WEED CONTROL IN COMMERCIAL SORGHUM (*Sorghum bicolor* L.) VARIETIES UNDER ZAMBIAN CONDITIONS

BY

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DECLARATION

I, M.C.Makungu, hereby declare that this thesis represents my own work and that it has not been submitted for a degree at this University or any other University.

Signature.............

Date: 07/09/99

APPROVAL

This dissertation of Mr. Melvin Chongo Makungu is approved as fulfilling part of the requirements for the ward of the degree of Masters of Science in Agronomy (Crop Science) of the University of Zambia.

Examiner's signature:	Date:
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DEDICATION

To my wife Sylvia and son Besa.

ABSTRACT

Commercially grown sorghum is slowly replacing maize in the expanding opaque beer brewing industry in Zambia. The lack of an established weed control package for commercial sorghum production has compelled farmers to use herbicide weed control methods recommended for maize in commercial sorghum fields.

Against this background a 5 x 2 factorial experiment with a split plot design comprising five weed control methods and two sorghum hybrid varieties, was set up at UNZA Field Station and Blue Gum Farm in the 1994/95 rainy season.

The first objective of this experiment was to test the efficacy of two herbicides (i.e., Atrazine and Cyanazine) for weed control in commercial sorghum production under Zambian conditions. The second objective of this experiment was to determine the cost effectiveness of using the two herbicides for weed control in sorghum fields. Atrazine (Gesaprim 50% FW) was applied at rates of 3.5 l/ha and 2.0 l/ha. Cyanazine (Bladex 50% SC) was applied at a rate of 2.0 l/ha. Zero weeding and clean weeding treatments were also included in the study as controls. Weed Control Methods, thus comprised the five levels that were assigned to the sub plots. Sorghum Hybrid Varieties, comprised the two levels that were assigned to the main plots and included two commercial sorghum hybrids, viz, MMSH 413 and MMSH 375.

Assessments of weed cover (%) and crop cover (%) were carried out at 2, 5, 8 and 11 weeks after sowing. Other parameters that were determined include plant height, panicle length, grain per panicle, panicles per plant, plants per hectare and 1000

sorghum grain weight. Economic analysis was conducted by subtracting the explicit sorghum production costs from the value of expected sorghum sales.

Results obtained from both locations show significant differences in the weed control efficacy of the three herbicide treatments at 5 weeks after sowing. This is the critical period for weed control in sorghum. The most effective herbicide treatment was Atrazine (Gesaprim 3.5 l/ha) because it reduced the weed cover to 11% of the total flora. This was followed by Atrazine (Gesaprim 2.0 l/ha) which reduced the weed cover to 22% of the total flora. The least effective herbicide treatment was Cyanazine (Bladex 50% SC 2.0 l/ha) with a weed cover of 33% of the total flora.

Economic analyses show that the most economical weed control method for both sorghum varieties was the usage of Atrazine (Gesaprim 50% FW 3.5 l/ha) which had a net profit of 85.4% associated with its average grain yield of 2.9 tons. This was followed by Atrazine (Gesaprim 50% FW 2.0 l/ha) with an average grain yield of 1.8 tons/ha and a net profit of 14.9%. The least economical herbicide treatment was Cyanazine (Bladex 50% SC 2.0 l/ha) with a net profit -21.5 % associated with its average grain yield of 1.2 tons/ha.

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LIST OF ABBREVIATIONS

a.i	Active ingredient
Ann	Annual
Brd	Broadleaf
Brd-wds	Broadleaf weeds
C.V (%)	Coefficient of variation (percentage)
df	Degrees of freedom
DMRT	Duncan's Multiple Range Test
EC	Emulsifiable Concentrate
FW	Flowable
Rate (*l*/ha)	Rate of application
SC	Suspension Concentrate
SE	Standard Error
UNZA	University Of Zambia
WAS	Weeks After Sowing (of sorghum)
ZMK	Zambian Kwacha (Currency)

1.0 INTRODUCTION

Sorghum (*Sorghum bicolor* L.), is a small grain cereal which is utilized in different ways by various peoples of the world. In most developing countries sorghum is ground into a fine flour which is used in making porridge and baking bread, although in countries like the Sudan and India sorghum grain is consumed as whole boiled grain. (Gomez *et al*., 1992). Doggett (1988) cited Zambia as an example of a country where sorghum is the second most important cereal crop and is a staple food mostly for people living in the semi- arid valley areas which receive erratic rainfall of less than 800mm annually.

Jambunathan (1980) explained that sorghum in most developed countries is only used as the energy base in stockfeeds. In Nigeria, sorghum malts have replaced barley malts in clear beer brewing industries whereas in other countries it has been recorded as being a major ingredient in the production of ethanol and composite baking flour. In Zambia, sorghum is replacing maize in the opaque beer brewing industry. The latter has created a sorghum demand in Zambia which has encouraged farmers to grow sorghum commercially.

Commercial sorghum production is constrained among other factors, by weed infestation. Uncontrolled weed infestation in sorghum fields can lead to losses of at least 30% of the potential grain yield or more. The extensive nature of commercial sorghum fields, coupled with the close inter-row spacing, have rendered mechanical weeding impracticable within the critical period of weed-crop competition.

The usage of herbicides for weed control in commercial sorghum fields has consequently been viewed as a viable option. However, the lack of herbicides that have been tested and consequently recommended for weed control in commercial sorghum production, has compelled sorghum farmers to use herbicides such as Atrazine and Cyanazine at rates that are recommended for weed control in maize fields. This practice could result in low weed control efficiency and/or crop injury. This is because different flora genotypes possess varying levels of susceptibility to varying rates of different herbicides (Lebaron and Gressel, 1982). The first objective of this research work was therefore to test the efficacy of the herbicides Atrazine (Gesaprim 50% FW) and Cyanazine (Bladex 50% SC) for weed control in commercial sorghum production under Zambian conditions. The second objective was to determine the cost effectiveness of using the two herbicides for weed control in commercial sorghum varieties.

2.0 LITERATURE REVIEW

2.1 Sorghum Production in Zambia

The earliest evidence of sorghum production in Zambia has been traced as far back as the seventh century AD by Maggs (1980) at Ingombe Ilede in the southern part of Zambia. Until recently, however, the subsequent historical bias towards maize consumption as the staple food for most people in Zambia, has left sorghum to be predominantly grown by subsistence farmers who grew traditional cultivars only. Consequently, commercial sorghum production levels in Zambia have for the last decade remained relatively static, wereas, those of maize have increased. Appendix 1 shows that 60,370 hectares of sorghum were planted in 1981 as compared to 48,465 hectares that were planted in 1990. In comparison, the number of hectares of maize planted increased from 973,151 to 1,456,385 in 1981 and 1990 respectively (Anonymous, 1991).

The annual rainfall recorded in tropical Africa, which encompasses Zambia, has however, decreased in the past decade to levels that are too low to support viable maize production which requires at least 900mm of rainfall annually. The Lusaka City Airport meteorological station recorded 417.9mm of rain in the 45 days of rain in the 1994/95 season, whereas the corresponding figures for York Farm meteorological station were 733.7mm in the 40 days of rainfall (Appendix 6). This situation of decreased annual rainfall has for the past decade been prevalent in the central and southern maize growing regions of Zambia where crop failure has largely been associated with moisture stress.

Unlike the situation with maize, sorghum has been recorded by Stout *et al.*, (1978) as being a drought tolerant crop which performs better than maize when subjected to water stress. This was found to be empirically true by Doggett and Jowett (1966) who explained that sorghum outyields maize when annual rainfall recorded falls below 300mm.

Jambunathan (1980) explained that the appreciably growing number of uses of sorghum worldwide coupled with its drought tolerance, have encouraged substantial breeding programmes which have resulted in the availability of a large number of hybrid cultivars which have proven to be higher yielding than traditional types. This is also true for Zambia, where locally bred sorghum seed is now available for commercial production of sorghum. However, despite the fact that sorghum has the above qualities and drought tolerance properties, its profitable commercial production is dependent among other factors, on effective weed control.

2.2 Weeds

2.2.1 Weeds and Their Effects on Sorghum Yield

Weeds are defined as plants growing where they are not desired (Klingman and Ashton, 1982). Under uncontrolled conditions, weed growth in sorghum fields can cause losses of at least one third or more, of potential grain yield (Wellving, 1983). As such, any method of weed control employed in sorghum fields especially in the early days of crop growth proves to be essential for good yields (Doggett, 1988). Burnside (1977) restricted the critical period for weeding, in sorghum fields, to the first month after sowing. Thereafter the sorghum plants will have developed enough to compete effectively with weeds. In addition, Akobundu (1987) explained that sorghum fields should be kept weed free for the first five weeks after sowing in order to prevent grain yield reduction.

2.2.2 Weeds and Their Effects on Other Aspects of Sorghum Production

(a) Production Costs

Labour and financial requirements for weeding have been recorded as some of the major factors that constitute crop production costs. Akobundu (1987) gave Nigeria as an example of a country where labour requirements for weeding in sorghum fields account for 37% of the total labour requirements under traditional sorghum farming systems, whereas, Klingman and Ashton (1982), reported that weeding costs account for 42% of the total crop protection costs on commercial farms in the United States of America.

(b) Harvest Impediment

Heavy infestations of weeds such as *Commelina benghalensis* have been known to jam some mechanical harvesters and as such impede harvest operations. Hand harvesting has been known to be hampered by weed species such as *Rottboellia cochinchinensis* and *Mucuna pruriens* (Akobundu, 1987).

(c) Harvest Quality

Seed and/or vegetative parts of weeds contaminate mechanically harvested sorghum grain. Attempts to separate them from the sorghum grain have shown to increase the cost of harvesting (Akobundu, 1987).

2.2.3 Weed Control in Commercial Sorghum Production

Burnside (1977) explained that the extensive nature of commercial sorghum fields, coupled with the associated close inter-row spacing, have rendered mechanical weeding impracticable within the critical period of weed-crop competition. The usage of herbicides in commercial sorghum production has been identified by agronomists as being particularly cardinal for weed control in developed countries (Doggett, 1988). In this respect, the usage of herbicides that have been tested for weed control in the commercial sorghum fields of Zambia is equally important. Unfortunately, there currently are no herbicides that are specifically recommended for weed control in the Zambian commercial sorghum fields. Wellving (1983) generally stated that any available and current herbicide recommendation should be used for weed control in sorghum fields. The Zambia Seed Company's Sorghum Agronomy Guide, has generally recommended that chemical weed control in sorghum should entail the usage of half the herbicide rates recommended for weed control in maize fields (Anonymous, 1990). However, Marshall and Nell (1978) explained that differences in susceptibility to different herbicides exist between specific flora genotypes. As such, caution has to be exercised when dealing with application rates. In addition, Lebaron and Gressel (1982) explained that different flora genotypes possess varying levels of susceptibility to varying rates of different herbicides. Vernon (1980) listed some maize herbicides that could be used in sorghum (Appendix 2). Vernon (1980) however, warned that caution has to be exercised when using the listed herbicides because very little research had been done to test the efficacy of the listed herbicides for weed control in sorghum fields.

3.0 MATERIALS AND METHODS

3.1 Introduction

One experiment was conducted at two locations in the 1994/95 rainy season. The objectives of this experiment were to test the efficacy of Atrazine (Gesaprim 50% FW) and Cyanazine (Bladex 50% SC), for weed control in commercial sorghum varieties and to determine the cost effectiveness of using the two herbicides.

3.2 Experimental Sites

The sites that were used in the experiments were as follows:

3.2.1 University of Zambia Field Station

This field station is located at the University Of Zambia in Lusaka. The land use type is that of rainfed crop cultivation. The site normally receives 800mm to 1000mm annual rainfall. The soil depth exceeds 20cm in the surface (Ap) horizon and the textural class of the soil is sandy loam. The soil had moderate pH which ranges from pH($CaCl_2$) 5.8 to pH($CaCl_2$) 7.4 (Appendix 5).

3.2.2 Blue Gum Farm

Blue Gum commercial farm is situated 27 km west of Lusaka on the road to Nampundwe mine. The land use type is that of rainfed crop cultivation. The site receives 800mm to 1000mm annual rainfall. The soil depth at the site exceeds 20cm in the surface (Ap) horizon and the textural class of the soil is sandy clay loam. The soil had a moderate pH ranging from pH($CaCl_2$) 5.0 to pH($CaCl_2$) 6.1 (Appendix 5).

3.3 Experimental Design

A split plot design with two factors was employed in this study.

3.3.1 Factor A: Sorghum Hybrid Varieties

This factor was assigned to the main plots and had the two levels stated below:

(a) MMSH-375 variety denoted as V1.

(b) MMSH-413 variety denoted as V2.

3.3.2 Factor B: Weed Control Method

Vernon (1980) has listed a number of maize herbicides that could be used with caution in sorghum fields (Appendix 2). Out of the herbicides listed in Appendix 2, Propachlor and Terbutryne are no longer available on the Zambian market. Schmid *et al.*, (1994) tested the efficacy of the available herbicides for weed control in commercial sorghum fields. The results from the study that are stated in Appendix 3 clearly show that the most promising of the available herbicides is Atrazine (Gesaprim 50% FW), followed by Cyanazine (Bladex 50% SC). Since Atrazine (Gesaprim 50% FW) showed satisfactory phytotoxicity at the rates, 5.0 l/ha and 3.5 l/ha on both, weeds and sorghum, the lower rate of 3.5 l/ha, which is more economical, was selected for re-testing in this study. A lower rate of 2.0 l/ha Atrazine (Gesaprim 50% FW) which is even more economical and environmentally friendly was introduced in this study for efficacy testing. On the other hand, Cyanazine (Bladex 50% SC), which showed satisfactory phytotoxicity on weeds but had unsatisfactory effects on sorghum was also included in this study for re-testing but at a lower rate of 2.0 l/ha. The three herbicide treatments were together with two control treatments assigned to the sub plots. The five weed control treatments are stated below:

(a) Atrazine (Gesaprim 50% FW 3.5 l/ha), pre-emergence soil applied herbicide denoted as A1.

(b) Atrazine (Gesaprim 50% FW 2.0 l/ha), pre-emergence soil applied herbicide denoted as A2.

(c) Cyanazine (Bladex 50% SC 2.0 l/ha), pre-emergence soil applied herbicide denoted as CY.

(d) Clean weeding, was done at ten day intervals using hand hoes and was denoted as CL.

(e) Zero weeding was denoted as, ZW.

3.3.3 Treatment Combinations

The following treatment combinations were used:

V1A1, V1A2, V1CY, V1CL, V1ZW, V2A1, V2A2, V2CY, V2CL and V2ZW.

3.3.4 Plot Sizes

The sub plots were 3m x 10m and the main plots were 10m X 30m.

3.4 Materials

The basic materials that were used included, a soil auger, hand hoes, basal dressing fertilizer (10N : 20 P_2O_5 :10 K_2O, Compound D), top dressing fertilizer (Ammonium Nitrate), certified sorghum seed, Gesaprim 50% FW, Bladex 50% SC, measuring tape, harvest knives, harvest sacks and an electronic balance. Tractor drawn disc plough, and disc harrow, were used for seedbed preparation.

3.5 Agronomic Practices

Agronomic practices that were employed at the two locations are summarized in Table 1.

3.6 Data Collection and Analysis

The harvest area which measured 1.5m x 8m was used as the sampling area for the four weed cover and crop cover assessments that were carried out during the study period. The assessments were done at 2, 5, 8 and 11 weeks after sowing (Table 2).

Weed identification during the assessment was done with reference to arable weed identification guidelines that are prescribed by Vernon (1983). The assessments were based on estimates of weed cover (%) and crop cover (%), using a scale ranging from zero to one hundred percent cover. Weed frequency for each weed species was determined by dividing the summation of the number of sub plots in which each weed species occurred, by the total number of sub plots at each site. The average plant height and average panicle length were derived from heights and panicle lengths of half the number of sorghum plants that were randomly sampled from harvest areas of each sub plot. The said panicle lengths and plant heights were measured using a meter rule. The 1,000 grain weight was based on a sample of 1000 grains taken from each plot.

The data was analysed using the MSTAT computer programme with reference to Gomez and Gomez (1984). Means separation was done using Duncan's Multiple Range Test (DMRT). Economic analysis involved the calculation of the expected profit per hectare. Expected profit is the balance that is left from subtracting the explicit expenses of production, from expected sales (Hanson, 1980). Expected profit was calculated by multiplying the yield per hectare (kg/ha) by the sorghum price per kilogram (ZMK), to obtain the gross benefit per hectare (ZMK). The total input cost per hectare (ZMK), was then subtracted from the gross benefit per hectare. The difference was the net return per hectare (ZMK). The net return per hectare was then divided by the total input cost per hectare and then multiplied by 100 to obtain the net profit per hectare (%).

Table 1: Agronomic practices employed.

	Location	
	UNZA	BLUE GUM FARM
Land preparation (Tractor ploughing)	15/12/94	19/12/94
Sowing (Hand drilling)	16/12/94	20/12/94
Seed rate	10kg/ha	10kg/ha
Intra-row spacing	drilled	drilled
Inter-row spacing	0.75m	0.75m
Basal dressing fertilizer (300kg/ha)	At sowing for both sites	
Top dressing fertilizer (100kg/ha)	21/1/95	25/1/95
Harvest area	8m x 1.5m per plot	
Harvest date	30/4/95	4/5/95

Table 2: Field assessment dates for UNZA and Blue Gum Farm.

Assessment times (weeks after sowing)	UNZA	BLUE GUM FARM
2	30/12/94	3/1/95
5	19/1/95	23/1/95
8	8/2/95	12/2/95
11	1/3/95	5/3/95

4.0 RESULTS

4.1 Weed Flora Observed

Broadleaf weeds were predominant at UNZA and Blue Gum Farm (Table 3).

4.2 Effect of Different Weed Control Treatments on Weed Cover

4.2.1 University of Zambia

The data from the UNZA experimental location shows that the different weed control treatments had significantly different effects on weed cover (Appendix 4.1). The results are presented in Table 4. The three herbicide treatments were ranked in the following order of decreasing weed phytotoxicity at the UNZA field station:

(a) Atrazine (Gesaprim 50% FW) at 3.5 l/ha.

(b) Atrazine (Gesaprim 50% FW) at 2.0 l/ha.

(c) Cyanazine (Bladex 50% SC) at 2.0 l/ha.

The clean weeding treatment was the most effective weed control method whereas the zero weeding treatment had the highest weed cover (Table 4).

4.2.2 Blue Gum Farm

The data from Blue Gum Farm also shows that the different weed control treatments had significantly different effects on weed cover (Appendix 4.2). The results are presented in Table 5. The three herbicide treatments were ranked in the following order of decreasing weed phytotoxicity at Blue Gum Farm:

(a) Atrazine (Gesaprim 50% FW) at 3.5 l/ha.

(b) Atrazine (Gesaprim 50% FW) at 2.0 l/ha.

(c) Cyanazine (Bladex 50% SC) at 2.0 l/ha.

As was the case at UNZA field station, clean weeding treatment was the most effective weed control method whereas the zero weeding treatment had the highest weed cover (Table 5).

4.3 Effect of Different Weed Control Treatments on Sorghum Cover

4.3.1 University of Zambia

The data from UNZA shows that the different weed control treatments had significantly different effects on sorghum cover (Appendix 4.3). The results are shown in Table 6. The three herbicide treatments were ranked in the following order of decreasing effects on sorghum cover:

(a) Atrazine (Gesaprim 50% FW 3.5 l/ha).

(b) Atrazine (Gesaprim 50% FW 2.0 l/ha).

(c) Cyanazine (Bladex 50% SC 2.0 l/ha).

Sorghum cover was highest in the clean weeding treatment plots whereas the lowest sorghum cover was recorded in the zero weeding treatment plots. This is shown in Table 6.

4.3.2 Blue Gum Farm

The data from the Blue Gum Farm shows that the different weed control treatments had significantly different effects on sorghum cover (Appendix 4.4). The results are presented in Table 7. The three herbicide treatments were ranked in the following order of decreasing effects on sorghum cover:

(a) Atrazine (Gesaprim 50% FW 3.5 l/ha).

(b) Atrazine (Gesaprim 50% FW 2.0 l/ha).

(c) Cyanazine (Bladex 50% SC 2.0 l/ha).

Sorghum cover was highest in the clean weeding treatment plots whereas the lowest sorghum cover was recorded in the zero weeding plots. This is shown in Table 7.

4.4 Correlation Between Weed Cover and Sorghum Cover

The correlation between sorghum cover and weed cover at both UNZA and Blue Gum Farm was negative (Table 8).

4.5 Effect of Weed Control Treatments on Sorghum Grain Yield

The interaction of responses of grain yield components to the environment is the main factor that determines grain yield per unit area in cereals (Wild 1988). Grain yield components of sorghum include, number of plants per unit area, panicles per plant, panicle length, number of grain per panicle, 1000 grain weight and plant height.

4.5.1 University of Zambia

Results from UNZA show that weed control treatments did not have significantly different effects on the yield components; 1000 grain weight; number of plants per hectare and the number of panicles per plant. Weed control treatments however had significantly different effects on plant height, panicle length, grain per panicle, and consequently on the grain yield (Table 9).

4.5.2 Blue Gum Farm

Results from Blue Gum Farm show that weed control treatments did not have significantly different effects on plant height, 1000 grain weight, panicles per plant and plant population. The weed control treatments however had significantly different effects on panicle length, grain per panicle and consequently on the grain yield (Table 10).

4.6 Correlation Between Weed Cover and Grain Yield

The results that were obtained from UNZA and Blue Gum Farm showed that the correlation between weed cover and grain yield was negative at 2, 5, 8 and 11 weeks after sowing. The results are presented in Tables 11 and 12.

4.7 Economic Returns of Weed Control Treatments at UNZA and Blue Gum Farm

Results from economic analyses that were done for weed control treatments at both UNZA and Blue Gum Farm are presented in Tables 13 and 14.

Table 3: Weed flora in the Experimental area at UNZA field Station and Blue Gum Farm.

Location	Weed Species	Average weed cover in each treatment at 5 WAS* (%)					Frequency (%)
UNZA		ZW	CY	A2	A1	CL	
	Ageratum conyzoides	1	T	T	T	0	12
	Amaranthus hybridus L.	5	4	4	2	0	80
	Amaranthus spinosus L.	4	3	1	T	0	80
	Bidens pilosa	2	1	T	T	0	64
	Bidens shimperi	T	T	T	T	0	8
	Bothriocline laxa	1	T	T	T	0	58
	Commelina benghalensis	T	T	1	1	0	22
	Cynodon dactylon	1	1	1	1	0	52
	Eleusine indica L.	1	T	1	1	0	38
	Erlangea misera	1	2	1	2	0	14
	Euphorbia heterophylla	4	6	5	3	0	76
	Hibiscus meeusei	1	1	2	T	0	54
	Ipomea dichroa	1	1	2	T	0	44
	Leucus martinicensis	2	2	1	T	0	78
	Nicandra physalodes (L.) Gaerth	6	5	3	2	0	70
	Panicum maximum	1	T	T	T	0	10
	Rottboellia cochinchinensis	T	2	1	T	0	8
	Setaria verticillata (Steud.) Chiov	1	T	T	T	0	18
	Sonchus oleraceus	T	T	T	T	0	30
	Tagetes minuta L.	1	1	T	T	0	18
	Trichodesma zeylanicum	T	T	T	T	0	4
	Triumfetta annua	T	2	T	T	0	10

Table 3 continued.

Location	Weed Species	Average weed cover in each treatment at 5WAS* (%)					Frequency (%)
Blue Gum		ZW	CY	A2	A1	CL	
	Acanthospermum hispidum	1	T	1	T	0	32
	Amaranthus hybridus L.	7	4	5	3	0	78
	Amaranthus spinosus L.	5	4	2	1	0	80
	Bidens pilosa L.	3	2	2	T	0	80
	Bidens schimperi (Shultz.) Bip	1	T	T	T	0	56
	Bothriocline laxa	T	T	T	T	0	16
	Cassia obtusifolia	T	1	T	T	0	6
	Celosia trigyna	1	T	T	T	0	20
	Commelina benghalensis	T	T	T	T	0	52
	Cynodon dactylon	T	T	T	T	0	14
	Eleusine indica	T	T	T	T	0	24
	Erlangea misera	1	1	1	T	0	34
	Euphorbia heterophylla	6	12	7	5	0	72
	Hibiscus meeusei L.	1	1	1	T	0	56
	Ipomea dichroa	T	T	T	T	0	50
	Leucus martinicensis	T	1	T	T	0	62
	Millenes repens	1	T	1	T	0	68
	Nicandra physalodes (L.) Gaerth.	5	4	2	1	0	72
	Panicum maximum	T	T	T	T	0	78
	Setaria verticillata	T	T	T	T	0	50
	Tagetes minuta L.	T	T	T	T	0	54
	Trichodesma zeylanicum	T	T	T	T	0	10

* 5WAS is the abbreviation for five weeks after sowing, which is the critical period for weed control in sorghum.

Key: The letter, T, has been used to represent average cover of all weed species that occurred in traces (i.e. with less than 1 % average cover).

Table 4: Influence of different weed control treatments on weed cover in rainfed sorghum at UNZA.

Treatment	Average weed cover (%)				
	2WAS	5WAS	8WAS	11WAS	Mean*
Zero weeding	25.20a**	32.80a	37.90a	43.30a	34.80
Cyanazine (Bladex 2.0 l/ha)	17.20b	30.50b	35.20b	42.30a	31.30
Atrazine (Gesaprim2.0 l/ha)	8.10c	22.50c	27.40c	31.40b	22.35
Atrazine (Gesaprim3.5 l/ha)	7.70c	11.70d	15.60d	18.00c	13.25
Clean weeding	0.00d	0.00e	0.00e	0.00d	0.00
Mean	11.64	19.5	23.22	27.00	
Se	0.31	0.380	0.29	0.47	
C.V(%)	8.38	6.90	4.05	5.50	

* This is the mean of the average weed cover at 2, 5, 8 and 11 weeks after sowing.

** Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple Range Test.

WAS = Weeks After Sowing.

Table 5: Influence of different weed control treatments on weed cover in rainfed sorghum at Blue Gum Farm.

Treatment	Average weed cover (%)				
	2WAS	5WAS	8WAS	11WAS	Mean*
Zero weeding	22.60a**	32.30a	38.00a	46.40a	34.725
Cyanazine(Bladex2.0 l/ha)	17.30b	30.60b	34.10b	41.50b	30.89
Atrazine(Gesaprim2.0 l/ha)	7.70c	22.20c	28.10c	32.00c	22.50
Atrazine(Gesaprim3.5 l/ha)	6.70c	10.20d	14.30d	17.80d	12.25
Clean weeding	0.00d	0.00e	0.00e	0.00e	0.00
Mean	10.86	19.06	22.9	27.54	
SE	0.37	0.46	0.36	0.38	
C.V(%)	10.87	7.70	5.00	4.43	

* This is the mean of the average weed cover at 2, 5, 8 and 11 weeks after sowing.

** Means in the same column followed by the same letter are not significantly different at $P \leq 0.05$ according to Duncan's Multiple RangeTest.

WAS = Weeks After Sowing.

Table 6: Influence of different weed control treatments on sorghum cover at UNZA.

Treatment	Average sorghum cover (%)				
	2WAS	5WAS	8WAS	11WAS	Mean*
Clean weeding	14.60a **	43.4a	73.0a	84.5a	53.87
Atrazine(Gesaprim 3.5 l/ha)	10.20b	37.6b	59.7b	78.5b	46.50
Atrazine(Gesaprim 2.0 l/ha)	8.6c	25.5d	53.4c	62.2c	37.67
Cyanazine(Bladex 2.0 l/ha)	8.3c	29.5c	39.6d	50.7d	32.02
Zero Weeding	7.9e	18.8e	30.1e	32.7e	22.37
Mean	9.92	30.96	38.02	61.92	
SE	0.26	0.53	0.53	0.78	
C.V (%)	8.36	5.42	3.28	4.02	

* This is the mean of the average sorghum cover at 2, 5, 8 and 11 weeks after sowing.

** Means in the same column followed by the same letter are not significantly differently at $p \leq 0.05$ according to Duncan's Multiple Range Test.

WAS = Weeks After Sowing.

e 7: Influence of different weed control treatments on sorghum cover at Blue Gum Farm.

atment	Average Sorghum cover (%)				
	2WAS	5WAS	8WAS	11WAS	Mean*
an weeding	14.00a**	42.40a	75.60a	84.40a	54.10
azine (Gesaprim 3.5 l/ha)	9.90b	37.10b	56.10b	79.50b	45.65
azine (Gesaprim 2.0 l/ha)	8.10d	32.80c	51.40c	64.30c	39.15
nazine(Bladex 2.0 l/ha)	8.90c	27.40d	41.00d	53.00d	32.57
o weeding	7.20e	16.90e	30.20e	32.30e	21.65
an	9.62	31.32	50.86	62.70	
	4.90	7.83	8.47	8.38	
' (%)	16.30	7.91	5.27	2.99	

his is the mean of the average sorghum cover at 2,5,8 and 11 weeks after sowing.

leans in the same column followed by the same letter are not significantly ifferent at $p \leq 0.05$ according to Duncan's Multiple Range Test.

/AS = Weeks After Sowing.

Table 8: Correlation between sorghum cover and weed cover at UNZA and Blue Gum Farm.

Location	Correlation between Sorghum cover and Weed cover (r) at $P \leq 0.05$
UNZA	- 0.957
Blue Gum Farm	- 0.0848

Table 9: Influence of weed control treatments on yield and yield components of sorghum at UNZA.

Treatment	Average Yield and Yield components						
	PHt	PnL	1Gw	Gn/Pn	Pn/P	P/ha	GY
Clean weeding	130.7a*	23.15a	23.43a	1312.1a	1.00	116,400 a	3512.1a
Atrazine (Gesaprim 3.5 l/h)	124.4b	23.25a	23.32a	1068.7b	1.00	124,200 a	2829.5b
Atrazine (Gesaprim 2.0 l/ha)	120.2b	23.50a	23.16a	647.1c	1.00	121,000 a	1758.4c
Cyanazine (Bladex 2.0 l/ha)	114.3c	19.04b	23.36a	436.8d	1.00	120,200 a	1176.9d
Zero weeding	111.1c	17.80b	23.20a	152.4e	1.00	119,600 a	427.0e
Mean	120.14	21.35	23.29	723.4	1.00	120,240	1940.78
Se	1.52	0.45	0.11	10.66	0.00	6.50	56.63
C.V (%)	4.02	6.66	1.57	4.66	0.00	3.01	9.32

Key: PHt = Plant Height (cm).
PnL = Panicle Length (cm).
1Gw = 1,000 Grain weight (g).
Gn/Pn = Grain per Panicle.
Pn/P = Panicles per plant.
P/ha = Plants per hectare.
GY = Grain Yield (kg/ha).

* Means in the same column followed by the same letter are not significantly different at $p \leq 0.05$ according to Duncan's Multiple Range Test.

Table 10: Influence of weed control treatments on yield and yield components of sorghum at Blue Gum Farm.

Treatment	Average Yield and Yield components						
	PHt	PnL	1Gw	Gn/Pn	Pn/P	P/ha	GY
Clean weeding	128.3a*	24.25a	23.66a	1245.6a	1.00	124,400a	3314.1a
Atrazine (Gesaprim 3.5 l/ha)	132.9a	24.70a	23.16a	1083.5b	1.00	121,600a	3080.3a
Atrazine (Gesaprim 2.0 l/ha)	129.3a	23.20a	23.25a	650.6c	1.00	122,400a	1782.7b
Cyanazine(Bladex 2.0 l/ha)	128.6a	23.50a	23.23a	453.8d	1.00	116,900a	1256.5c
Zero weeding	128.4a	20.85b	23.50a	184.9e	1.00	126,100a	509.8d
Mean	129.50	23.30	23.36	723.68	1.00	122,280	1988.68
Se	3.62	0.59	18.78	18.78	0.00	7.30	124.03
C.V (%)	4.32	8.13	3.36	8.21	0.00	2.37	19.72

Key: PHt = Plant Height (cm).
PnL = Panicle Length (cm).
1Gw = 1,000 Grain weight (g).
Gn/Pn = Grain per Panicle.
Pn/P = Panicles per plant.
P/ha = Plants per hectare.
GY = Grain Yield (kg/ha).

* Means in the same column followed by the same letter are not significantly different at $p \leq 0.05$ according to Duncan's Multiple Range Test.

Table 11: Correlation between weed cover and sorghum grain yield at specific stages of sorghum growth at UNZA.

	Sorghum Growth Stage			
	2 WAS	5 WAS	8WAS	11 WAS
Correlation (r) at $P \leq 0.05$	- 0.895	- 0.925	- 0.922	- 0.917

Key : WAS = Weeks After Sowing.

Table 12: Correlation between weed cover and sorghum grain yield at specific stages of sorghum growth at Blue Gum Farm.

	Sorghum Growth Stage			
	2 WAS	5WAS	8WAS	11 WAS
Correlation (r) at $P \leq 0.05$	- 0.797	- 0.849	-0.830	- 0.834

Key : WAS = Weeks After Sowing.

Table 13: Economic returns of the weed control treatments at UNZA.

Item	Weed control treatment				
	CL	A1	A2	CY	ZW
Mean yield (kg/ha)	3,512.10	2,829.50	1,758.40	1,176.90	427.00
Price per kg (ZMK)	111.11	111.11	111.11	111.11	111.11
Gross benefit (ZMK)	390,229	314,385	195,375	130,765	47,443
Labour input (man days/ha)	90	70	70	70	65
Labour rate (ZMK/man day)	1,500	1,500	1,500	1,500	1,500
Labour cost (ZMK)	135,000	105,000	105,000	105,000	97,500
Equipment cost (ZMK)	20,000	20,000	20,000	20,000	20,000
Depreciation (25%)	1,000	1,000	1,000	1,000	1,000
Total equipment cost (ZMK)	21,000	21,000	21,000	21,000	21,000
Herbicide cost (ZMK)	0.00	22,000	15,000	18,000	0.00
Agronomic input cost (ZMK)	30,000	30,000	30,000	30,000	30,000
Total cost (ZMK/ha)	186,000	178,000	171,000	174,000	148,000
Net return (ZMK/ha)	204,229	136,385	24,376	-43,394	-100,557
Net Profit % (Net return/Total cost)	109.6	76.4	14	-24	-67

Key : A1 = Atrazine (Gesaprim 3.5 l/ha). Cy = Cyanazine (Bladex 2.0 l/ha).
A2 = Atrazine (Gesaprim 2.0 l/ha). ZMK = Zambian Kwacha (Currency).
CL = Clean hand hoe weeding. ZW = Zero Weeding.

Table 14: Economic returns of Weed Control treatments at Blue Gum Farm

Item	Weed control treatment				
	CL	A1	A2	CY	ZW
Mean yield (kg/ha)	3,314.1	3,080.30	1,782.70	1,256.50	509.80
Price per kg (ZMK)	111.11	111.11	111.11	111.11	111.11
Gross benefit (ZMK)	368,229	342,252	198,075	139,609	56,643
Labour input (man days/ha)	90	70	70	70	65
Labour rate (ZMK/man day)	1,500	1,500	1,500	1,500	1,500
Labour cost (ZMK)	135,000	105,000	105,000	105,000	97,500
Equipment cost (ZMK)	20,000	20,000	20,000	20,000	20,000
Depreciation (25%)	1,000	1,000	1,000	1,000	1,000
Total equipment cost (ZMK)	21,000	21,000	21,000	21,000	21,000
Herbicide cost (ZMK)	0.00	22,000	15,000	18,000	0.00
Agronomic input cost (ZMK)	30,000	30,000	30,000	30,000	30,000
Total cost (ZMK/ha)	186,000	178,000	171,000	174,000	148,000
Net return (ZMK/ha)	182,229	164,252	27,076	-34,390	-91,356
Net Profit % (Net return/Total cost)	97.8	92.1	15.8	-19	-61

Key: A1 = Atrazine (Gesaprim 3.5l/ha).
A2 = Atrazine (Gesaprim 2.0 l/ha).
CL = Clean hand hoe weeding.
Cy = Cyanazine (Bladex 2.0 /ha).
ZMK = Zambian Kwacha (Currency).
ZW = Zero Weeding.

5.0 DISCUSSION

5.1 Effects of Herbicide Treatments on Weed Cover (%)

The results that were obtained from UNZA and Blue Gum Farm at the critical period show that the Atrazine and Cyanazine treatments had significantly different effects on weed cover (Appendices 4.1 and 4.2). This is most probably because Atrazine and Cyanazine interfered with metabolism of susceptible weed species at varying levels. Atrazine and Cyanazine belong to the symmetrical Triazine (*s*-Triazine) class of herbicides. Herbicides that are classified as *s*-Triazines have the potential of interfering with metabolism of susceptible plants, mainly by inhibiting the process of photosynthesis. The s-Triazine herbicides inhibit photosynthesis of susceptible plants by interrupting the Hill reaction's light driven flow of electrons from water to nicotinamide adenine dinucleotide (NADP) and consequently the evolution of oxygen from water (Kearney and Kaufman, 1975). The *s*-Triazine herbicides can interfere with deoxyribonucleic acid (DNA) metabolism, which consequently results in accelerated protein synthesis. This results in undesirable increase in dry matter and protein accumulation in parts of susceptible plants (Kearney and Kaufman, 1975). Akobundu, (1987) explained that *s*-Triazine herbicides can interfere with the process of incorporation of nitrogen into organic molecules by inhibiting enzyme catalysed reactions that support the reduction of nitrates and oxidation of ammonium molecules.

The *s*-Triazine herbicides can also interfere with metabolism of susceptible plants by acting like growth regulators. Copping *et al.*, (1972), explained that, when applied at sub lethal concentration, *s*-Triazine herbicides stimulate undesirable growth of susceptible plants. The application of very high concentrations of *s*-Triazine herbicides to susceptible plants results in damaged cell organelle membranes (Hill *et al.*, 1968). The level of interference in the metabolism of a susceptible plant, by a herbicide, is dependent on selectivity and bioavailability of a herbicide.

(a) Herbicide Selectivity

The results from UNZA and Blue Gum Farm show that weed cover (%) had a declining trend with the highest cover occurring in the zero weeding plots followed by the Cyanazine (Bladex 50% SC 2.0 l/ha), Atrazine (Gesaprim 50% FW 2.0 l/ha), Atrazine (Gesaprim 50% FW 3.5 l/ha) and lastly the zero weeding plots (Tables 4 and 5). The declining trend of the weed cover (%) in the herbicide treatment plots is most probably because of the selective phytotoxicity.

Kearney and Kaufman (1975) explained that some plant species have the potential to detoxify some or all of the *s*-Triazine herbicides. Jachetta and Radosevich (1981), explained that herbicide selectivity in plants is mainly dependent on the rate at which specific plants are able to detoxify herbicides. Plants that are resistant to *s*-Triazine herbicides posses pathways that are able to detoxify the *s*-Triazine herbicides faster than those found in susceptible plants. The weed cover at UNZA and Blue Gum Farm showed a similar trend, whereby there was a higher weed cover in the cyanazine (Bladex 50% SC) plots than the two Atrazine (Gesaprim 50% FW) plots. This could imply that the weed species at both locations had a higher potential to detoxify Cyanazine than Atrazine.

(b) Bioavailability

The mechanism and mode of action of a herbicide in a plant is dependent on the availability of ideal quantities of the herbicide at the intended site(s) of action. Soil applied herbicides like Atrazine and Cyanazine are taken up by plant roots from soil solution. Bioavailability of soil applied herbicides to plants is governed by the equilibrium between adsorption to soil colloids and solubility of the herbicides in soil water (Kearney and Kaufman, 1975). This means that the more a herbicide is soluble in soil water, the more available it will be to plants. In this respect, the rate of application of a herbicide is no exception. This means that if the same herbicide is applied at different rates, the higher rate will contribute to higher herbicide concentration in soil solution than the lower rate. The bioavailability of the herbicide with the higher application rate will similarly be higher. This is probably the reason why the Atrazine (Gesaprim 50%FW 3.5 l/ha) plots had a lower weed infestation than the Atrazine (Gesaprim 50% FW 2.0 l/ha).

5.2 Effects of Herbicide Treatments on Sorghum Cover

The weed control treatments that were used at both experimental locations had significantly different effects on sorghum cover (Appendices 4.3 and 4.4).

At both locations sorghum cover was highest in the clean weeding plots followed by the Atrazine (Gesaprim 50% FW 3.5 l/ha) plots (Tables 6 and 7). At both locations sorghum cover was higher in the Atrazine (Gesaprim 50% FW 3.5 l/ha) plots than the Atrazine (Gesaprim 50% FW 2.0 l/ha). This is in contrast with the concept of bioavailability of herbicides at different application rates that was discussed earlier in 5.1 (b). The contrast has been noted because sorghum cover was higher in plots where Atrazine was applied at a higher rate than the cover that was recorded from plots where Atrazine was applied at a lower rate. This implies that sorghum has the potential to detoxify Atrazine. At both locations sorghum cover was higher in both the Atrazine (Gesaprim 2.0l/ha and 3.5l/ha) treatment plots than the Cyanazine treatment plots. This agrees with the idea of herbicide selectivity that was discussed earlier in 5.1 (b) and implies that the sorghum plants at both locations could have selectively detoxified Atrazine (Gesaprim 50% FW) more than Cyanazine (Bladex 50% SC).

The results in addition show that sorghum cover at both locations was highest in the plots where weed cover was lowest. In actual fact the correlation between sorghum cover and weed cover at both locations was negative (Table 8). This negative correlation could have been as a result of interference with sorghum growth by weeds through allelopathy and/or competition for light, nutrients and water. If the negative correlation was as a result of competition between weeds and sorghum for water, then the low and unevenly distributed annual rainfall recorded for the 1994-95 season, in Appendix 6 could have contributed to the low sorghum cover in all the plots where weed infestation was high.

5.3 Yield and Yield Components

(a) Plant Height

The different weed control treatments had no significant effect on plant height at

Blue Gum Farm, but had significant effects on plant height at UNZA (Appendices 4.5 and 4.6).

Table 9, shows that plant height at UNZA was highest in the clean weeding treatment plots followed by the Atrazine (Gesaprim 50% FW 3.5 l/ha) which was the same as that of the Atrazine (Gesaprim 50% FW 2.0 l/ha) plots. Plant height in the zero weeding and the Cyanazine (Bladex 50% SC 2.0 l/ha) plots were not significantly different. This decreasing trend in plant height implies that the herbicide weed control treatments at UNZA did not have direct effects on plant height. However, the herbicide treatments could have had indirect effects on plant height through their significant effects on the weed cover. The weed cover had a trend opposite to that of plant height. The highest weed cover was recorded in the zero weeding treatment sub plots, followed by Cyanazine (Bladex 50% SC 2.0 l/ha), Atrazine (Gesaprim 50% FW 2.0 l/ha) and Atrazine (Gesaprim 50% FW 3.5 l/ha). The lowest weed cover was recorded in the clean weeding treatment plots. Appendix 6 shows that the annual rainfall that was received at UNZA was lower than that received at Blue Gum Farm in the 1994/95 cropping season. The competition between sorghum and weeds for water must have consequently been higher at UNZA than that experienced at Blue Gum Farm. Plant growth is dependent among other factors on adequate water supply. This may be the reason why there were significant plant height differences at UNZA.

(b) Panicle Length

The results from both locations show that the weed control treatments had significantly different effects on panicle length (Appendices 4.5 and 4.6). The results from UNZA show that the two Atrazine (Gesaprim 50% FW 2.0 and 3.5 l/ha) treatments had the same effect on panicle length as the clean weeding treatments. The Cyanazine (Bladex 50% SC 2.0 l/ha) treatment had a lower effect on panicle length. The effect of Cyanazine (Bladex 50% SC 2.0 l/ha) was equal to that of the zero weeding treatments. At Blue Gum Farm, the clean weeding treatments had the same effect on panicle length as all the herbicide treatments. The zero weeding treatments had the shortest panicle length. The panicle length results that were obtained from UNZA and Blue Gum Farm show a trend similar to that of sorghum plant height. This trend indicates that the different herbicide treatments did not have direct effects on the panicle length. However, they had indirect effects on the panicle length through their significant effects on weed cover. The weed cover had a trend opposite to that of panicle length with the longest panicle length recorded in the clean weeding treatment plots. This was followed by the Atrazine (Gesaprim 50% FW 3.5 l/ha), Atrazine (Gesaprim 50% FW 2.0 l/ha) and the Cyanazine (Bladex 50% SC 2.0 l/ha) plots. The shortest panicle length was recorded in the weed infested zero weeding treatment plots. The weeds may have particularly competed with the sorghum plants for water, which is essential for plant growth. This may be the reason why the UNZA field station which received lower annual rainfall, had insignificantly different panicle lengths for the Cyanazine (Bladex 50% SC 2.0 l/ha) and the zero weeding plots, which had higher weed cover than the clean weeding plots and the plots that were treated with Atrazine (Gesaprim 50 % FW, 2.0 l/ha and 3.5 l/ha).

(c) 1000 Grain Weight

The results in Appendices 4.5 and 4.6 show that all the weed control treatments did not have significantly different effects on the 1000 grain weight at both UNZA and Blue Gum Farm. These results could be related to genotype improvements that have been done on the two varieties by breeders. Welsh (1981) explained that genotype improvements do help in stabilising plant performance against environmental stresses that are as a result of inadequate moisture, air pollution, water pollution etc. In this respect genotype improvements could have stabilised the two sorghum cultivars to an extent that prevented all the weed control treatments from having significant effects on the 1000 grain weight.

(d) Grain per Panicle

The weed control treatments had significantly different effects on number of grain per panicle (Appendices 4.5 and 4.6). The results from UNZA and Blue Gum Farm show that the number of grain per panicle were highest in the experimental plots where weed infestation was lowest. The highest number of grain per panicle was recorded in the clean weeding treatments followed by the plots that were treated with Atrazine (Gesaprim 50 % FW 3.5 l/ha). The next highest number of grain per panicle were recorded in the plots that were treated with Atrazine (Gesaprim 50 % FW 2.0 l/ha) followed by the Cyanazine (Bladex 50 % SC 2.0 l/ha) treatment plots. The lowest number of grain per panicle were recorded in the zero weeding plots (Tables 9 and 10). This implies that the herbicide weed control treatments at UNZA and Blue Gum Farm did not have direct effects on grain per panicle. However, the herbicide treatments may have had indirect effects on grain per panicle through their significant effects on the competing weed cover. Weeds compete with crops for water and nutrients for growth and development. Growth and development of sorghum includes the number of grain set per panicle.

(e) Panicles per plant

The results from UNZA and Blue Gum Farm showed that the weed control treatments did not have significantly different effects on panicles per plant (Tables 9 and 10). This could be as a result of the genotypes of the specific cultivars that were used in the research. Verma (1992) described MMSH 375 and MMSH 413 as sorghum cultivars that bear both the male and female inflorescence on a single terminal panicle.

(f) Plant Population

The results that are presented in Tables 9 and 10 show that the weed control treatments did not have significantly different effects on the plant population at UNZA and Blue Gum Farm. This could have been because of the ability of the sorghum seedlings to tolerate the competition for water and nutrients that may have been introduced by weeds. This could also have resulted from the inherent ability of the sorghum cultivars to tolerate the herbicide treatments to such an extent that the population of sorghum in the field was not significantly affected.

(g) Grain Yield

The results that are presented in Tables 9 and 10, show that there were significant difference in the grain yield at UNZA and Blue Gum Farm. Grain yield was highest in the plots that had the lowest weed infestation levels. In actual fact the correlation between weed cover and grain yield was negative at both locations (Tables 11 and 12). Negative correlation between weed cover and grain yield means that increased weed infestation in sorghum fields results in reduced grain yields. The reduction of grain yield could have resulted from the reduction of grain per panicle and panicle length. The reduction of grain per panicle and panicle length could have resulted from competition for water and nutrients that may have been introduced by weeds. The reduction of grain yield could also have been as a result of allelopathic effects that may have been introduced by the competing weed species. This implies that the weed control treatments did not have direct effects on the grain yield, but had indirect effects on the grain yield through their significant effects on weeds.

(g) Economic Returns

Positive returns were recorded at UNZA and Blue Gum Farm for the clean weeding treatments and both Atrazine (Gesaprim 50% FW 2.0 l/ha and 3.5 l/ha) weed control treatments. Negative returns were recorded at both locations for the Cyanazine (Bladex 50% SC 2.0 l/ha) and zero weeding treatments (Tables 13 and 14). These results show that the better of the treatments are those bearing positive returns exceeding 70% net profit levels. These are Atrazine (Gesaprim 50% FW 3.5 l/ha) treatment and the clean weeding treatment. Since it is very difficult to practice clean weeding in large commercial sorghum fields, the usage of Atrazine (Gesaprim 50% FW 3.5 l/ha) for weed control in commercial sorghum production is therefore the most reliable treatment out of the three herbicide weed control treatments.

6.0 CONCLUSION

The objective of this research was to test the efficacy of the herbicides Atrazine (Gesaprim 50 % FW) and Cyanazine (Bladex 50 % FW) for weed control in commercial sorghum production under Zambian conditions.

The results suggest that the most economical weed control treatment is the clean weeding treatment, which had an average net profit of 103.4% associated with it. However, this weed control method is not practical in the large and close inter-row spaced commercial sorghum fields, within the critical period of weed-crop competition. The most practical and economical weed control treatment therefore, is the Atrazine (Gesaprim 50% FW 3.5 l/ha) which had an average net profit of 84.5%, as opposed to the Atrazine (Gesaprim 50% FW 2.0 l/ha), Cyanazine (Bladex 50% SC 2.0 l/ha) and the zero weeding treatments which had average net profits of 14.9%,-21.5% and -41.5%, respectively.

The usage of Atrazine (Gesaprim 50% FW 3.5*l*/ha) is recommended for weed control in commercial sorghum production under Zambian conditions.

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APPENDIX

APPENDIX 1: Maize and Sorghum production areas in Zambia, 1981-90.

Year	Area planted (ha)	
	Maize	Sorghum
1981	973,151	60,370
1982	604,190	21,450
1983	728,207	16,570
1984	715,598	21,780
1985	800,476	24,811
1986	857,541	59,550
1987	978,400	47,484
1988	1,081,087	47,448
1989	1,401,983	52,008
1990	1,456,385	48,465

Source: Crop Production Fact Sheet, Department of Agriculture, Lusaka, 1991.

APPENDIX 2: Herbicides proposed for use in sorghum

Active Ingredient (a.i)	Trade Name	Rate (*l*/ha)	Weeds Controlled
	Pre-emergence Herbicides		
Atrazine	Gesaprim (50% FW)	2 - 3.5	Ann grasses + Brd-Wds
Cyanazine	Bladex (50% SC)	2 - 3	Ann grasses + Brd-Wds
Propachlor	Ramrod (65% WP)	4 - 6	Ann grasses + Brd-Wds
Terbutryne	Igran (50% FW)	2 - 4	Ann grasses +Brd-Wds
	Post-emergence Herbicides		
2-4D	Shellamine (50% EC)	1 - 1.4	Brd-Wds
Bentazon	Basagran (48% EC)	2 - 3	Small Brd-Wds

Source: Vernon (1980).

Key: Ann = Annual. FW = Flowable.
Brd = Broadleafed. Wds = Weeds SC = Suspension Concentrate.
EC = Emulsifiable Concentrate. WP = Wettable Powder

APPENDIX 3: Comparative studies of herbicides in sorghum.

Active ingredient (a.i)	Trade name	Rate (l/ha)	Effect on	
			Sorghum	Weeds
Atrazine	Gesaprim (50% FW)	5	Satisfactory	Satisfactory
Atrazine	Gesaprim (50% FW)	3.5	Satisfactory	Satisfactory
2-4D	Shellamine (48% EC)	3	Unsatisfactory	Unsatisfactory
Bentazon	Basagran (48% EC)	3	Unsatisfactory	Satisfactory
Cyanazine	Bladex (50 % SC)	3	Unsatisfactory	Satisfactory

Source: Schmid *et al*., (1994).

Key: EC = Emulsifiable Concentrate.

FW = Flowable.

SC = Suspension Concentrate.

APPENDIX 4: Analysis of Variance (ANOVA)

4.1: Effects of weed control treatments on weed cover in rainfed sorghum at UNZA.

Source of variation	*df*	Mean Squares			
		2 WAS	5 WAS	8 WAS	11 WAS
Replication	4	2.730*	1.300*	1.220*	2.200*
Variety	1	2.000*	27.380*	33.620*	9.680*
Replication x Variety	4	1.150*	1.480*	1.142*	1.080*
Weed Control Treatment	4	945.83**	1869.95**	2434.32**	3322.85**
Variety x Treatment	4	28.550*	27.830*	23.220*	56.830*
Error	32	0.953	1.465	0.883	2.203
Total	49				

Key: *df* denotes degrees of freedom.

*denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

4.2: Effects of weed control treatments on weed cover in rainfed sorghum at Blue Gum Farm.

Source of variation	*df*	Mean Squares			
		2 WAS	5 WAS	8 WAS	11 WAS
Replication	4	0.830*	0.430*	5.200*	11.330*
Variety	1	56.180*	12.500*	48.020*	36.620*
Replication x Variety	4	1.630*	5.450*	4.020*	1.870*
Weed control treatment	4	811.33**	1900.28**	2247.15**	3559.48**
Variety x treatment	4	24.030*	7.700*	29.770*	56.620*
Error	32	1.237	2.153	1.310	1.487
Total	49				

Key: *df* denotes degrees of freedom.

* denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

4.3: Effects of weed control treatments on sorghum cover at UNZA.

Source of variation	*df*	Mean Squares			
		2WAS	5 WAS	8WAS	11 WAS
Replication	4	0.370*	1.930*	3.880*	4.320*
Variety	1	46.080*	60.552*	35.280*	23.120*
Replication x Variety	4	1.030*	3.370*	1.180*	2.120*
Weed control treatment	4	76.070**	946.630**	2830.230**	4415.220**
Variety x Treatment	4	69.930*	100.170*	49.030*	119.420*
Error	32	0.688	2.813	2.817	6.195
Total	49				

Key: *df* denotes degrees of freedom.

* denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

4.4: Effects of weed control treatments on sorghum cover at Blue Gum Farm.

Source of variation	*df*	Mean Squares			
		2 WAS	5 WAS	8 WAS	11 WAS
Replication	4	1.620*	4.370*	7.630*	6.450*
Variety	1	19.220*	154.880*	0.500*	84.50*
Replication x Variety	4	0.520*	1.830*	2.350*	14.250*
Weed control treatment	4	69.870**	954.170**	2909.680**	4434.850**
Variety x Treatment	4	29.470*	7.030*	43.700*	61.850*
Error	32	2.458	6.137	7.190	3.513
Total	49				

Key: *df* denotes degrees of freedom.

* denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

4.5: Effects of weed control treatments on grain yield and grain yield components of sorghum at UNZA.

Source of variation	df	Average Yield and Yield components						
		PHt	PnL	1GW	Gn/Pn	Pn/P	P/ha	GY
Replication	4	10.030*	2.788*	0.609*	1974.4*	0.000*	4.820*	10542.22*
Variety	1	1959.38*	190.15*	1881.5*	483145*	0.000*	35.280*	2532600.2*
Replication x Variety	4	13.130*	0.863*	0.532*	918.00*	0.000*	10.480*	21931.880*
Weed control treatment	4	613.73**	73.528**	0.127*	2199505**	0.000*	78.520*	15417937**
Variety x Weed control treatment	4	127.930*	193618*	0.242*	5564.75*	0.000*	48.680*	229495.93*
Error	32	23.293	2.022	0.134	1136.585	0.000	13.150	32074.075
Total	49							

Key: *df* denotes degrees of freedom.

* denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

PHt = Plant Height (cm).

PnL = Panicle length (cm).

1GW = 1000Grain Weight (g).

Gn/Pn = Grain per Panicle.

Pn/P = Panicles per Plant.

P/ha = Plants per hectare.

GY = Grain Yield (Kg/ha).

4.6: Effects of weed control treatments on grain yield and grain yield components of sorghum at Blue Gum Farm.

Source of variation Average	*df*	Yield and Yield components						
		PHt	PnL	1 GW	Gn/Pn	Pn/P	P/ha	GW
Replication	4	61.900*	1.888*	0.473*	718.57*	0.000*	20.920*	212323.72*
Variety	1	1.30.58*	848.72*	1545.59*	378798*	0.000*	81.920*	5496601.7*
Replication x Variety	4	66.980*	3.982*	0.803*	3309.6*	0.000*	6.620*	16848.980*
Weed control treatment	4	37.650*	22.288**	0.451*	1925827**	0.000*	14.270*	14284934*
Variety x Weed control treatment	4	41.830*	9.183*	0.858*	4389.93*	0.000*	3.970*	338990.08*
Error	32	31.265	3.591	0.615	3530.583	0.000	8.4070	153825.20
Total	49							

Key: *df* denotes degrees of freedom.

* denotes not significant at $p \leq 0.05$.

** denotes significance at $p \leq 0.05$.

PHt = Plant Height (cm).

PnL = Panicle Length (cm).

1GW = 1000 Grain weight (g).

Gn/Pn = Grain per Panicle.

Pn/P = Panicles per plant.

P/ha = Plants per hectare.

GY = Grain yield (kg/ha).

APPENDIX 5: Soil Test Results

Location	Depth(cm)	pH(cacl 2)	N%	OM%	p(mg/kg)
UNZA	5	7.4	0.17	2.7	7.2
	10	7.8	0.2	3.0	8.7
	15	6.8	0.22	3.3	9.1
	20	5.4	0.22	3.2	3.2
Soil Type: Sandy Loam (Sand 58% : Clay 17% : Silt 24.4%)					
Blue Gum	5	6.1	0.15	2.4	10.3
	10	5.6	0.17	1.8	6.7
	15	5.2	0.21	2.3	6.2
	20	5.0	0.2	2.7	5.9
Soil Type: Sandy Clay Loam (Sand 57.2% : Clay 25.2% : Silt 17.6%).					

APPENDIX 6: RAINFALL DATA (OCTOBER 1994 - APRIL 1995)

Location	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Total
UNZA (Lusaka City Airport Meteorological Station)								
Rainfall(mm)	39.3	43.5	107	91.8	110.3	23.9	1.9	417.9
Rain days	3	4	13	11	12	4	1	45
Blue Gum Farm (York Farm Meteorological Station)								
Rainfall(mm)	11.9	46.2	122.8	86.2	425.8	13.6	Nil	733.5
Rain days	3	4	11	8	12	1	Nil	39

Source: Crop Weather Bulletin, Department of Meteorology, Lusaka, 1995.

Key: Lusaka City Airport Meteorological Station covers University of Zambia.

York Farm Meteorological Station covers Blue Gum Farm.