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Impact of Mechanical and Chemical Weed Control on Yield of Groundnut (*Arachis Hypogaea* L.) Var. Nyanda at Rattray Arnold Research Station in Zimbabwe

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Abstract:
Weed control is a major challenge to smallholder farmers in Zimbabwe. Manual weed control is the predominant weed control method among these farmers but it is expensive. A study was carried out at Rattray Arnold Research Station in Zimbabwe during the2014/15 summer season to evaluate weed control methods that can be adopted by smallholder farmers in groundnut. The variables measured among others, include pod yield, weed density, phytotoxicity and haulm yield. The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments and three replications. Weed control methods evaluated were manual control (farmer practice), chemical control only and an integration of chemical and mechanical control. All weed control treatments significantly (P<0.05) increased groundnut yield and reduced weed density and weed biomass. Pre-emergence application of Bateleur gold at 1.0l a.i./ha along with one hand weeding at 42 DAS resulted in the best weed control with a pod yield of 3685 kg/ha. Pre-emergence application of Bateleur gold along with post-emergence application of Agil at1.0l a.i./ ha achieved a yield of 3649 kg/ha, pre-emergence application of Metolachlor at 1.0l a.i./ha along with post-emergence application of Agil achieved a yield of 3567 kg/ha and pre-emergence application of Metolachlor along with one hand weeding at 42 DAS achieved a yield of 3403 kg/ha. Hand weeding twice at 21 and 42 DAS achieved a yield of 2791kg/ha and the weedy check treatment achieved 980 kg/ha. The un-weeded control treatment had the most weed-infested plots with a total weed density of 59 weeds /m^2 and was higher than the Bateleur gold and Agil treatment with weed density of 4 weeds/m^2. Maximum net return was obtained from Bateleur gold + hand hoeing at 42 DAS (US$1749.00) treatment. Highest benefit cost was obtained from Metolachlor + Agil (US$103.00).Results of this work show that it is advantageous to use pre and post-emergence herbicides alone or in combination with hand weeding (42 DAs) to control weeds in groundnut.

Keywords: *Groundnut, herbicides, pre and post-emergence, yield, economics, weed control.*

1. Introduction

Agriculture in Africa has a crucial role to play in spurring economic growth, overcoming poverty, and enhancing food security (World Bank, 2008). Groundnut (*Arachis hypogaea* L.) is one of the major edible oilseed crops extensively cultivated in the world. It is the sixth most important oilseed crop in the world and is known as the *'king'* of oilseeds. It contains 48-50% oil and 26-28% protein, and is a rich source of dietary fiber, minerals, and vitamins (Khidir, 1997). Groundnut has been traditionally grown by women throughout all districts of Zimbabwe, and is one of the important crops of the smallholder-farming sector in Zimbabwe. These smallholder farmers raise income through sale of unshelled and shelled nuts. Groundnut is an important component of the diet of the rural and urban people because of its protein. It is also a cash crop of significance to the economy of Zimbabwe due to its demand by the oil-pressing industry and confectioners (USAID, 2010).

Women in most rural parts of Zimbabwe process nuts into peanut butter for home consumption and for sale, either in their local areas or in towns and cities. Traditionally, groundnuts were processed into peanut butter by pounding the roasted nuts in a pestle and mortar and then ground to a fine paste on a milling stone. The process is very labor intensive and has a low throughput. Since peanut butter is very nutritious, it can be used in many ways; adding to porridge especially, to feed young children; making a sauce of vegetable and dried meat relish; adding to cooked cereals, especially rice and maize sump and spreading on bread. Fresh groundnuts are eaten fresh, boiled or roasted. The dry seed can be eaten raw, boiled or roasted and commonly boiled in a mixture with cereals like maize and sorghum (Chiteka and Zharare, 1992).

One of the major constraints in groundnut production is weed competition. Besides competing for nutrients, sunlight and soil moisture, weeds inhibit pegging, pod development and interfere with harvesting processes. The critical period for weed competition in groundnut ranges from three to ten weeks after sowing. Weed competition is at maximum during the early growth stages because of slow initial growth and less foliage cover (Yaduraju, Kulshrestha, and Mani, 1980). Timely and effective weed control during this critical period of weed competition becomes necessary for attaining maximum yield (Akobundu, 1987). Weeds in groundnuts range from grasses to broad-leaf weeds and sedges, and can cause substantial yield losses (15-75%) which are more in bunch type than in Virginia runner types (Murthy, Agasimani, Banalad, and Prathiba, 1994).In the production of various crops in Zimbabwe, chemical weed control has been found to be easier; less time consuming and more cost effective and efficient compared to hand weeding (Chivinge, 1990).It is therefore imperative that farmers manage production costs by being as efficient in their production practices as possible.

2. Materials and Methods

2.1. Study Area

A field experiment was conducted to evaluate the performance of twelve weed control treatments on groundnuts at Rattray Arnold Research station (17.67^{o}S, 31.17^{o}E; 1452 m. above sea level) in Zimbabwe during the 2014/2015 growing season. The area receives an average annual rainfall of 803 mm which range from 425 mm to 1235 mm per year.

The hot summer is between September and December, with October being the hottest month of the year with mean maximum temperatures above 30^{o}C. Average day length is 14 hours in summer and 11 hours in winter. However, after the rainy season, a transitional season follows during which both rainfall and temperature decreases. The cool dry season then lasts from May to August (World Weather Online, 2014).

2.2. Soil Characteristics and Analysis

The soil at Rattray Arnold Research Station is well-drained reddish brown sandy clay loam of the fersiallitic group (Nyamapfene, 1991). Agriculturally, this is regarded as the most important soil type in Zimbabwe because of its fertility, widespread occurrence and the versatility in crop production. A soil samplefrom 10 different locations (0.5kg) was taken from the study site for laboratory tests before planting and was used as a basis for the fertilizer to be applied. The analyzed properties included soil pH, soil texture and available nutrients including N, available P, and exchangeable bases, Ca^{2+}, Mg^{2+} and K^+.

2.3. Experimental Design

The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments and three replications. Each experimental unit was 12.60m^2 gross plot sizeand 7.65 m^2 net plot size.

Treatment No	Description
Trt 1	Metolachlor (Pre-emergence only)
Trt 2	Metolachlor + Agil (Pre and post-emergence)
Trt 3	Metolachlor + Classic (Pre and post-emergence)
Trt 4	Bateleurgold (Pre-emergence only)
Trt 5	Bateleurgold + Agil (Pre and post-emergence)
Trt 6	Bateleurgold + Classic (Pre and post-emergence)
Trt 7	Metolachlor (Pre-emergence) + Hand Hoeing at 42DAS
Trt 8	Bateleurgold (Pre-emergence) + Hand Hoeing at 42DAS
Trt 9	Control (Weed free) Hand hoeing up to harvest.
Trt 10	Hand hoeing at 21 DAS + Agil (Post-emergence)
Trt 11	Hand hoeing at 21 DAS + Classic (Post-emergence)
Trt 12	No weeding (Weedy check)

Table 1: List of weed control treatments evaluated to efficacy in the control of weeds on groundnut in the experiment.

2.4. Trial Establishment and Management

2.4.1. Planting

The land was ploughed to a depth of 0.30m using a tractor drawn plough and a disc plough was used to provide a weed free seed bed with a fine soil tilth. Thegroundnut variety Nyanda, a bunch type was used in this experiment. It is a short-season variety that takes 75-90 days to mature depending on altitude. It is a drought and heat stress tolerant cultivar that gives yields ranging from 2 t/ha to 4 t/ha in marginal rainfall areas. Planting was done at a depth of 0.04-0.06m on the 25th of October 2014. The plant spacing was 0.45m inter-row and 0.075m in-row giving a plant population of 266 600 plants per ha and 53 plants per 4 m row.

2.4.2. Fertilizer Application

At planting, compound D was applied in furrows as a basal dressing at the recommended rate of 250 kg/ha based on soil analysis. Top dressing was done with gypsum at a rate of 300 kg/ ha split into equal amounts. The first gypsum application was at the beginning of pegging when the crop was forty (40) days after sowing (DAS) and second application was done at65 DAS.

2.4.3. Weeding

All pre-emergence herbicide treatments were applied at planting and post emergence herbicides (Agil and Classic) were applied at 42 days after sowing (42 DAS). Herbicide application rate was based on the manufacturer's recommendation. All pre-emergence herbicides (Metolachlor and Bateleur gold) were applied at 1.1l/ ha using a knapsack sprayer, whilst post-emergence herbicide (Classic) was applied at a rate of 35g/ ha and Agil was applied at 1l/ ha. Hand hoeing was performed twice in the control treatment, at 21 and 42 days after sowing (DAS) respectively. In treatment 7, 8, 10 and 11, hand hoeing was performed as per schedule (Table 3.1).

2.5. Data Collection and Variables Measured

2.5.1. Percent Emergence.

Crop emergence was assessed in order to find emergence percentage per plot. The number of emerged plants at 14 DAS was counted from a random sample of five rows in every plot. This was used to calculate the percent plant stand based on the expected number of plants in the plots.

2.5.2. Phytotoxicity Assessment

Phytotoxicity is the capacity of a compound such as a herbicide to cause temporary or long-lasting damage to plants. The assessment of the phytotoxicity was done during crop emergence, and at flowering using the following methods;

1. Plant emergence: this was done by counting emerged plants in treated plots in days or in relative percentage of emergence against the untreated plots.
2. Thinning: counting the number of affected plants per plot after emergence is complete.
3. Delay in reaching growth stages: counting the number of plants not yet flowering against plants that has reached the flowering stage.

2.5.3. Weed Counts.

Weed measurement was done by counting the total number of all weeds present in each plot at 20, 40, 60 and 80 DAS, and at harvest. Both grasses and broad leaved weeds were recorded in all the experimental units and the average was established by summing up the total weeds for each treatment and divide by the number of replications. Weeds occurring within 7.60m^2 were uprooted in each experimental plot at crop harvest. The uprooted weeds were oven dried for 72 hours at a constant temperature of 65^{O}C until a constant weight was achieved, and weed biomass was recorded using an electronic balance. Weed control efficiency (WCE) was calculated using the formula:

$$\text{WCE} = \frac{\text{Weedy check biomass} - \text{managed treatment biomass}}{\text{Weedy check biomass}} * 100$$

2.5.4. Plant Height

Plant height was measured at forty-five (45) days after sowing. An average of five plants from the inner five rows per row from each experimental unit was picked at random and measured. The recorded data for all the measured plants was summed up and divided by the total number of plants (25). This was used as the average plant height for each plot.

2.5.5. Harvesting and Final Yield Assessment.

Harvesting was carried out when the crop was physiologically mature at 110 days after sowing. Yield was measured based on dry pod yield, grain yield, stover dry matter weight and shelling percentage.

2.5.6. Pod Weight

Mature pods from plants uprooted from a 2.2 m^2 area were detached from the haulms and weighed. This was recorded as total pod fresh weight. A sub-sample of 200 g was drawn from the total quantity of the pods and weighed (sub-sample pod fresh weight), and oven dried for 72 hours at 65^{O}C and used to calculate the pod and grain yield.

Pod yield was calculated as:

$$\text{Podyield (kg/ ha)} = \frac{\text{TotalPodFW(g)} * S\text{ub} - \text{samplePod D W (g)} * 10}{\text{Sub} - \text{sample PodF W(g)} * \text{Netareaharvested (2.2 m2)}}$$

2.5.7. Stover Yield

At harvesting, the above ground plant biomass was measured from the 2.2 m^2 area of each plot which had been reserved for yield assessment. All the above ground parts of the harvested plants and the fallen leaves were collected and weighed. This was recorded as the total fresh weight of above ground biomass. A 200 g sub-sample was drawn, weighed and oven dried at 65^{O}C for 72 hours until constant weight was achieved. The sub-samples were re-weighed to determine the dry weight. From the sub-sample values of fresh weight (FW) and dry weight (DW) obtained above, the stover yield was calculated using the formula below:

$$\text{Haulm Yield (kg/ha)} = \frac{\text{Total}Haulm\text{FW(g)} * S\text{ub} - \text{sample}Haulm\text{ D W (g)} * 10}{\text{Sub} - \text{sample } Haulm\text{F W(g)} * \text{Netareaharvested (2.2 m2)}}$$

The husk and haulm yield were then used to calculate the Stover yield using the formula;

Stover Yield (kg/ha) = Haulm Yield + Husk Yield

2.5.8. Shelling Percentage

The oven dried pod sub-samples taken from the entire harvest of each experimental plot were weighed (pod dry weight) and then hand shelled. The shelled grain and the husks were weighed separately and the shelling percentage was calculated using the formula;

$$\text{Shelling percentage} = \frac{\text{Weight of seed}}{\text{Weight of Unshelled Pods}} * 100$$

Husk Yield (kg ha-1) was calculated as;
Husk Yield = (1- (Shelling percentage/100)) * Pod Yield

From the obtained shelling percentage, the final grain yield was calculated basing on the formula:
Grain Yield = (Shelling percentage/100) X dry pod yield

2.6. Economic Analysis

To assess how beneficial each weed management strategy was, a simple cost benefit analysis was computed soon after harvesting taking into account the current price of various inputs. Weeding cost was considered as the variable cost to evaluate if it warranted investing in herbicide use at small scale farming level focusing on the benefit cost and net returns obtained in different weeding method.

Benefit cost ratio was calculated basing on this formula: $\text{BCR} = \frac{\text{Gross return}}{\text{Total cost}}$

Weeding cost used to calculate variable costs was the purchase price of herbicides and hand hoeing cost per hectare. Farm gate price obtained from farmer groups and bulk buyers such as Agriseeds, GMB, REAPERS, Lyons Maid and Nutresco in consultation with the local extension officer of the study area was taken as the average groundnut market price to compute income in the experimentation year.

2.7. Data Analysis

The statistical package GenStat 14th Edition was used for data analysis. The data was subjected to Analysis of Variance (ANOVA) for determining the effects of the different treatments.The least significant difference (LSD) test ($\alpha = 0.05$) was used to separate the means.

3. Results

3.1. General Crop Growth in Response to Weeding Method

3.1.1. Percent Emergence

Emergence assessment was carried out on the 14^{th} day after sowing for most of the plants had already emerged. Plots without application of pre-emergence herbicides were statistically different ($P<0.05$) from the treated plots with an average of 94%. Plots that were treated with Metolachlor at the recommended rate were the least with an average emergence of 87% and plots treated with Bateleur gold had an average emergence of 91% (Table 1). Though some plots had emergence percentage as low as 86.33% (Metolachlor + Agil), the grand mean for the whole experiment was 90.97%.

3.1.2. Phytotoxicity

Some plants showed stunted growth (phytotoxicity) in plots treated with both pre and post-emergence herbicides and these plants did not properly catch up with other plants in both growth and reproduction vigour (Table 1). Plots that were treated with the herbicides were statistically different ($P<0.05$) from all other treatments regarding phytotoxicity score. Plots treated with Metolachlor 1.0 l a.i./ha were more effected with regard to germination and growth. Plots treated with Bateleur gold 1.0l a.i./ha suffered less phytotoxicity with an average of 2% loss. The effect of phytotoxicity was also observed in average plant height at 45DAS. Plants that were affected by herbicides showed some thinning effect and failed to reach the flowering stage by two weeks. Plots that were not treated with herbicides showed no effect of phytotoxicity (Table 1).

3.1.3. Plant Height

There were significant differences ($P<0.05$) in plant vigour in plots treated with herbicides and those without herbicide treatment. Plots treated with pre-emergence herbicides recorded the lowest plant height at 45 DAS and were statistically different ($P<0.05$) from all other treatments. These plots had an average of 26cm in height whereas those without the herbicide treatments were at 30cm and the highest plant height was recorded in the weedy check treatment (32.33cm) and this might be due to the competition of the crop for sunlight and spacewith the weeds (Table 2).

Treatment	Germination %	Phytotoxicity germination [a]	Phytotoxicity at flowering[a]	Plant height
Metolachlor (only)	89.00[ab]	2.310[d]	2.887[e]	24.67[a]
Metolachlor + Agil	86.33[a]	2.583[e]	2.710[d]	26.00[ab]
Metolachlor + Classic	87.67[a]	2.583[e]	2.650[d]	25.33[a]
Bateleurgold (only)	92.33[bc]	1.623[b]	1.820[b]	26.33[ab]
Bateleurgold + Agil	92.33[bc]	1.623[b]	1.910[bc]	26.00[ab]
Bateleurgold + Classic	90.67[b]	1.820[b]	2.080[c]	26.00[ab]
Metolachlor + HH	87.00[a]	2.310[d]	2.710[d]	27.67[b]
Bateleurgold + HH	90.67[b]	2.080[c]	2.160[c]	28.00[b]
Control (Weed free)	94.33[c]	1[a]	1[a]	30.00[c]
Hand hoeing + Agil	94.00[c]	1[a]	1[a]	30.33[c]
Hand hoeing + Classic	94.00[c]	1[a]	1[a]	30.00[c]
No weeding	93.33[bc]	1[a]	1[a]	32.33[d]
Significance of F	***	***	***	***
CV %	**1.9**	**6.8**	**5.2**	**3.8**

Table 2: Means for germination percentage, phytotoxicity score at germination and at flowering and plant height at 45 days after sowing.

***, denote significance at P<0.001; H H = hand hoeing. Within a column, means followed by the same letter are not significantly different at P=0.05

[a]Data separated using transformed values for phytotoxicity at germination and phytotoxicity at flowering using square root of X+1 transformation

3.2. Weed Characterization.

The crop was infested with both broad leaf and grass weeds. Of broad leaf weeds, *Richardia scabra*(Mexican clover), *Leucas martinicensis*(Bobbin weed) and *Commelina benghalensis*(Wandering jew) were dominant while for the grasses, *Cynodon dactylon*(Couch grass) was the most dominant. A total of 17 weeds species belonging to 10 families were encountered in the growing season comprised of 14 broad leaf weeds and 3 grasses (Table 3). Family Compositae/ Asteraceae had 5 species, Gramineae had 3 species, Convolvulaceae had 2 species. Other weed species belonged to the family such as Rubiaceae, Solanaceae, Commelinaceae, Tiliaceae, Amaranthaceae, Lamiaceae, and Malvaceae had one species (Table 3). The weeds are ranked in order of abundance.

	Weed species	Life cycle	Family
1	*Richardia scabra* (Mexican clover)	ABL	Rubiaceae
2	*Commelina benghalensis* (Wandering Jew)	ABL	Commelinaceae
3	*Leucas martinicensis* (Bobbin weed)	ABL	Lamiaceae
4	*Cynodon dactylon* (Couch grass)	PG	Gramineae
5	*Nicandra physaloides* (Apple of Peru)	ABL	Solanaceae
6	*Ipomoea purpurea* (Morning glory)	ABL	Convolvulaceae
7	*Ipomoea plebia* (Sabi Morning glory)	ABL	Convolvulaceae
8	*Amaranthus hybridus* (Pig weed)	ABL	Amaranthaceae
9	*Corchorus tridens* (Wild jute)	ABL	Tiliaceae
10	*Acanthospermum hispidum* (Upright starbur)	ABL	Compositae
11	*Bidens pilosa* (Black jack)	ABL	Compositae
12	*Conyza albida* (Fleabane)	ABL	Compositae
13	*Hibiscus meeusei* (Stockrose)	ABL	Malvaceae
14	*Tagetes minuta* (Mexican marigold)	ABL	Compositae
15	*Rottboellia cochinchinensis* (Itchy grass)	AG	Gramineae
16	*Galinsoga parviflora* (Gallant soldier)	ABL	Compositae
17	*Dactyloctenium aegyptium* (Crow's foot)	AG	Gramineae

Table 3: Ranked weed species composition of the experimental plots.
Key: ABL (Annual broadleaf); PBL (Perennial broadleaf); AG (Annual grass); PB (Perennial grass)

3.3. Total Weed Density, Total Weed Biomass at Harvest, and Weed Control Efficiency.

There were significant differences (P<0.05) among treatments for weed density at harvest (Table 4). Highest total weed density of 59 weeds per m^2 was recorded in weedy check treatment. The data showed that a combination of pre-emergence application of Bateleur gold 1.0l a.i./ha along with post-emergence application of Agil 1.0l a.i./ha at recommended rates induced the highest effect on total weed density (4 weeds per m^2) all over the tested period (Table 4). There were no significant differences in treatments with Bateleur gold plus Classic, Bateleur gold plus hand hoeing and the positive control (weed free) with an average of 6 weeds per m^2.

On the other hand, no significant differences were recorded between Metolachlor plus Agil, sole application of Bateleur gold, and hand hoeing at 21 DAS plus Agil. Among the post-emergence herbicide treatments after hand hoeing at 21 DAS, Agil had more effect (7 weeds per m^2) than Classic (9 weeds per m^2) regarding total weed density.In general, application of pre-emergence herbicides only at planting had less effect than in combination with other post-emergence or in combination with mechanical methods. From the foregoing results, the mechanical methods were less effective regarding weed control than the tested herbicides at recommended rates during the most critical weed competition period for growing groundnut (45DAS). Best herbicidal response to weed density was recorded from Bateleur gold plus Agil and was statistically different (P<0.05) from all other treatments.

Weed biomass was significantly different (P<0.05) and influenced by various weed management strategies and followed the same trend as weed density (Table 3). Weedy check treatment had the highest biomass. Pre-emergence application of sole Metolachlor recorded the lowest measure from all other weed management strategies (Table 3). The weedy free check recorded the lowest weed biomass.

Significant differences (P<0.05) were noted in weed control efficiency. Plots treated with Bateleur gold + Agil recorded the highest weed control efficiency, and was followed by treatments with Bateleur gold + hand hoeing. No significant differences were recorded between Metolachlor + Agil, sole application of Bateleur gold and hand hoeing at 21 days after sowing + post-emergence application of Agil. Bateleur gold plus Classic and weed free treatment had both 89.13% weed control reduction. Pre-emergence application of sole Metolachlor and Bateleur gold plus Classic had the least weed control efficiency.

Treatment	Total Weed density	Weed biomass	Weed control efficiency (%)
Metolachlor (only)	11^{c}	117.2^{c}	81.35
Metolachlor + Agil	7^{b}	61.6^{b}	88.13
Metolachlor + Classic	11^{c}	44.2^{ab}	81.35
Bateleurgold (only)	7^{b}	85.1^{bc}	88.13
Bateleurgold + Agil	4^{a}	14.3^{a}	93.22
Bateleurgold + Classic	6^{ab}	13.3^{a}	89.83
Metolachlor + Hand hoeing	9^{bc}	75.3^{b}	84.74
Bateleurgold + Hand hoeing	5^{ab}	33.3^{a}	91.52
Control (Weed free)	6^{ab}	12.3^{a}	89.83
Hand hoeing + Agil	7^{b}	83.2^{bc}	88.13
Hand hoeing + Classic	9^{bc}	58.5^{b}	84.74
No weeding (Weedy check)	59^{d}	955.1^{d}	0
Significance of F	***	***	
CV %	**11.3**	**16.8**	

Table 4: Means for total weed density and weed biomass at harvest.

***, denote significance at P<0.001.Within a column, means followed by the same letter are not significantly different at P=0.05
WCE = {(weed density in unwedded control –weed density in managed treatment)/ weed density in unweeded control} x 100.

3.4. Yield in Response to Weeding Method.

Herbicide application increased groundnut yield. Results indicated that all the herbicidal treatments as well as the weed free check resulted in significant increase in yield and yield attributing characters of groundnut along with reduction in weed population and weed biomass production, compared to the un-weeded control. The effect of different weed control treatments on yield and yield attributing parameters of groundnut such as number of matured pods per plant, pod yield, haulm yield and grain yield was significantly different (P<0.05), except in the case of 100 seed kernel weight (g) and Shelling percent (Table 4). Pod yield, haulm yield and grain yield were maximum with the treatments that received the post-emergence application of Agil at 1.0 l/ha. It was significantly superior to treatments that received Classic at 35g/ha (Table 4.6).One hand weeding + an application of Agil or Classic were statistically the same in all yield components (Table 4).

3.5. Mature Pods Per Plant

There were significant differences (P<0.05) on mature pods per plant at harvest (Table 4). Pod number per plant ranged from 28 to 42. The lowest pod number per plant was observed on the negative control (weedy check) whilst the highest was recorded in Metolachlor plus hand hoeing at 42 DAS treatment (Table 4). Bateleur gold alone, Bateleur gold + Agil, Bateleur gold + Classic, Bateleur gold + hand hoeing at 42 DAS, hand hoeing + Agil and the control (weed free) treatment did not differ in their effect on mature pods per plant (Table 4).

3.6. Haulm Yield

The weedy check recorded significantly lowest haulm yield and the highest haulm yield was recorded with Bateleur gold + hand hoeing at 42 DAS. The haulm yield was not statistically different between Metolachlor + Agil, Bateleur gold + Agil, Metolachlor + hand hoeing at 42 DAS and Bateleur gold + hand hoeing at 42 DAS treatments (Table 4). In addition, the weed free (control) treatment and hand hoeing at 21 DAS + Agil followed the superior treatments with 3489 kg/ha and 3328 kg/ha respectively. Pre-emergence application of Bateleur gold alone achieved haulm yield of 2869 kg/ha whilst pre-emergence application of sole Metolachlor achieved haulm yield of 2251 kg/ha (Table 4).

3.7. Kernel Yield.

Significant differences (P<0.05) were recorded in all the treatments, and these followed the same trend with pod and haulm yield. In most cases, plots treated with Bateleur gold + one hand weeding at 42 DAS produced the highest values of yield. For instance, with respect to seed/ kernel yield, Bateleur gold + one hand weeding at 42 DAS produced maximum yield of 2603 kg/ha. There was no significant difference between other treatments like; Bateleur gold + Agil with 2543kg/ha, Metolachlor + Agil with 2520 Kg/ha and Metolachlor + one hand weeding at 42 DAS with 2402 Kg/ha. These treatments were statistically the same in all the parameters regarding yield (Table 4). This might be due to the application of pre-emergence herbicides that suppresses the weed growth at early stage of the crop and results in a better crop stand. The lowest kernel yield was recorded in weedy check treatment which produced 669 kg/ha.

3.8. Pod Yield

The pod yield of groundnut was influenced significantly (P<0.05) by various treatments. Bateleur gold plus one hand hoeing at 42 DAS and Metolachlor + Agil, Bateleur gold + Agil and Metolachlor + hand hoeing at 42 DAS produced the maximum pod yield. Hand hoeing twice at 21 and 42 DAS resulted in significantly less pod yield (2791 kg/ha) than mostherbicide treatments(Table 4). The absolute weedy check condition produced the minimum pod yield, in comparison to herbicide treatments and mechanical practices and showed a pod yield decreased to 74%. Among the herbicide combinations, application of Bateleur gold + Agil and Metolachlor + Agil were statistically the same with regard to pod yield but were significantly higher than Bateleur gold + Classic and Metolachlor + Classic (Table 4).

→ 100-kernel weight and shelling percent in response to weeding method.

Weeding method showed no significant (P>0.05) effect on both shelling % and 100-kernel weight (Table 4).

Treatment	Pod yield kg/ha	Haulm yield kg/ha	100-kernel weight(g)	Mature pods /plant	Kernel Yield kg/ha	Shelling %
Metolachlor (only)	1800^{b}	2251^{b}	37.67	32^{b}	1267^{b}	70.33
Metolachlor + Agil	3567^{f}	4103^{e}	38.33	40^{d}	2520^{f}	70.67
Metolachlor + Classic	1655^{b}	2069^{b}	37.33	34^{bc}	1163^{b}	70.33
Bateleurgold (only)	2495^{cd}	2869^{c}	38.33	37.67^{cd}	1763^{cd}	70.67
Bateleurgold + Agil	3649^{f}	4196^{e}	37.67	38^{cd}	2543^{f}	69.67
Bateleurgold + Classic	3200^{e}	3680^{de}	38.00	37^{cd}	2228^{e}	69.67
Metolachlor + HH	3403^{ef}	3913^{e}	38.33	42^{d}	2402^{ef}	70.67
Bateleurgold +HH	3685^{f}	4237^{e}	38.00	39^{cd}	2603^{f}	70.67
Control (Weed free)	2791^{d}	3489^{d}	37.67	39^{cd}	1952^{d}	70.00
Hand hoeing + Agil	2662^{cd}	3328^{d}	38.33	37^{cd}	1863^{cd}	70.00
Hand hoeing + Classic	2383^{c}	2978^{cd}	38.00	36^{c}	1674^{c}	70.33
No weeding (Control)	980^{a}	1225^{a}	36.00	28^{a}	669^{a}	68.33
Significance of F	***	***	**NS**	***	***	**NS**
CV %	**7**	**7**	**2.9**	**6.3**	**6.4**	**2**

Table 5: Means for yield and yield attributes of groundnut.

***, denote significance at P< 0.001; NS denote non-significance at P>0.05 and HH = hand hoeing. Within a column, means followed by the same letter are not significantly different at P=0.05

3.9. Cost-benefit Analysis

Maximum gross margin was obtained from Bateleur gold + hand hoeing at 42 DAS (US$1749.00) treatment. This was followed by Bateleur gold + Agil and Metolachlor + Agil treatments with US$1746.40 and US$1705.20 respectively. Among the sole application of pre-emergence herbicides, Bateleur gold obtained higher gross margin (US$1060.00) than Metolachlor with US$651.00. Among post-emergence application of herbicides after hand hoeing at 21 DAS, Agil obtained higher gross margin (US$1141.20) than Classic which realized US$975.80. Among all the treatments, lowest gross margin was obtained from weedy check (US$168.00). Highest benefit; cost ratio was obtained from Metolachlor + Agil (US$103.50) and this was followed by Bateleur gold + Agil (US$69.60) and Bateleur gold + Classic at 42 DAS (US$63.40). The control (weed free) produced the lowest benefit; cost ratio value of 18.10 (Table 5.). Weeding benefit followed the same trend with the gross margin and the gross return.

Treatment	[a]Gross return $	Input cost $	Weeding cost $	Total variablecost $	Gross margin $	[c]Weeding benefit $	[b]Benefit/cost
Metolachlor (only)	1080	420	9	429	651	483.00	54.70
Metolachlor + Agil	2140.2	420	15	435	1705.2	1537.20	103.50
Metolachlor + Classic	993	420	13	433	560	392.00	31.20
Bateleurgold (only)	1497	420	17	437	1060	892.00	53.50
Bateleurgold + Agil	2189.4	420	23	443	1746.4	1578.40	69.60
Bateleurgold + Classic	1920	420	21	441	1479	1311.00	63.40
Metolachlor + H H	2041.8	420	39	459	1582.8	1414.80	37.30
Bateleurgold +H H	2211	420	42	462	1749	1581.00	38.60
Control (Weed free)	1674.6	420	60	480	1194.6	606.60	18.10
Hand hoeing + Agil	1597.2	420	36	456	1141.2	973.20	28.00
Hand hoeing + Classic	1429.8	420	34	454	975.8	807.80	24.80
No weeding (Control)	588	420	0	420	168.	0.00	0.00

Table 6: Cost-benefit analysis of groundnut with respect to weed control treatment

[a]Gross return = Pod yield x $600 /t; [b]Benefit cost = {(gross return –gross return control)/ weeding cost}; [c]Weeding benefit = {(Gross return-Control's gross return) – weeding cost} H H = hand hoeing cost US$30; Metolachlor cost = US$9/ l; Bateleur gold cost = US$17/ l; Classic cost= US$4/ 35g; Agil cost= US$6/ l. Input cost = (ploughing = 60; 5 x 50 kg compound D at US$30 / bag; Gypsum 6 x 50 kg at US$6 / bag; Seed 80 kg = US$144; and 60 labour days = US$30).

4. Discussion

Despite the presence of improved cultivars with disease resistance in Zimbabwe, the productivity of groundnuts has declined in the smallholder farming sector with pod yield averaging less than 500 kg per hectare. This study was therefore designed to come up with Best Management Practices (BMPs) especially the weeding aspect in groundnut production based on scientific premises.

4.1. Percent emergence and Phytotoxic effect of herbicides.

Crop emergence was low in plots that were treated with herbicide as compared to untreated plots. Therefore, the significant differences ($P<0.05$) in germination indicates that application rate of pre-emergence herbicides had an inhibitory effect in germination. Pre-emergence application of Metolachlor had greater germination inhibitory effect as compared to Bateleur gold both at recommended rates. It is therefore imperative that farmers should read the label and try to reduce the application rate by at least 80 percent and also to be consistent when applying herbicides. These results agree with what Meier, (2001) observed in an experiment on germination and growth stages of Mono-and Dicotyledonous plants. It was observed that some pre-emergence herbicides inhibit germination when the application rate does not suit the soil type in terms of the clay content (Meier, 2001).

It is important to have an assessment of phytotoxicity when using compounds such as herbicides as a weed control measure. In this study however, significant differences ($P<0.05$) observed at crop emergence and during growth indicated the effect of phytotoxicity due to herbicides. Plots raised under pre-emergence herbicides had less plant vigor as compared to the untreated. This was evident to plant height at 45 DAS which showed a constant variability among these plots. Untreated plots had an average height of 30cm yet plots that were subjected to herbicides were averaging 26cm (Table 1).

The fact that some plants in plots treated with herbicide were thinning, stunted and delaying in reaching some growth stages was a clear evident of phytotoxic effect. The findings agree with Daugovish, Thill, and Shaft, (2003), they observed that some herbicides may depress groundnut growth early in the season but vigorous seedlings are most likely to outgrow this effect. The observation by Daugovish*et al*., (2003), was supported in this study as evident by the final yield of the crop. The crop had a compensatory effect in yield. It is clear that even the plant vigor was low in herbicide treated plots, yield was not reduced.

4.2. Weed Spectrum

It was observed that the most abundant broad leaf weeds species encountered at Rattray Arnold Research Station were Bobbin weed (*Leucas martinicensis*), Wandering jew (*Commelina benghalensis*) and Mexican clover (*Richardia scabra*). Couch grass (*Cynodon dactylon*)was the most abundant grass weed species. These different weed types have been variously reported to be associated with groundnut and the sand clay loam soils (Chivinge, 1990). Mangosho, Mabasa, Jasi, and Makanganise,(1999) also observed that the predominant weeds in sandy clay loam soils in Zimbabwe associated with groundnuts were *C. benghalensis*, *Acanthospermum hispidum, L. martinicensis*, *C. dactylon*, *R. scabra*, *Dactyloctenium aegyptium*, *Hibiscus meeusei* and *Nicandra physaloides*.

4.3. Total Weed Density and Weed Control Efficiency

All weed control treatments were significantly effective in reducing the weed density and weed biomass compared with weedy check plots (Table 4). However, sole application of Metolachlor did not effectively control weed species as evident from the total weed density at 80DAS, weed biomass at harvest and weed control efficiency compared to sole application of Bateleur gold.The result is due to the fact that Bateleur gold has long residual effect in suppressing weed germination as compared to Metolachlor.It was also observed that hand hoeing twice at 21 and 42 DAS had equally the same effect with sole application of Bateleur gold in terms of total weed density and weed control efficiency. The only difference was on the weeding cost. The results are in agreement with Ayeni, (1997), who observed that sole application of pre-emergence herbicide had the same effect in weed control efficiency with two hand weedings. Weed control efficiency of 93.22% (Table 4) in the Bateleur gold + Agil treatment followed the same trend in total weed density and weed biomass. This was due to the herbicides combination which had a long residual effect to suppress weed growth.The reduction in weed density and weed biomass in plots raised under Bateleur gold along with a post-emergent Agil, Bateleur gold + one hand hoeing at 42 DAS, plots receiving two hand hoeing at 21 and 42 DAS and plot with Bateleur gold along with Classic was evident as further fresh flush of weeds were arrested by these treatments. Sukhadian, Ramani, Asodaria and Modhwadia., (1998), also reported similar results with total weed density and weed control efficiency reduced by a combination of chemical and cultural method of weed control. Sole application of pre-emergence herbicides at planting had less effect than in combination with other post-emergence or in combination with mechanical methods.

The above results are in line with the results of Sumathi, Chandrika, Babum, Nagavani, (2000), Hassan, Ahmed, El-Bastawesy, (1994) and Kumar, Shaktawat, Singh, Gill, (2003) who observed that a combination of both pre- and post-emergence herbicides was most effective for controlling several grassy and broadleaved weeds. Therefore, combining weed control methods can help keep weed damage below economic threshold levels.

4.4. Final Yield

Pre-emergence application of herbicide followed by one hand weeding was most effective to control weeds in groundnut and increased pod yield because early and effective weed control allowed absorption of more nutrients from soil. The pod yield loss in groundnut ranged from 14 to 74% in this study and it was due to the density and type of weed flora. The yield loss agreed with Gnanamurthy and Balasubramaniyan,(1998), they observed a yield loss of 75% in comparison with the control treatment. Since groundnuts are weak competitors during the early growth stages; early season control is very important. One of the prime factors which influence the growth and yield of groundnut is the critical period of crop weed competition.

In this study, the productivity of groundnut was reduced considerably when weed competition occurs during the early stages of crop growth. The most critical period of weed competition in groundnut ranged from three to six weeks after sowing. The control treatments that wasweeded 21 DAS by hand hoeing wassignificantly different (P<0.05) from those that were treated with pre-emergence herbicides from the onset of plant growth (Table 5).

The control treatment had an average yield of (2971 kg/ha) which was a 21% decrease in pod yield and 18% haulm yield, as compared to the plots that were treated with pre-emergence herbicides. This result is in line with Joshi, (2001) who observed that delaying weeding in groundnuts up to 35 DAS reduces crop output by 33% and haulm yield by 43%.

A combination of pre-emergence herbicides and hand hoeing at 42 DAS gave higher yields because hand weeding at that stage allows pulverization of soil, better aeration, root proliferation, better nodulation and more pod formation, ultimately increasing pod yield. Combining herbicides gave better results for better weed control as compared to sole application of pre-emergence herbicides. The results agree with Buhler *et al*., (1992), who observed that a combination of herbicides give better yields. Pre-emergence treated plots were 98% weed free early in the season, but weeds emerged later and reduced pod yield hence the need to combine (Buhler *et al*., 1992). The main reason for better yield advantage in all the weed control treatments is traceable to a reduction in weed competition. The enhancement of yield parameters under Bateleur gold along with one hand hoeing at 42 DAS may be explained by better weed control efficacy.

Therefore, it is advantageous to chemically and mechanically control weeds during the initial 6 weeks of groundnut growth. As evident in this study, pod and haulm yield decreased with increased crop weed competition up to harvest (Table 4 and 5). Also in a study by Nambi and Sundari (2008), highest pod yield was realized under completely weed free condition. Maintaining weed free environment resulted in maximum yields in groundnut as reported by Paulo, Kasai and Carichioli*,* (2001). There was no significant difference (P>0.05) in shelling percent and 100-kernel weight in all the treatments. This might be due to split application of gypsum.

4.5. Economic Analysis

Yield responded positively to all weed treatments hence the cost benefit analysis was conducted focusing on each weeding method. Maximum gross margin was obtained from Bateleur gold + hand hoeing at 42 DAS (US$1749.00) treatment. After the cost benefit analysis, it was advantageous to use the Metolachlor + Agil treatment which had the highest cost benefit of US$103.00. The main reason is that the weeding cost for Metolachlor + Agil was cheaper as compared to the other treatments. However, Metolachlor + Classic were even cheaper but the gross return was very low. The cost of hand hoeing is on the higher side hence it influences the benefit cost as compared to all the herbicides treatment in the study.

The benefit; cost ratio obtained in plots raised with Bateleur gold + Agil and Metolachlor + Agil may be ascribed to increase in yield occasion by better weed control efficiency compared to all other treatments. Sardana, Walia, and Kandhola, (2006) reported that benefit; cost ratio of groundnut was highest with the use of pendimethalin at 1.0 kg /ha followed by a post emergence. Though pre-emergence application of herbicides followed by one hand hoeing at 42 DAS were among the treatments with high gross margin and weeding benefit, they were low with regards to benefit; cost ratio. This was as a result of the weeding cost which was on the higher side. Hand hoeing influenced the benefit; cost ratio negatively because it is expensive as compared to the cost of herbicides.So it can be revealed that application of Bateleur gold + Agil and Metolachlor + Agil can be more effective than hand hoeing twice at 21 and 42 DAS.

5. Conclusion and Recommendations

It has been established from the study that pre-emergence application of Bateleur gold at recommended rate along with one hand weeding at 42 DAS was found to be the most effective weed control regime with the advantage of suppressing weeds for longest.This is considered as the most critical period for groundnut plant growth. It was concluded that all chemical control treatments reduced weed pressure and thus increased the dry pod weight of groundnuts. It was also concluded that Metolachlor + Agil had the highest benefit ratio as compared to all other treatments.

This study did not exhaust all of the intricate factors in groundnut production under the environmental conditions and factors explained here. Aspects such as nutrient uptake rates during weed competition, nutrient use efficiency and the average nutrient recovery need to be determined. Further research needs to ascertain protein and oil content under the studied factors and conditions.

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