CROP PROTECTION PROGRAMME

Weed management options for cotton-based systems of the Zambezi valley

R7474 (ZA 0339)

FINAL TECHNICAL REPORT

Start and End dates
(October 1999 to December 2002)

Project Leaders
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Acronyms

AREX	Department of Agricultural Research and Extension
AGRITEX	Former Department Agricultural Extension
BPGs	Best practice guidelines
COTTCO	Cotton Company of Zimbabwe
CPP	Crop Protection Programme
DRSS	Former Department of Research and Specialist Services
DAP	Draft animal power
FAO	Food and Agriculture Organisation of the United Nations
OPV	Open pollinated varieties
NGO	Non Government Organisation
NRI	Natural Resources Institute
SRI	Silsoe Research Institute
UZ	University of Zimbabwe
wace	weeks after crop establishment
WAE	weeks after establishment

The currency used in this report is Zimbabwe dollars (Z$). Current exchange rates are:

Official	**Parallel market**
US $1=Z$ 55	US $1=Z$ 600
£ 1=Z$ 88	£1=Z$ 1500

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FINAL TECHNICAL REPORT

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CONTENTS

EXECUTIVE SUMMARY

A very brief summary of the purpose of the project the research activities, the outputs of the project and the contribution of the project towards DFID's development goals. (Up to 500 words).

Project Purpose:
Integrated cotton pest management needs assessed, and strategies developed and promoted.

Outputs and activities

Understanding of the impact of weeds in cotton-maize production systems and of the opportunities for and constraints to improved weed management.

An initial planning meeting with project partners and stakeholders clarified issues relating to cotton production and a detailed programme for the project to be finalised. This centred on communal farming areas in the Zambezi Valley. Community workshops reinforced with a formal survey provided detailed information on farmers' livelihoods, knowledge and practices in cotton production. A major constraint to improving productivity was weed management. In many years, especially when rainfall is above average, weeds become an impossible burden and whole fields of both cotton and maize are abandoned.

It was determined that farmers preferred methods of receiving knowledge is through exchange visits, demonstrations and field days. Use of leaflets, posters, radio or TV and formal training, although useful, were not favoured, least of all by women. This has implications for future scaling up activities.

Evaluation of innovative options for crop and weed management identified using a combination of traditional and scientific knowledge.

A period of characterisation and learning from farmers, followed by a stakeholder review workshop led to two seasons of on-farm evaluation of researcher-farmer-extension identified options for improved weed management. These included the use of low cost herbicides either on their own or integrated with hand hoeing and draft animal implements, designed to meet the needs of households with access to different levels of resources. Land preparation and method of crop establishment were also evaluated. Research was undertaken both on-farm and under researcher control on land provided by a local primary school.

Mid and end of season evaluations, were jointly undertaken by all project partners. Results from a study of the critical period of weed competition indicate weeds must be controlled during cotton establishment for at least 8-10 weeks if yields are not going to be effected. In "drier" seasons it is important to begin weeding by two weeks after crop emergence. The method of weeding is unimportant. Early winter ploughing was shown to conserve soil moisture, and to reduce weeds, promote earlier crop establishment and increase cotton yields. Shortages of labour and draft animals make the use of herbicides particularly attractive to farmers, either on their own or integrated with other measures. Although farmers are keen to use herbicides, the deteriorating political and macro-economic situation has led to rapid price increases (relative to the price of cotton) and will delay adoption especially by poorer farmers. However herbicides are now being provided through individual and group loans by the Cotton Company, COTTCO, who are active in promoting their use in a programme of integrated weed management.

Promotion and dissemination of findings

Research findings were promoted through field days and annual workshops, Papers detailing project outputs were presented at International Conferences in 2001 and 2002 Close collaboration of partners in a participatory process improved each institution's capacity to participate with rural communities (including women) in the identification of local constraints, testing and evaluation of potential solutions.

The project has prepared "Best Practice Guidelines" aimed at extension workers on land preparation, crop establishment, weed management and knapsack use for use in further dissemination activities.

Contribution of Outputs to Project Goal:

The project identified three options for reducing the impact of weeds in cotton production systems: 1) using herbicides either on their own or 2) integrated with hand hoeing, ox-drawn cultivator or plough and 3) early winter ploughing. Hand hoeing and ox-cultivator remain the lowest cost options, but are not feasible over large areas given labour and draft animal shortages. Option 3 remains low cost, but has practical limitations, in that it can only be used by those with access to draft power and only after a maize crop. Option 1, although best suited to those with least labour and draft (the poorest resourced) requires herbicides to be available, cash investment and training in the use of herbicide technology. It is therefore likely to be used only by those who can access and afford the chemical. Integrating herbicides with hand hoe or draft animal weeding offers the best option for most farmers.

BACKGROUND

Information should include a description of the importance of the researchable constraint(s) that the project sought to address and a summary of any significant research previously carried out. Also some reference to how the demand for the project was identified.

Importance of the researchable constraint

Approximately 70% of cotton, Zimbabwe's second largest agricultural export, was produced from 240,000 ha by the smallholder farming sector in 1998, for which the crop is an important enterprise for 150,000 rural households. These smallholder cotton farmers recognise the need to reduce weed competition and to keep a receptive soil surface to capture available rain-water, as yield loss is significant when weeds are left uncontrolled.

Demand for the project

The problem of weed management was highlighted as a priority area for research by small scale (communal area) farming communities of Muzarabani District in the Zambezi Valley. Provincial and District based extension staff, representatives of the Regional District Council (RDC) and Zimbabwe Farmers Union (ZFU), and the Cotton Company of Zimbabwe (COTTCO). This was documented by a CPP project development study completed in Muzarabani in August 1998 (Twomlow and Chatizwa, 1998), where farmers interviewed prior to the establishment of this project ranked weeding as the most labour intensive activity of the cotton crop cycle. In some cases, farmers fail to control weeds adequately and end up having to abandon whole fields, placing great strain on their family's' financial security and livelihood. The availability of labour is likely to further decline as a result of HIV/Aids.

While cotton is the cash crop in the area, with a yield range of 0 to 1100 kg ha^{-1}, maize is the preferred staple for food security. Maize is often weeded just once because labour and draught animals are allocated to the cotton crop, resulting in low yields of less than 700 kg ha^{-1}. Alleviating the weeding constraint in cotton, through the release or better management of labour and draught animal power, should therefore facilitate improved management of maize and provide opportunity for other non-farm activities.

Weeds and weed control are also major constraints to cotton production elsewhere in southern Africa. In Zambia for instance, 74% of smallholders in three areas reported that weeds pose a major production problem (Javaid, 1992). Cotton uses many purchased inputs, particularly seed, fertiliser and insecticides, but when the crop suffers competition from weeds, the full benefit from these investments is not realised (Gill, 1982; Hillocks, 1995).

Previous research

Weed management is one of the important elements of agricultural systems (Kropff and Lotz, 1992). The significance of weeds is often overlooked because unlike other pests and diseases, weeds can substantially reduce crop yield without obvious damage (Michaela, 1997). Cotton is particularly sensitive to weed competition because seedling growth is slow and full ground cover is not achieved for eight or more weeks. Cotton/weed competition studies conducted in Zimbabwe in commercial systems have shown that the critical period for competition is from six to eight weeks from crop emergence, but that in "drier seasons" yield loss is significant when weeds are left uncontrolled between two and four weeks (Schwerzel and Thomas, 1971). The current blanket recommendation to all cotton farmers in Zimbabwe is that the crop must be kept weed-free for the first ten weeks (Cotton Growers Association, 1998), but there are no real suggestions as to which techniques are the most efficient and no account is taken of the resources available to farmers to achieve this. Schwerzel and Thomas (1971) also demonstrated that weeds remove more moisture and up to 3 - 4 times more nitrogen, potassium and magnesium from the soil than the crop. Detailed studies indicate that priority should be given to maintaining a weed free band 30 cm wide along the crop row, in which case the cotton will tolerate competition from inter-row weeds until these are about 45 cm tall, provided there is no moisture stress (Richards, 1979). The importance of keeping the soil surface receptive to rainfall has also been demonstrated (Richards and Thomas, 1971). When rainfall in the growing season was less than 400 mm, shallow cultivation in addition to pre-emergence herbicide use resulted in higher cotton yield compared to use of herbicide alone.

Smallholder cotton farmers in Zimbabwe recognise the need to reduce weed competition and to keep a receptive soil surface to capture available rain-water. In Muzarabani some farmers claim to begin weeding within one week of emergence and may weed 4 to 6 times during the season (Twomlow and Chatizwa, 1998). However, work elsewhere in the communal farming sector of Zimbabwe has revealed considerable inter-household variability in access to both draught animal power and labour. These are key determinants of the ability to weed on time - as much as 35% of the community, the poorest households, do not have access to adequate levels of these resources, neither do they have sufficient cash to hire labour or purchase herbicides (Riches *et al.,* 1998). Weed control using hand hoes is the most labour demanding pre-harvest activity in crop production with weeding labour requirements for maize production, for example, being as high as 60% of the total labour requirement (Ellis-Jones and Riches, 1992). With women and children providing the greater part of this labour (Mortimer, 1994), many children will not attend school regularly as a result (Labrada and Parker, 1994).

Given this situation, a move towards greater use of animal traction for weeding is an alternative in order to reduce the drudgery associated with hand weeding. The main implements used for cultivation purposes in Zimbabwe are cultivators and mouldboard ploughs (with or without the mouldboard attached). Cultivation using ox-drawn implements is much faster than hand weeding, reducing labour requirements by between 50 – 70 % (Chatizwa, 1993). However, their use is not without limitations. Firstly, a farmer needs to have access to implements and draught animals. If these are available, many implements, especially ox-cultivators, are too heavy for women to use. The use of animal drawn implements predominantly weeds inter-row, therefore there is still a requirement for hand hoe weeding within the crop row. Also, the use of animal traction for other activities, such as tillage operations, can coincide with dry periods (October-November) when most animals are in bad condition due to inadequate and poor grazing. At such times, they are unable to provide enough draught power. This situation has been exacerbated by a decline in animal live weights. Oxen used in the 1970s had live weights of at least 500 kg (Howard, 1980), while two decades later the estimates are between 300 – 400 kg (Hagman and Prasad, 1995).

It is no surprise then that in Muzarabani farmers have ranked weeding as the most labour intensive activity of the cotton crop cycle and have indicated that alleviation of the constraints of weeds and weed control is a research priority. If innovative approaches to soil and water management are to be further developed, and more importantly, readily adopted, it is essential that we fully understand the constraints faced by the farmers, for whom they are intended, such as equipment, labour and draught animal availability. To date, the majority of projects, developing innovative methods of soil management (conservation tillage, improved weeding, mulching, green manures) have assumed a level of draught power availability and management skill that does not currently exist at the smallholder level. In recent RNNRS-funded projects implemented in Zimbabwe (R4840, R6655 and R5472), the poor performance of improved draught 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 a better knowledge of implement design, use and maintenance than is the case at present for new technologies to be adopted.

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 weed control practices within an integrated crop management context. Weed growth within the crop is a reflection not only of the weeding practices in operation, but also of prior land preparation methods, tillage and planting practices. Soil moisture available to the crop can be enhanced by careful manipulation of tillage and conserved by timely weeding (Mashavira *et al.,*1997; Twomlow *et al.,* 1997b; Twomlow *et al.,* 1998; van der Meer *et al.,*1999). The success with which the system is managed depends on household assets and access to resources (Ellis-Jones and Mudhara, 1997). Working with the farming community in a process of participatory technology development, involving the extension service and NGOs, ensures that farmers can evaluate and select technologies appropriate to their circumstances and provides the conceptual framework for the proposed research.

PROJECT PURPOSE

The purpose of the project and how it addressed the identified development opportunity or identified constraint to development.

The project purpose, being an Output of the Crop Protection Programme is:

'Integrated cotton pest management needs assessed and strategies developed and promoted.'

The project has given emphasis to improving weed management in cotton-maize systems through a process that has encouraged farmers, working with the extension service and NGOs, to use participatory technology development approaches. This has enabled farmers to select from available and novel tillage and weed management technologies and to test those options they consider best suited to their circumstances.

RESEARCH ACTIVITIES

This section should include detailed descriptions of all the research activities (research studies surveys etc.) conducted to achieve the outputs of the project. Information on any facilities expertise and special resources used to implement the project should also be included. Indicate any modification to the proposed research activities and whether planned inputs were achieved.

Understanding the impact of weeds in cotton

The main emphasis of this activity was to gain an in-depth understanding of existing farming systems within the Muzarabani area. Lower Muzarabani had been selected as being typical of a wider agro-ecological zone covering parts of Mozambique, Zambia as well as Zimbabwe. Within Zimbabwe the area had largely been settled in the period following independence in 1980 as a result of easy availability of land in the communal areas, low population density and suitability for cotton production.

Planning meeting including identification of participating farmers

Project activities were initiated at a planning meeting involving project stakeholders in October 1999 (Twomlow *et al*., 1999). This involved representatives from Muzarabani District Council, AREX, Zimbabwe Farmers Union, Cotton Training Centre (CTC), Cotton Company of Zimbabwe (COTTCO), relevant NGOs and representatives of local farmer groups. The meeting identified communities in Lower Muzarabani in the Zambezi valley with whom we could work to implement the project, defined the roles and responsibilities of project partners and agreed a work programme.

Identifying farmers' perceptions of weed management

<u>*Community workshops*</u>

Six community workshops were held primarily for local farmers in order to gain an understanding of their perceptions and knowledge of their cotton-maize production systems in general and weed management and crop production techniques in particular (Chatizwa *et* *al*., 2000). These workshops provided opportunity for the project team and other stakeholders to:

1) Gain an understanding of livelihood systems, resource categories of farmers, farming systems and weeding problems.
2) Introduce the project to farmers and seek their participation in the research activities and;
3) Provide opportunity for the project team to build upon the linkages developed with other stakeholders at the project initiation workshop in November 1999.

The areas selected for the focus groups were based on the following criteria:

- Ensuring that a cross-section of villages in Muzarabani District in the Zambezi valley was covered.
- Ensuring all major soil types were included.
- Including recently settled as well as older settled areas.
- Including the original inhabitants (*Kore-kore*) as well as more recent migrants (*Karanga*) to the area.
- Including areas both close to and far from Muzarabani Growth Point.
- Including a number of different institutions who are presently working with farmers in the area (particularly ZFU and COTTCO).
- Including areas close to the escarpment where the rainfall is greater, as well as more distant locations where rainfall is lower.

The areas selected (Map 1) and the main characteristics of each are shown in Table 2. The main history of the Muzarabani area can be summarised (Box1)

Map 1: Map of Lower Muzarabani showing location of primary and secondary sites

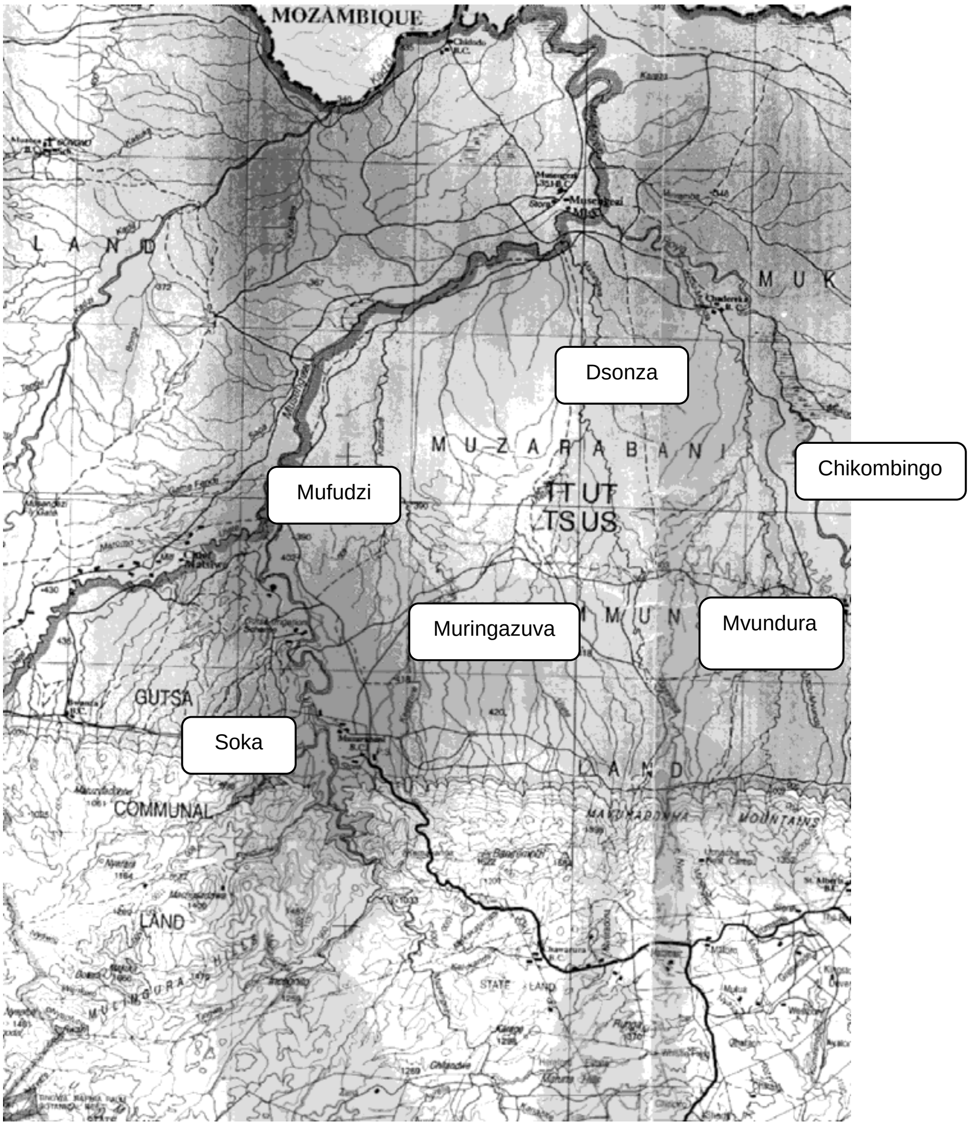


Table 1: Areas selected for farmer focus group discussions and their main characteristics

	Soka[1]	**Dsonza**[2]	**Chikombingo**[2]	**Mvundura**[2]	**Mufudzi**[1]	**Muringazuva**[1]
Soils	Red	Red/black	Red/black	Mixed	Mixed	Red
Rainfall (*relative to Muzarabani*)	Similar	Lower	Lower	Lower	Lower	Similar
When settled	Older	Recent	Recent	Mixed	Mixed	Older
Inhabitants	Karanga	Karanga Kore-kore	Karanga Kore-kore	Karanga Kore-kore	Karanga Kore-kore	Karanga
Distance from Muzarabani	Close	Far	Far	Medium	Medium	Close
Access in rains	Easy	Problems	Problems	Problems	Usually OK	Easy
Institutions	ZFU COTTCO	RDC	RDC	AREX	COTTCO	COTTCO

[1] Selected as primary sites due to accessibility in the rainy season
[2] Secondary sites due to lack of access in the rainy season

Box 1: Historical profile of the District

Time	Event
Prior to 1960s	Relatively few people, plenty of cattle, abundant wildlife, people farmed relatively small lands. Main crops were maize, sorghum and finger millet for home consumption. Vegetables grown on river alluvial soils on residual moisture in winter. People settled largely along river banks. People started growing cotton in the valley.
1965-70	War came to the Valley. People moved and kept in keeps near Gutsa.
1975	ARDA started growing cotton under irrigation on the estate and the Growth Point established.
1975-79	Most cattle lost during the war.
1979	Cease fire People moved out of the keeps back to their old lands.
1980s	Major resettlement started with people coming from Masvingo, Mazoe, Guruve, Chivu and other areas. Cattle number started increasing. People started expanding their areas of cotton with assistance provided by donors.
1980s	RDCs formed with Wards and VidCos. Role of traditional authorities reduced Immigration continues
1984	Road construction started and water supplies improved. Credit available for cotton production.
mid 1980s	Problems of weeds in cotton started to increase as new weeds came in.
1992/93	Large number of cattle lost during the drought. People survived on weeds and fish
1990s	More people came and settled in the Valley
1998	Cotton ginnery opened at Muzarabani
1999-2000	Conflicts over the use of land common. Role of RDCs and traditional authorities not always clear. New settlers still arriving

Community mapping exercises confirmed the recent large expansion of arable areas as well as more recent development of infrastructure, particularly roads and water supplies in the area.

Farmers in lower Muzarabani earn their living mainly from crop production and livestock rearing. Poorer farmers also rely to a greater extent on hiring out labour in exchange for food, cash, draught power and others. Agriculture is the main source of livelihood either through direct production or hiring out of labour often for food. Major crops produced in the area are cotton, maize and groundnuts in order of importance. Sorghum and millet are also grown but have minor importance to the livelihoods of farmers. Major livestock owned by farmers are cattle, goats and sheep. Cotton is ranked the most important crop which contributes to household income. Maize is the most important food crop followed by gardening and groundnuts. Cotton was however ranked the most difficult and labour demanding crop. Cattle play a significant role in providing draught power, also provides meat, milk and cash from hiring out draught and cattle sales. Goats also play a significant role in providing immediate cash and meat.

Off farm activities for builders, carpenters, blacksmiths are limited and there were very few people deriving their livelihoods from these activities. Remittances from family members living in towns are decreasing due to the high cost of living in the towns. In fact a growing number of rural households are sending goods to the towns to support their extended families. CAMPFIRE wildlife programmes were of benefit as when animals were killed the proceeds were used for projects such as schools and boreholes.

Farmers generally grouped themselves into four categories

- Rich (well resourced) – Resource Group 1
- Average, (average resources) – Resource Group 2
- Poor (few resources) – Resource Group 3
- Very poor (very few resources) – Resource Group 4

The most frequently mentioned criteria were based on size of arable land, livestock ownership, homestead structures, implement ownership, yield levels, labour utilization, ownership of other businesses, daily food consumption and education levels (Table 2).

Table 2: Wealth categories in Lower Muzarabani[1]

Indicator	Well resourced Rich (RG1)	Average resources (RG2)	Few resources Poor (RG3)	Very few resources Very poor (RG4)
Size of arable land	More than 12 acres Land borrowed from other	12 acres	12 acres Land lent to others	0-5 acres
Livestock				
Cattle	>20	5-15	Nil	Nil
Goats and sheep	>30	5-15	Nil	Nil
Poultry	Plenty	Many	A few	Nil
Homestead structures	Brick under asbestos, toilet, granary	Brick and mud under grass, toilet and granary	Pole and dagga under grass, no toilet, no granary	Pole and dagga under grass, no toilet, no granary
Implements	Tractor, full range of implements	Full range of animal drawn implements	Hoe, sprayer	Hoe only
Yields achieved				
Cotton (bales)	>20	5-15	0-4	0-1
Maize (bags)	>20	5-20	1-5	1-3
Groundnuts (bags)	>10	10	1-5	1-3
Labour utilization	Hire labour Has 1-2 permanent workers	Hires labour Works for others	Hires out labour	Hires out labour
Other Business	Most have larger stores	Some have small stores	Nil	Nil
Food consumption	>3 meals per day	2-3 meals per day	1-2 meals per day	1 meal per day
Education level	Form 6+	Form 4	Grade 7	Nil
Range in each category	5-10%	30-50%	20-30%	10-20%

Generally poor category farmers were those with few resources unable to fully utilize the land available to them, they lend out their land and hire out their labour in search for cash, food and other necessities leaving their land unattended. This contributes to poor levels of production, often insufficient for their own needs. Average category farmers are better-endowed and able to produce adequately for their needs. Rich category farmers have adequate resources and hence their production capacity is high.

The opportunity to grow cotton, particularly since the opening of the ginnery in Muzarabani, and the prospect of virgin land continues to drive inward migration to lower Muzarabani. However, a number of farmers have commented that yields have fallen after only three to four years cultivation of new fields. The land has been perceived as rich and fertile so fertiliser use is limited. Pair wise matrix ranking identified weeding as the most difficult and laborious farming operation, which required more labour and occupied nearly half of the season's time, often involving very hard work and being problematic in the field. The farmers ranked 1) weeding, 2) cotton picking, and 3) spraying as the most difficult tasks.

Other constraints included:

- Shortage of cattle (DAP),
- Shortage of water for both animals and people especially in the dry months
- Insufficient implements.
- Some farmers indicated that fertiliser can burn plants due to lack of moisture.

The problem weeds mentioned by farmers across the six sites were numerous.

Trichodesma zeylanicum, Cochorus spp, *Boerhavia erecta, Panicum spp* and *Rottboellia cochinensis* were found to be the common problem weeds in all the sites. These were ranked as problem weeds due to their difficulty in control and persistence.

The common methods of weed control are hand hoeing, ox cultivation and ox ploughing. Farmers indicated that these implements are not effective as some weeds have deep root systems and tough above ground foliage and stems. Timely weeding was reported to be difficult for some farmers due to the shortage of draught power, human labour, capital to hire labour and some social commitments. As a result weeds are left up the time of harvesting and these weeds hinder harvesting as some are itchy and the seed attaches to the cotton lint decreasing the quality, e.g. *Trichodesma zeylanicum* and *Boerhavia ereta*. It was also highlighted from the focus group discussions that weeds grow fast in the Zambezi valley due the high temperatures. Some weeds mature and seeds are dispersed before weeding is completed. These germinate again in the same season and will require further weeding, hence some farmers said that they weed up to 6 times per season in cotton.

<u>Household survey</u>

A household survey was undertaken to provide quantitative information on livelihoods, farming systems and weed management to support that provided in the community workshops. A draft survey was field tested in August 2000, modified and applied in September 2000. SNAP, a survey software package was used for design and analysis of the survey (Ellis-Jones *et al*., 2001). This survey was informed by and has provided additional detail to the community workshops and was undertaken in the same five villages where community workshops were undertaken. Respondents to the survey included 149 households, selected randomly in each area so as to obtain a cross-section of households. Households were categorised according to their access to resources based on participatory wealth ranking exercises undertaken during the community workshops (Chatizwa *et al.,* 2000) The indicators used for categorising survey respondents were livestock and implement ownership (Table 3)

Table 3: Summary statistics showing the mean for each resource categories (n=149)

	RG1 (n=39)	**RG2** (n=44)	**RG3** (n=34)	**RG4** (n=33)
% of farmers in each resource category	26%	29%	23%	22%
% male HoH (Head of Household)	82%	75%	88%	82%
Predominant age group of HoH	56-<65	36-45	25-25	25-35
Average household size	10.9	9.7	8.4	6.4
% belonging to groups	47%	46%	29%	25%
Average income levels (Z$ in 2000)	39000	20225	14577	4235
Main sources of income *in order of importance*	Cotton Maize Cattle Goats	Cotton Groundnuts Maize Gardens	Cotton Maize Groundnuts Poultry	Cotton Maize Working locally Buying and 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	0
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
Cash expenditure on crop inputs (Z$)	11853	7003	3784	2188

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

Characterising the weed flora and problems related to weeds

Weed species abundance was recorded on four farmer-managed fields in each of three villages in the project area in 1999/200 season. The weed flora (Table 4) includes a range of annual species of which *Eragrostis aspera*, *Panicum maximum*, *Sphaeranthus flexuosus* and *Vernonia poskeana* are the most abundant (Mavudzi *et al.,* 2001). Participatory research in the area confirmed that farmers consider inadequate weed control a major constraint for cotton yield and area harvested. The effect of additional weeding on maize and cotton yields was assessed through paired plot experimentation on farmers' fields. At each site one of the plots was farmer managed while the other was researcher managed and kept weed free throughout the growing season. Cotton yields under farmer management in Muzarabani observed in this study averaged well below 1 tonne ha^{-1}. The yield gap due to weeds at current levels of management averaged 9%, but are as high as 21% for the households with average resources. Additional weeding for the farmers in the latter group, who often plant larger areas than can be adequately managed, showed positive marginal rates of return. Poorer households plant small areas of cotton and weed by hoe. The absence of a demonstrable yield gap in cotton crops of poor households (Resource category 3–4) may reflect the smaller area planted which is therefore easier to weed in a timely manner (Muzenda and Ellis-Jones, 2000). On the other hand cotton areas are often determined by the resources available to purchase seed and insecticide. However, poorer households may use sub-optimum levels of fertiliser and pesticides, reducing the potential benefit of additional weeding. Maize, the staple food, kept weed free for the season, produced significantly (P<0.05) higher yields, 12% (+177 kg ha^{-1}) more than those under farmer management.

Farmers tend to concentrate labour resources on cotton to the detriment of maize (Chatizwa *et al*, 2000, Muzenda and Ellis-Jones, 2000). Practices that reduce the labour requirement for weed control in cotton could allow additional resources to be invested in the maize to the benefit food security in the area. Although the yield increases following additional weeding on the observation plots set up in cotton were not large, farmers have reported that they regularly abandon areas of the crop due to weed infestation, a factor not included in the analysis reported here. Low labour input methods of weed management are therefore needed, not only to assure good yields, but also to enable a greater proportion of the planted area to be harvested. The majority of farmers in Muzarabani are familiar with pesticide application for insect control. The use of a pre-emergence herbicide could offer an option to relieve the weeding labour constraint. The mixed species weed flora of relatively easy to control annuals recorded during this study will require a broad-spectrum treatment. Preliminary trials at a range of sites demonstrated good weed control with a tank mix of alachlor (0.96 kg a.i. ha^{-1}) and cyanazine (0.55 kg a.i. ha^{-1}), both of which are available at stores in the area. Used as a banded application along the crop row in combination with inter-row weeding with a cultivator or plough, the herbicide system results in 20-30% saving in input costs compared to hiring labour for one hand weeding. This would be particularly appropriate for the 35 to 60% of households with access to their own draught power and was the preferred option in mid season trials (Ellis-Jones *et al*., 2001b). Increasing the area that is harvested through improved weed control will also provide more employment opportunities for hired labour during the cotton harvest.

Table 4: Main problem weed species found in the Lower Muzarabani area of the Zambezi Valley

Shona Name	**Species**	**English Common name**	**Grass**	BROAD LEAVED WEED
Most common				
Kavanzi	*Vernonia poskeana*	Vernonia		✓
Pisa imba	*Eragrostis aspera*	Rough love grass	✓	
Chigwande	*Boerreria scabra*	Button weed		✓
Goso/Nyarumundu	*Trichodemsa zeylanicum*	Late weed		✓
Chinhuwenhuwe	*Ocimum canum*	Wild basil		✓
Pemu,/chidyahurudza	*Sphaeranthus flexuosus*			✓
Mundawarara	*Celosia trigyna*	Silver spinach		✓
	Ceratotheca sesamoides			✓
Derere/ Nyenje/Kapishe	*Corchorus olitorius*	Wild jute		✓
Barahanga /Hoka	*Panicum novemnerve*	Panicum	✓	
Chigwande	*Boerhavia erecta*			✓
Other important weeds				
Goche/Chidyahumba	*Commelina benghalensis*	Wandering dew		✓
Kapinga /Tsangadzi	*Cynodon dactylon*	Couch grass	✓	
Vave,/Handifeni	*Rottboellia cochinchinensis*	Itch or Shamva grass	✓	
Mhande	*Urochloa panicoides*	Garden Urochloa	✓	
Chinzungu/Murira	*Richardia scabra*	Mexican clover		✓
Tsine	*Bidens pilosa*	Black jack		✓

Assessment of the condition of tillage implements and spraying equipment

A survey was conducted to assess the condition of animal-drawn tillage implements (mouldboard ploughs, cultivators and harrows) and spraying equipment owned by farmers in Muzarabani (Koza, Sibanda and Mashingaidze, 2001). Nineteen households were visited in three project areas of Mufudzi, Gutsa and Muringazuva. Ploughs were generally in poor condition. Drawbar hitch assemblies, bolts and nuts, and stays were missing on the majority of ploughs. Worn shares and landsides were found on 63.2% and 57.9% of the ploughs, respectively. About 20% of the ploughs were in good condition. Farmers owned two Zimplow/Bulawayo Steel Products cultivator models (BS 41 and BS 221) and two-thirds of the assessed cultivators were BS 41s. Cultivators were also poorly maintained with many of them having unstable and loose frames, missing bolts and bent beams. About 60% of the cultivators had loose, bent or missing tines. Farmers removed two front tines on more than half of cultivators so as to reduce the amount of trash accumulating on the tines during weeding. Only five of the nineteen households owned harrows and the commonest type was the triangular spike-toothed harrow. All except one were in good working order. Four different types of sprayers were owned, namely, Taurus/Berthoud, Cooper Pegler (CP15), Jacto-AgVenture, and Osatu. Although most sprayers were in a fair condition, farmers were experiencing leakages due to worn seals and loose pipe connections. 8.3% of sprayers had poor pumping mechanisms and 16.7% had missing nozzles. Farmers improvised pipe grips, straps and buckles. In order to try and overcome the various problems faced by farmers in their cotton production systems, there is a need to train them in the correct use, repair and maintenance of tillage implements and spraying equipment. Training would cover aspects of correct setting of implements and safe use of chemicals. A reliable supply of affordable spares is a requirement for farmers to enable them to service their equipment.

Assessing strengths and weaknesses of current dissemination methods

Work undertaken by Chuma (2001) identified key dissemination objectives as being: (i) improving farmers' ability to identify and select appropriate soil, water and weed management options, (ii) supporting these farmers by appropriate on-farm research and encouraging extension through effective research-extension-farmer partnerships. Preferred means of receiving new knowledge were identified through pairwise ranking with training and demonstration, field days, exchange visits and agricultural shows being the most popular (Table 5).

Table 5: Preferred means of receiving new knowledge (1=best, 12=worst)

Means	Group 1	Group 2
Pamphlets, posters/magazines	12/13/6	7/5/8
Workshops	5	4
Road shows	7	10
In field training and demonstration	**1**	**1**
Field days	**3**	**2**
Agricultural shows	**4**	**9**
Exchange visits	**2**	**3**
Radio	10	6
Film and video	9/11	11
Drama	7	12

Most favoured shown in bold

The advantages of the most favoured methods centred on group learning, active participation of all, getting practical experience and close contact with research and extension (Table 6)

Table 6: Farmer assessment of the advantages and disadvantages of the preferred knowledge transfer methods.

Dissemination method	**Advantage**	**Disadvantage**
On farming training and demonstration	• There is a great deal of farmer participation • Farmers can be corrected during the training • First hand information obtained • Both theory and practical are covered	• Not all can participate • Funding can limit the frequency of the demonstrations • Expensive • Only experts ca carry out the training
Workshops	• Sharing of ideas and group discussions • Farmer-extension-research linkages are strengthened • Theory and practical are combined	• Too much technical information is provided • Involves too few people • Some people feel shy and inferior
Exchange visits	• Sharing of ideas • First hand practical information from other farmers is received	• Limited time • Number of visits limited • Cost • Benefits few people • Information may not be passed on
Field days	• People can discuss problems as a group • Copying and competition are encouraged	• Too infrequent • Only possible during the season

Review workshops

Project stakeholders convened in September 2000 (Ellis-Jones *et al*., 2001) to consider the characterisation studies undertaken over the previous nine months. Options for improving soil, water and weed management, relative to household resource availability were identified and a programme of on-farm research agreed for the following two seasons. This included a range of soil, water, weed and crop management practices, suitable for use by different resource groups involving low cost, animal drawn implements and the integration of reduced dosage herbicide use in cotton.

A 'mother-daughter-granddaughter' approach was used, where the mother trial was totally researcher-managed and located at a local primary school in Mafudzi. The daughter trials were on-farm researcher-managed, while granddaughter trials were totally farmer managed and only took place in the final season, facilitated by local extension workers. Options included:

- Hand hoeing, with and without herbicide.
- Ox-drawn implements (cultivators and ploughs) with and without herbicides
- In addition, the mother trial provided the opportunity to look at time of land preparation (winter or early summer, after the rains), method of planting (behind the plough or with a ripper) and alternative weeding implements.

Details of these treatments tested are documented in the next section. Prior to the season starting farmer groups from each area were taken on field visits to the cotton growing areas of Sanyati and Gokwe to evaluate different conservation tillage and weed management techniques used by farmers in those areas. These exchange visits exposed Muzarabani farmers to cotton production techniques, allowing full discussion of the merits and constraints of the different practices from farmers' perspectives.

Evaluation of innovative options on crop and weed management

Determining the critical period of weed competition for cotton

This trial, to determine optimum weeding time for the cotton crop under Muzarabani conditions, was undertaken in 200-01 and 2001-02 at Mafudzi school. Full details of the methods used are reported in Mavudzi *et al.,* 2002. Essentially the trial was set up to examine the length of the period from planting when the crop will tolerate weeds and the point in the season after which additional weeding has no further effect on crop yield. The following weeding treatments, all undertaken by hand hoe were used:

Weed free/weedy period

T1 First 2 weeks weed free and weedy for the rest of the season
T2 First 4 weeks weed free and weedy for the rest of the season
T3 First 6 weeks weed free and weedy for the rest of the season
T4 First 8 weeks weed free and weedy for the rest of the season
T5 First 10 weeks weed free and weedy for the rest of the season
T6 Weed free for a full season

Weedy/weed free period

T7 First 2 weeks weedy and weed free for the rest of the season
T8 First 4 weeks weedy and weed free for the rest of the season
T9 First 6 weeks weedy and weed free for the rest of the season
T10 First 8 weeks weedy and weed free for the rest of the season
T11 First 10 weeks weedy and weed free for the rest of the season
T12 Weedy for a full season

The experiment was set up as a Randomised Complete Block Design with three replicates. At harvest one row was discarded on either side of each plot leaving a net plot of 10 m * 4 m to provide a yield estimate. Seed cotton yield, plant height, number of balls per plant, weed density and weed biomass was analysed using analysis of variance and means separated using Fisher’s protected LSD. Weed density data was square root transformed (x+0.5) to achieve normal distribution and homogeneity of variances before analysis of variance. Regression analyses was carried out to determine the relationship between duration of weed interference and weed free maintenance on cotton yield. The relative yield loss was calculated by dividing the yield for each week and the yield obtained from the weed free full season plots. A partial budget analysis was also undertaken to compute economic returns.

Farmer led experimentation

The field trials were conducted in Lower Muzarabani during the 2000/01 and 2001/02 seasons. Rainfall received in each season was 1446mm and 539mm compared to an expected 450 - 650 mm per annum. High summer temperatures, in excess of 40 ^{0}C were experienced. The three areas in which the trials were undertaken are listed in Table 2 (Soka, Mufudzi and Muringazuva).

Integrated weeding options

The "mother and daughter" trial approach (used to ensure farmer involvement in the research process including identification of treatments, implementation, monitoring and evaluation) was characterised by two levels of experimentation:

- A researcher implemented **mother trial** with replicated plots undertaken on land owned by Mufudzi Primary School (**on-station**);
- **Daughter trials** undertaken **on-farm** with the participation of the farmers and with no replication at individual sites.

Treatments were allocated to farmers according to their resources. Participating farmers were identified by the community according to wealth categories established in group discussions (Chatizwa *et al*., 2000). The farmers, with supervision from the researchers, planted the on-farm daughter trials and also participated in weeding, harvesting and evaluation.

The treatments, as agreed on during the stakeholders review workshop held in September 2000, were as follows:

Non-mechanical methods

1.	Overall hand hoeing at 3, 6, and 9 weeks after crop emergence (wace).	HH
2.	Pre-emergence application of Cyanazine (550g a.i. ha^{-1}) plus Alachlor (960g a.i. ha^{-1}) in 30 cm wide bands along the crop row at cotton. planting, followed by inter-row weeding with a hand hoe at 3 ,6 and 9 wace.	Hca, HH
3.	Hand hoe weeding of crop rows at 2 wace followed by post-emergence application of Cyanazine (550g a.i. ha^{-1}) in the crop inter-rows at 3 wace.	HH, Hc
4.	Pre-emergence application of Cyanazine (550g a.i. ha^{-1}) plus Alachlor (960g a.i. ha^{-1}) over the whole plot area followed by hand weeding at 3, 6 and 9 wace.	Hca
Mechanical methods		
5.	Hand hoe weeding at 2 wace along the row followed by inter-row cultivation with an ox-drawn cultivator at 4 wace.	HH,OC, HH
6	Inter-row cultivation using an ox cultivator at 3 and 6 wace accompanied by hoe weeding in the cotton row.	OC,HH
7	Inter-row cultivation using an ox plough with mouldboard at 3 and 6 wace accompanied by hand hoe weeding in the cotton row.	OP+D,HH
8	Inter-row cultivation using an ox plough without the mouldboard at 3 and 6 wace accompanied by hand hoe weeding in the cotton row.	OP-D,HH
9	Pre-emergence application of Cyanazine (550g a.i. ha^{-1}) plus Alachlor (960g a.i. ha^{-1}) in 30 cm wide bands along the crop row at cotton planting and inter-row cultivation using an ox plough with mouldboard at 3 and 6 wace accompanied by hoe weeding in the cotton row.	Hca, OP+D, HH
10	Pre-emergence application of Cyanazine (550g a.i. ha^{-1}) plus Alachlor (960g a.i. ha^{-1}) in 30 cm wide bands along the crop row at cotton planting and inter-row cultivation using an ox plough without the mouldboard at 3 wace and 6 wace accompanied by hoe weeding in the cotton row.	Hca, OP-D, HH
11	Pre-emergence application of Cyanazine (550g a.i. ha^{-1}) plus Alachlor (960g a.i. ha^{-1}) in 30 cm wide bands along the crop row at cotton planting and inter-row cultivation using an ox cultivator at 3 and 6 wace accompanied by hoe weeding in the cotton row.	Hca, OC, HH

The mother trial (on-station) included treatments 1, 2, 3, 4, 5, 6, 7, 9 and 11 and was laid out as a randomised complete block design with 3 replicates.

On-farm, the daughter trials consisted of single strips of treatments with farms as replicates. The treatments were divided into the two categories listed above (non-mechanical and mechanical), suitable for farmers in two broad resource categories:

- For farmers without draught power the treatments were based on the use of a hand hoe integrated with herbicides. These farmers were allocated treatment 1, 2, 3 and 4 (although in the first season the herbicide was not always applied on treatment 3 and such plots were hand hoes weeded only) due to rapid weed growth..

- For farmers who own draught power and ox-drawn implements the treatments involved integration of herbicide use with inter-row cultivation by a cultivator (BS-41-5 tine, OC) or plough (Zimplow, OP or OP-D). The plough was used either with or without a mouldboard. This group of farmers were allocated treatment 5, 6, 7, 8, 9,10 and 11.

Each set of treatments was allocated to three farmers in each of Gutsa, Mafudzi and Muringazuva villages, thereby giving 18 participating farmers (6 in each area). Gross plots measured 10 * 6 m and 30 * 10 m for mother and daughter trials, respectively. All the plots were spring ploughed and a mouldboard plough was used to open the furrows for planting.

Cotton cultivar SZ 87-14 was planted at all sites in November 2000 and 2001. The seed was dribbled in the plough furrows, at a spacing of 1 m between the rows and 0.3 m in row spacing. Cotton plants were thinned to one plant per station three weeks after crop emergence (wace), resulting in a plant population of 33,333 as recommended for the area. Fertiliser application rates were 150 kg ha^{-1} compound L (5% N, 18% P, 10% K) and 100 kg ha^{-1} for ammonium nitrate (34.5% N). Spraying against cotton pests was done after weekly scouting, based on economic thresholds for each individual pest (Commercial Cotton Growers Association, 1998). Weeds were counted before any weeding operation at 3 random positions in each of the gross plots in a 0.3 * 0.3 m quadrat. The seed cotton yield was determined from net plots of 30 m * 6 m on-farm and 10 * 4 m in the mother trial at harvest.

Analysis of treatment effects on cotton yield was carried out using ANOVA, with farms nested in villages as the blocking factor for the on-farm trials. Yield means were compared by Fisher's protected LSD test. Weed counts were transformed by square root (x+0.5) before analysis to achieve normal distribution and homogeneity of variances.

Land preparation, method of crop establishment and weeding implement trial

This **mother trial** was carried out on-station only (Mafudzi School) and involved the use of the same three animal drawn mechanical weeding implements as used in the on-farm trials, the BS-41- 5-tine cultivator (OC), the Zimplow mould board plough (OP), and the Zimplow mould board plough with the body removed (OP-D). However, as well as investigating the efficacies of these three weeding implements, the trial was designed to also assess the interactive effects of different land preparation and crop establishment techniques. A strip plot design with primary land preparation as the main strip factor (*winter ploughing vs. spring ploughing*), mechanical weed control as the sub strip factor (*OC, OP or OP+D*), method of crop establishment as sub plot factor (*open plough furrow planting vs. ripping*) and use of a pre-emergent herbicide as the sub-sub plot factor (*herbicide or no herbicide*) was employed. The two tillage strips for each primary land preparation treatment were 32.4m wide by 120 m long. In each strip there were 6 sub-strips, 5.4 m wide, 2 sub-strips per weeding implement, sub-divided again into 6 sub-sub plots, making a total of 72 split plots on the whole trial field. This design facilitated three replicate blocks in which all treatment combinations were covered. A 5-m discard area (headland) was left at the end of each plot to facilitate turning by the traction animals.

The crop establishment methods used were either open plough furrow planting (OPFP), where seed was planted into furrows opened with a single pass of a mouldboard plough at the desired inter-row spacing, and subsequently covered with a hand hoe, or planting into a rip line (RIP) created by a ripper tine mounted on a standard plough beam. The experimental procedure is summarised in Table 6.

Table 6: Experimental design for assessment of land preparation and crop establishment methods on cotton production

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

+ dish = mould board retained, -dish = mould board removed

The cotton cultivar SQ 4314 was planted in 0.9m rows and thinned to an in-row spacing of 0.40 m after crop emergence. Where applicable, banded pre-emergent herbicide was applied as a tank mix of 550 g a.i. ha^{-1} cyanazine and 960 g a.i. ha^{-1} alachlor. Basal fertiliser was applied at a rate of 102 kg N ha^{-1} (ammonium nitrate) and 34 kg N ha^{-1} as top-dressing 6 weeks after planting. All plots were mechanically weeded at 3 and 6 weeks after crop emergence (wace) with supplementary hoe weeding where necessary. For the third weeding (at 9 wace) all plots were hand-hoe weeded.

During the first, second and third weeding the following measurements were made:
- The depth of cut for each weeding implement in cm was measured using a 30-cm rule (two measurements per plot). The different weeding implements were set to 7 - 9 cm depending on moisture condition. The width of cut for cultivators was typically set at 60 cm while the OP+D and OP-D required two runs between the cotton rows to attain the same width of cut.
- A dynamometer was connected between the check chain and the hitch assembly of the weeding implement. A load meter was then attached to the dynamometer to record the pulling force of the draft animals. 12 readings per run for a total of 6 runs 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.
- Theta probe readings and core cylinder masses were taken at depth intervals of 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm per station per plot. The 2 sets of readings were used to determine soil moisture content.
- Time taken for supplementary hand hoe weeding on each plot was measured in minutes and the number of people weeding each plot was recorded.
- Penetrometer readings were taken at levels from the surface at 3.5 cm depth intervals up to 35.0 cm. The readings were used to calculate shear strength of the soil.
- 3 weed counts were done using 30 cm square quadrants just before each weeding operation and the 4th was done just before harvesting and weed density was recorded.
- Plant characteristics were measured i.e. number of rotten cotton bolls, number of un-rotten cotton bolls and number of split cotton bolls to determine the percentage yield loss due to boll rot. Cotton plant population was recorded at harvest.
- A net plot was determined, encompassing the 4 middle rows of cotton. The cotton in the net plots was harvested and immediately weighed (in kg). Three sequential harvests were done from the end of April 2001 to mid June 2001 for the first season and from Mid April 2002 to end of May 2002 for the second season.

Data were analysed using ANOVA, testing for individual effects of land preparation (winter vs. spring ploughing), crop establishment (OPFP vs. ripping), weeding implement (OC, OP, or OP-D) and herbicide (with or without), plus all the different interactions.

Joint evaluation of trials using both farmer and researcher criteria

Trials were monitored closely by both farmers and researchers regularly during both seasons. Evaluations by farmers, researchers and extension workers were undertaken during the middle of the season and after harvest after results were available and had been analysed at end of season workshops.

Mid season evaluations

Four Field Days were held at different locations in 2001[1] (Tables 7 and 8), with farmers hosting each occasion, except at Mufudzi Primary School where the Headmaster was the host. After introduction of local farmers and visitors, the participants at each site split into groups. Each group was given a tour of the trials, during which the practices that had been carried out on each plot were explained and discussed. Farmers then evaluated each treatment using pairwise ranking, making an assessment of the strengths and weaknesses of each option. At this stage of the season, scoring was based largely on plant vegetative vigour and knowledge of the resources required to achieve the present situation.

[1] No field days were possible during 2002, as this coincided with Presidential elections and large meetings of local people were banned.

Overall banded herbicide used with an ox cultivator was regarded as the best mechanical option (Table 7). Two groups however preferred other options. The Mahwenda group preferred the use of a plough either with or without the dish (mouldboard). Notably the women's group at Gutsa preferred the use of the ox cultivator with no herbicide. This was largely related to the cost of the herbicide. All other groups opted for the use of the herbicide due to the saving in labour that was experienced.

Table 7: Ranking of mechanical options by each farmers group

Herbicide	Implement	Mufudzi Mixed	Mahwenda Mixed	Gutsa Women	Gutsa Men	Mshinya Mixed	Average of rankings	Overall Rank
Band	OC	1=	3=	3=	1	1	1.8	**1**
Band	OP+D	1=	1=	2	5=	7	3.2	**4**
Band	OP-D	3	1=	6	2	2	2.8	**2**
Nil	OC	4=	3=	3=	3	3	3.2	**3**
Nil	OP+D	4=	5	5	5=	6	5	**6**
Nil	OP-D	6	6	7	4	5	5.6	**7**
Nil	HH+OC		7	1	5=	4	4.25	**5**

Two groups, largely men, preferred herbicide use either overall or banded between the rows in the non-mechanical options (Table 8). One group, largely women preferred the nil herbicide option, relying totally on hand weeding.

Table 8: Ranking of non-mechanical options by each farmers group

Herbicide	Implement	Mahwenda *Emmanuel*	Gutsa *Bete*	Average Rank	Overall Rank
Nil	HH	4	1	2.5	**2**
Band between rows	HH	2	4	3	**3**
Overall	HH	1	3	2	**1**
Band within row	HH	3	2	2.5	**2=**

Farmers identified the strengths and weaknesses of the mechanical and non-mechanical options are summarised in Tables 9 and 10, respectively. There are some anomalies, largely based on farmers' own experiences (soil types, implement ownership etc.).

Table 9: Farmer views on strengths and weaknesses of mechanical weeding options during mid season evaluation

Treatment	Strengths	**Weaknesses**
Banded herbicide OC	➢ Fastest ➢ Cheapest (reduced labour) ➢ Cultivator width of cut is adjustable ➢ Loosens the soil for water infiltration	➢ Often too heavy for DAP available ➢ Does not encourage infiltration
Banded herbicide OP+D	➢ Covers small weeds ➢ Helps moisture conservation ➢ Weeds do not grow in furrow	➢ Most DAP required ➢ Takes twice the time of a cultivator ➢ Covers herbicide seal, rendering it less effective ➢ Plough encourages soil erosion ➢ Covers cotton plants at 3 weeks ➢ Plough may not be available as it is being used for ploughing operations
Banded herbicide OP-D[1]	➢ Requires less draft power ➢ Encourages aeration and moisture conservation ➢ Less soil erosion than OP+D	➢ Two runs are required to weed each inter-row ➢ Does not invert the soil resulting in re-establishment of weeds when it is rainy ➢ Encourages water logging when soil is wet
Nil herbicide OC	➢ One run required in the inter-row makes its use fast ➢ Causes little erosion.	➢ More labour required weeding along the rows in the absence of herbicides ➢ Encourages water logging when soil is wet
Nil herbicide OP+D	➢ Buries weeds next to the crop rows ➢ Encourages moisture conservation	➢ Two runs are required to weed each inter-row ➢ It is expensive & time consuming ➢ Not suitable for slopy lands ➢ Tends to uproot crops ➢ Buries young cotton plants
Nil Herbicide OP-D[1]	➢ Less DAP than OP+D ➢ Encourages moisture conservation ➢ Can be used at three weeks and not bury cotton	➢ Weeds can re-establish easily ➢ Crops can become stunted as there is poor moisture conservation
Nil herbicide HH first then OC	➢ Weeding is undertaken when it is critical at 2 weeks ➢ Cotton is not effected by the use of cultivator ➢ It is saves time	➢ Too much labour is required ➢ Encourages more weeds ➢ Does not encourage soil aeration ➢ Cannot use cultivator when land is waterlogged

HH= Hand Hoe, OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC= Ox Cultivator,

Table 10: Farmer views on strengths and weaknesses of non-mechanical weeding options during mid season evaluations

Treatment	Strengths	Weaknesses
Overall hand hoe *Applicable to people who own small fields*	➢ It is possible to weed near the plant and this is quite efficient as one has an opportunity to shake the soil off the weeds to prevent germination of weeds ➢ There is also less root damage to the crop ➢ It is possible to start weeding when the crop is still small	➢ There is too much labour required and it takes a lot of time to finish the fields ➢ If one has to hire labour where there is hand hoe weeding only, it is expensive ➢ Hand hoe weeding doesn't capture moisture when it rains and there is more runoff
Pre-emergence band herbicide and hand hoe	➢ Less time required for weeding because it is not required in the herbicide band ➢ Targeted herbicide use in the band, therefore this is cheaper than overall application	➢ This will require planting early when there is moisture for the herbicide ➢ This will require knowledge of herbicide use ➢ This will require good land preparation so that no weeds will be at the surface at planting
Overall herbicide	➢ There is no root damage due to implements ➢ Less labour because (1) the weeds come out late therefore less weeding is required and (2) only one person is required to apply the herbicide	➢ There is more herbicide used so this is an expensive option ➢ Only a few weeds will germinate after applying the herbicide, meaning organic matter input from the weeds is reduced - these weeds are seen to increase soil fertility ➢ There are no ways to capture the moisture during the season because the herbicide seal must not be disturbed
In-row hand hoe weeding and post-emergence herbicide	➢ Less time consuming because people weed early between the rows when there are few weeds ➢ This method is cheaper since the herbicide used is small in quantity compared to overall application ➢ Less labour and time is required to weed inter-row spaces	➢ The post emergent herbicide applied in-row can damage the crop if one doesn't have shields or it is not applied carefully ➢ Requires herbicide knowledge

End of season evaluations

1) On-station evaluation of integrated weeding options

During the first season, weed control practice had a significant effect on cotton plant height but there was no effect on boll number per plant or seed cotton yield (Table 11). Highest plants were observed on plots on which banded herbicides and post plant ridging with the plough had been used. In the 2001-2 season, when lower rainfall resulted in 63% lower average yields than in the previous year, treatment had a significant effect (P<0.05) on both plant height and cotton yield. Highest yields were obtained from treatments which provided for early weed control along the crop row either by hand weeding at two weeks followed by weeding on the inter-rows with a cultivator (treatment 5), or by use of the pre-emergence herbicide followed by hand hoeing at subsequent weeding dates (treatment 2). These two treatments significantly out-yielded all other weed control options except where hand weeding was used in the row at two weeks to be followed by a herbicide application, directed in between the crop rows at 6 wace (treatment 3).

Table 11. Effect of weed control methods on seed cotton yield and yield components in the mother trial at Mufudzi School

	2000-2001 season			**2001-2002 Season**		
Treatments (code)	Bolls per plant	Plant height (cm)	Yield kg ha^{-1}	Bolls per plant	Plant height (cm)	Yield kg ha^{-1}
1 HH	19.0	137.5	1833	7.13	75.1	516
2 Hca+HH	21.3	148.1	1875	10.47	77.4	987
3 HH+Hc	20.3	153.5	1583	9.67	84.5	620
4 Hca	26.7	148.9	1333	5.67	80.2	468
5 HH+OC	17.7	147.8	1500	10	77.4	948
6 OC+HH	25.3	154.9	1667	8.40	64.7	363
7 OP+D+HH	24.7	152.8	1625	7.73	75.9	485
9 Hca, OP+D	23.0	168.8	1792	8.13	69.1	452
11 Hca+OC	23.7	142.3	1208	7.20	69.5	535
S.E.D (16 d.f.)	4.34	8.06	292.6	1.859	5.49	184.9
Significance	Ns	*	ns	ns	*	*
L.s.d		16.12			10.98	369.8

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator,
ns = not significant * = P<0.05.
Treatments 8 and 10 were not undertaken on station

Weed control practice has a significant impact on weed density at 3 and 6 wace in 2000-01 and at all recording dates in the second season (Table 12). In 2001-2 the treatments that were applied the pre-emergence herbicides were found to be have lower weed counts than other treatments. In the first year there was a trend for lowest weed counts to be associated with plots on which pre-emergence herbicides had been applied, an effect which was more noticeable in year 2. In 2001-02 considerably more weeds emerged following weed control operations at 3 wace but in this season the effect of pre-emergence herbicide use on weed density was still apparent at 6 wace, particularly in treatments 3, 4 9 and 11. A later post-emergence application of cyanazine at 3 wace also resulted in low weed densities at the 6 week assessment in 2001-02. Indeed, this treatment led to significantly lower weed density at 6 weeks than either hand weed alone or combinations of mechanical weeding with the plough or cultivator plus supplementary hand weeding at 3 weeks. Weeding practice significantly affected weed biomass in both seasons at all observation dates except 9 wace in 2000-01 (Table 13). Lowest weed biomass at three weeks after crop emergence was as expected found on plots treated pre-emergence with the cyanazine/alachlor mixture. Across both seasons an overall application of herbicide followed by regular hand weeding at planting resulted in excellent weed control for the first 9 weeks of the crop growth cycle. The weeds that did survive the initial herbicide application were well controlled by hoeing so that no more than 5 g m^{-2} weed biomass was present at any assessment date.

Table 12. Effect of weed control practice on the weed density in cotton the mother trial at Mufudzi School

	2000-2001 season			2001-2002 Season		
Treatments	Weed density Number/m^2 3wace	Weed density Number/m^2 6wace	Weed density Number/m^2 9wace	Weed density Number/m^2 3wace	Weed density Number/m^2 6wace	Weed density Number/m^2 9wace
1 HH	3.55	8.68	2.98	9.11	12.98	9.73
2 Hca+HH	1.72	6.51	2.19	0.71	14.25	8.27
3 HH+Hc	3.48	7.09	1.41	3.03	4.21	10.88
4 Hca	1.21	8.47	2.11	0.71	7.87	8.02
5 HH+OC	2.27	7.56	1.96	12.58	17.39	10.31
6 OC+HH	1.33	7.84	2.27	15.20	7.21	16.55
7 OPD+HH	2.17	6.99	2.77	10.04	11.55	11.29
9 Hca,OP+D	1.70	8.00	2.08	0.71	8.61	9.59
11 Hca+OC	2.02	9.09	3.71	4.62	8.24	12.04
S.E.D (16 d.f.)	0.783	0.799	0.682	1.726	2.530	2.378
Significance	*	*	Ns	***	***	*
L.s.d	1.566	1.598		3.452	5.06	4.756

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine), OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator, Treatments 8 and 10 were not undertaken on station

Table 13. Effect of weed control practice on weed dry weight in cotton the mother trial at Mufudzi School

	2000-2001 season			2001-2002 Season		
Treatments	Weed biomass g/m^2 3wace	Weed biomass g/m^2 6wace	Weed biomass g/m^2 9wace	Weed biomass g/m^2 3wace	Weed biomass g/m^2 6wace	Weed biomass g/m^2 9wace
1 HH	63.6	39.9	25.1	47.1	1.2	1.15
2 Hca+HH	18.3	16.9	16.4	2.1	0	0.89
3 HH,Hc	2.4	2.4	18.5	30.7	0.5	0.82
4 Hca	0.4	1.6	5.0	0	1	0.97
5 HH+OC	95.5	77.8	24.8	20.1	0	0.99
6 OC+HH	82.7	62.5	36.2	33.9	131.9	7.09
7 OP+D+HH	79.3	48.4	25.9	58.8	10.9	1.73
9 Hca,OP+D, HH	21.0	26.3	14.0	16.5	1.9	1.31
11 Hca,OC, HH	4.6	3.3	17.4	2.7	0.9	1.02
S.E.D (df)	13.7	11.00	8.47	17.23	22.9	1.009
Significance	***	***	Ns	***	***	***
L.s.d	27.4	22.00		34.46	45.8	2.018

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine), OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator, Treatments 8 and 10 were not undertaken on station

2) On-farm evaluation of non-mechanical weed control options.

Seed cotton yields were not affected by weed control practices used in either season. (Table 14).

Table 14. Mean effect of non-mechanical weed control methods on cotton yield and yield components at nine on-farm sites in Muzarabani.

	2000-2001 season			**2001-2002 Season**		
Treatments	Bolls per plant	Plant height cm	Yield kg ha^{-1}	Bolls per plant	Plant height cm	Yield kg ha^{-1}
1 HH	16.70	129.72	1461	9.49	79.84	917
2 Hca + HH	19.18	129.83	1712	9.02	78.50	788
3 HH + Hc	-[1]	-	-	10.77	80.32	794
4 Hca	16.16	129.82	1625	10.93	85.33	873
S.E.D	1.259	2.814	165	1.128	2.395	132.9
Significance	*	Ns	ns	ns	*	ns
L.s.d	2.518				4.79	

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
ns = not significant P>0.05; *** = P<0.001; * = P<0.05 . Means followed by the same letter in a column are not significantly different. This applies to all subsequent tables.
[1]- Treatment not applied.

In 2000-01 treatments had no significant effect on weed number for the first 6 weeks of the cotton cycle (Table 15). In the following year herbicide use either pre-emergence or as an early post-emergence application resulted in significantly less weed density than hand weeding. Weed biomass (Table 16) showed a similar trend although this was significantly higher following post-emergence herbicide treatment suggesting that a few individual weeds that escaped control grew large by 6 wace

Table 15. Mean effect of non-mechanical weed control methods on total weed density (number m^2) at nine on-farm sites in Muzarabani.

	2000-2001 season			**2001-2002 Season**		
Treatments	Weed density 3wace	Weed density 6wace	Weed density 9wace	Weed density 3wace	Weed density 6wace	Weed density 9wace
1. HH	6.56	7.16	10.53	18.41	8.54	7.48
2. Hca + HH	5.91	6.04	9.90	3.90	6.62	6.86
3. HH + Hca	-[1]	-	-	11.62	5.48	9.64
4. Hca	5.05	6.41	8.00	5.30	5.67	6.01
S.E.D (df.96)	0.657	0.666	1.558	1.806	1.178	1.049
Significance	Ns	NS	*	***	*	***
L.s.d			3.116	3.612	2.356	2.098

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
[1]- Treatment not applied.

Table 16. Mean effect of non-mechanical weed control methods on weed dry weight (g m^{-2}) at nine on-farm sites in Muzarabani.

	2000-2001 season			2001-2002 Season		
Treatments	Weed biomass 3wace	Weed biomass 6wace	Weed biomass 9wace	Weed biomass 3wace	Weed biomass 6wace	Weed biomass 9wace
1 HH	1.23	20.9	2.61	57.5	12.3	6.84
2 Hca + HH	2.08	14.4	1.01	4.6	11.2	2.30
3 HH + Hca	-	-	-	27.4	38.2	3.20
4 Hca	1.35	13.7	0.69	9.8	3.0	0.42
S.E.D	1.203	9.46	1.109	10.15	11.06	2.258
Significance	Ns	Ns	Ns	***	*	*
L.s.d				20.3	22.12	4.516

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
[1]- Treatment not applied.

3) *On-farm evaluation of mechanical weed control options.*

Use of various mechanical weed control practices resulted in statistically similar cotton yields, which were also similar to the yield of the crop kept weeded by hand hoe (Table 17). All methods reduced weed density to below 13 weeds m^{-2} by 3 weeks after crop emergence (Table 18). Significantly fewer weeds were observed on plots treated pre-emergence with cyanazine and alachlor in both seasons.

Table 17. Mean effect of mechanical weed control methods on cotton yield and yield components at nine on-farm sites in Muzarabani.

	2000-2001 season			**2001-2002 Season**		
Treatments	Bolls per plant	Plant height cm	Yield kg ha^{-1}	Bolls per plant	Plant height cm	Yield kg ha^{-1}
5 HH +OC	14.21	108.77	1812	12.12	83.54	981
6 OC+HH	16.30	118.78	1910	12.19	86.01	1077
7 OP+D+HH	18.03	126.91	2001	13.31	83.02	938
8 OP-D+HH	16.77	122.85	1806	11.94	81.02	902
9 Hca+OP+D+HH	17.12	130.31	1945	14.62	87.28	1020
10 Hca+OP-D+HH	22.09	132.52	2100	11.26	82.46	863
11 Hca +OC+HH	20.49	129.57	1940	12.60	85.74	997
S.E.Ddf.546(69) and 615	1.290	2.846	0.1495	1.012	2.426	0.1137
Significance	***	***	ns	*	ns	ns
L.s.d	2.58	5.692		2.024		

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator,

The weed control effectiveness of following the pre-emergence herbicide application by inter-row cultivation with either an ox-drawn cultivator or a plough without a mouldboard is indicated by the significantly lower weed biomass recorded at 3 wace from plots weeded with these methods (Table 19).

Table 18. Mean effect of mechanical weed control methods on weed density (numbers^{-2}) at nine on-farm sites in Muzarabani.

	2000-2001 season			**2001-2002 Season**		
Treatments	Weed density 3wace	Weed density 6wace	Weed density 9wace	Weed density 3wace	Weed density 6wace	Weed density 9wace
5 HH +OC	10.38	3.91	9.78	10.71	9.80	10.64
6 OC+HH	13.78	3.36	9.95	10.85	9.24	10.29
7 OP+D+HH	11.42	2.70	9.35	12.98	9.46	10.94
8 OP-D+HH	12.03	2.69	10.24	10.70	6.76	9.43
9 Hca+OP+D+HH	8.77	2.06	7.56	2.48	8.26	11.01
10 Hca+OP-D+HH	6.20	3.14	6.75	3.74	7.79	11.23
11 Hca +OC+HH	6.51	3.75	6.84	3.26	9.31	9.52
S.E.D (df)	1.869	0.850	1.365	1.436	1.363	1.232
Significance	***	NS	*	***	NS	NS
L.s.d	3.738		2.73	2.872		

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator,

Table 19. Mean effect of mechanical weed control methods on weed dry weight (g^{-2}) at nine on-farm sites in Muzarabani.

	2000-2001 season			2001-2002 Season		
Treatments	Weed biomass 3wace	Weed biomass 6wace	Weed biomass 9wace	Weed biomass 3wace	Weed biomass 6wace	Weed biomass 9wace
5 HH +OC	11.2	22.9	12.12	11.2	3.9	7.23
6 OC+HH	35.2	11.1	34	35.2	6.7	0.07
7 OP+D+HH	13.1	15.6	16	13.1	18.6	0.22
8 OP-D+HH	27.8	14.6	28	27.8	5.	1.32
9 Hca+OP+D+HH	13.4	10.5	13.1	13.4	15.8	2.46
10 Hca+OP-D+HH	1.4	2.8	4.0	1.4	8.0	3.47
11 Hca +OC+HH	7.2	5.1	15.9	7.2	2.4	1.34
S.E.D (df	9.03	5.86	9.25	9.03	7.87	3.580
Significance	**	*	*	**	Ns	Ns
L.s.d	18.06	11.72	18.5	18.06		

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator,

4) On-station evaluation of land preparation and crop establishment options

Draught force

- There was a significant difference (P<0.001) in the power requirements of the 3 weeding implements. The OC required more draught power than the OP and OP-D.
- Crop establishment by use of a ripper resulted in greater draught force requirement at subsequent weeding than the use of open plough furrow planting, although this was limited to 3 wace during the second season.
- By carrying out winter ploughing, less draught force was required during subsequent weeding operations, averaged over the three implements. There was a 9% reduction in power requirements from the first weeding to the second.
- The use of herbicides did not affect weeding draught power requirements significantly.

Table 20 summarises the key draught performance characteristics of each implement/crop establishment practice.

Table 20. Draught force (kN) at weeding (3 and 6 wace) as affected by land preparation, crop establishment, weeding implement and herbicide use for 2000/2001 and 2001/2002 seasons.

	Draught force (kN) 00/01 @ 3 wace	Draught force (kN) 01/02 @ 3 wace	Draught force (kN) 00/01 @ 6 wace	Draught force (kN) 01/02 @ 6 wace
Land preparation				
Winter plough	0.560	0.524***	0.523*	0.526***
Spring plough	0.583	0.547***	0.530*	0.624***
Crop Establishment				
Open Furrow Planting	0.578	0.526***	0.520	0.575
Ripping	0.584	0.546***	0.541	0.576
Weeding Implement				
Ox-cultivator	0.688**	0.675***	0.675**	0.720***
Ox-plough plus dish	0.556**	0.497***	0.491**	0.537***
Ox-plough minus dish	0.500**	0.436***	0.427**	0.469***
Herbicide				
No	0.592	0.536	0.521	0.574
Yes	0.570	0.536	0.541	0.576
SEDs				
Land preparation	*0.006*	0.005	*0.019*	*0.005*
Crop Establishment	*0.006*	0.005	*0.005*	*0.005*
Weeding implement	*0.007*	*0.006*	*0.025*	*0.007*
Herbicide	0.006	0.005	*0.005*	*0.005*
% CV	*36.1*	*34.9*	*34.5*	*33.8*

Significant treatment effect, *P<0.01, **P<0.001

Work rates

Table 21 gives the work rates required at weeding operations for each implement/crop establishment practice.

- There was a significant effect (P<0.5) of land preparation on work rates at 3 and 6 wace for the 2 seasons, with winter plough requiring less time to weed a hectare.
- There was a significant effect (P<0.001) of weeding implements on work rates. The OC takes half the time required by the other 2 implements to weed the same area, as they need twice the number of runs due to their operation widths being narrower.
- The use of herbicides did not effect subsequent work rates during weeding operations.

Table 21. Work rates (Hr per ha) at weeding (3 and 6 wace) as affected by land preparation, crop establishment, weeding implement and herbicide use for 2000/2001 and 2001/2002 seasons.

	Work rates (Hr/ha) 00/01 @ 3 wace	Work rates (Hr/ha) 01/02 @ 3 wace	Work rates (Hr/ha) 00/01 @ 6 wace	Work rates (Hr/ha) 01/02 @ 6 wace
Land preparation				
Winter plough	7.71*	9.78*	7.72*	10.11
Spring plough	7.96*	10.07*	7.90*	10.06
Crop Establishment				
Open Furrow Planting	7.81	9.93	7.73*	10.00*
Ripping	7.86	9.92	7.89*	10.17*
Weeding Implement				
Ox-cultivator	5.00***	6.40***	4.98***	6.57***
Ox-plough plus dish	8.80***	10.84***	8.77***	11.08***
Ox-plough minus dish	9.71***	12.54***	9.69***	12.60***
Herbicide				
No	7.67	9.94	7.67	10.01
Yes	8.00	9.90	7.95	10.16
SEDs				
Land preparation	0.134	0.339	*0.134*	*0.195*
Crop Establishment	0.134	0.339	*0.134*	*0.195*
Weeding implement	*0.161*	*0.416*	*0.165*	*0.238*
Herbicide	*0.134*	*0.339*	*0.134*	*0.196*
% CV	*7.3*	*14.5*	*7.3*	*8.2*
Significant treatment effect, *P<0.01, **P<0.001				

Work rates refer to the time taken (in hours) needed to weed a hectare using any of the 3 animal drawn implements.

Supplementary hand hoe weeding

The amount of supplementary hand weeding required after mechanical weeding operations as effected by land preparation, crop establishment, weeding implement and herbicide use is presented in Table 22.

- Land preparation effected the labours hours for hand weeding significantly (P<0.05) with winter plough requiring less hours at 3, 6 and 9 wace.
- The labour hours were not effected by the method of crop establishment.
- There was a significant variation in labour hours for hand weeding over the 3 implements with OP requiring the least hours and OC the highest.
- When herbicides were used, the time required for supplementary hand weeding was only 20% of the time needed to weed plots with no herbicide.
- Labour hours were highest at 9 weeks, as no mechanical weeding was done between the rows of cotton. At this stage the cotton will have spread in such a manner that implements can not move in between the rows without damaging the plants.

Table 22. Labour hours (Hrs/ha) in hand hoe weeding as affected by land preparation, crop establishment, weeding implement and herbicide use.

	Labour-hrs/ha @ 3 wace	Labours-hrs/ha @ 6 wace	Labour-hrs/ha @ 9 wace
Land preparation			
Winter plough	28.92* (18.12)**	29.61* (18.98)**	38.81* (-)
Spring plough	31.49* (21.26)**	32.18* (23.66)**	41.32* (-)
Crop Establishment			
Open Furrow Planting	29.89 (19.55)	30.58 (21.26)	39.78 (-)
Ripping	30.52 (19.83)	31.21 (21.38)	40.35 (-)
Weeding Implement			
Ox-cultivator	31.38 (19.80)*	32.41**(23.23)*	41.58** (-)
Ox-plough plus dish	28.55 (18.43)*	28.55**(19.29)*	37.64** (-)
Ox-plough minus dish	30.65 (20.83)*	31.72** (21.43)*	40.98** (-)
Herbicide			
No	49.84***(26.12)***	51.21***(28.06)***	67.62*** (-)
Yes	10.58***(13.26)***	10.58***(14.58)***	12.52*** (-)
SEDs			
Land preparation	*0.871 (0.942)*	*0.871 (1.435)*	*0.869 (-)*
Crop Establishment	*0.871 (0.942)*	*0.871 (1.435)*	*0.869 (-)*
Weeding implement	*1.066 (1.154)*	*1.066 (1.757)*	*1.064 (-)*
Herbicide	*0.871 (0.942)*	*0.871 (1.435)*	*0.869 (-)*
% CV	12.2 (20.3)	12.0 (28.6)	9.2 (-)
Significant treatment effect, *P<0.5, **P<0.01, ***P<0.001			

The numbers in brackets are results for the 2001/2002 season.
Labour hrs/ha refer to the time taken (in hours) by one person to weed a hectare.

Moisture Content

Table 23 below gives average soil moisture content (% oven dry weight) of 2 stations within a plot averaged over 4 depths of 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm.

- Land preparation significantly affected moisture content levels, with winter plough giving higher results at 3, 6 and 9 weeks after crop emergence in both years.
- Crop establishment gave inconsistent effects on moisture content throughout both seasons.
- During the first weeding, the 3 different weeding implements did not affect moisture content levels.
- At the second and third weeding there was a significant difference (P<0.001) in moisture content levels between the 3 implements. The OP gave the highest moisture content retention in the soil followed by OP-D and then OC.
- The use of herbicides affected moisture content retention levels (P<0.5) with the application of herbicides resulting in more moisture retention.

Table 23. Soil moisture content (%) as affected by land preparation, crop establishment, weeding implement and herbicide use for the 2000/2001 and 2001/2002 season.

	Moisture Content @ 3 wace		Moisture Content @ 6 wace		Moisture Content @ 9 wace	
Land preparation						
Winter plough	16.87*	(12.63)***	16.83***	(22.53)***	21.42***	(21.13)***
Spring plough	15.94*	(10.79)***	15.10***	(21.14)***	20.42***	(18.72)***
Crop Establishment						
Open Furrow Planting	16.87	(11.74)	16.02*	(21.50)*	20.93	(20.09)*
Ripping	15.94	(11.68)	15.71*	(22.18)*	20.90	(19.77)*
Weeding Implement						
Ox-cultivator	16.12	(11.78)	15.40*	(21.04)**	19.42***	(18.84)***
Ox-plough plus dish	16.44	(11.70)	16.24*	(22.83)**	24.01***	(22.10)***
Ox-plough minus dish	16.66	(11.65)	15.95*	(21.64)**	19.12***	(18.84)***
Herbicide						
No	17.01	(11.42)*	15.47**	(21.77)	20.71*	(19.76)*
Yes	15.80	(12.00)*	16.26**	(21.90)	21.13*	(20.10)*
SEDs						
Land preparation	*1.43*	*(0.33)*	0.34	(0.43)	*0.20*	*(0.33)*
Crop Establishment	*1.43*	(0.33)	0.34	(0.43)	*0.20*	*(0.33)*
Weeding implement	*1.75*	*(0.41)*	*0.42*	*(0.52)*	*0.24*	*(0.41)*
Herbicide	*1.43*	*(0.339)*	*0.34*	*(0.43)*	*0.20*	*(0.33)*
CV %	34.4	(23.2)	18.3	(16.6)	8.1	(14.1)

*Significant treatment effect *P<0.05,* **P<0.01, ***P<0.001

The numbers in brackets are results for the 2001/2002 season

Penetration Resistance

Table 24 gives average penetration resistance.

- Land preparation affected penetration resistance levels (P<0.001) with winter plough giving lower resistance at 3, 6 and 9 weeks after crop emergence.
- Crop establishment did affect penetration resistance but fluctuated from one weeding to the next throughout the season.
- During the first weeding, the 3 different weeding implements did not affect penetration resistance. At first weeding there was no variation in the weeding implements as penetration resistance depended on the land preparation and method of crop establishment.
- At the second and third weeding there was a significant difference (P<0.001) in penetration resistance over the 3 implements. The OP gave the lowest resistance followed by OP-D and then OC.

Table 24. Penetration Resistance (kN/m^2) as affected by land preparation, crop establishment, weeding implement and herbicide use for the 2000/2001 season only.

	Penetration Resistance @ 3 wace	Penetration Resistance @ 6 wace	Penetration Resistance @ 9 wace
Land preparation			
Winter plough	2231***	2108***	1974***
Spring plough	2401***	2359***	2102***
Crop Establishment			
Open Furrow Planting	2330*	2213*	2047
Ripping	2302*	2254*	2059
Weeding Implement			
Ox-cultivator	2321	2290**	2101**
Ox-plough plus dish	2325	2157**	1949**
Ox-plough minus dish	2302	2253**	2064**
Herbicide			
No	2330*	2254*	2062*
Yes	2302*	2213*	2014*
SEDs			
Land preparation	*38.1*	*38.6*	*37.2*
Crop Establishment	*38.1*	*38.6*	*37.2*
Weeding implement	*46.7*	*47.3*	*45.6*
Herbicide	*38.1*	*38.6*	*37.2*
CV %	*22.1*	*23.2*	*24.5*

*Significant treatment effect *P<0.05,* **P<0.01, ***P<0.001

Bulk Density

Table 25 shows the effect of the different treatment combinations on bulk density for both seasons.

- Land preparation affected bulk density (P<0.001) with winter plough giving lower results at 3, 6 and 9 weeks after crop emergence.
- Crop establishment did affect bulk density throughout the season, with rip planting typically giving a higher bulk density compared to open plough furrow planting.
- During the first weeding the 3 different weeding implements did not affect bulk density. At first weeding there was no variation in the weeding implements as bulk density only depended on the land preparation and method of crop establishment.
- At the second and third weeding there was a significant difference (P<0.001) in bulk density levels over the 3 implements. The OP gave the lowest bulk density in the soil followed by OP-D and then OC.

Table 25. Bulk Density (g/cm^3) as affected by land preparation, crop establishment, weeding implement and herbicide use for the 2000/2001 and 2001/2002 season.

	Bulk Density @ 3 wace		Bulk Density @ 6 wace		Bulk Density @ 9 wace	
Land preparation						
Winter plough	1.45***	(1.46)***	1.42	(1.34)***	1.36***	(1.37)***
Spring plough	1.40***	(1.50)***	1.42	(1.37)***	1.38***	(1.39)***
Crop Establishment						
Open Furrow Planting	1.42	(1.47)*	1.42	(1.36)*	1.365*	(1.37)*
Ripping	1.43	(1.48)*	1.42	(1.35)*	1.368*	(1.38)*
Weeding Implement						
Ox-cultivator	1.45**	(1.48)	1.42*	(1.36)*	1.39***	(1.38)***
Ox-plough plus dish	1.41**	(1.47)	1.41*	(1.34)*	1.33***	(1.36)***
Ox-plough minus dish	1.40**	(1.48)	1.42*	(1.36)*	1.39***	(1.39)***
Herbicide						
No	1.42*	(1.48)*	1.43**	(1.35)	1.37*	(1.38)*
Yes	1.43*	(1.47)*	1.41**	(1.35)	1.36*	(1.37)*
SEDs						
Land preparation	*0.013*	*(0.006)*	*0.006*	*(0.007)*	*0.004*	*(0.005)*
Crop Establishment	*0.013*	*(0.006)*	*0.006*	*(0.007)*	*0.004*	*(0.005)*
Weeding implement	*0.016*	*(0.007)*	*0.007*	*(0.009)*	*0.005*	*(0.007)*
Herbicide	*0.013*	*(0.006)*	*0.006*	*(0.007)*	*0.004*	*(0.005)*
CV %	7.7	(3.2)	*6.6*	*(9.4)*	*2.5*	*(3.3)*
*Significant treatment effect *P<0.05,* **P<0.01, ***P<0.001						

The numbers in brackets are results for the 2001/2002 season

Weed Densities

Table 26 below gives the weed densities, which were obtained by using a 30-cm square quadrant and were later changed to weed density per m^2. Because some readings were zeros the data was transformed using a (sqrt[weed density+0.5]) before analysis.

- Land preparation affected weed counts significantly (P<0.001) at 3 weeks and (P<0.01) at 6 and 9 weeks, with winter ploughing resulting in lower weed counts compared to spring ploughing only.
- Crop establishment either by ripping or open plough furrow planting did not affect weed densities throughout the season.
- There was a significant difference in the weed densities during the first 3 weedings when the 3 weeding implements were used. The OP was the most effective and the OC was the least effective.
- The use of herbicides resulted in low weed densities for the all three weeding periods.
- At harvest, the results did not show any significant variation between any of the variables.

Table 26. Weed Counts (WC) as affected by land preparation, crop establishment, weeding implement and herbicide use.

	Weed Counts @ 3 wace	Weed Counts @ 6 wace	Weed Counts @ 9 wace	Weed Counts @ harvest
Land preparation				
Winter plough	10.76** (6.11)**	10.90* (8.06)**	15.09* (15.74)	8.62
Spring plough	13.69** (7.24)**	12.17* (9.66)**	16.15* (15.68)	8.94
Crop Establishment				
Open Furrow Planting	12.25 (6.71)	11.40 (8.55)*	15.59 (15.80)	9.03
Ripping	12.20 (6.64)	11.66 (9.17)*	15.65 (15.62)	8.53
Weeding Implement				
Ox-cultivator	12.75 (6.94)	13.08** (9.05)*	16.73** (15.68)*	8.57
Ox-plough plus dish	11.94 (6.44)	10.12** (8.27)*	14.43** (14.96)*	8.79
Ox-plough minus dish	11.98 (6.65)	11.40** (9.26)*	15.70** (16.48)*	8.98
Herbicide				
No	16.16** (11.29)***	17.13** (11.37)***	17.89** (16.33)*	9.36*
Yes	8.29** (2.06)***	5.94** (6.35)***	13.39** (15.08)*	8.20*
SEDs				
Land preparation	*0.508 (0.400)*	*0.460 (0.443)*	*0.430 (0.535)*	*0.428*
Crop Establishment	*0.508 (0.400)*	*0.460 (0.443)*	*0.430 (0.535)*	*0.428*
Weeding implement	*0.622 (0.490)*	*0.563 (0.543)*	*0.527 (0.656)*	*0.524*
Herbicide	*0.508 (0.400)*	*0.460 (0.443)*	*0.430 (0.535)*	*0.428*
CV %	30.5 (44.0)	29.3 (36.8)	29.3 (25.0)	29.3

Significant treatment effect *P<0.01, **P<0.001

The numbers in brackets are results for the 2001/2002 season

Cotton Yield

Table 27 below shows the amount of cotton harvested at Mafudzi Primary School in tonnes/ha. The yield figures shown are a summation of the harvests that were done over 2 months.

- Land preparation affected yield significantly (P<0.01) with winter plough giving a higher yield than spring plough for the 2 seasons.
- The use of herbicides resulted in higher yields (P<0.05) for the 2 seasons as compared to non use of herbicide.
- The method of crop establishment did not result in a significant variation in yield.

Table 27. Yield response as affected by land preparation, crop establishment, weeding implement and herbicide use.

	Cotton Yield (tonnes /ha) 00/01 Season	Cotton Yield (tonnes /ha) 01/02 Season
Land preparation		
Winter plough	2.651**	0.570*
Spring plough	2.196**	0.515*
Crop Establishment		
Open Plough Furrow Planting	2.468	0.544
Ripping	2.380	0.542
Weeding Implement		
Ox-cultivator	2.338	0.526*
Ox-plough plus dish	2.500	0.572*
Ox-plough minus dish	2.432	0.530*
Herbicide		
No	2.311*	0.508**
Yes	2.536*	0.578**
SEDs		
Land preparation	*0.0864*	*0.0293*
Crop Establishment	*0.0864*	*0.0293*
Weeding implement	*0.1059*	*0.0359*
Herbicide	*0.0864*	*0.0293*
% CV	15.1	22.9

*Significant treatment effect *P<0.05,* **P<0.01, ***P<0.001

Promotion and dissemination

Research findings were promoted through mid season field days and end of season annual project workshops, the proceedings from which were widely distributed. Other project outputs have been disseminated through presentation at international conferences. Collaborating institutions have worked with rural communities in identifying problem priorities, existing coping mechanisms, seeking possible solutions and ensuring that community institutions and organisations have participated in planning, and implementation and evaluation process. The preparation of joint reports and publications was given priority in ensuring capacity building of local organisations. Draft Best Practice Guidelines on soil, water and weed management and knapsack use were presented and discussed at the 2002 end of project Workshop and subsequently modified before wider distribution. These are now being used by stakeholders in further dissemination of outputs through project R8191.

OUTPUTS

The research results and products achieved by the project. Were all the anticipated outputs achieved and if not what were the reasons? Research results should be presented as tables graphs or sketches rather than lengthy writing and provided in as quantitative a form as far as is possible.

Understanding the impact of weeds in cotton production and the opportunities for and constraints to improved weed management

Critical time of weeding trials

Trials at Mafudzi school indicated that for the farmer to avoid significant yield loss it was necessary to maintain the crop weed-free during the period from 2 – 8 weeks in the 2000-1 season and from 2 – 6 weeks in 2001-2. There was an increase in the cotton yield, ball mass and plant height as the period of weed competition was reduced. Increasing the time of weed interference increased the weed biomass and weed density while the yield decreased. To avoid significant yield loss farmers in Muzarabani need to begin hand or draft animals weeding by 2 weeks after crop emergence or apply a pre-emergence herbicide, which will suppress weed growth from planting. The trial results indicate that weeds should be controlled for up to the first 10 weeks and 6 weeks of crop growth in wetter season and drier season respectively. Thereafter there is less competition as the crop provides increasing ground cover and weeds receive less light. It will be uneconomic to weed after this time, as a further increase in duration of weed free days does not influence final yield with the greatest returns from weeding being in the first in the first 6-10 weeks after planting depending on the rainfall pattern (Table 28, Figures 1 and 2).

Table 28. Yields of cotton under various weeding regimes and partial budgets for cotton production during for the 2000-1 and 2001-2 seasons

Treatment	2000-1			2001-2		
	Seed Cotton yield (kg/ha)	***Yield increase(kg)***	***Yield benefit Z$/ha***	***Seed Cotton Yield (kg/ha***	***Yield increase (kg)***	***Yield benefit (Z$/ha)***
Weed free then weedy						
T1 2 weeks	524	0	0	199	0	0
T2 4 weeks	881	357	21420	336	137	8220
T3 6 weeks	1886	1005	60300	556	220	13200
T4 8 weeks	2368	482	28920	640	84	5040
T5 10 weeks	2702	334	200400	747	107	6420
T6 12 weeks	2535	-167	-10020	1062	315	18900
Weedy then weed free						
T7 2 Weeks	2729	780	46800	818	531	31860
T8 4 Weeks	1949	-62	-3720	287	204	12240
T9 6 Weeks	2011	1035	62100	83	45	2700
T10 8 Weeks	976	130	7800	38	-22	-1320
T11 10 Weeks	846	185	11100	60	32	1920
T12 12 Weeks	661	0	0	28	0	0
Significance	0.001	-	-	<0.01	-	-
s.e.d (df)21	550.6	-	-	181.1	-	-
L.s.d	1101.2	-	-	362.2	-	-

Cotton price=Z$60 per kg

In 2000/1-losses per ha for not weeding in the first two weeks were Z$46800 increasing to Z$62100 if no weeding is undertaken in the first six weeks, representing over one tonne of cotton (Table 11). In 2001/2-losses per ha were Z$31860 when weeding was delayed for two weeks, increasing to Z$44100 when weeding is delayed four weeks and Z$46800 after 6 weeks representing 880 kg of cotton lost if no weeding in the first six weeks. This represents the cost of not weeding and indicates the amount that could be spent on weeding to avoid such losses

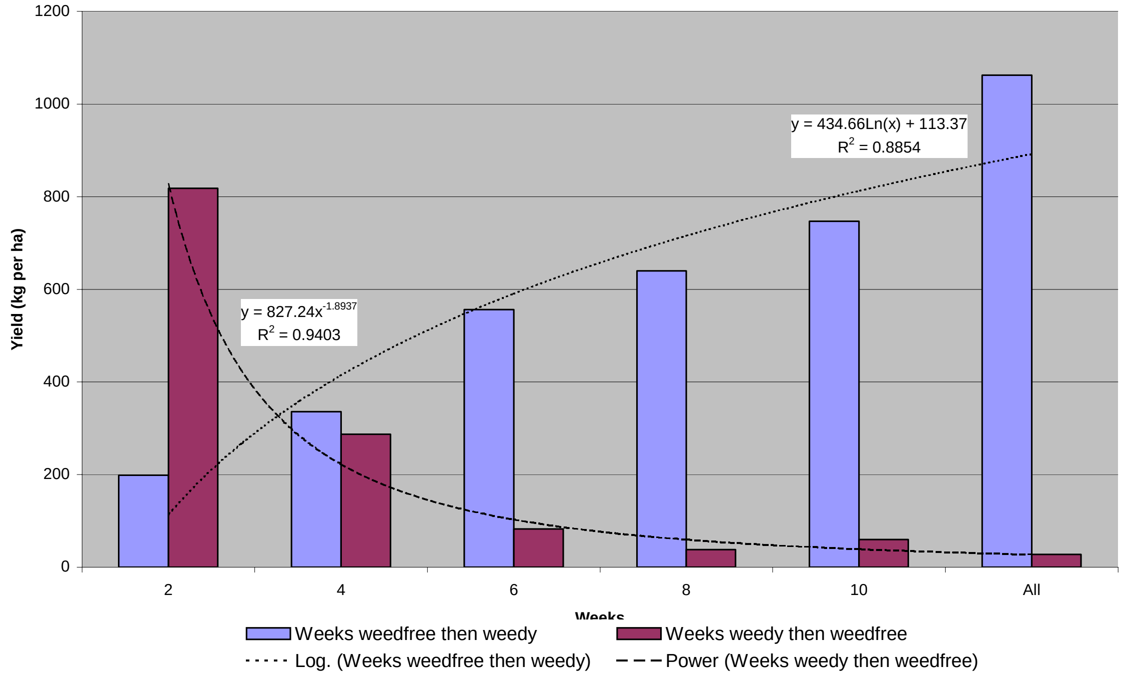


Figure 1: *Cotton yields (2002) with trend lines*

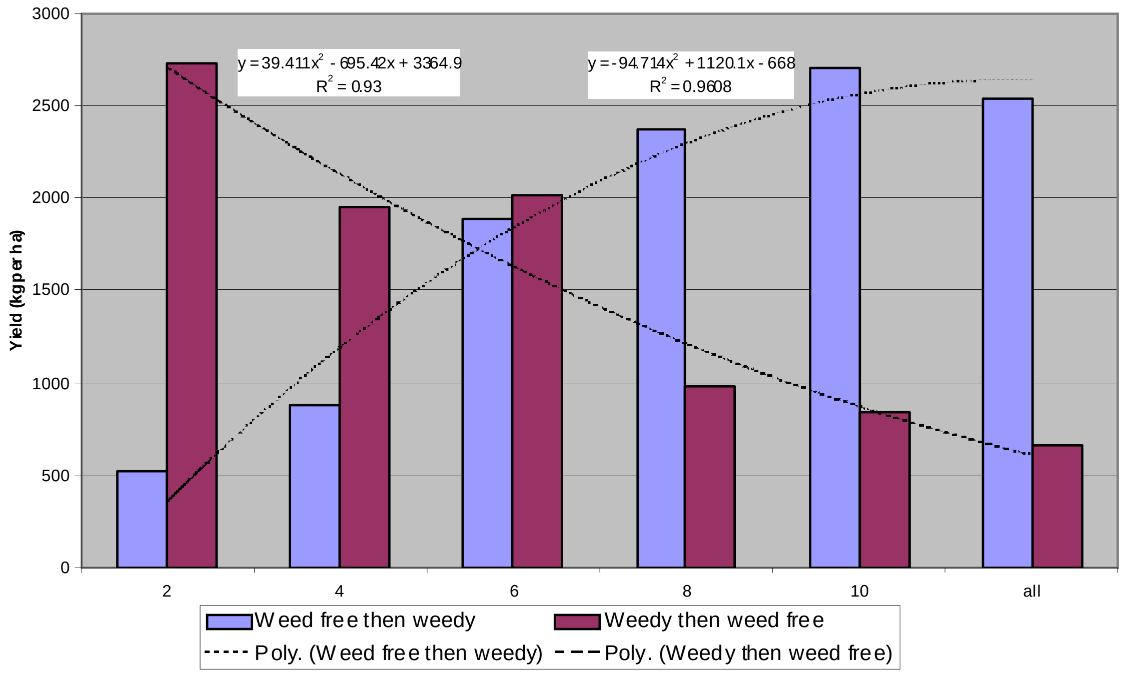


Figure 2: *Cotton yields (2001) with trend lines*

Identifying options and constraints for improved weed management

There are two components to the weed problem in cotton in Muzarabani. On the one hand farmers are unable to weed all the land that is planted and so fail to realize harvest on substantial areas. Secondly yield reduction due to weeds exists on fields that are weeded suggesting that with current practices farmers are unable to prevent weed competition effectively. Through farmer group discussions, it became clear that both components are related to a shortage of draught animals and labour for weeding. The series of trials detailed on page 16 have sought to evaluate a number of alternative weed control practices, which can alleviate these constraints. However, in field trials on relatively small plots, labour and draught availability is not an issue. The trials undertaken can only, therefore, provide an indication of the efficacy of different methods in terms of weed control and cotton yield performance when these are implemented in a timely manner. All of the methods tested resulted in adequate weed suppression during the critical period of two to eight weeks after crop emergence when the cotton crop is at most risk from weed competition (Mavudzi *et al*., 2002). Weed densities prior to weeding operations at 3 and 6 weeks after cotton emergence never exceeded 20 plants per m^{-2}. Weed dry weights were below 85 g m^{-2} with the exception of one treatment in the mother trial at Mafudzi trial. in 2001-02. This was the only site * season combination in which weed pressure was great enough to impact significantly on yield. In this case mean weed dry weight on plots weeded with a cultivator at 3 weeks followed by hand hoeing at later weeding dates was in excess of 130 g m^{-2} at 6weeks after planting. The resulting seed cotton yield of 363 kg ha^{-1} was the only case in which yield was below 450 kg ha^{-1} across all treatments in all trials. In general therefore cotton crops were protected from weed competition and yield loss by all of the practices or combinations of the practices tested. Weed counts and biomass assessments indicated a significant advantage for treatments including a pre-emergence herbicide e.g. in the on-farm trials on plots for which the herbicide was followed up by inter-row weeding with a cultivator or plough from which the mouldboard had been removed, or when herbicide application was compared to hand weeding. This suggests that use of the herbicide at planting will reduce subsequent labour requirements for weeding when this is to be done with a hoe. The better weed suppression during the first three weeks of the season may also increase the time "window" before it is necessary to begin a second weeding with animal draught, although this would need to be confirmed in the field and may depend on soils moisture conditions. Previous work (Riches *et al*., 1997) has emphasised that weeding with a plough with the mouldboard in place is useful for enhancing soil moisture conservation as well as providing a labour efficient weeding option. In the current trials there was also indication of higher yields where the plough was used for weeding compared to other methods.. It is interesting to note however that in both seasons weed biomass at 6 weeks was higher on plots weeded with a plough with body compared to where the plough was used after removal of the body. This may indicate that weeds were able to exploit greater moisture availability and hence grow larger on plots that were "ridged" with the unmodified plough.

Innovative options for crop and weed management identified

Weed management

The trials have demonstrated that weeds can be adequately suppressed in cotton by timely use of a number of herbicide and non-herbicide weed control methods (Table 29). The method of choice will be influenced by the resources available to the farmer, in particular access to draught animals and implements, the availability of labour (household supplied or hired) and, cash for hiring that labour or for purchasing herbicide.

Table 29: Average yields for each treatment (before adjustment) for non-mechanical and mechanical for mother and daughter trials (kg per ha)

Treatment			Mother trials[1]		Daughter trials[2]	
			2000/2001	**2001/2002**	**2000/2001**	**2001/2002**
1	Non mechanical	HH-	1833	516	1461	917
2		Hca, HH	1583	620	1712	788
3		HH, Hc	1875	987	1428	794
4		Hca	1333	468	1625	873
		Average	**-**	**-**	**1557**	**843**
	Significance				ns	ns
	Sed				165	132.9
5	Mechanical	HH, OC. HH	1500	948	1812	981
6		OC. HH	1667	363	1910	1077
7		OP+D, HH	1625	485	2001	938
8		OP-D, HH	-	-	1806	902
9		Hca, OP+D, HH	1792	432	1945	1020
10		Hca, OP-D, HH	-	-	2100	863
11		Hca, OC, HH	1208	535	1940	997
		Average	**1602**	**595**	**1931**	**968**
	Significance		ns	*	ns	ns
	Sed		292.6	184.9	0.1495	0.1137
	Lsd		585.2	369.8	546	615

HH= Hand Hoe, Hca =Herbicide (cyanazine and alachlor), Hc =Herbicide (cyanazine),
OP =Ox Plough, D= minus Dish or mouldboard, +D =with Dish or mouldboard, OC=Ox Cultivator,
- = Treatment not applied

[1] Trials undertaken on land provided by Mafudzi School, being effectively on-station researcher managed with average yields cover both non-mechanical and mechanical weeding options

[2] Average for 8 farmers, on-farm researcher managed trials with average yields shown separately.
ns=not significant, *=P<0.05

The price of cotton in 2002 was Z$ 60 per kg, made up of an early payment of Z$45 and a later payment of Z$15 per kg.

Input Costs

Labour for hand weeding

Farmers either use household labour (1st preference) or hired labour (2nd preference) for weeding purposes. Farmers negotiate the prices they pay for weeding based on 70 metre rows. Rates are highly negotiable and can be paid either as cash, food or in exchange for ploughing or cultivating with oxen.

In the first season, although farmers took measurements of the time they took to weed each plot at each weeding, these figures were difficult to interpret and were discarded for analysis purposes. In the second season, a research assistant recorded the time taken for weeding on six selected farms, three non-mechanical and three mechanical. Two of the three weedings were recorded, the third weeding being unrecorded due to political problems in the area at this time. Farmer's estimates for the third weeding, being half the time of the second weeding, were therefore used for analysis purposes. Weeding times proved to be highly variable between farms, being largely related to weed density at the time of weeding (Figure 3). These labour hours have been valued at the local daily rate converted to hours for hiring general labour. The 2002 rate was $200 per day ($33 per hour) in cash and Z$ 100 in kind (food, or exchange in kind). The time of weeding measured in the second year has been applied to both seasons.

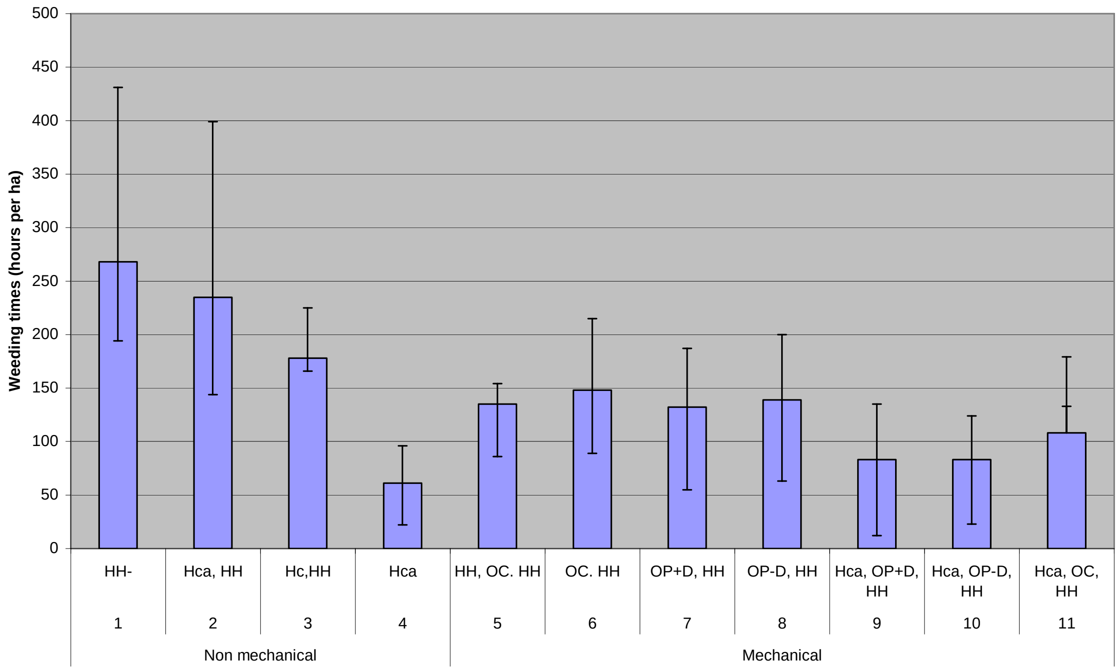


Figure 3: Average labour required for weeding showing low and high range for each treatment (hours per ha)

DAP weeding costs

These were based on 2001-02 market prices for undertaking contract weeding work. Where household supplied DAP was used, this has also been costed at contract prices (Table 30). This does not take into account actual rates of work or power requirements as determined by Sibanda *et al*., (2002), but reflects the market for each operation.

Table 30: Contract rates for weeding with DAP implements in Muzarabani (Z$)

Implement	Per ha	Per acre
Cultivator	1750	700
Ox plough (- dish)	3500	1400
Ox plough (+ dish)	3500	1400

Herbicide costs

Herbicide costs have been based on market prices in November 2001 (Table 31). Most farmers already own a knapsack for spraying insecticides and will only incur additional costs of purchasing herbicide nozzles and some additional maintenance costs and not the full costs as shown.

Table 31: Herbicide and sprayer prices (Z$) in Muzarabani, November 2001.

Item	Rate- (litres/ha)	Cost per litre	Full application	Band application[1]
Cyanazine	1.1	2491	2740	1262
Alachlor	2	951	1902	913
Knapsack[2]			800	800

[1]Band width = 0.30m
[2]Knapsack Purchase price = Z$10000 with a lifespan of 5 years (annual cost or depreciation = Z$2000), interest at 25%, therefore Z$1250 per year. Annual maintenance 10% of purchase price= Z$1000 per year. Total annual cost=Z$4000. Total annual cost per ha over 5 ha Z$ 800.

It should be noted that there has been a rapid escalation in herbicide costs (relative to the price of cotton), along with that of other purchased inputs over the life span of the project and that this is expected to continue for the foreseeable future.

Total costs
The total costs for each treatment indicate that the lowest cost options are an overall herbicide and herbicide with hand hoeing in the non-mechanical category and hand hoe with ox-cultivator in the mechanical categories.

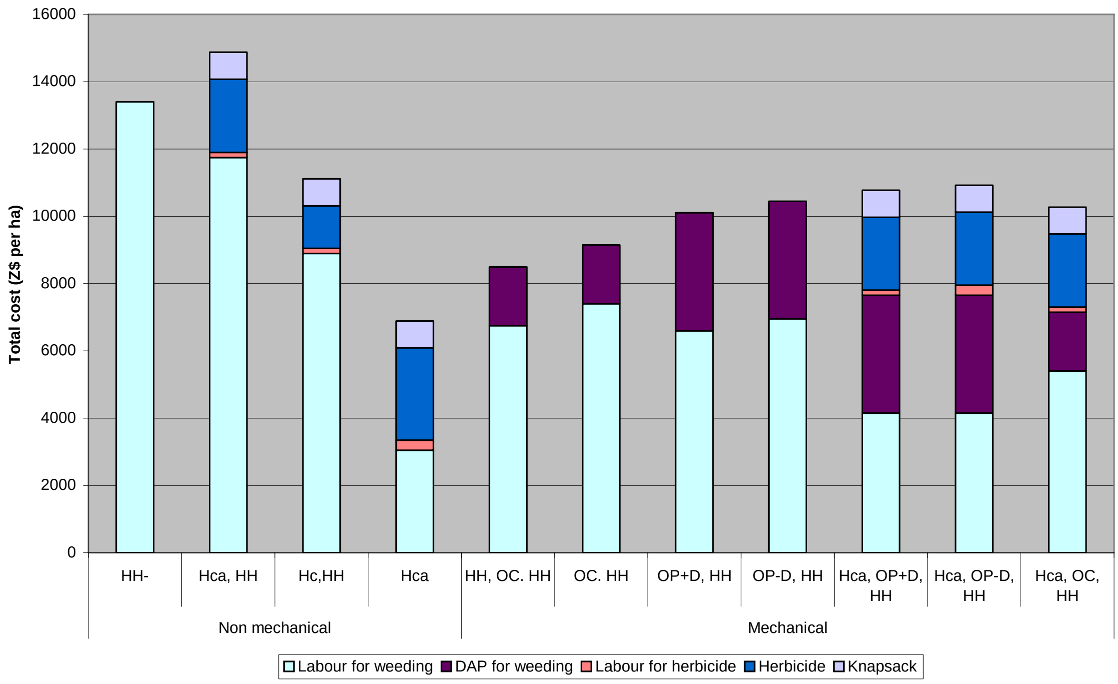


Figure 4: Total costs of weed management options

This analysis presupposes that labour and draft animals are actually available when required, which in practice may not be the case. The time of weeding trial (Mavudzi *et al*., 2002) indicates that the indirect cost of not weeding to be far in excess of even the highest direct costs incurred (Figure 4). Weeding late or missing a weeding can mean severe yield penalties and hence financial losses. For example, failing to weed for 4 weeks, a common practice, can incur a yield loss of up to 60% of the potential yield (Figure 5).

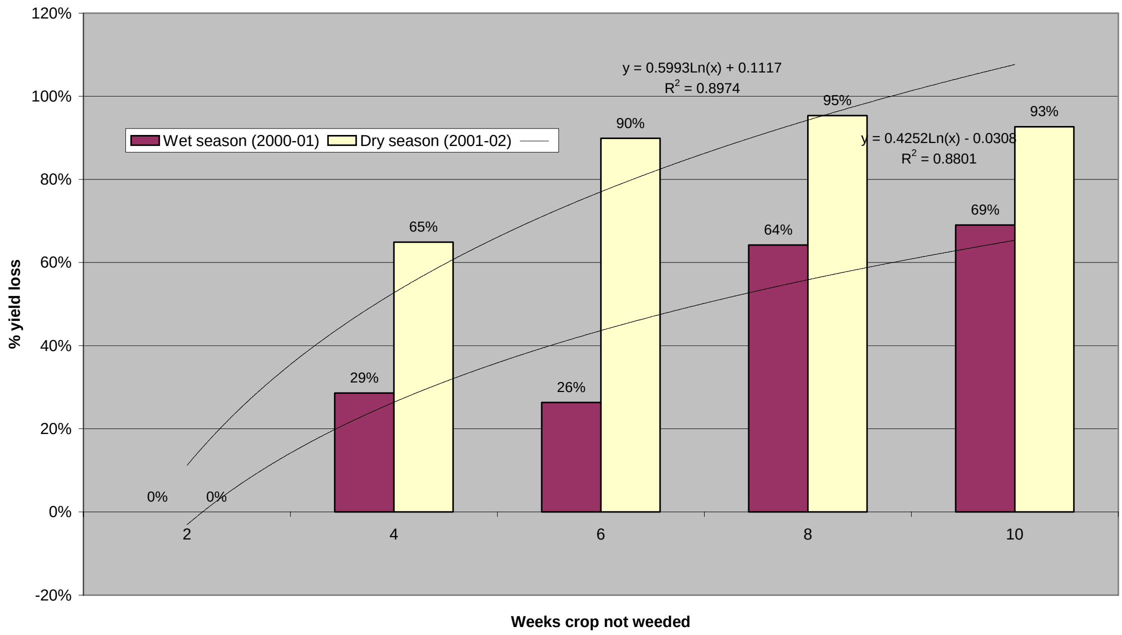


Figure 3: Percentage cotton yield losses (2001 and 2002)

When these percentage losses are applied to average yields achieved in 2001 and 2002, over 300kg per ha, valued at nearly Z$ 20000 per ha, will have been foregone. This is sufficient to pay for even the most expensive weed management option shown in Figure 3. The cost of having to abandon land due to weeds is far greater and can amount to a total loss in yield valued at over Z$ 70000 in a good (wet) season and nearly Z$36000 in a dry season (Table 32). In addition there will be loss of the value of labour and purchased inputs used to establish the crop.

Table 32: Yield and financial losses as a result of not weeding (Z$ per ha)

Weeks crop not weeded	Crop yield loss (kg per ha)			Crop value loss (Z$ per ha)		
	2000-01	***20001-2***	***Average***	***2000-01***	***20001-2***	***Average***
	Wet season	***Dry season***		***Wet season***	***Dry season***	
2	0	0	0	0	0	0
4	320	357	339	19224	21420	20322
6	641	476	558	38448	28560	33504
8	961	565	763	57672	33915	45794
10	1121	595	858	67284	35700	51492
All	1202	595	898	72090	35700	53895
Average yield	1602	595				

Partial budget analysis for both mother and daughter trials for each season (Ellis-Jones *et al.*, 2002) reflect yields adjusted for any significant differences in mean treatment yields and indicate the most appropriate weeding option provided there is no shortage of resources.

In the first season, there were no significant differences in yields. HH and OCHH required the most labour and Hca and OP+D, HH least labour in non-mechanical and mechanical methods respectively. OP+D (or–D), HH required the most DAP. Lowest overall cost giving greatest returns to labour was Hca in non-mechanical weeding. For mechanical weeding lowest overall cost was HH, OC, HH but Hca, OP+D, HH gave the highest returns to labour.

In the second season, Hca again gave the lowest overall cost and highest returns to labour. For mechanical weeding HcHH and HH, OC, HH gave significantly higher yields, probably due to the drier season and more effective capturing of rainfall within the soil before run-off.

As a result these two options gave the greatest net benefits (benefits less costs). Hca still however gave the greatest returns to labour.

On the on-farm daughter trials in the first season, there were no significant differences between yields. Hca and Hca, OC, HH were the lowest cost weeding options giving the highest productivity for non mechanical an mechanical weeding options respectively. Highest returns to labour were derived from Hca and OP+D (or-D), HH. The second season gave similar results. Again there were no significant differences between yields. As in the first season Hca and Hca, OC, HH were the lowest cost weeding options with highest productivity being achieved with Hca and HH, OC, HH. Highest returns to labour were derived from Hca and OP+D (or-D), HH.

Sensitivity analysis indicates that the price and hence the availability of labour is key. When this is easily available (or not valued) traditional farmer systems (HH and OC, HH) are the most productive. As the labour price increases, due to unavailability or opportunity elsewhere, herbicide systems become more productive. The research confirmed that timely weed management is essential to achieving higher productivity. Weeds can be economically controlled by a number of different weed management strategies, which include use of herbicides, hand hoe, ox plough (with or without the dish) or ox cultivator or an integration of these methods. The cost of failing to weed is greater than even the most costly of the options available

Results are summarised according to possible farmers' objectives (Table 33). If the farmer wants to maximise yields, there is little difference to choose between weeding methods, although on the mother trial in the second (dry) season, soil disturbance to maximise rainfall capture was important, showing the value of Hc, HH and HH, OC, HH options. Where labour is limiting Hca and Hca, OP+D, HH should be considered. Lowest overall weeding cost (labour and herbicide) and greatest productivity is achieved with Hca and HH, OC, HH. Highest returns to labour are given y Hca and Hca, OP+D, HH in a wet year and HH, OC, HH in a dry year.

The strategy best adopted is dependant on the household resources available (Table 34). RG1s, who have 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. Those with limited DAP in RG2s and RG3s should consider using a herbicide in combination with an ox plough. RG4s with limited labour and DAP need to consider the use of a herbicide (either Hca or HH, Hc) or reduce the area that they cultivate.

Table 33: Weeding option most appropriate to farmers' objectives

	2000-01		*2001-02*	
	Mother	***Daughter***	***Mother***	***Daughter***
Highest production				
Non mechanical	Ns	ns	Hc, HH	ns
Mechanical	Ns	ns	HH, OC, HH	ns
Lowest labour				
Non mechanical	Hca	Hca	Hca	Hca
Mechanical	Hca, OP+D, HH	Hca, OP+D, Hh	Hca, OP+D, HH	Hca, OP+D, HH
Lowest cash investment				
Non mechanical	HH	HH	HH	HH
Mechanical	HH, OC, HH	HH, OC, HH	HH, OC, HH	HH, OC, HH
Lowest weeding cost				
Non mechanical	Hca	Hca	Hca	Hca
Mechanical	HH, OC, HH	HH, OC, HH	HH, OC, HH	HH, OC, HH
Highest productivity				
Non mechanical	Hca	Hca	Hca	Hca
Mechanical	HH, OC, HH	HH, OC, HH	HH, OC, HH	HH, OC, HH
Highest returns to labour				
Non mechanical	Hca	Hca	Hca	Hca
Mechanical	Hca OP+D HH	Hca OP+D HH	HH, OC, HH	HH, OC, HH
Lowest risk				
Non mechanical	HH	HH	HH	HH
Mechanical	HH, OC, HH	HH, OC, HH	HH, OC, HH	HH, OC, HH

Table 34: Weed management options for different resource groups

	Resource category				
	RG1	**RG2**	**RG2/3**	**RG2/3**	**RG4**
Resource availability					
Labour	Unlimited	Limited	Limited	Unlimited	Limited
DAP	Unlimited	Unlimited	Limited	Limited	Limited
Implements					
Hand hoe	X	X	X	X	X
Ox plough	X	X	X	X	
Ox cultivator	X	X			
Weed management options					
HH	X			X	
Ox plough	X	X	X		
Ox cultivator	X	X			
Herbicide	X	X	X	X	X
Reduce area	X	X	X	X	X

It will be important that every assistance is given to farmers as they try out these new options, that they be given the opportunity to learn how and when to apply the different herbicides that are available, which should include the use and maintenance of knapsack sprayers.

Assessment of land preparation and weeding implement options

The results of the trials (Tables 20-27) have been summarised according to their implications for farmer management practices (Table 35)

Table 35: Implications for trial results for management practices

Parameters	Best		Worst
Yields	***Highest-1***	***2***	***Lowest-3***
Land preparation	WP	SP	
Crop establishment	-	-	-
Weeding implement	OP+D	OP-D	OC
Use of herbicide	Yes	No	
Weed count	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	-	-	-
Weeding implement	OP+D	OP-D	OC
Use of herbicide	Yes	No	
Work rates-DAP	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	-	-	-
Weeding implement	OP+D	OP-D	OC
Use of herbicide	Yes	No	
Work rates-hand hoe	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	-	-	-
Weeding implement	OP+D	OP-D	OC
Use of herbicide	Yes	No	
Draught force	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	OPFP	RIP-	-
Weeding implement	OP-D	OP+D	OC
Use of herbicide	Yes	No	
Soil moisture content	***Highest-1***	***2***	***Lowest-3***
Land preparation	WP	SP	
Crop establishment	OPFP	RIP-	-
Weeding implement	OP-D	OC	OP+D
Use of herbicide	Yes	No	
Bulk density	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	OPFP	RIP-	-
Weeding implement	OP-D	OP+D	OC
Use of herbicide	Yes	No	
Penetration resistance	***Lowest-1***	***2***	***Highest-3***
Land preparation	WP	SP	
Crop establishment	OPFP	RIP-	-
Weeding implement	OP+D	OP-D	OC
Use of herbicide	Yes	No	

WP=Winter plough, SP=Spring plough, OPFP=Open plough furrow plant, OP+D=Ox plough plus dish (mouldboard) OP-D=Ox plough minus dish (mouldboard), OC =Ox cultivator

The main conclusions from this work are as follows:

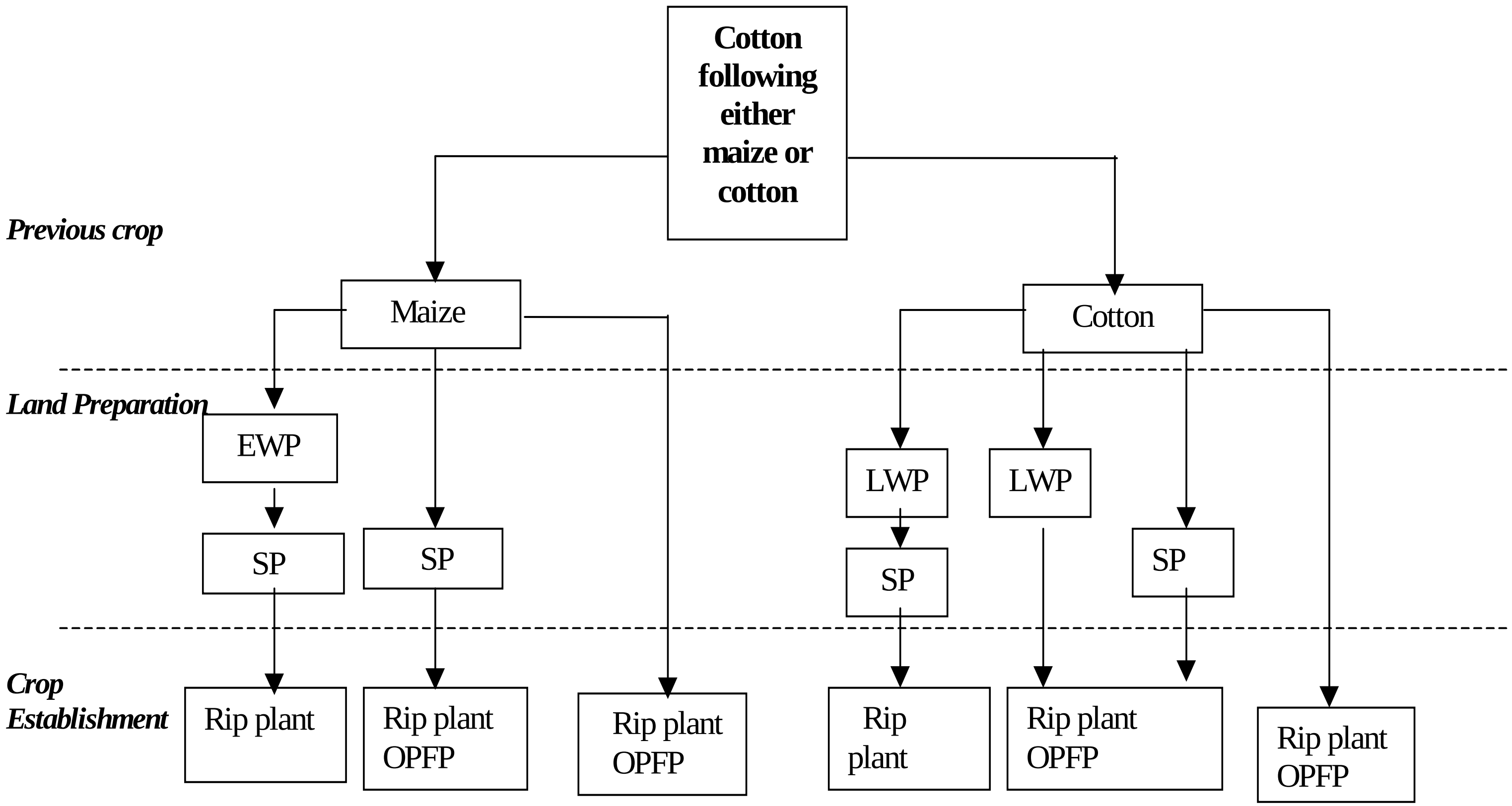
i) The results clearly indicate that ploughing land in winter is an effective land preparation technique for a number of reasons. Firstly, the subsequent draught power requirements at weeding are reduced, therefore the efficiency to be gained from the draught animals will be greater. Work rates are also reduced during weeding, meaning that the operation can be carried out in a shorter time, thereby freeing up time for other activities, such as attending to the maize crop. Winter ploughing also helps to reduce the weed burden, particularly during the early part of the season. This is an important factor to bear in mind when dealing with a weed-sensitive crop such as cotton, and again, helps to facilitate more time for other on-farm or off-farm activities. The results also show that soil moisture levels under winter ploughed land are higher throughout the season, particularly important during droughty periods as were experienced in the second season. Such differences in weed density and moisture retention will have been contributory to the higher yields achieved on the winter ploughed plots compared to the spring ploughed plots. The main limitation with this technique is that it is most appropriate following a maize crop rather than a cotton crop, since harvests of the latter crop is usually not completed until May/June. By this time, the animals will be in a poorer condition to carry out any ploughing operations, therefore spring ploughing may be the only option available.

ii) The second conclusion that can be drawn from this work, corroborating the results that were presented from the on-farm and on-station weeding trials, is the advantage to be gained in applying herbicide to the cotton crop. This results in a significantly reduced weed burden, much reduced supplementary hand weeding and thus higher moisture retention in the soil (as there are less weeds to take up water). These factors resulted in a higher cotton yield under the herbicide treated plots, approximately 9% higher in the first season, and 14% higher in the second season, when moisture levels were more limiting. However, presently farmers have little knowledge of herbicides and will require a continuation in training for handling and effective application

iii) Although the ox cultivator was shown to require fewer hours to carry out weeding operations compared to the two plough options, the draught power requirement is significantly higher. Furthermore, the efficiency with which the implement clears weeds is less than the plough, as demonstrated by both the additional time required for supplementary hand weeding and higher weed counts. Therefore, for farmers without a cultivator, the plough represents a viable tool with which to carry out weeding inter-row. Furthermore, the results of soil moisture content under the plots weeded with the plough with mouldboard suggest this technique is advantageous for its ability to increase moisture retention compared to the cultivator and the plough without the mouldboard. The greater degree and depth of disturbance afforded by the plough will have created a soil surface more receptive to rainfall, similar to ridge and furrow landform. This attribute is especially important during droughty spells, as in the 2001/02 season, and will have likely contributed to the significantly higher cotton yield achieved under the OP compared to OC and OP-D. However, caution should be exercised in promoting and using this technique, to ensure that risk of soil erosion from the increase in soil disturbance is minimised. This can be achieved by making sure that panting is carried out along the contour.

iv) The experiment clearly demonstrated that 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.

Figure 4 summarises the land preparation and crop establishment options for cotton available to farmers, whether it follows maize or whether it follows cotton in the rotation.



EWP = Early Winter Ploughing
LWP = Late Winter Ploughing
SP = Spring Ploughing
OPFP = Open Plough Furrow Planting (no dish)

Figure 4: Options for land preparation and crop establishment

The strategy best adopted is again dependent on the household resources (Table 36). RG1 and 2s, who have greatest access to DAP, have therefore the largest number of options from which to choose. RG2s with limited DAP are likely to select SP and OPFP, although reciprocal arrangements may give them access to DAP for EWP or LWP. Those with limited DAP in RG3s and RG4s should consider using OPFP in combination with a herbicide.

Table 34: Weed management options for different resource groups

	Resource category				
	RG1	**RG2**	**RG2/3**	**RG2/3**	**RG4**
Resource availability					
Labour	Unlimited	Limited	Limited	Unlimited	Limited
DAP	Unlimited	Unlimited	Limited	Limited	Limited
Implements					
Hand hoe	X	X	X	X	X
Ox plough	X	X	X	X	
Ox cultivator	X	X			
Land preparation and crop establishment options					
EWP	X	X	(X)		
LWP	X	X	(X)		
SP	X	X	X		
OPFP	X	X	X	X	X
RIP	X	X			

It will be important that every assistance is given to farmers as they try out these new options, that they be given the opportunity to learn how and when to apply the different herbicides that are available, which should include the use and maintenance of knapsack sprayers.

Promotion and dissemination of findings

Research findings promoted

Research findings were promoted through the mid season field days and end of season annual project workshops, the proceedings from which were widely distributed. Additionally, presentations on the results from the project have been made at international conferences (Mavudzi *et al*., 2001; Sibanda *et al*., 2002) and appropriate publications.

Best Practice Guidelines on soil, water and weed management and knapsack use were prepared in draft for discussion at the 2003 Workshop and subsequently modified before wider distribution to extension workers through project R8191.

Developing collaborating institution’s capacity

Collaborating institutions have worked with rural communities in identifying problem priorities, existing coping mechanisms, seeking possible solutions and ensuring that community institutions and organisations have participated in planning, and implementation and evaluation process. The preparation of joint reports and publications was given priority in ensuring capacity building of local organisations

Dissemination of best practice guidelines

Best practice guidelines for crop, weed, soil and water management in cotton were developed and are now being used by stakeholders in extension of the project findings elsewhere within Zimbabwe.

CONTRIBUTION OF OUTPUTS TO DEVELOPMENTAL IMPACT

Include how the outputs will contribute towards DFID's developmental goals. The identified promotion pathways to target institutions and beneficiaries. What follow up action/research is necessary to promote the findings of the work to achieve their development benefit? This should include a list of publications, plans for further dissemination, as appropriate. For projects aimed at developing a device, material or process specify:

The ultimate beneficiaries of the work undertaken by this project are small-scale farmers and their families who should have access to a greater range of options for maintaining or improving their crop productivity. This will lead to a strengthening of the rural economy with consequent advantages to local artisans and traders. By approaching crop production constraints systematically, the impact of different soil and water management practices on crop establishment and weeding has been evaluated. The opportunity to use these practices should reduce the labour demand for weeding and hence the burden on women and children, providing them with more time for other household duties. There is considerable inter-household variability in access to both draught animal power and labour. These are key determinants of the ability to weed on time - as much as 35% of the community, the poorest households, do not have access to adequate levels of these resources, neither do they have sufficient cash to hire labour or purchase herbicides (Ellis-Jones *et al*., 2001). It is therefore recognised that some of the technologies developed by this project do not have general application in the farming community. For all farmers to benefit equally may require institutional change which is beyond the scope of this project. However, no negative impact on any particular group is foreseen. The displacement of labour through herbicide use is not anticipated as any reduction in labour for weeding will relieve "bottlenecks" and provide labour for other farm or non-farm enterprises.

The project has identified three options for reducing the impact of weeds in cotton production systems: through 1) using herbicides either on their own or 2) integrated with hand hoeing, ox-drawn cultivator or plough and 3) early ploughing. Hand hoeing and ox cultivator remain the lowest cost options, but are not feasible over large areas given labour and draft animal shortages. Option 3 remains low cost but has practical limitations, in that it can only be used by those with access to draft power and only after a maize crop. Option 1, although best suited to those with least labour and draft (the poorest resourced) requires herbicides to be available, cash investment and training in the use of herbicide technology. It is therefore likely to be used only by those who can access and afford the chemical. Integrating herbicides with hand hoe or draft animal weeding offers the best option for most farmers.

Intermediate users (development organisations, extension workers and researchers) have benefited from the knowledge generated both from the participatory process as well as the development of alternative soil, water, weed and alternative crop production practices. This has increased awareness on the constraints faced by farmers and the process is already being used to promote wider farmer testing of technology options, facilitated by extension and development organisations.

The dissemination of improved weed management systems has contributed to improved productivity of smallholder cotton systems and has alleviated a major production constraint identified by farmers. The adoption of low cost, labour efficient weeding practices in cotton should release resources for other crops, particularly maize production, in addition to non-farm activities. The combination of these outcomes in the long term should raise household incomes and improve basic food security. It is envisaged that the drudgery associated with hand weeding, frequently carried out by women and children, should be alleviated.

The greatest threat to adoption of these technologies is the rapidly deteriorating economy and the on-going drought situation within the country.

HOW THE OUTPUTS WILL BE MADE AVAILABLE TO INTENDED USERS?

Research outputs from this project, as well as other CPP funded projects undertaken in Zimbabwe over the period 1996-2002, are being promoted through a CPP-funded dissemination project R8191, communicating the knowledge gained to stakeholders, including extension workers and farmers. It is an enabling project led by the University of Zimbabwe, that involves a number of NGOs, on-going development projects and commercial companies in developing a process for demonstration and further testing of a range of crop establishment and weed management technologies, targeted at poor farmers in the small scale sector. It incorporates a process for scaling-up aiming to improve the capabilities of participating organisations though improved research-extension-farmer-private sector linkages. This aims to improve access by farmers to information about technologies which can lead to increased crop yields, sustainable crop production, environmental conservation, increased income generation and improved livelihoods options

It is now accepted by many agricultural development agencies, that farmers need to be provided with a basket of technology options for testing on their own fields rather than prescriptive recommendations as was the case in the past. The latter approach did not result in farmers adopting some of the technologies as the socio-economic situation and knowledge base of the farmer tended to be ignored. Crop establishment and weeding options tested on-farm by this project as well as R6655 were being used outside the trial plots by some collaborating farmers when the project ended and there has been limited exposure to some communities by AREX (Chikwanda *et al*., 2002). The Mashonaland East Province AREX management team have also indicated the need for this project to assist with their extension efforts in promoting wider testing of sustainable cotton production practices and to scale up promotion of new weeding techniques The project is fully supported by University of Zimbabwe, which will coordinate activities and is already working with various developmental agencies in the smallholder farming sector

The project will involve staff with a range of relevant skills from a number of institutions, which have recent proven track records working on projects supported by DFID funds.

The University of Zimbabwe (UZ) has wide experience of undertaking adaptive research and community-based developmental projects within the rural areas of Zimbabwe. They also run short-term courses related to technologies for the smallholder farming sector. This includes an on-going programme on farmer participatory on-farm trials of weeding practices for wetlands in Masvingo Province. Staff who contribute to this, include weed scientists Prof O Chivinge (Dean, faculty of Agriculture), AB Mashingaidze (Crop Science Department) and soil scientist and NR Specialist, Edward Chuma (Soil Science Department). AREX in Mashonaland East are keen to use Participatory Extension Approaches (PEA) and has staff available in their information and training branch with expertise in the preparation and publication of information leaflets and booklets.

COTTCO, a private company operating in both Masvingo and Muzarabani, is active in promoting cotton through a strong extension programme providing individual and group loans to cotton producers and also provide training on various aspects of cotton production and marketing. They have already agreed to provide loan finance for the purchase of herbicides in the Zambezi valley. AGRICURA and MONSANTO are major suppliers of crop chemicals in Zimbabwe and are expected to participate in the project in the development and printing of information for delivery to farmers through the supply chain.

SRI (Jim Ellis-Jones, leader R7473 and R7474) and NRI (Charlie Riches, leader R5742, R7189 and R6655), will provide back-stopping on tillage, crop management and socio-economics aspects of information to be produced by the project. Nicola Harford, a communication specialist based in Harare who has recently assessed agricultural information sources in Masvingo for CARE, will provide support on ensuring appropriate communication strategies are used.

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Listing and reference to key datasets generated:

All datasets collected during the project are available electronically and are included with the Final technical report.

Biometricians Signature
The projects named biometrician must sign off the Final Technical Report before it is submitted to CPP. This can either be done by the projects named biometrician signing in the space provided below, or by a letter or email from the named biometrician accompanying the Final Technical Report submitted to CPP. (Please note that NR International reserves the right to retain the final quarter's payment pending NR International's receipt and approval of the Final Technical Report, duly signed by the project's biometrician)

I confirm that the biometric issues have been adequately addressed in the Final Technical Report:

Signature:

Name (typed): Rodger White

Position: Biometrician

Date: January 2003

R7474 Project Logical framework

Narrative Summary	Objectively Verifiable Indicators	Means of Verification	Important Assumptions
Goal			
Impact of significant pests of cotton systems minimised	To be completed by Programme Manager	To be completed by Programme Manager	To be completed by Programme Manager
Purpose			
Integrated cotton pest management needs assessed, and strategies developed and promoted.	To be completed by Programme Manager	To be completed by Programme Manager	To be completed by Programme Manager
Outputs			
1.Understanding of the impact of weeds in cotton production in Muzarabani and of the opportunities for and constraints to improved weed management. 2. Evaluation of innovative options for crop and weed management identified using a combination of traditional and scientific knowledge. 3. Promotion and dissemination of findings	1. Characterisation of traditional crop, weed and land husbandry practices and adoption constraints compiled by Sept 00. 2. Appropriate crop and land husbandry solutions identified by Dec 00. Improved practices established and adopted/adapted by March 03 3. Findings promoted through field days, workshops, and popular and refereed publications.	Project reports Reports of collaborating institutions Publications in popular and scientific publications Information generated used in the design of extension materials.	-Stakeholders involvement from the initial design of the project, through implementation will facilitate achievement of this Output.
Activities	**Inputs**	**Means of Verification**	**Important Assumptions**
1.1 Planning meeting including identification of participating farmers 1.2 PRA of farmers' perceptions of weed management and crop production techniques, institutional constraints and the farmers decision making process, (Will include farmer visits to the cotton growing areas of Sanyati and Gokwe) supported by surveys to characterise biophysical and socioeconomic issues and constraints, with a specific focus on weed management. 1.3 Assess strengths and weaknesses of current dissemination methods. 1.4 Review workshop with all project Stakeholders to identify possible points for interventions relative to resource status (economic and biophysical) of households.	**£267,541**	1.1 Proceedings of planning meeting available Dec 99. 1.2 Surveys and diagnostic evaluations completed by Dec 2000. Literature survey, surveys and discussions with stakeholders compiled into a report April 2000. 1.3 SWOT analysis completed by July 00. 1.4 Workshop held Aug 00 and Proceedings April 01. Draft detailed work programme by Sept 00.	-Climatic conditions favourable - Farmers are willing to participate in diagnostic surveys and evaluations - Suitable in-country stakeholders from extension, research, NGOs and commercial organisations are identified and willing to collaborate - Stakeholders have the resource to publish and promote guidelines - In-country collaborators willing to acknowledge guidelines produced and incorporate findings into future research initiatives.
2.1 Farmers led experimentation of proven interventions and testing of novel ideas for each cropping system and each farmer resource category with special reference to the marginalised groups. 2.2 Joint evaluation of trials using both farmer and researcher criteria.		2.1 and 2.2 Evaluations of innovative practices completed by Sept 02.	
3.1 Research findings promoted through field days, end of project workshop and appropriate publications. 3.2 Develop collaborating institution's capacity to participate with rural communities, particularly women, in the identification and solution of systems constraints. 3.3 Dissemination of best practice guidelines for use in study areas and extension to other programmes in the region.		3.1 A final project workshop held by Aug 02. Two published articles 3.2 Capacity of collaborating institutions to carry out participatory research strengthened by Dec 02. 3.3 Guidelines' dissemination initiated by March 01 in study areas.	