IMPACT OF MECHANICAL AND CHEMICAL WEED CONTROL ON YIELD OF GROUNDNUT (*Arachis hypogaea* L.) var. NYANDA AT RATTRAY ARNOLD RESEARCH STATION IN ZIMBABWE

A DISSERTATION SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION

BY

AID TARUVINGA

FACULTY OF AGRICULTURE AND NATURAL RESOURCES

AFRICA UNIVERSITY

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ABSTRACT

Weed control is a major challenge to smallholder farmers in Zimbabwe. Groundnut (*Arachis hypogaea* L) is highly susceptible to weed infestation because of its slow growth in the first 40 days after sowing (DAS). 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 the 2014/15 summer season to evaluate weed control methods that can be adopted by smallholder farmers. The major objective was to evaluate the impact of weed control methods on yield in groundnut and to compare effective herbicides combinations for weed control. 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. Each plot was 12.60 m^2 gross plot size and 7.65 m^2 net plot size. Weed control methods evaluated were manual control (farmer practice), chemical control only (pre-emergence Bateleurgold 48 EC and Metolachlor 960 EC; post-emergence Classic 25DF and Agil 10 EC) 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 as compared to the un-weeded control. 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 significantly ($P<0.05$) higher pod yield (3685 kg/ha). Pre-emergence application of Bateleur gold along with post-emergence application of Agil 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. These three treatments were statistically the same with pre-emergence Bateleur gold + hand weeding at 42 DAS. 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. 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. There were no significant differences among shelling percent and 100- kernel weight. Maximum net return was obtained from Bateleur gold + hand hoeing at 42 DAS (US$1749.00) treatment. This was followed by Bateleur gold + Agil (US$1746.40) and Metolachlor + Agil treatments with US$1705.20. However, highest benefit cost was obtained from Metolachlor + Agil (US$103.00) and this was followed by Bateleur gold + Agil (US$69.60). Chemical weed control is a better method than mechanical and forms an integral part of the modern groundnut production cultivation.

DECLARATION

I Taruvinga Aid do hereby declare that this work is an outcome of my investigation undertaken at Rattray Arnold Research Station (SeedCo), Harare, Zimbabwe, under the supervision of Dr. W. Manyangarirwa and Dr. Z. A. Chiteka, in partial fulfillment of the requirements for the degree of Master of Science in Crop Production and has not been submitted to any university for the award of any other degree.

Researcher: Signature………………………………………

[A. Taruvinga]

Date:…………../………………/……..2015

APPROVED FOR COMPLIANCE.

Supervisor 1: Signature……………………………………..

[Dr. W. Manyangarirwa]

Date:…………../………………/……..2015

Supervisor 2: Signature……………………………………..

[Dr. Z. A. Chiteka]

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I thank you all for cooperatively working together with me for the success of this project and in fostering the battle of bringing out new and improved technologies to our farmers. This shall enable them to produce enough in quantity and quality to feed the ever growing world population. **God bless you all.**

DEDICATION

IN MEMORY OF MY LATE FATHER MR. KILLIAN MBUNDIRE.

“DAD THIS WAS ALWAYS YOUR DREAM”

To the one that bears the sweetest name ‘my wife’, may the God Almighty add more years to you.

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LIST OF ABBREVIATIONS

AN	Ammonium Nitrate
DAS	Days After Sowing
FAO	Food and Agriculture Organization (United Nations)
RCBD	Randomized Complete Block Design
kg/ha	Kilograms per Hectare
a.i.	Active ingredient
BMP	Best Management Practice
CSO	Central Statistics Office
SADC	Southern African Development Community
°C	Degrees Celsius
WCE	Weed Control Efficiency

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CHAPTER 1

INTRODUCTION

1.1 Background

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. 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).

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. Groundnut yield and quality is significantly influenced by agronomic practices employed by the farmers. Among these practices is the issue of weed management (Subrahmaniyan, Kalaselvan, and Arulmozhi, 2002).

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). Therefore, there is need to carry out studies on groundnut weed management to continuously improve yield and quality. Weed management is very crucial in groundnut production since it influences yield and quality to a large extent. 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). It is therefore imperative that farmers manage production costs by being as efficient in their production practices as possible.

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). This leads to the production of higher yields of greater quality so that the farmers can enjoy maximum profits per unit of cultivated land. This therefore signals for the adoption of best management practices (BMPs) so that farmers can realize maximum economic yields.

1.2 Overview of groundnut production in Zimbabwe

Groundnut (*Arachis hypogaea* L.) is an important cash crop for smallholder farmers in Zimbabwe where more than 60% of national production occurs (Central Statistics Office, 2004). Resource limited-farmers grow groundnuts mainly for own consumption. Spanish groundnut cultivars are largely grown in all districts. They have a growing period of 100-130 days depending on altitude. However, in cooler and wetter areas, some Valencia cluster cultivars are also grown (Hildebrand, Nigam, Upadhyaya, and Yellaiah, 2005). In Zimbabwe, groundnuts are principally grown by communal and resettlement farmers in Natural Regions 2 to 3 under dry land conditions and in Regions 4 and 5 under irrigation. Principal growers of groundnuts are smallholders and in this farming sector, the crop is predominantly considered a woman's crop (Government of Zimbabwe, 2012). Commercial groundnuts producers are estimated to be below ten thousand farmers (GOZ, 2012). The peasant sector dominated groundnut production up until 1980, contributing over 90% of the deliveries to the Grain Marketing Board (GMB). Delivery of groundnuts to the GMB peaked in the early 1970s but has since been declining (Chiteka and Zharare, 1992).

The decline in groundnut production was attributed to low producer price in relation to alternative crops and high labor demands coupled with low yields, use of poor seed, drought, and poor cultural practices (Chiteka and Zharare, 1992). National commercial demand for groundnuts is estimated at between 120 000 t and 130 000 t pod weight per year (USAID, 2010). Production figures for the 2010/11 and 2011/12 seasons were 230 475 t and 120 000 t pod weight respectively (GOZ, 2012). However, not all the produce is marketed formally due to weak marketing arrangements for groundnuts produced by smallholders. The figures for groundnuts consumed by producers themselves (mainly as fresh, roasted and in the form of peanut butter) and informally marketed are not readily available. This suggests that the proportion of local commercial demand met through local smallholder produce is difficult to establish without undertaking a comprehensive study of all processors big and small in terms of the make-up of their groundnuts raw materials (USAID, 2010).

As such, the 120 000 t to 130 000 t demand estimate may refer to commercially marketed or handled produce rather than the total demand. Overall, processors meet their raw material demands through local produce and imports from within the region mainly from Malawi and Zambia (USAID, 2010). The bulk of the groundnut crop in Zimbabwe is produced on light textured soils ranging from coarse and fine sands to sandy loams. These soils are highly weathered, and are of low Ca, Mg, P, and Zn status and are usually acidic, giving rise to high hydrogen ion (H^+) concentrations as well as toxicities of aluminum (Al) ions. Deep well-drained soils with a pH of 6.5-7.0 and high fertility are ideal for groundnuts (Mupangwa and Tagwira, 2005).

1.3 Statement of the problem

The productivity of groundnuts has declined in the smallholder–farming sector, with pod yield averaging less than 500 kg per hectare despite the presence of improved cultivars with disease resistance. Among other major factors limiting groundnut productivity is the issue of poor cultural practices (CSO, 2004). Timing in weeding is critical because farmers are sometimes committed to other enterprises like planting of other field crops, weeding and spraying. The main reason is that groundnut farming is regarded as a woman's crop, hence the weeding will be done last and in maize, tobacco, and cotton producing areas, groundnuts are lower on the crop packing order. Generally a woman's crop, land and labor allocation is often sub-optimal for groundnuts as smallholder households give priority to food and cash crops (GOZ, 2012).

The question to ask therefore is; does chemical weed control improve yield and quality? Once pegs are safeguarded, then chances of them developing into pods are increased and this subsequently increases pod yield. It is, however, not clear on the best timing and weed control methods to use so as to increase yield and quality of groundnuts. By virtue of the main producers being in the smallholder sector, extension services are mainly provided by AGRITEX. Contracted farmers under REAPERS, Agriseeds and Willards are provided with private sector related extension. Currently, the extension services for the subsector are weak, a function of both supply and demand constraints (GOZ, 2012).

Weak in the sense that farmers, grow the crop under the notion that it is a simple, non-cash crop and therefore allocate the least resources to its production. Hence, groundnut production suffers from poor agronomic practices (GOZ, 2012).

Currently there are no financial services targeting producers in the groundnut subsector, even in smallholder irrigation schemes. Available financial services are only structured in relation to cash crops. More so, providers of financial services lack adequate experience to structure groundnut financing (GOZ, 2012).

1.4 Justification for the study

Smallholder rain-fed crop production in Zimbabwe is characterized by poor productivity caused by poor management practices. A recent survey by ICRISAT showed that up to 30% of all smallholder farmers in Zimbabwe always face food deficit due to low productivity. The SADC region is generally food insecure because of reliance on cereals which do not contain more oil and protein like groundnuts (FAO, 1999).

Groundnut farming like any other business seeks to maximize profit. This can be achieved through controlling production costs by adopting best management practices (BMPs) among other strategies where possible. Currently, farmers use mechanical methods, for example hand hoeing and cultivators for weed control and these in turn damage pegs and pods. These damaged parts become entry points for fungi such as *Aspergillus flavus* which produce aflatoxins. Awuah and Kpodo, (1996) noted that high total aflatoxin levels were associated with damaged kernel samples. Late weeding of groundnut due to other commitments leads to infestation of the crop by insect pests such as *Hilda petruelis* which normally starts at early pod formation and is caused by un-weeded surroundings. It feeds on the roots and immature pods until the plant wilts and then suddenly dies off (Weaving, 1980).

This study is therefore designed to evaluate the efficacy of using Bateleur gold, Metolachlor, Agil and Classic either alone or integrated with hand weeding practices in comparison with mechanical weeding for weed control and its influence on productivity of groundnut in terms of yield and economic returns. If the best weeding method is applied followed by an appropriate fertilizer regime, farmers are likely to benefit more from the reduced production and handling costs. Farmers will also benefit from higher crop yields of high quality and the crop will fetch high prices on the market. Best Management Practices especially the weeding aspect in groundnut production based on scientific premises are clearly required hence the need to carry out this study.

1.5 Objectives of the study

1.5.1 Main objective

To evaluate the impact of weeding method, on total weed density and subsequent effect on groundnut yield and quality.

1.5.2 Specific objectives

a) To compare weed control methods in yield and yield components of groundnut.
b) To evaluate the efficacy of a range of pre- and post-emergent herbicides in groundnut.
c) To evaluate the cost benefit analysis for different weed management strategies in groundnut.

1.5.3 Research Questions

The research work is designed to answer the following questions.

a) Does chemical weed control have an effect on growth, yield and quality of groundnuts?

b) Does a combination of both mechanical and chemical weed control give higher yield?

c) Does application of Bateleur gold, Metolachlor, Agil and Classic produce higher net return and high benefit cost ratio in groundnut?

CHAPTER 2

LITERATURE REVIEW

2.1 Importance of groundnuts in Zimbabwe

Groundnut (*Arachis hypogaea* L) is an important food crop and a source of both fat and protein. It is the second major legume crop grown after beans (*Phaseolus vulgaris* L.) in the world (Okello, Biruma, and Deom, 2010). The crop is cultivated in more than 100 countries on six continents. The crop is cultivated in most tropical, sub-tropical and temperate countries between 40ºN to 40ºS of the equator. Most communal areas are situated in areas with predominately light sandy soils of granite origin. These soils are low in nitrogen and phosphorus and have a low pH. Its inclusion among other legumes in the cropping system improves soil fertility levels especially soil N replenishment (Okello *et al,* 2010). Groundnut is an important legume component of the cropping system in Zimbabwe, and one of the few crops that can be successfully grown on light sandy soils. The crop generates residual nitrogen that benefits subsequent crops, especially when groundnut residues are incorporated into the soil during ploughing. The plant residues also provide a very nutritious animal feed. Even though groundnut cultivation is labor-intensive, particularly during weeding and harvesting, about 260 000 ha are grown in Zimbabwe, mostly by smallholder farmers, and mainly for home consumption to supplement the staple food, maize. Poor cultural practices and inadequate weed management are the main problems limiting production of groundnuts and early removal of weeds is important before flowering and during pegging because the crop cannot compete effectively with weeds, particularly 3-6 weeks after sowing (Page, Busolo-Bulafu, and Chancellor, 2002).

Groundnuts are rich in nutrients, containing practically over 30 essential nutrients and phyto-nutrients. The cake derived from oil expression is normally used for stock-feed. They are a good source of niacin, folate, fiber, vitamin E, magnesium and phosphorus (Kipkoech, Okiror, Okalebo, and Maritim, 2007). Naturally, groundnuts are free of trans-fats and sodium, and contain about 25% protein. Groundnut kernels contain 47-53% oil and 25-36% protein (Young, 1996). Groundnut oil is composed of mixed glycerides and contains a high proportion of unsaturated fatty acids, in particular, oleic (50-65%) and linoleic 18-30% (Young, 1996). The fatty acid in groundnut oil significantly affects the quality and flavor of peanut and their products (Hassan and Ahmed, 2012). Groundnut oil also contains cardiovascular protective properties (Tang, Gao, He, Han, Shan, Zhong, Zhou, Jiang, Li and Zhuang, 2007). The risk of colorectal cancer in women is reduced by frequent intake of groundnuts and its products, by demonstrating its anti-proliferating effect (Yeh, You, Chen and Sung, 2006).

2.2 Origin, History and Distribution of groundnut production in the world.

The earliest archeological records of groundnut cultivation are from Peru, dated 3750-3900 years before present (BP). Domestication of groundnuts took place in Bolivia and Paraguay, where the wildest strains grow today. The Portuguese apparently took them from Brazil to Western Africa and then to South Western India in the 16th century (Gibbons, Buntings, and Smartt, 1972). At the same time the Spaniards introduced them from Mexico to the Western Pacific where they were spread to China, Indonesia and

Madagascar. The Dutch also probably took them from Brazil to Indonesia by the middle of the 17th century (Gibbons *et al*., 1972).

In the United States, they were probably introduced through slave ships from Africa, though they may have been introduced directly from the Caribbean Islands (Gibbons *et al*., 1972). Groundnuts were grown primarily as a garden crop in the United States until 1870. As a field crop, they were frequently used for pig pasture until about 1930 (Gibbons *et al*., 1972). In Zimbabwe, groundnuts have been grown since 1890 in the summer under irrigated or rain-fed conditions (Chiteka and Zharare, 1992).

2.3 Description of the Groundnut Plant.

Groundnut is a self-pollinating, indeterminate, annual, herbaceous legume which takes between 2.5 to 5 months to mature depending on altitude and variety. The plant can grow up to 50 cm tall and the leaves are opposite, pinnate with four leaflets (two opposite pairs; no terminal leaflet); each leaf is about 1 to 7 cm long and about 1 to 3 cm across (Ntare, Diallo, Ndjeunga, and Waliyar, 2008). There are two main types of groundnut crop, the bunch and the runner type, and this describes their growth habits. Bunch varieties mature in 60 - 75 days and runner varieties mature in 90 – 100 days (Ntare *et al*., 2008). The flowers are a typical pea flower in shape, 2 to 4 cm across, yellow with reddish veining. Natural cross-pollination occurs at rates of less than 1% to greater than 6% due to the action of bees. After pollination, the flower falls and what remains is a crimson-colored and cone-shaped peg that grows and penetrates the soil, where the pod develops (Ntare *et al*., 2008). The pods are normally 3 to 8 cm in length, containing 1 to 5 seeds, depending on the variety (Ntare *et al*., 2008). Groundnut emergence is intermediate between the epigeal and hypogeal. Three major stems from one seed then develop, that is, two stems from the cotyledonary axillary buds equal in size to the central stem during early growth (Ntare *et al*., 2008).

The yellow flowers produced are located on the inflorescences resembling spikes in the axils of the leaves. At four to six weeks after planting, first flowers appear and maximum flower production occurs between six to ten weeks after planting. Pods reach maximum growth after two to three weeks in the soil (Mwariri, Kamidi, Wanjekeche, Omamo, Okumu and Wanyonyirr, 2005). The crop reaches maturity after seven to nine weeks in the soil and this is indicated by the presence of darkened veining and browning splotching inside the pod. Depending on the variety planted, groundnuts usually require a minimum of 100 to 150 days from planting to maturity (Ntare *et al*., 2008).

2.4 Environmental Requirements

2.4.1 Climate

Groundnuts require a frost free period and high temperatures. In areas with low temperatures during the growing season, groundnuts will not reach optimum maturity for a marketable yield to justify commercial production. Optimum temperatures are 27-33 °C for vegetative growth and 24-28 °C for reproductive growth. Groundnuts should be sown when the minimum average temperatures are above 18 °C because they are very sensitive to low temperatures (Ntare *et al*., 2008). Moisture is a critical factor for successful groundnut production. Medium to late maturing large-seeded varieties need about 1000-1200 mm while early maturing small-seeded varieties require 300-500mm of rainfall (Nyakanda and Hildebrand, 1999).

2.4.2 Soils

Groundnuts favour well-drained fertile, sandy to sandy loam soils. Very heavy soils with too much clay are not suitable for groundnut production. Soils with more than 20% clay and stones will results in poor yield and make harvesting difficult. Shallow and compacted soils are not desirable because the taproot can penetrate up to 2m deep. Groundnut will not grow well or fix nitrogen in acidic or infertile soils hence soils should have a pH between 5.3 and 7.3 (Mwariri *et al.,* 2005). Groundnut plants are sensitive to salinity, and high soil acidity (pH<5) because they have a very low salt tolerance. Therefore, calcium should be added in this type of soil, to maintain the pH above 6.

2.5 The groundnut subsector in Zimbabwe

The groundnut crop is grown throughout Zimbabwe but mainly concentrated in ecological regions 2-4 of the country with parts of Manicaland and Mashonaland East provinces being the major producing areas in terms of area planted and output. Groundnut production in Zimbabwe is dominated by smallholder farmers with women playing a central role in both the production and marketing. Smallholders contribute 75% of output and grow the crop in light soils (GOZ, 2012). The production has traditionally been viewed as women's socioeconomic activity, mainly for household consumption and to supplement household income through local sales of shelled and unshelled nuts as well as peanut butter (SNV-Zimbabwe 2009). A few commercial producers grow the crop under both irrigation and rain-fed conditions, with a general preference for long season varieties. Long season varieties of groundnuts have a higher yield potential than short season ones (Hildebrand *et al.,* 2005).

The area planted was on the increase during the last decade partly because of the land reform program and also because of the contract farming promotion of the crop by companies like Reapers and Agri-seeds (GOZ, 2012). This means that with a ready market and supported production, smallholder farmers can take up the production of groundnuts to a semi-commercial level. The unofficial market commands a price at least 50 percent higher than the standard producer price and this leaves small-scale farmers with an option of selling their groundnut produce to any market of their choice. Many farmers shifted from groundnut to maize, cotton, and tobacco production (GOZ, 2012).

2.6 Groundnut varieties grown in Zimbabwe

A number of cultivars that were released have been grown over the past 40 years. The bunch and the runner types are the two main vegetative types of groundnut crop grown in Zimbabwe. Plover was released in 1982 (Hildebrand *et al.,* 2005), and Falcon in 1990 (Chiteka, unpublished). Bunch varieties grow mostly erect stems and do not spread out like the runner types and mature in 60-75 days depending on altitude (GOZ, 2012). The runner varieties have a spreading growth habit because lateral branches are long and grow close to the ground and mature in 90-100 days and therefore require a longer growing season (Hildebrand *et al.,* 2005). Of the eleven varieties developed since 1950 by the government, SeedCo in particular has bred three groundnut seed varieties namely; SC Orion, SC Mwenje and SC Nyanda (Hildebrand *et al.,* 2005). Short duration cultivars grown commonly in the region include the South African cultivars Natal Common and

Kwarts, and the Zimbabwean cultivars Falcon, Mwenje, Nyanda, Plover and Jesa (Hildebrand *et al.,* 2005).

Other short-season cultivars that were being grown are Valencia R1, Valencia R2, Bob White and Natal Common. These four cultivars were officially discouraged because of low yield, restricted adaptability, poor seed size, color and shape. However, Valencia R2 in particular was discontinued due to irregular seed shape and unattractive color (Chiteka and Zharare, 1992). Long-duration cultivars grown commonly in the region include Makulu Red and CG 7 which have red seeds and high yields; Flamingo, a high yielding Zimbabwean cultivar with light red seed; and SC Orion. Currently, Flamingo is the main cultivar grown and has proved popular with buyers and processors. It has a slight yield advantage over the other two long-season varieties (Hildebrand *et al.,* 2005).

The Cultivar Nyanda is an early-maturing, high-yielding, Spanish breeding line developed at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, India during the 1990s. Although the variety is almost similar to Falcon in shelling outturn and seed size, it out-yielded the popular Falcon cultivar by 13.5% and matures earlier by six days (Hildebrand *et al.,* 2005). It was derived from a cross between two early-maturing advanced breeding lines, ICGV 86063 and ICGV 86065, developed at ICRISAT, Patancheru. The former is a Spanish germplasm line from USA and the later being early-maturing Virginia bunch type (Hildebrand *et al.,* 2005).

SC Nyanda has a more open bunch type growth habit and has a remarkable drought and heat stress tolerance and gives good yields in marginal rainfall areas (Hildebrand *et al.,* 2005).

2.7 Agronomic practices in groundnut Production

2.7.1 Land Preparation

Land preparation provides suitable soil conditions for rapid and uniform germination, good root penetration and growth, and steady pod development. Primary soil cultivation is necessary on virgin soils or any other soil type in order to remove debris and break the plough layer (Mwariri *et al.,* 2005). For sowing to be done early in the rains, land preparation should be done early before the rains start. Seed beds should be smooth to provide good soil-to-seed contact after sowing. A uniform seedbed with sufficient planting depth and spacing, good germination, weed control and sufficient moisture retention is imperative for good yields (Mwariri *et al.,* 2005).

2.7.2 Sowing and Spacing

Seeds should be sown at a depth of 5 cm to 7 cm and when soil temperature is 18 °C or above. This planting depth ensures that the plant develops and produces optimally (Hildebrand *et al.,* 2005). A furrow 5-6cm in depth should be made along the rows for planting to ensure uniform sowing depth, germination and crop stand. Once the seed has been planted at the right depth and spacing, the soil should be pressed down to ensure good contact with the seeds, enabling them to effectively extract moisture. To ensure a more uniform pod maturity, better seed quality and maximize yield, seeds should be sown in rows and at the right spacing (Hildebrand *et al.,* 2005). Spacing depends on the growth habit and variety. In Zimbabwe, small seeded Spanish types (bunch) are spaced at 30-45 cm between rows and 7.5-10 cm within rows (Hildebrand *et al.,* 2005).

Large seeded Virginia types (runner) are spaced at 60 cm between rows and 10-15 cm between plants giving an optimum plant population of 90 000 plants per hectare. The preferred or optimum population density is 167 000 plants per hectare under dry-land and 280 000 plants per hectare under irrigation (Hildebrand *et al.,* 2005). Groundnut plants planted close to each other result in individual plants setting fewer pods, but over a short period of time. Hence, the pods will be of a similar age and stage of development and, therefore, make it easier to decide when to harvest. It is recommended to use a seeding rate of 80-100 kg /ha. Although it is usually recommended that rows be spaced 450 mm apart, closer spacing (300 mm) will allow earlier ground cover and prevent serious weed problems (Hildebrand *et al.,* 2005).

2.7.3 Fertilizer application

Groundnuts require adequate levels of phosphorus and potassium for normal growth and development, magnesium and mostly calcium for maximizing yield and good quality (Mwariri *et al.,* 2005). In rural fields, the level of P is generally low and hence P should be applied. A reasonable level of organic matter must be maintained in light, weakly structured, tropical soils. For farmers who can afford artificial fertilizers, application of Single Super Phosphate (SSP) or Triple Super Phosphate (TSP) at the rate of 100-125 kg/ha and 80-90 kg/ha respectively will boost yield (Kipkoech *et al.,* 2007). In areas where there is a high incidence of pops, treatment with Gypsum is required at a rate of 200-400 kg/ha at early flowering and then 4 weeks later (Kipkoech *et al.,* 2007). It is important to have soil analysis before planting. In situations where less than 100 mg/kg of Ca is present in the soil, gypsum should be added at a rate of 200 kg/ha (Mwariri *et al.,* 2005).

Since groundnuts are leguminous crops, they can fix atmospheric nitrogen (N). Groundnuts with effective root bacteria do not need additional nitrogen. On a negative side, an oversupply of potassium in the soil can induce a calcium deficiency, which is reflected in a lower yield and quality (Mwariri *et al.,* 2005). Calcium (Ca) is very important for seed development and is regarded as an essential element in groundnut production. Boron (Bo) deficiency is common in sandy soils and can affect quality (Nyakanda and Hildebrand, 1999). Groundnut will not grow well or fix nitrogen in acidic or infertile soils. The soil pH should be between 5.3 and 6.5 ($CaCl_2$). The crop should not be grown on soils of pH above 7.5 (Kipkoech *et al.,* 2007). Most soils in Zimbabwe contain small amounts of phosphorus and sulphates for groundnuts, and sometimes too little potash or boron. Groundnut should receive 150-250 kg /ha single super phosphate (19% P_2O_5), or 150-200 kg/ha Compound L (5:18:10 + 0.25% boron) (Nyakanda and Hildebrand, 1999).

2.7.4 Rotation

Groundnut is a leguminous crop that fits into a wide range of farming systems and has the ability to fix 60% to 70% of its nitrogen requirement from the atmosphere under ideal conditions (Mwariri *et al.,* 2005). It can follow both cereals (maize, pearl millet and sorghum) and root crops (cassava and sweet potatoes) in a rotation. Groundnuts in a rotation offer several advantages for the producer (Kipkoech *et al.,* 2007). Yield is increased when the crop is planted after a non-legume because of the following factors; disease and insect cycles become disrupted; alternative herbicides can be used to kill grassy weeds; and soil nutrients are used efficiently (Kipkoech *et al.,* 2007).

Groundnut does well on virgin land or immediately following a grass fallow or a well fertilized crop such as maize. Crops that may cause a build-up of soil-borne diseases and nematodes should be avoided in rotation with groundnuts. Clean-weeded crops such as cassava, sweet potato and sunflower are ideal for rotation with groundnut (Kipkoech *et al.,* 2007).

2.8 Weeds in groundnut production

2.8.1 Diversity of weeds in groundnut fields in Zimbabwe

Common groundnut weeds in light textured sandy loam soils in most parts of Zimbabwe include mexican clover (*Richardia scabra*), black jack (*Bidens pilosa*), Upright starbur (*Acanthospermum hispidum*), Wild jute (*Corchorus acutangulus*), Crab grass (*Digera arvensis*), Purslane (*Portulaca oleracea*), grasses such as Rapoko grass (*Eleusine indica*) and Shamva grass (*Rottboellia cochinchinensis*) and few broad leaved species such as Wandering jew (*Commelina benghalensis*) and Apple of peru (*Nicandra physalodes*), Purple nutsedge (*Cyperus rotundus*), Couch grass (*Cynodon dactylon*), Panicum (*Panicum repens*) and Crow’s foot (*Dactyloctenium aegyptium*), (Chivinge, 1990). In India, *Cyperus rotundus*, *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Eleusine stagnina*, *Euphorbia hirta* , *Amaranthus spinosus*, and *Commelina benghalensis* are major weeds in red sandy loam soils (Subrahamaniyan and Arulmozhi, 1998). In the sub-tropical region, Acalypha (*Acalypha indica*), Goosefoot (*Chenopodium album*), *Euphorbia hirta*, *Cynodon dactylon* and *Cyperus rotundus* are the major weeds under sandy loam soil conditions (Kavimani, Christopher, Geethalakshmi, and Raveendran, 1991).

2.8.2 Weed competition on growth and yield components

Weed competition reduces plant height, leaf area and crop dry matter production and inhibits pegging in groundnuts and also affect partition of biomass in groundnuts and leaf area index (Singh and Giri, 2001). A weed free environment increases the plant height, number of pods per plant and pod weight (Singh and Giri, 2001). Weeds can reduce pod yield by 25-70% depending on the intensity of weed infestation (Singh and Giri, 2001).

2.8.3 Critical period of crop weed competition

Yield of groundnuts is considerably reduced when crop weed competition occurs during the early stages of crop growth. The growth and yield of groundnut is decided by this critical period of crop weed competition (Kipkoech *et al.,* 2007). The groundnut crop is much affected by weeds during the first 45 days of its growth and the most critical period of weed competition is from three to six weeks after sowing (Kipkoech *et al.,* 2007). Weed free conditions from 15 to 40 days after sowing was essential for the achievement of maximum yield (Singh and Giri, 2001).

2.8.4 Weeds as hosts for insect pests and diseases

Besides competing for sunlight, space, moisture and soil nutrients, weeds serve as hosts for insect pest and diseases. In a national survey done in Zimbabwe in 1985/86, four additional host plants for groundnut plant hopper (*Hilda patruelis*) namely Mexican marigold (*Tagetes minuta*), Stockrose (*Hibiscus meeusei*), fish bean plant and a common Asteraceae weed (*Veronia poskeana*) were observed (PPRI, 1986).

The extent of damage by *Hilda* to groundnut can often be of economic importance. Plants are attacked below the soil surface at the base of the stem and on roots. The hoppers are also found feeding on pegs and pods and they tend to jump off when disturbed. Breeding occurs in both host plants and groundnut plants throughout the year. Clusters of small silvery-blue elongated eggs (usually 10-50) are laid on the stems, roots, pegs and pods. Eggs hatch in 10-15 days, and each generation takes about 37-42 days. *Hilda* has an obligate symbiotic relationship with several ant species which protect it from predators (Weaving, 1980 and NRI, 1996).

These hoppers survive the dry season on the roots of weeds or volunteer groundnut plants and later move into groundnut fields. Sucking pests (*Aphis craccivora*), foliage feeders (*Spodoptera littoralis*) and pod feeders (*Microtermes* sp, *Elasmolomus sordidus*) hibernate in weeds (Weaving, 1980 and NRI, 1996).

2.9 Weed management in groundnut production.

Weed control is one of the most expensive farming activities faced by communal and small-holder farmers in Zimbabwe. It is a laborious activity and if not properly done, or on time it can lead to crop yield losses of up to 70% (Chivinge, 1995). In all sub-Saharan countries, weeding has been cited as one of the main constraints in crop production for smallholder poor farmers. Weeding normally takes up to 50% of the available season time and accounts for 40-55% of the total labor input (Nyakanda and Hildebrand, 1999). There are two options to increase production namely; increase acreage or intensify production by increasing yield per unit area. It is essential to manage weed populations on farmers' fields in order to succeed with either of these strategies (Lekezime, 1988).

2.9.1 Timing of weeding

Early removal of weeds is important because groundnuts cannot compete effectively with weeds, particularly up to 6 weeks after sowing. In general, two to three weedings are recommended. The first before flowering and the second one during pegging. The last cultivation is dependent on weed growth, but should not be delayed later than 60 days after planting (Page *et al*., 2002). Weeds that come up later are smothered by the canopy generated by vigorous growth of the crop and that is if early weeding is done well. However, maximum attention is needed when weeding a flowering groundnut crop in order not to disturb flowering plants. Hand or machine cultivation is recommended until flowering begins but earthing-up during weeding should be avoided (Page *et al*., 2002).

2.9.2 Mechanical weeding

Manual weeding is the age old practice for weed control in groundnuts and is laborious, time consuming and expensive especially when there is dearth of manpower (Chivinge, 1995).The first operational pre-requisite in reducing the weed problem is primary tillage. A greater proportion of weeds are buried at lower depths in the soil by primary tillage and this can possibly reduce the total weed population (Page *et al*., 2002)

Rotary hoe and cultivator were noted to be valuable implements for weed control in groundnut production if operated properly and about 70% weed control can be achieved by rotary hoeing until weeds are 1-3 leaf stage (Lekezime, 1988). The effect of weeds in groundnuts can also be reduced by harrowing the field before planting. Disking kills the weeds that are growing though it can bring weed seed to the surface (Page *et al*., 2002) Mechanical weeding is effective in terms of loosening up the soil, but it is very important to avoid covering the developed plant with earth as this can increase diseases, reduces flowering and pod development and therefore reduce pod yield (Nyakanda and Hildebrand, 1999). It is advisable to weed by pulling weeds up by hand rather than by using a hoe once flowering and pegging begins, because this is less likely to disturb developing pods (Page *et al*., 2002). Groundnuts can be hand weeded 2-3 times to achieve adequate weed control (Chivinge, 1995). It is comparatively faster and less labor intensive to use mechanical weed control than hand weeding. It has been reported that weeding using an ox-drawn weeder can play an important role in improving agricultural productivity and alleviating the labor shortages experienced during weeding operations (Chivinge, 1990). It is a much faster and less tiring operation when weeding using oxen as compared with hand weeding. This ox-drawn operation can allow timely weeding which in turn can subsequently lead to better groundnut yields per hectare (Lekezime, 1988). Mechanical weed control not only uproots the weeds between the crop rows but also keeps the soil surface loose, ensuring better soil aeration and water intake capacity (Chivinge, 1990).

2.9.3 Chemical weed control

Herbicides offer an additional tool to a farmer in controlling weeds. Selective herbicides can control most weeds. Commercial farmers normally use Pre- and Post-emergence herbicides to eradicate weeds. Several herbicides are registered for utilization and classified as selective and non-selective herbicides. However, the choice of herbicide and the concentration applied will largely depend on the species of weeds involved and the level of infestation (Page *et al*., 2002).

Herbicides such as Metolachlor, Bateleur-gold and alachlor (Lasso) can be used before crop and weed emergence. Classic, Agil and bentazone (Basagran) can then follow after the weeds and crop has emerged (Okello *et al*., 2010). It is advisable to follow the manufacturers' instructions with regard to dosage. Herbicide labels should be studied carefully and emphasis should be placed on the waiting period for both ensuing and previous crops, application rate based on clay percentage of the soil and application time and conditions (Page *et al.*, 2002). Herbicides are applied within a narrow range of rates, if too low, there will be inadequate control and they will kill plants if too high (Bastiani, Suilva, Ferreia, and Cardoso, 2000).

Residues from application of herbicides to previous crops can cause groundnut production problems, for example atrazine applied to a previous maize crop can reduce groundnut stand and yield (Bastiani *et al*., 2000). Some herbicides such as metribuzin and bentazon which proved to be effective in the temperate region may cause phytotoxicity or may give poor weed control at recommended rates in the tropics (Bastiani *et al*., 2000). In groundnuts, Metolachlor and Batelur-gold control a wide range of weeds and these include, *Bidens pilosa, Ricardia scabra*, *Datacloctenium aegyptium*, *Digitaria sanguinallis*, *Echinochloa crusgalli*, *Echinochloa colonum*, *Elusine indica*, *Setaria verticillate*, *Amararathus hybridus*, *Amaranthus thurmbergil*, *Commelina benghalensis*, *Nicandra physalodes*, and a wide range of grasses and broad-leaved weeds and sedges (Bastiani *et al*., 2000).

Herbicides can be systemic, contact, soil acting or foliage acting compounds. Systemic herbicides are quickly absorbed by the leaves and transported in the symplast; thus are effective in controlling perennial weeds and killing underground buds as well as apical meristems. Contact herbicides can only achieve better weed control for broad-leaved annual weeds because they are not translocated (Page *et al*., 2002).

2.9.3.1 Pre-plant incorporated (PPI) herbicides for weed management.

Metolachlor, Dual Magnum, Pursuit 70DG (imazethapyr), Sonalan 3HFP (ethafluralin), Bateluer-gold, Prowl H20 3.8 CS (pendimethalin) and Outlook 6EC (dimethenamid-p) can be applied as pre-plant incorporated herbicides for weed management in groundnut. They control some annual grasses and some small seeded broadleaf weeds. They also control or suppress yellow nutsedge but not purple nutsedge. Incorporation with implements other than power tiller requires two passes, preferably at cross angles and too deep incorporation may reduce effectiveness (Bastiani *et al*., 2000).

Heavy rainfall after planting and or non-uniform incorporation may cause crop injury. Generally, pre-plant incorporated (PPI) treatments provide better control of yellow nutsedge (Bastiani *et al*., 2000). Pursuit 70DG (imazethapyr) and Pursuit 2AS control Purple nutsedge (*Cyperus rotundus*) and Yellow nutsedge (*Cyperus esculentus*), Pigweed (*Amaranthus hybridus*) and several other annual species (Okello *et al*., 2010). These incorporated treatments are more persistent than both pre- and post-emergence applications and normally result in carryover. Accurate herbicide application requires proper system calibration and safety devices to prevent environmental contamination and provide effective weed control (Bastiani *et al*., 2000).

2.9.3.2 Pre-emergence (PRE) herbicides for weed management in groundnut

Pre-emergence application of herbicides is appropriate not only in minimizing early weed control, but also for reducing the demand on labor during the peak period. This also avoids at least one or two inter- row cultivations during the first 3-4 weeks and control weeds in both the intra and inter row spaces (Baker and Terry, 1991). Pre-emergence application of herbicides can control weeds up to 55 percent and when combined with one hand weeding can control up to 85 percent (Guggari, Manjappa, Desai and Chandranath, 1995).

Pre-emergence treatments generally provide better broadleaf weed control and or suppression. If Dual Magnum was used as a PPI treatment, then, any additional applications of this herbicide should be delayed until groundnuts begin emerging (at cracking). In order to improve control of sickle pod, yellow and purple nutsedge, multiple applications of pre-plant incorporated herbicides like Metolachlor, followed by at cracking (germination) treatments is required (Guggari *et al*., 1995).

Rainfall is needed for proper activation of Pursuit 70DG (imazethapyr) after a surface application. Pre-emergence herbicides should be applied immediately after planting and no later than 2 days after planting. If applied 3 or more days after planting, significant injury to crops may occur. Groundnuts should not be irrigated at cracking as rainfall or irrigation at this stage will cause temporary crop injury because of the compounds in herbicides (Hildebrand *et al.,* 2005).

2.9.3.3 Post-emergence herbicides for weed management in groundnut

Post-emergence herbicides for groundnut include Classic 25DF (chlorimuron), Agil 100EC, Cobra 2EC (lactofen), Pursuit 70 DF (imazethapyr), Ultra Blazer 2S (acifluorfen), Storm 4S (bentazon + acifluorfen), Basagran 4S (bentazon) and Gramoxone SL 2S (paraquat). Gramoxone is a restricted pesticide and provides effective suppression of yellow and purple nutsedge but can result in increased foliar groundnut burn (Baker and Terry, 1991).

Basagran is a post-emergence herbicide for control of yellow nutsedge, Mexican clover, upright starbur, morning glory, prickly sida, gallant soldier, billygoat weed, black jack and other weeds (Baker and Terry, 1991). Treatment is best when broadleaf weeds are small and actively growing. Application of Classic applied from 60 days after crop emergence to 45 days before harvest may cause an increase in Tomato Spotted Wilt Virus (TSWV) symptoms (Guggari *et al*., 1995). A combination of Classic and 2.4-D should not be used on Spanish and Southern runner cultivars because this will result in significant foliar crop injury (Baker and Terry, 1991).

2.9.4 Biological weed control

This involves suppression of weeds by insects, plants and micro-organisms. Plant pathogens are used to control weeds in groundnuts and have been successful in temperate agriculture (Buhler, Gunsolus, and Raiston, 1992). Some groundnut cultivars have allelopathic effects that give a competitive effect against weeds, for example Sickle pod and velvet leaf (Buhler *et al.,* 1992). In developing countries, the use of living and dead mulch as means of biological control have been reportd (Guggari *et al*., 1995).

2.9.5 Integrated weed management

This involves the combination of two or more weed control measures in order to increase effectiveness and efficiency. A combination of weed control methods can be effective in keeping weed damage below the economic threshold. Rotary hoeing followed by cultivation results in higher groundnut yield than cultivation alone (Buhler *et al.,* 1992). A combination of herbicides and mechanical weeding often achieves better weed control as compared to sole herbicides application (Guggari *et al*., 1995). Pre-emergence herbicides alone can give almost 98% control early in the season, but weeds that emerge later can reduce pod yield, hence the need to combine weed management techniques (Guggari *et al*. 1995).

CHAPTER 3

MATERIALS AND METHODS

3.1 Study site

A field experiment was conducted to evaluate the performance of twelve weed control treatments on groundnuts at Rattray Arnold Research station (17.67ºS, 31.17ºE; 1452 m. above sea level) in Zimbabwe during the 2014/2015 growing season. The station is about 35 km from Harare along the Harare-Shamva road. The area receives an average annual rainfall of 803 mm which range from 425 mm to 1235 mm per year and temperature mean maximum are from 18ºC (July) to 32ºC (October). The hot summer is between September and December, with October being the hottest month of the year with mean maximum temperatures above 30ºC. 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).

3.2 Soil Characteristics

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.

3.3 Soil analysis

A soil sample (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^{+}.

3.4 Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with twelve treatments and three replications (Table 3.1). Each experimental unit was 12.60 m^2 gross plot size and 7.65 m^2 net plot size.

Table 3.1 List of weed control treatments evaluated to efficacy in the control of weeds on groundnut in the experiment.

Treatment No	Description
Trt 1	Metolachlor (Pre-emergent only)
Trt 2	Metolachlor + Agil (Pre and post-emergence)
Trt 3	Metolachlor + Classic (Pre and post-emergence)
Trt 4	Bateleurgold (Pre-emergent 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)

3.5 Trial establishment and management

3.5.1 Planting

The land was ploughed to a depth of 0.30 m using a tractor drawn plough and a disc plough was used to provide a weed free seed bed with a fine soil tilth. The groundnut 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 0.04-0.06 m on the 25th of October 2014. The plant spacing was 0.45 m inter-row and 0.075 m in-row giving a plant population of 266 600 plants per ha and 53 plants per 4 m row.

3.5.2 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 at 65 DAS.

3.5.3 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 35 g/ 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).

3.6 Variables measured.

3.6.1 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.

3.6.2 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 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.

3.6.3 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 7.60 m^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:

$$WCE = \frac{Weedy\ biom\check{a}ss - managed\ treatment\ biomass}{Weedy\ biom\check{a}ss} * 100$$

3.6.4 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.

3.6.5 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.

3.6.6 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:

$$Pod\ yield\,(kg/ha) = \frac{Total\ Pod\ F\,W\,(g) * Sub - sample\ Pod\ D\,W\,(g) * 10}{¿ - sample\ Pod\ F\,W\,(g) * Net\ area\ harvested\,(2.2\,m2)}$$

3.6.7 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:

$$\text{Haulm Yield (kg/ha)} = \frac{Total\ Haulm\ F\,W\,(g) * Sub - sample\ Haulm\ D\,W\,(g) * 10}{¿ - sample\ Haulm\ F\,W\,(g) * Net\ area\ harvested\,(2.2\,m2)}$$

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

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

3.6.8 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;

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

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

3.6.9 Cost-benefit 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: $BCR = \frac{Gross\ return}{Total\ cost}$

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.

3.7 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.

CHAPTER 4

RESULTS

4.1 Soil characteristics of the experimental site

Texturally, the test showed that the soil was a medium grained sandy-clay-loam with a moderate pH of 6.1 (Table 4.1). Since the pH level was within the acceptable range for crop growth, no correction measures for pH were taken. The extractable P on the site was classified under the low category after soil analysis. According to London (1991), if the available P is < 15 ppm it is regarded as low, 15-30 ppm as medium and 30-50 ppm as high. The exchangeable bases on the site were on the acceptable levels except for K which was low, and available N was also low. Generally, the soil was considerably of low fertility level when taking into account the major nutrients like N and P which are also nutrients of high influence to the overall crop yield.

Table 4.2 Soil analysis results from experimental plots.

Sample ref	Color	Texture[a]	pH	Initial N (ppm)	After incub N (ppm)	Avail P (ppm)	Exchangeable cations Mg equivalents/ 100g		
							K	Ca	Mg
Web 3	LB	mgSCL	6.1	16	25	10	0.19	12.93	0.3

[a]Texture; mg=medium-grained; SCL=Sandy-clay-loam LB=light brown. General fertility range interpretation; [b]Mineral-N measured after a 14-day incubation of soil at field capacity and at 35 ^{O}C: <20=very low; 20-30=low; 30-40=medium; >40=high. [c]Available-P (resin-extracted): <7=very low; 15-30=medium; 30-50=high. [d]Exchangeable K: <0.15=very low; 0.15-0.3=low; 0.3-0.5=medium; >0.5=high. [e]Exchangeable Ca: <5=very low; 5-10=low to medium; >10=high. [f]Exchangeable Mg: <0.1=very low; 0.1-0.2=low to medium; >0.2=high.

4.2 General crop growth in response to weeding method.

4.2.1 Percent emergence

Emergence assessment was carried out on the 14th 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 4.2). Though some plots had emergence percentage as low as 86.33% (Metolachlor + Agil), the grand mean for the whole experiment was 90.97%. Therefore, there were significant differences ($P<0.05$) in germination percentage (Table 4.2).

4.2.2 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 4.2). 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 1.0 l 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 4.2).

4.2.3 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 26 cm in height whereas those without the herbicide treatments were at 30 cm and the highest plant height was recorded in the weedy check treatment (32.33 cm) and this might be due to the competition of the crop for sunlight and space with the weeds (Table 4.2).

Table 4.3 Means for germination percentage, phytotoxicity score at germination and at flowering and plant height at 45 days after sowing.

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**

***, 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

4.3 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 4.3). 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 4.3). The weeds are ranked in order of abundance.

Table 4.4 Ranked weed species composition of the experimental plots.

	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

Key: ABL (Annual broadleaf); PBL (Perennial broadleaf); AG (Annual grass); PB (Perennial grass)

4.4 Total weed density

There were significant differences ($P<0.05$) among treatments for weed density at harvest (Table 4.4). 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 1.0 l a.i./ha along with post-emergence application of Agil 1.0 l 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 4.4). Pre-emergence treatment with sole Metolachlor at recommended rate was not significantly different ($P>0.05$) from Metolachlor plus Classic which had 11 weeds per m^2. There were no significant differences ($P>0.05$) 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 ($P>0.05$) 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.

Table 4.5 Means for total weed density and weed biomass at harvest.

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**	

***, 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.

4.5 Total weed biomass at harvest, and weed control efficiency.

Weed biomass was significantly different (P<0.05) and influenced by various weed management strategies and followed the same trend as weed density (Table 4.4). Weedy check treatment had the highest biomass. Pre-emergence application of sole Metolachlor was the worst and significantly different (P<0.05) from all other weed management strategies (Table 4.4). The weedy free check recorded the lowest weed biomass. Treatment 5 (Bateleur gold and Agil), treatment 6 (Bateleur gold and Classic), treatment 8 (Bateleur gold and hand hoeing) and the weed free treatment were statistically the same with regard to weed biomass (Table 4.4).

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. There were no significant differences ($P>0.05$) 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. The weedy check recorded significantly lowest weed control efficacy over all other treatments.

4.6 Effect of weed control treatment on most abundant weed species.

Significant differences ($P<0.05$) were noted on most abundant weed species at 80 days after sowing. Best herbicidal response to weed density and most abundant weed species was recorded in treatments with pre-emergence application of Bateleur gold at 1.0 l a.i./ha along with post-emergence application of Agil 1.0 l a.i./ha at 42 days after sowing. The absolute weed free condition recorded the least number of weeds across all the most abundant weed species. This was followed by pre-emergence application of Bateleur gold at 1.0 l a.i./ha along with post-emergence application of Agil 1.0 l a.i./ha at 42 DAS. Application of Bateleur gold at 1.0 l a.i./ha as a pre-emergence herbicide controled both broad and narrow leaves in comparison to Metolachlor at 1.0 l a.i./ha.

Pre-emergence application of Metolachlor was statistically different ($P<0.05$) from application of Bateleur gold, and had more weed density regarding all the most abundant weed species. Post emergence application of Agil at 1.0 l a.i./ha managed to reduce *Cynodon dactylon* (Couch grass) in all the treatments that were applied with the herbicide. There were no significant differences among these treatments, Metolachlor plus Agil, Bateleur gold plus Agil and hand hoeing plus Agil (Table 4.5).

Post-emergence application of Classic at 35 g a.i./ha managed to reduce most abundant broad leaf weed species as compared to Agil which was only significantly effective in controlling grass weeds like *Cynodon dactylon*. Pre-emergence application of Metolachlor 1.0 l a.i./ha along with post emergence application of Classic 35g a.i./ha had significantly less controlling effect in all the most abundant weed species (Table 4.5). In general, hand hoeing at 21 days after sowing + Agil managed to reduce *Cynodon dactylon* and other grass weeds whilst hand hoeing + Classic managed to control most broad leaf weeds (Table 4.5)

Table 4.6 Means for most abundant weed species at 80 days after sowing.

Treatment	Couch grass	Wandering Jew	Mexican clover	Bobbin weed
Metolachlor (only)	1.67^{b}	3.33^{bc}	3.67^{c}	1.33^{b}
Metolachlor + Agil	0.33^{a}	1.67^{a}	3.33^{c}	1.00^{ab}
Metolachlor + Classic	2.33^{b}	3.33^{bc}	1.00^{a}	0.33^{a}
Bateleurgold (only)	0.67^{ab}	2.00^{b}	1.33^{ab}	1.67^{bc}
Bateleurgold + Agil	0.00^{a}	1.67^{a}	1.67^{ab}	0.33^{a}
Bateleurgold + Classic	0.67^{ab}	1.67^{a}	1.00^{a}	2.00^{b}
Metolachlor + Hand hoeing	1.67^{b}	1.67^{a}	3.33^{c}	2.33^{c}
Bateleurgold + Hand hoeing	0.33^{a}	1.33^{a}	1.00^{a}	0.33^{a}
Control (Weed free)	1.00^{a}	0.67^{a}	2.00^{b}	2.33^{c}
Hand hoeing + Agil	0.33^{a}	2.33^{b}	2.00^{b}	2.33^{c}
Hand hoeing + Classic	2.33^{b}	3.67^{c}	1.33^{ab}	1.67^{bc}
No weeding (Weedy check)	6.33^{c}	6.67^{d}	13.00^{d}	6.00^{d}
Significance of F	***	***	***	***
CV %	**40.8**	**24.9**	**17.3**	**32**

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

4.7 Yield and yield components 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 4.6).

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 35 g/ha (Table 4.6). One hand weeding + an application of Agil or Classic were statistically the same in all yield components (Table 4.6).

4.7.1 Mature pods per plant

There were significant differences ($P<0.05$) on mature pods per plant at harvest (Table 4.6). 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 4.6). 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 4.6).

4.7.2 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 4.6). 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 4.6). This shows that they were statistically different.

4.7.3 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 and yield components. 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 these treatments; 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 components and yield (Table 4.6). 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.

4.7.4 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 most herbicide treatments but was tateleur gold alone, hand hoeing + Agil, and hand hoeing + classic (Table 4.6).

The absolute weedy check condition produced the minimum pod yield, in comparison to herbicide treatments and mechanical practices. Chemical and /or mechanical or both increased pod yield of groundnut as compared to the un-weeded control and pod yield decreased to 74% in relation to the un-weeded condition (weed checky). 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 4.6).

4.7.5 100-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 4.6). Hundred-kernel weight ranged of 36 to 38.33 g. However, the weedy check treatment recorded the lowest 100-kernel weight (g) against the rest of the treatments (Table 4.6). On the other hand shelling percent ranged from 68.33 to 70.67 %. Lowest shelling percent was again recorded from the weedy check treatment (Table 4.6).

Table 4.7 Means for yield and yield attributes of groundnut.

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**

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

4.8 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 4.7). Weeding benefit followed the same trend with the gross margin and the gross return.

Table 4.8 Cost-benefit analysis of groundnut with respect to weed control treatment

Treatment	[a]Gross return $	Input cost $	Weeding cost $	Total variable cost $	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

[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).

CHAPTER 5

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.

5.1 Percent emergence

Crop emergence was low in plots that were treated with herbicide as compared to untreated plots. Plots without application of pre-emergence herbicides had an average crop emergence of 94 percent. Metolachlor treated plots at recommended rate was the least with average emergence of 87 percent and plots treated with Bateleur gold had an average of 91 percent. Therefore the significant differences ($P<0.05$) in germination indicates that 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 maybe by 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).

5.2 Phytotoxic effect of herbicides.

It is important to have an assessment of phytotoxicity when using compounds such as herbicides as a weed control measure. However, the basic principles for phytotoxicity assessment are the same whether the compound tested is an herbicide, fungicide, insecticide or any other type of plant protection product. The difference only lies in the experimental design and not in the method of assessment (Meier, 2001). In this study, 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 4.2).

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.

5.3 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 *Commelina benghalensis*, *Acanthospermum hispidum, Leucas martinicensis*, *Cynodon dactylon*, *Richardia scabra*, *Dactyloctenium aegyptium*, *Hibiscus meeusei* and *Nicandra physaloides*.

5.4 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 4.4). However, sole application of Metolachlor at 1.0l a.i./ha a pre-emergence herbicides 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 treatment. 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 weed 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 4.4) 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 at recommended rate along with a post-emergent Agil at 1.0 l a.i./ha, Bateleur gold 1.0 l a.i./ha + one hand hoeing at 42 DAS, plots receiving two hand hoeing at 21 and 42 DAS and plot with Bateleur gold 1.0 l a.i./ha along with Classic 35 g a.i./ha 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. Groundnut being a deep rooted legume crop proliferation of the root at early stage is essentially required to establish the sufficient numbers of nodules and better crop growth for pegging. Weed growth is faster than crop growth at early stage so controlling of weeds at early stage reduced the crop weed competition and thus improving nutritional security to the crop as result of better pod yield.

Pre-emergence application of Bateleur gold 1.0 l a.i./ha reduced monocot and dicot populations in the early stages of crop growth which permitted better growth of the crop, pod bearing and increased pod yield. In comparison, both pre-emergence herbicides at recommended rates controlled annual grasses and most broad leaf weeds but Bateleur gold had more residual effect than Metolachlor.

Rathi, Sharma, and Dubey, (1986) also reported similar observations and went on to state that pre-emergence application of Pandimethalin @ 1.5 kg a.i./ha was as effective as two hand weedings. In general, 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.

5.5 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 was weeded 21 DAS by hand hoeing was significantly different ($P<0.05$) from those that were treated with pre-emergence herbicides from the onset of plant growth (Table 4.6).

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 (Table 4.6). 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 1.0 l a.i./ha 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 4.4 and 4.6). 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 were 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.

5.6 Economic analysis.

Yield and yield components 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 both yield and yield components occasion by better weed control efficiency compared to all other treatments. Similar results were recorded by (Subrahmaniyan *et al.,* 2002 and Mutnal, 2006).

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 post emergence application of Agil. 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.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

It has been established from the study that all weed control treatments were effective in weed suppression and improving groundnut yield compared to the weedy check. However, 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.

Weed interference in groundnut causes significant yield reductions. Pre-emergence application of Bateleur gold or Metolachlor herbicides followed by either post-emergence application of Agil or Classic at recommended rates or one hand weeding on 42 days after sowing (DAS), can keep the weed density and dry weight below the economic threshold level and increase the pod yield and net return in groundnut.

The results also showed that pre-emergence application of Bateleur gold alone induced the highest effect on total weed suppression followed by Metolachlor at 42 days after sowing. 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 best benefit ratio as compared to all other treatments.

6.2 Recommendations for further research

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.

The study should therefore be also carried out in other groundnut growing regions of Zimbabwe for the benefit of all smallholder farmers in the country so as to see how the performance will be during that season and in other regions. This will enable researchers to give a detailed advice to farmers.

Further research needs to ascertain protein and oil content under the studied factors and conditions.

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APPENDICES

Appendix 1: Weed counts/ m^2

Treatment Number	Total Weed Counts /m^2				
	20 DAS	**40 DAS**	**60 DAS**	**80 DAS**	**At haverst**
1	3	7	9	11	18
2	4	9	4	7	11
3	3	8	5	11	14
4	1	3	4	7	12
5	1	4	2	4	7
6	2	4	3	6	9
7	3	6	4	9	13
8	1	4	3	5	5
9	8	3	3	6	10
10	13	7	4	7	9
11	15	6	5	9	11
12	17	42	51	59	67

Appendix 2: Field plan layout

[2] **1**	**[9]** **2**	**[10]** 3	**[7]** **4**	**[6]** **5**	**[12]** **6**	**[8]** **7**	**[11]** **8**	**[4]** **9**	**[3]** **10**	**[5]** **11**	**[1]** **12**

1 m pathway

[7] **24**	**[6]** **23**	**[2]** 22	**[10]** **21**	**[5]** **20**	**[1]** **19**	**[12]** **18**	**[11]** **17**	**[8]** **16**	**4[]** **15**	**[3]** **14**	**[]** **13**

1 m pathway

[4] **25**	**[11]** **26**	**[5]** 27	**[8]** **28**	**[1]** **29**	**[2]** **30**	**[7]** **31**	**[3]** **32**	**[12]** **33**	**[6]** **34**	**[9]** **35**	**[10]** **36**

Appendix 3: Rainfall (mm) distribution during the period of the experiment.

Date	**Rainfall (mm) 2014/15 Growing Season by Month**				
	Nov	**Dec**	**Jan**	**Feb**	**Mar**
1				17	
2					16
3			22		TR
4				16	
5		TR			
6					TR
7			TR		
8				15	
9				TR	
10		15			TR
11				26	
12		55	TR		
13					
14				34	
15					
16		36	17		
17					
18		23		55	
19		65			
20			34		
21			26		
22		55		47	
23			50		
24			55		
25	TR				
26				TR	
27	26		26		
28		34			
29	14		TR		
30					
31		46			
Total	**40**	**246**	**230**	**210**	**16**
Total to date	**40**	**304**	**534**	**744**	**760**

TR =Trace rainfall < 0.05 mm

Appendix 4: Analysis of variance (Germination percent)

Variate: Germination Percent

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Trt	11	273.639	24.876	8.14	<.001
Residual	24	73.333	3.056		
Total	**35**	346.972			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**2.946**

***** Stratum standard errors and coefficients of variation *****

Variate: Germination

d.f.	s.e.	cv%
24	1.748	**1.9**

Appendix 5: Analysis of variance (Phytotoxicity at Germination)

Variate: phytotoxicity_at germination

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Trt	11	13.23482	1.20317	86.03	<.001
Residual	24	0.33567	0.01399		
Total	**35**	13.57049			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**0.1993**

***** Stratum standard errors and coefficients of variation *****
Variate: phyto_at

d.f.   s.e.   cv%

24	0.4714	**6.8**

Appendix 6: Analysis of variance (Phytotoxicity at Flowering)

Variate: Phytotoxicity_at flowering

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	18.580122	1.689102	171.43	<.001
Residual	24	0.236467	0.009853		
Total	**35**	18.816589			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**0.1673**

***** Stratum standard errors and coefficients of variation *****

Variate: Phyto_at

d.f.	s.e.	cv%
24	0.4410	**5.2**

Appendix 7: Analysis of variance (Plant Height at 45 DAS)

Variate: P_Height

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	193.222	17.566	16.21	<.001
Residual	24	26.000	1.083		
Total	**35**	219.222			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**1.754**

***** Stratum standard errors and coefficients of variation *****

Variate: P_Height

d.f.	s.e.	cv%

24	1.041	**3.8**

Appendix 8: Analysis of variance (Total Weed Density no/m^2 at 80 DAS)

Variate: Weed counts at 80 DAS

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	7464.750	678.614	387.78	<.001
Residual	24	42.000	1.750		
Total	**35**	7506.750			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**2.229**

***** Stratum standard errors and coefficients of variation *****

Variate: Weed counts

d.f.	s.e.	cv%
24	1.323	**11.3**

Appendix 9: Analysis of variance (Weed Biomass g/m^2)

Variate: Weed biomass

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	2266607.0	206055.2	437.61	<.001
Residual	24	11300.9	470.9		
Total	**35**	2277907.9			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**36.57**

***** Stratum standard errors and coefficients of variation *****

Variate: Weed biomass

d.f.	s.e.	cv%
24	21.70	**16.8**

Appendix 10: Analysis of variance (*C. dactylon* Couch grass)

Variate: *C. dactylon* (Couch grass)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	98.3056	8.9369	24.75	<.001
Residual	24	8.6667	0.3611		
Total	**35**	106.9722			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**1.013**

***** Stratum standard errors and coefficients of variation *****

Variate: Couch grass

d.f.	s.e.	cv%
24	0.601	**40.8**

Appendix 11: Analysis of variance (*C. benghalensis* Wandering Jew)

Variate: *C. benghalensis* (Wandering Jew)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	83.6667	7.6061	19.56	<.001
Residual	24	9.3333	0.3889		
Total	**35**	93.0000			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**1.051**

***** Stratum standard errors and coefficients of variation *****

Variate: Wandering

d.f.	s.e.	cv%
24	0.624	**24.9**

Appendix 12: Analysis of variance (*R. scabra* Mexican clover)

Variate: *R. scabra* (Mexican clover)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	365.5556	33.2323	132.93	<.001
Residual	24	6.0000	0.2500		
Total	**35**	371.5556			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**0.8426**

***** Stratum standard errors and coefficients of variation *****

Variate: Mexican_

d.f.	s.e.	cv%
24	0.5000	**17.3**

Appendix 13: Analysis of variance (*L. martinicensis* Bobbin weed)

Variate: *L. martinicensis* (Bobbin weed)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	77.6389	7.0581	21.17	<.001
Residual	24	8.0000	0.3333		
Total	**35**	85.6389			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**0.9729**

***** Stratum standard errors and coefficients of variation *****

Variate: Bobin_weed

d.f.	s.e.	cv%
24	0.5774	**32.0**

Appendix 14: Analysis of variance (Pod yield kg/ha)

Variate: Pod_Yld kg/ha

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	25130639.	2284604.	64.80	<.001
Residual	24	846167.	35257.		
Total	**35**	25976807.			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**316.4**

***** Stratum standard errors and coefficients of variation *****

Variate: Pod_Yld

d.f.	s.e.	cv%
24	187.8	**7.0**

Appendix 15: Analysis of variance (Haulm yield kg/ha)

Variate: Haulm_Yield (kg/ha)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	29885607.	2716873.	53.67	<.001
Residual	24	1214967.	50624.		
Total	**35**	31100574.			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**379.2**

***** Stratum standard errors and coefficients of variation *****

Variate: Helm_Yld

d.f.	s.e.	cv%
24	225.0	**7.0**

Appendix 16: Analysis of variance (Kernel yield kg/ha)

Variate: Kernel Yield (kg/ha)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	12544018.	1140365.	77.61	<.001
Residual	24	352659.	14694.		
Total	**35**	12896676.			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**204.3**

***** Stratum standard errors and coefficients of variation *****

Variate: Kernel_Yld

d.f.	s.e.	cv%
24	121.2	**6.4**

Appendix 17: Analysis of variance (Mature Pods / Plant)

Variate: Mature Pods/Plant

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	473.639	43.058	8.03	<.001
Residual	24	128.667	5.361		
Total	**35**	602.306			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**3.902**

***** Stratum standard errors and coefficients of variation *****

Variate: Pods/plant

d.f.	s.e.	cv%
24	2.315	**6.3**

Appendix 18: Analysis of variance (100- Kernel weight g)

Variate: 100-kernel weight (g)

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	14.306	1.301	1.06	0.427
Residual	24	29.333	1.222		
Total	**35**	43.639			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**1.863**

***** Stratum standard errors and coefficients of variation *****

Variate: knl_wgt_

d.f.	s.e.	cv%
24	1.106	**2.9**

Appendix 19: Analysis of variance (Shelling %)

Variate: Shelling %

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Trt	11	14.889	1.354	0.70	0.730
Residual	24	46.667	1.944		
Total	**35**	61.556			

*** Least significant differences of means ***

Table	Trt
rep.	3
d.f.	24
l.s.d.	**2.350**

***** Stratum standard errors and coefficients of variation *****

Variate: Shelling

d.f.	s.e.	cv%
24	1.394	**2.0**