EVALUATION OF HERBICIDES AND FUNGICIDES ON GROUNDNUT (*Arachis hypogaea* L.) QUALITY AND PRODUCTIVITY

BY

STEPHEN ARTHUR

BED. Agriculture (Hons.)
(University of Education, Winneba – Ghana)

NOVEMBER 2016

KWAME NKRUMAH UNIVERSITY OF SCIENCE AND TECHNOLOGY,

SCHOOL OF GRADUATE STUDIES

DEPARTMENT OF CROP AND SOIL SCIENCES

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A Thesis submitted to the Department of Crop and Soil Sciences, Faculty of Agriculture, Kwame Nkrumah University of Science and Technology, Kumasi, in partial fulfillment of the requirements for the degree of

MASTER OF PHILISOPHY

IN

AGRONOMY (Weed Science)

DECLARATION

I hereby declare that this submission is my own research work towards the Master of Philosophy (MPhil) and that to the best of my knowledge, it contains no material previously published by another person which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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ABSTRACT

To determine the contribution of the interactive effect of weed control methods and fungicides application on groundnut growth, yield and quality, two experiments were conducted in the major and minor seasons of 2015 at the Council for Scientific and Industrial Research – Crops Research Institute (CSIR-CRI), Kwadaso station. Experiments were factorial laid in RCBD with four replications and variety Yenyawso was planted. Weed control treatments in the major season were: 3X Hand weeding (HW), Butachlor (preemergence), Bentazone @ 3 weeks after planting (WAP), Propaquizafop @ 3 WAP + HW @ 5 WAP, Bentazone + Propaquizafop @ 3 WAP, Butachlor + Bentazone + Propaquizafop @ 5 WAP, and Butachlor + HW @ 5 WAP. Minor season weed control treatments were: Metolachlor (PRE), Imazethapyr (POST) @ 3 WAP, PRE + POST, PRE + HW @ 5 WAP, POST + HW @ 5WAP, PRE + POST + HW @ 5 WAP, 2X HW, and a Non-weeded control. Fungicide treatments were: No Fungicides application or Terbuconazole (4 and 6 WAP) followed by Azoxystrobin (5 and 7 WAP) for both seasons. No fungicides and herbicide interaction ($p>0.05$) were recorded due to the dry weather conditions in 2015, which did not support disease development, apart from the tolerance of the variety planted. Bentazone was effective on *Commelina benghalensis* while Imazethapyr effectively suppressed *Commelina benghalensis* and *Euphorbia heterophylla.* All weed control treatments except preemergence only or the non -weeded effectively ($p<0.05$) reduced weed density and growth; and enhanced peanut growth and yield. Pod yield of 2.1 – 2.2 tons/ha was recorded for 2-3X HW, herbicides - manual weeding integration recorded 1.6 -2.3 tons/ha, and preemergence followed-up with postemergence, 1.7 – 2.1 tons/ha. Preemergence only and non-weeded resulted in yield loss of 43 – 71%. The weight of 100 seed lots were, however, similar ($P>0.05$) regardless of treatments. While preemergence herbicides only or non-weeded treatments had ≤ 55% unfilled pods, ≤ 20% unfilled pods were recorded for other weed control treatments. Aflatoxin levels of fresh and dried seeds were very low (≤ 2.0 ppb). Herbicides – manual weeding integration reduced weed control time requirement by 55 – 70% relative to manual weeding only (64 -67 man-days/hectare/season). Cost of manual weeding was

GH₵790.00 – 1,668.00 depending on farmer practice and herbicide – manual weeding integration reduced manual weeding cost by 26 – 66%.

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DEDICATION

This work is dedicated to Mercy, my wife, and Nana Ama, my daughter; to my parents, Mr. Samuel. B. Arthur and Mrs. Gladys Arthur, and siblings Christie, Ebenezer, Eunice, Dorcas and Tina. It is also dedicated to every member of Kwamo Church of Christ, especially Elder Philip Agyapong and his family. God richly bless you all for the seeds you have sown in my life; I am forever indebted to you.

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LIST OF ABBREVIATIONS

ANOVA	:	Analysis of Variance
CRI	:	Crops Research Institute

CSIR	:	Council for Scientific and Industrial Research
DAP	:	Days After Planting
Fung	:	Fungicide
HW	:	Manual Hand Weeding (Hoeing)
PMIL	:	Peanut and Mycotoxin Innovation Laboratory
POST	:	Postemergence Imazethapyr
ppb	:	Parts Per Billion
PPI	:	Pre Plant Incorporated
PRE	:	Preemergence metolachlor
SARI	:	Savanna Agricultural Research Institute
USDA	:	United States Department of Agriculture
SED	:	Standard Error of Difference
WAP	:	Weeks After Planting
WC	:	Weed Control
WC x Fung	:	Weed control – Fungicide Interaction
WCE	:	Weed Control Efficacy
WRB	:	World Reference Base
+ (PLUS)	:	Followed by

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Groundnut (*Arachis hypogaea* L.) has attained status as a food and cash crop due to its importance in both the domestic and export markets. Being the fourth most important oilseed crop and second most important source of vegetable oil in the world, its products are for both domestic and industrial use (Guchi, 2015; Kombiok *et al*., 2012). Groundnut is cultivated in over 100 countries worldwide (Khidir, 1997). Developing countries cultivate 97% of the global area under cultivation and over 90% of the world's groundnuts are produced in developing countries. The production of groundnut is concentrated in Asia and Sub-Saharan Africa (56% and 40% of the global area and 68% and 26% of the global production, respectively) (El Naim *et al*., 2010; Angelucci and Bazzucchi, 2013).

Groundnut production and area under cultivation in Ghana increased by 69 and 47% respectively between 1999 and 2010 even though production is done mainly by peasants with less than one hectare to four hectares of arable lands (Angelucci and Bazzucchi, 2013; Bolfrey-Arku *et al*,. 2006; Yussif, 2014). Though groundnuts form significant part of Ghanaian diet, production is constrained by poor cultural practices, inadequate pest (including weeds) and disease management practices coupled with improper postharvest handling which often leads to high levels of produce and product contamination. Consequently, aflatoxin levels in most products exceed those defined as safe for human consumption.

Early management of weeds within 3–6 weeks after planting is important in groundnut production because the crop is not able to compete effectively with weeds, particularly before flowering and during pegging (SARI, 2014). Prolonged weedgroundnut interference is a contributing factor to low haulm and pod yield. Early good weed control together with other agronomic practices if followed, promotes vigorous crop growth that can suppress subsequent weed growth (El Naim *et al*., 2010) especially crop cultivars with running growth habit.

Hand weeding (hoeing) is the most widely practiced cultural weed control method for most field crop production because of the assumed prohibitive costs of herbicides, fear of toxic residue coupled with the lack of knowledge on appropriate herbicides and rates for various crops including groundnut production (El Naim *et al*., 2010; Bolfrey-Arku, personal communication). Chikoye *et al*. (2007) reported that 50 – 70% of total labour time of the smallholder farmers is spent on hand weeding; while women provide more than 90% of the weeding labour (Ukekje, 2004). Thus, majority of farm women become so constrained and stressed, not having much time to engage in other socioeconomic activities.

Disease management practices are also rarely carried out during field production and /or post harvest handling, imposing a lot of stress on crop; this paves way for aflatoxin contamination (Guchi, 2015). Hence, developing countries are not able to sell large quantities of groundnuts on the international market because of aflatoxin contamination (FAO, 2002) and more than $750 million is lost due to aflatoxin contamination of groundnuts and other cereals (Coulibaly *et al.*, 2008).

To mitigate these constraints was the inception of the Peanut and Mycotoxin

1.2 Problem statement

Smallholder farmers in sub-Saharan Africa including Ghana realize 70% lower yields than on research fields mostly due to inappropriate and untimely weed and disease management practices as well as labour constraints. About 40% to 70% of agricultural cost of production worldwide is accounted for by labour and weed control alone is reported to constitute about 40% of the total farm labour. Previous surveys indicate that about 96% of groundnut farmers in Ghana rely on manual weed control (hoe- 91% and cutlass - 4%), whereas only 4% use herbicides. It is believed that most farmers in Ghana cultivate small areas principally because of weed control issues, and unavailability and high cost of labour for manual weed control in the production regions. Agricultural productivity consequently has become limited through time consumption, drudgery and increased monetary investments. Aflatoxin contamination of the rather limited yields also occurs and increases at all steps of the groundnut supply chain including production in the field. Hence, a well-timed weed and disease management practices including a comprehensive cost analysis are major key operations needed for yield and quality improvement for a sustainable groundnut industry.

1.3 Justification

It is evidently clear that, effective weed management and disease control regimes which
Innovation Laboratory (PMIL), a collaborative project between the US and

Ghana, aimed at improving groundnut production, storage and processing and as well encourages practices that will reduce aflatoxin contamination. remove weed interference and disease incidence will increase cultivated area and groundnut haulm, pod and kernel yield. Control of noxious weeds which affect pod development and create secondary pathways for pathogens and disease incidence will also improve pod and kernel quality. A combined method approach toward weed and disease management therefore has the potential to increase the efficiency and effectiveness of weed and disease control, reduce time spent on weed management, reduce cost of weed control, reduce th e possible health risks involved in manual weeding (especially hoeing), increase cultivated area and yields, reduce stresses on the crop and hence aflatoxin incidence, and ultimately increase profit of both peasants and large scale farmers.

1.4 Main Objective

The major objective of the study was to assess pest and disease management options for enhanced groundnut productivity to mitigate aflatoxin incidence.

1.5 Specific Objectives

The specific objectives were to:

1. Evaluate the effect of h erbicides and hand weeding on weed incidence and control.
2. Determine the interactive effect of herbicides and fungicides application on groundnut growth, yield, and pod and kernel quality/aflatoxin level.
3. Assess the economics of the weed management strategies.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin and Botany of Groundnut

Groundnut, also known as peanut or groundpea, is well adapted to a range of environments. It originated from South America and was introduced into Africa by the Portuguese after they had had contact with Brazil in the 1500s (Boriss and Kreith, 2013). It is an annual herbaceous plant which grows to about 30 to 50 cm high with its leaves being opposite and pinnate with four leaflets, two opposite pairs without terminal leaflet. It bears yellow-petaled, orange-veined pea-like self-pollinating flowers in axillary clusters above ground. Flowers wither after pollination and the stalk at the base of the ovary (pedicel) elongates rapidly and turns downward and pushes the ovary underground where the mature fruit (groundnut pod) develops. The pods have wrinkled shells that are tapered between pairs of the one to four seeds per pod depending on the type (Grichar *et al*., 2013).

2.2 Types of Groundnut

Based on morphological and physiological characteristics, cultivated groundnuts species *Arachis hypogaea* L. is subdivided into ssp. *hypogaea* and spp. *fastigiata* Waldron. The subspecies *hypogaea* is further put into two botanical varieties, var. hypogaea (Virginia botanical type) and var. *hirsuta* (Runner botanical type) whereas the subspecies *fastigiata* Waldron, var. *fastigiata* (Valencia botanical type), var. *vulgaris* (Spanish botanical type) *aequatoriana* and *peruviana* (Moretzsohn *et al*., 2004).

2.3 Groundnut Production

2.3.1 World Groundnut Production

worldwide. It is mainly grown in the tropical, subtropical and warm temperate climates (Cuc *et al*., 2008). The crop grows well in light sandy loam soil with an annual rainfall of 380 to 650 mm or its equivalent in irrigation (Grichar *et al*., 2013).

Global groundnut production for the 2014/15 production year stood at 39.42 million metric tons with a total of 23.65 million hectares of area under cultivation and an average yield of 1.67 tons/ha (Table 2.1). China, India, Nigeria and The United States are the world's leading producers with 41.81, 12.43, 7.61 and 5.96% share of world production, respectively (USDA, 2015).

2.3.2 Ghana Production Trends

Ghana occupies the 12th position on the world ranking (2014/15 production year) with an annual production of 0.44 million metric tons (1.12% of world groundnut production), 0.40 million hectares of area under cultivation and an average yield of 1.10 tons/ha (USDA, 2015).

Although groundnuts are grown in all ecological zones of Ghana (Sudan, Guinea and Coastal Savannas, Forest-Savanna, Transitional and Forest Zones), the three Northern Regions (Northern, Upper East and Upper West) are believed to produce between 85

Cultivated groundnut (*Arachis hypogaea* L.) is one of the most important oilseed crops and 94% of national groundnut supplies (Marfo *et al*., 2000; Angelucci and

Bazzucchi,

2013). The Northern Regions fall within the Guinea Savannah agroecological zone

Table 2.1 Global groundnut production 2014/15

Rank	Country	Area (million ha)	Yield (metric tons/ha)	Production (Million metric tons)
	World	23.65	1.67	39.42
1	China	4.60	3.58	16.48
2	India	4.60	1.07	4.90
3	Nigeria	2.50	1.2	3.00
4	USA	0.54	4.40	2.35
5	Burma	0.89	1.55	1.38
6	Argentina	0.34	3.48	1.19
7	Indonesia	0.63	1.83	1.15
8	Sudan	1.25	0.77	0.96
9	Senegal	0.88	0.76	0.67
10	Cameroon	0.47	1.36	0.64
11	Vietnam	0.22	2.20	0.47
12	Ghana	0.40	1.10	0.44
13	Chad	0.50	0.80	0.44
14	Malawi	0.37	1.03	0.38
15	Congo	0.48	0.78	0.37

Source: USDA Foreign Agricultural Service; Table 13 Groundnut Area, Yield, and Production (February 2015)

2.3.3 Current Production Practices in Ghana

Most agronomic practices carried out by farmers in both Northern and Southern Ghana

with a uni-modal rainfall pattern, receiving between 900 and 1,100 mm rainfall per annum. are similar except a few. In Northern Ghana, land preparation on large fields

is done by tractors whereas that of smaller fields is done by bullock plough or hand

hoeing

(Tsigbey *et al*., 2003). Dankyi *et al*. (2005) reported that majority of fields (96%) in southern Ghana are tilled with tractors while a few are animal-ploughed. Bolfrey-Arku *et al*. (2006), however, reported slash and burn, the use of tractors, and tillage with hand implements as the three most used land preparation methods in southern Ghana

(Ashanti, Brong Ahafo, Eastern, and Volta regions).

A little above half (54%) of farmers prefer mixed cropping system (mostly with maize). Seeding is done by hand, usually in a random order and for some farmers, in rows on flatlands, ridges or mounds usually with seeds from farmers' own stock or bought from the local market. Cultivars planted usually mature at 90 or 120 days after planting. Planting is done between January and September depending on the rainfall pattern (Yussif, 2014; Tsigbey *et al*., 2003; Dankyi *et al*., 2005; Bolfrey-Arku *et al.*, 2006).

The crop is produced strictly under rain-fed conditions. Hoeing is by far the predominant weed control method practiced, with only 4% and 9% of farmers in southern and northern Ghana, respectively using herbicides. Farmers weed their fields once, twice or thrice (Bolfrey-Arku *et al.*, 2006; Dzomeku *et al*., 2009). Farmers in the north practice no form of disease control (Tsigbey *et al*., 2003). Majority of farmers in the south do not control disease on their farms; few (13%) remove diseased plants whereas a very few (4%) suppress foliar diseases by spraying synthetic fungicides or local soap (Dankyi *et al*., 2005).

2.4 Weed-Crop Interactions

Weed – Crop interactions occur in a variety of ways: through serving as alternate host for insect pests, nematodes and plant diseases and interfering with crop growth through allelopathy or competition (Patterson, 1995). Competition occurs between two or more plants when the availability of growth resource is not adequate to meet their combined demands (Patterson, 1995; Akobundu, 1987). The basic negative impact of weeds on crops usually occurs through competition for limited environmental plant growth dependent resources like water, light, nutrient, oxygen and carbon dioxide.

Factors that influence competition may include weed species, time of emergence (Weeds that emerge before or with crops are the most competitive), rate of seedling growth and density relative to crop, spatial distribution and life cycle of weed and crop, weed root system, reproductive ability/strategies, photosynthetic ability and morphological features among others (Swanton *et al*., 2015; Patterson, 1995; Akobundu, 1987). Groundnuts, as reported by Jordan (2014) cannot effectively compete with weeds especially in the early phase of development and requires higher weed control levels than most agronomic crops to prevent yield losses.

2.5 Critical periods of weed interference

The critical period for weed control is defined as the stage or phase in the cycle of crop growth during which weeds should be controlled to prevent crop yield losses (Zimdahl, 1988). Gianessi and Williams (2011) stated it as the period after which weed growth does not affect crop yields and estimates it at approximately the first one-third to one-half of the life cycle of the crop. Knowing the critical period for weed control of a specific crop is useful for making decisions on the need for, and timing of, weed control (Knezevic *et al*. 2002), and for the design of sustainable integrated crop-weed management systems (Knezevic and Datta, 2015).

El Naim *et al*. (2010) and SARI (2014) stated the critical period of weed control in groundnuts as between 3 and 6 weeks after planting whereas Everman *et al*. (2007) put it at between approximately 3 and 9 weeks after planting. Results from experiments conducted by Webster *et al*. (2007) revealed a yield loss of 10% for the initial 4 weeks of Bengal dayflower (*Commelina bengalensis*) interference with groundnut and 100% reduction in pod yield for initial 6 weeks of interference in 2004. In 2005, 5% and 51% yield reductions were recorded for the initial 2 weeks and season long interference respectively. Season long interference with wild poinsettia (*Euphorbia heterophylla* L.) was also found to have caused a yield reduction ranging between 75 and 82% (Bridges *et al*., 1992).

2.6 Methods of Weed Control in groundnut

2.6.1 Manual Hand Weeding

Hand weeding, the oldest method of weed control which involves pulling and slashing of weeds by hand and hoeing, remains the predominant method of weed control on smallholder farms in sub-Saharan Africa (Gianessi and Williams, 2011). One to three weeding may be done in groundnut fields depending on the season, days to maturity and weed situation. It is, however, advisable not to weed by hoeing but hand-pulling once pegging begins. Hoeing breaks and loosens the soil particles to facilitate pegging, pod development and improving aeration. In an experiment to determine the best weeding frequency in groundnut, two hand-weeding at 15 and 30 days after planting was most effective at controlling weeds and improving growth characteristics of groundnuts (El Naim *et al*., 2010; Bhale *et al*., 2012).

2.6.2 Chemical weed control

Herbicides are alternatives to manual weed control (hand weeding) and may be classified based on the time of application. They can be pre-plant incorporated (PPI) into soil, applied preemergence (PRE) to the soil at planting or a few days after planting before crops or weeds emerge, applied postemergence (post-E) after emergence of crops/weeds, or pre-plant (PP) either to existing vegetation or to the soil before crops are planted. Small scale farmers in sub-Saharan Africa have a very low (5%) adoption rate for herbicides use especially when there are crops on the field relative to large scale plantation farms (Gianessi and Williams, 2011). The low use is attributable to inadequate information on appropriate herbicides as well as availability which includes price and access.

Several combinations of periodic application of herbicides are used because herbicides applied pre-plant incorporated or preemergence rarely provides seasonlong weed control (Jordan *et al*., 2003). Some preemergence herbicides labeled for groundnut production include Pendimethalin, Metolachlor, Butachlor, Norflurazone, Diclosulam, Flumioxazin, and Dimethenamid, and postemergence, Imazethapyr, Imazapic, Quzalofop ethyl, Acifluorfen, Bentazone, and Paraquat among others (Grey *et al*., 2002; Jordan *et al*., 2003; Jhala *et al*., 2005; Bhale *et al*., 2012, Jordan, 2014;). Most of these products are listed on the Environmental Protection Authority (EPA) certified list of pesticides for 2014. The risks of development of weeds and/or environmental pollution are issues that are often raised against herbicide application.

However, research abounds on the rotation of herbicides with different mode of action to prevent weed-herbicide resistance build up.

2.6.3 Hand weeding and herbicide integration

Due to the myriad weed species, most weed control research reports recommend the combination of herbicide treatments with manual weeding for sustainable production.

While the use of preemergence herbicides delay weed incidence, and prevent cropweed competition in the early stages of the crop, manual weeding loosens the soil particles and facilitates pegging and pod development resulting in better yields. Research done by Jhala *et al*. (2005), Bhale *et al*. (2012) and Gunri *et al*. (2014) have shown that an integrated weed management practice of herbicides and manual weeding were effective at weed control, supported groundnut growth and increased yield.

2.7 Diseases of Groundnuts

Groundnuts are affected by a range of diseases. In Ghana, the major diseases of concern are early and late leaf spots, groundnut rosette, rust, root rot and southern stem rot. Leaf blotch and lesion nematode infection are also present but of minor concerns (Tsigbey *et al*., 2003).

Early Leaf spots is caused by *Cercospora arachidicola* Hori and late leaf spots by *Cercosporidium personatum* Berk. and Curt. These two fungi do no only attack groundnut leaves but stem, petioles and pods may be affected as well, causing pod loss of up to 78% (Twumasi, 2014; Tsigbey *et al*., 2003).
The causal agent of rust is *Puccinia arachidis* Spegazzini and can cause yield loss of up to 50%. Rust together with leaf spots can cause yield loss of 70% or more (Twumasi, 2014).

Groundnut rosette is a 3 viral component complex of groundnut rosette virus genus *Umbravirus*, groundnut rosette assistor virus and a satellite RNA, which depends on groundnut rosette virus for replication, transmitted mainly by aphids, *Aphis craccivora.*

Yield loss of up to 100% may result from rosette infection (Lamptey and Anno-Nyako, 2014).

Close to 100% yield losses may be caused by foliar diseases particularly in the wet seasons and farmers abandon ha rvesting groundnuts. Most farmers in Ghana link defoliation to groundnut maturity and have no knowledge of the fact that defoliation is caused by foliar diseases (Tsigbey *et al*., 2003).

2.8 Disease Control in Groundnuts

Groundnut cultivars vary in their strength at resisting major groundnut diseases ranging from highly susceptible to moderately resistant. Avoiding susceptible cultivars is the first step towards disease management but because no groundnut cultivar is fully immune to diseases, some other measures are necessary for disease management/control. Good cultural practices and rotation are some of the effective means of avoiding diseases in the field (Shaw, 2014).

For rosette management, maintaining optimal plant densities for adequate ground cover to lessen aphid attack, since they are attracted by the brown uncovered soil spaces, is also necessary. In Ghana, the use of local soaps (*Alata samina* 1 g or *Amonkye* 2 g/l of water) is helpful in controlling the vectors (Lamptey and Anno-Nyako, 2014).

In controlling foliar diseases a combination of rotation, crop residue burial and the application of fungicides have been used. It is, however, important that crops attacked by similar diseases with groundnut (e.g. soybean) are not added in rotations (Shaw, 2014). A multiple application of fungicide is necessary because rotation and burial does not totally remove inoculum (Monfort *et al*., 2004). Fungicides are limited in curative activities and must be applied shortly before or after infection (Shaw, 2014).

Many fungicides are available for the management of foliar and soilborne diseases. Usually, multiple applications every 14 days starting from 30 days after planting (DAP) are necessary to reduce losses caused by diseases (Woodward *et al*., 2013). Fungicides currently used for disease control in groundnuts include Chlorothalonil, a broad-spectrum fungicide for leaf spot management which has been in use since the 1970s; tebuconazole and azoxystrobin also broad spectrum and effective on foliar and soilborne diseases/fungus. Triazoles, carboximides and strobilurins are other options available to groundnut farmers (Woodward *et al*., 2013).

Results from several research have proven that the application of fungicides have the potential of controlling fungal diseases and improving groundnut yields up to 50% (Adomou *et al*., 2005). Results from work done by Tsigbey *et al*. (2003) indicated that the application of tebuconazole resulted in a disease severity score of 2.3 on the Florida scale, a pod yield of 1,700kg/ha and haulm yield of 9,900kg/ha as compared to a disease score of 9.5, pod yield of 700kg/ha and haulm yield of 4,000kg/ha when no fungicides were applied.

2.9 Aflatoxins

Aflatoxins are a group of structurally related toxic polyketide-derived secondary metabolites (mycotoxins) produced by certain strains of *Aspergillus flavus* and *Aspergillus parasiticus* (Waliyar *et al.*, 2006). They contaminate numerous agricultural produce including maize, groundnuts, rice, soybeans, wheat, sunflower, cottonseeds and coffee (Guchi, 2015). It has been found to be associated with many health risks in both humans and animals including suppression of immunity, aflatoxicoses, carcinogenicity, jaundice in neonates and retarded growth (Bankole *et al*., 2006).

There are four main types of aflatoxins: B_1, B_2, G_1 and G_2, but B_1 is the most predominant and potent in groundnut. Owing to the health risk of aflatoxin, nations have set acceptable levels that can be consumed by humans and animals. Whereas the US and Ghana accept 20 parts per billion (ppb), Portugal allows up to 25ppb, France and Denmark allow 1ppb of B_1 and EU, 15ppb (8ppb for B_1) in groundnuts intended for further processing, and 4ppb (2ppb for B_1) in groundnuts for direct consumption (Otsuki *et al*., 2001; Masters *et al*., 2013).

Fungal growth is supported in many parts of sub Saharan Africa due to the high ambient temperatures and relative humidity in the region and this predisposes crops in the region to mycotoxin contamination than in the temperate regions (Bankole *et al*., 2006). It results in substantial economic losses in the agricultural sector worldwide. In Africa, losses of over US$750,000,000 are incurred annually due to aflatoxin contamination of groundnuts and cereal crops (Cardwell *et al*., 2004). Aflatoxin contamination of groundnuts is affected by many factors and because the fungus spores are found both in the air and soil, contamination may occur before, during and/or after harvesting (Guchi, 2015).

Factors that may influence *Aspergillus flavus and A. parasiticus* attack of groundnuts before harvesting include cultivar, fungi species, drought stress, high soil temperatures, insect damage, agricultural practices, phytoalexin production, and plant stress due to weed competition (Diao *et al*., 2015) as well as their interactions. Groundnut plants synthesize antimicrobial substances called phytoalexin when challenged by fungi including *Aspergillus flavus*. So far as the groundnut plant has the capacity of producing phytoalexin, aflatoxin contamination does not occur (Diao *et al*., 2015). According to Dorner *et al*. (1989), phytoalexin production ceases when the groundnut plant is under drought stress. Cole *et al*. (1995) reported that aflatoxin contamination is predominant when groundnuts are subjected to a prolonged period (30 – 50 days) of drought stress and at high temperatures (29 $^{\circ}$C - 31°C) during pod maturation. Damages caused by insects create entry points for fungus and subsequently high aflatoxin levels (Waliyer *et al*., 2008). The use of cultivars that are resistant to stress may help reduce aflatoxin incidence on the field.

Aflatoxin contamination of groundnuts may occur if pods are harvested when they are over matured or not matured. Weather conditions and mechanical damage of pods and seeds during harvesting may influence aflatoxin levels (Diao *et al*., 2015).

Drying ground nut to moisture content of less than 10%, sorting of contaminated pod/seeds, grading and removal of debris from pods/seeds before storage may insure groundnuts from aflatoxin contamination during storage (Dorner, 2008; Cole *et al*. 1995).

2.10 Effect of weeds on pod quality

Apart from yield losses, weeds also cause quality losses of agricultural produce and limit their potential of being used for various foods or feed. According to Frick (2002), weeds affect the quality of agricultural commodities by causing losses in kernel, or pod size and weight, discolouration of kernels, and creation of entry points for pathogenic attack. For instance, the rhizomes of spear grass (*Imperata cylindrica*) have the ability to pierce or penetrate underground pods creating entry points for pathogens and insect pest invasion. Tubers of sedges are also known to contaminate groundnuts and reduce its pod or kernel purity/quality (Johnson and Mullinix, 2003).

2.11 Economics of Weed Control

More than 50% of farm labour and 50 – 70% of the entire labour time of smallholder farmers are spent on weed control because manual weeding is the most practiced weed control method used by these farmers (Labrada, 1997; Chikoye *et al.*, 2007). According to Ishaya *et al*. (2007), 309 and 324 hours of hand weeding were required per hectare of maize and sorghum respectively in northern Nigeria. The supply of labour for agriculture has significantly reduced due to migration to urban communities, thus increasing the cost of labour. The cost of manual weed control also increases with the density of weeds and increases at an increasing rate when it competes with other activities on the farm (Auld and Menz, 1997). Unfavourable environmental conditions, unavailability and increased cost of labour and time consumption reduce the effectiveness of relying on manual weeding during peak periods of weeding. The need for an economically viable alternative is the concern for most weed scientists and farmers and the use of herbicides or their combination with manual weeding is considered among other options (Singh, *et al*., 2013; Gianessi and Williams, 2011).

The use of herbicides in groundnut production can save up to three weeks of time which would allow farmers to engage in other activities or increase the area under cultivation substantially (Schilling, 2003). In an experiment conducted by Moyo *et al*. (2013) in Malawi, 32.6 - 48 man-days were needed to manually control weeds in one hectare of cassava field costing an equivalent of 70.40 to 103.70US dollars. The use of herbicides only, required 0.9 – 1.3 man-days and reduced weed control cost by 53 – 77% whereas herbicides in combination with manual weeding required 7.8 to 27 mandays. In a research conducted in Vietnam by Tan *et al*. (1997), manual weeding on a hectare of rice field cost US$105 to US$130 whereas the use of herbicides cost US$45 to US$60. In an experiment done in Zimbabwe, there was a reduction from an estimated 107 hours per hectare of manual weeding to 0.4 hours per hectare when herbicides were used (Benson, 1982). Also, in Nigeria, cost of weed control was reduced by 50% and yield increased by 55% on cassava, soybean and yam when herbicides were used (Chikoye *et al.*, 2007).

CHAPTER THREE

3.0 Materials and Methods

3.1 Experimental Site

The experiment was conducted at the Council for Scientific and Industrial Research – Crops Research Institute (CSIR-CRI), Kwadaso Station, in both major and minor seasons of 2015. The site falls within latitude 06°40'42.172" North and 001°40'34.889" West in the forest agro-ecological zone and has a bimodal rainfall pattern. The soil type according to Sadick *et al.* (2015) is Cutanic Lixisol on the World Reference Base (IUSS, 2006). Total rainfall observed during the experimental periods was 252.8mm and 151.3mm respectively for major and minor seasons.

3.2 Experimental design and treatments

The major season experiment was 7 x 2 factorial while that of the minor season was 8 x 2 factorial; all were arranged in a Randomized Complete Block Design (Table 3.1). Each plot measured 4m x 3m with a 1m alley separating plots within a replicate and a 2m alley between replications. Yenyawso, an early maturing improved variety obtained from CRI, Fumesua was planted 1 seed per hill at a spacing of 0.5m x 0.2m. Herbicides and fungicides were applied using Matabi Knapsack sprayers calibrated to dispense 200 liters of water per hectare. Preemergence herbicides were applied on moist soil 1 and 2 DAP for major and minor seasons respectively.

2 X

Table 3.1: Treatment List for major and minor seasons

Major season		Minor season	
Treatment	**Rate**	**Treatment**	**Rate**
Weed control		***Weed control***	
Hand weeding (HW) @ 3, 6 and 9 WAP	3 X	Hand weeding (HW) 3 and 6 WAP	
	2.5 l/ha	Metolachlor (PRE)	
	2.5 l/ha	Imazethepyr (POST) @ 3 WAP	
	1.2 l/ha	Metolachlor + Imazethepyr (PRE + POST) @ 3 WAP	
Bentazone & Propaquizafop @ 3 WAP		Metolachlor + HW (PRE + HW) @ 4-5WAP	
Butachlor + Bentazone & Propaquizafop 4-5WAP		Imazethepyr + HW (POST + HW) @ 5 WAP	
Butachlor + Hand weeding @ 4-5WAP		Metolachlor + Imazethepyr + HW (PRE + POST+ HW)	
Adjacent field (Control)		Non-weeded control	
Fungicide		***Fungicide***	
No Fungicides		No Fungicides	
Tebuconazole (4 and 6 WAP) fb	0.23 l/ha	Tebuconazole (4 and 6 WAP) fb	0.23 l/ha
Azoxystrobin (5 and 7 WAP)	0.75 l/ha	Azoxystrobin (5 and 7 WAP)	0.75/ha

Butachlor (PRE1)	1.5 l/ha
Bentazone (POST1) @ 3 WAP	0.36 l/ha
Propaquizafop (POST2) @ 3 WAP + HW 5 WAP	

3.3 Data collected

3.3.1 Weed Count/Assessment

Weed assessments were on weed species and types (individual weed species, broadleaves, grasses and sedges) prior to land preparation and at 2, 4, 6, and 8 WAP. A quadrat measuring 0.45m x 0.45m was thrown randomly for ten times along the two diagonals of the field for assessments before land preparation while a 0.3m x 0.5m quadrat was thrown thrice randomly within the 3 central rows of each plot during assessments after planting. Averages were calculated and extrapolated to $1m^2$.

For major season, weeds on the adjacent field were used as control.

3.3.2 Weed Biomass

Weed biomass was measured following weed assessment by harvesting the above ground part of weeds in the three quadrat throws per plot. Samples were air dried for 3 days and then dried in a Thelco laboratory oven to a constant weight at 80^0C. The dried weeds were weighed on an electronic balance; averages were calculated and extrapolated to $1m^2$. Data from weed biomass were used to calculate Weed Control Efficacy (WCE) as "$\frac{Wbc - Wbt}{Wbc} * 100$". Where Wbc is the weed biomass of the untreated (g/m^2) and Wbt is the weed biomass of the treated plot (g/m^2). For major season, weeds on the adjacent field were used as control.

3.3.3 Crop Establishment and Phytotoxicity.

Plant population and the number of injured plants for both herbicides (phytotoxicity) and manual weeding treatments were assessed within the 3 central rows of each plot.

Percentage crop establishment was calculated as $\frac{PPc}{PPe} * 100$ where PPc is total plant population counted and PPe is total plant population expected. Percentage injury was also calculated as $\frac{number\ of\ injured\ plants}{total\ number\ of\ plants\ counted} * 100$.

3.3.4 Crop Height and Canopy

Ten randomly selected groundnut plants within the 3 central rows (3rd, 4th and 5th rows) of each plot were tagged. Height of each tagged plant was measured from the base to the tip of the apical meristem of the main axis using a meter rule. Canopy was taken by horizontally measuring the distance from one end to the other of the lateral branches (canopy) of each tagged plant with a meter rule.

3.3.5 Number of pegs

Number of pegs was estimated by harvesting 4 plants within the central rows (2nd and 6th rows) at 7WAP. The number of pegs for each plant was counted after which averages were calculated for each plot.

3.3.6 Haulm weight

The above ground vegetative part of the 4 plants harvested for pegs count and that of the 10 tagged plants within the 3 central rows were used to estimate haulm weight at 7 WAP and at harvest respectively. The haulms were dried in a Thelco laboratory oven for 120 hours to a constant weight at 80 ^{0}C. Haulms were weighed on an electronic balance and averages were then calculated per plant.

3.3.7 Disease Assessment

Disease severity assessment was done visually on a scale of 1 – 5 (Olorunju *et al*., 2001) where 1 indicates a healthy plant, 2 = minimum infection (1-20% of crop leaf infected), 3 = medium infection (21-50%), 4 = highly infected (51-70%) and 5 = severe infection (above 70% infection or total def oliation). Disease incidence was scored as percentage of groundnut plants infected within the 3 central rows.

3.3.8 Pod and Seed Yield

Dry pod and seed yield from the 3 central rows were weighed on an electronic balance in grams and converted to kilograms per hectare.

3.3.9 Aflatoxin Analysis

Aflatoxin analysis was done using Rveal Q+ for Aflatoxin procedure (Neogen Corporation, 2014).

3.3.10 Time required for weed control

Time required for weed control was estimated by measuring the amount of time used for the application of every weed control treatment per plot using a stop watch. Workers were not made aware of the recording of time. Timing was done in seconds/plot, converted to hours/ha and then to man-days/ha (man – day = 6 hours).

3.3.11 Cost of weed control estimation

The cost of weed control was estimated based on the following cost items: Butachlor = GH₵19 / l, Bentazone = GH₵ 25/l, Propaquizafop = GH₵ 21/ 0.25l, Metolachlor =

GH₵ 25/l, Imazethapyr = GH₵ 21/ 0.25l. Cost of water (including labour for fetching) / ha = GH₵ 5, knapsack hiring = GH₵ 5/day; two different costing procedures based on current farmer practices were used to estimate labour for herbicide application (spraying), (1) GH₵ 10/bottle (maximum 1 liter) and (2) GH₵ 20 /acre (area). For estimation of cost of manual weeding, two different costing procedures based on current farmer practices were used, (1) Hiring labour on man -day basis in which case 1 m an-day cost GH₵ 15 to GH₵ 30 depending on weed density, growth stage and/or location (cost 1); the most predominantly charged fee of GH₵25 was however used for estimation. (2). Acreage contract basis, where labourers are paid a minimum of GH₵160/ acre (cost 2).

3.4 Data analysis

Data was analyzed with Statistix 9 Analytical Computer Software Package (2008). ANOVA was generated and treatment means separated by standard error of means (SED) at 5% level of probability. Correlation analysis was also done. Count data were transformed by square root transformation and score data by arcsine transformation for analysis but original data are presented in results.

CHAPTER FOUR

4.0 RESULTS

4.1 Effect of Weed Control Methods on Weed Incidence and Control

4.1.1 Major season weed composition before land preparation

Initial weed population was dominated by grasses (46.2%) followed by broadleaves (33.7%) while sedges were the minority (Table 4.1). Predominant grass species included: *Brachiaria deflexa, Digitaria ciliaris and Panicum maximum* while *Ageratum conyzoides, Euphorbia heterophylla, Commelina benghalensis, Synedrella nodiflora, Talinum triangulare and Mimosa spp* dominated the broadleaves weeds.

Cyperus rotundus was the only sedge before land preparation.

4.1.2 Major season weed composition after field establishment

After land preparation, *Brachiaria deflexa, Digitaria ciliaris, Panicum maximum and Rottboellia cochinchinensis* were the predominant grasses that re-infested the field (Table 4.2). *Ageratum conyzoides, Boerhavia diffusa, Commelina benghalensis, Celosia trigyna, Euphorbia heterophylla, Mollugo nudicaulis, Mimosa spp, Ipomea spp, Synedrella nodiflora,* and *Phyllanthus amarus* were the predominant broadleaves weed. *Cyperus rotundus* was the only sedge weed species that re-infested the fields.

4.1.3 Effect of major season weed control methods on weed density

Preemergence application of butachlor significantly ($P<0.05$) reduced total weed density by 45.5 - 77.7% at 2 weeks after planting (WAP) and 36.1 – 72.4% at 3 WAP compared to the other treatments (Plate 3.0, Table 4.3). It effectively reduced density of *Ageratum conyzoides, Celosia trigyna, Commelina benghalensis, Synedrella nodiflora*, and *Phyllanthus amarus* (Table 4.2) but was not effective on the grasses.

At 5 WAP, manual hand weeding (HW) or bentazone + propaquizafop treatments significantly ($P<0.05$) reduced total weed density compared to butachlor only and the control. Postemergence application of bentazone effectively reduced broadleaves (100%) and general weed density (69%) relative to propaquizafop. On the other hand, propaquizafop totally controlled all grasses in plots where it was applied (Table 4.3). Bentazone completely controlled *Ageratum conyzoides*, *Commelina benghalensis, Ipomea spp, Synedrella nodiflora* and *Tridax procumbens;* and reduced density of *Mollugo nudicaulis*, *Mimosa spp* by a little above 50% compared with the control. All the treatments significantly reduced weed density at 10 WAP compared to the control. However, the densities of grasses on the HW, propaquizafop + HW, or butachlor + HW plots were exceedingly lower (93 – 100%) than bentazone (Table 4.3). Also, density of broadleaves weeds on propaquizafop + bentazone treated plots was high (52 – 92%) compared to HW, propaquizafop + HW, butachlor + HW, butachlor + propaquizafop + bentazone, or bentazone treatments.

4.1.4 Effect of major season weed control methods on weed growth (dry biomass).

Weed growth was substantially reduced by butachlor (72%) compared to the other treatments (had not been applied by then) at 3 WAP (Table 4.3). At 5 WAP, bentazone reduced weed growth by 67% compared to the control, 43% compared with propaquizafop and 35% compared with butachlor only, while propaquizafop reduced weed growth by 42% relative to the control. However, the application of bentazone + propaquizafop effectively reduced weed growth (100%) compared to their individual effects (Table 4.3). By 10 WAP, all weed control methods reduced weed growth/biomass compared to the control. However, butachlor + HW (99.5%), propaquizafop + HW (87%) or HW (99%) treatments significantly ($P<0.05$) reduced weed growth than herbicides only (18 - 60%) treatments (Figure 4.1).

Table 4.1 Weed density and species composition before land preparation.

MAJOR SEASON				MINOR SEASON			
WEEDS	**NUMBER /m^2**	**PERCENTAGE**		**WEEDS**	**NUMBER /m2**	**PERCENTAGE**	
GRASSES		***GENERAL***	***TYPE***	***GRASSES***		***GENERAL***	***TYPE***
Brachiaria deflexa	189	20.3	44.0	*Digitaria ciliaris*	36	10.7	29.1
Digitaria ciliaris	127	13.6	29.5	*Sorghum halepense*	78	23.2	63.6
Panicum maximum	31	3.4	7.3	*Rottboellia cochinchinensis*	9	2.7	7.3
Other grasses	82	8.9	19.2				
Total grasses	**429**	**46.2**	**100.0**	**Total grasses**	**123**	**36.6**	**100.0**
BROADLEAVES				***BROADLEAVES***			
Ageratum conyzoides	62	6.7	19.9	*Ageratum conyzoides*	22	6.5	10.9
Commelina benghalensis	22	2.4	7.0	*Celosia trigyna*	16	4.8	7.6
Euphorbia heterophylla	93	10.0	29.8	*Commelina benghalensis*	22	6.5	10.9
Mimosa spp	13	1.4	4.3	*Euphorbia heterophylla*	49	14.6	23.9
Syndrella nodiflora	71	7.7	22.7	*Euphorbia hirta*	9	2.7	44.3
Talinum triangulare	16	1.7	5.0	*Ipomoea spp*	4	1.2	2.2
Other broadleaves	36	3.8	11.3	*Phyllanthus amarus*	4	1.2	2.2
				Syndrella nodiflora	11	3.3	5.4
				Talinum triangulare	67	19.9	32.6
Total broadleaves	**313**	**33.7**	**100.0**	**Total broadleaves**	**204**	**60.7**	**100.0**
SEDGES				**SEDGES**			
Cyperus rotundus	187	20.1	100	*Cyperus rotundus*	9	2.7	100.0
Total sedges	**187**	**20.1**	**100**	**Total sedges**	**9**	**2.7**	**100.0**

17 3 13 2

TOTAL	**929**	**100.0**	**TOTAL**	**336**	**100.0**

Table 4.2 Density of dominant weed species during major season

	Grasses (m^{-2})			**Broadleaves** (m^{-2})										
Treatment	***Brachiaria deflexa***	***Panicum maximum***	***Rottboellia cochinchinensis***	***Ageratum conyzoides***	***Boerhavia diffusa***	***Celosia trigyna***	***Commelina benghalensis***	***Euphorbia heterophylla***	***Ipomoea indicia***	***Mimosa spp***	***Mollugo nudicaulis***	***Phyllanthus amarus***	***Synedrella nodiflora***	***Tridax procumbens***
							2WAP							
Hand weeding (HW)	0	1	5	1	5	24	19	1	2	6	13	1	11	0
Propaquizafop + Bentazone	1	3	4	1	1	36	19	0	4	12	53	1	6	0
Butachlor (But)	0	3	1	0	5	2	2	0	1	12	24	0	2	0
Bentazone (Bent)	1	3	8	1	5	7	16	2	9	9	16	1	8	0
Propaquizafop +HW	0	4	2	11	1	21	14	1	2	4	20	3	13	0
But + HW	0	0	4	0	3	9	4	1	2	5	11	0	4	0
But + Propaquizafop + Bent	1	1	4	0	2	2	5	1	1	5	8	0	5	0
SED (P=5%)	**1**	**1.4**	**3.6**	**3.1**	**3.5**	**7.8**	**5.0**	**1.2**	**4.2**	**4.9**	**12.9**	**1.1**	**3.9**	**0**
							3WAP							
Hand weeding (HW)	5	1	6	8	5	41	21	1	2	8				
Propaquizafop + Bentazone	6	1	1	10	5	53	19	1	1	15				
Butachlor (But)	0	0	1	1	5	4	4	0	0	12				
Bentazone (Bent)	16	3	5	7	6	35	23	1	1	9				
Propaquizafop +HW	3	1	1	27	4	46	13	0	0	4				

38	2	8	2
22	0	5	0
12	4	5	3
37	11	10	0

But + HW	4	1	7	1	5	21	7	1	3	6	27	0	5	1
But + Propaquizafop + Bent	0	1	1	2	4	11	4	2	3	6	9	0	4	0
SED (P=5%)	**5.4**	**0.9**	**3.4**	**8.0**	**4.0**	**12.0**	**4.8**	**0.9**	**1**	**5.7**	**14.7**	**4.5**	**3.4**	**1.0**

Table 4.3 Effect of weed control methods on major season weed densities and growth (dry weed biomass).

	***2 Weeks After Planting (WAP)/* m²**				***3 Weeks After Planting (WAP)/* m²**				***Weed Biomass (g/m²)***	
Treatment	**Grasses**	**Broadleaves**	**Sedges**	**Total**	**Grasses**	**Broadleaves**	**Sedges**	**Total**	**3 WAP**	**5 WAP**
Hand weeding (HW)	12.0	85.0	4.0	101.0	21.0	127.0	8.0	156.0	54.7	0.0
Propaquizafop + Bentazone	17.0	142.0	16.0	175.0	12.0	170.0	11.0	193.0	47.8	0.0
Butachlor (But)	4.0	51.0	0.0	55.0	3.0	56.0	0.0	59.0	10.4	39.7
Bentazone (Bent)	18.0	80.0	6.0	104.0	25.0	114.0	5.0	144.0	40.1	25.9
Propaquizafop +HW	7.0	120.0	11.0	138.0	9.0	177.0	13.0	199.0	32.6	45.8
But + HW	5.0	42.0	2.0	49.0	14.0	77.0	1.0	92.0	17.0	55.6
But + Propaquizafop + Bent	7.0	32.0	0.0	39.0	6.0	49.0	0.0	55.0	10.1	37.0
Control	-	-	-	-	-	-	-	-	-	78.9
SED (P=5%)	**5.6**	**19.7**	**4.0**	**22.1**	**7.4**	**30**	**3.2**	**29.1**	**7.9**	**8.9**

	***5 Weeks After Planting (WAP)/*m²**				***10 Weeks After Planting (WAP)/*m²**				***Weed Biomass (g/m²)***	
Treatment	**Grasses**	**Broadleaves**	**Sedges**	**Total**	**Grasses**	**Broadleaves**	**Sedges**	**Total**	**7 WAP**	**10 WAP**
Hand weeding (HW)	0.0	0.0	0.0	0.0	0.0	5.0	0.0	5.0	15.3	0.9
Propaquizafop + Bentazone	0.0	2.0	0.0	2.0	2.0	63.0	0.0	65.0	55.3	50.9
Butachlor (But)	5.0	53.0	0.0	58.0	4.0	41.0	0.0	45.0	69.7	100.3
Bentazone (Bas)	37.0	0.0	0.0	37.0	15	30.0	0.0	45.0	44.8	78.8
Propaquizafop +HW	0.0	119.0	2.0	121.0	1.0	19.0	1.0	21.0	0.0	15.8
But + HW	15.0	69.0	1.0	85.0	0.0	13.0	0.0	13.0	11.5	0.6

But + Propaquizafop + Bas	9.0	56.0	0.0	64.0	4.0	28.0	0.0	32.0	32.6	48.3
Control	57.0	132.0	5.0	194.0	63.0	143.0	3.0	209	102.3	123.2
SED (P=5%)	**5.5**	**14.0**	**0.8**	**15.0**	**4.2**	**9.8**	**0.7**	**11.9**	**12.4**	**18.1**

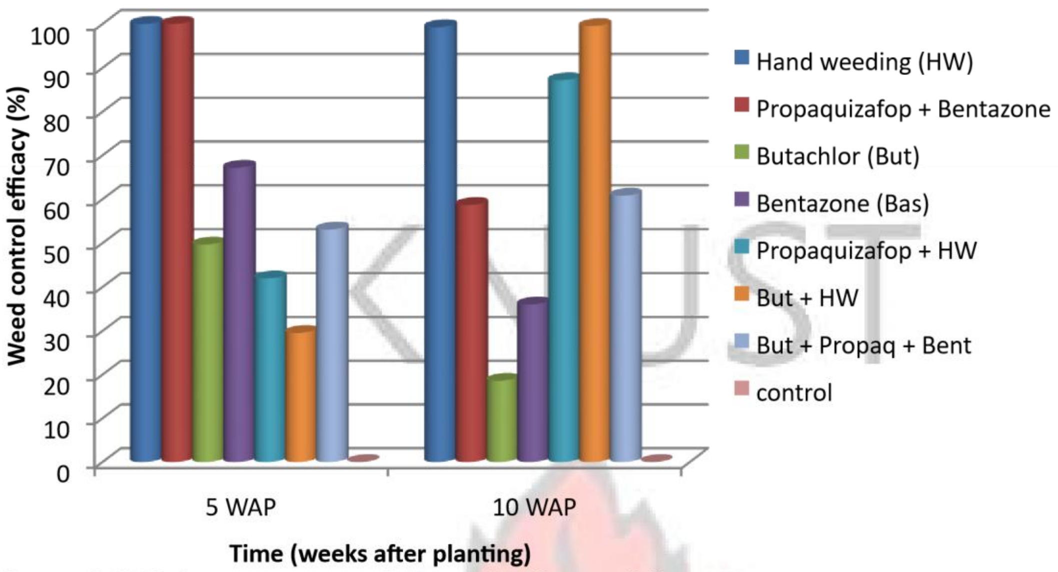

Figure 4.1 Major season weed control efficacy (%)

Plate 1. *Weed density of Butachlor (left) and no preemergence (right) treated plots at 3WAP*

Plate 2. *Weed density of Butachlor + HW (left) and Butachlor + Propaquizafop + Basagran (right) at 7 WAP*

4.1.5 Minor season weed composition before land preparation

Broadleaves constituted 60.7% of weeds, grasses 36.4%, then sedges, 2.6% (Table 4.1). Dominant grass species were *Digitaria ciliaris, Sorghum halepense* and *Rottboellia cochinchinensis.* Broadleaves were dominated by *Talinum triangulare, Euphorbia heterophylla, Ageratum conyzoides, Commelina benghalensis, Celosia trigyna, Synedrella nodiflora, Euphorbia hirta, Phyllanthus amarus* and *Ipomea spp. Cyperus rotundus* was the only sedge.

4.1.6 Minor season Weed composition after field establishment

Brachiaria deflexa, Digitaria ciliaris, Rottboellia cochinchinensis and Sorghum halepense were the predominant grasses that re-infested the field after field establishment (Table 4.4). *Commelina benghalensis, Euphorbia heterophylla, Euphorbia hirta, Synedrella nodiflora, Phyllanthus amarus, Talinum triangulare,* and *Tridax procumbens* were the predominant broadleaves weed while *Cyperus rotundus* was the only sedge weed.

4.1.7 Effect of minor season weed control methods on weed density

Metolachlor applied preemergence effectively ($P<0.05$) reduced grass density by 82.6 – 98.6% and broadleaves by 8.7 to 42.6% at 3 WAP compared to plots that did not receive preemergence treatment (Table 4.5). It reduced total weed density by 23.8 – 54.8% at 3 WAP compared to plots that did not receive preemergence treatment; and 29.3% and up to 34.6% at 5 WAP compared to imazethapyr or non-weeded respectively. At 5 WAP, metolachlor reduced grass density by 85.3% and 96.3% compared to nonweeded and HW treatments respectively, while reducing broadleaves density by 21.9% compared to non-weeded control. Metolachlor was effective (90-100%) on grass species such as *Brachiaria deflexa*, *Digitaria ciliaris and Sorghum halepense* (Table 4.4). It controlled (70-88%) *Synedrella nodiflora*, *Talinum triangulare* and *Tridax procumbens* and reduced (about 50%) densities of *Commelina benghalensis and Phyllanthus amarus.* Metolachlor was however, not effective on *Euphorbia heterophylla* (Table 4.4) which accounted for 80 - 90% and 84% of broadleaves and total weed density respectively of metolachlor treated plots and 50 - 59% and 42% of broadleaves and total weed density respectively of plots that did not receive preemergence treatment at 3 WAP.

At 6 WAP, PRE + HW treatment reduced weed density by 87.8% and HW treatment by 30.9% as against the non-weeded control. Imazethapyr (POST) reduced weed density by 34.4% relative to the non-weeded control; but was not as effective as the 89.4% weed density reduction achieved when applied as follow up to metolachlor. While the sole application of imazethapyr (3 WAP) reduced broadleaves density by 30.2%, grasses by 35.2% and general weed density by 32.2% between 3 WAP and 6 WAP, PRE + POST application reduced broadleaves density by 84.4%, grasses by 33.3% and general weed density by 83.9 for the same period (Table 4.5). Imazethapyr was effective on *Euphorbia heterophylla*, *Tridax procumbens*, C*ommelina benghalensis*, *Brachiaria deflexa*, *Sorghum halepense* and C*yperus rotundus.* At 10 WAP, all weed control methods effectively controlled weeds (up to 93%) compared to the non-weeded, except PRE only (32%) (Table 4.5). Two HW, however, achieved the best weed control while weed density generally declined after 10 WAP.

4.1.8 Effect of minor season weed control methods on weed growth (dry biomass).

Metolachlor application reduced weed growth by 28% at 3 WAP compared to plots that did not receive preemergence treatment and at 5 WAP, HW (98%) or PRE + HW (59%) effectively ($P<0.05$) reduced growth of weeds compared with non-weeded treatment (Table 4.4). While sole application of imazethapyr reduced weed growth by 28% compared to non-weeded, PRE + POST herbicide application reduced weed growth by 54% and PRE only, 6% (Figure 4.2). Weed growth generally declined after 8 WAP. At 10 WAP, all weed control methods except PRE only efficiently ($P<0.05$) reduced weed growth compared with non-weeded control.

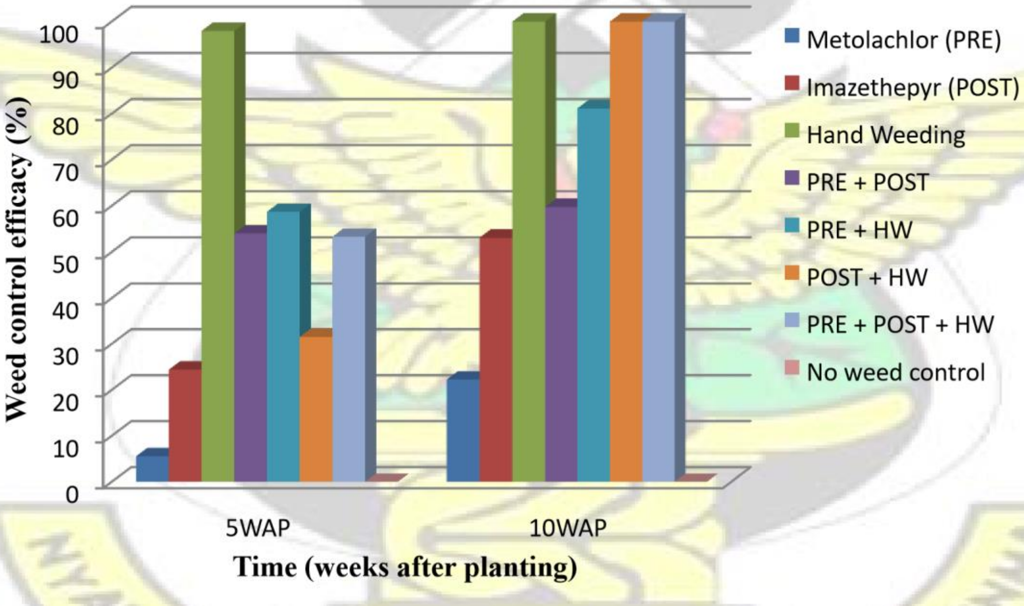

Figure 4.2. Minor season weed control efficacy (%)

0.0 3.0 7.0 37.0 4.0 9.0

Table 4.4 Density of dominant weed species in minor season

	GRASSES (m^{-2})				BROADLEAVES (m^{-2})						GRASSES (m^{-2})			BROADLEAVES (m^{-2})				
Treatment	***Brachiaria deflexa***	***Digitaria Ciliaris***	***Rottboellia cochinchinensis***	***Sorghum halepense***	***Commelina benghalensis***	***Euphorbia heterophylla***	***Phyllanthus amarus***	***Synedrella nodiflora***	***Talinum triangulare***	***Tridax procumbens***	***Digitaria ciliaris***	***Rottboellia cochinchinensis***	***Sorghum halipens***	***Commelina benghalensis***	***Euphorbia heterophylla***	***Synedrella nodiflora***	***Talinum triangulare***	***Tridax procumbens***
	3 Weeks After Planting										**5 Weeks After Planting**							
Metolachlor (PRE)	0.0	0.0	1.0	0.0	3.0	125.0	3.0	10.0	4.0	2.0	1.0	2.0	1.0	1.0	123.0	23.0	5.0	11.0
Imazethepyr (POST)	2.0	44.0	0.0	0.0	7.0	142.0	0.0	31.0	10.0	43.0	42.0	0.0	0.0	4.0	90.0	42.0	24.0	14.0
Hand Weeding	1.0	54.0	4.0	4.0	4.0	114.0	2.0	11.0	28.0	44.0	134.0	0.0	0.0	1.0	29.0	2.0	22.0	69.0
PRE + POST	0.0	0.0	2.0	1.0	2.0	181.0	0.0	4.0	2.0	6.0	0.0	0.0	0.0	1.1	93.0	6.0	3.0	4.0
PRE + HW	0.0	0.0	1.0	1.0	3.0	116.0	1.0	9.0	2.0	4.0	4.0	2.0	1.0	1.1	70.0	17.0	1.0	26.0
POST + HW	2.0	56.0	3.0	0.0	6.0	115.0	1.0	38.0	19.0	33.0	51.0	0.0	0.0	3.0	103.0	52.0	29.0	24.0
PRE + POST + HW	0.0	0.0	3.0	0.0	2.0	171.0	0.0	9.0	1.0	8.0	1.0	0.0	0.0	1.0	104.0	8.0	4.0	3.0
No weed control	2.0	15.0	3.0	2.0	5.0	124.0	4.0	27.0	6.0	51.0	14.0	13.0	8.0	6.0	84.0	46.0	14.0	31.0
SED (P=0.05)	**1.1**	**14.5**	**2.2**	**1.6**	**2.4**	**41.3**	**2.1**	**10.6**	**7.3**	**9.1**	**17.1**	**3.0**	**2.7**	**1.3**	**27.5**	**19.6**	**10.2**	**13.2**
	6 Weeks After Planting										**10 Weeks After Planting**							
Metolachlor (PRE)	0.0	0.0	12.0	8.0	1.0	166.0	0.0	32.0	7.0	10.0	2.0	4.0						
Imazethepyr (POST)	0.0	33.0	0.0	0.0	0.0	9.0	1.1	81.1	30.0	41.0	3.0	0.0						
Hand Weeding	0.0	93.0	4.0	5.0	4.0	29.0	0.0	16.0	23.0	26.0	0.0	0.0						
PRE + POST	0.0	1.0	0.0	0.0	0.0	17.0	0.0	6.0	0.0	4.0	2.0	1.0						
PRE + HW	0.0	2.0	1.0	0.0	1.0	21.0	0.0	2.0	3.0	7.0	2.0	1.0						
POST + HW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.0	4.0						
PRE + POST + HW	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0						
No weed control	0.0	20.0	7.0	16.0	0.0	110.0	0.0	69.0	21.0	41.0	1.0	4.0						

0.0 3.0 38.0 38.0 10.0 28.0

0.0 1.0 6.0 1.0 1.0 5.0

0.0 0.0 46.0 13.0 3.0 8.0

1.0 1.0 26.0 4.0 4.0

22.0 0.0 2.0 12.0 1.0

6.0 5.0

0.0 1.0 16.0 2.0 3.0 12.0

1.0 5.0 79.0 47.0 14.0 33.0

SED (P=0.05)	**0.28**	**11.5**	**6.4**	**6.7**	**1.1**	**24.9**	**0.3**	**22.1**	**8.4**	**9.5**	**1.5**

Table 4.5 Effect of weed control on minor season weed density and growth (dry weed biomass)

Treatment	*3 Weeks After Planting (3 WAP)* /m^2				Weed Biomass (g/m^{-2}) 3 WAP	*5 Weeks After Planting (5 WAP)* /m^2				Weed Biomass 5 WAP (g/m^{-2})
	Grasses	**Broadleaves**	**Sedges**	**Total**		**Grasses**	**Broadleaves**	**Sedges**	**Total**	
Metolachlor (PRE)	2.0	152.0	4.0	158.0	24.1	5.0	168.0	10.0	183.0	116.7
Imazethapyr (POST)	54.0	242	5.0	301.0	38.8	44.0	185.0	8.0	237.0	93.4
Hand Weeding	69.0	218.0	5.0	293.0	36.0	135.0	131.0	7.0	273.0	2.5
PRE + POST	3.0	199.0	3.0	205.0	27.3	1.0	109.0	3.0	113.0	56.8
PRE + HW	1.0	139.0	1.0	141.0	22.1	8.0	122.0	3.0	132.0	51.0
POST + HW	73.0	231.0	9.0	312.0	35.8	53.0	224.0	3.0	280.0	84.6
PRE + POST + HW	4.0	195.0	0.0	199.0	27.3	2.0	125.0	1.0	128.0	57.7
No weed control	23.0	241.0	5.0	269.0	29.8	34.0	215.0	10.0	259.0	123.6
SED (P=0.05)	**15.7**	**41.8**	**4.1**	**43.7**	**6.1**	**17.4**	**37.7**	**6.5**	**44.9**	**21.5**
	6 Weeks After Planting (6 WAP) /m^2					*10 Weeks After Planting (10 WAP)* /m^2				**Weed Biomass**
Treatment	**Grasses**	**Broadleaves**	**Sedges**	**Total**		**Grasses**	**Broadleaves**	**Sedges**	**Total**	**10 WAP (g/m^{-2})**
Metolachlor (PRE)	21.0	194.0	12.0	227.0		5.0	126.0	10.0	141.0	82.7
Imazethepyr (POST)	35.0	169.0	0.0	204.0		5.0	120.0	1.0	126.0	49.9
Hand Weeding	120.0	105.0	8.0	215.0		1.0	13.0	1.0	15.0	0.0
PRE + POST	2.0	31.0	0.0	33.0		2.0	71.0	8.0	81.0	42.8
PRE + HW	2.0	36.0	0.0	38.0		6.0	59.0	1.0	66.0	20.0
POST + HW	0.0	0.0	0.0	0.0		22.0	26.0	0.0	48.0	0.0
PRE + POST + HW	0.0	0.0	0.0	0.0		2.0	36.0	5.0	43.0	0.0
No weed control	42.0	255.0	14.0	311.0		8.0	181.0	16.0	206.0	106.4
SED (P=0.05)	**13.4**	**28.7**	**6.9**	**34.5**		**4.8**	**22.8**	**7.2**	**24.4**	**14.5**

2.3	0.9	2.3	15.2	14.4	4.5	8.2

4.2 Interactive effect of herbicides and fungicides on groundnut growth, yield,

4.2.1 Groundnut emergence and establishment in the major season

Application of butachlor did not negatively affect groundnut germination and emergence (Table 4.6). Also, weed control, fungicides or their interaction did not negatively affect groundnut population from establishment through to harvesting. However, post emergence application of bentazone caused phytotoxic injuries (necrosis) in groundnut plants (Plate 3.0, Table 4.6). High proportions of herbicide injuries were recorded for propaquizafop + bentazone (up to 58%) than bentazone only (26%). Hand weeding also resulted in a few (<5%) injured groundnut plants. All injured plants, however, recovered 2 weeks after the treatment.

Plate 3. *Phytotoxic effect of Basagran on groundnut*

4.2.2 Groundnut growth in the major season

Fungicides, as well as weed control methods and fungicides interactions did not influence groundnut height and canopy formation from crop establishment through to **kernel quality/aflatoxin level** harvesting (Table 4.7). Weed control methods on the other hand influenced groundnut canopy formation from 4 WAP through to harvesting, and height from 6 WAP through to harvesting. Generally, butachlor application produced taller plants with wider canopy width compared with bentazone, propaquizafop + bentazone or propaquizafop + HW treatments (Table 4.7).

Weed control methods and fungicides interaction did not influence groundnut dry matter (biomass) production per plant (Table 4.8). Weed control methods or fungicides application however, significantly influenced groundnut dry matter production per plant. Butachlor + propaquizafop + bentazone produced 7.8 g per plant, propaquizafop + HW produced 6.9 g and HW, 6.8 g; these were considerably more dry matter than 5.5 g and 5.7 g per plant for bentazone or propaquizafop + bentazone respectively at 6WAP. Hand weeding produced groundnut plant dry matter of 29.6 g per plant relative to 23.3 g per plant in bentazone or 21.1 g per plant in propaquizafop + bentazone treatments at harvest. Groundnuts treated with fungicides produced much dry matter than no fungicides treatment (Table 4.8). Weed control methods, fungicides treatment or their interactions, however, did not significantly affect the production of groundnut pegs at 6 WAP (Table 4.8).

4.2.3 Disease (leaf spot) incidence and severity in the major season

While weed control methods influenced leaf spot disease incidence at 4 WAP and 12 WAP, fungicides application as well as weed control methods and fungicides interaction had no significant influence on disease incidence (Table 4.9). Disease severity was, however, not significantly influenced by weed control methods, fungicides or their interaction. Generally, high leaf spot incidence (23-59%) but at minimal severity level was recorded at the early stages (4 WAP) than the latter

(12 WAP) stages (Table 4.9). Butachlor recorded high disease incidence of 59% and severity score of 2.4 at 4 WAP compared to disease incidence of 23-42 % on the other weed control treatments except butachlor + propaquizafop + bentazone which had incidence of 44%. At 12 WAP, leaf spot incidence was 30% with severity of 2.2 in the HW treatments compared to the 8-19 % from the other treatments. Butachlor treatments had 19% of infected plants compared to 8 and 9 % in propaquizafop + bentazone or propaquizafop + HW respectively.

Table 4.6 Effect of major season treatments on percentage crop density and phytotoxicity

	Percentage Plant population									Percentage Injury percentage					
	3WAP			4 WAP			6 WAP			4WAP			6 WAP		
Weed control	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
Hand weeding (HW)	86	87	86	86	87	86	86	87	86	4	0	2	0	0	0
Propaquizafop + Bentazone	90	83	86	90	83	86	90	83	86	51	64	58	2	2	2
Butachlor (But)	86	89	88	86	89	88	86	89	88	0	0	0	0	0	0
Bentazone (Bent)	87	86	87	87	86	87	87	86	87	31	22	26	0	0	0
Propaquizafop + HW	87	86	87	87	86	87	87	86	87	0	0	0	0	0	0
But + HW	88	85	87	88	85	87	88	85	87	0	0	0	0	0	0
But + Propaquizafop + Bent	90	95	92	90	95	92	90	95	92	0	0	0	57	52	55
Mean	88	87		88	87		88	87		13	12		8	8	8
SED (P=5%)	WC x Fung = 3.4			WC x Fung = 3.4			WC x Fung = 3.4			WC x Fung = 10.4			WC x Fung = 4.1		
	WC = 2.4			WC = 2.4			WC = 2.4			WC = 7.4			WC = 2.9		
	Fung= 1.3			Fung = 1.3			Fung = 1.3			Fung = 3.4			Fung = 1.6		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

Table 4.7 Interactive effect of herbicides and fungicides on groundnut height and canopy in the major season

	Plant height (cm)									Canopy spread (cm)								
major season	4WAP			6 WAP			10 WAP			4 WAP			6 WAP			10 WAP		
Weed control	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No fungicide	Mean	Fungicide	No fungicide	Mean	Fungicide	No fungicide	Mean
Hand weeding (HW)	8.6	9.1	8.9	21.7	21.7	21.7	24.8	26.0	25.4	22.7	27.2	26.9	45.6	44.9	45.2	52.0	52.3	52.1
Propaquizafop + Bentazone	9.9	9.2	9.5	21.4	19.7	20.6	25.5	22.7	24.1	25.3	24.1	24.7	41.4	39.3	40.4	48.6	43.8	46.2
Butachlor (But)	9.8	8.9	9.3	27.0	24.3	25.6	30.9	27.2	29.0	26.7	26.4	26.5	48.1	46.6	47.4	59.2	52.9	56.0
Bentazone (Bent)	11.1	9.9	10.5	22.3	20.4	21.3	25.9	23.5	24.7	26.8	23.2	25.0	42.9	39.0	41.0	51.5	47.3	49.4
Propaquizafop + HW	9.8	9.0	9.4	20.0	20.7	20.3	24.0	23.8	23.9	25.6	24.8	25.2	41.5	42.5	42.0	48.6	47.5	48.1
But + HW	10.5	10.1	10.3	22.9	22.3	22.6	26.2	25.7	25.9	27.9	27.7	27.8	42.4	44.7	43.6	53.2	52.3	52.7
But + Propaquizafop + Bent	9.3	10.1	9.8	24.6	24.0	25.3	28.8	27.3	28.0	27.3	27.8	27.5	46.0	47.0	46.5	54.1	52.2	53.2
Mean	9.8	9.5		22.8	21.8		26.6	25.2		26.6	25.9		44.0	43.4		52.3	49.9	
SED (P=5%)	WC x Fung = 1.2 WC = 0.8 Fung=0.5			WC x Fung =2.0 WC = 1.4 Fung= 0.7			WC x Fung = 2.2 WC = 1.6 Fung=0.8			WC x Fung = 1.4 WC = 1.0 Fung= 0.5			WC x Fung = 2.8 WC = 2.0 Fung= 1.0			WC x Fung =4.2 WC = 3.0 Fung= 1.6		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

Table 4.8 Effect of major season treatments on plant biomass and pegs production

	Plant biomass (g/plant)						Number of pegs/plant		
	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	6 WAP			At Harvest			6 WAP		
Hand weeding (HW)	7.2	6.3	6.8	29.9	29.3	29.6	15.0	14.0	14.0
Propaquizafop + Bentazone	5.5	6.0	5.7	25.5	16.5	21.1	13.0	16.0	14.0
Butachlor (But)	6.9	6.4	6.7	25.4	22.7	24.1	17.0	15.0	16.0
Bentazone (Bent)	5.8	5.2	5.5	25.1	21.1	23.3	15.0	12.0	14.0
Propaquizafop +HW	7.0	6.7	6.9	26.9	24.5	25.7	17.0	20.0	19.0
But + HW	6.7	6.3	6.5	30.4	23.5	26.9	16.0	16.0	16.0
But + Propaquizafop + Bent	7.5	8.2	7.8	25.2	23.3	24.2	17.0	17.0	17.0
Mean	6.6	6.5		26.9	23.1		16.0	16.0	
SED (P=5%)	WC x Fung = 0.7 WC = 0.5 Fung= 0.3			WC x Fung = 4.3 WC = 3.0 Fung= 1.6			WC x Fung = 2.5 WC = 1.8 Fung= 1.0		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

Table 4.9 Effect of treatments on disease incidence and severity in the major season

	Leaf spot disease incidence (%)						Leaf spot severity levels					
	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	4 WAP			12 WAP			4 WAP			12 WAP		
Hand weeding (HW)	40.0	44.0	42.0	28.0	31.0	30.0	2.3	2.3	2.3	2.3	2.1	2.2
Propaquizafop + Bentazone	23.0	24.0	23.0	11.0	5.0	8.0	2.3	2.0	2.1	2.0	1.8	1.9
Butachlor (But)	67.0	51.0	59.0	28.0	11.0	19.0	2.3	2.5	2.4	2.1	2.1	2.1
Bentazone (Bent)	49.0	21.0	35.0	12.0	10.0	11.0	2.3	2.0	2.1	2.0	2.0	2.0
Propaquizafop +HW	25.0	34.0	29.0	6.0	11.0	9.0	2.0	2.1	2.1	2.1	2.0	2.1
But + HW	44.0	37.0	40.0	15.0	19.0	17.0	2.1	2.3	2.2	2.3	2.1	2.2
But + Propaquizafop + Bent	53.0	34.0	44.0	11.0	12.0	12.0	2.3	2.3	2.3	2.1	2.0	2.1
Mean	43.0	35.0		16.0	14.0		2.3	2.2		2.1	2.0	

	WC x Fung = 11.0	WC x Fung = 6.7	WC x Fung= 0.2	WC x Fung =0.2
SED (P=5%)	WC = 7.9	WC = 4.8	WC = 0.2	WC = 0.1

	Fung= 4.3	Fung= 2.5	Fung= 0.1	Fung= 0.1

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.2.4 Groundnut pod, kernel yield and quality (major season)

Fungicides or weed control methods and fungicide interaction did not result in any considerable differences in groundnut yield (Table 4.10). Weed control methods on the other hand influenced pod and kernel yields, and 100 pods weight. Butachlor + HW, HW on ly, butachlor + propaquizafop + bentazone or bentazone only treatments significantly produced high groundnut pod and kernel yields per hectare compared to propaquizafop + bentazone or butachlor only treatments (Table 4.10). Butachlor only resulted in pod yield loss of up to 43% and kernel yield loss of up to 36% compared to butachlor + HW, HW, butachlor + propaquizafop + bentazone or bentazone only treatments. Butachlor + HW, propaquizafop + HW or HW only treatments produced greater percentage (73 – 79%) of filled pods per plant compared with butachlor only (56%). Regardless of treatment, pods had an average of 2 kernels. Similar dry kernel weight of 0.3g/kernel was obtained for all treatments at moisture content of <10%.

Generally, very low aflatoxin le vels were recorded (<2.0 ppb) in both fresh and dry kernels. Propaquizafop + HW, HW only, butachlor + HW or bentazone only treatment recorded lower aflatoxin levels in fresh kernels than butachlor only. Also, fungicides treatment resulted in lower aflatoxin levels (P<0.05) than no fungicide treatments. The interactive effect of weed control and fungicide did not significantly affect aflatoxin levels of both fresh and dry kernels.

Table 4.10 Effect of major season treatments on groundnut yield

	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	Major season											
	Pod yield (ton/ha)			kernel yield (ton/ha)			100 pods weight (g)			Pods / plant		
Hand weeding	2.2	2.2	2.2	1.4	1.4	1.4	98.0	93.0	95.5	21.0	21.0	21.0
Propaquizafop + Bentazone	1.6	1.3	1.5	1.0	0.8	0.9	87.7	78.5	83.1	17.0	14.0	16.0
Butachlor (But)	1.3	1.2	1.3	0.9	0.9	0.9	81.7	83.9	82.8	16.0	12.0	14.0
Bentazone (Bent)	2.5	1.7	2.1	1.5	1.1	1.3	99.6	102.4	101.0	20.0	19.0	20.0
Propaquizafop +HW	1.8	1.8	1.8	1.1	1.1	1.1	95.7	95.3	95.5	18.0	16.0	17.0
But + HW	2.1	2.5	2.3	1.3	1.5	1.4	101.6	100.4	101.0	19.0	21.0	20.0
But + Propaquizafop + Bentazone	2.1	2.0	2.1	1.2	1.3	1.3	96.3	97.8	97.1	20.0	18.0	19.0
Mean	1.9	1.8		1.2	1.2		94.4	93.0		19.0	17.0	
SED (P=5%)	WC x Fung=0.4 WC = 0.3 Fung= 0.1			WC x Fung=0.3 WC = 0.2 Fung= 0.1			WC x Fung= 9.0 WC = 6.3 Fung= 3.4			WC x Fung=3.9 WC = 2.7 Fung= 1.5		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.2.5 Groundnut emergence and establishment in the minor season

Groundnut germination and emergence were not negatively affected by metolachlor application. Weed control methods, fungicides application or their interaction neither affected groundnuts establishment negatively nor caused phytotoxic injuries in groundnut plants. At 12 WAP however, groundnut population was, influenced by weed control with PRE + POST, PRE + HW or POST + HW treatments having considerably more groundnut population than the PRE only or non-weeded treatments

(Table 4.11).

Table 4.11 Effect of minor season treatments on percentage crop density.

MINOR SEASON	Percentage Plant population 3 WAP			6 WAP			12 WAP		
Weed control	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
Metolachlor (PRE)	83	86	84	83	86	84	69	71	70
Imazethepyr (POST)	80	94	87	80	94	87	78	81	80
Hand Weeding	81	83	82	81	83	82	78	82	80
PRE + POST	88	87	88	88	87	88	87	84	85
PRE + HW	84	88	86	84	88	86	81	87	84
POST + HW	88	82	85	88	82	85	83	80	82
PRE + POST + HW	86	80	83	86	80	83	81	78	80
No weed control	86	86	86	86	86	86	68	61	65
Mean	85	86		85	86		78	78	
SED (P=5%)	WC x Fung = 6.1			WC x Fung = 6.1			WC x Fung = 7.4		
	WC = 4.3			WC = 4.3			WC = 5.2		
	Fung=2.1			Fung = 2.1			Fung=2.6		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.2.6 Groundnut growth in the minor season

Fungicides or their interaction with weed control methods did not influence groundnut height, canopy formation and dry matter production from crop establishment to harvesting (Table 4.12 and 4.13). Weed control methods on the other hand significantly ($P<0.05$) influenced groundnut height and canopy formation from 4 to 10 WAP. Generally, PRE only or non-weeded control treatments produced taller plants with narrow canopies (Table 4.12). Weed control methods again influenced dry matter production at 7 WAP and at harvest with non-weeded, PRE only or POST only treatments producing less groundnut dry matter at 7 WAP; and non-weeded or PRE only treatments producing less dry matter at harvest compared to PRE + POST + HW,

HW, POST + HW, PRE + HW or PRE + POST treatments (Table 4.13, Plate 4.0). Furthermore, non-weeded and PRE only treatments significantly produced the least numbers of groundnut pegs at 7 WAP (Table 4.13).

Plate 4. *Dry haulm of 4 plants from HW (1), PRE + HW (2), PRE only (3), Non - weeded (4), PRE + POST + HW (5) and PRE + POST (6) treatments at 7 WAP.*

Table 4.12 Interactive effect of herbicides and fungicides on groundnut height and canopy in the minor season

	Plant height (cm)									Canopy spread (cm)								
	4WAP			6 WAP			10 WAP			4WAP			6 WAP			10 WAP		
Weed control	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
Metolachlor (PRE)	16.3	16.3	16.3	23.5	26.2	24.9	24.5	28.1	26.3	20.0	22.9	21.5	22.1	29.7	25.9	29.5	35.3	32.4
Imazethepyr (POST)	14.1	14.5	14.3	19.2	20.4	19.8	21.0	22.1	21.6	23.3	22.4	22.9	32.6	31.2	31.9	43.7	42.7	43.2
Hand Weeding	12.0	13.5	12.8	19.4	20.8	20.1	21.1	22.0	21.6	22.5	24.7	23.6	32.1	35.8	33.9	41.0	47.4	44.3
PRE + POST	14.8	14.3	14.5	20.1	21.7	20.9	21.9	22.9	22.4	24.8	24.8	24.8	33.9	35.7	34.8	44.7	47.0	45.8
PRE + HW	13.7	14.7	14.2	20.3	21.9	21.1	22.6	22.4	22.5	22.9	27.2	25.1	34.3	39.4	36.8	45.2	49.9	47.5
POST + HW	16.5	13.2	14.8	20.3	18.5	19.4	22.9	21.5	22.2	24.7	22.3	23.5	37.5	32.8	35.1	46.7	43.9	45.3
PRE + POST + HW	12.1	17.1	14.6	17.0	20.8	18.9	19.8	24.1	21.9	22.3	25.0	23.6	34.0	36.2	35.1	46.2	50.5	48.4
No weed control	12.0	13.5	16.3	25.8	24.8	25.3	27.7	25.9	26.8	20.1	19.9	20.0	21.0	22.8	21.9	31.9	29.4	30.7
Mean	14.4	15.0		20.7	21.9		22.7	23.6		22.6	23.7		31.1	32.7		41.1	43.3	
SED (P=5%)	WC x Fung = 1.7			WC x Fung =2.3			WC x Fung =1.8			WC x Fung = 2.3			WC x Fung= 4.2			WC x Fung = 3.9		
	WC = 1.2			WC = 1.4			WC = 1.2			WC = 1.6			WC = 2.9			WC = 2.7		
	Fung=0.6			Fung=0.7			Fung= 0.6			Fung= 0.8			Fung= 1.5			Fung= 1.4		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

Table 4.13 Effect of minor season treatments on plant biomass and pegs production

	Plant biomass (g/plant)						Number of pegs		
	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	7 WAP			At Harvest			7 WAP		
x Metolachlor (PRE)	5.4	7.0	6.2	8.7	7.8	8.2	7.0	11.0	9.0 WC
Imazethepyr (POST)	8.8	8.4	8.6		14.1	14.1	14.1	12.0	11.0 11.0
Hand Weeding	12.3	12.1	12.2	23.6	22.1	22.9	18.0	19.0	19.0
PRE + POST	13.9	12.8	13.3	18.4	16.6	17.5	15.0	15.0	15.0
PRE + HW	11.6	15.3	13.5	21.7	18.3	20.0	18.0	20.0	19.0
POST + HW	10.8	11.9	11.3	21.9	19.6	20.7	15.0	14.0	15.0
PRE + POST + HW	12.5	14.7	13.6	21.7	24.7	23.2	17.0	17.0	17.0
No weed control			4.4			6.2			7.0
Mean									
SED (P=5%)	WC x Fung = 1.9 WC = 1.3 Fung= 0.7			WC x Fung = 2.8 WC = 2.0 Fung= 1.0			WC x Fung = 2.8 WC = 2.0 Fung= 1.0		
	4.9	3.8		6.2	6.2		8.0	6.0	
	10.0	10.7		17.0	16.2		14.0	14.0	

Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.2.7 Disease (leaf spot) incidence and severity in the minor season

While fungicides application or weed control methods and fungicide interactions did not affect leaf spot incidence and severity at 6 WAP and 12 WAP, weed control methods significantly ($P<0.05$) influenced leaf spot disease incidence and severity (Table 4.14). The incidence of leaf spot at 6 WAP, on the HW, PRE + HW or PRE + POST treatment was 34 – 49% with severity score of 2.2 – 2.8 compared to POST, PRE, POST + HW or the non-weeded treatments. Hand weeding or PRE + HW treatments had considerably higher leaf spot incidence of 86 – 91% with severity score of 3.0 at 12 WAP compared to 29-74 % incidence and severity score of 2.0-2.7 on POST + HW, PRE + POST + HW, POST only, PRE only or the non-weeded treatments. However, PRE and non-weeded treatments significantly (P<0.05) recorded the least incidence of 29 – 36% with a severity score of 2.0 – 2.3.

Table 4.14 Effect of minor season treatments on leaf spot disease incidence and severity

	Leaf spot disease incidence (%)						Leaf spot severity levels					
	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	Minor season											
	6 WAP			12 WAP			6 WAP			12 WAP		
Metolachlor (PRE)	15.0	21.3	18.1	37.5	35.0	36.3	2.2	2.2	2.2	2.0	2.5	2.3
Imazethepyr (POST)	17.5	20.0	18.8	60.0	60.0	60.0	2.2	2.0	2.1	2.7	2.5	2.6
Hand Weeding	55.0	42.5	48.8	97.5	85.0	91.3	3.0	2.6	2.8	3.0	3.0	3.0
PRE + POST	33.8	35.0	34.4	77.5	70.0	73.8	2.2	2.2	2.2	2.7	2.7	2.7
PRE + HW	43.0	45.0	44.4	82.5	90.0	86.3	2.8	2.8	2.8	3.0	3.0	3.0
POST + HW	16.3	18.8	17.5	67.5	70.0	68.8	2.2	2.0	2.1	2.5	2.5	2.5
PRE + POST + HW	32.5	20.0	26.3	77.5	57.5	67.5	2.5	2.0	2.2	3.0	2.5	2.7
No weed control	7.5	11.3	9.4	32.5	25.0	28.8	2.0	2.0	2.0	2.0	2.0	2.0
Mean	27.7	26.7		66.6	61.6		2.3	2.3		2.6	2.5	
SED (P=5%)	WC x Fung = 9.5 WC = 6.7 Fung= 3.4			WC x Fung=11.9 WC = 8.4 Fung= 4.2			WC x Fung =0.3 WC = 0.2 Fung= 0.1			WC x Fung =0.3 WC = 0.2 Fung= 0.1		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.2.8 Groundnut pod and kernel yield, and quality (minor season)

Pod and kernel yields per hectare, 100 pods weight, number of pods per plant, number of seeds per pod and percentage filled pods per plant were not influenced (P>0.05) by fungicide application as well as fungicide and weed control interaction. However, weed control methods influenced groundnut pod and kernel yields, and number of pods per plant (Table 4.15). Two HW treatment produced pod yield of 2.1 tons/ha, herbicides combined with HW produced pod yield of 1.6 - 2.1 tons/ha, PRE + POST treatment produced 1.7 tons/ha and POST, 1.4 tons/ha (Table 4.15). PRE only or nonweeded treatments caused pod yield loss of up to 71.4% with reference to manual weeding.

Also, PRE only and non-weeded treatments produced up to 64% and 68% lower groundnut pods per hectare respectively compared to HW. While HW, PRE + POST, POST + HW, PRE + HW or PRE + POST + HW treatments had 71 – 75% of filled pods, only 56 to 61% of the rather few pods of PRE only and non-weeded were filled with kernels. Regardless of treatments, each pod was filled with an average of 2 kernels. In spite of the low (<2.0 ppb) fresh and dry kernel aflatoxin levels, nonweeded recorded high levels of aflatoxin than other weed management treatments for both fresh and dry kernels. Fungicides treatment recorded lower aflatoxin levels in fresh kernel compared with no fungicide treatment. No differences were, however, recorded for dry kernel aflatoxin levels. Weed control methods and fungicides application interaction did not affect aflatoxin levels. Dry weight/kernel of 0.3 - 4g was recorded across treatments, at moisture content of <10%.

Table 4.15 Effect of minor season treatments on groundnut yield

	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean	Fungicide	No Fungicide	Mean
	Pod yield (ton/ha)			kernel yield (ton/ha)			100 pods weight (g)			Pods / plant		
Metolachlor (PRE)	0.6	0.6		0.4	0.4	0.4	100.0	97.8	98.9	8.0	7	8
Imazethepyr (POST)	1.3	1.4	1.4	0.7	0.7	0.7	105.8	93.4	99.6	14	13	13
Hand Weeding	1.9	2.3	2.1	1.0	1.2	1.1	114.0	117.3	115.6	20	24	22
PRE + POST	1.7	1.6	1.7	0.9	0.9	0.9	112.5	116.5	114.5	17	15	16
PRE + HW	1.9	1.3	1.6	1.0	0.7	0.9	115.8	125.5	120.6	18	16	17
POST + HW	2.4	1.8	2.1	1.2	1.0	1.1	118.3	120.5	119.4	22	17	20
PRE + POST + HW	1.4	2.2	1.8	0.7	1.2	1.0	109.5	88.3	98.9	17	23	20
No weed control				0.4	0.2	0.3	93.5	89.8	91.6	6	8	7
Mean	1.5	1.5		0.8	0.8		108.7	106.1		15	15	
	WC x Fung =0.5			WC x Fung= 0.3			WC x Fung = 17.5			WC x Fung=3.9		
SED (P=5%)	WC =0.4			WC = 0.2			WC = 12.4			WC = 2.8		0.7
0.5 0.6												
	Fung=0.2			Fung= 0.1			Fung = 6.2			Fung= 1.4		

WC x Fung = weed control x fungicide interaction, WC = weed control, Fung = fungicide

4.3 Economics of weed control in groundnut production.

4.3.1 *Major season*

A total of 64 man-days were required for manual weed control in 1 hectare groundnut. Application of herbicides reduced total time required for weed control by 96 – 99% while herbicides combined with manual weeding reduced time required by 67 – 70% compared to manual weeding (Table 4.16). There was a fairly strong positive correlation (r=0.54, P<0.001) between weed population and time requirement. Also, follow up manual weeding on plots treated to preemergence herbicides required less time than the otherwise. Cost of manual hand weeding depending on farmer practice was GH₵ 1,086.00 – 1600.0, herbicide alone was GH₵ 73.00 – GH₵ 391.00, and in combination with manual weeding was GH₵ 468.00 - GH₵ 661.00 (Table 4.16). The use of herbicides reduced cost of weed control by 67 – 96%, while herbicides – manual weeding integration reduced cost by 49 to 66% in relation to the manual HW only. Manual weed control cost determined on per unit area tended to be lower than when determined on daily hired labour.

Table 4.16 Time requirement and cost of weed control in the major season

Treatments	Time requirement (man-day/ha)		Cost of weed control (GH₵/ha)			
	Total	Hand weeding	Bottle* + Area**	Bottle* + Man-day**	Area* + Area**	Area* + Man-day**
Hand weeding (HW)	64.0	64.0	1,086.40	1,600.20		
Propaquizafop + Bentazone	2.3	-	256.30	256.30	283.30	283.30
Butachlor (But)	0.6	-	72.50	72.50	107.50	107.50
Bentazone (Bent)	1.4	-	97.50		122.50	122.50
Propaquizafop +HW	20.9		553.9		555.90	661.00
But + HW	19.3		467.60		502.60	574.10
	2.6		328.80		390.80	390.80
					1,086.40	1,600.20
				97.50		
		20.0		659.00		

	18.7	539.10
But + Propaquizafop + Bent	-	328.80

** basis for costing herbicide weed control, ** = basis for costing manual weed control, + = plus*

4.3.2 Minor season

Manual weed control required a total time of 66.7 man-day/ha (Table 4.17). Herbicide application (PRE, POST, PRE + POST) reduced time by 98 – 99.9% while herbicides – manual weeding integration (PRE + HW, POST + HW and PRE + POST+ HW) reduced required time by 55 – 62%. Less time (25 man-day) was required for follow up weeding of plots treated with preemergence herbicides compared to HW or POST + HW (29 – 33 man-day). A significant correlation (r=0.64, p<0.001) was observed between weed density and time required for manual weeding. Manual weeding cost of GH₵ 790.00 – 1,668.00 depending on farmer practice was expensive than all other weed control treatments (Table 4.17).

Herbicide application (PRE, POST and PRE + POST) reduced weed control cost by 76 – 97% while herbicide – manual weeding integration reduced weed control cost by 26 – 59% compared to manual weeding.

Table 4.17 Time requirement and cost of weed control in the minor season

	Time requirement (man-day/ha)		Cost of weed control (GH₵/ha)			
	Total	Hand weeding	Bottle* + Man-day**	Bottle* + Area**	Area* + Man-day**	Area* + Area**
Metolachlor (PRE)	0.6	-	62.50	62.50	97.50	97.50
Imazethepyr (POST)	0.7	-	54.40	54.40	89.40	89.40
Hand Weeding	66.7	66.7	790.12	1,668.20	790.12	1,668.20
PRE + POST	1.3	-	116.90	116.90	186.90	186.90
PRE + HW	25.4	24.8	457.60	683.80	492.60	718.80
POST + HW	30.0	29.3	449.50	786.80	484.50	821.80

PRE + POST + HW	25.8	24.4	512.00	726.60	582.0	796.6
No weed control	-	-	-	-	-	-

* *basis for costing herbicide weed control, ** = basis for costing manual weed control, + = plus*

CHAPTER FIVE

5.0 Discussion

5.1 Effect of weed control on weed incidence and control

The effective weed control achieved through preemergence herbicide application in the early stages is very important for crop growth since groundnuts cannot compete favourably with weed in the early stages of growth. Similar findings were made by Lopes Ovejero *et al*. (2013) and Usman (2013) where residual preemergence herbicides at 3 - 4 WAP achieved up to 100% weed control depending on weed species present.

The effectiveness of herbicides on obnoxious weeds especially that achieved with metolachlor and bentazone on *Commelina benghalensis*, and of butachlor and imazethapyr on *Commelina benghalensis* and *Euphorbia heterophylla* was important since *Commelina benghalensis* and *Euphorbia heterophylla* are known to be capable of causing pod yield loss of up to 100 and 82% respectively (Webster *et al*., 2007; Bridges *et al*., 1992). *Commelina benghalensis* is also difficult to control with manual weeding.

Metolachlor, on the other hand, was not effective on *Euphorbia heterophylla*, thus emergence of the weed was synchronal with crop and was capable of competition. It is therefore important that selection of a better preemergence herbicide is done based on weed species composition before land preparation. A better and timely follow up treatment (post emergence or weeding) should also be done depending on the species of weeds present after field establishment to avoid crop – weed competition. Similarly, Lopes Ovejero *et al*. (2013) reported metolachlor to be effective on

Commelina benghalensis (89-94%) but poor against *Euphorbia heterophylla* (5%). Wilson (1981) reported that bentazone was effective against *Commelina benghalensis* especially when applied in the early growth stages of the weed. Bhale *et al*. (2012) and Kade *et al*. (2014) also indicated that imazethapyr was effective for the control of *Commelina benghalensis*, *Euphorbia heterophylla* as well as other broadleaves and grasses. Reports by Panda *et al*. (2015) also indicated that propaquizafop is effective for the control of grasses.

Preemergence herbicides and post imazethapyr have residual effect, and thus controlled the germination of most weed seeds as compared to HW only where weed seeds were still viable. Turning of the soil through hand weeding brought these viable weed seeds unto the surface where conditions are more favourable for germination. For this reason, high weed density but low weed biomass (growth) was often recorded on the HW treatment compared with herbicides + HW or PRE + POST treatments.

Also, 2 - 3 times of manual weeding were required to keep weed density and growth (growth) under control for HW treatment, whereas only one follow up weeding was required for herbicide(s) + HW treatments. Weed density and growth also declined in the latter stages of the crop because groundnut canopy closure prevented weeds from receiving enough growth resources. Also, most of the annual weeds reached the peak of their growth cycle, especially *Euphorbia heterophylla*. Similarly, Habimana *et al*. (2013), Bhale *et al*. (2012) and Gunri *et al.* (2014) reported that HW, Herbicide + 1 follow up weeding or PRE + POST herbicides were effective at controlling weed density and reducing weed growth (biomass). Knežević *et al*. (2003) demonstrated that weed density after follow up cultivation on plots which have received preemergence herbicides reduced compared to the otherwise.

5.2 Interactive effect of herbicides and fungicides on groundnut growth, yield, kernel quality/ aflatoxin level

5.2.1 Groundnut establishment

Groundnut population does not only determine yield potential per area but is also a determining factor of how early groundnut canopy closure would be attained and indirectly affects weed suppression as well as soil moisture conservation (Rodenburg and Johnson, 2013). It is therefore, important to ensure that weed control method(s) does/do not reduce the population of groundnut per given area. The reduced population density (at 10 WAP) on PRE only or non-weeded treatments in the minor season may be due to crop – weed competition for growth resource. Also, some groundnut plants were attacked by insects (crickets and grasshoppers) which were haboured in the weedy plots (Patterson, 1995). According to Takim and Uddin II (2010) and Bhale *et al*. (2012), apart from the competition that weeds have with crops, they habour and act as alternative host for insect pests that affect the survival of crops. Optimum weed management is, therefore, a prerequisite to ensuring better crop density throughout the production season. The high injury observed with propaquizafop + bentazone application compared with bentazone application only may be due to the synergistic effect of the two herbicides. Jordan (2014) and Jordan *et al*. (2003) indicated that groundnut injury following bentazone application may be greater with the application of certain active ingredients.

5.2.2 Groundnut growth

The competition for growth resources which affects groundnuts growth (height and canopy width) is influenced by stage of crop at which weed incidence is recorded, weed species, density and growth rate, and morphological features (Swanton *et al*., 2015; Patterson, 1995; Akobundu, 1987). Bhale *et al*. (2012) reported that the use of preemergence herbicides resulted in better growth of groundnut plants because of reduced weed density before crop canopy closure. Similarly, report by Rathi *et al*. (1986) indicated that growth achieved with the use of preemergence herbicides was similar to that achieved with 2 hand weeding. Also, Bhale *et al*. (2012) and Abouziena *et al*. (2013) confirmed that manual weeding and herbicides combined with manual weeding enhances crop growth not only because of the effective control of weeds but also because hand weeding pulverizes the soil and improves aeration.

Weed competition before postemergence herbicides application and competition from uncontrolled weeds due to herbicide selectivity of propaquizafop or bentazone treatments, as well as the injuries sustained from bentazone treatment may have accounted for the reduced growth in height, canopy width and low plant biomass of bentazone, propaquizafop + bentazone, and propaquizafop + HW. In an experiment conducted by Grichar (1998) groundnut growth was significantly reduced by the injuries sustained earlier in growth compared to groundnut that were not injured.

Early incidence of weeds and the high weed density especially of *Euphorbia heterophylla* and its competitive growth nature especially in height resulted in etiolation and reduced biomass of groundnut plants on non – weeded and metolachlor plots. Conversely, El Naim *et al.* (2010) recorded reduced plant height with weed competition. The contrast might have resulted from the differences in weed composition for the different experiments as well as the growth resource competed for. In the report of El Naim *et al.* (2010), none of the individual weed species recorded exceeded 27% of the total weed composition, however, in the minor season of this work, *Euphorbia heterophylla* constituted up to 80% and 55% of weeds on Metolachlor only and non – Metolachlor plots, respectively. Because *Euphorbia heterophylla* also grows rapidly in height, light, nutrient and space would be highly competed for, and for this reason groundnut plants channeled growth resources to growth in height in order to intercept more sunlight resulting in an increase in height instead of canopy formation.

5.2.3 Disease (leaf spot) incidence and severity

The dry weather during the 2015 season was not favourable for disease development and might have accounted for the low severity of diseases recorded (Kumar *et al*., 2011). Multiple of factors might have also accounted for the levels of disease incidence recorded, especially in the minor season. Environmental conditions in the minor season did not permit the second application of azoxystrobin (7 WAP) and this must have resulted in the escalation of incidence at 12 WAP. Also, a fairly strong negative correlation was recorded between *Euphorbia heterophylla* and disease incidence (r= 0.60, $P<0.001$) and severity (r= -0.53, $P<0.001$) in the minor season. This might have resulted in the non-significance of fungicides, raising questions about whether *Euphorbia spp* have fungicidal properties as reported by Tanveer *et al*. (2013).

The throwing of contaminated soils unto crops during manual weeding may also increase disease incidence (Jordan, 2014). Soil contamination may result from drop of old infected leaves, this may explain why hand weeding or herbicide(s) followed by hand weeding might have recorded high disease incidence. According to Baysinger *et al*. (1999), certain herbicides can increase or decrease the incidence of crop diseases (including fungus). Kantan and Eshel (1973) explained that disease incidence may be increased with herbicides application possibly due to direct stimulating effect on pathogens, increasing the virulence of pathogens, increasing susceptibility of the host plant, and suppression of microorganisms antagonistic to the causal pathogen; while the reverse may also decrease disease incidence with herbicides.

5.2.4 Groundnut yield

Results obtained for yield and yield parameters were in agreement with Bhale *et al*. (2012), Gunri *et al*. (2014) and Jhala *et al*. (2005). Manual hand weeding is effective for weed control and also has an added advantage of loosening the top soil which enhances pegging and pod development, apart from improving soil aeration and water peculation. Preemergence herbicides provide effective weed control and prevent/reduce competition in the early stages of crop growth; follow up postemergence herbicides and or manual weeding extends weed control with the added advantages of manual weeding to enhance groundnut yield. On large scale farms o r in situations where farmers are pressed for time and manual weeding would not be feasible, the use of preemergence herbicides followed up with postemergence is capable of giving appreciable yields.

Gaikpa *et al*. (2015) rated Yenyawso as being moderately tolerant to leaf spot disease. This and the low severity levels of disease might explain why fungicides application and its interaction with weed control did not significantly influence yield components.

Yield losses of 43 – 71% recorded were consistent with those of Fayed *et al*. (1992), Agostinho *et al*. (2006), Bridges *et al*. (1992) and Royal *et al*. (1997) who reported yield losses of between 42 and 92% due to competition with weeds.

5.2.5 Pod and Kernel quality/ aflatoxin level

The continuous cropping of groundnut on the same piece of land increases fungal and aflatoxin build up (Ortiz *et al*., 2011); and cropping history might have contributed to the general low levels of aflatoxin since the area used was not cultivated to any crop in the two previous seasons. According to Diao *et al*. (2015), aflatoxin production does not occur after the invasion of aflatoxigenic fungus until the breakdown of natural resistance mainly through environmental stress (drought and temperature). It is possible that stress imposed by weed pressure and/or competition between weeds and groundnut crop for water especially in a dry year as experienced might have influenced some level of natural resistance breakdown in butachlor only, metolachlor only and non-weeded treatments, which significantly recorded increased aflatoxin levels than other weed management methods. These treatments also recorded high levels of weed density agreeing with Anderson *et al.* (1975) who stated that high density of plants appears to positively influence aflatoxin contamination. The reduced aflatoxin levels of groundnut with the application of fungicides was in agreement with findings of D'mello *et al*. (1998) who reported that fungicides can inhibit growth of aflatoxigenic fungi and subsequent aflatoxin synthesis before harvest.

Crops under environmental stress would channel most assimilates to the parts that would be responsible for its survival in the next generation (Pereira and Chaves, 1993) which in the case of groundnut would be the setting of few but quality kernels. This explains why similar seed/kernel weight was recorded regardless of the weed control method. Gaikpa *et al*. (2015) reported weight of 0.35g/kernel for the same variety as used in this study.

5.3 Economics of weed control *5.3.1 Effect of herbicides and manual weeding on time requirement and cost of weed control*

Results obtained corroborated those of Ishaya *et al*. (2007) and Moyo *et al*. (2013) where manual weeding required 52, 54, and 33 - 48 man-days to control weeds on a hectare of land cropped to maize, sorghum and cassava respectively. Also, reports of

Moyo *et al*. (2013) and Benson (1982) indicated that the use of herbicides only required 0.9-1.3 and 0.4 man-days per hectare which represented 96-98% and 99.6% respectively of their respective manual weeding time. The combination of herbicides and manual weeding similarly required 7.8 - 27 man -days per hectare which represented 44 – 76% of manual weeding time. Manual weeding time may be influenced by weed density, weed type and growth stage, crop cultivated, stage of crop growth and crop spacing.

With regards to cost of weed control, similar results were obtained by Tan *et al*. (1997) and Chikoye *et al.*, (2007) where combining herbicides with manual weeding reduced weed control cost by 53 - 57% in Vietnam and 50% in Nigeria; compared to the 26 – 66% cost reduction recorded in this work. The reduction in cost and time would allow peasants to increase area under cultivation, improve productivity and undertake other socioeconomic activities.

CHAPTER SIX

6.0 Conclusions and Recommendations

6.1 Conclusions

Integrating herbicides and manual weed control proved effective for sustainable groundnut productivity.

- Integration of preemergence and or postemergence herbicides with manual weeding effectively reduced weed density and growth as did 2-3 times manual weeding or preemergence herbicide followed with post emergence herbicide.
- The interactions of fungicides and weed control were not significant on crop growth, yield, and disease incidence and severity; most likely because climatic conditions were unfavorable for disease development, apart from groundnut variety being tolerant to leaf spot disease. Though aflatoxin levels of fresh and dried kernels were low (<2.0 ppb), manual weeding alone or integration with herbicides and fungicide treatments resulted in significantly lower levels.
- Pod yield of 2.1 – 2.2, 1.6 -2.3, and 1.7 – 2.1 tons/ha were recorded for 2-3 times manual weeding, herbicides - manual weeding integration, and preemergence followed with postemergence herbicides respectively, while preemergence only and non-weeded treatments resulted in yield loss of 43 – 71%.
- Herbicide application reduced weed control labour time by 96 – 99.9% and herbicides – manual weeding integration, by 55 – 70% relative to manual weeding (64 -67 man-days/hectare/season). Cost of manual weeding was GH₵790.00–1,668.00 depending on farmer practice, while herbicide – manual weeding integration reduced manual weed control cost by 26 – 66%.

6.2 Recommendations

- Additional work is needed to ascertain the effect of fungicides on groundnut growth and yield in Ghana using different varieties under good environmental conditions.
- More integrated systems must be investigated, including the use of simple mechanical weeders for cultivation.

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