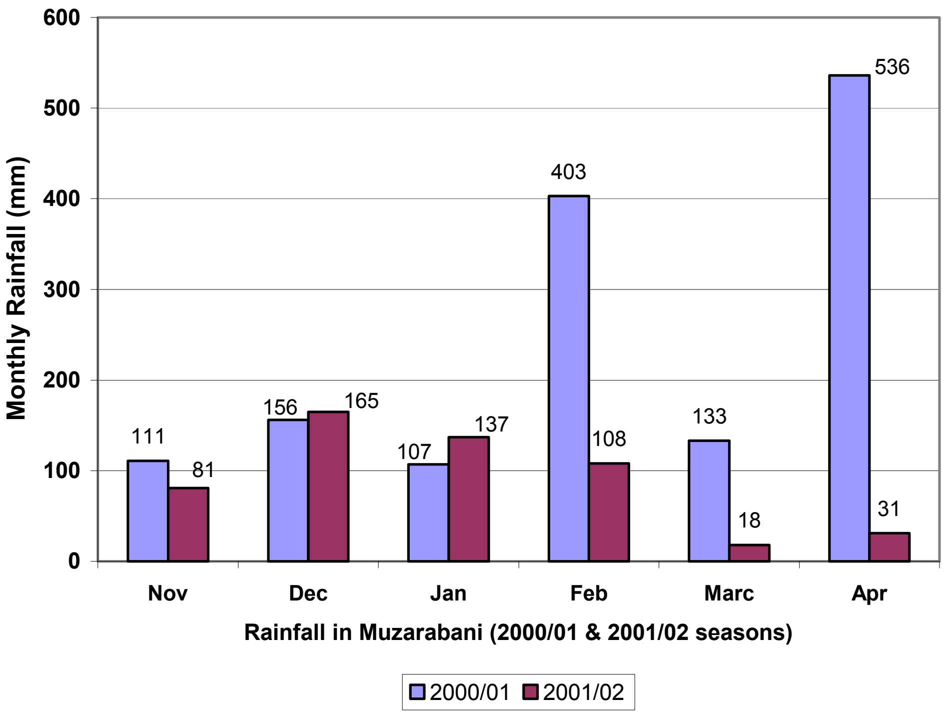

Figure. 6.1: Rainfall data for Gutsa, Muringazuva and Mfudzi villages for the 2000/01 and 2001/02 seasons.

The total annual rainfall was 1446mm for the 2000/01 season and 540mm for the 2001/02 season. The 2000/01 season was marked by good and excessive rains, which were distributed throughout the growing season. For the 2001/02 season, rainfall was concentrated in the months of November, December, January and February. There was a sharp decline in rainfall events from the month of February, with very little rainfall being received in March and April.

6.5.2 Off season soil moisture content

Table 6.1 shows the average percentage soil moisture content of the winter and spring ploughed portion and the spring ploughed only portion taken during the off season period in the moths of June and October of each research year.

Table 6.1: Percentage soil moisture content measured during the off seasons for the areas to be winter and spring ploughed and the spring ploughed only area for the 2 seasons

	Percentage soil moisture for the 1999/2000 season		Percentage soil moisture for the 2000/2001 season	
	June reading	October reading	June reading	October reading
Wp + sp	20.52	16.01	21.67	15.76
Sp only	20.57	13.21	21.58	12.98
SEDs	0.17	0.33	0.11	0.27
Significance	ns	*	ns	*

Moisture content is given as average moisture content of 12 stations within each portion, as a percentage, averaged over 6 levels of 0-5 cm, 5-10 cm, 10-15 cm.-20 cm, 20-25cm, 25-30cm. Data is a mean for 1999/2000 and 2000/2001 seasons. ns not significant, *P<0.05.

There were no significant variations in the average percentage soil moisture content for the winter (June) readings while there significant variations ($P<0.05$) for the spring (October) for the two seasons for the winter and spring ploughed portion and the spring ploughed portions. The portion that was wp gave higher percentage moisture content of average 15.89 before the onset of rains compared to 13.10 for the area to be spring ploughed only.

6.5.3 Soil moisture content and soil penetration resistance

Tables 6.2 and 6.3 summarise the key percentage soil moisture content and soil penetration resistance characteristics of the mother trial at Mfudzi primary School and baby trials respectively for the 2000/01 and 2001/02 seasons.

In table 6.2 comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. In table 6.3 comparisons are being done separately between methods of mechanical weeding and use/no use of herbicides and the interaction between mechanical weeding and use/no use of herbicides.

Table 6.2: Percentage soil moisture content and soil penetration resistance when weeding, as affected by land preparation, crop establishment, weeding implement and pre-emergence herbicide use in a cotton crop for the mother trial for the 2 seasons

	Percentage Soil Moisture Content						***Soil Penetration Resistance (N m^{-2})***					
PLOT	**@ 3 wace**		**@ 6 wace**		**@ 9 wace**		***@ 3 wace***		***@ 6 wace***		***@ 9 wace***	
FACTOR	**00/01**	**01/02**	**00/01**	**01/02**	**00/01**	**01 /02**	***00/01***	***01/02***	***00/01***	***01/02***	***00/01***	***01/02***
Land preparation												
Winter + spring	20.76*	21.66*	20.70*	20.75*	23.34*	20.66***	2037*	2196*	2108*	2446*	1873*	2429*
Spring only	17.34*	18.14*	16.45*	14.88*	18.79*	17.47***	2407*	2591*	2351*	2994*	2076*	2759*
Crop Establishment												
Open Furrow	19.01(ns)	19.87(ns)	18.42(ns)	17.72 (ns)	21.06 (ns)	19.10 (ns)	2236 (ns)	2395(ns)	2171(ns)	2715(ns)	1984(ns)	2604 (ns)
Ripping	19.09(ns)	19.94(ns)	18.72(ns)	17.92 (ns)	21.07 (ns)	19.02 (ns)	2208(ns)	2393(ns)	2211(ns)	2724(ns)	1965(ns)	2585 (ns)
Weeding Implement												
OC	19.03 (ns)	19.90(ns)	17.74a***	15.89a***	20.09a***	8.44a***	2213 (ns)	2435(ns)	2290a*	2905a***	2063a*	2746a***
OP+D	19.08 (ns)	19.96 (ns)	20.28b***	21.14b***	22.90b***	0.28b***	2221 (ns)	2363(ns)	2030b*	2415b***	1835b*	2328b***
OP - D	19.03 (ns)	19.84 (ns)	17.71a***	16.42a***	20.20a***	8.47a***	2231 (ns)	2383(ns)	2253a*	2839a***	2026a*	2709a***
Herbicide												
No	18.99 (ns)	19.73 (ns)	18.59 (ns)	17.66 (ns)	21.15(ns)	19.16(ns)	2232 (ns)	2396(ns)	2207 (ns)	2733 (ns)	1999(ns)	2618 (ns)
Yes	19.11 (ns)	20.08 (ns)	18.56 (ns)	17.97 (ns)	20.98 (ns)	18.96 (ns)	2212 (ns)	2391(ns)	2175 (ns)	2706 (ns)	1950(ns)	2570 (ns)
SEDs												
Land preparation	0.156	0.264	0.243	0.213	0.114	0.055	73.4	92.3	35.3	(119.2)	43.6	(43.6)
Crop Estab.	0.185	0.194	0.181	0.255	0.158	0.225	37.9	39.9	38.3	(39.0)	36.8	(36.8)
Implement	0.290	0.312	0.317	0.327	0.250	0.202	61.1	49.1	73.0	(74.4)	76.6	(76.6)
Herbicide	0.185	0.194	0.181	0.255	0.158	0.225	37.9	39.9	38.3	(39.0)	36.8	(36.8)
CV %	13.8	10.4	11.0	16.1	8.4	13.3	22.9	23.4	23.4	(39.0)	25.0	(19.0)

Moisture content is given as average moisture content of 2 stations within a plot, of the soil, as a percentage, averaged over 7 levels of 0-5 cm, 5-10 cm, 10-15 cm.-20 cm, 20-25cm, 25-30cm, 30-35. Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant, ***P<0.001 *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 6.3: Effect of implement treatments on soil moisture content and penetration resistance in subsequent weeding operations of baby trials for the 00/01 & 01/02 seasons.

	Percentage Soil Moisture Content						***Soil Penetration Resistance (N m^{-2})***					
PLOT	**@ 3 wace**		**@ 6 wace**		**@ 9 wace**		***@ 3 wace***		***@ 6 wace***		***@ 9 wace***	
FACTOR	**00/01**	**01/02**	**00/01**	**01/02**	**00/01**	**01 /02**	***00/01***	***01/02***	***00/01***	***01/02***	***00/01***	***01/02***
Weeding												
OC	19.57(ns)	16.69 (ns)	19.35a***	19.79a***	20.51a***	16.92a***	*2249(ns)*	*2366 (ns)*	*2244a****	*2469a****	*2293a***	*2401a****
OP+D	19.60ns)	16.62(ns)	21.59b***	22.74b***	23.87b***	19.37b***	*2263(ns)*	*2397 (ns)*	*1930b****	*2207b****	*2083b***	*2181b***
OP - D	19.56(ns)	16.56(ns)	19.64a***	19.85a***	20.21a***	16.74a***	*2270(ns)*	*2397 (ns)*	*2084c ****	*2484a****	*2155a***	*2386a***
Herbicide												
No	19.57(ns)	16.64(ns)	20.10(ns)	20.80(ns)	21.51(ns)	17.59(ns)	*2260(ns)*	*2400(ns)*	*2075(ns)*	*2485 (ns)*	*2179(ns)*	*2324(ns)*
Yes	19.58(ns)	16.61(ns)	20.29(ns)	20.78(ns)	21.54(ns)	17.77(ns)	*2261(ns)*	*2373(ns)*	*2097(ns)*	*2388 (ns)*	*2175(ns)*	*2322(ns)*
Weeding * Herbicide												
OC, HH	19.62(ns)	16.70(ns)	19.27(ns)	19.83(ns)	20.45(ns)	16.93(ns)	*2250 (ns)*	*2373(ns)*	*2250(ns)*	*2455(ns)*	*2298(ns)*	*2398 (ns)*
OP+D, HH	19.61(ns)	16.61(ns)	21.48(ns)	22.83(ns)	23.90(ns)	19.30(ns)	*2265 (ns)*	*2406(ns)*	*1895(ns)*	*2204(ns)*	*2081(ns)*	*2189 (ns)*
OP-D, HH	19.48(ns)	16.62(ns)	19.55(ns)	19.74(ns)	20.19(ns)	16.54(ns)	*2264 (ns)*	*2422(ns)*	*2079(ns)*	*2496(ns)*	*2160(ns)*	*2384(ns)*
Hca, OC, HH	19.52(ns)	16.89(ns)	19.43(ns)	19.76(ns)	20.57(ns)	16.92(ns)	*2247 (ns)*	*2360(ns)*	*2237(ns)*	*2484(ns)*	*2288(ns)*	*2404 (ns)*
Hca,OP+D,HH	19.58(ns)	16.63(ns)	21.69(ns)	22.65(ns)	23.83(ns)	19.44(ns)	*2260 (ns)*	*2388(ns)*	*1965(ns)*	*2211(ns)*	*2085(ns)*	*2172 (ns)*
Hca,OP-D,HH	19.63(ns)	16.51(ns)	19.74(ns)	19.95(ns)	20.23(ns)	16.95(ns)	*2276 (ns)*	*2372(ns)*	*2089(ns)*	*2471(ns)*	*2151(ns)*	*2389 (ns)*
SEDs												
Weeding	0.1491	0.1779	0.147	0.142	0.132	0.115	*29.5*	*29.9*	*29.6*	*30.6*	*30.7*	*30.1*
Herbicide	0.1217	0.1452	0.120	0.116	0.108	0.094	*24.1*	*24.4*	*24.2*	*24.9*	*25.1*	*24.5*
*Weeding*Herb.*	0.2109	0.2516	0.208	0.200	0.186	0.163	*41.7*	*42.3*	*41.9*	*43.2*	*43.4*	*42.5*
CV %	10.5	14.7	10.0	9.4	8.4	9.0	*21.4*	*20.6*	*23.4*	*21.0*	*23.2*	*21.3*

Moisture content is given as average moisture content of 2 stations within a plot, of the soil, as a percentage, averaged over 7 levels of 0-5 cm, 5-10 cm, 10-15 cm.-20 cm, 20-25cm, 25-30cm, 30-35. Data is a mean for 2000/2001 and 2001/2002 seasons. ns not significant, ***P<0.001 *P<0.05. Means followed by the same letter in a column are not significantly different.

6.5.3.1 Land preparation

From table 6.1, land preparation significantly affected ($P<0.05$) percentage soil moisture content levels and soil penetration resistance ($P<0.05$). Winter ploughing followed by spring ploughing (wp + sp) gave higher percentage soil moisture at 3, 6 and 9 weeks after crop emergence (wace) in subsequent weeding operations, for the two seasons compared to spring ploughing (sp) only. At the same time wp + sp gave lower soil penetration resistance at 3, 6 and 9 wace in subsequent weeding operations, for the two seasons compared to sp only.

6.5.3.2 Crop establishment

Crop establishment did not significantly affect percentage soil moisture content levels and soil penetration resistance in subsequent weeding operations for the two seasons. There were no soil moisture and penetration variations between the two methods in the 0-35cm depth. In this depth the average percentage soil moisture content was 19.20 and 19.28 while the average soil penetration resistance was 2351 kNm^{-2} and 2347 kNm^{-2} for the OPFP area and the ripper tine planted area respectively.

6.5.3.3 Mechanical weeding method

There was a significant difference ($P<0.001$) in the percentage soil moisture content levels and soil penetration resistance of the three weeding implements at 6 and 9 wace weeding operations for the two seasons (except at 3 wace), for the mother and baby trials (Tables 6.2 and 6.3). The OP+D gave the highest percentage soil moisture content and lowest soil penetration resistance at 6 and 9 wace (Figures 6.2 to 6.5). But there was no significant variation in percentage soil moisture content and soil penetration resistance between OP-D and OC. Figures 6.2 to 6.5 give the average percentage soil moisture content and soil penetration resistance against depth for the first and second seasons.

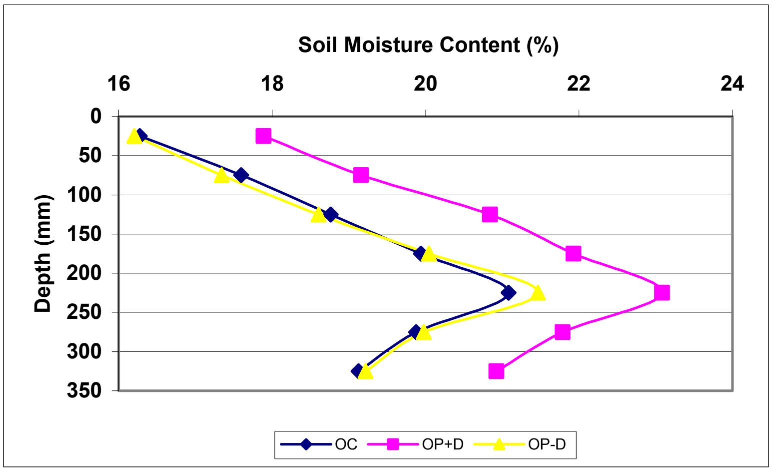

Figure 6.2: The average percentage soil moisture content with depth of the 3 weeding implements for the 2000/01 season.

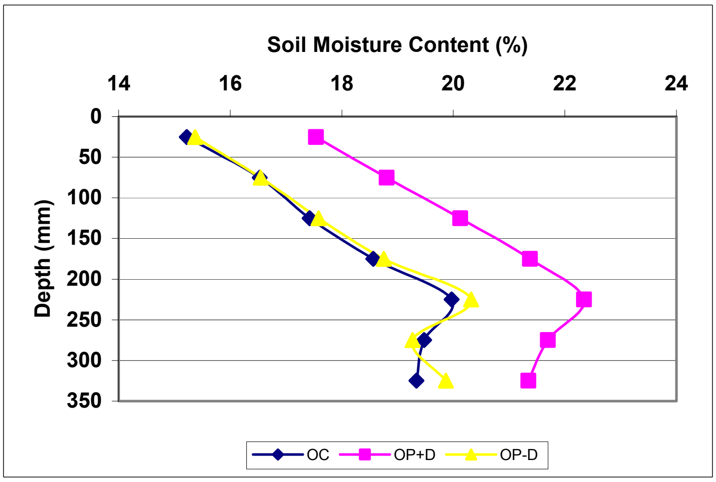

Figure 6.3: The average percentage soil moisture content with depth of the 3 weeding implements for the 2001/02 season.

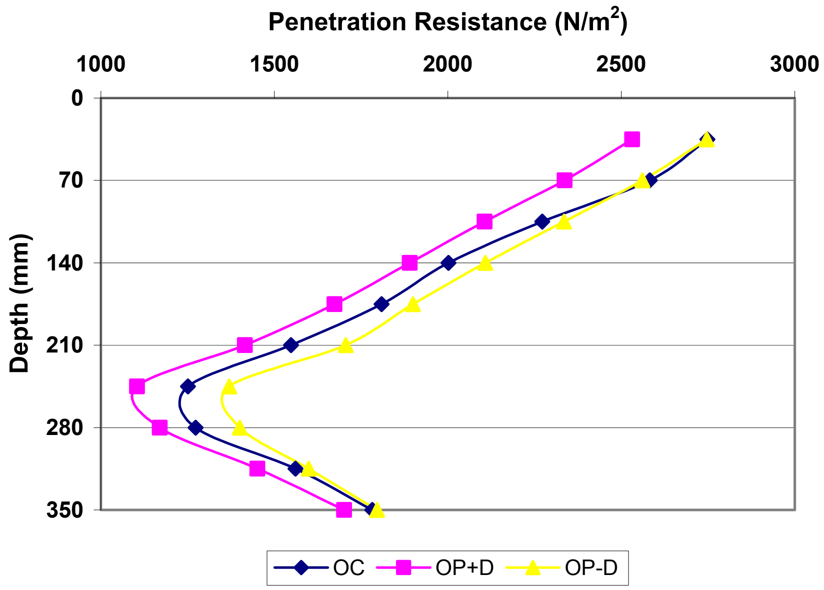

Figure 6.4: The average penetration resistances with depth of the 3 weeding implements for the 2000/01 season.

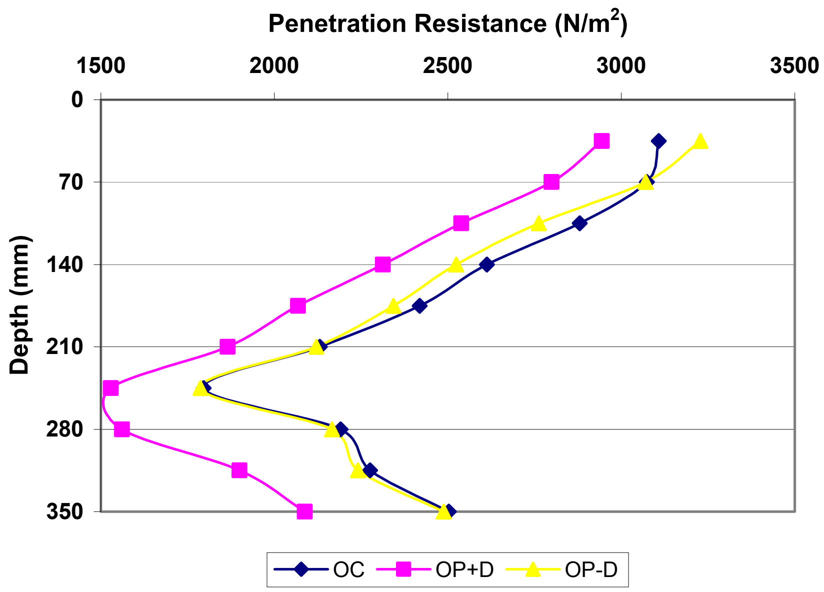

Figure 6.5: The average penetration resistances with depth of the 3 weeding implements for the 2001/02 season.

6.5.3.4 Use/no use of pre-emergence herbicide

The use of herbicides did not significantly affect percentage soil moisture content and soil penetration resistance in subsequent weeding operations for the two seasons. There was no soil moisture and penetration variation between the two methods in the 0-35cm depth. In this depth the average percentage soil moisture content was 19.43 and 19.36 while the average soil penetration resistance was 2269 kNm^{-2} and 2287 kNm^{-2} for the area that was applied with the herbicide and that without herbicide use respectively.

6.5.3.5 Interactions of land-preparation/implement

Interactions of land-preparation/implement significantly affected ($P<0.05$) percentage soil moisture content retention and soil penetration resistance at 6 and 9 wace weeding operations for the two seasons. The use of OP + D under wp + sp gave the highest percentage soil moisture content while the least soil moisture retention was attained when OC was used under sp (Figures 6.6 to 6.9). The least soil penetration resistance was found under OP+D where wp + sp were applied while the highest soil penetration resistance was attained when either OC or OP-D was used under sp only (Figures 6.6 to 6.9).

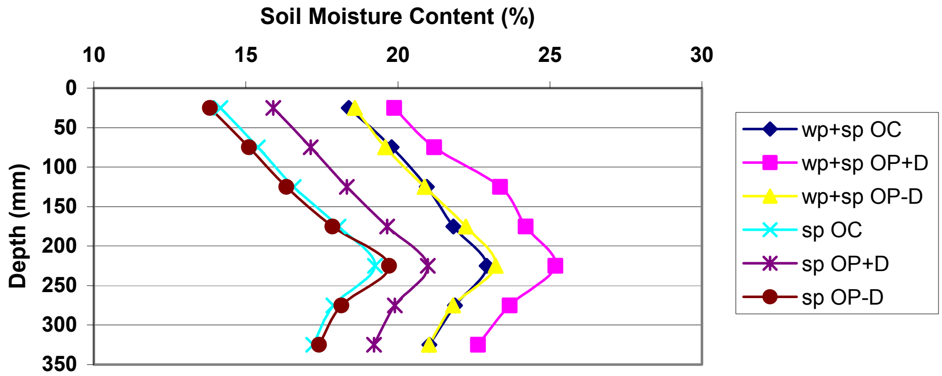

Figure 6.6: Average percentage moisture content retention for 00/01 season of the 3 implements under wp + sp and sp.

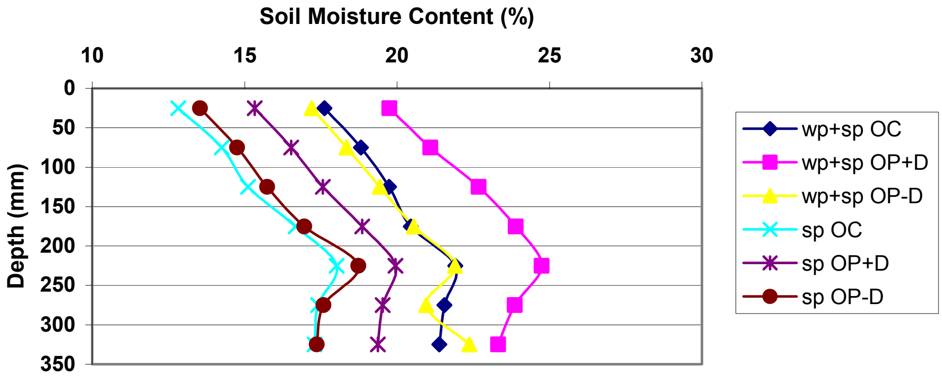

Figure 6.7: Average percentage moisture content retention for 01/02 season, of the 3 implements under wp + sp and sp.

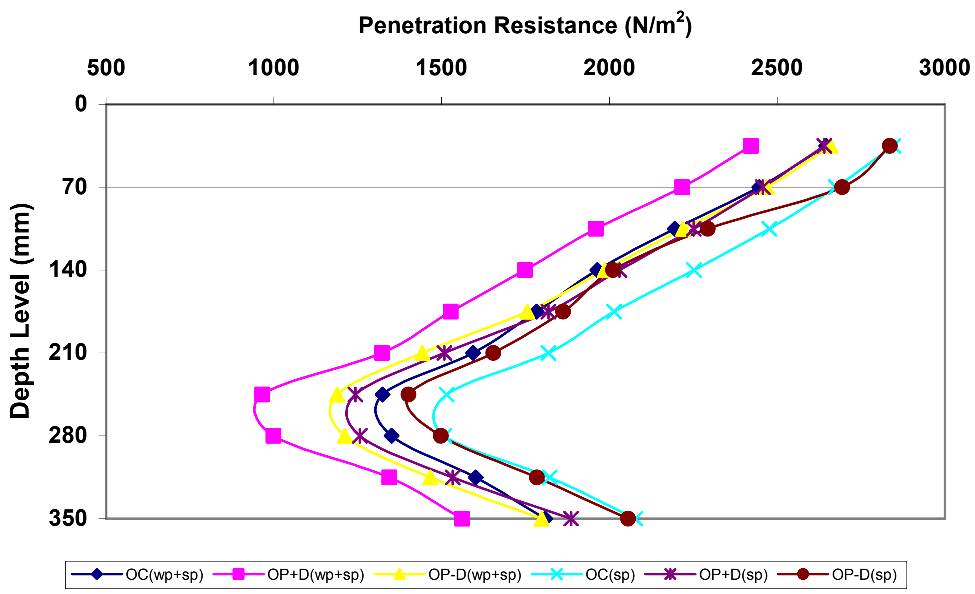

Figure 6.8: Average soil penetration resistance averaged at 3 and 6 wace for 00/01 season, of the 3 implements under wp + sp and sp.

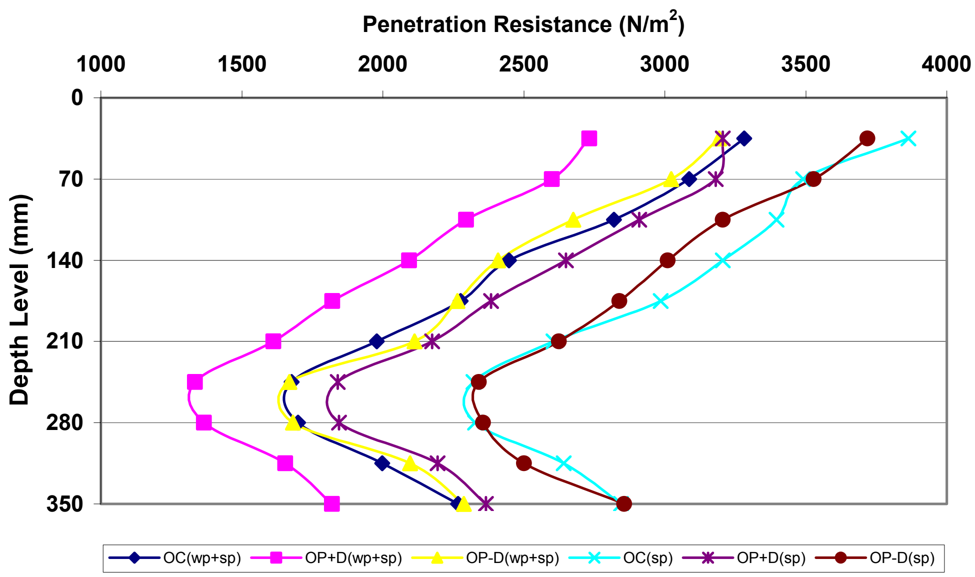

Figure 6.9: Average soil penetration resistance averaged at 3 and 6 wace for 01/02 season, of the 3 implements under wp + sp and sp.

6.6 Discussions

6.6.1 Rainfall data

During the two seasons the amount of rainfall and distribution significantly varied but still the amount that was recorded in the second season was within the total precipitation that is on average received in the area. In terms of rainfall data related variations (soil moisture content and soil penetration resistance), these were minor as the readings for 3, 6 and 9 wace weeding operations were taken between mid December and the second week of February. During this period the rainfall was almost the same in the two seasons. For the second year the 108mm of rain recorded in February fell within the first 10 days of the month while the rest of the month was dry, the 18mm in March fell in the middle of the month. The data that was affected by rainfall disparity between the two seasons are plant characteristics and cotton yield which were reduced as very little rain fell between mid February and end of April for the second season for the crop to reach maturity well. The months of February and March coincide with the cotton ball formation stage in the physiological development of the cotton crop. The dry spell that was experienced in the second season during this period resulted in fewer balls formed and abortion of some already formed balls.

6.6.2 Off season soil moisture content

Generally soils in Muzarabani are rich alluvial with high clay content (more than 30% clay content). The soils lose moisture during the off-season period and subsequently dry out leaving behind a hard soil mass that is difficult to break and work. Most farmers have to wait for the first two or three storms before they can plough their lands. When winter ploughing is done the end of season rains that fall in May/June find a receptive soil surface and easily infiltrate through the soil and moisture is conserved. Winter ploughing (wp) also removes weeds that germinate towards the end of season for the maize/ground nut crops and this removal reduces the loss of moisture from the soil by evapotranspiration of the weeds. Ploughing in winter, in April/May after a maize/ground nut crop removes all weeds and preserves any residual moisture. When wp is not done by the end of season the soils would have dried out. Drying is compounded by the fact that the last mechanical weeding operation can only be done at 9 wace beyond this period the crop is grown and canopied such that any mechanical weeding breaks the branches resulting in loss of cotton balls. The end of season rains find a hard soil surface difficult to infiltrate and most of the water is lost as run off.

6.6.3 Soil moisture content and soil penetration resistance

6.6.3.1 Land preparation

Wp + sp after the rains was found to suffice to loosen the soil so that they can retain more soil moisture and at the same time be easily penetrated by implements compared to sp only.

There is however arguments that winter ploughing cuts and invert the soil at the same time creating a weed free surface and these two factors increase the surface area exposed to the sun and thus encouraging more evapotranspiration. The explanations given to support the above results are: -

(i) Winter ploughing creates a receptive soil surface to capture the end of season rain fall;

(ii) Winter ploughing conserves any residual moisture from the previous season;

(iii) Winter ploughing removes weeds (weeds remove more moisture from the soil than the crop (Riches, 1999) after harvesting and thus creating a weed free surface that eliminates evapotranspiration through plants and/or weeds.

(iv) Winter ploughing creates a receptive soil surface to capture the rains received early in the season before any meaningful land preparation has been done.

Therefore, the net effect considering the pros and cons, as far as the results obtained in this research, is wp + sp results in more soil moisture retention than sp only.

6.6.3.2 Crop establishment

The method of crop establishment was found not to influence the moisture content retention levels in the soil and soil penetration resistance. It was expected that since in ripper planting, deeper depth of cut was achieved this should have resulted in looser soil (easier to penetrate also) that encourages water infiltration resulting in higher moisture retention in the soil and lower penetration resistance. On the contrary the use of the mould board plough with the mould board attached achieved a wider width of cut than the ripper thus disturbing a reasonable volume of soil (loosening) to cause significant water infiltration in the soil and soil easy to work. Consequently the only reason that can be given for no significant variation between the two methods of crop establishment is that the advantages obtained by a deeper depth of cut for the ripper was offset by the wider width of cut obtained when using the plough with the mould board attached.

6.6.3.3 Mechanical weeding method

At first weeding there was no variation in the weeding implements as soil moisture content and soil penetration resistance only depended on the land preparation. In the subsequent weeding operations OP + D gave the highest soil moisture content levels as a result of deeper depth of cut and its soil inversion properties that create a furrow and ridge landforms, which encourages water infiltration. In subsequent weeding operations OP+D gave the lowest soil penetration resistance as a result of a deeper depth of cut and loose soil tilth. The other two implements merely scratched the soil and did not disturb it much so as to encourage infiltration.

6.6.3.4 Use/no use of pre-emergence herbicide

The pre-emergence herbicide was applied as a 30cm band and did not interfere with the area to be mechanical weeded and therefore did no affect the area between rows. For the 30cm band along the crop row with/without the herbicide a variation was expected. The plots without the herbicide had weeds along the crop row and these drew moisture from the soil and lost it through evapotranspiration but at the same time created a canopy that reduced evaporation through the soil surface. The weeds were never allowed to outgrow the crop to cause meaningful water loss from the soil and lose it through evapotranspiration. According to this research the net effect was not significant and therefore the use/no use of herbicide did not affect soil moisture retention and subsequently soil penetration resistance.

6.6.3.5 Interactions of land-preparation/implement

OP + D achieved the highest soil moisture retention and the lowest soil penetration resistance under wp + sp as result of: -

(i) Residual moisture retention under wp as a result of a weeds free surface. Ploughing at the end of the season creates a surface that captures the end of season rain fall.

(ii) Its ability to cut and invert the soil and thus creating a furrow landform that retains moisture.

6.7 Conclusions

The practice of wp + sp after the first rains loosen the soil resulting in significantly (P<0.05) improved soil moisture retention levels. Looser soil results in lower penetration resistance of the soil reducing force draft requirements. As a result better moisture conservation is achieved in subsequent weeding operations. Further wp (deeper ploughing of 15-20cm) conserves any residual moisture in the soil for the next season. Winter ploughing is performed when the draft animals are strong so a depth of 15-20cm is easily achievable and this can be followed by shallow ploughing of 10-15cm after the first rains as the condition of animals will be poor. Therefore in low rainfall areas like Muzarabani farmers are encouraged to practice this method to enhance moisture conservation.

For areas that experience low rainfall like Muzarabani the use of OP + D can be important during drought years. Its use as a weeding implement results in significantly (P<0.001) higher moisture conservation as a result of deeper depth of cut and soil inversion capabilities of the plough compared to the other two. The furrow landform created by the OP + D during weeding encourages soil moisture retention. To enhance moisture conservation farmers can consider tying the ridges. This is even more important for farmers who do not own OCs as they can use the OP + D both as a primary and secondary cultivation implement. Care should be taken that the planting lines and hence crop rows do not run along the slope as the use of OP + D can result in excessive run off along the open furrow and cause serious erosion.

There was no significant variation in the method of crop establishment i.e. between open plough furrow planting and ripping. Farmers are; therefore, free to choose any of the methods depending on availability of implements. However, use of a ripper has the advantage of achieving a deeper depth of planting. But this deeper depth of planting can be a problem to cotton, which only requires less than 1cm depth of soil on top of the seed at planting. As far as soil moisture conservation is concerned farmers are free to choose any of these two methods.

There was no significant variation between portions where herbicides were applied and where none were applied and this did not influence soil moisture content and soil penetration resistance. Therefore, use/no use of herbicides does not affect soil moisture retention and soil penetration resistance, as a result farmers' decision in their use should be based on the ability to control weeds and not moisture.

7. DETERMINATION OF THE EFFECT OF THE THREE MECHANICAL WEEDING METHODS ON CROP CHARACTERISTICS.

7.1 Effects of weeding systems on weeding efficiency and crop characteristics

Weed control is often the operation with the highest labour demand in the cropping cycle. The area that can be kept free of weeds often restricts the amount of land a farmer can crop. Improved and efficient weed control may therefore enable a farmer to cultivate more land and hence increase total yield (Kwiligwa *et al*, 1992). In addition, the time the farmer gains from improved weed control may be devoted to the cultivation of additional crops or to more profitable off-farm employment (Lewis and Watson, 1972). Excessive weed growth is a critical factor limiting smallholder crop production in Zimbabwe (Chivinge, 1984). Farmers in Muzarabani (where 95% of households produce cotton), identified weed control as a major problem limiting yield, total area cultivated and therefore productivity of the farming system (Chatizwa *et al*, 2000).

The significance of weeds is often overlooked because unlike other pests and diseases, weeds can substantially reduce crop yield without apparent damage to the crop (Michaela, 1997). Weeds also remove more moisture and three to four times more nitrogen, potassium and magnesium from the soil than the crop does (Riches, 1999). The benefits derived from optimum levels of all agricultural inputs like seed, fertiliser, pesticides, irrigation can be completely overshadowed when the crop suffers from weeds (Gill, 1982). It should also be noted that cotton uses purchased inputs, particularly insecticides, but when the crop suffers weed competition, the full benefit from investment in pest control is not realised (Hillocks, 1995). In the Zambezi valley high weed growth due to high temperature results in farmers performing a series of costly weedings, which result in reduced profits.

In work discussed in this chapter weed density is defined as weed numbers per m^2 that are not uprooted after a weeding operation.

7.2 Hypothesis

The use of chemical and mechanical methods for weeding significantly improves weeding efficiency, crop characteristics and crop yields compared to mechanical weeding only.

7.3 Objectives

To compare the weeding efficiency, crop characteristics and yield responses of the three mechanical weeding methods with/without the use of pre-emergence banded herbicide.

1. To compare the weeding efficiency, crop characteristics and yield responses of the three implements attained on winter followed by spring ploughed area to a spring ploughed area only.
2. To compare the weeding efficiency, crop characteristics and yield responses of the three implements attained on an area where the crop is established by open plough furrow planting compared to one where crop establishment is by ripping.
3. To compare the weeding efficiency, crop characteristics and yield responses of the three implements attained on an area where a 30cm banded pre-emergence herbicide has been applied along the crop row to one where none has been applied.

7.4 Methodology

Plots for the mother trial measured 15m * 6 rows of cotton while the baby trials measured 30m * 12 rows of cotton. The spacing between rows was 0.9m while the in-row spacing was 0.4m.

7.4.1 Plant characteristics

7.4.1.1 Weeding efficiency

For all treatments weed counts were done at 3, 6 and 9 weeks after crop emergence (wace), these were carried just before the weeding operation. A 30 cm square quadrant was thrown at random within each plot and weed numbers, and weed species (Mavhudzi *et al*, 2002) were identified. Three readings were taken per plot. All the weeds found in the quadrant were uprooted and later oven dried and weighed to determine weed biomass (Mavhudzi, *et al*, 2002). Because some readings were zeros the data were transformed using a (√[number of weeds per m^2+0.5]) before analysis according to Little and Hills (1978).

7.4.1.2 Plant heights and cotton balls per plant

Just before the first harvest plant characteristics were measured. This involved randomly selecting 10 plants per plot for the baby trials and 5 plants per plot for the mother trial. The cotton plant heights were measured (in cm) using a graduated stick. Cotton balls were counted differentiating between the number of rotten cotton balls and the number of healthy cotton balls to determine the percentage yield loss due to ball rot. Cotton plant population per plot was recorded at harvest by physically counting all the plants within a net plot which measured 15m x 4 rows for the mother trial and 30m x 8 rows for the baby trials. (The mother trial was smaller in size than the baby trials as a result of limited space at the school as the land was shared with other two MPhil students).

7.4.1.3 Cotton harvest and labour

At harvest a net plot was determined, 8 middle cotton rows, 30m long, for the baby trials and 4 middle rows of cotton, 15m long, for the mother trial. The cotton in the net plots was harvested and immediately weighed (in kg). A series of harvests were done from end of April to end of June for each year and the weight of cotton obtained in the same plot was totaled. Farmers either used household labour as a first option or hired labour as a second option for weeding and harvesting purposes. Expenses of hiring labour were paid using the market rates in 2000/2001 season.

7.5 Results

7.5.1 Weeding efficiency

Tables 7.1 and 7.2 give the numbers of weeds per m^2 for the mother trial and baby trials respectively.

In table 7.1 comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. In table 7.2 comparisons are being done separately between methods of mechanical weeding and use/no use of herbicides and the interaction between mechanical weeding and use/no use of herbicides.

Table 7.1: Number of weeds per m^2 when weeding, as affected by land preparation, crop establishment, weeding implement and pre-emergence herbicide use in a cotton crop of the mother trial for the 2 seasons.

	Number of weeds per m^2 @ 3 wace		**Number of weeds per m^2 @ 6 wace**		**Number of weeds per m^2 @ 9 wace**	
	00/01	**01/02**	**00/01**	**001/02**	**00/01**	**01/02**
Land preparation						
Winter + spring	10.70*	6.11*	11.21*	8.39*	17.05(ns)	17.56 (ns)
Spring only	14.28*	8.68*	13.84*	10.12*	16.91(ns)	17.77 (ns)
Crop Establishment						
Open Furrow Planting	12.59(ns)	7.34(ns)	12.70(ns)	9.00(ns)	17.06(ns)	17.64(ns)
Ripping	12.39(ns)	7.45(ns)	12.35(ns)	9.50(ns)	16.89(ns)	17.69(ns)
Weeding Implement						
OC	12.75(ns)	7.58(ns)	13.35a**	9.05a**	17.76a***	18.76a***
OP+D	12.64(ns)	7.25(ns)	11.07b**	8.27a**	15.28b***	15.08b***
OP-D	12.08(ns)	7.36(ns)	13.06c**	10.44b**	17.89a***	19.16a***
Herbicide						
No	16.69***	11.49***	18.31***	12.15***	17.21(ns)	17.85(ns)
Yes	8.29***	3.30***	6.74***	6.35***	16.75(ns)	17.49(ns)
SEDs						
Land preparation	*0.449*	*0.544*	*0.427*	*0.311*	*0.560*	*0.383*
Crop Establishment	*0.435*	*0.327*	*0.314*	*0.418*	*0.302*	*0.410*
Weeding implement	*0.944*	*0.614*	*0.470*	*0.666*	*0.684*	*0.502*
Herbicide	*0.435*	*0.327*	*0.314*	*0.418*	*0.302*	*0.410*
CV %	25.6	32.5	18.4	33.2	13.1	17.1

Data is a mean for 2000/2001 and 2001/2002 seasons. Number of weeds per m^2 are given as average of values of number of weeds per m^2 of 3 stations within a plot. The number of weeds per m^2 has been angular transformed. ns not significant, ***P<0.001, **P<0.01, *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 7.2: Effect of implement treatments on number of weeds per m^2 in subsequent weeding operations for the baby trials for 2000/01 and 2001/02 seasons.

Number of weeds per m^2						
Treatment	**3 wace**		**6 wace**		**9 wace**	
	00/01	**01/02**	**00/01**	**01/02**	**00/01**	**01/02**
Weeding						
OC	7.94(ns)	7.06 (ns)	7.69(ns)	8.28(ns)	8.73(ns)	9.91(ns)
OP + D	8.89(ns)	7.73(ns)	7.69(ns)	7.44(ns)	8.66(ns)	10.98(ns)
OP – D	9.33(ns)	7.22(ns)	8.32(ns)	8.35(ns)	8.67(ns)	10.33(ns)
Herbicide						
No	11.95***	11.51***	9.85***	9.97 ***	8.74(ns)	10.22(ns)
Yes	5.49***	3.16***	5.95***	6.08 ***	8.63(ns)	10.59(ns)
Weeding * Herbicide						
OC, HH	10.54a	10.85a	9.95a	9.93a	8.78(ns)	10.22(ns)
OP+D, HH	11.60a	12.98a	9.35a	9.46a	8.81(ns)	10.54(ns)
OP-D, HH	13.73a	10.70a	10.24a	10.51a	8.64(ns)	9.43(ns)
Hca, OC, HH	5.35b	3.26b	5.42b	6.63b	8.68(ns)	9.52(ns)
Hca, OP+D, HH	6.18b	2.48b	6.02b	5.41b	8.51(ns)	11.01(ns)
Hca, OP-D, HH	4.94b	3.74b	6.40b	6.19b	8.70(ns)	11.23(ns)
SEDs						
Weeding	1.211	0.934	0.839	0.689	0.157	0.872
Herbicide	0.989	0.763	0.685	0.563	0.128	0.712
Weeding * Herbicide	1.713	1.321	1.187	0.975	0.221	1.233
CV %	61.8	66.2	55.2	44.7	9.4	43.5

Data is a mean for 2000/2001 and 2001/2002 seasons. Number of weeds per m^2 are given as average of values of number of weeds per m^2 of 3 stations within a plot. The number of weeds per m^2 has been angular transformed. ns not significant, ***P<0.001, **P<0.01, *P<0.05. Means followed by the same letter in a column are not significantly different.

7.5.1.1 Land preparation

Land preparation significantly affected ($P<0.05$) number of weeds per m^2 at 3 and 6 wace (but did not at 9 wace) for the two seasons (Table 7.1). The number of weeds per m^2 was reduced by 22% when winter followed by spring ploughing (wp + sp) was practised compared to spring ploughing (sp) only.

7.5.1.2 Crop establishment

Crop establishment either by ripping or open plough furrow planting did not affect the number of weeds per m^2 in subsequent weeding operations for two seasons. The average number of weeds per m^2 for the OPFP area across implements for the two seasons was 12.72 while for the ripper planted area was 12.71.

7.5.1.3 Mechanical weeding method

There where significant differences ($P<0.01$) in the number of weeds per m^2 at 6 and 9 wace weeding operations (Table 7.1), OP + D being the most effective, giving the lowest number of weeds per m^2. There were no significant variations between OC and OP-D for the two seasons. For the baby trial there were no significant variations in the number of weeds per m^2 between weeding methods (Table 7.2). The average number of weeds per m^2 at 6 and 9 wace averaged over the two seasons for OP+D was 12.43 while for OC and OP-D were 14.72 and 15.14 respectively.

7.5.1.4 Use/no use of pre-emergence herbicide

The use of banded pre-emergence herbicides significantly influenced ($P<0.001$) the number of weeds per m^2 at 3 and 6 wace weeding operations for the two seasons (but did not at 9 wace). The use of the pre-emergence herbicide resulted in lower number of weeds per m^2 for subsequent weeding operations during the two seasons. The number of weeds per m^2 were reduced to 40% of those found in portions without herbicide treatment (along the crop row) when banded pre-emergence herbicides were applied. The average number of weeds per m^2 at 6 and 9 wace averaged over the two seasons for the area that was applied pre-emergence herbicide was 6.17 while for the area without the herbicide was 14.66.

7.5.1.5 Interactions of land-preparation/implement/herbicide

Interactions of land-preparation/implement/herbicide significantly affected ($P<0.05$) the number of weeds per m^2 at 6 and 9 wace for the two seasons (Table 7.3). The use of OP + D with pre-emergence herbicide application under wp + sp was the most efficient, removing more weeds, hence resulting in the lowest number of weeds per m^2. The use of OP - D under sp only was the least efficient at 6 wace while OC was the least efficient at 9 wace (in both cases without the herbicides) as shown in Table 7.3.

Table 7.3: Number of weeds per m^2 as affected by the land preparation/implement/herbicide interactions for the 2001/2002 season at 6 and 9 wace.

Land preparation	Weeding	Treatment HH,OC	Hca ,OC, HH	HH, OP+D	Hca, OP+D, HH	HH, OP-D	Hca, OP-D, HH	Sign.	SEDs
Winter + spring	at 6 wace	10.08b	6.29c	9.96b	5.58d	12.33a	6.09c	P<0.05	0.23
Spring only		13.67b	7.48d	10.37c	7.17d	16.5a	6.85d	P<0.05	0.31
Winter + spring	at 9 wace	18.43a	18.68a	14.76b	14.30b	18.97a	18.75a	P<0.05	0.38
Spring only		19.12a	18.80a	15.50b	15.78b	19.06a	18.86a	P<0.05	0.35

Means followed by the same letter in a row are not significantly different

7.5.2 Plant characteristics

Tables 7.4 and 7.5 show, the cotton plant heights, average number of balls per cotton plant and the cotton harvested (tonnes ha^{-1}) at Mfudzi Primary School and baby trials respectively for the 2000/01 and 2001/02 seasons.

In table 7.4 comparisons are being done separately between methods of land preparation, crop establishment, mechanical weeding and use/no use of herbicides. In table 7.5 comparisons are being done separately between methods of mechanical weeding and use/no use of herbicides and the interaction between mechanical weeding and use/no use of herbicides.

Table 7.4: Crop characteristics when weeding, as affected by land preparation, crop establishment, weeding implement and pre-emergence herbicide use in cotton for the mother trial for the 2 seasons.

	Cotton Plant Height (cm)		Average Balls/ plant		Cotton Yield (kg ha^{-1})	
	00/01	**01/02**	**00/01**	**01/02**	**00/01**	**01/02**
Land preparation						
Winter + spring	146.9*	107.3*	24.4 *	14.3*	2703*	610*
Spring only	135.5*	82.4*	21.1 *	8.9*	1969*	479*
Crop Establishment						
Open Furrow Planting	143.7*	93.6(ns)	23.2 (ns)	11.7 (ns)	2366(ns)	531(ns)
Ripping	138.7*	96.1(ns)	22.4 (ns)	12.1 (ns)	2306(ns)	558(ns)
Weeding Implement						
OC	139.6(ns)	94.2a*	23.6a,b*	11.7a*	2338(ns)	552(ns)
OP + D	145.6(ns)	98.8b*	24.1b*	13.0b*	2430(ns)	571(ns)
OP – D	138.4(ns)	91.6a*	20.5a*	10.2a*	2242(ns)	510(ns)
Herbicide						
No	138.8*	92.7*	21.7*	10.7*	2204***	486***
Yes	143.6*	97.0*	23.8*	12.5*	2469***	603***
SEDs						
Land preparation	*2.524*	*2.27*	*0.458*	*1.156*	*153*	*28.7*
Crop Establishment	*1.629*	*2.23*	*0.782*	*0.704*	*49.9*	*22.9*
Weeding implement	*3.984*	*2.38*	*1.148*	*0.902*	*98.0*	*37.0*
Herbicide	*10.9*	*22.3*	*0.782*	*0.704*	*49.9*	*22.9*
% CV	*10.9*	*22.3*	*32.6*	*57.5*	*9.1*	*17.8*

Data is a mean for 2000/2001 and 2001/2002 seasons. Cotton plant height and cotton balls per plant are given as average of values of 5 plants per plot. ns not significant, ***P<0.001, **P<0.01, *P<0.05. Means followed by the same letter in a column are not significantly different.

Table 7.5: Effect of implement treatments on crop characteristics in subsequent weeding operations for the baby trials for the 2000/01 and 2001/02 seasons.

	Crop Characteristics					
Treatment	**Plant Height (cm)**		**Cotton Balls/plant**		**Cotton Yield (kg ha^{-1})**	
	00/01	**01/02**	**00/01**	**01/02**	**00/01**	**01/02**
Weeding						
Ox cultivator	123.38a**	85.34a***	14.36a,b**	10.59a,b**	1918 (ns)	1036(ns)
Plough + dish	129.44b**	87.49b***	15.53a**	11.63b**	1965(ns)	979 (ns)
Plough-dish	127.53c**	81.74c***	12.89b**	9.63a**	1933(ns)	883 (ns)
Herbicide						
No	122.30a***	81.74a***	12.90a***	10.43(ns)	1895(ns)	972 (ns)
Yes	129.70b***	87.97b***	15.63b***	10.81(ns)	1982(ns)	960(ns)
Weeding * Herbicide						
OC, HH	117.91(ns)	81.18a	12.14a	9.94a,b	1902(ns)	1076(ns)
OP+D, HH	126.41(ns)	83.02a	13.40a,b	11.12b,c	1990(ns)	938 (ns)
OP-D, HH	122.59(ns)	81.02a	13.16a,b	10.21a,b	1793 (ns)	902 (ns)
Hca, OC, HH	128.86(ns)	89.50b	16.58b,c	11.23b,c	1934(ns)	996 (ns)
Hca, OP+D, HH	132.48(ns)	91.97b	17.67c	12.14c	1940(ns)	1020 (ns)
Hca, OP-D, HH	127.76(ns)	82.46a	12.63a	9.04a	2072(ns)	864 (ns)
SEDs						
Weeding	2.014	1.587	0.835	0.584	99.5	83.1
Herbicide	1.644	1.296	0.682	0.477	81.2	67.8
Weeding * Herbicide						
	2.848	2.245	1.181	0.827	140.7	117.5
CV %	15.2	17.7	44.1	52.2	15.4	25.8

Data is a mean for 2000/01 and 2001/02 seasons. Cotton plant height and cotton balls per plant are given as average of values of 5 plants per plot. ns not significant, ***P<0.001, **P<0.01, *P<0.05. Means followed by the same letter in a column are not significantly different.

7.5.2.1 Land preparation

Land preparation significantly affected (P<0.05) plant height with wp + sp giving taller cotton plants. This also significantly (P<0.05) increased the number of cotton balls per plant, and hence higher yield for the wp + sp treatment compared to the sp treatment over the two seasons (Table 7.5). Wp + sp resulted in a cotton crop with an average plant height of 127.1cm, average cotton balls per plant of 19.4 and yield of 1657 kg ha^{-1} averaged over the three implements. The figures for sp only were average plant height of 109.0cm, average cotton balls per plant of 15.0 and yield of 1224 kg ha^{-1} averaged over the three implements.

7.5.2.2 Crop establishment

The method of crop establishment did not significantly affect the cotton plant height, number of cotton balls per plant and cotton yield for the two seasons. The OPFP area resulted in a cotton crop with an average plant height of 118.7cm, average cotton balls per plant of 17.5 and yield of 1449 kg ha^{-1} averaged over the three implements. The figures for ripper planting were average plant height of 117.4cm, average cotton balls per plant of 17.3 and yield of 1432 kg ha^{-1} averaged over the three implements.

7.5.2.3 Weeding method

The method of mechanical weeding significantly affected ($P<0.05$) plant height in the mother trial (Table 7.5). It also significantly ($P<0.001$) affected the baby trials, for the two seasons. The OP + D gave taller cotton plants; this resulted in significantly ($P<0.05$) more cotton balls per plant and higher cotton yield for the two seasons, though yield was not statistically significant. The use OP+D resulted in a taller cotton crop of height 115.3 cm with more cotton balls per of average 16.0 and yield of 1486 kg ha^{-1}. OC and OP-D had a cotton crop of 110.6 cm and 109.8cm, average cotton balls per plant of 15.1 and 13.3 and yield of 1461 and 1392 kg ha^{-1} respectively.

7.5.2.4 Use/no use of pre-emergence herbicides

The use of banded pre-emergence herbicides significantly affected ($P<0.001$) plant heights with portions that had the herbicides giving taller cotton plants than portions without, for the two seasons. The taller cotton plants of height 114.6cm resulted in significantly ($P<0.05$) more cotton balls per plant (15.7 per plant) and this in turn resulted in significantly ($P<0.05$) higher yield of average 1536 kg ha^{-1} for the mother trial.

7.5.2.5 Interactions of land preparation/implements/herbicide

Interactions of land preparation/implements/herbicide significantly effected ($P<0.05$) yield for the two seasons as shown in table 7.6. It was observed that higher yields were achieved under wp + sp compared to sp only. Herbicide treatment gave higher yields than those without when comparing the same weeding implement. The use of the OP + D with the banded pre-emergence herbicide under wp + sp gave the highest yield of 3010kg ha^{-1} for the first season and 740 kg ha^{-1} for the second season. The lowest yields were achieved interchangeably when OP-D and OC without herbicide and under sp only were used.

Table 7.6: Cotton yields in kg ha^{-1}achieved under different land-preparation/implement/herbicide interactions for the Mother trial for the 2000/01 and 2001/02 seasons.

Land preparation	**Treatment**						
	HH, OC	Hca, OC, HH	HH, OP+D	Hca, OP+D, HH	HH, OP-D	Hca, OP-D, HH	Sign.
	Cotton yield in kg ha^{-1} for the 2000-01 season						
Winter + spring	2593c	2793b	2652b,c	3010a	2238d	2933a	P<0.05
Spring only	1897c	2068a	1990b	2067a	1852d	1943c	P<0.05
	Cotton yield in kg ha^{-1} for the 2001-02 season						
Winter + spring	540c	680b	542c	740a	495d	665b	P<0.05
Spring only	415d	573a	447c,d	557a	478b,c	402d	P<0.05

Means followed by the same letter in a row are not significantly different

7.6 Discussions

7.6.1 Weeding efficiency

7.6.1.1 Land preparation

Wp removes and buries any weeds that germinate and grow after the last weeding of the previous season. Sp after the first rains and before planting removes any weeds that will have germinated after the first rains and ensures a weeds free surface very conducive for pre-emergence herbicide application. As a result portions which were wp + sp had significantly lower number of weeds per m^2 compared to sp only. To create weeds free surface under sp only especially in Muzarabani will require deeper ploughing to cut and invert and bury all weeds, this is difficult as a result of the poor condition of animals at the beginning of the season.

7.6.1.2 Crop establishment

The use of open plough furrow planting or ripping did not affect number of weeds per m^2 as it was done immediately after ploughing the land and therefore could not affect the germination or elimination of weeds.

7.6.1.3 Weeding method

The use of OP + D results in some soil thrown over and burying of small weeds and smothering them at the same time (could also be a problem where pre-emergence herbicides have been applied) resulting in lower weed density. This reduces weed density drastically and, as alluded by Riches, *et al*, (1997), in some instances no supplementary weeding was required when OP + D was used as a weeding implement. Riches, *et al*, (1997) in his work in

Masvingo province concluded by reporting that the OC was the least efficient, followed by the OP - D while the most efficient was the OP + D.

7.6.1.4 Use/no use of pre-emergence herbicides

At 3 and 6 wace weeding operations, there were significant variation between portions with pre-emergence herbicide and those without as a result of the effect of the herbicide on the weeds. The pre-emergence banded herbicides suppressed weeds for a period of 6-8 weeks. Weed counts done along the band reflected lower densities for the first and second weeding operation, as the critical period for weeding cotton is 6-10 weeks. At 9 wace there were no significant variation in weed densities for plots with/without herbicides since by 9 weeks the herbicide will have disintegrated in soil as the half-life of the cynazine/alachlor mix is 6 - 8 weeks.

7.6.1.5 Interactions of land preparation/Implement/Herbicide

The lowest weed density was observed when OP + D was used in areas with the pre-emergence herbicide under wp + sp. This was as a result of the combined effect of: -

(i) ploughing twice in winter and spring, winter to remove weeds germinating after the last weeding and end of season rains, spring, to remove weeds germinating after the first rains before land preparation.

(ii) OP + D cuts and inverts soil, throwing it over the weeds thus smothering them.

(iii) The effect of the banded pre-emergence herbicide that suppresses weeds for a period of 6 weeks during the critical period of weeding.

7.6.2 Plant characteristics

7.6.2.1 Land preparation

The use of wp + sp resulted in higher moisture retention in the soil and lower weed density than sp only. Crop growth is enhanced when there is enough moisture in the soil and nutrients are available to the crop. Reducing weed density reduces the competition for nutrients between the crop and weeds. According to Riches, 1999 weeds remove three to four times more nitrogen, potassium and magnesium from the soil than the crop does. These two factors consequently, contributed to a taller cotton crop with more cotton balls per plant and ultimately a higher yield.

7.6.2.2 Crop establishment

For the planting of cotton more than 10 seeds were put per station so as to avoid or limit any gap filling, as a result the germination was good for both open plough furrow planting and rip planting. For all treatments thinning was done so as to leave behind a recommended plant population. And since the method of crop establishment did not affect (soil moisture retention levels) and weed density there were no variations, in cotton plant height, number of balls per plant and yield that were observed.

7.6.2.3 Mechanical weeding method

From the trials it was expected that OP + D would give higher yields as a result of its ability to cut and invert soil creating a furrow-ridge landform that is able to retain soil moisture and its high weeding efficiency but this did not happen. This could be attributed to the thorough timely three weeks interval weeding that never gave this method an advantage over longer periods. The advantage might be realised when the fields are larger and the farmer takes more than three weeks between one weeding and the next. Generally farmers in Muzarabani do not complete their weeding cycle in three weeks as the areas planted are up to 10 acres. The other contributing factor to no variation could be as a result of the fact that for the first season there was enough rain that fell through out the season so that there was no need to conserve moisture. For the second season there was no moisture from the period of ball formation to maturity so that all treatments were stressed. Ellis-Jones, *et al*, 1993 did some work in Masvingo which showed that the OC gave the highest maize yield 4552 kg ha^{-1}, followed by the OP + D with 4345 kg ha^{-1}while the OP - D gave 2766 kg ha^{-1}.

7.6.2.4 Use/no use of pre-emergence herbicides

Use of banded pre-emergence herbicide suppressed weeds along the cotton row providing a weed free or low weed density surface during the critical period of weeding and hence giving a taller crop with more cotton balls per plant and, therefore, higher yields. A weed free surface (or lower weed density) reduces competition for nutrients between crop and weeds. As a result an indirect increase in yields by use of herbicides occurs by releasing labour from one crop where herbicides have been used for an improved care of another.

7.6.2.5 Interactions of land preparation/Implement/Herbicide

The highest yield was achieved when OP + D was used in areas with the pre-emergence herbicide under wp + sp. This was as a result of the combined effect of: -

(i) ploughing twice in winter and spring, which reduced weed density and at the same time increased soil moisture levels.

(ii) The ability of OP + D to cut and invert soil (results in soil moisture retention), throwing it over the weeds thus smothering them reducing weed density.

(iii) The effect of the banded pre-emergence herbicide that suppresses weeds for a period of 6 weeks during the critical period of weeding.

The increase in soil moisture and the reduction in weed density gave a very conducive environment for the growth of cotton resulting in a higher yield.

The lowest cotton yield was achieved when either OC or OP – D were used in areas without the herbicide under sp only. The use of OC and OP – D resulted in higher weed density and lower moisture retention in the soil. This is compounded when no herbicide is used as weeds quickly overwhelm the crop. Spring ploughing only results in poor land preparation (more weeds) and lower soil moisture retention. These factors resulted in a lower cotton yield.

7.7 Conclusions

Wp + sp significantly ($P<0.05$) reduced weed densities and therefore it would be important for farmers to consider this fact. Lower weed densities help reduce weed burden especially early in the season when there are labour bottlenecks. This means that labour can then be released to other crops like maize and groundnuts or for off-farm activities.

Lower weed densities led to a better crop stand with more cotton balls per plant and hence higher yield. Yield increased by 33% on average for the two seasons when additional wp was carried out. (Wp can be achieved if crop rotation is practised and maize and groundnuts are grown alongside cotton).

There is no advantage gained over the other weeding implements when any of them is used in terms of yield response, therefore farmers are free to choose any of them. Availability and affordability of the implement are the only factors that influence the choice in this instance. The other factor that can be considered is the labour requirements commensurate with each method of weeding as OP+D resulted in reduced weed density. Thus requiring lesser time for supplementary hand weeding, subsequently availing more time for the attention of other crops or off farm activities. In some way reduced labour requirements are an indirect increase in yield by releasing labour to other crops.

The use of banded pre-emergence application of cyanazine and alachlor resulted in a significantly ($P<0.05$) suppressed weed density especially during the critical period of weeding, resulting in enhanced cotton yield. As far as the research is concerned farmers are encouraged to consider the use of herbicides. But before adoption there is a need to carry out a cost benefit analysis to determine whether the additional yield obtained from use of herbicide will offset the cost of the herbicide. The highest cotton yield was attained when OP+D was used as the weeding implement with pre-emergence herbicide application under winter followed by spring ploughing.

8. ECONOMIC ANALYSIS OF MECHANICAL WEEDING AND, INTEGRATED MECHANICAL AND HERBICIDE USE, IN WEED CONTROL.

8.1 Introduction

Over 70 percent of the Zimbabwean population reside in rural areas where agriculture is the major source of livelihood. It follows that raising agricultural productivity is a *sine qua non* for raising the standards of living of the average person (Rukuni & Eicher, 1994). Over the past years, rural agriculture has not been a source of growth. Most rural farmers are poverty stricken, food insecure and earn low incomes from their production and this can be attributed to poor capital asset base (Mehretu, 1994). This is due to declining agricultural productivity attributable to small sizes of land holdings, unfavourable agro-ecological conditions, limited access to credit, poor access to extension services, poor access to input and output markets and lastly limited access to appropriate technical information on agricultural production. Among the lack of access to appropriate technical information are integrated weed control methods. Weeding, like any other cropping operation, is crucial and, if not properly done can reduce the returns to other complementary inputs like pesticides and fertilisers, resulting in lower yields (Chivinge, 1984). Yield losses to weeds can be as much as 100 percent with some fields being abandoned to weeds when the weed burden becomes great (Mashingaidze and Chivinge, 1999).

It is important to note that most communal farmers undertake most agricultural activities without the knowledge of the viability of these activities yet it is assumed that their objectives in doing these activities is to maximise their incomes and welfare (Muzenda and Ellis-Jones, 2000). Given such condition of farmers relying on agriculture production for their living, assessment of viability becomes crucial as we determine the returns from these activities and also in turn the farmers can rely on production for their living. It is upon this background that this chapter considers and highlights the costs and benefits derived from the use of different weeding management options.

8.2 Hypothesis

The use of chemical and mechanical weeding methods is significantly cheaper than mechanical weeding only.

8.3 Objectives

To assess the economic merits of three mechanical weeding methods with the use of pre-emergence banded herbicide with those of mechanical weeding only.

1. To compare the overall benefits derived when using the three weeding implements on winter followed by spring ploughed area to a spring ploughed area only.
2. To compare the overall benefits derived when using the three weeding implements on an area where the crop is established by open plough furrow planting compared to one where crop establishment is by ripping.
3. To compare the overall benefits derived when using the three weeding implements on an area where a 30cm banded pre-emergence herbicide has been applied along the crop row to one where none has been applied.

8.4 Methodology

8.4.1 Winter ploughing and mechanical weeding

The cost of winter ploughing (wp) using an ox drawn mould board plough per ha was recorded for 2000-01 and 2001-02 seasons.

8.4.2 Herbicide application

Treatments for the mother and baby trials were divided into herbicide and non-herbicide. Herbicides were applied as pre-emergence and as a 30cm band. Herbicides were applied using knapsack sprayers. Most of the sprayers were supplied with two-herbicide nozzles at purchase and for farmers' without the nozzles the project supplied. The cost of the herbicides was recorded based on market prices in November of 2000 and 2001. The cost per ha of a band application of cynazine was $152 and for alachlor was $120 (see appendix 10 for calculations).

8.4.3 Labour for supplementary hand weeding

The time taken to weed each plot/treatment was recorded using a LR 41,Quartz timer stopwatch and then extrapolated to one ha. Farmers either used household labour (first preference) or hired labour (second preference) for weeding purposes. Farmers negotiated payment for weeding based on 70 metre rows. Rates were highly negotiable. This method has been referred to as the payment using the prevailing market rate (PMR) price in this chapter and was used by about 90% of farmers in Muzarabani (Ellis Jones *et al*, 2001). In the case of PMR labour was hired for a specific piece job. The price for payment of labour using the PMR per 70m rows was recorded at 3, 6 and 9 weeks after crop emergence (wace). The prices were $10 per 70m row for plots with no herbicides, $5 per 70m row for plots with herbicides for the 3 and 6 wace weeding operations. At 9 wace the price was $10 per 70m row for plots with/without herbicides

Another method of price negotiation was the ARDA daily rate (ADR). The ADR was derived from the rates paid by ARDA, which were basically government-gazetted rates for the agricultural sector. This kind of costing was found to be suitable for farmers with seasonal or permanent labour force. Farmers with permanent labour or seasonal labour used the ADR with a fixed salary depending on the time the employee provided labour per month.

Farmers performed three supplementary hand-weeding operations at 3, 6 and 9 wace along the cotton crop row. Farmers in Muzarabani considered an acre to consist of 70 rows of cotton, 70m long and 0.9m wide. All their calculations were based on these dimensions and multiplying the values by 2.5 then gives one hectare.

In this chapter only the PMR is considered as it was used by most farmers and amongst the farmers that the research dealt with none were using the ADR. The two seasons have been dealt with separately, as the first was a good season with an above normal rainfall while the second was a drought season.

8.4.4 Partial budgets

Partial budgets allowing marginal analysis have been calculated for each weeding option for both seasons (2000-01 and 2001-02). Where there were no significant differences between yields these have been averaged to reflect the statistical analysis. Where there were significant differences between yields these have been used without adjustment.

Input and output values for both seasons have been based on market prices pertaining to the first season. This has included cotton output prices and weeding costs (labour, draft animal power (DAP), and herbicide), whether they were household supplied or purchased. This is so, as the research is seeking recommendations on weeding rather than price levels and since benefits from one season were not carried into the next.

8.5 Results

8.5.1 Supplementary hand hoe weeding times and costs

8.5.1.1 Supplementary hand hoe weeding

Table 8.1 gives summation of the times taken to weed one hectare at 3, 6 and 9 wace weeding operations for each treatment.

Table 8.1: Total labour hours ha^{-1} per treatment for supplementary weeding for the mother and baby trials for the 2000-01 and 2001-02 seasons.

Treatment	Mother Trial		Baby Trials	
	2000-01	2001-02	2000-01	2001-02
OC,HH	193a	155a	196a	210a
OP+D,HH	169b	131b	170b	182b
OP-D,HH	191a	155a	204a	210a
Hca, OC,HH	96c	92c	114c	116c
Hca, OP+D,HH	81d	71d	93d	93d
Hca, OP-D, HH	97c	93c	113c	117c
Significance	P<0.05	P<0.05	P<0.05	P<0.05
SEDs	3	2	4	3

Means followed by the same letter in a column are not significantly different

For both the mother and baby trials the plots without the use of pre-emergence herbicide had higher supplementary hand weeding requirements than those that were applied with the banded pre-emergence herbicide. Amongst the weeding implements, OP+D had the least supplementary hand-weeding requirement while there were very small differences between OC and OP-D.

8.5.1.2 Supplementary weeding costs using the PMR

Table 8.2 shows the total weeding cost of each treatment, which is summation of each weeding at 3, 6 and 9 wace.

Table 8.2: Total costs per season in supplementary weeding in Z$ ha^{-1} for the mother and baby trials based on the prevailing market rates.

Treatment	Mother trial	Baby trials
	Cost of weeding (Z$/ha)	Cost of weeding (Z$/ha)
OC,HH	5250	5250
OP+D,HH	5250	5250
OP-D,HH	5250	5250
Hca, OC,HH	3500	3500
Hca, OP+D,HH	3500	3500
Hca, OP-D, HH	3500	3500

Each weeding costs was obtained by; cost of weeding one 70m row * 70 rows/ acre * 2.5 (to convert to one hectare). The PMR was $10 per 70m row of cotton where no herbicide were applied and $5 where pre-emergence herbicides were applied. Farmers in Muzarabani considered only two price levels depending on whether herbicides had been applied or not. For the portions without herbicide $10 was charged regardless of weed density. For the portions with herbicide weed density was very low but farmers still charged $5. These figures only applied at 3 and 6 wace for each season, while at 9 wace the rate for the non-herbicide portions was used for the areas where herbicides were used as the half-life of the herbicide is 6-8 weeks.

From table 8.2 for both the mother and baby trials the plots without the use of pre-emergence herbicide had higher supplementary hand weeding cost than those that were applied with the banded pre-emergence herbicide.

8.5.2 Total weeding costs (mechanical and chemical)

The total weeding costs include the cost of, hiring labour for supplementary hand weeding (three per season), hiring DAP for mechanical weeding (2 per season and see appendix 9), herbicide use where applicable, hiring labour for herbicide application and knapsack sprayer usage.

8.5.2.1 Total weeding costs using the PMR

Table 8.3 gives weeding costs for the mother-baby trials calculated based on the prevailing market rates in Muzarabani. Values for the mother trial were similar to those of the baby trials.

Table 8.3: Total weeding costs ha^{-1} per season based on the prevailing market prices.

	Labour Costs	DAP Costs	Herbicide Costs	Knapsack costs	Spraying Costs	Total costs
OC,HH	5250	2000	0	0	0	**7250**
OP+D,HH	5250	4000	0	0	0	**9250**
OP-D,HH	5250	4000	0	0	0	**9250**
Hca, OC,HH	3500	2000	272	175	50	**5997**
Hca, OP+D,HH	3500	4000	272	175	50	**7997**
Hca, OP-D,HH	3500	4000	272	175	50	**7997**

These figures pre-suppose that labour and draft animals are actually available where required, which in practice may not be the case. The DAP costs are derived from appendix 9 while the herbicide and knap sack sprayer costs are derived from appendix 10. The DAP costs are the summation of the cost of the first mechanical weeding at 3 wace and the second mechanical weeding at 6 wace. The cost of the knap sack sprayer are based on depreciation as calculated in appendix 10.

For both the mother and baby trials the plots without the use of pre-emergence herbicide had higher total weeding costs than those that were applied with the banded pre-emergence herbicide. The only exception was for OC, which had a lower total weeding costs when used without herbicide than OP+D or OP-D when used in conjunction with banded pre-emergence herbicides. Amongst the weeding implements, OC had the least total weeding costs requirement while there were no differences between OP+D and OP-D.

8.5.3 Cost benefit analysis for the mother trial

Table 8.4 shows the cost benefit analysis for the mother trial at Mfudzi School, comparing the method of land preparation and use of banded pre-emergence herbicide used in conjunction with animal powered mechanical weeding and hand hoe weeding (Z$ ha^{-1}), averaged over the three implements.

Table 8.4: Cost benefit analysis for the mother trial for 2000/01 and 2001/02 seasons based on the prevailing market rates.

2000/ 2001 season				2001/ 2002 season			
Increased Benefits		**Increased Costs**		**Increased Benefits**		**Increased Costs**	
Land preparation		***Land preparation***		***Land preparation***		***Land preparation***	
Increased yield kg/ha*				Increased yield kg/ha*			
(Winter + spring)[1]	734			(Winter + spring)[1]	131		
Value (Z$/ha)[3]	25	Cost of winter		Value (Z$/ha)	25	Cost of winter	
Income	**18 350**	ploughing per ha	**3750**	Income	**3275**	ploughing per ha	**3750**
Use of herbicide		***Materials***		***Use of herbicide***		***Materials***	
Increased yield (kg/ha)[2]	265	Herbicides cost[5]	272	Increased yield (kg/ha)[2]	117	Herbicides cost[5]	272
Value (Z$/ha)[3]	25	Maintenance sprayer cost[6]	175	Value (Z$/ha)[3]	25	Maintenance cost[6]	175
Income	**6 625**	*Sub-total*	**447**	Income	**2925**	*Sub-total*	**447**
Labour Saving[4]				***Labour Saving[4]***			
1st weeding	875	***Increased labour***		1st weeding	875	***Increased labour***	
2nd weeding	875	Spraying herbicide[7]	50	2nd weeding	875	Spraying herbicide[7]	50
3rd weeding	0			3rd weeding	0		
Sub-total	**1750**	*Sub-total*	**50**	*Sub-total*	**1750**	*Sub-total*	**50**
Total additional benefit	**27 725**		**4410**	**Total additional benefit**	**7 950**		**4410**
Net Benefit	**22 315**			**Net Benefit**	**3 540**		

Notes from table 8.4

[1]Difference in average yields between wp + sp and sp only (derived from table 7.4);

[2]Difference in average yields between portions with and without banded herbicide for averaged over the three weeding implements (derived from table 7.4);

[3]Price of cotton for the 2000/01 season. Obtained from Cotton Company of Zimbabwe;

[4]Labour saving;

[5]Cost of herbicide use per ha i.e Cynazine and Alachlor for the 2000/01 season ;

[6]Annual sprayer maintenance cost for the 2000/01 season ;

[7]Cost (labour) of spraying herbicide per ha for the 2000/01 season.

From table 8.4 there was an increase in cotton yield when winter ploughing was carried out in addition to spring ploughing (wp + sp). In the first and second seasons Z$18 350 and $3 275 respectively, per ha was realised as additional income arising from this practice. (During the research period Z$55 = 1US$). In the same seasons the additional cost incurred for wp was Z$3 750 per ha. There was a significant increase in yield (table 7.4) when the pre-emergence herbicides were used and the value of the increase in yield was far much higher than the extra cost incurred in the purchase of the herbicides and the cost of the use of a knapsack sprayer for both seasons.

Many man-hours of supplementary hand weeding were saved as a result of herbicide use. The amounts saved, as a result of limited weeding because of use of herbicide versus the extra labour required for the application of the herbicide was quite significant.

8.5.4 Partial budgets for the mother and baby trials

Partial budgets for the mother and baby trials are going to be discussed in the following sub sections. These reflect yields and supplementary weeding costs adjusted for significant differences (or not) in mean treatment and indicate the most appropriate weeding option provided there are no shortages of resources.

8.5.4.1 Partial budgets based on PMR

Tables 8.5 to 8.8 show partial budgets based on the PMR for supplementary hand weeding for the mother trial and baby trials for the 2000/01 and 2001/02 seasons.

Table 8.5: Partial budget analysis based on the PMR for the Mother trial for 2000-01 season.

	Benefits		Weeding costs	Benefit less costs	Analysis	Returns to labour
Treatments	Yields kg/ha	Value of yield Z$	Weeding* Labour (hrs ha^{-1})	Total Weeding ha^{-1} in Z$	Margin analysis Z$	Z$ /hr
OC, HH	2204	55100	193	7250	47850	247.93
OP+D, HH	2204	55100	169	9250	45850	271.30
OP-D, HH	2204	55100	191	9250	45850	240.55
Hca, OC, HH	2469	61725	96	5997	55728	580.50
Hca, OP+D, HH	2469	61725	81	7997	53728	663.31
Hca, OP-D, HH	2469	61725	97	7997	53728	553.90

Table 8.6: Partial budget analysis based on the PMR for the Mother trial for 2001-02 season.

	Benefits		Weeding costs	Benefit less costs	Analysis	Returns to labour
Treatments	Yields kg/ha	Value of yield Z$	Weeding Labour (hrs ha^{-1})	Total Weeding ha^{-1} in Z$	Margin analysis Z$	Z$ /hr
OC, HH	486	12150	155	7250	4900	31.60
OP+D, HH	486	12150	131	9250	2900	45.04
OP-D, HH	486	12150	155	9250	2900	18.71
Hca, OC, HH	603	15075	92	5997	9078	98.67
Hca, OP+D, HH	603	15075	71	7997	7078	99.69
Hca, OP-D, HH	603	15075	93	7997	7078	76.11

Table 8.7: Partial budget analysis based on the PMR for baby trials for 2000-01 season.

	Benefits		Weeding costs	Benefit less costs	Analysis	Returns to labour
Treatments	Yields kg/ha	Value of yield Z$	Weeding Labour (hrs ha^{-1})	Total Weeding ha^{-1} in Z$	Margin analysis Z$	Z$ /hr
OC, HH	1922	48050	196	7250	40800	208.16
OP+D, HH	1922	48050	170	9250	38800	228.24
OP-D, HH	1922	48050	204	9250	38800	190.20
Hca, OC, HH	1922	48050	114	5997	42053	368.89
Hca, OP+D, HH	1922	48050	93	7997	40053	430.68
Hca, OP-D, HH	1922	48050	113	7997	40053	354.45

Table 8.8: Partial budget analysis based on the PMR for baby trials for 2001-02 season.

	Benefits		Weeding costs	Benefit less costs	Analysis	Returns to labour
Treatment	Yields kg/ha	Value of yield Z$	Weeding Labour (hrs ha^{-1})	Total Weeding ha^{-1} in Z$	Margin analysis Z$	Z$ /hr
OC, HH	968	24200	210	7250	16950	80.71
OP+D, HH	968	24200	182	9250	14950	82.14
OP-D, HH	968	24200	210	9250	14950	71.19
Hca, OC, HH	968	24200	116	5997	18303	156.92
Hca, OP+D, HH	968	24200	93	7997	16203	174.23
Hca, OP-D, HH	968	24200	117	7997	16203	138.49

For the mother trial in the two seasons, there were significant differences between herbicide treatments and non-herbicide treatments while there were no significant differences in yields between the individual weeding implements in the same category (table 8.5 and 8.6). As a result the values for herbicide treatments were averaged and the same done to non-herbicide treatments.

From the tables 8.7 and 8.8, the values for the cotton yield for the 2000/01 and 2001/02 seasons for the baby trials are similar, as there was no significant variation in yield. Herbicide treatments had, shorter times for supplementary weeding as a result of low weed density compared to no-herbicide treatments, and hence lower weeding costs.

8.6 Discussions

8.6.1 Supplementary hand hoe weeding times and costs

8.6.1.1 Supplementary hand hoe weeding

The use of OP +D as weeding implement resulted in soil inversion and the soil being thrown over the crop row, thus covering the weeds and smothering them at the same time resulting in lower weed density. As a result OP + D required lesser time for supplementary hand weeding than OC and OP – D.

Times spent weeding plots with pre-emergence herbicides were low as a result of low weed densities due to the effect of the herbicide. The differences were more significant for the first and second weeding at 3 and 6 wace as the half-life of the cynazine/alachlor mix is 6 -8 weeks.

8.6.1.2 Supplementary hand weeding costs using the PMR

The charge by farmers for supplementary hand weeding in plots without banded pre-emergence herbicides was higher than that of plots with pre-emergence herbicide. Farmers based their charges on weed density and only used two charge levels, one for plots with pre-emergence herbicide where weed density was lower and another for plots without pre-emergence herbicides where weed density was higher. The charge for the plots without the herbicide was double, for the first and second weeding that of plots with the herbicide while the charge was the same for all plots for the third weeding.

Farmers used the charges regardless of the weeding implement as they only considered whether pre-emergence herbicides had been used or not and did not consider the weeding implement. As a result there were not variation with this method between implements.

8.6.2 Total weeding costs (mechanical and chemical)

Plots with pre-emergence herbicides generally had lower total weeding costs as they had lower supplementary hand weeding cost because of the herbicide that suppresses weeds resulting in a lower weed density. Exception is for the OC without the herbicide that had lower weeding costs than OP+D or OP-D with herbicides. The cost of, herbicide, use of knapsack sprayer, and hiring labour for spraying herbicide, was far much lower than the additional cost of supplementary hand weeding in plots without the herbicide.

OC had the lowest total weeding cost as a result of lower DAP cost. When using OC, farmers charged half the cost of mechanical weeding with OP+D or OP-D as two passes were made between rows when the later implements were used compared to one pass for OC as it has a wider operational width of 60cm. OP+D and OP-D had narrower operational widths of between 22cm and 28cm. The difference between the DAP costs of OC and OP+D was far much higher than the difference in supplementary hand weeding costs between the 2 implements (OP+D had a lower supplementary hand weeding cost). The difference in costs in mechanical weeding with OC is so big that its total weeding costs without the herbicide is lower than of OP+D and OP-D when used in conjunction with pre-emergence herbicides.

8.6.3 Cost benefit analysis for the mother trial

From Table 8.4 in a good season (2000/01) with a favourable rainfall pattern of at least 450mm distributed over 4 months the additional cost incurred in wp was offset by the increase in cotton yield associated with ploughing, first in winter and later in spring after the first rains.

In a bad season (2001/02) with an unfavourable rainfall pattern, (though 540mm were received the rains were only distributed over 2 ½ months) the converse was true, the benefit derived from additional wp were lower than the extra cost of wp. When only considering the cost of land preparation it is not recommended to carry out wp as the net benefit is negative.

The monetary value increase in cotton yield as a result of herbicide use was $6 625 and $2925 per ha for the first and second seasons respectively. During the same period the cost of the herbicide per ha plus the maintenance cost per ha of using a knapsack sprayer for the herbicide was $447. The critical period of weeding cotton is up to 10 wace and during this period the plots with the pre-emergence herbicides were not overwhelmed by weeds. The crop grew faster, was taller, had more cotton balls per plant and hence higher yield (table 7.3)

The amount saved per ha as a result of labour savings because of the use of herbicides was $1750. This figure easily offset the extra cost incurred in spraying the herbicide per ha, which was $50.

Consequently the total net benefit of using additional wp in conjunction with mechanical weeding and banded pre-emergence herbicide was quite significant for the two seasons. At mid-season evaluations, farmers indicated a preference for use of banded herbicides, firstly in conjunction with the cultivator, secondly using the plough minus mould board and thirdly using the plough with mould board attached (Ellis-Jones *et al*., 2001b). The total net benefit of using additional wp in conjunction with mechanical weeding and banded pre-emergence herbicide was drastically reduced in the second season as a result of poor rainfall distribution.

8.6.4 Partial budgets for the mother-baby trials

8.6.4.1 Based on P MR in Muzarabani

From tables 8.5 to 8.8 the cost of mechanical weeding, supplementary hand weeding and the cost of herbicides and use of knapsack sprayer could only be influenced by the lowest cost weeding option that would give the highest productivity. (Considering the worst scenario of similar yield output). In each of the herbicide and non-herbicide group of implements the OC gave the least DAP weeding costs compared to the use of OP+D and OP-D, which were double. Consequently Hca, OC, HH had the least total weeding cost option. OC with a banded herbicide application Hca, OC, HH, therefore, gave the greatest productivity or the least cost weeding option. Consequently Hca, OC, HH gave the highest gross margin for both seasons.

The highest return to labour was influenced by the option with the least supplementary hand weeding costs. And this was given by OP+D as a result of its ability to cut and invert the soil throwing it over the weeds and thus smothering them and reducing weed density. Even less supplementary hand weeding was required when OP + D was integrated with pre-emergence herbicide band application of cynazine and alachlor. Therefore Hca, OP+D, HH gave the highest returns to labour or the weeding option with the least supplementary hand weeding requirements in both seasons.

8.7 Conclusions

There was a marked increase in cotton yield when wp + sp was carried out and this was as a result of lower weed densities which help reduce weed burden especially early in the season when there are labour bottlenecks. Lower weed densities lead to a better crop stand with more cotton balls per plant and hence higher yield. In a good season with a favourable rainfall pattern, it is recommended to carry out wp + sp as the additional cost incurred in wp is easily offset by the increase in cotton yield. In a season with unfavourable rainfall pattern, when only considering costs (ignoring draft force requirements, field efficiency and supplementary weeding requirements) the net benefit of carrying out wp is lower than the extra cost of wp.

From chapter 5 it was concluded that the use of the ox cultivator as a weeding implement resulted in the highest work rates as one pass per row is required. As a result of high work rates the cost of DAP for mechanical weeding is lowest giving the lowest cost weeding option with the highest productivity. The mould board plough has a high weeding efficiency resulting in the least time required for supplementary hand weeding and hence giving the highest returns to labour. The use of pre-emergence herbicides in conjunction with mechanical weeding is effective resulting in a significantly reduced weed burden and reduced times taken for supplementary handing weeding. The economic analysis also show that the benefit of herbicide use will always offset the costs associated with the use of herbicides, though a sensitivity analysis needs to be carried out.

But for farmers to make a decision it will depend on the possible farmers' objectives (Table 8.9). If the farmer wants to maximise yields, there is very little difference to choose between weeding methods except to consider land preparation i.e. wp + sp or consider pre-emergence herbicide application. Where labour is limiting Hca, OP+D, HH should be considered. Lowest overall weeding cost (labour and herbicide) and greatest productivity is achieved with Hca, OC, HH. Highest returns to labour are given by Hca, OP+D, HH.

Table 8.9: Weeding option most appropriate to farmers' objective.

	2000-01 Favourable rainfall pattern	2001-02 unfavourable rainfall pattern
Highest production	Hca, OC, HH	Hca, OC, HH
Lowest Labour	Hca, OP+D, HH	Hca, OP+D, HH
Lowest cash investment	OC, HH	OC, HH
Highest returns to labour	Hca, OP+D, HH	Hca, OP+D, HH
Lowest risk	OC, HH	OC, HH

The strategy best adapted is dependent on the household resources available (appendix 1). Resource categories RG1s who have the greatest access to resources, have therefore the largest number of options from which to choose. RG2s with limited labour, but no shortage of DAP are likely to choose OC, HH. Those with limited DAP in RG2s and RG3s should consider using a herbicide with an ox plough. RG4s with limited labour and DAP need to consider the use of a herbicide either as a overall application or banding either between rows or along rows with supplementary hand hoe weeding.

9. GENERAL DISCUSSIONS, CONCLUSIONS, RECOMMENDATIONS AND SUGGESTIONS FOR FUTURE STUDY.

9.1 General discussions

9.1.1 The condition, use and repair of weeding implements in Muzarabani district

The condition of most ploughs and cultivators (at least 70%) was average to good as most were relatively knew with an average age of less than 6 years. Parts like frogs, draw bar hitch assembly, u-piece and screw, u-clamp, handles and stays in ploughs and most parts in cultivators were rarely replaced. Most smallholder farmers did not understand the functions of some plough and cultivator parts. Parts like regulator hakes and the hitch assembly were removed to make the plough lighter according to farmer beliefs. Improperly adjusted regulator hakes are the main source of excessive wheel and axle wears and unnecessary tiring of animals when the wheel sinks in the soil increasing the plough draft requirements and fatigue on the operator. The same scenario was also observed with cultivators. Most farmers removed the two front tines of cultivators leaving behind three tines so as to reduce the draft power requirements. Farmers did not know that cultivators needed to be set in order to meet the different soil and weed conditions. Information gathered from the survey showed that most cultivators wore out competely without having been adjusted since procurement. Depth regulators were never adjusted, and the spare part set of hillers normally bought attached to the frame was also never used.

Most of the information on implement use, repair and maintenance flowed from father to child (about 40%) or family member to family member (about 45%). Since most farmers (about 80%) had not received training they passed on to others information they believed was correct without verification. This included removal of the hitch assembly and adjusting depth using the wheel and wheel arms for ploughs and the non-adjustment for depth in cultivators. However, should AREX intensify its training on farm mechanisation there is scope for an increase in farmer knowledge on the use, setting and maintenance of ploughs and cultivators. This is evidenced by the fact that about 35% of farmers received formal and informal training resulting in close to 30% of them setting they implements properly.

9.1.2 Effects of winter and spring ploughing

This study revealed that the practice of wp + sp resulted in significantly ($P<0.05$) lower draft force requirements than sp only. In the work done in Muzarabani it was found out that with an average span of two oxen with a body weight of 285kg all the implements could be comfortably used on wp + sp land for weeding without straining the animals. When sp only was practised the draft force requirements for pulling a cultivator using a span of oxen with an individual body weight of 285kg was in both seasons higher than 12% of the body weight of draft animals (the recommended one is 10-12%). This means that the level of draft force required to pull the cultivator using an average span of oxen in Muzarabani district strained the animals. Considering that the live weight of 285kg was an average, for farmers with a span of cows with an average live weight of 225kg (see appendix 6) the draft capacity of the animals to pull an ox cultivator (OC) was as high as 17%. Therefore, for a farmer to comfortably use his span of oxen to pull a 5-tine cultivator, he needs to consider wp + sp.

Results also show that work rates were significantly increased ($P<0.05$) by 20% and field efficiency (FE) significantly increased ($P<0.05$) by more than 10% at 3 wace (first) weeding operation when wp + sp operations were performed. Work rates were 12 hrs ha^{-1} when wp + sp was done compared to 10 hrs ha^{-1} sp only. FEs was increased by more than 10% from 70% from sp only to wp + sp. This then enabled the weeding operations to be completed in a shorter time. One major limitation to cotton production is the disproportionate times spent in hand weeding; this is reduced by 30% when wp + sp is practised.

It also emerged that better soil moisture retention was achieved when wp + sp was practised. The practice loosens soil, encourages infiltration and this also reduces soil penetration resistance by implements. Winter ploughing conserves any residual moisture in the soil for the next season. This factor is important to the Zambezi valley, which generally does not receive good rains. Another important fact is that winter ploughing is performed when the draft animals are strong so a depth of 15 - 20cm is achievable and this can be followed by shallow ploughing in spring of 10-15cm after the first rains when the condition of animals will be poor.

Wp + sp resulted in significantly lower ($P<0.05$) weed densities compared to sp only for the period up to 6 wace. During this period the wp + sp portions had 27% lower number of weeds per m^2 than the sp only portions. Lower weed densities helped reduce the weed burden especially early in the season when there were labour bottlenecks. The lower weed densities led to a better crop stand with more cotton balls per plant and hence higher yield.

9.1.3 Implement performance

The ox cultivator (OC) required fewer hours (6 hrs ha^{-1}) to carry out weeding operations compared to the two plough options of ox plough with (OP+D) or without (OP-D) the mould board attached. Its use further gave higher FEs of up to 90% but the draft force requirements were significantly higher ($P<0.001$) than the two plough options. During the trials the draft force requirements were found to be in excess of 0.7kN, which then gave draft capabilities of more than 12%. According to Goe, (1983) this deems the implement heavy for the DAP. It then follows that the use of OC is only effective where there is sufficient draft. Another limitation derived from the study is that the weeding efficiency of the OC is significantly less ($P<0.001$) than the OP + D, as demonstrated by both the additional time required for supplementary hand weeding and higher weed density. When OC was used for weeding the time required for supplementary hand weeding on one hectare was about 56 hours on average, compared with about 40 hrs for OP+D.

Weeding with the OP + D significantly ($P<0.001$) increased moisture retention compared to the OC and the OP - D. The greater degree and depth of disturbance afforded by the plough created a soil surface, which was more receptive to rainfall, similar to the ridge and furrow landform. This attribute is especially important during drought seasons, as in the 2001/02 year, and will have likely contributed to the significantly higher cotton yield achieved under the OP+D compared to OC and OP-D. However, caution should be exercised in promoting and using this technique, to ensure that the risk of soil erosion from the increase in soil disturbance is minimised. This can be achieved by making sure that planting is carried out along the contour. The draft force requirements were significantly ($P<0.001$) less than OC requiring less than 0.6kN for either of the plough options. This figure was found to be within the draft capabilities of all the span of DAP animals that were used in this study. The major limitation of use of the plough options are the low FEs of about 60% and the low work rates of more than 10 hrs ha^{-1} as a result of the number of passes made between rows. Despite the lower FE and lower work rate the plough represent a viable tool with which to carry out weeding inter-row.

9.1.4 Plant performance

The results from the on-station trial corroborate those from the on-farm weeding trials, highlighting the advantage to be gained in applying herbicide to the cotton crop. The introduction of banded pre-emergence herbicides (cynazine and alachlor) resulted in a significantly ($P<0.001$) reduced weed burden and supplementary hand-weeding requirement.

The weed densities were reduced by 60% while supplementary hand weeding requirements were reduced from 64 hrs ha^{-1} to 21 hrs ha^{-1}. Time saved in weeding can be used for other purposes that might better the lives of farmers.

The banded pre-emergence herbicide applied along the crop row suppressed weeds for 6-8 weeks and thus drastically reducing times needed for supplementary hand weeding along crop row. From the mother trial the suppression of weeds during this period allowed the cotton plants to grow significantly ($P<0.001$) taller and producing significantly ($P<0.05$) more balls per plant. This then translated to significantly higher ($P<0.05$) cotton yield under the herbicide treated plots. In the first season cotton yield increased by 9% (265kg ha^{-1}) while in the second it increased by 14% (117 $kgha^{-1}$). (The first season was characterised by good rains while the second was a complete opposite).

There was little difference between using the open plough furrow planting technique and the ripper tine for crop establishment for the variety of parameters looked at. Where significant differences did occur, they were inconsistent, either through the season or between years.

9.1.5 Economic analysis

There was a marked increase in cotton yield when wp + sp was carried out. In the first and second seasons Z$18 350 ha^{-1} and $3 275 ha^{-1} respectively were realised as additional income arising from this practice. During the period of research Z$55 = US$1. In the same seasons the additional cost of winter ploughing was Z$3 750 ha^{-1}. Therefore, in good season with a favourable rainfall pattern the additional cost incurred in winter ploughing was offset by the increase in cotton yield associated with double ploughing. While in bad season with a unfavourable rainfall pattern the additional cost incurred in winter ploughing was higher than the increase in cotton yield associated with double ploughing.

The economic analyses also revealed that the benefit of herbicide use would always offset the costs associated with the use of herbicides, though sensitivity analyses need to be carried out. The monetary value increase in cotton yield as a result of herbicide use was $6 625 ha^{-1} and $2 925 ha^{-1} for the first and second seasons respectively. During the same periods the total cost of the herbicide use (herbicide and sprayer maintenance) were $ 447 ha^{-1}.

In both seasons OP + D required the least amount of time for supplementary hand weeding as a result of its ability to cut and invert the soil throwing it over the weeds and thus smothering them and reducing weed density. This translated into the least supplementary hand weeding costs for OP + D. Herbicide treatments had shorter times for supplementary weeding when compared to the non-herbicide treatments, and hence lower weeding costs. From this fact the highest returns to labour were given by OP + D with a banded herbicide application, Hca, OP+D, HH. For the baby trials the returns to labour were \$430.68 hr^{-1} and \$174.23 hr^{-1} for the 2000/01 and 2001/02 seasons respectively. The values per hour were \$368.89 and \$354.45 for the first season and \$156.92 and \$138.49 for the second season for Hca, OC, HH and Hca, OP-D, HH respectively.

In the herbicide and non-herbicide group of treatments the OC gave the least total weeding cost option as a result of the cheaper cost of mechanical weeding compared to the use of OP+D and OP-D which is double. Total weeding costs consisted of DAP mechanical weeding cost, herbicide cost and supplementary weeding cost. As a result OC with a banded herbicide application Hca, OC, HH gave the greatest productivity or the least cost weeding option. The total weeding costs per ha for Hca, OC, HH was \$5 997 compared to \$7 997 each for the 2 plough options. The highest gross margin was therefore, given by Hca, OC, HH as it had the lowest total weeding cost.

9.2 Conclusions

The condition of most ploughs and cultivators was average to good. From the survey it is concluded that farmers did not understand functions of some parts as revealed by them removing them to make the implement lighter. The hitch assembly (regulator) was removed from most ploughs while the two front tines were removed from cultivators to make the implements lighter. The removal of the regulator from ploughs indicates that farmers are not setting their ploughs properly. Farmers use the wheel and axle for depth adjustment and widen or shorten the frog for width adjustment. In cultivators most farmers knew how to adjust the width of operation while very few farmers ever adjusted the depth of cut.

There has not been a deliberate attempt by the extension wing to train farmers on the correct use and maintenance of implements as this has been left to farmers to pass information amongst themselves either from father to child or between family members. For the situation to improve AREX has to re-introduce on a larger scale the master farmer training courses. The courses are to include the use, setting and maintenance of ploughs and cultivators.

This study has clearly demonstrated that ploughing land in winter followed by spring ploughing is an effective technique compared to the spring ploughing only for a number of reasons as:

- it reduces subsequent draft force requirements at weeding;
- the work rates are increased during weeding, meaning that the operation can be carried out in a shorter time availing time for other on or off farm activities;
- it helps to reduce the weed burden, particularly during the early part of the season and this reduces labour bottlenecks;
- it improves soil moisture levels throughout the season, particularly important during drought periods as were experienced in the second season;
- it results in higher yields;

However, the main limitation with winter ploughing is that it is only appropriate following maize or groundnut crop rather than a cotton crop, since harvests of the latter are usually not completed until July/August. In Muzarabani, 40 - 55% of land is dedicated to cotton alone. Cutting and burning of cotton stalks is completed by mid-September. By this time, the animals will be in a poorer condition and the soils will be drier, therefore it is difficult for animals to carry out any ploughing operations. Therefore winter followed by spring ploughing is a viable option only for half the farmers in Muzarabani.

From the study it was clearly shown that when only considering implement performance under limited draft force, the best results are achieved when OP + D is used under wp + sp. It gives lower draft force requirements, which are within the draft capabilities of most draft animals in Muzarabani. Its ability to cut and invert the soil resulting in higher soil moisture conservation was an additional advantage. This is despite its lower work rates compared to the other implements. This information is important to the ministry of lands and agriculture to provide recommendations for the design specifications to the manufacturing industry. The BS-5 tine cultivator, for example, is no longer suitable for the smaller DAP animals that are available in the communal areas except when used under wp + sp.

For farmers to make a decision on the best weeding option it will depend on the possible farmers' objectives. If the farmer wants to maximise yields, there is very little difference to choose between three weeding implements except to consider land preparation i.e. wp + sp or consider pre-emergence herbicide application. Where draft power and labour are available OC is the best option. For farmers with limited draft power the two plough options can be chosen.

Where labour for supplementary hand weeding along the crop row is limiting OP+D, should be considered. When the farmer wants to obtain the highest returns to labour, Hca, OP+D, HH is the choice. Lowest overall weeding cost (labour and herbicide) and greatest productivity is achieved with Hca, OC, HH.

The strategy best adapted is dependent on the household resources available. Resource categories RG1s who have the greatest access to resources, have therefore the largest number of options from which to choose. RG2s with limited labour, but no shortage of DAP are likely to choose HH, OC, HH and/or OC, HH. Those with limited DAP in RG2s and RG3s should consider using a herbicide with an ox plough. RG4s with limited labour and DAP need to consider the use of herbicides either as overall application or banding either between rows or along rows with supplementary hand hoe weeding.

9.3 Recommendations

- Farmers lack knowledge on the proper setting and correct use of ploughs and cultivators as a result of limited extension services. Farmers, therefore, require training in the proper use, repair, maintenance and storage of tillage implements. Production of pictorial materials, which show how implements are set, maintained and stored would be useful, as not all farmers are literate. Farmers require good and reliable supply of spares for their equipment, which, are very close to their homes.
- Farmers in Muzarabani need to practice crop rotation of maize, groundnuts and cotton among other reasons and to afford winter ploughing. As long as cotton occupies a bigger acreage the benefits of winter ploughing cannot be fully exploited. Crop rotation will also ensure that farmers have enough land available to grow maize crop, their staple food. Introduction of groundnuts would be agronomically important, as they are bio-nitrogen fixers. Again of late the price of groundnuts is lucrative.
- Despite the fact that the ox plough with the mould board attached gave many advantages as a weeding implement if applied to weed cotton at 3 wace it tends to bury the cotton. It would be useful for farmers with mould board ploughs only to remove the mould board of the plough at 3 wace and use the share as the operational blade. Once the cotton is tall and strong at 6 wace replace the mould board to exploit its moisture conservation properties.
- Ploughing in winter and in spring after the first rains was done at the same depth of 15-20cm. It would be interesting to try shallower ploughing after the first rains at 10-15cm in spring after winter ploughing at 15-20cm to ascertain whether the various variables would

be affected. Shallow ploughing would be appropriate, as the condition of animals is poor at the start of the season.

- Crop establishment by use of a ripper can also reduce draft force requirements at planting at the same time achieving a deeper depth of planting. This could help in destroying the plough pan usually found at the 15-20cm depth, thus allowing shallow plough depths during spring.

9.4 Suggestions for further study

The study only focused on the three weeding implements, namely, ox plough with/without the mould board attached and the ox cultivator. A more comprehensive study considering other weeding implements like the 3 tine cultivator, cultivators with hillers etc would be needed in order to get a clearer picture of draft force requirements of weeding implements visa- viz. animal sizes. Again conclusions are based on draft force requirements for the three implements used under the siallitic soils of Muzarabani, it would be important to consider soils in other areas. The factors to be considered are:

- Determining draft force requirements, during winter ploughing at a depth of 15-20cm and after the first rains (spring ploughing) at 10-15cm and compare them to spring ploughing only after the first rains at 15-20cm.
- Determining the draft force requirements at crop establishment level between open plough furrow planting and ripping and how the two methods affect germination percentages.
- Assessing how simple opening the planting furrow after the first rains (winter ploughing earlier on) with/without pre-planting herbicide use affect draft force requirements, germination percentages, weed densities and cotton yield.

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Appendix 1: Characteristics of households in four resource categories in Muzarabani (n=149)

	RG1 (n=39)	RG2 (n=44)	RG3 (n=34)	RG4 (n=33)
% of farmers in each category	26	29	23	22
% of male Head of Household	82	75	88	82
Predominant age group	56-<65	36-45	25-35	25-35
Average Household size	10.9	9.7	8.4	6.4
% belonging to groups	47	46	29	25
Average income levels (Z$, 2000)	39000	20225	14577	4235
Main sources of income	Cotton	Cotton	Cotton	Cotton
In order of importance	Maize	groundnuts	Maize	Maize
	Cattle	Maize	G/nuts	Working locally
	Goats	Gardens	Poultry	Buying & Selling
Livestock **(**head per household)				
Cattle	19	8	3	0
Donkeys	1	0	0	0
Goats and sheep	10	6	4	1
Implements (Number per household)				
Plough	2	1	1	1
Cultivator	2	1	0	0
Scotch cart	1	1	0	0
Arable area cropped (ha)				
Cotton	3.3	2.2	1.7	1.2
Maize	1.5	1.6	0.9	0.8
Groundnuts	0.5	0.5	0.3	0.2
Other crop	0.2	0.1	0.2	0.0
Fallow	0.5	0.5	0.5	0.6
Average crop yields per ha				
Cotton (bales-250 kg)	6	5	5	3
Maize (50 kg bags per acre)	21	12	18	14
Groundnuts (bags per acre)	33	29	19	21
Total crop sales (Z$)	89605	43196	27490	11428
Cash expenditure on crop inputs	11853	7003	43784	2188

Adopted from Ellis-Jones *et al,* 2001

Appendix 2: Main problematic weeds in Muzarabani district classified as grass or broad leaf.

Weed Species (Broad Leaf Weed)	Weed Species (Grass Weed)
Vernonia poskeana (Pisaimba)	*Eragrostis aspera*
Borerria scabra (Chidzungu)	*Rottobolia cochinensis (Barahanga)*
Trichodesma zeylanicum (Goso)	*Panicum maximum*
Ocimum canum (Chinhuwenhuwe)	*Urochloa panicoides*
Sphaeranthus flexuosus (Demu or Pemu)	
Celosia trigyna	
Ceratotheca sesamoides	
Corchorus olitorius (Derere)	
Boerhavia erecta (Chigwande)	
Bidens pilosa	

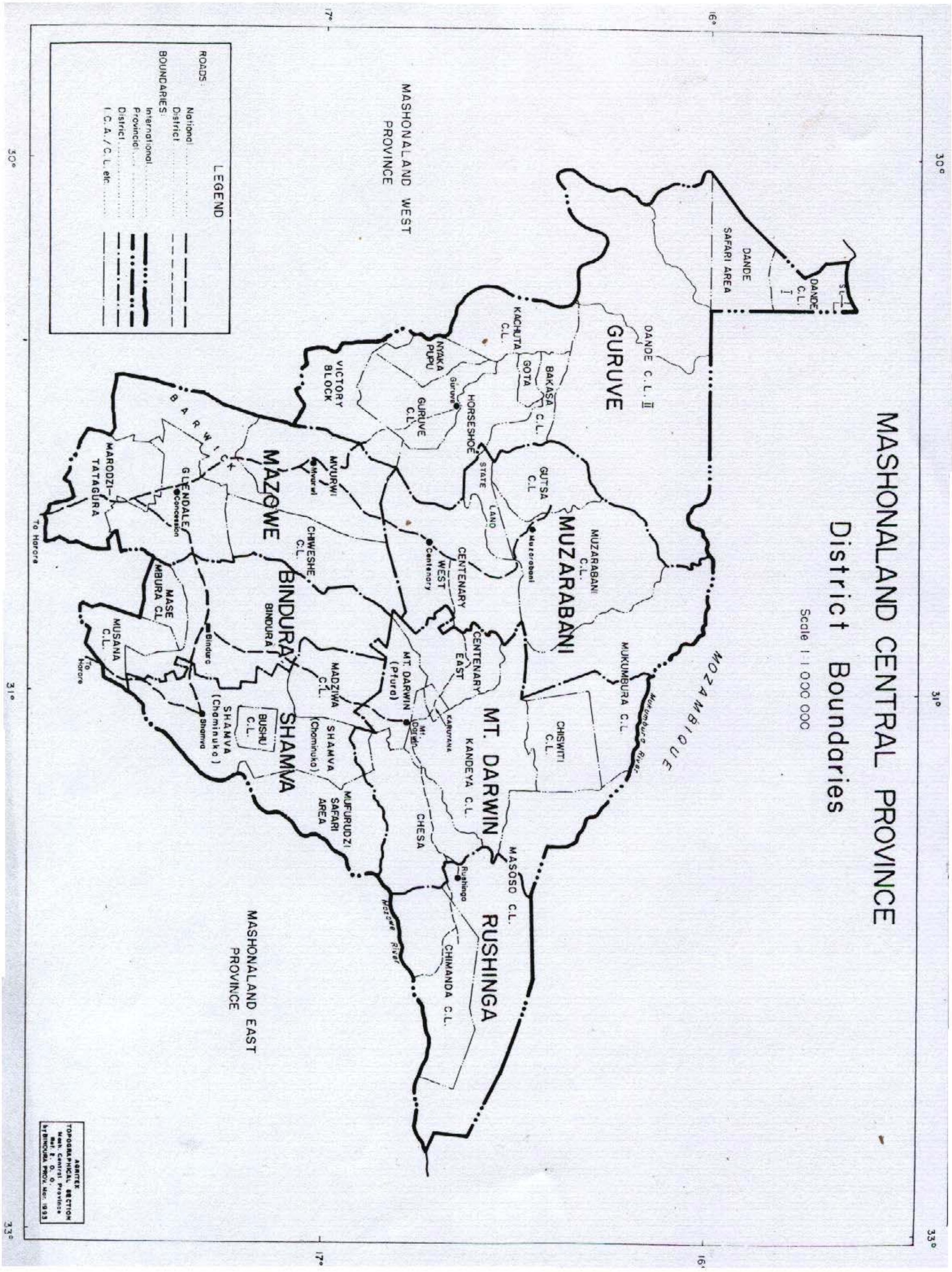
Source: Ellis-Jones *et al.,* 2001.

Appendix 3: Populations of draft animals in selected Sub-Saharan African countries

Country	**Cattle**	**Donkeys**
Mali	300 000	150 000
Niger	18 000	10 000
Ghana	20 000	1 000
Angola	300 000	5 000
Cameroon	55 000	40 000
Ethiopia	6 000 000	5 500 000
Tanzania	840 000	220 000
Kenya	700 000	-
Botswana	355 000	140 000
Lesotho	180 000	105 000
Zambia	240 000	-
South Africa	500 000	300 000
Zimbabwe	850 000	325 000

Sources: Goe (1989); Prasad *et al.* (1991);

Appendix 4a: Map for Mashonaland Central Province

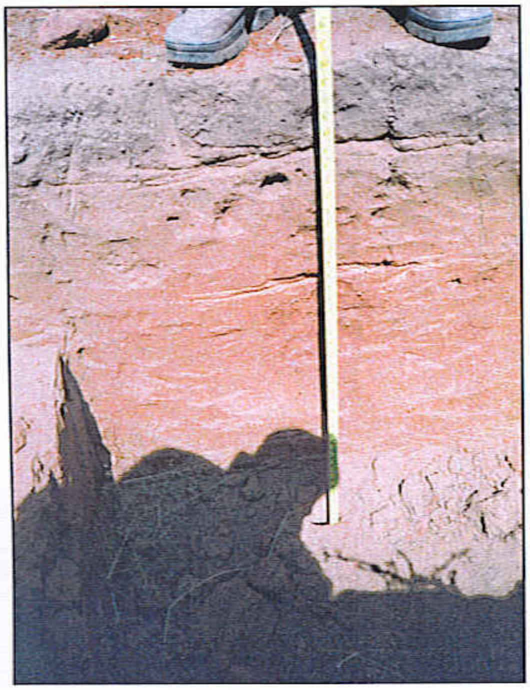


Appendix 4b: Pit soil profile for Muzarabani district

Profiles 16 – 21, Muringazuva

Site 16: Oliver Emanual

Site 17: Mutomba



Site 18: Diza

Site 19: Mushinye

Appendix 5: Questionnaire on the assessment of the condition of weeding implements in Muzarabani district.

Appendix 6: Average weight of 44 DAP Animals in Muzarabani district.

Farmer	**Sex** (animal)	**Mass (kg)** (animal)
Mr. Mutangi	M	400
	M	405
Mrs Mapfumo	M	340
	M	320
Mr. Magetsi	M	350
	M	320
Mrs Madzivanzira	F	220
	F	225
Mr. Sitoro	F	225
	F	220
Mr. Bhokisi	M	250
	F	235
Mr. Mutomba	M	320
	M	290
Mr. Mahwenda	M	250
	F	225
Mr. Emmanuel	M	220
	M	235
Mr. Reeds	F	240
	F	245
Mr. Mushinye	M	290
	M	330
Mr. Diza	M	350
	M	335
Mr. Magwenzi	M	300
	M	310
Mrs. Dundundu	M	285
	M	300
Mr. Soka Snr.	M	325
	M	345
Mr. Soka Jnr.	M	355
	M	345
Mr. Mhungu	M	335
	M	340
Mr. Bete	F	230
	M	220
Mr. Sibanda	M	240
	F	235
Mr. Chibooka	M	265
	M	280
Mr. Kambuzuma	M	265
	M	260
Mr. Chisasa	M	255
	F	230
Average Weight		**285.45**

Appendix 7: Calculation of moisture content from theta probe readings

To determine which implement was effective in soil moisture conservation a theta probe and core cylinder were used. A Theta probe is a 3-pronged instrument that is inserted through the ground and translates the mineral content of the soil in a formula to moisture content. A theta probe measures in units of m^3/m^3. A core cylinder is a cylinder open at both ends with a volume of $200cm^3$. It is inserted in the station where the theta probe was inserted and is pushed through the ground by firmly exerting a uniform force on its upward end either using a flat object or ones foot. These 2 readings are used to determine volumetric moisture content

Moisture content was calculated using the following method:

Mass of wet soil M_w = Total mass of soil + mass of core cylinder (M_t)- mass of core cylinder (M_c)

Mass of dry soil M_d = M_w - (Theta probe reading * core cylinder volume cm^3)

= $M_w - (T_r * M_c)$

% Moisture content = $\frac{M_w - M_d}{M_d} * 100$

Appendix 8: Conversion factor of penetrometer readings to shear strength.

Considering 1 kg Force and a penetrometer with a cone of diameter 12.83mm.

F = M * A,

where F = Force, N; M = mass, kg; A = acceleration, m/s^2;

A = G, where G = acceleration due to gravity = 9.8 m/s^2

Therefore Force = 1 kg * 9.81 m/s^2 = = 9.81 kgm/s^2 = 9.81 N

P = F/A where P = pressure, N/m^2 ; A= area, m^2;

Pressure $= \frac{9.81 \text{ kg m/s}^2 * 4}{(3.142 * 0.01283^2) \text{ m}^2}$ = 75 870 N/m^2 = 75.87 kN/m^2 = 75.87 Kpa

Appendix 9: Cost of hiring draft animal power for mechanical weeding

Mechanical weeding was performed twice per season at 3 and 6 wace. The DAP weeding costs were based on 2000-01 market prices for undertaking contract-weeding work. Where households supplied DAP was used, this has also been costed at contract prices.

Cost of hiring draft animal power, (Z$), for mechanical weeding

Implement	Cost/weeding Per ha	Cost/ season Per ha
Ox Cultivator	1000	2000
Ox plough (-dish)	2000	4000
Ox plough (+dish)	2000	4000

Appendix 10: Cost of pre –emergence herbicide

Cynazine and Alachlor prices (Z$) when used as pre-emergence herbicide in cotton.

Item	Rate (litre/ha)	Cost / litre	Full application	Band application
Cynazine	1.1	415	457	152
Alachlor	2	180	360	120
Knapsack			175	175

Total annual cost/ha of the November 2000 knapsack sprayer is $350. Calculation for the use of sprayer are shown below.

For the year 2000

Price of knapsack sprayer price in November 2000 = $3 500

Life span of knap sack sprayer = 5 years

Annual cost or depreciation = $\frac{\$\ 3500}{5\ \text{years}}$ = **$700**

Interest rate of 20%, the amount chargeable sprayer = $3 500 * 0.2 = **$ 700**.

Annual maintenance cost of sprayer (10% purchase price) = $ 3 500 * 0.1 **= $ 350**

Therefore, the total annual costs of the sprayer = $700 + $700 + $350 **= $1 750**

Total annual cost/ha of (most fields are or 5 ha) = $\frac{\$1\ 750}{5}$ = **<u>$350</u>**