Evaluation of Weed Control Methods for Small Scale Farmers in the Production of Rainfed Wheat (*Triticum aestivum* L.)

by

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APPROVAL

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To my Father and late Mother. May her soul rest in peace.

ABSTRACT

On-farm experiments were conducted in the 1992-93 cropping season at Kasisi and Mufubushi. The objective of the experiment was to test alternative weeding methods to the present use of the hand hoe, for weeding in rainfed wheat production in Zambia.

Six weed control treatments were used and included use of the hand hoe (farmers practice), the dutch hoe, the weed wiper and the ox-drawn cultivator as well as clean and no weeding as controls. Weeding in the treatments was done once, except in the clean weeding treatment.

A high weed infestation after weed control was observed at Kasisi. None of the weed control methods performed well in reducing weed re-infestation. Grain yield of rainfed wheat at Kasisi was very poor (38 kg/ha average) and was observed not to be negatively correlated with weeds. Negative economic returns were obtained in all selected weed control methods. According to the results of the partial budget for Kasisi, the dutch hoe, weed wiper and ox-drawn cultivator had lower weeding cost compared to hand hoe weeding, thus being a potential alternative to the hand hoe. Kasisi seems to be agro-ecologically not suitable for rainfed wheat.

Results of the experiments at Mufubushi showed that weeds were contributing to a reduction in grain yield of rainfed wheat. *Nicandra physalodes*, particularly, was observed to reduce grain yield. All selected weed control methods resulted in good yields (1577 kg\ha average) and economic returns (K 193,200/ha average). The use of the hand hoe at Mufubushi was observed to perform better than any other weed control method in terms of reducing weed competition and increasing grain yield. The hand hoe weeding also had the highest economic returns (K 174,000/ha). However, it had the highest weeding cost (K 54,000/ha) due to labour input cost (K 51,300/ha). According to the results, the weed wiper and the ox-drawn cultivator weeding methods, despite their lower economic returns, had the lowest weeding cost (K 25,000/ha and K 15,000/ha, respectively). This makes them potential alternatives to the use of hand hoe.

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LIST OF ABBREVIATIONS.

C.V .... Coefficient of variation.

B/n .... between

Compd............. Compound

ctrl .... Control

cultr............. cultivator

df .... Degree of freedom.

DMRT .... Duncan Multiple Range Test.

gly .... glyphosate

no .... Number

P.a .... Per annum

Prepn.............. Preparation.

SE .... Standard error

Sig .... Significance

WAS .... Weeks after sowing.

Z-Kw .... Zambian Kwacha.

1.0 INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the crops that the Zambian government is trying to promote, so that it is produced locally in order to reduce the foreign exchange bill. Wheat consumption has continued to grow (Anonymous, 1989) and efforts are being made to meet this demand. The increase has been attributed to a change in food preferences and an increasing population. One of the main objectives of the Fourth National Development Plan for the period 1989/93 is to attain self sufficiency in wheat production by encouraging rainfed wheat production among small scale farmers (Anonymous, 1989). About 2 389 ha were in production in the 1991/92 cropping season, reflecting 37 percent increase above projected for the year (Anonymous, 1992). The area could be more if farmers were encouraged to increase their hectarage. At the moment small scale farmers are being encouraged to plant manageable sizes of fields due to labour constraint mostly at weeding (Anonymous, 1991).

There is a high potential in Zambia to attain self sufficiency in wheat through the growing of rainfed wheat by small scale farmers. This requires an increase in the number of farmers and in the hectarage under rainfed wheat. One of the major drawbacks to the attainment of the goal is the insufficient labour for hand-hoe weeding. To encourage farmers to grow more wheat, better weeding methods have to be identified and tried under research before they are introduced to replace the current use of the hand hoe for weeding.

The objective of the study was to test alternative weeding methods to the present hand-hoe weeding method used in small scale rainfed wheat production.

2.0 LITERATURE REVIEW

2.1 WHEAT PRODUCTION IN ZAMBIA

Zambia is importing two thirds of its national wheat consumption and only one third is grown locally under irrigation (Hurd, 1981). Wheat production in the 1970s virtually disappeared because of cheap imports in form of donations. This coincided with an increase in consumption of wheat, a high price for wheat at the world market and reduction in the source of foreign exchange due to a reduction on copper prices. Zambia could not afford the prices. As a result, some countries gave Zambia cheap wheat which made the locally grown wheat to be very expensive. These cheap imports discouraged farmers from growing wheat.

Most wheat grown in Zambia is irrigated and due to the high investment involved, this has been pushing up the price of locally produced wheat. The Zambian government has been trying to reduce the cost of wheat production by encouraging cheaper ways of producing wheat through production of rainfed wheat.

In 1976, research on rainfed wheat started and since then work has been concentrating on finding suitable varieties that could grow in the rain season conditions. The research initially placed emphasis on the production of rainfed wheat on a large scale. This could be seen from most recommendations, as they could not be met by small scale farmers. For example, recommendations on the use of herbicides such as Buctril-M, 2,4-D amine, MCPA etc (Zam-Can, 1982; Anonymous, 1990) cannot be met by an average small scale farmer. Despite the emphasis on large scale rainfed wheat production, little is grown by commercial farmers because of low yield potentials (0.1 to 2.0 ton./ha). This leaves the small scale farmers as the only potential producers for rainfed wheat production.

Most of the rainfed wheat is produced in the northern provinces of Zambia. Due to high rainfall in this area, most soils are leached and acidic. The wet condition encourages the development of diseases such as *Helmithosporium sativum, Xanthomonas campestris, Fusarium species, Puccinia graminis* and *Puccinia recondita*, with the first being the most predominant and causing severe yield losses (De Milliano, 1983). Wheat varieties that have been recommended, have both, pH (Aluminium toxicity) and *Helminthosporiumm sativum* resistance. The first of such varieties was "Whydah" followed by "Hornbill" (Anonymous, 1990). The most recent one is "Coucal" which is tolerant to Aluminium toxicity and shows higher *Helminthosporium sativum* tolerance (Anonymous, 1990). It is also fairly tolerant to lodging and thus may permit higher nitrogen application to obtain higher yields. It yields better than other varieties on farmers fields (about 2 ton./ha).

There are mainly two rainfed wheat cropping systems in Zambia, namely the early and the late rainfed wheat. The early rainfed wheat is sown between November and January and is practised where rainfall ceases in March (De Milliano, 1983). The late rainfed wheat is sown in late January or February and is practised in the Northern Province. The other which is becoming important is the partly rainfed, which is supplemented by furrow irrigation and is usually grown in dambos.

Agronomically, rainfed wheat is grown either in 20 - 25 cm rows or broadcasted by small scale farmers (Anonymous, 1990; De Milliano, 1983). Fertilizer application is split into two; basal, which is applied at sowing as a broadcast using the recommended 'C' compound (18N: $54P_2O_5$:$36K_2O$: 30S: 0.3B) and urea (46 N) or Ammonium Nitrate (as a top dressing 4 weeks after sowing. Weed control in small scale rainfed wheat production is done using the hand hoe in row planted wheat and by hand pulling in broadcasted wheat (Anonymous, 1990). Since farmers tend to use virgin land for wheat production, weeding is done only when necessary. When old fields are used, weeding is a must and if not done, yields will be reduced. The activity is very labour demanding. Little or no research has been carried out to identify weeding methods suitable for small scale rainfed wheat production. Rainfed wheat does not usually suffer from bird damage, probably due to abundant natural food supplies during the months of March and April. Bird damage has been reported in the Northern Province, possibly caused by *Quellea intermedia,* the main bird that is a threat to cereals in the province (Jones and Pope, 1977). The birds seem to prefer wheat to other cereals and damage wheat from the milky stage to the late dough stage. Harvesting wheat is by hand, using sickles. Threshing is done by beating with sticks or pounding in mortars.

During a tour made to the Northern Province of Zambia, weeding was emphasised to be one of the major problems causing farmers not to extend their wheat fields. Most farmers depend on family labour and cannot plant more than they can manage with the available family labour. Weeds have been known to reduce yields of wheat (Anonymous, 1991; Sharma *et al.*, 1985). Weeding becomes imperative and is a major labour consuming operation. In developing countries small scale farmers use 70 percent of their labour input to do the operation (Koch, 1992). Introduction of labour saving weeding methods can help to reduce this high labour requirement and thereby increase the hectarage planted to rainfed wheat.

2.2 WEEDS AND THEIR EFFECTS ON CROP DEVELOPMENT AND YIELD

A weed has been defined as a plant growing where it is not desired (Combellack, 1992; Klingman, 1966; Vernon, 1983; Zimdahl, 1980). Weeds interfere with crops by competing for moisture, nutrients or light (Kasasian, 1971; Koch, 1992; Vernon, 1983 Zimdahl, 1980) thus reducing the yield and quality. Weed competition has been known to be one of the major limiting factors in the production of rainfed wheat (Gebre *et al.*, 1987; Sharma *et al.*, 1985). Katyal *et al.* (1980) and Mani *et al.* (1987) (both quoted by Sharma, 1985) reported yield losses ranging from 34 to 82 percent, under severe weed infestation. Weed competition in cereals like wheat, generally reduces crop vigour, tillering, head size and grain weight (Zimdhal, 1980). Godel (1935, cited by Zimdahl, 1980), reported ear length reduction and decreased tillering due to weeds and observed a slight effect on grain weight. The work carried out by Mulenga (1991), showed that grain yield of wheat was reduced the longer weeds remained in the field. Similar specific studies with *Avena fatua* by Gelleaspie and Nalewaja (1988) also showed, that delayed weed control reduced both, the wheat grain yield and the economic benefit realised from weed control. Weed species and density have been pointed out to be the most important attributes of yield loss in wheat (Gebre *et al.*, 1987; Sharma *et al.*, 1985; Tanner and Giref, 1991).

The most common weeds in Zambia include *Nicandra physalodes, Amaranthus spp., Galinsoga parviflora, Bidens pilosa, Datura stramonium, Cyperus species, Acanthospermum spp., Commelina spp., Cynodon dactylon, Eleusine indica, Digitaria milanjiana, Rottboellia cochinchinensis,* etc. (Vernon, 1983). In Northern Province of Zambia, *Eleusine indica, Achyranthes aspera, Bothriocline laxa* and *Tagetes minuta* are common (Aulakh and Rimpkus, 1987).

2.3 WEEDING METHODS

Weeding is a major cultural activity which is labour intensive (Table 1). More time is spent on the activity than any cultural activity in the production of crops (Akobundu, 1987 and Koch, 1992). The high weed infestation and rapid weed growth during the rain season, make it necessary to do frequent weeding even in the short-season crops. As seen from Table 1, the weeding operation is time consuming in traditional farming. For yield (economic)

Table 1: Labour use for selected crops in Africa under traditional farming systems (man-days* per crop/ha).

Country	Crop	Land prepn. and planting.	Weeding	Harvesting	Total	Weeding (% of total labour)
Ethiopia	Maize	21	39	12	72	54
Ghana	"	54	43	16	113	38
Malawi	"	26	57	36	119	48
Nigeria	"	33	30	20	83	36
Zambia	"	38	65	33	136	48
Upper Volta	"	25	42	11	78	54
Nigeria	Sorghum	28	25	15	68	37
Senegal	G/nuts	28	63	35	126	50

Adapted from Akobundu, (1987).
* Based on 6 hours per day.

increments, weed control is imperative. In Ethiopia yield increments with weed control have been reported to range from 17 to 236 percent relative to the unweeded check (Tanner and Giref, 1991).

There are various methods that are used to combat the weed problem. Some methods that are in place in many developing countries do not permit faster weeding and they are labour intensive. Some are rather slow and tiresome. The hand hoe is probably the oldest weed control method and is widely used here in Zambia and other tropical countries. It is used for post-emergence control of weeds and is ideal for small cultivated areas, as more time is needed. Unavailability of and competition for labour during critical times makes it impossible for farmers to increase their field sizes due to weeding (Tanner and Giref, 1991). Here in Zambia, most farmers first use labour in the production of staple foods such as cassava, maize, etc. The competition for labour discourages farmers from extending fields under rainfed wheat. Inadequate family labour, especially at weeding, forces farmers to plant only manageable fields under rainfed wheat (Anonymous, 1991). Carson (1987) reported that the hand hoe weeding practice requires high labour input (15 man-days/ha) and it is inherently slow and, therefore, exacerbates weed competition leading to high crop losses. Allan (1974, quoted by Akobundu 1987) reported that more time is spent on weeding with heavy hand hoes than lighter ones. In Ethiopia it has been estimated that the labour requirement for hand hoe weeding in wheat ranges from 20 to 75 man-days/ha (Tanner and Giref, 1991).

The use of dutch hoes has been recognised to be suitable for small scale farmers, as it is faster and lighter than the traditional hoes (Kasasian, 1971). The dutch hoe is a light implement and easy to work with, and it is also used for post-emergence weed control. Weeding is done by scrapping on top of the soil to cut the weeds. Its use may keep weeds at moderate levels, thus minimising yield losses due to weeds. It may not be useful for rhizomatous weeds. Druijff and Kerkhoven (1970, cited by Kasasian, 1971) reported that the replacement of the traditional hoe with the dutch hoe increased the weeding efficiency up to 40 percent in Kenya. No such information has been reported for the Zambian case.

Most recommendations on the use of herbicides to control weeds in rainfed wheat (Anonymous, 1990) seem to favour commercial farmers. Use of recommended herbicides requires using complicated sprayers. The method itself is not feasible for various reasons. There are the problems of money to buy the equipment and calibration, not to mention the direct hazard which makes it even more difficult to use the dangerous chemicals. The weed wiper is a relatively safe equipment that can be used by small scale farmers (Davison and Parker, 1983). The weed wiper uses glyphosate, a non-selective herbicide with water in the ratio of 1:2. Application of the herbicide is simply done by wiping weeds just a little with the wiper. Translocation of the herbicide takes place on the treated plants resulting in their death later on. Care should be taken not to wipe the crop. The best use of the wiper could be in fields where weeds come up first, so that the risk of killing the crop is minimised. Use of a wick applicator is a faster method for dealing with weeds. The wick applicator (weed wiper) is the safest way of applying non-selective herbicides and is ideal for small scale farmers (Dale, 1979; Davison and Parker, 1983), as it does not require calibration. The possibility of local manufacture and modification is there. The use of wick applicators with glyphosate in soybeans (*Glycine max* L.) was effective on johnson grass (*Sorghum halpense* (L.) Pers.) and resulted in 51 percent increase in yield compared to the untreated control (Dale, 1979). It is most effective if used when weeds are still small (Davison and Parker, 1983).

The use of animal draught is being encouraged in most third world countries. In Zambia scarcity of foreign exchange makes it not feasible for small scale farmers to invest in motorised land tillage equipment. The use of animal draught power for weeding has to be encouraged because of low investments. Bansal *et al.* (1989) reported increased average yields with the introduction of improved animal drawn implements. This could probably be due to increased hectarages. Farmers with animal draught power can easily manage the weeding of a large hectarage as compared to those using labour intensive methods such as the hand hoe. At Njala University in Sierra Leone, Starkey and Verhaeghe (1982) reported significant weed regrowth reduction following weeding with ox-drawn weeding tines, than when the hand hoe was used for weeding in maize. The use of ox-drawn implements also resulted in an increased productivity of maize, as farmers increased land under maize more than when the hand hoes were used (Starkey and Verhaeghe, 1982). The use of ox-drawn cultivators in weed control has been successful in most row crops such as maize here in Zambia (Anonymous, 1980). Animal draught power is being encouraged in Zambia for use by small scale farmers in rainfed wheat, to enable them increase their field sizes and overall productivity (Anonymous, 1989, 1991). No information is available in Zambia on the use of animal draught power for weeding in wheat.

The effectiveness of any weed control programme may be influenced by the environment. Environmental factors that may affect or modify the effectiveness of a weed control programme include weed species, crop present, weather condition such as rainfall pattern and amount of rainfall and wind (Bleasdale, 1960). Edaphic factors that may influence or modify weed control include soil type, soil moisture, soil compaction and other physical and chemical characteristics (Zimdahl, 1980).

3.0 MATERIALS AND METHODS

3.1 INTRODUCTION

On-farm experiments were conducted in the 1992 - 93 growing season to study and identify alternative weeding methods to the hand hoe weeding in small scale rainfed wheat production. The experiments were conducted at Kasisi (Lusaka) and Mufubushi (Mpika - Northern Province). The sites received normal rainfall during the season despite a few drought days. There was a termite attack at Kasisi due to these days without rain, the damage of which contributed to the poor yields at the site. Dusban was sprayed to prevent further attack of the pest. No termite attack was experienced at Mufubushi. On the other hand bird damage was experienced at Mufubushi, but not at Kasisi. No disease incidence was observed at both locations.

Weeding at all the locations was done once in all treatments except the clean weeding treatment, where three weedings were carried out.

3.2 EXPERIMENTAL SITES

Kasisi (15^0 16'S 28^0 26'E) is 7 kilometres away from the Lusaka International Airport and is in the medium rainfall zone, receiving between 800 and 1000 mm. In the 1992-93 season, Kasisi received quite a normal total rainfall of 809 mm between November 1992 and March 1993 (Appendix B). There used to be occasional short dry spells (Appendix B), which encouraged termite attack. The soils at Kasisi are sandy loams with low pH ($CaCl_2$) (4.9 to 5.2) in the top 20 cm of the soil (Appendix C). The site is a missionary in-service training centre for small scale farmers and the major crops that are grown are maize (*Zea mays* L.), groundnuts (*Phaseolus vulgaris* L.) and sunflower (*Helianthus annuus*). Vegetables are also grown to provide the in-service farmers with cash. The experimental area had maize grown on it the previous season.

Mufubushi (11^0 16'S 28^0 51'E) is about 48 kilometers from Mpika on the Serenje-Mpika Great North Road. It is also in the medium rainfall zone and received 956 mm of rainfall between November 1992 and March 1993 (Appendix B). The site has clay soils which are well drained, with an average pH ($CaCl_2$) of 4.53 in the top 20 cm (Appendix C). The soils at Mufubushi have been classified as tropeptic haplustox, oxic paleustalf or ferrasols (Mulenga, 1991). The site has been continuously grown under a rotation of maize (*Z. Mays*), sunflower (*H. annuus*) and beans (*Phasuolas vulgaris* L.). Maize was grown at the site in the previous season.

3.3 EXPERIMENTAL DESIGN

3.3.1 TREATMENTS

Six treatments were used. These were:-

(i) no-weeding

(ii) clean weeding

(iii) traditional hand hoe (farmers own practice)

(iv) dutch hoe

(v) wick applicator (or weed wiper) using glyphosate (Roundup)

(vi) ox-drawn cultivator.

Treatments (iii), (iv), (v) and (vi) were applied 3 weeks after sowing. In treatment (ii), three weedings were done by a combination of hand weeding and hand hoe at 2, 3 and 4 weeks after sowing (WAS). In the no-weeding treatment, weeds were allowed to grow undisturbed.

3.3.2 EXPERIMENTAL DESIGN AND FIELD LAYOUT

A Randomised Complete Block Design was used and each treatment was replicated five times. The plots were laid in such a manner that oxen moved only in the treatments where the ox-drawn cultivator was used without disturbing other nearby plots. Each plot was 2 m x 12 m and were separated by a 25 cm path. Block size was 12 m x 12 m and were separated by a 1.5 m path (Appendix D).

3.4 MATERIALS

Basic materials used are as given in Table 2 below

Table 2 : Basic materials used

Hand hoes
Dutch hoes - 17.5 cm blade (REKORD).
Weed wiper: T-shaped (MINI) single head model. Capacity: 425 ml*
Modified ox-drawn cultivator (LENCO): Three inter row weeder.
Roundup (glyphosate)
Seed : variety " Coucal"
Fertilizer; basal : " C" compound (18 N: 54 P_2O_5: 30 S: 0.3 B)
top dressing : urea (46 N)
Quadrant (71 cm x 71 cm)
Sickles
pair of oxen (hired)
Dusban

* See Appendix E

3.5 AGRONOMIC PRACTICES

Land preparation at Kasisi was done by tractor while at Mufubushi oxen were used. At both sites the variety "Coucal", one of the recommended varieties under rainfed wheat, was used. The seed was hand drilled at the rate of 120kg/ha. Each plot had 8 rows, with an inter-row spacing of 25 cm (Table 3).

Table 3: Agronomic practices

Item	Location: Kasisi	Location: Mufubushi
Soil type	Sandy loam	Clay loam
pH ($CaCl_2$)	4.9 - 5.2	4.4 - 4.7
Land prepn.	By tractor (14/12/92)	By oxen (14/01/93)
Sowing	15/12/92	14/01/93
Variety	Coucal	Coucal
Seed rate	120 Kg/ha	120 Kg/ha
Spacing	25 cm b/n rows	25 cm b/n rows
Fertiliser		
(a) Basal	"C" compd. @ 300 Kg/ha at sowing.	"C" compd. @ 300 Kg/ha at sowing.
(b) Top	Urea @ 150 Kg/ha 4 weeks after sowing.	Urea @ 150 Kg/ha 4 weeks after sowing.
Assessments		
1	28/12/92	30/12/93
2	18/01/93	17/02/93
3	29/01/93	05/03/93
Harvesting	By hand (12/04/93)	By hand (5/05/93)
Harvesting area	1.5 m x 10 m	1.5 m x 10 m

Two fertilizer applications was done. A basal dressing of "C" compound (18 N: 54 P_2O_5: 30 S: 0.3 B) was applied at an approximate rate of 300 Kg/ha and was broadcasted at the time of sowing (Table 3). Urea was applied four weeks later at the rate of 150 Kg/ha as a top dressing. Weeding in the paths was done whenever need arose. Bird scaring was started at 50 % heading up to the time when the grain hardened at Mufubushi.

At harvesting only the inner six rows were hand-harvested after trimming a meter at both ends of a plot and the outer rows to minimise border effects. Threshing was done by beating the wheat in jute grain bags. After winnowing and cleaning, fresh weight of grain yield was recorded.

3.6 DATA COLLECTION AND ANALYSIS.

Weed and crop growth assessment was done as percentage cover at two points within a plot using a 71 cm x 71 cm quadrant. Three assessments were done at 2, 5 and 7 WAS (weeks after sowing). The first weed and crop assessment (at 2 WAS) was done just before treatment application. Assessments at 5 and 7 WAS were done after treatment applications. At treatment application, data on time used to accomplish a weeding task was recorded for selected weed control methods, for use in analyzing the economic impact of the weed control methods. This included the hand hoe, dutch hoe, weed wiper and ox-drawn cultivator.

Data for yield and its components were collected from the inner six rows. Data were analyzed using the MSTAT programme. The weed and crop covers were first transformed by the arcsine transformation procedure as described by Gomez and Gomez (1984) and Snedecor and Cochran (1980), and followed by the necessary analysis. After analysis, the figures were converted to the original figures for interpretations. The time data were used to establish a partial budget for the weed control methods.

4.0 RESULTS

4.1 WEED FLORA

4.1.1 Kasisi.

Weeds at Kasisi comprised mainly of broad leaved species with *Nicandra physalodes* (L.) Gaerth (apple-of-peru) as the dominant species (Table 4). Fewer grass species were present and of these *Eleusine indica* (L.) was predominant. The weed density at Kasisi was very high (50 percent cover) and *N. physalodes* contributed most to this density.

4.1.2 MUFUBUSHI

At Mufubushi, weeds were mainly of the broad leaved type with *Nicandra p.*, *Galinsoga parviflora* Cav. and *Acmella uliginasa* (Sw) Cass. being the most common (Table 4). *A. uliginasa* came later than the others but formed quite a dense stand underneath the wheat plants. The weed density was not high compared to the one at Kasisi.

4.2 WEED DEVELOPMENT.

Kasisi was visually observed to have a higher weed pressure as compared to Mufubushi despite the wrong picture given in Table 5, which arose from subjective assessment. At Kasisi the pressure was so high, that the wheat could not head in the no-weeding treatment. The weed cover at Kasisi continued to increase from 2 to 7 weeks after sowing (WAS). The weed cover increase was mainly due to an increase in *N. physalodes* as can be observed in Table 6.

At Mufubushi, a high increase in the weed cover from 2 to 5 WAS was observed (Table 5). This was mainly due to an increase in both major weeds, i.e *N. physalodes* and *G. parviflora* (Table 6). From 5 to 7 WAS, there was a reduction in weed cover probably due to a reduction in *G. parviflora* cover (Table 6).

Table 4: Weed species at the experimental locations.

Location	Weed species	Family
Kasisi	*Amaranthus hybridus* L.**	Amaranthaceae
	Celosia trigyna L.	Amaranthaceae
	*Bidens pilosa***	Asteraceae
	Bidens shimperi Shultz Bip.**	Asteraceae
	Tagetes minuta L.	Asteraceae
	Commelina bengalensis L.	Commelinaceae
	Commelina forskalaei Vahl.	Commelinaceae
	Convolvulus sagittatus Thunb.	Convolvulaceae
	Cyperus esculentus L.	Cyperaceae
	Acalypha segetalis Muell. Arg.	Euphorbiaceae
	Leucas martinicensis (Jacq.) R.Br	Lamiaceae
	Hibiscus cannabinus L.	Malvaceae
	Hibiscus trionum L.	Malvaceae
	Eleusine indica (L.)**	Poaceae
	Digitaria horizontalis Wild.**	Poaceae
	Paspalum scrobiculatum L.	Poaceae
	Setaria homonyma (Steud.) Chiov.	Poaceae
	Oxygonum sinuatum (Meisn.) Dammer.	Polygonaceae
	*Spermacoce stachadea***	Rubiaceae
	Nicandra physalodes (L.) Gaerth**	Solanaceae
Mufubushi		
	Achyranthes aspera L.	Amaranthaceae
	Amaranthus spinosus L.	Amaranthaceae
	Acmella uliginasa (Sw) Cass.**	Asteraceae
	Bidens pilosa L.	Asteraceae
	Galinsoga parviflora Cav.**	Asteraceae
	Sonchus oleraceae L.	Asteraceae
	Leucas martinicensis (jacq.) R.Br	Lamiaceae
	Hibiscus cannabinus L.	Malvaceae
	Axonopus compressus (Sw) P. Beauv.	Poaceae
	Chloris pilosa L.	Poaceae
	Dactyloctenium aegyptium (L.) P. Beauv.	Poaceae
	Eleusine indica (L.)	Poaceae
	Eragrostis viscosa (Retz.) Trin.	Poaceae
	Paspalum scrobiculatum L.	Poaceae
	Pennisetum polystachyon (L.) Shult.	Poaceae
	Rottboellia cochinchinesis	Poaceae
	Nicandra physalodes (L.) Gaerth**	Solanaceae

** denotes weed species that were more common.

Table 5: Weed development in no-weeding plots.

	Average Weed Cover (%)			
	Time of Assessment			
Location	2 WAS	5 WAS	7 WAS	Mean[1]
Kasisi	16.4	42.1	92.6	50.4
Mufubushi	24.0	71.0	53.6	49.5

1 denotes the average weed cover for the three assessments.

Table 6: Development of specific weed species in no-weeding plots.

		Average Weed Cover (%)			
		Time of assessment			
Location	Weed species	2 WAS	5 WAS	7 WAS	Mean1
Kasisi	*N. physalodes*	6.4	24.1	58.7	29.7
	E. indica	2.7	1.3	1.4	2.7
Mufubushi	*N. physalodes*	7.6	33.9	44.2	28.6
	G. parviflora	6.4	28.0	18.2	17.5

1 denotes average weed cover for the three assessments.

4.3 EFFECTS OF WEED CONTROL METHODS ON WEED DEVELOPMENT

4.3.1 KASISI

An even weed emergence was observed in all the experimental plots before weed control treatment application. At 2 WAS, weed cover ranged from 17 to 25 percent (Table 7).

A general decline in weed cover was observed after weed control at 5 WAS, except in the no-weeding treatment. Weed cover at this stage ranged from 1 to 42 percent with an average of 11 percent (Table 7). All weed control except the no-weeding showed decreased weed cover (Table 7). Reduction in the prominent *N. physalodes* weed at 5 WAS was observed (Appendix Table A.3). Also *E. indica* showed a reduction (Appendix Table A.5).

At 7 WAS, there was a general increase in weed cover in all weed control treatments. Weed covers of the weed control treatments ranged from 1 to 92 percent with the highest in the no-weeding. *N. physalodes* was observed to increase at the stage (Appendix Table A.3), while *E. indica* showed a slight increase in incidence (Appendix Table A.5).

On the average, the no-weeding treatment showed increased weed cover with 27 percent above average. The clean weeding showed the best effect on weeds i.e. it had the highest reduction in weed cover (Table 7 and Figure 1). The weed wiper and the dutch hoe weeding treatments also showed to reduce weed incidence (Table 7 and Figure 1). All the control methods except the clean weeding and the weed wiper showed little effect on *N. physalodes* cover (Appendix Table A.3 and Figure 1), whereas all weeding treatments showed an effect on *E. indica*. The ox-drawn cultivator weeding, however, showed very little effect (Appendix Table A.5).

All weed control methods except the weed wiper weeding could not give adequate control of weeds near and within the rows. This problem was most expressed in the ox-drawn cultivator weeding. These weeds together with late

Table 7: Influence of different weed control treatments on weed cover in rainfed wheat at Kasisi.

	Average weed cover (%)			
Treatments*	2 WAS**	5 WAS**	7 WAS**	Mean[1]
No-weeding	23.9a	40.4a	74.3a	57.4a
	(16.4)	(42.1)	(92.6)	(70.9)
Ox.cultivator weeding	24.4a	21.8b	47.7b	34.7b
	(17.0)	(13.8)	(54.7)	(32.5)
Hand hoe weeding	30.0a	19.5b	47.7b	33.6b
	(25.0)	(11.2)	(54.7)	(30.6)
Dutch hoe weeding	27.9a	16.3b	41.0b	28.6b
	(21.9)	(7.8)	(41.0)	(22.9)
Weed wiper weeding	27.4a	14.0bc	33.3b	23.7b
	(21.3)	(5.9)	(30.1)	(16.1)
Clean weeding	27.5a	4.1c	4.7c	4.4c
	(21.3)	(0.5)	(0.7)	(0.6)
Mean	26.8	19.4	41.4	30.4
	(20.3)	(11.0)	(43.7)	(25.6)
SE	3.4	3.5	4.8	3.8
C.V (%)	28.2	40.1	26.2	28.2

* Treatment means in the same column followed by the same letter did not differ significantly at $P < 0.05$ using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are the original mean values.

1 Means expressed as mean values after weed control application.

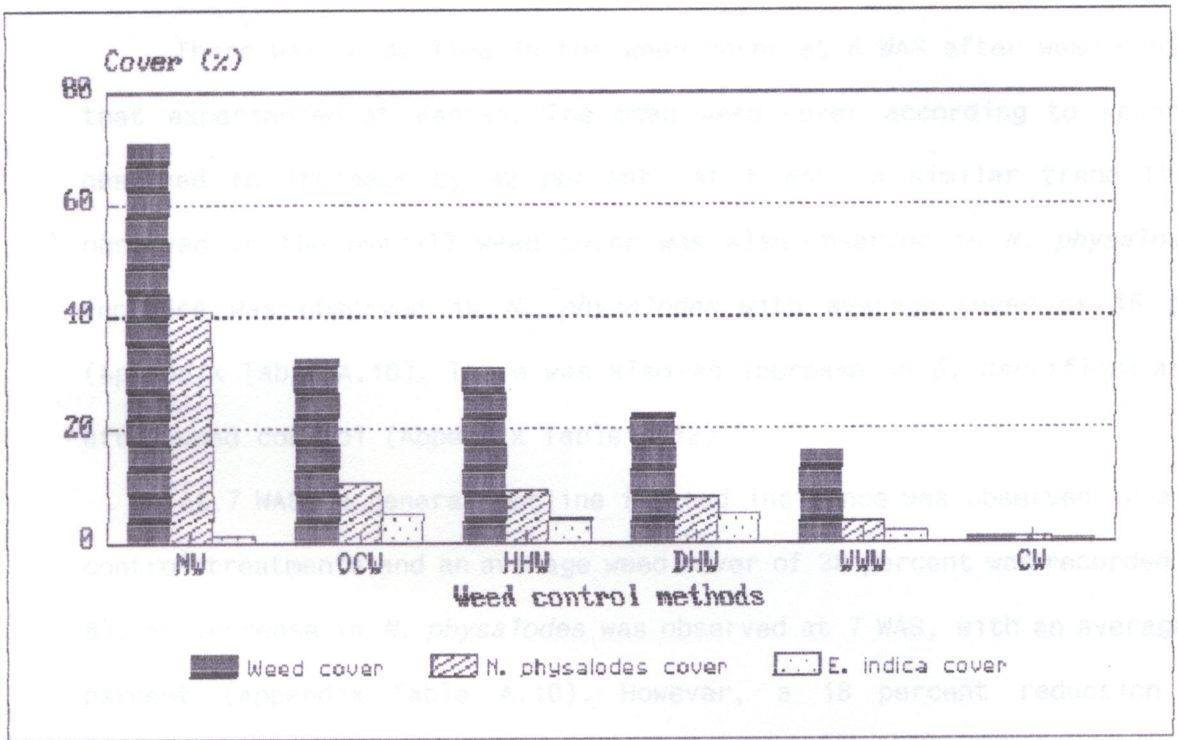

Figure 1: Effect of weed control treatments on average weed cover in rainfed wheat at Kasisi (original figures)

Key

NW = no-weeding.

CW = clean weeding.

HHW = hand hoe weeding.

DHW = dutch hoe weeding.

WWW = weed wiper weeding.

OCW = ox-drawn cultivator weeding.

infestation contributed to the high weed incidence experienced after weeding at Kasisi.

4.3.2 MUFUBUSHI

At Mufubushi, an even emergence of weeds in all the experimental plots was observed. It comprised mainly of broad leaved species. At 2 WAS before weed control treatment application, an average of 15 percent weed cover was recorded (Table 8).

There was no decline in the weed cover at 5 WAS after weed control as that experienced at Kasisi. The mean weed cover according to records was observed to increase by 42 percent. At 5 WAS, a similar trend that was observed in the overall weed cover was also observed in *N. physalodes*. An increase was observed in *N. physalodes* with average cover of 15 percent (Appendix Table A.10). There was also an increase in *G. parviflora* at 5 WAS after weed control (Appendix Table A.12).

At 7 WAS, a general decline in weed incidence was observed in all weed control treatments and an average weed cover of 38 percent was recorded (Table 8). An increase in *N. physalodes* was observed at 7 WAS, with an average of 18 percent (Appendix Table A.10). However, a 18 percent reduction in *G. parviflora* was observed (Appendix Table A. 12). This contributed to the general decline in weed incidence at this stage.

After weed control, the weed wiper weeding had the highest average weed cover of 71 percent, showing that weeding with the method was not very effective in reducing weed cover (Table 8 and Figure 2). Its effects on the weeds was no better than the no-weeding. The two had weed cover of more than 60 percent (Table 8 and Figure 2).

The dutch hoe and ox-drawn cultivator weeding had similar effects on weed incidence. They showed a good control of weeds. Their weed cover was

Table 8: Influence of different weed control treatments on weed cover in rainfed wheat at Mufubushi.

	Average weed cover (%)			
Treatments*	2 WAS**	5 WAS**	7 WAS**	Mean[1]
Weed wiper weeding	27.9ab	59.1a	55.4a	57.1a
	(21.9)	(73.6)	(67.7)	(70.5)
No-weeding	29.3a	57.4a	47.1ab	52.2ab
	(24.0)	(71.0)	(53.6)	(62.4)
Dutch hoe weeding	26.3ab	39.6b	38.6ab	39.1ab
	(19.7)	(40.6)	(39.0)	(39.8)
Ox.cultivating weeding	20.0b	37.7b	39.8ab	38.8ab
	(11.7)	(37.5)	(41.0)	(39.3)
Hand hoe weeding	30.8a	32.7b	33.4b	32.3bc
	(26.2)	(30.0)	(30.3)	(28.6)
Clean weeding	4.1c	12.9c	12.6c	12.7c
	(0.5)	(5.0)	(4.7)	(4.8)
Mean	23.1	39.9	37.8	38.7
	(15.4)	(41.1)	(37.6)	(39.1)
SE	2.9	4.8	5.6	4.9
C.V (%)	28.3	27.1	33.4	28.6

* Treatment means in the same column followed by the same letter did not differ significantly at $P < 0.05$ using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in the parentheses are original mean values.

1 means expressed as mean values after weed control application.

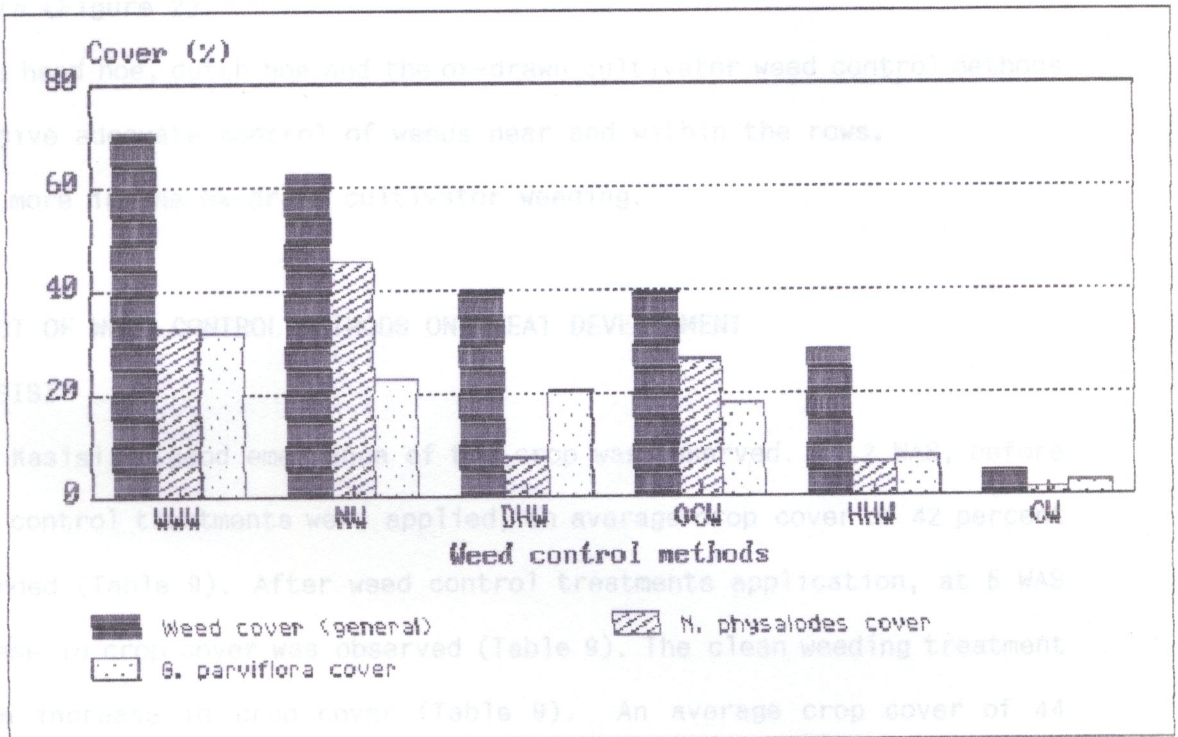

Figure 2: Effect of weed control treatments on average weed cover in rainfed wheat at Mufubushi (original figures).

Key

NW = no-weeding.
CW = clean weeding.
HHW = hand hoe weeding.
DHW = dutch hoe weeding.
WWW = weed wiper weeding.
OCW = ox-drawn cultivator.

below the overall average after weed control (Table 8 and Figure 2). The use of the dutch hoe resulted in good control of *N. physalodes* and while the ox-drawn cultivator controlled *G. parviflora* better (Figure 2).

The hand hoe showed good effectiveness in reducing the weed incidence (Table 8 and Figure 2). Only the clean treatment performed better than the hand hoe in terms of weed incidence reduction (Table 8 and Figure 2). The use of the hand hoe also resulted in good control of both *N. physalodes* and *G. parviflora* (Figure 2).

The hand hoe, dutch hoe and the ox-drawn cultivator weed control methods did not give adequate control of weeds near and within the rows. This was more in the ox-drawn cultivator weeding.

4.4 EFFECT OF WEED CONTROL METHODS ON WHEAT DEVELOPMENT

4.4.1 KASISI

At Kasisi, a good emergence of the crop was observed. At 2 WAS, before the weed control treatments were applied, an average crop cover of 42 percent was recorded (Table 9). After weed control treatments application, at 5 WAS an increase in crop cover was observed (Table 9). The clean weeding treatment showed an increase in crop cover (Table 9). An average crop cover of 44 percent for all the treatments was recorded at 5 WAS (Table 9). At 7 WAS, a 11 percent decline in average crop cover was observed, while the clean weeding also showed a 4 percent reduction (Table 9). But generally, all weeding treatments showed poor crop development at the site.

The dutch hoe weeding and the hand hoe weeding showed no differences statistically in their crop cover (Table 9 and Figure 3). These two weed control treatments reduced effects of weeds and they had a fair crop cover above the average (Table 9).

The ox-drawn cultivator and the no-weeding had crop cover below average

Table 9: Influence of different weed control treatments on wheat cover at Kasisi.

Treatment*	Average crop cover (%)			
	2 WAS**	5 WAS**	7 WAS**	Mean[1]
Clean weeding	41.5ab	47.6a	52.0a	51.0a
	(44.0)	(55.0)	62.2)	(60.4)
Dutch hoe weeding	45.4a	48.0a	38.3ab	43.1a
	(50.8)	(55.3)	(38.3)	(46.7)
Hand hoe weeding	37.4b	47.5a	38.7ab	41.3a
	(36.9)	(54.4)	39.1)	(43.6)
No-weeding	42.3ab	42.7a	30.8bc	36.8a
	(45.3)	(46.0)	(26.2)	(35.9)
Ox.cultivator weeding	40.7ab	41.2a	31.8bc	36.5a
	(42.6)	(43.3)	(27.8)	(35.4)
Weed wiper weeding	35.6b	22.9b	18.5c	20.7b
	(33.9)	(15.1)	(10.1)	12.5)
Mean	40.5	41.7	35.0	38.2
	(42.2)	(44.3)	(32.9)	(38.2)
SE	2.3	3.7	5.4	3.7
C.V (%)	12.6	19.7	34.2	21.4

* Treatment means in the same column followed by the same letter did not differ significantly at $P < 0.05$ using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after weed control application.

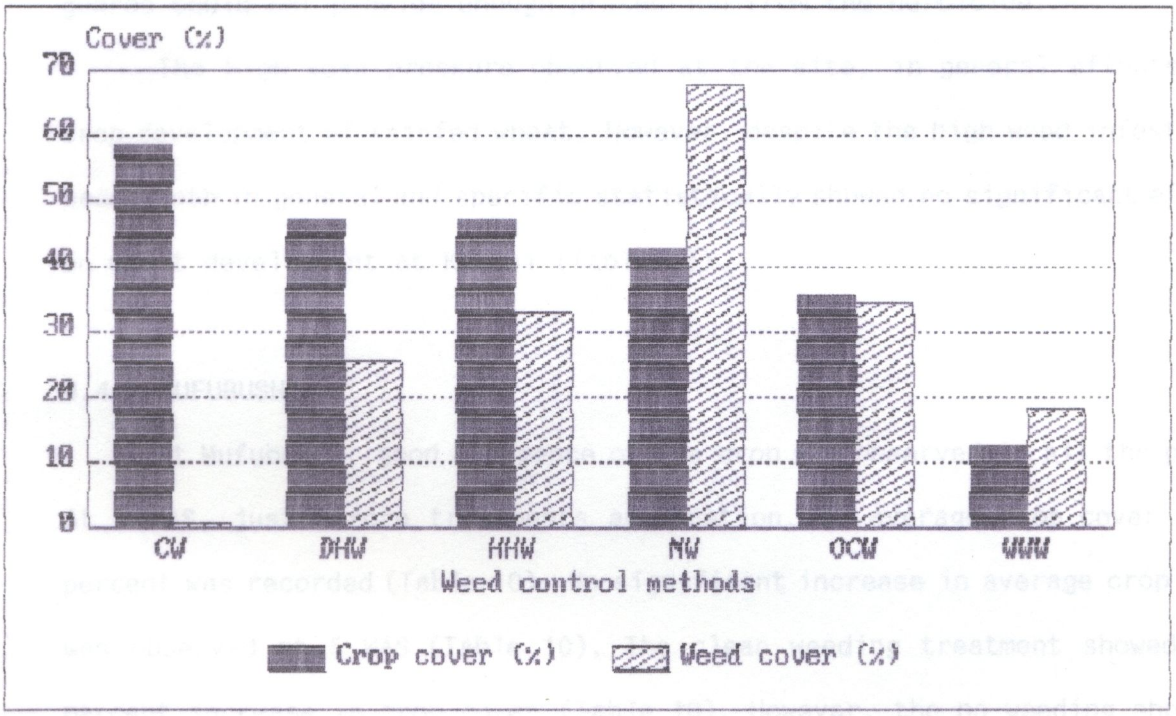

Figure 3: Effect of weeds on wheat development after weed control at Kasisi (original figures).

Key

NW = no-weeding.
CW = clean weeding.
HHW = hand hoe weeding.
DHW = dutch hoe weeding.
WWW = weed wiper weeding.
OCW = ox-drawn cultivator weeding.

(Table 9). The use of the ox-drawn cultivator showed good control of weeds but was not effective in controlling weeds near and within the rows and it is these weeds together with the late infestation that contributed to low crop cover (Table 9 and Figure 3). No damage of the crop by the method was observed.

The weed wiper control method though showing good control of weeds, its use resulted in crop herbicide injury (Table 9 and Figure 3). The improvised guards could not provide enough protection from the herbicide.

The high weed pressure observed at the site, in general affected the crop development of rainfed wheat. However, despite the high weed infestation weeds both in general and specific statistically showed no significant effects on wheat development at Kasisi (Table 12).

4.4.2 MUFUBUSHI

At Mufubushi, good emergence of the crop was observed in all the plots. At 2 WAS, just before treatments application, an average crop cover of 57 percent was recorded (Table 10). No significant increase in average crop cover was observed at 5 WAS (Table 10). The clean weeding treatment showed a 16 percent increase in crop cover (Table 10). However, the no-weeding showed a reduction in crop cover (Table 10). At 7 WAS again, an increase in crop cover of the clean weeding was observed while the average crop cover for all weeding treatments showed a slight decrease (Table 10). The clean weeding maintained a good crop stand and the highest crop cover (Table 10 and Figure 4).

The use of the hand hoe for weeding at Mufubushi resulted in a good crop development. It had 70 percent crop cover (Table 10). Its effectiveness on reducing weed incidence made it able to achieve the second best wheat crop stand (Table 10 and Figure 4).

The use of the dutch hoe and ox-drawn cultivator for weeding in rainfed

Table 10 : Influence of different weed control treatments on wheat cover at Mufubushi.

Treatments*	Average crop cover (%)			
	2 WAS**	5 WAS**	7 WAS**	Mean[1]
Clean weeding	59.2a	75.5a	76.2a	69.7a
	(73.8)	(93.7)	(94.3)	(88.0)
Hand hoe weeding	50.1abc	57.3b	55.8b	57.1ab
	(58.8)	(70.8)	(68.4)	(70.5)
Dutch hoe weeding	45.6bc	50.4b	50.8b	51.6abc
	(51.1)	(59.4)	(60.1)	(61.4)
Ox.cultivator weeding	53.9ab	51.33b	49.3b	50.2bc
	(65.3)	(61.0)	(57.5)	(59.1)
No-weeding	44.3bc	34.1c	33.9c	34.0cd
	(48.7)	(31.5)	(31.2)	(31.3)
Weed wiper weeding	40.7c	30.9c	31.2c	31.0d
	(42.5)	(26.4)	(26.8)	(26.5)
Mean	49.0	49.9	49.5	49.0
	(57.0)	(58.5)	(57.8)	(57.0)
SE	3.8	4.5	4.1	4.4
C.V (%)	17.5	20.3	12.1	20.3

* Treatment means in the same column followed by the same letter did not differ significantly at $P < 0.05$. using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after treatment weed application.

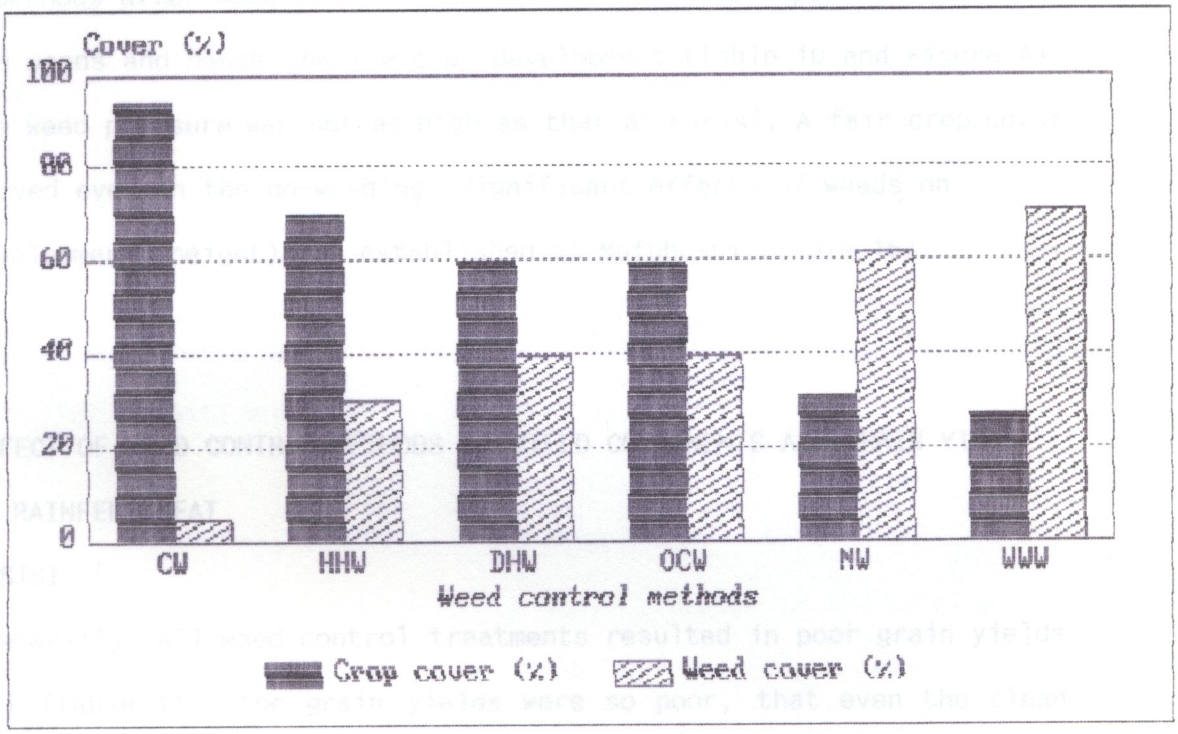

Figure 4: Effect weeds on crop development after weed control at Mufubushi (original figures).

Key

NW = no-weeding.
CW = clean weeding.
HHW = hand hoe weeding.
DHW = dutch hoe weeding.
WWW = weed wiper weeding.
OCW = ox-drawn cultivator weeding.

wheat at Mufubushi, also showed a good crop stand (Table 10). Their crop covers were above 57 percent (Table 10). They showed good control of weeds and hence good crop development (Table 10 and Figure 4). However, their performance in reducing weed incidence in wheat was much less than the hand hoe (Figure 4).

No crop herbicide injury was experienced at Mufubushi in the weed wiper weeding. The weed wiper had lower crop cover than the average for all weed control methods after weed control (Table 10). The weed wiper showed little effect on weeds and hence the low crop development (Table 10 and Figure 4).

The weed pressure was not as high as that at Kasisi. A fair crop cover was observed even in the no-weeding. Significant effects of weeds on wheat development (height) was established at Mufubushi (Table 15).

4.5 EFFECT OF WEED CONTROL METHODS ON YIELD COMPONENTS AND GRAIN YIELD OF RAINFED WHEAT

4.5.1 KASISI

Generally, all weed control treatments resulted in poor grain yields at Kasisi (Table 11). The grain yields were so poor, that even the clean weeding control treatment performed poorly. It had the highest grain yield (152 Kg/ha) but was far below the expected yield of 1000 to 2000 Kg/ha. Weed control treatments with high weed cover showed yield reductions (Figure 5). Both the weed wiper and the no-weeding treatments gave no yields (Table 11). The reason for the weed wiper not yielding anything was crop death due to herbicide injury. Wheat in the no-weeding did not head hence the zero yield.

With respect to grain yield, the clean weeding treatment performed better than the hand hoe, dutch hoe and ox-drawn cultivator weeding treatments

Table 11: Influence of different weed control treatments on yield components and grain yield of rainfed wheat at Kasisi.

Trtnt*	N_0T/P	Pht (cm)	El (cm)	$N_0S\backslash E$	NoG/E	GWT/E (g)	1GWT (g)	GY (Kg/ha)
CW	2.5a	110.7a	6.8a	13.7a	21.6a	0.5a	22.7a	150a
DHW	1.9a	114.5a	6.9a	13.8a	23.3a	0.5a	19.5a	30b
HHW	1.5a	114.7a	6.6a	12.4b	19.8a	0.4b	18.0a	28b
OCW	2.2a	116.2a	5.9b	12.3b	21.5a	0.3b	18.9a	18b
WWW	0.4b	0.0c	0.0c	0.0c	0.0b	0.0c	0.0b	0b
NW	1.8a	97.1b	0.0c	0.0c	0.0b	0.0c	0.0b	0b
Mean	1.7	92.2	4.4	8.7	14.4	4.4	13.2	38
SE	0.3	2.7	0.3	0.4	1.4	0.3	5.6	24
CV (%)	44.1	6.5	15.6	10.9	21.0	15.6	16.3	141

* Treatment Means in the same column followed by the same letter did not differ significantly at $P < 0.05$ using DMRT.

Key

Trtnt = Treatment.

N_0T/P = Number of tillers per plant

Pht = Plant height (cm).

El = Ear length (cm)

N_0S/E = Number spikelet per ear.

N_0G/E = Number grain per ear.

GWT/E = Grain weight per ear (g).

1GWT = 1000 Grain weight (g).

GY = Grain yield (Kg/ha).

OCW = Ox-drawn cultivator weeding.

CW = Clean weeding.

WWW = Weed wiper weeding+ glyphosate.

HHW = Hand hoe weeding.

NW = No-weeding.

DHW = Dutch hoe weeding.

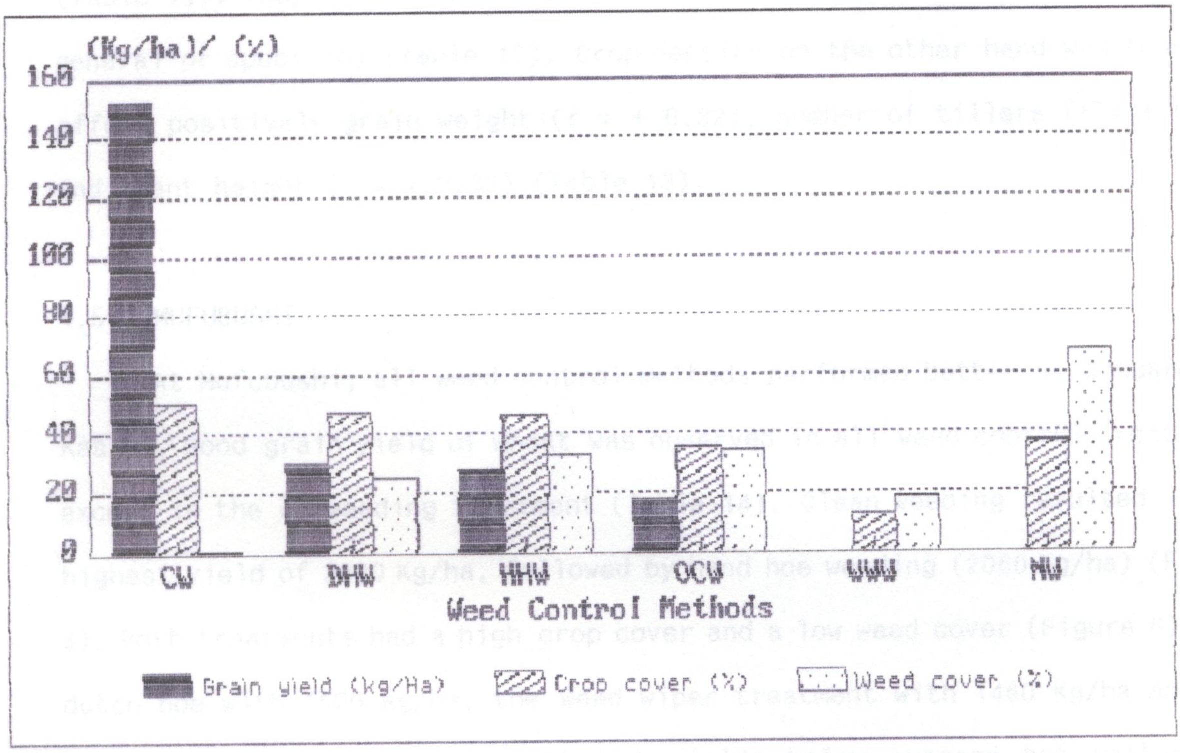

Figure 5: Effect of weed cover and crop cover after weed control on grain yield of rainfed wheat at Kasisi.

Key

NW = no-weeding.

CW = clean weeding.

HHW = hand hoe weeding.

DHW = dutch hoe weeding.

WWW = weed wiper weeding.

CW = ox-drawn cultivator weeding.

(Table 11).

No significant negative relationship was established between average weed cover after weed control and grain yield (table 12). This indicates that weeds (both in general and specific) were not statistically contributing to reduction in grain yield (Table 12). Crop density also did not affect grain yield significantly (Table 13).

Similar to grain yield, most yield components were on the low side (Table 11). They also showed not to be affected statistically by weeds (both general or specific) (Table 12). Crop density on the other hand was found to affect positively grain weight (r = + 0.82), number of tillers (r = + 0.86) and plant height (r = + 0.83) (Table 13).

4.5.2 MUFUBUSHI

At Mufubushi, all weed control methods performed better as compared to Kasisi. Good grain yield of wheat was observed in all weed control treatments except in the no-weeding treatment (Table 14). Clean weeding resulted in the highest yield of 2320 Kg/ha, followed by hand hoe weeding (2060 Kg/ha) (Figure 6). Both treatments had a high crop cover and a low weed cover (Figure 6). The dutch hoe with 1500 Kg/ha, the weed wiper treatment with 1460 Kg/ha and the ox-drawn cultivator weeding all had yields below average but within the expected yield (Table 14). The no-weeding with its low crop cover and high weed cover, had the lowest grain yield (700 Kg/ha) (Table 14 and Figure 6). While at Kasisi no yield was realised in the weed wiper due to herbicide injury, this was not so at Mufubushi. The weed wiper had resulted in good yield, but failed to reduce weed incidence (Table 8 and Figure 6)

The clean weeding performed better than the dutch hoe, weed wiper weeding and the ox-drawn cultivator weeding in grain yield. The clean weeding

Table 12: Correlations between weeds after weed control, crop cover, yield components and yield of rainfed wheat at kasisi.

	Cr c.	Gra yld.	1 gwt.	Gra wt.	No g/e	No splt/e	Ear len	No til/p	plht
Wcg	-0.23	-0.65	-0.54	-0.57	-0.48	-0.51	-0.54	-0.18	+0.16
	ns	ns	ns	ns	ns	ns	ns	ns	ns
WcN	-0.14	-0.48	-0.57	+0.35	-0.54	-0.56	-0.56	+0.62	+0.15
	ns	ns	ns	ns	ns	ns	ns	ns	ns
WcE	-0.54	-0.43	+0.41	-0.48	-0.54	-0.49	-0.48	+0.73	+0.36
	ns	ns	ns	ns	ns	ns	ns	ns	ns

ns denotes correlation coefficients were non significant.

Table 13: Correlations between crop cover after weed control, yield components and yield of rainfed wheat at Kasisi.

Gra yld	1 gwt.	Gra wt.	No g/e	No splt/e	Ear len	No til/p	plht
+0.78	+0.78	+0.82	+0.73	+0.76	+0.76	+0.86	+0.83
ns	ns	*	ns	ns	ns	*	*

* and ns denotes correlation coefficients significant at 5 % and non significance, respectively.

Key

Cr. c = crop cover
Gra yld = grain yield
1 gwt = 1000 grain weight
No g/e = number of grains per ear
No splt/e= number of spikelets
Ear le = ear length
No til/p = number tillers per plant
Plht = plant height

Wcg = weed cover general
WcN = *N. physalodes* cover
WcE = *E. indica* cover

treatment, however, did not statistically differ from differ from the hand hoe weeding.

Differences in yield in the weed control treatments at Mufubushi were mainly due to differences in number of grains and grain weight per plant.

High weed infestation reduced grain yield (r = - 0.82) (Table 15). *N. physalodes* infestation was specifically established to contribute more to reduction in grain yield (r = - 0.89) (Table 15). On the other hand, density of the crop canopy did not affect grain yield (Table 16).

Just like grain yield, most yield components were good (Table 14). High weed infestations showed to have strong reductive effects on grain weight (r = - 0.93), number of grains (r = - 0.99) and plant height (r = - 0.93) (Table 15). The reduction in number of grains per ear and grain weight was more expressed in the weed wiper, no-weeding and the ox-drawn cultivator treatments. These experienced high weed re-infestation after weed control. *N. physalodes* was specifically established to strongly reduce plant height (r = - 0.92) but showed less reduction on number of grains per ear of wheat (r = - 0.87) and grain weight (r = -0.83) (Table 15). Crop density on the other hand did not affect these yield components (Table 16).

Weed infestation showed slight reductive effects on number of spikelets (r = - 0.82) and only *G. parviflora* was established to contribute significantly to the reduction (r = - 0.87) (Table 15). Crop density did not show significant effects on this yield component (Table 16).

Weed infestation both in general and specific, and on the other side density of crop cover did not affect number of tillers, ear length and 1000 grain weight (Tables 15 and 16).

Table 14: Influence of different weed control treatments on yield components and grain yield of rainfed wheat at Mufubushi.

Trtnt*	N_0T/P	Pht (cm)	El (cm)	N_0S/E	N_0G/E	GWT/E (g)	1GWT (g)	GY (Kg/ha)
CW	3.4a	116.2a	7.6a	15.9a	39.4a	1.4a	36.4a	2320a
HHW	2.7a	114.9ab	7.1ab	15.7a	36.8ab	1.3a	36.3a	2060ab
DHW	3.0a	114.9a	6.8b	15.7a	35.0ab	1.3a	37.1a	1500b
WWW	2.8a	114.0a	6.9b	15.0a	32.4b	1.1c	32.3b	1460b
OCW	2.8a	114.0a	7.0ab	15.9a	35.3ab	1.2abc	34.5ab	1420b
NW	2.7a	113.4a	7.0ab	15.5a	32.3b	1.2bc	35.8a	700c
Mean	2.9	114.5	7.1	15.6	35.2	1.3	35.4	1576.7
SE	0.3	1.0	0.3	0.3	1.6	5.5	0.8	221.5
CV (%)	12.8	5.3	6.9	5.5	10.2	9.9	5.3	31.4

* Treatment means in the same column followed by the same letter did not differ significantly at P = 0.05 using DMRT.

KEY

Trtnt.= Treatment.

N_0T/P = Number of tillers per plant.

Pht. = Plant height (cm).

El = Ear length (cm).

N_0S/E = Number of spikelets per ear.

N_0G/E = Number of grains per ear.

GWT/E = Grain weight per ear (g).

1GWT = 1000 Grain weight (g).

GY = Grain yield (Kg/ha).

OCW = Ox-drawn cultr. weeding.

WWW = Weed wiper weeding +gly.

CW = Clean weeding.

HHW = Hand hoe weeding.

NW = No-weeding.

DHW = Dutch hoe weeding.

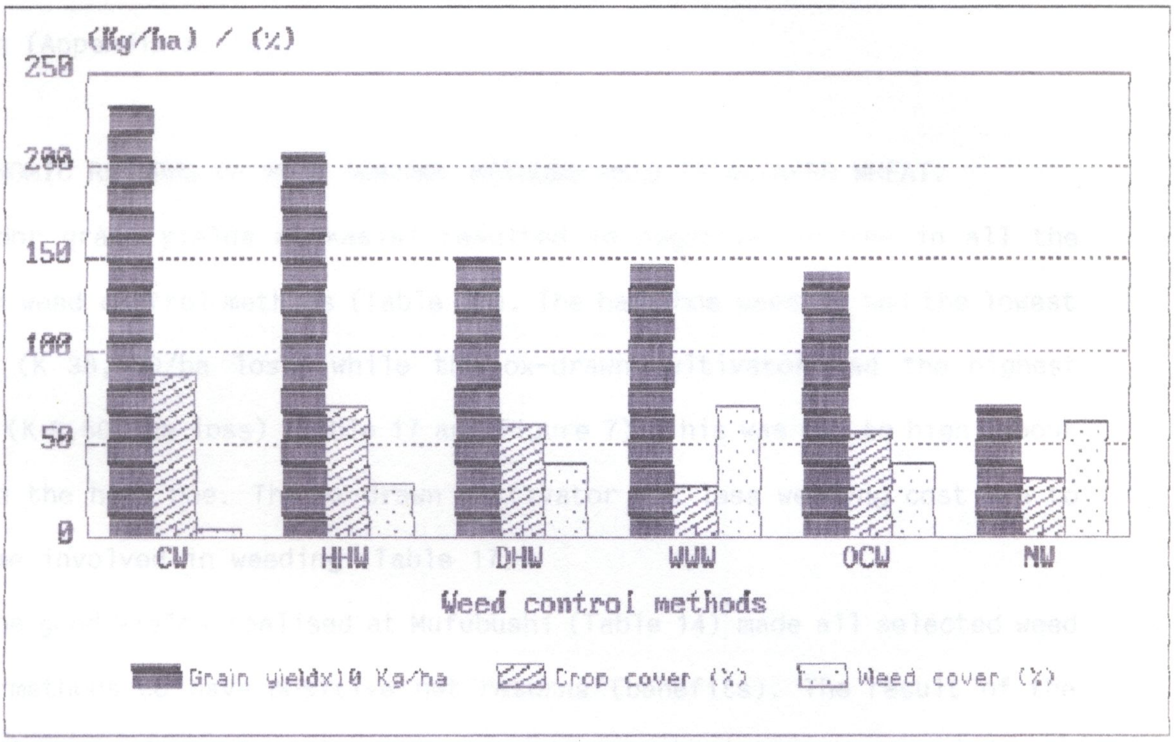

Figure 6: Effect of weed cover and crop cover after weed control on grain yield of rainfed wheat at Mufubushi.

Key

NW = no-weeding.

CW = clean weeding.

HHW = hand hoe weeding.

DHW = dutch hoe weeding.

WWW = weed wiper weeding.

OCW = ox-drawn cultivator weeding.

4.6 EFFECTS OF WEED CONTROL METHODS ON GRAIN YIELD OF RAINFED WHEAT ACROSS LOCATIONS.

Weed control treatments were observed to affect yield of rainfed wheat significantly across the two locations (Appendix A. 15). Among the weed control methods, the hand hoe performed best (Appendix Table A. 16). The location was also observed to affect the yield of rainfed wheat significantly. The Kasisi crop yielded 38 kg/ha while the one in Mufubushi yielded 1500 kg/ha on average. There was no interaction between weed control treatments and location (Appendix A. 15).

4.7 ECONOMIC RETURNS OF WEED CONTROL METHODS USED IN RAINFED WHEAT.

Poor grain yields at Kasisi resulted in negative returns in all the selected weed control methods (Table 17). The hand hoe weeding had the lowest returns (K 38,300/ha loss) while the ox-drawn cultivator had the highest returns (K 9,500/ha loss) (Table 17 and Figure 7). This was due to high labour input in the hand hoe. The ox-drawn cultivator had less weeding cost due to less time involved in weeding (Table 17).

The good yields realised at Mufubushi (Table 14) made all selected weed control methods to have positive net returns (benefits). The result of the partial budget of the hand hoe, the weed wiper and the ox-drawn cultivator weeding methods at Mufubushi (Table 18) showed good returns, with the hand hoe scoring highest (K 169,300/ha profit). The dutch hoe weeding had the lowest return, but still profitable (K 121,400/ha profit).

It may be noted, however, that the hand hoe weeding had the highest total weeding cost due to high labour input (table 18 and figure 8). The use of the ox-drawn cultivator resulted in the lowest total weeding cost (K 15,600/ha) followed by the weed wiper (K 37,000/ha) (Table 18 and Figure 8). The two had less weeding cost mostly due to less time (labour) involved.

Table 15: Correlations between weeds after weed control, crop cover, yield components and yield of rainfed wheat at Mufubushi.

	Cr c.	Gra yld.	1 gwt.	Gra wt.	No g/e	No splt/e	Ear len	No til/p	plht
Wcg	+0.34 ns	-0.82 *	-0.63 ns	-0.93 **	-0.99 **	-0.82 *	-0.77 ns	-0.72 ns	-0.93 **
WcN	-0.16 ns	-0.89 *	-0.57 ns	-0.83 *	-0.87 *	-0.55 ns	-0.45 ns	-0.64 ns	-0.92 **
WcG	-0.41 ns	-0.65 ns	-0.40 ns	-0.70 ns	-0.88 *	-0.87 *	-0.69 ns	-0.65 ns	-0.77 ns

*, **, and ns denotes correlation coefficients significance at 5 %, 1 % and nonsignificant.

Table 16: Correlations between crop cover after weed control, yield components and yield of rainfed wheat at Mufubushi.

Gra yld	1 gwt.	Gra wt.	No g/e	No splt/e	Ear len	No til/p	plht
+0.57 ns	+0.25 ns	+0.46 ns	+0.66 ns	+0.25 ns	+0.58 ns	+0.56 ns	+0.17 ns

ns denotes correlation coefficients non significance.

Key

Cr. c = crop cover
Gra yld = grain yield
1 gwt = 1000 grain weight
Gra wt. = grain weight
No g/e = number of grain ear
No spli/e = number of spikelet per ear
Ear length= ear length
No til/p = number of tillers per plant
Plht = plant height

Wcg = general weed cover
WcN = *N. physalodes* cover
WcG = *G. parviflora* cover

The ox-drawn cultivator had the lowest labour input (Table 18).

Table 17: Economic returns of weed control methods in rainfed wheat at Kasisi (partial budget).

Item	Weed control methods			
	HHW	DHW	WWW	OCW
Mean yield (Kg/ha)	28	30	0	20
Gross benefit (Kw/ha) @ K 10,000 per 90 Kg bag	3,100	3,300	0	2,200
Labour input (man-days/ha)	49	30	7	8
Equipment total cost (Kw)	11,000	9,066	15,200	31,000
Labour cost (Kw/ha)#	33,100	20,300	4,700	5,400
Equipment cost (Kw/ha)*	2,750	2,266	3,800	3,100
Herbicide (glyphosate) cost (Kw/ha)	--	--	17,700	--
Oxen (hiring) cost Kw/ha	--	--	--	3,000
Total cost (Kw/ha)	35,850	22,566	26,200	11,500
Net Benefit (Kw/ha)	-32,750	-19,266	-26,200	-9,500

* based on 25% depreciation except the ox-drawn cultivator which is depreciated at 10% p.a.

\# based on Z-Kwacha 650 per man-day (6 hrs).

Key

HHW= Hand hoe weeding.

DHW= Dutch hoe weeding.

OCW= Ox-drawn cultivator weeding.

WWW= Weed wiper weeding.

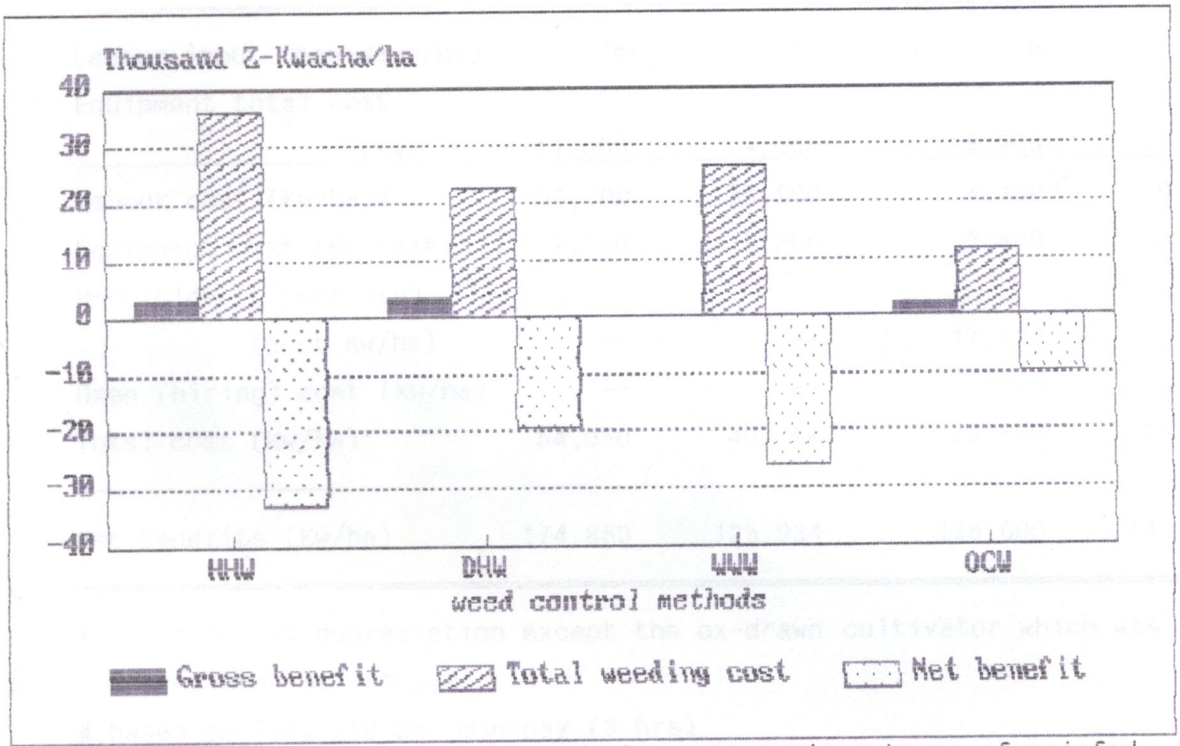

Figure 7: Effect of weed control methods on economic returns of rainfed wheat at Kasisi.

Key

HHW = hand hoe weeding.

DHW = dutch hoe weeding.

WWW = weed wiper weeding.

OCW = ox-drawn cultivator weeding.

Table 18: Economic returns of weed control methods in rainfed wheat at Mufubushi (partial budget).

Item	Weed control methods			
	HHW	DHW	WWW	OCW
Mean grain yield (Kg/ha)	2,060	1,500	1,460	1,420
Gross benefit @ K 10,000 per 90 kg bag	228,900	166,700	162,200	157,800
Labour input (man-days/ha)	76	57	6	14
Equipment total cost (Kw)	11,000	9,066	15,200	31,000
Labour cost (Kw/ha)#	51,300	38,500	4,100	9,500
Equipment cost (Kw/ha)*	2,750	2,266	3,800	3,100
Herbicide (glyphosate) (cost Kw/ha)	--	--	17,700	--
Oxen (hiring) cost (Kw/ha)	--	--	--	3,000
Total cost (Kw/ha)	54,050	40,766	25,600	15,600
Net Benefits (Kw/ha)	174,850	125,934	136,600	142,200

* based on 25% depreciation except the ox-drawn cultivator which was depreciated at 10% p.a

based on Z-Kw 650 per man-day (6 hrs)

Key

HHW= Hand hoe weeding.

DHW= Dutch hoe weeding.

OCW= Ox-drawn cultivator weeding.

WWW= Weed wiper weeding.

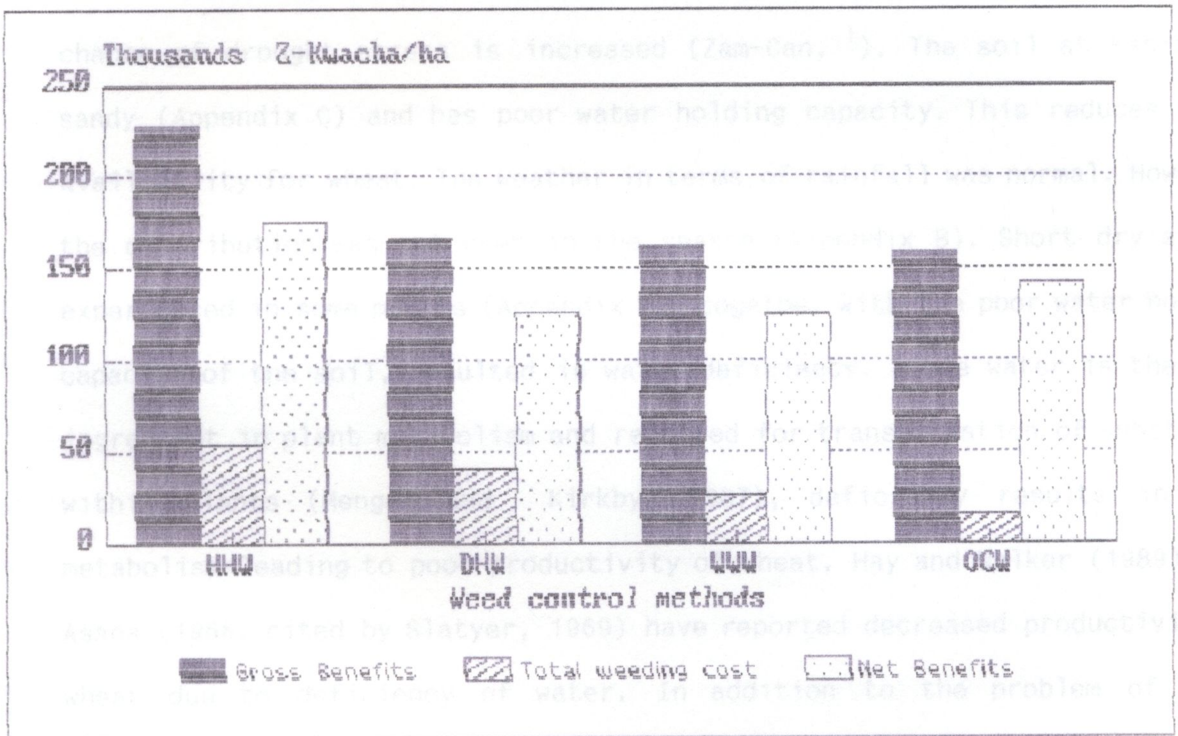

Figure 8: Effect of weed control methods on economic returns of rainfed wheat at Mufubushi.

Key

HHW = hand hoe weeding.

DHW = dutch hoe weeding.

WWW = weed wiper weeding.

OCW = ox-drawn cultivator weeding.

5.0 DISCUSSION

5.1 KASISI

Kasisi was characterised by poor wheat development and yield. Factors that have been known to affect wheat development are soil type, weather and weed flora etc (Bleasdale, 1960; Zimdahl, 1980). Appleby (1977) reported soil type to be one of the major factors that can affect wheat productivity. Wheat prefers heavy well drained soils for good yields. According to recommendations from Mount Makulu Research Station, light soils are not recommended as the chance of drought stress is increased (Zam-Can, [1]). The soil at Kasisi is sandy (Appendix C) and has poor water holding capacity. This reduces water availability for wheat. The weather in terms of rainfall was normal. However, the distribution was not even in the season (Appendix B). Short dry spells experienced in some months (Appendix B), together with the poor water holding capacity of the soil, resulted in water deficiency. Since water is the main ingredient in plant metabolism and required for transportation of substances within plants (Mengel and Kirkby, 1987), deficiency results in poor metabolism leading to poor productivity of wheat. Hay and Walker (1989); and Asana (1966, cited by Slatyer, 1969) have reported decreased productivity of wheat due to deficiency of water. In addition to the problem of water availability for plants, dry spells encouraged termite attack.

Weed development at Kasisi was generally high and comprised mainly broad leaved weeds. The density of weeds was so high in the no-weeding plots that the wheat crop was completely overwhelmed and did not even head (Table 11). Despite the high weed density at Kasisi, correlations between weeds (both in general and specific) after weed control, wheat cover and grain yield were non-significant (Table 12). This showed, that the contribution of weeds through competition to reduced crop development and yield at the site was

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[1] Zam-Can Wheat Project personal communication.

insignificant. However, the injury of the crop in the weed wiper treatment contributed to the distortion in the correlation analysis between weeds, crop cover and yield.

Despite the low weed incidence in the clean weeding, poor crop development and yield were realised (Tables 7, 9 and 11). This confirms that factors other than weed competition were contributing to the poor performance in crop development and yield. The poor result at the site in terms of crop development and yield, shows that agro-ecologically, Kasisi was not suitable for rainfed wheat production. De Milliano (1983) attributed the unsuitability to uneven rainfall distribution and soil type. The termite attack experienced due to the short dry spells also compounded yield loss.

A high weed re-infestation was observed at Kasisi in all weed control methods. This showed that the single weeding could not give adequate control of weeds at the site (Table 7), especially of the late weed infestation. None of the weed control methods could give adequate control of weeds near and within the rows. These weeds, despite the non-significant correlations with crop cover and yield, contributed to poor crop development and yield.

The use of the weed wiper resulted in the destruction of the wheat crop (Table 9). The improvised guards could not provide enough protection to the wheat plants from the non-selective glyphosate herbicide. Inadequate experience on the use of the weed wiper also contributed to the crop injury. Injury of wheat could have been caused by accidentally wiping leaves bending in between the rows.

Among the weed control methods, the use of the dutch hoe, weed wiper and ox-drawn cultivator at Kasisi resulted in less weeding cost compared to the hand hoe (Table 17 and Figure 7). The lower weeding cost of the these weeding methods is attributed to less labour (time) input (Table 17). Druijff and Kerkhoven (1970, cited by Kasasian, 1971) reported similar results on the dutch hoe. The low weeding costs due to the use of ox-drawn cultivator was due to less time used for weeding. Starkey and Verhaeghe (1982) reported similar results in maize where less time was used for weeding.

5.2 MUFUBUSHI

The area where the study was conducted is a small scale farming block. While most farmers in this area grow mainly maize, beans and sunflower, some grow rainfed wheat. During the season Mufubushi received 956 mm rainfall between November 1992 and March 1993. The rainfall was well distributed, unlike at Kasisi (Appendix B). The soils are mainly clay loams with pH ranging from 4.4 to 4.7 (Appendix C). As for Kasisi, the field has been in cultivation for more than five years. A combination of fallow and non-systematic rotation is done in the area. A few farmers use animal draught power for land preparation and weeding. The experimental area was ploughed by oxen and levelled using hand hoes before planting. The area had maize the previous season. At the time of treatment application, not all weed control treatment could be applied on the same day due to rains. Some treatments were applied few days later. The weed wiper weeding was applied first.

In general, good wheat development and yields were realised at Mufubushi (Tables 10 and 14). This may be attributed to the favourable conditions at Mufubushi. The soil, which is mostly clay loam (Appendix C) is recommended for wheat (Anonymous, 1990). Also, according to Zam-Can ([2]), heavier soils, which reduce the problem of water stress, are preferable for rainfed wheat production. The good percent of silt, clay and sand in the Mufubushi soil ensured good aeration, nutrient retention through adsorption, water retention and drainage. The good rainfall, both in amount and distribution through the season (Appendix B), together with the good water holding capacity of the

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2 Zam-Can Wheat Project personal contact

soil, ensured adequate water supply for the wheat. The season was disease and pest free, except for minor bird damage that was experienced. Weed infestation was lower at the site when compared with Kasisi.

The weed pressure was not as high as that at Kasisi, despite a higher figure portrayed compared to Kasisi (Tables 5, 6, 7 and 8). This is the weakness of the method that was applied to estimate weed and wheat cover. Weed infestation at Mufubushi was generally low. Weeds were found to negatively affect only grain yield (Table 15). This is supported by the significance of the correlation between weeds and grain yield (r = - 0.82). *N. physalodes* was specifically established to contribute to reduced yield (r = - 0.89) (Table 15). The result is in conformity with the work by Moyer *et al.* (1989), who reported reductions in wheat yield when the wheat yield was correlated with *Setaria* spp. density. The result also confirms Mulenga (1991), who reported a similar reducing effect of *N. physalodes* on yield of rainfed wheat. Yield reduction at Mufubushi was mainly due to competition for factors of grain formation and ultimate filling of these grains (Mengel and Kirkby, 1987). Any disturbance to photosynthesis and plant's metabolism, which can come about through weed competition for water, nutrient and sunlight, can therefore, reduce grain formation and ultimate filling of the grains. This then results in less seed formation and light weight seeds leading to poor yield. This aspect at Mufubushi is confirmed by the significance of the correlation between weeds and number of grains per ear (r = - 0.99); and grain weight (r = - 0.93) (Table 15).

Again *N. physalodes* was found to contribute to the reduction of number of grains per ear (r = - 0.83) and grain weight (r = - 0.87) (Table 15). With its good developed canopy and root system (Vernon, 1983), it competes better than wheat for light, nutrients and water, resulting in reduced photosynthesis and other metabolic reactions in wheat (Mengel and Kirkby, 1987). This leads to poor grain formation, grain filling and ultimately yield. Mulenga (1991) reported similar reduction in yield due to reduction in grain weight caused by competition between wheat and *N. physalodes.* The aspect of water stress which may arise due to weed competition has been reported by Asana (1966, cited by Slatyer,1969) to affect grain formation and filling which in turn affect grain weight resulting in reduced yield. Zimdahl, (1980) has reported similar effect of weeds on grain weight of wheat.

All the weed control treatments except the no-weeding treatment resulted in good yields (Table 14). The no-weeding treatment had the lowest yield. However, despite having a high weed cover, it performed better than the clean weeding treatment at Kasisi (Tables 11 and 12). This achievement of the no-weeding over that of the clean weeding at Kasisi could be due to differences in agro-ecological suitability. Soil type and climatic differences could be the main contributing factor, as pointed out above. The conditions at Mufubushi may provide sufficient growth factors for both weeds and wheat, thus minimising yield losses through competition. This aspect has been reported in rainfed wheat by Mulenga (1991) and Zimdahl (1980). Young (1988) also reported similar observations in spring wheat where adequate moisture made it possible for wheat to compete fairly with weeds.

None of the weed control methods could adequately control weeds near and within the rows. The weeds contributed to reduction in yield. This problem was most expressed in the ox-drawn cultivator.

The hand hoe performed better in both weed control effectiveness and yield, than any of the other selected weeding methods (Tables 8 and 14, and Figure 6). These were the dutch hoe, the weed wiper and the ox-drawn cultivator. The hand hoe had less weeds and outyielded the other weeding methods mentioned (Tables 14 and Figure 6). The differences in effectiveness between the hand hoe and the dutch hoe could probably be attributed to the methods differing in their effect on weeds under the given soil type and moisture conditions. While the hand hoe requires digging to remove weeds, the dutch hoe just cuts weeds by scrapping on top of the soil. The use of the dutch hoe may have bent some weeds without cutting them, allowing them to reestablish. Clay sticking to the cutting blade of the dutch hoe and dump soil, especially in the morning, may promote this bending. Soil type and moisture conditions of the soil have been reported by Kasasian (1971) to affect weeding efficiency, thus causing variation in effectiveness between weed control methods. People's bias towards the hand hoe and lack of exposure to the use of the dutch hoe before treatment application also may have contributed to the differences in effectiveness.

The high economic returns observed in the use of the hand hoe (Table 17 and Figure 8) can be attributed to the effectiveness of the method in reducing weed competition at the site. The other factor that may cause differences in yield is the digging done during hand hoe weeding. This digging promotes aeration and mineralisation of the soil, which leads to good growth and productivity. Little disturbance of the soil occurred in the dutch hoe when weeding. The only hindrance to the use of the hand hoe is the high weeding cost, due to high labour input (Table 17). This high labour input for the hand hoe is in conformity with labour inputs reported by Akobundu (1985), Carson (1987), Kasasian (1971), Koch (1992) and Tanner and Giref (1991).

If farmers were to increase their hectarage beyond one hectare, more time would be required for weeding wheat with the hand hoe. The increase in hactarage will entail an increase in the number of people to accomplish weeding. This will increase the cost of weeding in addition to the opportunity cost which the farmer incurs through the use of family labour. Labour for hiring may not be available, which is the case for rural areas and where it is available, the farmer may not afford the payments. These problems make it less feasible to increase field size while using the hand hoe weeding technique.

Lower yield and economic returns were realised in the dutch hoe weeding than in the hand hoe (Tables 14 and 18). However, the use of the dutch hoe had less weeding cost compared to the hand hoe (Tables 18 and Figure 8). This achievement is in conformity with Druijff and Kerkhoven (1970, cited by Kasasian, 1971) who reported less weeding time (cost) with the dutch hoe as compared to the hand hoe. Even less time of weeding with the dutch hoe than the one achieved could have been realised, if the people had the experience of working with it before applying the weed control treatments. Looking at the labour input for the dutch hoe at Mufubushi (Table 18), it also has a similar problem of high labour requirement like the hand hoe.

When comparing the weed wiper weeding with the hand hoe, it showed to control weeds less effectively (Table 8). The failure of the weed wiper to show a significant effect on weeds in Mufubushi may be due to the washing away of the herbicide (glyphosate) by the rain showers that followed the herbicide application. Rainfall occurring within six (6) hours of application is known to reduce the effectiveness of glyphosate (Thomson, 1990). The same effect of injury like the one experienced at Kasisi could have happened if the rain would not have washed away the herbicide after application. But despite the high figure of weeds portrayed, yield was good and within the expected yield of rainfed wheat (Table 14). The achievement of good yield (within the expected 1000 - 2000 kg/ha) despite the high weed incidence would either mean that poor assessment of the weed cover was done, or that the weeds were not causing much reductive effect on yield. As for the latter, the conditions at Mufubushi provided enough water, nutrients and sunlight resources for both the weed and wheat thus minimising effects of competition (Mulenga, 1991; Young, 1988; and Zimdahl, 1980). An outstanding feature of the weed wiper is its low weeding cost (Table 18 and Figure 8). Labour input was low, and despite the seemingly expensive herbicide, its use resulted in a good profit. Thus, with low labour input and affordable herbicide cost, a larger area could be put to rainfed wheat using the available family labour. However, an improvement in the guards needs to be done to reduce the effect of crop injury like the one experienced at Kasisi.

The use of the ox-drawn cultivator for weeding at Mufubushi showed good control of weeds (Table 8). The ox-drawn cultivator had a similar crop cover and effect on reducing weed incidence like the dutch hoe, but showed lower yield (Figures 4 and 6). The differences in yield could lay in their effectiveness in controlling weeds close to the rows. While it was easy to control weeds as close as possible to the row with the dutch hoe, it was not so with the ox-drawn cultivator. These weeds could have caused the difference in yield.

The ox-drawn cultivator had the lowest weeding cost of all the selected weed control methods (Figure 8). This is in conformity with results of Starkey and Verhaeghe (1982) who reported a similar achievement with the ox-drawn tines in weeding maize. The lower weeding cost, which was mostly due to less time used for weeding, would allow farmers to extend their hectarage under wheat. For farmers who hire oxen for weeding, extending fields of wheat may result in a reasonable low increase in cost, especially where costing is done on time spent rather than area covered. Also with the less time involved, the farmer who owns oxen will have more time to hire out his oxen.

5.3 COMPARISON OF WEED CONTROL METHODS AT THE TWO LOCATIONS.

In terms of weed control, the two sites had marked differences in the performance of the weed control methods. It was observed that one weed control method was effective in one area but failed in the other. The result of crop cover, weed cover, yield components and yield at the two sites have shown that competition of weeds and effectiveness of weed control methods is location specific. Appleby (1977), Bleasdale (1960) and Zimdahl (1980) have reported this ecological suitability aspect. It seems that weed flora, soil type, the age of the field and conditions prevailing when control was done influenced weed control effectiveness at the sites. The result of a combined analysis of different weed control methods across the two sites, have shown that both location and weed control treatments had a significant effect on wheat yield (Appendix A.15). The two sites differed in their agro-ecological suitability for rainfed wheat (Appendices B and C). The most striking difference between the sites was in their soil type and rainfall distribution (Appendices B and C). Mufubushi was agro-ecologically better for rainfed wheat than Kasisi. On the other hand, interactions between weed control methods and location was insignificant, meaning that only the differences in yield was mainly due to ecological aspects at the site.

6.0 CONCLUSION/ RECOMMENDATIONS.

The experiment was conducted in the 1992/93 crop growing season to identify alternative weeding methods to the hand hoe weeding (farmers practice) in rainfed wheat production.

The performance of the dutch hoe, weed wiper and the ox-drawn cultivator at Mufubushi was promising. Their low weeding cost due to less labour involvement makes them possible alternatives to the hand hoe. The use of the weed wiper fitted with proper guards, has a great potential for weeding. In conclusion, the dutch hoe, ox-drawn cultivator and the weed wiper are potential alternatives to the hand hoe for weeding in rainfed wheat.

From the results and the experience during the experiment, it is recommended that further experiments be done with the dutch hoe, weed wiper, and ox-drawn cultivator in Mpika and other Northern Province areas. The guards of the weed wiper should be improved for use in future experiments. To remove bias, participants in the research on the weed control methods, should be exposed to the new weeding methods before treatment application. Plant development in terms of plant population and plant height may also be monitored from emergence to harvesting. Where possible, the weed and crop above-ground biomass at harvesting may be taken to study the effect of weeds on crop biomass and vice versa. More locations of the experiments should be selected to facilitate a combined analysis.

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8.0 APPENDICES

APPENDIX A. Analysis of variance

Table A.1: Effect of different weed control methods on weed cover in rainfed wheat at Kasisi.

Source of Variation	Df	Mean Squares			
		2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	116.3	114.3	144.0	121.3
Weed control	5	26.8ns	721.7**	2572.4**	1480.1**
Error	20	56.5	60.2	117.4	73.2
Total	29				

*, ** denotes significance at P < 0.05 and 0.01, respectively.

ns denotes non significance.

Table A.2: Effect of weed control method on *N. physalodes* cover in rainfed wheat at Kasisi.

Source of variation	Df	Mean squares			
		2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	41.1	172.6	1330.0	597.8
Weed Control	5	50.4ns	369.5*	1158.9*	707.1*
Error	20	33.7	92.8	220.5	134.2
Total	29				

*, ** denotes significance at P< 0.05 and 0.01 respectively.

ns denotes non significance.

1 Means expressed as mean values after weed control application.

Table A.3: Influence of weed control treatments on *N. physalodes* cover in rainfed wheat at Kasisi.

Treatments*	Average weed cover (%) 2 WAS**	5 WAS**	7 WAS**	Mean[1]
No-weeding	14.6a	29.4a	50.0a	39.7a
	(6.4)	(24.1)	(58.7)	(40.8)
Ox.cultivator weeding	13.4a	13.2b	24.6b	18.9b
	(15.4)	(5.2)	(17.3)	(10.5)
Hand hoe weeding	17.5a	12.3b	22.8b	17.5b
	(9.1)	(4.5)	(14.97)	(9.1)
Dutch hoe weeding	19.9a	11.4b	21.1b	16.3b
	(11.6)	(3.9)	(13.0)	(7.9)
Weed wiper weeding	12.1a	8.8b	14.1b	11.4b
	(4.4)	(2.34)	(5.9)	(3.9)
Clean weeding	19.0a	4.10b	4.4b	4.3b
	(10.6)	(0.5)	(0.6)	(0.6)
Mean	16.1	13.3	22.8	18.0
	(7.6)	(5.2)	(15.0)	(9.5)
SE	2.6	4.3	6.6	5.2
C.V (%)	36.1	72.9	65.1	64.3

* Treatment means in the same column followed by the same letter did not differ significantly at P < 0.05 using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after weed control application.

Table A.4: Effect of weed control methods on *E. indica* cover in rainfed wheat at Kasisi.

Source of variation	Df	Mean squares 2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	23.1	8.4	81.4	17.5
Weed control	5	25.9ns	7.8ns	213.8ns	67.1ns
Error	20	27.6	7.3	118.7	35.8
Total	29				

ns denotes non significance.

1 Means expressed as mean values after weed control application.

Table A.5: Influence of different weed control treatments on *E. indica* cover at Kasisi.

Treatment*	Average weed cover (%) 2 WAS**	5 WAS**	7 WAS**	Mean[1]
Ox.cultivator weeding	12.3a (4.6)	7.6a (1.7)	18.8a (10.3)	13.2a (5.2)
Dutch hoe weeding	10.1a (3.1)	5.3a (0.8)	20.1a (11.8)	12.7ab (4.8)
Hand hoe weeding	14.7a (6.5)	6.7a (1.4)	16.0a (7.6)	11.6ab (4.0)
Weed wiper weeding	8.9a (2.4)	5.1a (0.8)	10.6a (3.4)	7.9ab (1.9)
No-weeding	9.5a (2.7)	6.4a (1.3)	6.9a (1.4)	6.7ab (1.3)
Clean weeding	9.5a (2.8)	4.1 (0.5)	4.1a (0.5)	4.1b (0.5)
Mean	10.8 (3.5)	5.9 (1.1)	12.8 (4.9)	9.3 (2.6)
SE	2.3	1.2	4.9	2.7
C.V (%)	48.6	46.0	85.4	64.2

* Treatment means in the same column followed by the letter did not differ significantly at P< 0.05 using DMRT

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after weed control application.

Table A.6: Effect of weed control methods on crop cover of rainfed wheat at Kasisi.

Source of variation	Df	Mean squares 2 WAS	5 WAS	7 WAS	Mean1
Replication	4	58.1	20.7	232.6	138.9
Weed control	5	62.4ns	466.6**	615.5*	508.9**
Error	20	26.1	67.3	143.8	67.0
Total	29				

*, ** denotes significance at P < 0.05 and 0.01, respectively.

ns denotes non significance.

1 mean expressed as mean values after weed control application.

Table A.7: Effect of weed control on grain yield and yield components of rainfed wheat at Kasisi.

Source of variation	Df	Mean squares							
		GY	1GWT	GWT	El	N_0G/E	N_0S/E	N_0T/P	Pht
Replication	4	3.0	17.45	0.01	0.06	6.59	1.22	1.12	56.37
Weed control	5	1.6*	533.34**	2.24**	57.54**	626.99**	228.28**	2.80**	10444.1**
Error	20	3.0	3.47	0.003	0.46	9.12	0.90	0.57	36.05
Total	29								

*, ** denotes significance at P < 0.05 and 0.01, respectively.

key

GY = Grain yield (Kg/ha).
1GWT = 1000 grain weight (g).
Pht = plant height (cm).
GWT = Grain Weight per ear (g).
El = Ear length per plant (cm).
N_0G/E = Number of grains per ear.
N_0S/E = Number of spikelets per Ear.
N_0T/p = Number of tillers per plant.

Table A.8: Effect of weed control methods on weed cover in rainfed wheat at Mufubushi.

Source of variation	df	Mean Squares			
		2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	317.9	107.5	343.0	208.6
Weed control	5	502.5**	1459.3**	1054.8**	1236.6**
Error	20	42.5	116.7	159.7	122.4
Total	29				

** denotes significance at P < 0.01.

1 Means expressed as mean values after weed control application.

Table A.9: Effect of weed control methods on *N. physalodes* cover in rainfed wheat at Mufubushi.

Source of variation	Df	Mean Squares 2 WAS	5 WAS	7 WAS	Mean1
Replication	4	213.6	7.1	28.3	42.5
Weed Control	5	105.6ns	746.8**	887.8**	937.9**
Error	20	49.2	102.8	109.1	112.0
Total	29				

**, ns denotes significant at P < 0.01 and non significance, respectively.

1 Means expressed as mean values after weed control application.

Table A.10: Influence of treatments on percent *N. physalodes* cover in rainfed wheat at Mufubushi.

Treatments*	Average weed cover (%) 2 WAS**	5 WAS**	7 WAS**	Mean[1]
No-weeding	16.0a (7.6)	35.6a (33.9)	41.7a (44.7)	42.4a (45.5)
Weed wiper weeding	14.3a (6.1)	33.7a (30.7)	36.2a (34.8)	34.9ab (32.7)
Ox.cultivator weeding	15.1a (6.8)	30.1a (25.1)	32.3a (28.5)	31.2ab (26.8)
Dutch hoe weeding	14.4a (6.2)	15.2b (6.9)	16.5b (8.1)	15.9bc (7.5)
Hand hoe weeding	16.1a (7.7)	12.8b (4.9)	17.8b (9.3)	15.1bc (6.8)
Clean weeding	4.1b (0.5)	6.8b (1.4)	7.4b (1.7)	7.1c (1.5)
Mean	13.4 (5.4)	22.4 (14.5)	25.3 (18.3)	24.4 (17.1)
SE	3.1	4.5	4.7	4.7
C.V(%)	52.5	45.3	41.3	43.3

* Treatments means in the same column followed by the same letter did not differ significantly at P < 0.05. using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after weed control application.

Table A.11: Effect of weed control methods on *G. parviflora* cover in rainfed wheat at Mufubushi.

Source of Variation	Df	Mean Squares 2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	135.9	90.7	164.1	129.3
Weed Control	5	135.1*	489.9**	419.9**	408.2*
Error	20	42.7	79.2	64.8	69.0
Total	29				

*, ** denotes significance at $P < 0.05$ and 0.01, respectively.

1 Means expressed as mean values after weed control application.

Table A.12: Influence of weed control treatments on *G. parviflora* cover in rainfed wheat at Mufubushi.

Treatment*	Average weed cover (%) 2 WAS**	5 WAS**	7 WAS**	Mean[1]
Weed wiper weeding	17.8a (9.3)	35.5a (33.8)	33.1a (29.9)	34.3a (31.8)
No-weeding	14.7ab (6.4)	32.0a (28.0)	25.3ab (18.2)	28.6ab (22.9)
Dutch hoe weeding	13.3ab (5.3)	29.8ab (24.6)	23.5ab (15.9)	26.7ab (20.2)
Hand hoe weeding	16.6ab (8.2)	28.1ab (22.2)	22.2ab (14.3)	25.2ab (18.1)
Ox. drawn cultivator	8.7bc (2.4)	17.5bc (9.1)	14.4bc (6.2)	16.0bc (7.6)
Clean weeding	4.1c (0.5)	9.4c (2.7)	6.7c (1.4)	9.5c (2.7)
Mean	12.5 (4.6)	25.4 (18.4)	20.9 (12.7)	23.4 (15.8)
SE	2.6	4.0	3.6	3.7
C.V (%)	45.7	35.1	38.6	35.5

* Treatment means in the same column followed by the same letter did not differ significantly at $P < 0.05$ using DMRT.

** Data were analyzed using figures from arcsine transformation procedure and figures in parentheses are original mean values.

1 Means expressed as mean values after weed control application.

Table A.13: Effect of weed control methods on crop cover of rainfed wheat at Mufubushi.

Source of variation	Df	Mean squares 2 WAS	5 WAS	7 WAS	Mean[1]
Replication	4	356.3	107.3	144.0	125.6
Weed control	5	231.9*	1322.7**	1334.1**	1049.7**
Error	20	73.6	103.0	83.4	98.9
Total	29				

*, ** denotes significance at $P < 0.05$ and 0.01, respectively.

1 Means expressed as mean values after weed control application.

Table A.14: Effect of weed control methods on grain yield and yield components at Mufubushi.

Source of variation	Df	Mean squares GY	1GWT	GWT	El	N_0G/E	N_0S/E	N_0T/P	Pht
Replication	4	14	3.53	0.02	0.78	26.75	1.10	0.67	17.48
Weed control	5	1600**	15.26*	0.06*	0.37ns	36.51*	0.50ns	0.37ns	5.42ns
Error	20	240	3.51	0.02	14.35	0.14	0.73	12.92	0.24
Total	29								

*, ** denotes significance at $P < 0.05$ and 0.01, respectively. ns denotes non significance.

Key

GY = Grain yield (kg/Ha).

1GWT = 1000 Grain weight (g).

GWT = Grain weight (g).

El = Ear length (cm).

N_0G/E = Number of grains per ear.

N_0S/E = Number of spikelets per ear.

N_0T/P = Number of tillers per plant.

Pht = Plant height (cm).

Table A. 15: Effect of different weed control methods on yield across locations.

Source of variation	Df	Mean Squares Yield over location
Replication	4	0.029
Weed control	5	0.69 *
Location	1	237.73 *
L x W	5	4.92 ns
Error	44	
Total	59	

* and ns denotes significance at P < 0.5 and non significant, respectively.

Table A. 16: Weed Control methods' effect on yield at different locations.

Treatment*	Mean Yield Kg\ha#
Clean Weeding	1240 A
Hand hoe weeding	1040 AB
Dutch hoe weeding	770 ABC
Ox-drawn cultivator weeding	720 ABC
Weed wiper weeding	650 BC
No-weeding	350 C
Mean	794
C.V (%)	47

* Treatments means followed by the same letter did not differ significantly at P < 0.05 using DMRT.

# denotes yield over location.

APPENDIX B. RAINFALL DATA.

Location		November	December	January	February	March	Total
Kasisi	R/fall (mm)	101.2	235.1	186.5	193.6	93.3	809.7
	N_0RD	7	17	17	17	10	68
Muf.shi	R/fall(mm)	104.2	219.7	251.2	118.4	262.4	955.9
(Mpika)	N_0RD	8	18	23	20	21	90

R/fall = Monthly Rainfall
N_0RD = Number of rain days.

APPENDIX C: Soil fertility test.

Location	Depth (cm)	pH ($CaCl_2$)	N (%)	O.M. (%)	P (mg/kg)
Kasisi	5	5.2	0.2	1.8	9.3
	10	5.0	0.2	2.3	12.8
	20	4.9	0.2	2.9	6.6
Soil texture	Silt % 21				
	Sand % 68				
	Clay % 11	Soil type: Sandy loam			
Mufubushi	5	4.7	0.2	4.0	12.7
	10	4.5	0.2	4.0	6.3
	20	4.4	0.2	4.2	9.1
Soil texture	Silt % 30				
	Sand % 11				
	clay % 59	Soil type: Clay loam.			

APPENDIX D: Field layout and randomisation of treatments.

Block	Plot no.	Weed ctrl treatment no.
BLOCK I	1	1
	2	2
	3	4
	4	5
	5	3
	6	6
BLOCK II	7	5
	8	3
	9	2
	10	6
	11	4
	12	1
BLOCK III	13	1
	14	4
	15	5
	16	3
	17	2
	18	6
BLOCK IV	19	3
	20	4
	21	2
	22	5
	23	6
	24	1
BLOCK V	25	5
	26	1
	27	2
	28	4
	29	6
	30	3

Key

1 = NW

2 = CW

3 = HHW

4 = DHW

5 = WWW

6 = OCW

Design : RCBD.

APPENDIX E: A schematic diagram of a weed wiper (Standard-single head).