IMPACT OF PRE-EMERGENCE WEED MANAGEMENT USING PENDIMETHALIN (456 g/L EC) AND OXADIARGYL (400 g/L SC) ON THE GROWTH, DEVELOPMENT AND MINIMUM RESIDUE LEVELS IN TWO ONION (*Allium cepa* L.) VARIETIES

BY

JAMES KWABENA OPOKU

(10636336)

THIS THESIS IS SUBMITTED TO THE UNIVERSITY OF GHANA, LEGON IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF MPHIL. IN CROP SCIENCE (AGRONOMY) DEGREE

CROP SCIENCE DEPARTMENT

UNIVERSITY OF GHANA

LEGON

JULY, 2019

DECLARATION

I, James Kwabena Opoku hereby declare that, except for references to works of other researchers which I have duly cited, this work is the result of my own original research and that this thesis has not been presented for a degree elsewhere neither in whole nor in parts.

....

JAMES KWABENA OPOKU

(10636336)

DATE....29-06-2020....

....

DR. (MRS) CHRISTIANA AMOATEY

(SUPERVISOR)

DATE....29-06-2020....

....

DR. JOSEPH HONGER

(CO-SUPERVISOR)

DATE....29-06-2020....

ii

ABSTRACT

Two field experiments were conducted at the University Ghana farm, Legon from September, 2018 to March 2019 to evaluate the impact of two herbicides(Oxadiargyl (400 g/L SC) and Pendimethalin 456 g/LEC) on weed management, soil microbial populations, growth and yield of two onion varieties (Dayo and Bawku red) as well as their residual effects on succeeding crops. The study also assessed the cost benefit of using the herbicides compared to hand weeding. The first experiment was laid out in a split plot design in RCBD with four replications and with herbicides treatments as the main plot and onion varieties as the sub plot. A reconnaissance survey was conducted to identify weed species including broadleaves, grasses and sedges in the experimental area prior to land preparation. Oxadiargyl 400g/L SC) applied at 0.5 L/ha (Manufacturer's recommended rate), and 0.4 L/ha, Pendimethalin 456 g/L EC) applied at 1.25 L/ha (manufacturers recommended rate) and1.00 L/ha and Hand weeding (control) were the main plot treatment while Dayo and Bawku Red (onion varieties) were the sub plot treatments. Data collected were percentage crop establishment, number of days to weed emergence, number of weeds, weed biomass, soil pH, soil microbial population, plant height, number of leaves, leaf length, leaf diameter, plant chlorophyll content, days to bulbing, stem girth, days to physiological maturity, average bulb weight, average bulb diameter, average bulb length, yield and residual levels of herbicides in bulbs. Data were analyzed using analysis of variance and the least significant difference test ($P < 0.05$) was used to separate the means where there were significant differences. Oxadiargyl treatments led to a significant ($P < 0.05$) longer number of days to weed emergence compared to Pendimethalin treatments which were also longer than hand weeding. Hand weeding produced the highest weed biomass than all the herbicide treatments. The pH of the soil was affected by weed management methods. Pendimethalin 1.25L/ha resulted in the highest number of

soil microbial population. For all treatments, Dayo established better than Bawku red. Dayo at Pendimethalin 1.25L/ha treatment produced the highest plant height. Pendimethalin 1.25L/ha treatments led to the highest number of leaves of onion plant. Pendimethalin 1.00L/ha led to the longest length of onion plant and largest leaf diameter than all the other treatments. Dayo with Pendimethalin (1.00L/ha) treatment resulted in higher leaf chlorophyll content throughout the growth period of the onion plant. Herbicide treatments had a positive effect on chlorophyll content of onion plants. Pendimethalin (1.00L/ha) led the largest stem girth of onion plants. Dayo with Pendimethalin (1.00L/ha) led to the highest plant biomass throughout the growth of the plant. Bawku Red with Oxadiargyl treatments led to the early bulbing of onion plants. Bawku Red with Oxadiargyl treatments also led to earliest maturity of onion plants. Bawku Red with Oxadiargyl (0.4L/ha) led to the largest diameter of onion bulbs. Herbicide treatments showed positive effect on bulb diameter. Pendimethalin (1.00L/ha) with Dayo onion variety showed the largest bulb length compared to other treatments. Bawku red with Oxadiargyl (0.4L/ha) led to the highest bulb weight of onion. Pendimethalin (1.00L/ha) with Bawku red led to the highest onion yield in tons per hectare with Dayo at hand weeding recording the lowest yield. Pendimethalin (1.00L/ha) resulted in the highest marketable yield of onion whiles. Dayo at hand weeding showed the lowest marketable yield. While no traces of Pendimethalin were observed in the onion bulbs, traces of Oxadiargyl (0.05 to 0.9) above the recommended maximum residue limit set by the European Union (0.01) were recorded in onion bulbs from plots treated with the two rates of the herbicide. It was more cost effective to use Pendimethalin at both rates in both varieties than hand weeding and Oxadiargyl. Cowpea bioassay revealed that there were no traces of Pendimethalin in the soil as it did not affect germination growth negatively. On the other hand, cowpea sown on Oxadiargyl treated plots died just after emergence indicating possible of Oxadiargyl.

TABLE OF CONTENTS

DEDICATION

I dedicate this work to the Almighty God, my parents James Arthur Gyening (late), and Veronica Ama Akyeamaa (late) and my lovely daughters Edith Adwoa Opoku, and Akosua Opoku Akyeamaah.

ACKNOWLEDGEMENT

I thank Almighty God for His grace, protection and guidance throughout my study. Sincere thanks go to my supervisors Dr. (Mrs) Christiana Amoatey and Dr. Joseph Honger for their suggestions, advice, guidance and concern that made the research and write up successful. I wish to extend my profound gratitude to the Head, Lecturers and Staff of Crop Science Department for their support and encouragement. My sincere gratitude to the Leventis Foundation for financial support for this research and finally to my family, colleagues and friends, I say thank you. God bless you all.

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DAT……………Days After Transplanting

WAT……………Weeks After Transplanting

WAP……………Weeks After Planting

g/L………………Gram per Litre

ha………………. Hectare

SC………………. Suspension concentrate

EC………………. Emulsifiable concentrate

ANOVA…………Analysis of Variance

LSD………………. Least Significant Differences

Kg………………. Kilogram

WP ………………Wettable powder

g…………………Gram

mL ………………Millilitre

LCMS……………Liquid Chromatography Mass Spectrometer

Ppb ……………. Part per billion

m²……………………… Square meter

mm………………Millimeter

cm………………. Centimeter

PSA……………. Primary Secondary Amine

NR………………Net Revenue

TR………………. Total Revenue

CP………………. Cost of Production

FA………………. Formic Acid

CAN……………. Acetonitrile

T1………………. Treatment 1

T2………………. Treatment 2

T3……………… Treatment 3

T4……………… Treatment 4

T5……………… Treatment 5

V1……………….Variety 1

V2……………….Variety 2

CHAPTER ONE

INTRODUCTION

1.1 Background

Onion (*Allium cepa* L.) is a cool season herbaceous bulb plant which belongs to the Alliaceae family and among the vegetables mostly grown in West Africa (Norman, 1992). It is one of the important vegetables with worldwide production estimated about 55 million tons (FAO, 2014). Worldwide production of onion is estimated at generating approximately 105 billion Pounds each year (NOA, 2011).

Countries leading in onion production in the world are China, India, United States, Turkey and Pakistan. In Africa, Egypt, Algeria, Morocco, Nigeria, South Africa and Niger are the leading producers of the crop (FAOSTAT, 2008). Onion is believed to be the most widely cultivated vegetable among the *Allianceae* family and it is produced globally. (Sinnadurai, 1992).

The crop is believed to have originated from the Near East and Central Asia. In Africa, it is mostly cultivated in Niger, Nigeria, Ghana, Burkina Faso and Senegal. Ghana in 2009 was ranked the 123rd in world ranking in onion production with a production of 76,785 Kg/ha (FAO, 2009). A total of 7,542.78 Mt of onion was produced from 645.23 hectares of land in onion producing areas of Ghana in 2013. However, the average yield of onion as compared to other countries in Africa such as Burkina-Faso and Niger is low (MoFA, 2013).

In Ghana, Onion is widely cultivated on commercial basis in the Northern and Upper regions especially in Bolgatanga and Bawku (Norman, 1992). Onion cultivation in northern Ghana is a source of revenue for farmers, input dealers, middlemen, transporters, and farm labourers (Ghana-Made, 2017). However, cultivation is picking up in other areas with suitable conditions such as Sogakokpe and Akatsi in the Volta Region, Ashaiman and Dawhenya in the Greater Accra Region, Nsawam in the Eastern Region and Prestea in the Western Region (Awuah *et al.*, 2009). The most popular cultivar grown by farmers is the 'Bawku Red' (Abbey *et al* 2000) which is a local variety and yields about 7t/ha (NARSP, 1994). Red Creole and Early Texas Grano are also some examples of the exotic varieties mostly produced by farmers in the country (Abbey *et al*, 2000).

Onion is mostly grown for its bulb but it can be eaten at its tender green stage or after its bulbs is fully developed or matured. It is endowed with flavour and high nutritional values. Onion can be either eaten raw or fresh in salads or cooked as a spice in cooked food items. Onions with high pungency are cooked before eating whiles those with mild pungency can be eaten raw. Highly pungent onions are used in the preparation of soups, stews, and are also preserved as pickles. Spring onion leaves are used in salad preparation and stews as well (Norman, 19992 and Opara, 2003). Onion is also important for culinary.

Nutritionally, onion contains 2.0 g protein, 70 mg calcium and 53 mg phosphorus (Ado, 2001). The crop also contains vitamins, thiamine, riboflavin and niacin (Mettananda and Fordham, 2001). Onions are free of sodium, fat, and cholesterol and provide a number of other important nutrients such as sugar, protein, minerals and water.

Research has it that, onions in our diet helps in preventing heart diseases and other ailments (Sangha and Baring, 2003). Onion is useful in lowering sugar and blood pressure levels and has also been found to be useful and effective in the treatment of boils and wounds (Ageless, 2015). Onion contains a lachrymatic agent, a strong antibiotic together with fungicidal, bacterial, anti-cholesterol, anti- cancer and anti-oxidant components such as quercetin (Baghizadeh *et al*., 2009), which is effective in reducing the risk of contracting cardiovascular diseases and cancers (Smith, 2003).

Onion is widely used world-wide for food and medication thus accounting for its year-round demand (Abbey and Oppong-Konadu, 1997). Supply of onions in Ghana is far below what consumers demand and this could be as a result of low yield resulting from weed infestation, time of planting and production scales (Abbey *et al* 2000).

This has necessitated the importation of dry onion into the country by spending huge foreign exchange. According to FAO (2013), about 34, 37 metric tons of onion is imported into the country annually.

For importations to be reduced in the country, onion farmers need to increase their level of production. As population is expected to increase in the coming years, production of onion has also to be substantially increased to meet consumption demands. This is only feasible when weeds as major constraint is controlled on growing fields as it appears to be a major constraint in onion production. Weeds are ubiquitous to most crops. Other constraints include incidence of disease and pests, unavailability of high-quality planting materials and poor agronomic practices. This is prudent as weeds does not only reduce yield and quality of onion but also make use of essential nutrients in the soil hence necessary for controlling to increase onion production. Weed problems and losses as a result weed competition are a global problem. The potential crop yield loss without proper weed control was estimated at 43% on a global scale (Oerke, 2006). Weeds compete with onions for moisture, light, space and nutrients thereby interfering with the plant's development by reducing bulb yield to about 40-80% (Verma and Singh, 1996). Weeds also habour pests (Boydston *et al*, 2008). Onion (*Allium cepa* L.) cannot endure extensive competition from weeds as a result of its inherent characteristics such as non-branching habit, slow growth rate after planting, shallow fibrous roots and small leaf canopy for shading the soil (Carlson and Kirby, 2005). The frequent watering also creates conducive atmosphere for the growth of weeds which results in competition.

Losses due to weeds vary from crop, weed species, and weed location as well as system of farming (Swinton *et al,* 1994). In direct seeded onions, weed competition is critical from the emergence of the seedlings up to the fourth week (Ghafoor *et al*, 2000). However, onions seeded directly are more sensitive to weed competition than bulbs and seedlings (Corgan *et al*, 2000; Gaskell *et al*, 1998). To reduce loss of yield in onion, onion plants need to be free from weeds for 8 weeks after its emergence since delay in controlling weeds at this period could half the final yield (Gazdag-Torma, 1997).

To reduce weed infestation, methods such as mechanical, biological, chemical and cultural weed managements are used. Also using hoe and cutlass as the most common cultural method of controlling weed is laborious, expensive, time consuming, cumbersome and also sometime not suitable as a result of scarcity of labour (Ckikoye *et al* 2005). This has also led to decrease in production scale.

There is, therefore, the need to adopt an effective weed control measure such as chemical weed management. The use of chemical weed control is wide-spread and had been identified to be effective in Ghana. Because it is cheaper, faster and give better weed control efficiency, it is seen to be better and efficient than any other single weed control measure (Chikkoye *et al*, 2005). According to Dinham (2003), about 87% vegetable farmers worldwide used chemicals to control pests and diseases. Herbicide is, however, the most pesticide used in vegetable production in Ghana. (Dinham, 2003). The nature of onion plant has called for the use of pre-emergence herbicide as one type of herbicide for the control of weeds. This is because, slow germination and slow growth of onion allows weeds to get a head start on it (Rubin, 1990).

In its initial growth cycle, onions do not compete well with weeds. (Rubin, 1990).

The crop also has narrow leaves which cannot inhibit its competitors. These therefore accounts for the need to use pre-emergence herbicide which are applied after soil is prepared or before seeds are sown or seedlings are transplanted to give the onions the opportunity in the growing period against weeds which grows fast and competes well.

A number of pre-emergence herbicides which include Oxadiargyl 400 g/L SC and Pendimethalin 500 glL EC have been introduced in Ghana for controlling weeds in vegetables. Pendimethalin 500 g/L EC has been employed for weed control in pepper and tomatoes but not extensively in onion. Oxadiargyl 400 g/L SC is used for weed control in rice and sugar cane but not extensively in vegetables such as onion.

The choice of herbicide is however often influenced more by availability than suitability. As such, most farmers are now using herbicides indiscriminately by not adopting the most suitable weed management and this has call for the need to assess the impact these herbicides have on the crop and the environment as it can affect the growth, development and quality of the onion produced. Pesticide residues could be left in vegetables and these are more than those taken in from water consumption and inhalation of air (Juraske *et al*, 2007). There is, therefore, also the need to monitor these residues to assess if they exist in vegetables and if they are, either they are above maximum residue limit or do not pose risk to the health of humans.

However, an assessment of the beneficial use of pre-emergence herbicides (Pendimethalin and Oxadiargyl) compared to the manual control in onion production has not been extensively critically examined. It is the line of the above that this study is being conducted to find out the impact of pre-emergence weed management using Pendimethalin and Oxadiargyl on the growth, development and minimum residue levels in two onion (*Alluim cepa* L.) varieties commonly cultivated in Ghana.

1.2 Objectives

The main objective of the study therefore was to assess the impact of pre-emergence weed management using Pendimethalin and Oxadiargyl on soil quality and on growth, development and residue levels in two onion (*Alluim cepa* L.) varieties.

1.3 Specific Objectives

The specific objectives of the study were therefore to:

- Evaluate the effect of the two herbicides (Oxadiargyl and Pendimethalin) on weed management.
- Assess the effect of the herbicides on growth and development of the two onion varieties (Dayo and Bawku Red).
- Assess the effect of the herbicides on soil micro-organisms.

  Determine the residual levels of the herbicides in onion bulb after cultivation for 140 days
- Assess the residual toxicity of the herbicides on succeeding crop (cowpea) using a bioassay.
- Ascertain the profitability of the use of the herbicides in onion cultivation.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Onion Ecology

Onion (*Allium cepa* L.) is a cool season crop but it thrives well over a wide range of temperatures. The crop requires low temperatures during its early stages of growth and development and warm temperature during bulbing, harvesting and curing. Bulbing is mostly determined by day length which ranges from 12 hours for the early maturing cultivars to 15 hours for the late maturing cultivars (Sinnadurai, 1992). High day temperature accelerates rate of bulbing whiles low day temperature delays bulbing of onion (Norman, 1992).

In the Northern part of West Africa, the growing season for onion is between November and April. During this period, the mean day temperature ranges from 33°c to 37°c while the mean night temperatures range from 15°c to 25°c and day length ranges from 12 hours to 18 hours (Tweneboah, 1997). According to Lancaster *et al.* (1996), the thermal time accumulated prior to bulb formation is related to the bulb diameter at bulbing. This implies that bulbing is attained when this photoperiod is reached. When these parameters are not reached, at the appropriate time, bulb formation is therefore likely to delay.

Onion thrives well in a fertile sandy loam soil and requires moderate rainfall. The ideal soil for onion is the one which can hold adequate moisture around the plant’s root zone. The soil should therefore be sandy loam or silt loam. This soil is expected to be fertile, rich in humus and loose to facilitated easy cultivation and expansion of bulbs (Obeng-Ofori *et al*., 2007, Norman, 1992).

Onions are destroyed in waterlogged areas but grow well in loamy soils which are well aerated and drained. Sandy and clayed soils are to be avoided as sandy soil requires organic manure to retain enough moisture whiles clayed soil easily becomes water logged. Heavy soils which are likely to become compacted after rainfall should be avoided in onion cultivation (Tweneboa (1998).

The pH of the soil for cultivation onion should range between 5.8 and 6.5 (Norman, 1992) or 5.8 to 7.0 (Sinnadurai, 1992). According to Raemaekers (2000) onions are sensitive to soils with low pH and can grow well within a pH range of 6.2 and 6.8.

2.2 Importance of Weeds in Crop Production

Weeds account for 45% of the total loss of agricultural produce annually (Rao, 2000). The potential crops yield loss without proper weed control was estimated at 43% on a global scale (Oerke, 2006). Weeds cause yield reduction in crops by competing with crops for nutrients and space and in some instances, using allelopathy to weaken the crop (Cheng and Cheng, 2015). The competiveness as one of the characteristics of weeds is mostly related to loss of crop yield since they make use of nutrients in the soil to the disadvantage of crops (Carralho *et al*, 2007). In onion cultivation, competition of weeds with the crop could result in about 96% yield loss (Bond and Burston, 1996).

Weeds also have other effects on farming. Weeding is tedious and time consuming (Bairtisia and Javier, 2008) and brings high labour and production cost. The high cost of human labour is what has led most farmers to opt for weed management practice which brings about reduction of cost of production (Silva *et al*, 2007). Seeds of weeds can contaminate cultivated crops and as such get reintroduced into fields during successive planting (Benvenuti, 2007). This could result in poor quality seeds and grains. Some weeds also habour pests which can impair crop yield and produce quality (Boydston *et al.*, 2008).

2.3 Weed – Crop Competition

Weeds are unwanted on the basis of competition, allopathy and serving as habitat for pests (Zaman *et al.*, 2011). Factors such as weed density, crop density, planting pattern of crops, rate of growth and mature heights of both weeds and crops as well as time of emergence of both weeds and crops (Liebman and Gallandt, 1997) determines weed-crop competition. Weed-crop competition is severe when resources that are available for the growth of crops become less and hence increase when weeds possess similar vegetative habits and demand same resources as the crop (Rao, 2000).

It has been reported that small seeded annual weeds such as pigweed produces seedlings which have a relative high growth rate than most seedlings of crops (Mohler, 2001). This, notwithstanding, because these weeds are small at emergence, their growth rate is 10 to 100 times slower than that of most crops. Quick growing vegetables such as potato that rapidly develops a closed leaf canopy can overcome competition of many weeds by making use of most of the light that is available. On the other hand, slow growing vegetables such as onion and carrot are highly at risk to weed competition (Mahler, 2001).

Many small-seeded vegetables like cabbage, pepper, lettuce and tomato when nursed and transplanted to the yield gives them a good lead start on weeds. Weeds that have severe impact on crops are those that emerges before the crop. However, those that emerges with or shortly after the cultivation crop can also reduce yield unless these weeds are controlled through cultivation of crops or through other means. On the other hand, the later the weed species emerge in connection to the crop, the less their effect becomes.

Weed-crop interaction is not simple for the various reasons: Firstly, several fields are composed of many weed species which compete to different levels and in different manners with the crop. For instance, fast-growing and tall weeds such as velvetleaf compete more seriously for light then the low-growing weeds species such as Bermuda grass (*Cynodon dactylon*) and nutsedge (*Cyperus rotundus*), however these low-growing weeds can also compete well for water and nutrients as a result of their root systems than tall and fast-growing weeds (Rice, 1995). Secondly, weeds also affect crops by releasing toxic substances through a phenomenon called allopathy (Rice, 1995). Thirdly, through soil microbe, weeds and crops can indirectly interact. This is because one plant species may promote or hinder other plants. Some plants such as the brassica and the sedges do not benefit from mycorrhiza but instead weakened by the fungal infection (Francis and Read, 1995, Vatovec *et al.*, 2005). Thus, mycorrhiza fungi rich soil may give grains, legumes and alliums a necessary edge over weed species such as pigweeds and nutsedge.

2. 4 Weed Control in Vegetable Crops

Weed control many be seen as the process of limiting infestation of weeds so that crops can grow well. Knowledge of the biology of weed species such as their life cycle and their ecology are necessary for adopting the best method and timing of weed control after weeds have been identified. The success of these rests on the period of the implementation (Forcella, 2000). Weed control should be targeted at the critical weed competition stage (Knezevic and Datta, 2015). The term ‘critical period’ refers to the period whereby weeds can be tolerated in the field without affecting yield of crops. First six weeks after transplanting is seen as the critical weed competition period for most vegetable crops (Usoroh, 1979).

There are several methods of weed control which have been adopted in vegetable cultivation. Some of the methods are applied individually whiles others are combined to achieve total weed control.

Methods of weed control may be classified as physical, mechanical, cultural, biological and chemical. The cost of a control method is an important factor that needs to be considered in vegetable weed control.

2.4.1 Physical and mechanical weed control.

Physical and mechanical weed control methods involve the use of tools and implements such as cutlass and hoe and implements such as ploughs and harrows to control weeds. In this method, weed species are removed before sowing vegetable seedlings. This ensures a head start for vegetable seedling to compete with weeds that will emerge at early stages. Hand weeding may be done depending on the degree of infestation of weeds on the field (Hamma and Ibrahim, 2013) as well as the actual season of cultivation. Lamptey (2007) hand weeding can also be used to support chemical weed control. Hand weeding when done properly can control weeds and promote healthy growth of vegetables. On the other hand, hand weeding has certain challenges such as high cost of/and access to labour which has become scarce (McErlich and Boysdston, 2013).

Aside hand weeding being laborious, slow and time consuming, it is something difficult to distinguish between the crop and weeds on the field at the initial growth stage (Rahman *et al*., 2012; Ahmed and Chaham, 2014). This can cause un-intended destruction and loss of the crop.

2.4.2 Cultural weed control.

Cultural weed control employs time, rate of sowing, fertilizer application, cropping systems and crop spacing to control or manage weeds (Verma and Singh, 2008). This method helps crop by reducing weed infestation (Singh, 2014). However, this method alone cannot control weeds sufficiently and is often combined with other methods of weed control (Hatcher and Melander, 2003).

2.4.3 Biological weed control.

Biological weed control encompasses the using of living organisms like insects, plants, birds, pathogens, etc. for controlling weeds on the field. Kolo and Daniya (2006) this method has not been developed fully, however, the use of cattle, sheep and goat for grazing in plantation is mostly practiced in Ghana. Wapshere *et al*. (1989) biological weed control can be based on introducing exotic natural enemies that is adapted to exotic weeds which is host specific, mass production and the release of natural enemies on weeds and also the artificial manipulation of the natural enemy population so as to restrict the level of attack on the weeds to achieve the desire level of control.

2.4.4 Chemical Weed Control.

Herbicides are the chemicals that are used to kill weeds on the field. Rao and Ladha (2013) herbicides have proven to provide economics, efficient and effective weed control that leads to higher crop yields. Several herbicides exist and they can be classified in many ways. One mode of classification is according to their mode of action. Under this classification scheme, herbicides are classified as systemic and contact herbicides (Varshney and Sondhia, 2008).

Contact herbicides act at points where they get in contact with the weeds and they do not move to other parts of the weed. These herbicides are mostly applied to weed foliage. For this to function effectively, adequate coverage and absorption of weed foliage is required. Raining soon after application of foliar contact herbicide will disrupt it functioning. On the other hand, systemic herbicides act by translocating throughout the weed in other to kill it. Examples of systemic herbicides include Pendimethalin, and Oxadiargyl.

Selectivity of herbicides also play a major role in controlling weeds as the application leads to the control of some specific weed type such as grasses, broadleaf or sedges. For instance, 2, 4-D, controls only broadleaf weeds. Herbicides such as paraquat and glyphosate kill almost all kinds of weeds. Therefore, another mode of herbicide classification is based on selectivity, which classifies the weed as selective or non-selective.

Another mode of classification of weeds is based on the time of emergence of the weeds. This places weeds into post emergence or pre-emergence groups.

2.5 Fate of Soil Applied Herbicide

In accordance with their formulation, soil-applied herbicides can control weeds within a time frame. However, the fate of soil applied herbicides rests in processes such as volatilization, leaching, degradation by microbes, plants and soil and chemical degradation (Sondhia, 2013).

Volatilization of herbicides occurs as herbicides pass into the gaseous phase and also move about on the breeze. It mostly occurs during the application of the herbicide but can also occur after deposition of herbicides on the surface of the soil. Primarily, the volatility of herbicide is determined by its molecular weight. According to Helling *et al*., (1971), volatility generally increases with temperature and moisture increases and a decrease in clay and organic matter content. Volatility of herbicides can be changed by the use of surfactant (Que Hee and Sutherland, 1981). However, in extreme cases, losses as a result of volatilization can be up to 80 or 90% of the total herbicide that is applied (Taylor and Glotfelty, 1988).

Leaching refers to the movement of herbicides through the soil with water. Some of this movement occurs naturally. This distributes the herbicide to different depths. Factors such as soil texture, soil structure, herbicide solubility and the amount and intensity of rainfall are what the loss of herbicides to leaching depends on (Moomaw *et.al.*, 1992). Heavy rainfall just after herbicide application may cause herbicides to leach from its active zone. This may result in poor weed control. Herbicides such as paraquat and glyphosate that can be absorbed strongly to soil particles cannot be leached unless these soil particles are carried by the water (Varshney and Sondhia, 2008). According to Sondhia, (2007), about 80% of Pendimethalin applied to clay loam soil was found to be present in 0-12 cm of the soil depth which indicates slow mobility of applied Pendimethalin in clay loam soil.

2.6 Degradation of Herbicide in Soil

The soil contains a mixture of living and non-living things which interact with each other. Many processes influence soil properties and affect the plants and animal population that are found in the soil. The fate of soil applied herbicide rests on the toxic concentration of the herbicide that enters the roots and or shoots of the weeds (Sherwani *et. al*., 2015)

A soil-applied herbicide becomes unavailable when it is applied into the soil layers such that it is beyond the reach of the roots of the weeds or when decomposed by soil microorganisms. The distribution of herbicides in the soil is primarily determined by the amount, type, surface area of clays and organic matter in the soil, amount and quality of soil moisture, soil temperature and soil pH (Helling *et al*., 1971). These can be strongly influenced by rainfall and amount of leaching.

2.7 Microbial Degradation of Herbicides

Herbicides which are used for the control of weeds when released into the environment sometimes come into contact with some no-targets organisms. Microbial degradation is about the decomposition through microbial metabolism. Different microbes can degrade different herbicides, however, the rate of microbial degradation rests or depends on the microbial community that is available or present in a given situation (Voos and Groffman, 1997). Microorganisms in the soil may include bacteria, fungi and actiriomcetes. Soil conditions such as warmth, pH levels affect microbial degradation. Herbicides may be degraded microbially through one of the two means. They may be directly metabolized when they serve as source of energy and carbon for microorganisms (Hutzinger, 1981) or they may be co-metabolized together with a naturally occurring good source that supports the microorganisms. Microorganisms may have the ability to attack, detoxify and use this herbicide applied to the soil as energy source. The population of these microorganisms that used the herbicide as energy source may increase, however, the population may return to the original level or a level greater than before herbicide application when the herbicide is degraded (Varshney and Sondhia, 2008). More rapid herbicide degradation may therefore occur through subsequent herbicide application when population increases (Varshney and Sondhia, 2008). Notwithstanding, microbes only have access to herbicides to degrade when they are in soil solution. This means that during drought, herbicides may be bind to the soil particles and may be less in soil solution.

2.8 Degradation of Herbicides in Plants

All biological organisms have the ability to develop a defensive mechanism that helps them to nullify the impact of some amount of chemicals. Herbicides are greatly absorbed by the leaves or roots of highly hydrated plants when moisture condition of the soil is normal. Herbicides are degraded by tolerant crops whiles susceptible ones die off (Rana and Rana, 2015) Drought-stressed plants are mostly less susceptible to herbicides or may require high rate of herbicide for effectiveness. During periods of drought, plants develop thicker cuticle which reduces transpiration and renders foliar uptake of the herbicide very difficult (Subramanian *et al*., 1990). According to Subramanian *et al*., (1990), plants are less able to degrade herbicides applied when they are under stress. Some herbicides are able to bind strongly to soil particles and released slowly into the soil water hence may remain longer than loosely bounded herbicides.

2.9. Chemical Degradation of Herbicides

Chemical degradation of herbicides occurs when a non-biological chemical reaction turns the active ingredients in the herbicide into a non-active secondary molecule. Chemical degradation of herbicide is degradation driven by chemical reactions such as hydrolysis, oxidation and disassociation. The most common chemical degradation is hydrolysis. This is dependent on pH and temperature. Degradation in hydrolysis is faster in acidic rather than in neutral or basic conditions and at high temperature.

In herbicides like the sulfonylureas, degradation is reduced or even stopped when pH rises above 7, however, moisture is required for the degradation to occur. Chemical degradation can take place across any section of the soil profile.

2.10 Fate of Herbicide and its residues in the Environment

In the last century, pesticides and agrochemicals has become an important factor in agriculture worldwide which results in an appreciable increase in the yield of crops (Alexandratos and Bruinsma, 2012). However, agrochemical residues in recent times is causing contamination of the terrestrial ecosystem and food poisoning as it spreads in the environment (EEA, 2013). In general, chemical compounds can undergo many chemical transformations and can therefore be transferred to other areas which are not within the application area and mount toxic effects on species that are not targeted (Taylor *et al*., 2003).

The most important factor that determines the fate of herbicides in the environment is its solubility in water (Hutzinger, 1981). Water-soluble herbicides mostly have low adsorption capacities and are more mobile in the environment. The use of herbicides for crop production has become integral part of most vegetable farmers in Ghana because of its effectiveness in terms of weed control. The main aim of herbicides application as a weed control method is to reduce the infestation of weeds so as to maximize the yield of crops. However, wrongful application can lead to pollution of the environment (Kerle *et al*., 2007). These can pollute surrounding water bodies, air, soil, plants and other organisms that lives in the soil. Herbicides in the environment can also be adsorbed on to organic matter.

2.11 Fate of Herbicides in Plants

The fate of herbicides in plants is very important because it influences its selectivity and usage. Herbicides predominantly enter plants by contact with the roots and the foliage. The herbicide will release its toxic effect at the site of contact or may move to other sites in the plant where its toxicity can be felt in either way

According to Mercado (1979), for herbicide to be phototoxic, it has to absorb in sufficient quantities, translocated to the site of action and stay in its active state for a reasonable length of time. Herbicides in plants undergo chemical reaction which is broken down by specific enzymes, however, some appear to be non-enzymatic. The rate at which herbicide is degraded within the plant in the course of its uptake and translocation rests on the concentration of herbicide at the site of action in the plant as only a fraction of herbicide applied to a plant gets to its site of action within the plant. Herbicides are also inactivated in plants through biochemical and chemical processes such as oxidation, hydrolysis, deamination, decarboxylation, dehalogenation, conjugation, etc. (Subramanian *et al*., 1999).

2.12 Composition and Mode of Action of Herbicides used in the Study.

2.12.1 TopStar (Oxadiargyl 400 g/L Sc)

The active ingredient in topstar is Oxadiargyl. Oxadiargyl (3- [2, 4-dichoro-5-(2-propynyloxy) phenyl]-5-(1, 1-dimethylethyl)-1, 3, 4-oxadiazol-2 (3H)-One) with CAS (Chemical Abstracts Service) number 39807-15-3 is a selective pre and post emergent herbicide that belongs to the Oxadiazole group. Oxadiargyl has a molecular weight of 341.1893, density of 1.484 (20°c), melting point of 131°c, vapour pressure of 2.5×10^{-3} m Pa, and water solubility of 0.37 mg/l.

It has an octanol-water partition coefficient (log P) of 3.70. The herbicide activity of Oxadiargyl lies in binding to the protoporphyrinogen oxidase 1X as an inhibitor which prevent light-induced peroxidation and interrupt photosynthesis as a result. Increase in the concentration of Oxadiargyl decreases the growth of roots and the main stem significantly. Oxadiargyl is developed to control annual grasses, annual sedges and broad-leaved weeds in rice (Dickman *et al*., 1997).

Phytotoxic symptoms include leaf and stem browning, reduction in number of tillers and crop stunting. Topstar (Oxadiargyl 400 g/L Sc) is both pre and early post emergent herbicide. Oxadiargyl is reported to be effective in the control of annual grasses, annual sedges and broad-leaved weeds in onion, sugarcane, rice, potato, sunflower, tomato, and many other crops (Mirza-Hasanuzzaman *et al.*, 2009).

Oxadiargyl was reported by Nikkolora and Baeva, (2000) to be highly effective in the control of annual grasses and broadleaves in vegetables such as onion, tomato, cabbage, pepper and celery. Oxadiargyl acts at germination as new shoots come in contact with treated soil (Dickmann *et al.*, 1997). It was effective in controlling annual grasses and broad-leaved weeds in some vegetable (onion, celery, tomato, cabbage and pepper) (Tracchi *et al.*, 1997). Oxadiargyl treatment decreased annual grasses significantly and increased growth and yield of onion (Gaikwad *et al.*, 2010)

2.12.2 Agristomp (Pendimethalin 456 g/L CS)

The active ingredient in Agristomp is pendimethalin. Pendimethalin (N- (1- ethylpropyl) 2, 6 – dinitro-3,4-xylidine) is a selective pre-emergent herbicide for the control of most annual grasses and many annual broadleaved weeds in onion and other crops such as in maize, rice, sorghum, cabbage, soy beans, groundnut, cowpea, cotton, sunflower, tomato and pepper.

It belongs to denitroanilines group. Pendimethalin is available as a granular, emulsifiable concentrate or wettable powder. Its soil half-life is 90 days (Miller and Bloese, 1999). Products containing pendimeethalin rang from slightly to highly flammable. It is decomposed slowly by light and highly absorbed in clay soil particles.

Pendimethalin has a chemical formula $C_{13}H_{19}N_3O_4$, molecular mass of 281.2gmol, melting point of 56c and a boiling point of 246.cPedimethalin range in volatility and susceptibility to photodegradation. Denitroaniline is not physically mixed into the soil and as such requires rainfall or moisture to wash it into the seed germination zone of the soil. Pendimethalin is influenced by cultivation practices, temperature of soil, soil moisture and also soil type (Smith *et al.*, 1997). Pendimethalin is also characterized by low water solubility, vapour pressure, strong adsorption to soil surface as well as high octanol water partition coefficients.

The movement of Pendimethalin in surface runoffs as well as leaching is low except in cases where soil erosion results in sediment transport of the adsorbed herbicide (Chopra *et al*., 2010). Singh *et al* (1994) found initial dissipation rate more acute during first 40 days in which more than 60% degrade and rate slowed down after 80 days and at 240 days 90% was dissipated. According to Roca *et al*., (2009), the U S Environmental Protection Agency has classified pendimethalin as persistent- bioaccumulative toxics.

Zimdahl *et al*., (1984) stated that, there is faster degradation of Pendimethalin with an increase in temperature and the level of moisture. It is generally degraded by oxidation of the benzene ring and the N-ethlpropyl group Pendimethalin is subject to a variety of abiotic as well as biotic transformation processes (Jazwa *et al*., 2009). It is absorbed by the roots and leaves and taken up by germinating seedlings and inhibit root growth, cell division and cell elongation. Affected plants die immediately after germination or emergence from the soil.

There is also microtubule assembly inhibition. Once absorbed into plants tissue, translocation is limited and break down via oxidation. Pendimethalin is taken up in small quantities by monocots and in moderate quantities by dicots. It may be removed from water by its strong tendency to bind to sediments and organic. Application of Pendimethalin alone or in combination with weeding showed the longest period to weed re-emergence ranging between 39 to 41 days (Tetteh *et al.*, 2011).

However, application of pre-emergence herbicide without supplementary weeding could not provide long weed control as they have short persistence (Olorunmaiye, 2009). The efficacy of Pendimethalin may be lost due to its volatile nature (Rao, 2000).

2.13 Effects of Herbicide on Soil Microbial population

Soil microbes have positive impact on many ecosystem services such as pedogenesis, improving soil structure, recycling nutrients, water regulation, climate regulation, etc. (Blouin *et al*, 2013). Bacteria, fungi, algae and actynomycetes which are the main organisms in the soil play critical roles in organic matter decomposition and nutrient cycling which both affect soil fertility and growth of plants (Pandey *et al.,* 2007).

The number of these soil microorganisms may be affected by agricultural practices such as herbicide weed control. Through the application of herbicide, more importantly pre-emergence herbicides, some of the organisms have the ability to degrade the herbicide whiles others are greatly affected depending on the rate of herbicide applied and the type of herbicide applied (Sebiomo *et al.*, 2011).

According to Tyuryukanova *et al.*, (1987), herbicides decrease microbial biomass in the soil. Khuntia *et al.,* (2013), reported that, all herbicides impacted detrimental effect on soil microflora up to 15 days after application which was later on recorded. Oxadiargyl at 0.1kkg/ha showed minimum bacteria population at 15 days after planting which could be attributed to phytotoxic effect of this chemical on rice plant and the soil

2.14 Comparison of Cost effectiveness of Weed control using cultural and chemical methods.

The choice of a cost-effective weed control method often calls for a debate. Many vegetable farmers perceive chemical weed control as expensive. Chemical weed control when properly used will bring many benefits. According to Chikoye *et al*., (2007), herbicides produce greater yield at lower cost than hand weeding thus its use in vegetable farming.

Hand weeding has proven to be effective in controlling weeds. According to Upadhyay and Chaudhary (1979), hand weeding or hoe weeding at three and six weeks after sowing was more economical as compared to applying herbicide. Application of hand hoeing recorded the highest yield and effective weed control in onion (Khan *et al*., 2005; El-Metwally *et al*., 2010). However, there is drudgery and cost associated with weed control by the use of hand weeding. Much energy is used in removing weeds by hand, yet there is low crop yield as a result of weed completion resulting from untimely and ineffective weed control (Chikoye *et al.,* 2004). Labour is costly in vegetable production. Whiles it cost continues to rise, its availability has also become very scarce. (Siresind *et al*., 2009).

It can be deduced from research that there is cost advantage and disadvantage regarding the use of both chemical and hand weeding weed control methods. The knowledge of cost effectiveness of using a certain weed control method will assist farmers to assess the cost involved in cultivating a particular crop. The method that costs least is always selected when cost and its benefit of the result reveals the same yield.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Introduction

Two different field experiments were conducted at the University of Ghana farm, Legon, in the Greater Accra Region of the Republic of Ghana. The experiments were conducted from September, 2018 to March, 2019.

The first experiment assessed the impact of pre-emergence weed management using Pendimethalin and Oxadiargyl on growth, development and minimum residue levels in two onion (*Allium cepa*) varieties ("Bawku Red" and Dayo).

3.2 Experimental Site

The experimental site located in the coastal savannah ecological zone of Ghana falls on latitude $5^{o}39'_{N}$ and longitude $0^{0}11'$W. The soil at the experimental site is the "Adenta" series. The topsoil was sandy loam, pale brown to brown soil, loose and inherently poor in fertility.

. This soil was classified by the soil Research Institute, Ghana in 1999 (FAO/UNESCO, 1990) as Ferric Acrisol.

Rainfall at experimental site is bi-modal. The main rainfall season is from April to July whiles the minor rainfall season is from August to October.

Rainfall and temperature readings at the experimental site during the study are indicated in Table 3.0 below. There was no rainfall in the month of January, 2019.

Table 3.1: Rainfall and temperature at experimental site during the experimental period.

YEAR	**MONTH**	**RAINFALL** (mm)	**TEMPERATURE (°C)**	
			Minimum	Maximum
2018	September	34.8	23.6	29.7
	October	133.3	23.7	30.9
	November	71.8	24.5	31.7
	December	6.0	24.6	32.5
2019	January	0.0	24.9	33.0
	February	53.2	25.4	32.9
	March	55.7	24.9	33.1

Source: Ghana Meteorological Agency, Mempeasem, Legon, Accra, Ghana.

3.3 Experimental design and treatments

The experimental design used for the research was split plot design in RCBD with five (5) herbicide treatments as main-plot factors and four (4) replications on two onion varieties as sub-plot factors. Two different types of pre-emergence herbicides were used at two different rates each which included the manufacture's rate and a lower rate. The two pre-emergence herbicides used were Topstar® (Oxadiargyl 400g/LSC) and Agristomp® (Pendimethalins 456 g/L EC). Hand weeding was used as the control.

The five (5) treatment**s** used were therefore as follows:

Topstar ® (Oxadiargyl 400g/L SC)

T1 = 0.5 L/ha (Manufacturer's recommended rate)

T2 = 0.4 L/ha (Lower rate)

Agristomp® (Pendimethalin 456 g/L EC)

T3 = 1.25 L/ha (manufacturers recommended rate)

T4 = 1.00 L/ha (Low rate)

Hand weeding

T5 = hand weeding (control)

A 15L knapsack sprayer with a flow rate of 1.01 L/min, swath width of 1.3m and a volume application rate of 250 L/ha was used for the herbicide application. Plots were moistened before treatments were applied. Both herbicides (Topstar and Agristomp) were applied one week before transplanting of onion seedlings.

3.4 Land preparation and experimental layout.

Prior to land preparation at the experimental site at Legon, the weed species at the site were identified by total reconnaissance survey. Germination test was also conducted on the two varieties (Dayo and Bawku Red) to ascertain the germination percentage.

The experimental site was slashed and ploughed and plots were pegged. Each plot measured 1.5m x 2.1m. The inter-plot distance was 0.5 m whiles inter-block distance was 1m. There were 140 plants (10 rows and 14 columns) at a spacing of 15cm by 15cm.

The 10 plants at the center of each plot were tagged and used as record plants for checking vegetative growth parameters.

3.5 Cultural practices

3.5.1 Nursery and its management

The Nursery area was cleared and nursey beds were prepared for the two onion varieties (Dayo and "Bawku" Red). The seeds of the two onion varieties were nursed on 14th August, 2018.

3.5.2 Transplanting

The seedling of both onion varieties was transplanted onto the main experimental plots on 24th September, 2018; a week after treatments were applied when they were six weeks old. Three days before transplanting, seedlings of both varieties were hardened off by reducing water while increasing intensity of sunlight at the nursery by removing the shade from the seedlings.

3.5.3. Irrigation

The plants on all plots were watered as and when necessary. This was done most of the time on daily basis taking into cognizance the soil and the climatic conditions at the experiment site. Watering was done to ensure that there was enough moisture in the soil at field capacity within the root area or zone of the plants. Watering was done using 12L watering cans with fine nozzle.

3.5.4 Weeding

Control plots were weeded every three (3) weeks. This was done to control weeds on control plots. Weeds on Pendimethalin treated plots were first weeded at week 9 while Oxadiargyl treated plots were not weeded throughout the experimental period. Inter-plot and inter-block weeds were cleared every fortnight by hoeing

3.5.5 Pest and Disease management

Insects such as grasshoppers, cutworms and semi loopers were controlled by spraying PROTECT 1.9 EC^{TM} (Emamectin Benzoate 19.2 g/L) and JMS STYLET-OIL (Paraffinic oil 97.1%) combined. First application was done at a rate of 30 ml of Protect plus 10 ml of JMS stylet oil in 15L knapsack sprayer and subsequent applications were done at a rate of 20 ml of protect plus 10 ml of JMS stylet oil. Application was repeated every two weeks till two weeks to physiological maturity. In controlling onion twister fungal disease infestation, Bendazim 50WP (carbendazim 500 G/KG) and Agrithane® (Mancozeb 80WP) were sprayed at two weeks interval. This was later reduced to one week upon severity of disease.

Antracol® 70WP (Propineb 70% WP) was sprayed at interval of 5 to 7 days to control purple bluch disease at 115-150 g per 15L knapsack.

3.6 Laboratory analysis of soil samples.

The analysis of soil was carried out at the Soil Science Department of University of Ghana, Legon.

Soil samples were taken randomly from the experimental site before herbicide treatments, one (1) month after treatments application and after harvesting. Soil samples were taken from a depth of 0-15cm. All plant materials that were not decomposed and stones were removed from the samples.

Fresh soil samples were used to check initial microbial count before air-drying for other analysis. After treatment application, and whiles plants were growing, soil samples were taking from the experimental plots for chemical analysis and microbial count. Samples drawn from a representative sample as two plots (variety 1 and variety 2) receiving the same rate of herbicide were put together and sampled from it to be one sample. This generated five samples per block whiles there were four (4) replications.

Same procedure was used for the final analysis which was done after harvesting to determine microbial population and other chemical properties.

3.6.1 Effect of pre-emergence herbicides (Pendimethalin and Oxadiargyl) and hand weeding (control) on soil microbial population.

Before herbicides were applied, soil samples were taken from the experimental site with the aid of a hand trowel. The soil samples were put in a zip-lock transparent polythene bag. All the labelled polythene bags were then placed in an ice chest which contain ice cubes and sent to the Soil Science Department of the University of Ghana, Legon for soil microbial population analysis to be carried.

This process was repeated one month after treatment application and after harvest. Soil samples were taken from two plots in one replication that received the same treatment and sampled from it to represent that treatment. Soil samples of various treatments were analysed at the Soil Science Department of the University of Ghana, Legon.

The analysis was done by weighting 35 g of nutrient agar and dissolving it in one litre (1L) of distilled water. This was autoclaved at 15 lbs at 121^{o}C for 15 minutes for sterilization. Ringer solution was prepared using sodium chloride, calcium chloride, potassium chloride and sodium thiosulphate salts. This was also autoclaved for 15 minutes for sterilization.

Ten (10g) grams of each soil sample was weighed into 90 mls of the diluent which was the ringer solution prepared from the salt samples. This was shaken for 30 minutes and allowed to settle. One (1ml) milliliter of the 10g in 90mls was transferred into test tubes containing 90m/s of the diluent and sterilized at 150^{o}C for 3-5 hours.

Using the pour plate method, 1ml of the minus three (-3) plated into a petri dish and 10 mls of the nutrient agar was added to the 1ml of the serial dilution of the minus three (-3), swirled to mix the diluent and the nutrient agar and allowed to set and incubated at a temperature of 37^{o}C for between 18-24 hours. Colonies that were formed in the Petri dishes were enumerated.

The process was carried out in a laminar flow cabinet to prevent contamination.

3.6.2 Determination of soil pH

Soil pH was determined using the electrometric method by Peech (1965). (Refer to appendix 2 for details)

3.7 Data collection

3.7.1 Data on weeds

3.7.1.1 Reconnaissance survey

Total reconnaissance survey was done at the experimental site to identify weeds present before land preparation and treatment application.

3.7.1.2 Weed Type

The type of weeds on all forty (40) experimental plots were recorded at weeks three, six, nine and twelve after transplanting.

3.7.1.3 Days to weed emergence

The number of days to weed emergence per treatment were recorded.

3.7.1.4 Number of weeds

The number of weeds on each plot was checked every three weeks. This was done by throwing a 20 cm by 20 cm quadrat three times on treatment plots. Weeds that fell within the quadrat were counted and averaged.

3.7.1.5 Weed biomass

Weed biomass per plot of the various treatments were recorded, oven-dried at 70°c for three days and dry weight recorded.

3.7.2 Vegetative growth characteristics of onion

Ten (10) bordered plants were tagged on each plot and used to check vegetative growth characteristics of onion.

3.7.2.1 Percentage crop establishment

Crop establishment 7 and 14 days after transplanting (DAT) were estimated by counting all the plants on each plot and dividing through by the number planted multiplied by 100 to determine percentage crop establishment.

3.7.2.2 Number of leaves per plant

The total number of leaves of the 10 plants that were tagged were counted every fortnight which commenced from week 4 after transplanting till week 12. The means number of leaves per tagged plants for each treatment plot was calculated.

3.7.2.3 Plant height (cm)

Plant height was taken from week 4 after transplanting and continued every fortnight till week 12. The height of plant was measured from the base of the plant on soil to the tip of the longest leaf. The mean plant height for the 10 tagged plants for each plot was determined.

3.7.2.4 Leaf length (cm)

The leaf length of all the 10 tagged plants was taken from week 4 after transplanting and continued till week 12. The longest leaf of the onion plant was measured with a meter rule. This was done from the base of the longest leaf to the apex of it and the mean for each treatment plot was determined.

3.7.2.5 Leaf diameter (mm)

The leaf diameter for all 10 tagged plants was determined. Leaf diameter was determined by measuring the largest or maximum diameter of the longest leaf. This was done by using a digital caliper. The mean leaf diameter for each plot was determined.

3.7.2.6 Neck girth (mm)

The stem girth for the 10 tagged plants was taken. This was done at week 12. This was done by using a pair of digital calipers to measure the girth of all the 10 tagged plants and the mean for each treatment plot was determined.

3.7.2.7 Chlorophyll content (spad)

Five record plants were used to check chlorophyll content. The longest leaf was splited and chlorophyll checked from three different spots.

3.7.2.8 Fresh and dry plan biomass

Five plants which had not been tagged from each plot were used. The fresh weights of the five plants were taken using an electronic balance. The sampled plants were then oven dried at 70^0C for 72 hours. The dried plant samples were later weighed by using the electronic balance.

3.7.2.9 Days to 50% bulb formation.

Tagged plants were closely monitored to determine the number of days it took for 50% of bulb formation of the plants within the one meter (1m) harvestable area. Bulb appearance started when there was an enlargement of the plant at its base regions. These regions assumed a purple colour which was the colour of the bulb.

3.7.2.10 Days to physiological maturity

Days to physiological maturity was determined by checking the number of days from transplanting to the day at which about 90% more of plants had their leaves turning yellow.

3.7.3 Yield and yield components

Plants within one-meter ($1m^2$) square were used for data on yield and yield components.

3.7.3.1 Mean bulb weight

Ten bulbs from the tagged plants were weighed with a digital weighting scaled and the mean bulb weight from each treatment plot was determined.

3.7.3.2 Bulb diameter

Bulb diameter was taken by taking the width at the middle of the bulb which is the widest point with a pair of vernier calipers. The mean bulb diameter was determined for each plot.

3.7.3.3 Bulb length

This was determined by measuring the length of the ten selected bulbs at their widest point using a pair vernier caliper. The mean bulb length was calculated for each treated plot.

3.7.3.4 Bulb grading

Based on bulb diameter, bulbs with a diameter less than 30 mm were graded as small, those with diameter between 31-50 mm were graded as medium whiles those with diameter greater than 50 mm were graded as large.

3.7.3.5 Total bulb yield

The total bulb yield for each treatment plot was computed based on the weight of the bulb harvested from $1m^2$ per plot. The weight values obtained from each treatment plot was converted into yield in tons per hectare.

3.7.3.6: Marketable bulb yield

Marketable bulb yield was determined after bulbs with diameter less than 10mm, rotten bulbs and discoloured bulbs were discarded. The mean marketable bulb yield for each treatment plot was determined.

3.7.3.7 Cost benefit analysis

Cost benefit analysis was determined to evaluate the profitability of Dayo and ‘’Bewku Red’’ onion production under the various soil treatments. The net revenue (NR) was determined from the total revenue (TR) and cost of production (CP). Mathernatically, NR=TR – CP

3.8 Laboratory herbicide residue analysis of onion bulbs

After harvesting, samples of onion bulbs were collected. This was done by putting bulbs from all replications together and later sampled for evaluation.

In all, ten samples were collected from the forty plots for the herbicide residue analysis.

Before the analysis, samples were labelled and kept in the refrigerator to help maintain chemical residues as drying could break the chemical down or lead to volatilization.

3.8.1 Determining herbicide (Pendimethalin and Oxadiargyl) residues in onion bulb

Samples of onion bulbs were analyzed at the Ghana Standard Authority to determine if there were traces of the herbicides used and how much or the level of herbicide present in the onion if any. The tool used for analysis was Liquid Chromatography coupled with Mass Spectrometer. The instrument used was the Agilent 6420 triple Quadruple LCMS.

The column used for the analysis was Agilent Eclipse plus C18 with a packing material of 1.8 microns (1.8u) at a length of 50mm. The software used for the analysis was Mass Hunter workstation software; LC/MS Data Acquisition for 6400 series Triple Quadrupole. The version was B.07.00.

The standards used were Pendimethalin and Oxadiargyl. The solvent used for the extraction was acetonitrile. This was what the standards dissolve in. Preparation of calibration was firs done in the reference standard room. There were four calibration used and these were 500 ppb, 200 ppb, 100ppb and 50ppb. These were done to feed the instrument for proper detection and quantification.

Before getting samples for the instrument, onions samples were homogenized at the sample preparation room by using Foss homogenizer 2096 for blending the onion samples.

Samples were taken to the extraction room and 10 g were taken from each sample by using a digital balance. 10 m/s of acetonitrile which was the extraction solvent was added to each sample and voltex for 2 minutes. Extraction salts were later added to each sample. Extraction salts used were

i. Magnesium sulphate anhydrous (4g)
ii. di- sodium hydrogen citrate sesquihydrate (0.5g)
iii. tri-sodium citrate dihydrate (1g)
iv. sodium chloride (1g)

Samples were put in the vortex for 5 minutes to shake them. These were later put in the centrifuge for five (5) minutes. It spined samples at 3500 revolution per minutes. Again, 6m/s of each sample was drawn and put into clean up salts. The clean-up salts used were primary secondary Amine (PSA) and Magnesium sulphate. Samples were again taken to the vortexes for 1 minute, after which they were sent to the centrifuge again for 5 minutes. 1ml out of the 6mls of each sample was taken and sent to be analysed.

Agilent 1290 liquid chromatograph using 0.1% Formic Acid (FA) in Acetonitrile (ACN) and 0.1% Formic acid (FA) in water (H_2O) was used in the chromatography process.

Samples from the chromatograph moved to the detector which is the mass spectrometer specifically Agilent 6420 triple Quadrupole LCMS for identification.

From the detector, sample moved to calibration to detect values; that is concentration against the response or area. For quality of work, acetonitrile, reagent blank and spike were prepared and used for quality control check.

Results were finally displayed to show which sample contained what component or standard and at what retention time, what response, what concentration in part per billion (ppb) and at what accuracy.

3.9 Evaluation of Residual toxicity of herbicides on succeeding crop (cowpea)

3.9.1 Introduction

Field evaluation was conducted at the University of Ghana research farm, Legon in the Greater Accra Region of the Republic of Ghana. The experiment was conducted from January, 2019 to March, 2019. Field evaluation of residual toxicity of the two herbicides was conducted 30 days after harvesting using cowpea bioassay.

3.9.2 Experiment design and treatments

Bioassay was used in Experiment 2 to evaluate the residual toxicity of the herbicide treatments on a succeeding crop (cowpea). Split-plot design was used. Herbicide treatments were already in the soil hence treatments were not applied again. Plots used for the experiment one were used for experiment two as cowpea were grown on all Dayo and Bawku red treatment plots. Thus cowpea on Dayo treatment plots and cowpea on Bawku red treatment plots. Plots were not combined nor shelved

3.9.3 Land preparation

Before land preparation for the second experiment, weeds that had emerged on each treated plot was assessed and identified. Plots were later cleared of all weeds to make room for sowing of cowpea seeds on 30th January, 2019, 4 weeks after harvest.

3.9.4 Cultural practices

3.9.4.1 Sowing of cowpea (black eye) seeds

Cowpea seeds were sown at a spacing 60 cm ×20 cm at two seeds per hill. Four plants at the centre of each of the treatment plots were tagged and used to check chlorophyll content at 2 and 4 weeks after transplanting.

3.9.4.2 Irrigation

The plants on all plots were uniformly watered as and when necessary.

3.9.5 Data collection

Field data was taken on weeds and cowpea.

3.9.5.1 Weed data

Total reconnaissance survey was done on all plots before land preparation and weeds present documented.

3.9.5.1.1 Weed biomass

Weed biomass of all experiment plots were checked and recorded. 20 cm ×20 cm quadrate was thrown and weeds within removed, identified, counted and over-dried at 70^{o}C for three days. Fresh weight after over-dried was also recorded. This was done at week two and week four.

3.9.5.2 Plant data

3.9.5.2.1 Days of seed emergence

Number of days it took for all seeds liable to germinate to emerge were recorded for all plots.

3.9.5.2.2 Number of seeds emerged

Number of seeds that emerged on each day till 7 days were counted and recorded. These were converted into percentages.

3.9.5.2.3 Plants chlorophyll content (spad)

Four plants at the center of each plot were tagged and used to check average chlorophyll of plants at week two and week four. Two trifoliate leaves on each plant was used and the average used to represent that plant. Average for all the four (4) plants were used to represent the plot.

3.9.5.2.4 Plant biomass

Ten plants were uprooted from each plot and used to check plant biomass. Fresh weight was taken for each plot before over- dried for 72 hours at 70^{o}C. Dry weight was finally taken using the electronic scale

3.10 Data analysis

Data collected was subjected to analysis of variance (ANOVA) using GenStat 12.0 edition software. Means were separated using the Least Significant Difference at P< 0.05

CHAPTER FOUR

4.0 RESULTS

4.1 Weed species identified on the experimental plots before and after application of herbicides

Thirty weed species belonging to twelve (12) weed families (Table 4.1) were identified on the field. Weed families that dominated were Poaceae, Fabeceae, Euphorbiaceae, Portulacaceae whiles Verbena, Amarantheceae, Aizoaceae and Cleomaceae constituted the minor weed families on the field. Broadleaved weed species dominated followed by grasses and then sedges.

Table 4.1. Weeds species identified on the experimental field before herbicide applications.

Genus and species name	Family	Classification
Indigofera hirsute	Fabaceae	Broad leaf
Stachytarpheta cayennensis	Verbena	Broad leaf
Trianthema portulaecastrum	Aizoaceae	Broad leaf
Cleome viscosa	Cleomaceae	Broad leaf
Celosia laxa	Amaranthaceae	Broad leaf
Memosa pudica	Fabaceae	Broad leaf
Phyllanthus amarus	Euphorbiaceae	Broad leaf
Euphorbia hirta	Euphorbiaceae	Broad leaf
Croton lobatus	Euphorbiaceae	Broad leaf
Senna obtusfolia	Fabaceae	Broad leaf
Acanthospernum hispidum	Asteraceae	Broad leaf
Synedrella nodiflora	Asteraceae	Broad leaf
Ageratum conyzoides	Asteraceae	Broad leaf
Portulaca quadrifida	Portulacaceae	Broad leaf
Talinum triangulare	Portulacaceae	Broad leaf
Oldenlandia corymbosa	Rubiaceae	Broad leaf
Richardia brasiliensis	Rubiaceae	Broad leaf
Commelina benghalensis	Commelinaceae	Broad leaf
Dactyloctenium aegyptium	Fabaceae	Grass
Digitaria horizontalis	Poaceae	Grass
Brachiaria lata	Fabaceae	Grass
Megathyrsus maximum	Fabaceae	Grass
Eleusine indica	Fabaceae	Grass
Setaria pallide-fusca	Fabaceae	Grass
Rottboellia cochinchinensis	Fabaceae	Grass
Pastaliem ordiculare	Fabaceae	Grass
Cyperus haspan	Cyperaceae	Sedge
Cyperus rotundus	Cyperaceae	Sedge

4.1.1 Effect of pre-emergence herbicide applications on weed emergence

Significant differences in the mean number of days to weeds emergence after pre –emergence herbicide application (P<0.05) at the experimental site was observed (Table 4.2). The longest number of days to re-emergence (48.0) was observed on plots treated with Oxadiargyl (0.5 l/ha). Hand weeded plots resulted in the shortest number of days to weeds emergence (7.0). There was no significant varietal effect on the number of days for weed re-emergence. Similarly, variety and herbicide interaction was not significant.

Table 4.2 Number of days to weeds emergence as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Treatments	Days to weed emergence		
	Bawku Red	Dayo	Mean
Hand weeding	7	7	7
Oxadiargyl 0.4 L/ha	46	45	45
Oxadiargyl 0.5 L/ha	46	48	47
Pendimethalin 1.00 L/ha	32	31	31
Pendimethalin 1.25 L/ha	32	32	32
Mean	33	33	

LSD (P ≤ 0.05); Herbicide = 2 Variety = NS Herbicide*Variety = NS

4.1.2 Effect of herbicide applications on the type of weeds that emerged after treatment applications

Nine weeks after transplanting when the onion bulbs were matured for harvesting, the types of weed species that had emerged were mostly broadleaves and sedges and varied slightly among the different treatments (Table 4.3). The types of weed species that emerged are listed in Table 4.3 below:

Table 4.3 Effect of hand weeding and pre-emergence herbicide applications and types of weed species that re-emerged on onion plots 9 weeks after transplanting.

Hand weeded	Oxadiagyrl(0.5 L/ha and 0.4 L/ha)	Pendimethalin(1.25 L/ha and 1.00 L/ha)
Cleome viscosa	*Cyperus rotundus*	*Cyperus rotundus*
Trianthema portulacastrum		*Synedrilla nodiflora*
Cyperus rotundus		*Commelina benghalensis*
Digitalia horizontalis		
Commelina benghalensis		
Synedrilla nodiflora		
Croton lobatus		

4.1.3: Effect of hand weeding and pre-emergence herbicide applications on weed density in onion plots

There was significant difference in weed density (P<0.05) on onion plots treated with the different weed control tactics at 3 weeks after transplanting onions (Table 4.4). Hand weeded plots had the highest weed density of 108/m^2 while the lowest of 5 /m^2 was recorded on both Pendimethalin treated plots. There was however no weed re-emergence on plots treated with Oxadiagyrl applied at both 0.4 L/ha and 0.5 L/ha

At 6WAT, the highest weed density of hand weeding had a significantly higher number of weeds of 53 with no weed for Oxadiargyl 0.5 L/ha. Hand weeding was significantly (P<0.05) different from herbicide treated plots but herbicide treated plots did not differ significantly (P<0.05) from each other.

At 9 WAT, hand weeded plots recorded a significantly higher number of weeds of 53 with Oxadiargyl 0.5 L/ha recording no weed presence. Hand weeding was significantly (P<0.05) different from herbicide treated plots but herbicide treated plots did not differ from each other.

At 12 WAT, hand weeded plots differed significantly (P<0.05) from herbicide treated plots by recording the highest number of weeds of 58 while Oxadiargyl 0.5 L/ha recorded 4 as the least number of weeds. There were no significant (P<0.05) interactions of herbicide and variety on weed density throughout the experimental period.

Additionally, varietal effect was also not significant with respect to number of weeds per treatment.

Table 4.4a: Number of weeds as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application

Herbicide	Number of weeds 3 WAP			Number of weeds 6 WAP		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	101.0 (9.7)	114.0 (10.6)	108.0 (10.2)	44.0 (6.6)	59.0 (7.6)	52.0 (7.1)
Oxadiargyl 0.4 L/ha	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)	0.0 (0.7)
Oxadiargyl 0.5 L/ha	0.0 (0.7)	1.0 (1.0)	1.0 (0.8)	0.0 (0.7)	1.0 (1.0)	1.0 (0.8)
Pendimethalin 1.00 L/ha	5.0 (2.0)	6.0 (2.2)	5.0 (2.1)	9.0 (2.6)	11.0 (3.2)	10.0 (2.9)
Pendimethalin 1.25 L/ha	5.0 (2.3)	5.0 (2.2)	5.0 (2.3)	14.0 (3.7)	14.0 (3.7)	14.0 (3.7)
Mean	22.0 (3.1)	25.0 (3.3)		14.0 (2.8)	17.0 (3.2)	

LSD ($P \leq 0.05$); Herbicide = 16.41 (1.10) 10.64 (1.15)
Variety = NS NS
Herbicide*Variety = NS NS
Numbers in parenthesis are transformed values

Table 4.4b: Number of weeds as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application on onion

Herbicide	Number of weeds 9 WAP			Number of weeds 12 WAP		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	50.0 (7.0)	55.0 (7.4)	53.0 (7.2)	56.0 (7.4)	61.0 (7.8)	58.0 (7.6)
Oxadiargyl 0.4 L/ha	3.0 (1.9)	3.0 (1.7)	3.0 (1.8)	5.0 (2.2)	6.0 (2.4)	5.0 (2.3)
Oxadiargyl 0.5 L/ha	2.0 (1.6)	3.0 (1.8)	3.0 (1.7)	3.0 (1.9)	4.0 (2.1)	4.0 (2.0)
Pendimethalin 1.00 L/ha	12.0 (3.4)	15.0 (3.8)	14.0 (3.6)	14.0 (3.7)	19.0 (4.3)	17.0 (4.0)
Pendimethalin 1.25 L/ha	17.0 (4.1)	17.0 (4.1)	17.0 (4.1)	18.0 (4.3)	19.0 (4.4)	19.0 (4.3)
Mean	17.0 (3.6)	19.0 (3.8)		19.0 (3.9)	22.0 (4.2)	
LSD ($P \leq 0.05$); Herbicide =	4.14 (0.46)				4.61 (0.40)	
Variety =	NS				NS	
Herbicide*Variety =	NS				NS	

4.1.4: Weeds fresh weight (g).

There was no significant interaction between herbicide and onion variety with respect to weed fresh weight was not significant throughout the experimental period. Additionally, there was no significant difference between the varieties. On the other hand, at 3WAT, hand weeding recorded the highest significant weeds fresh weight of 270 g differing significantly (P<0.05) from herbicide treated plots. However, herbicide treated plots were similar. At 6WAT, hand weeding attained the highest weight of 144.2g whiles oxadiargyl (0.4 L/ha) recorded no weeds. Hand weeded plots also differed significantly from herbicide treated plots. Pendimethalin treated plots differed significantly from Oxadiargyl treated plots but not from each other. At 9WAT, hand weeding was significantly different from herbicide treated plots and recorded the highest weight of 111.4 g whiles Oxadiargyl (0.4 L/ha) recorded the least weeds fresh weight of 3.6 g. Pendimethalin treated plots differed significantly from

Oxadiargyl treated plots but the difference between the two rates of the chemical was not significant (Table 4.5). The trend at 12WAT was the same as 9WAT on weeds fresh weigh

Table 4.5a: Weeds fresh weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Weeds fresh weight (g) 3 WAP			Weeds fresh weight (g) 6 WAP		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	180.0	360.0	270.0	150.6	137.7	144.2
Oxadiargyl 0.4 L/ha	0.0	0.0	0.0	0.0	0.0	0.0
Oxadiargyl 0.5 L/ha	0.0	1.0	0.0	0.0	2.4	1.2
Pendimethalin 1.00 L/ha	5.0	7.0	6.0	39.9	39.3	39.6
Pendimethalin 1.25 L/ha	6.0	6.0	6.0	47.6	42.9	45.3
Mean	38.0	75.0		47.6	44.5	
LSD ($P \leq 0.05$); Herbicide =	111.1			20.03		
Variety =	NS			NS		
Herbicide*Variety =	NS			NS		

Table 4.5b: Weeds fresh weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Weeds fresh weight (g) 9 WAP			Weeds fresh weight (g) 12WAP		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	112.2	110.6	111.4	117.2	125.3	121.2
Oxadiargyl 0.4 L/ha	3.6	3.6	3.6	4.1	4.4	4.3
Oxadiargyl 0.5 L/ha	3.9	5.2	4.5	3.4	3.8	3.6
Pendimethalin 1.00 L/ha	45.1	46.7	45.9	13.2	15.2	14.2
Pendimethalin 1.25 L/ha	52.3	45.8	49.1	11.2	12.7	12.0
Mean	43.4	42.4		29.8	32.3	
LSD ($P \leq 0.05$); Herbicide =	20.76			4.55		
Variety =	NS			NS		
Herbicide*Variety =	NS			NS		

4.1.5: Weeds dry weight (g).

From Table 4.6, there was no significant differences between the interaction of herbicide and variety. Additionally, there was no significant differences among the varieties.

However, there were significant differences ($P < 0.05$) among the various treatments. At 3 WAT, hand weeding recorded the highest weeds dry weight of 20.2g whiles Oxadiargyl 0.4 L/ha registered no weeds. The dry weight recorded on hand weeding plots differed significantly from herbicide treated plots. On the other hand, the dry weight recorded on the herbicide treated plots did not differ significantly from each other. At 6WAT, hand weeding recorded the highest weeds dry weight of 15.7g whiles Oxadiargyl 0.4 L/ha recorded no weeds. Weeds dry weight for hand weeding was significantly different $P < 0.05$ from herbicide treated plots. Additionally, Pendimethalin treated plots differed significantly from Oxadiargyl treated plots but from each other. At 9 WAT, plots treated to hand weeding recorded the highest weeds dry weight of 12.3 whiles Oxadiargyl 0.4 L/ha attained the least weeds dry weight 0.7. Weeds dry weight for hand weeding differed significantly from herbicide treated plots. Pendimethalin treated plots differed significantly from Oxadiargyl treated plots but not from each other.

At 12 WAT, there was significant difference ($P < 0.05$) in dry weight of weeds. The highest was recorded on hand weeded plots (11.2g) whiles Oxadiargyl (0.5 L/ha) recorded the least weeds dry weight of 0.5g. Hand weeding differed significantly $P < 0.05$ from herbicide treated plots on weeds dry weight. Pendimethalin also differed significantly $P < 0.05$ from Oxadiargyl treated plots but not between the different rates in terms of weeds dry weight.

Table 4.6a: Weeds dry weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application on onion.

Herbicide	Weeds dry weight (g) 3 WAT			Weeds dry weight (g) 6 WAT		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	22.1	18.3	20.2	17.2	14.3	15.7
Oxadiargyl 0.4 L/ha	0.0	0.0	0.0	0.0	0.0	0.0
Oxadiargyl 0.5 L/ha	0.0	0.2	0.1	0.0	0.7	0.4
Pendimethalin 1.00 L/ha	0.8	0.6	0.7	5.5	5.5	5.5
Pendimethalin 1.25 L/ha	1.0	1.0	1.0	22.5	7.5	15.0
Mean	4.8	4.0		9.0	5.6	
LSD (P ≤ 0.05); Herbicide =	4.61			9.86		
Variety =	NS			NS		
Herbicide*Variety =	NS			NS		

Table 4.6b: Weeds dry weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application

Herbicide	Weeds dry weight (g) 9 WAT			Weeds dry weight (g) 12 WAT		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	13.1	11.6	12.3	10.7	11.8	11.2
Oxadiargyl 0.4 L/ha	0.7	0.7	0.7	0.8	0.8	0.8
Oxadiargyl 0.5 L/ha	0.9	1.3	1.1	0.5	0.6	0.5
Pendimethalin 1.00 L/ha	6.5	5.9	6.25	3.4	3.6	3.5
Pendimethalin 1.25 L/ha	8.2	7.7	7.9	3.0	3.2	3.1
Mean	5.8	5.4		3.7	4.0	
LSD (P ≤ 0.05); Herbicide =	2.95			0.67		
Variety =	NS			NS		
Herbicide*Variety =	NS			NS		

4.2 Effect of pre-emergence herbicides application of Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC on onion growth and yield.

4.2.1 Crop Establishment.

As indicated in Table 4.7 the percentage crop establishment for Bawku Red and Dayo at 7 DAT with the average of 93.4 % and 97.6% respectively. The value for both varieties at 14DAT recorded an average 95.2 % and 97.2% respectively. There was significant difference (P<0.05) in crop establishment among varieties (Bawku Red and Dayo) at 7DAT and 14DAT but no significant differences (P<0.05) among various herbicide treatment means at 7 DAT and 14 DAT were observed.

Interaction between herbicides and varieties for crop establishment at 7 DAT was not significantly different (P<0.05) whiles there was a significant difference (P<0.05) between the interaction of herbicides and varieties at 14 DAT. At 7 DAT, Dayo under Pendimethalin 1.25 L/ha recorded the highest crop establishment (97.7) and this was significantly different (P≤0.05) from Bawku Red under Pendimethalin 1.00L/ha (90.0). On the other hand, Dayo under Pendimethalin, 1.00 L/ha recorded the highest crop establishment at 14DAT and was significantly different (P≤0.05) from Bawku Red under Pendimethalin 1.00L/ha (93.2). Both Pendimethalin at 1.25L/ha and 1.00 L/ha and Oxadiargyl 0.5L/ha differed significantly (P<0.05) from control but not with each other.

Table 4.7: Crop establishment as influenced by varieties and pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Crop Establishment 7 DAT			Crop Establishment 14 DAT		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	94.6 (77.0)	98.5 (85.1)	96.6 (81.0)	95.5 (78.1)	96.0 (79.8)	95.8 (79.0)
Oxadiargyl 0.4 L/ha	94.1 (76.3)	96.7 (80.5)	95.4 (78.4)	95.7 (78.9)	95.7 (78.9)	95.7 (78.9)
Oxadiargyl 0.5 L/ha	93.4 (75.6)	97.5 (83.5)	95.4 (79.5)	94.6 (77.3)	97.5 (81.8)	96.0 (79.6)
Pendimethalin 1.00 L/ha	90.0 (71.7)	97.5 (82.4)	93.7 (77.0	93.2 (74.9)	98.9 (85.1)	96.0 (80.0)
Pendimethalin 1.25 L/ha	95.1 (77.4)	97.7 (82.0)	96.4 (79.7)	96.8 (80.1)	98.0 (82.1)	97.4 (81.1)
Mean	93.4 (75.6)	97.6 (82.7)		95.1 (77.9)	97.2 (81.6)	

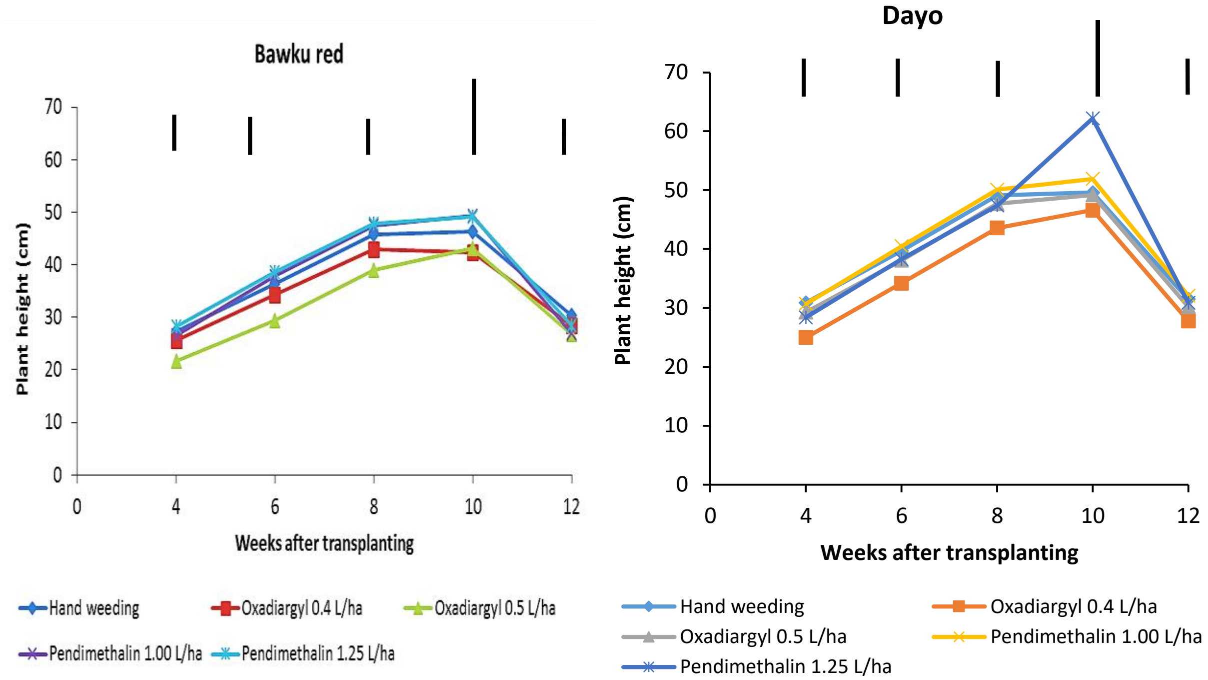
*Means in parenthesis are transformed values

	7 DAT	14 DAT
LSD ($P \leq 0.05$); Herbicide =	NS	NS
Variety =	1.40 (2.48)	1.09 (2.01)
Herbicide*Variety =	NS	3.38 (5.67)

4.2.2: Growth parameters of onion as influenced by pre-emergence weed management.

4.2.2.1: Plants height (cm) of onion

There were no significant differences in the height of both Bawku Red and Dayo under all herbicide treatments at 4, 6, and 10 WAT (Fig. 1). However, there were significant differences (P<0.05) in the height of varieties at 8 WAT and 12 WAT (Fig. 1). At 8 WAT after transplanting, Dayo under Pendimethalin (1.00L/ha) recorded the highest plant height of (50.1 cm) while Bawku Red under Oxadiargyl 0.5L/ha recorded the least height (39.0cm). At 12 WAT, Dayo under Pendimethalin (1.00L/ha) recorded the tallest the height (32.1cm) while Bawku Red under Pendimethalin 1.00 L/ha recorded the least height (27.0cm). There was no significant difference (P‹<0.05) between herbicide treatments and the interaction between herbicides and varieties

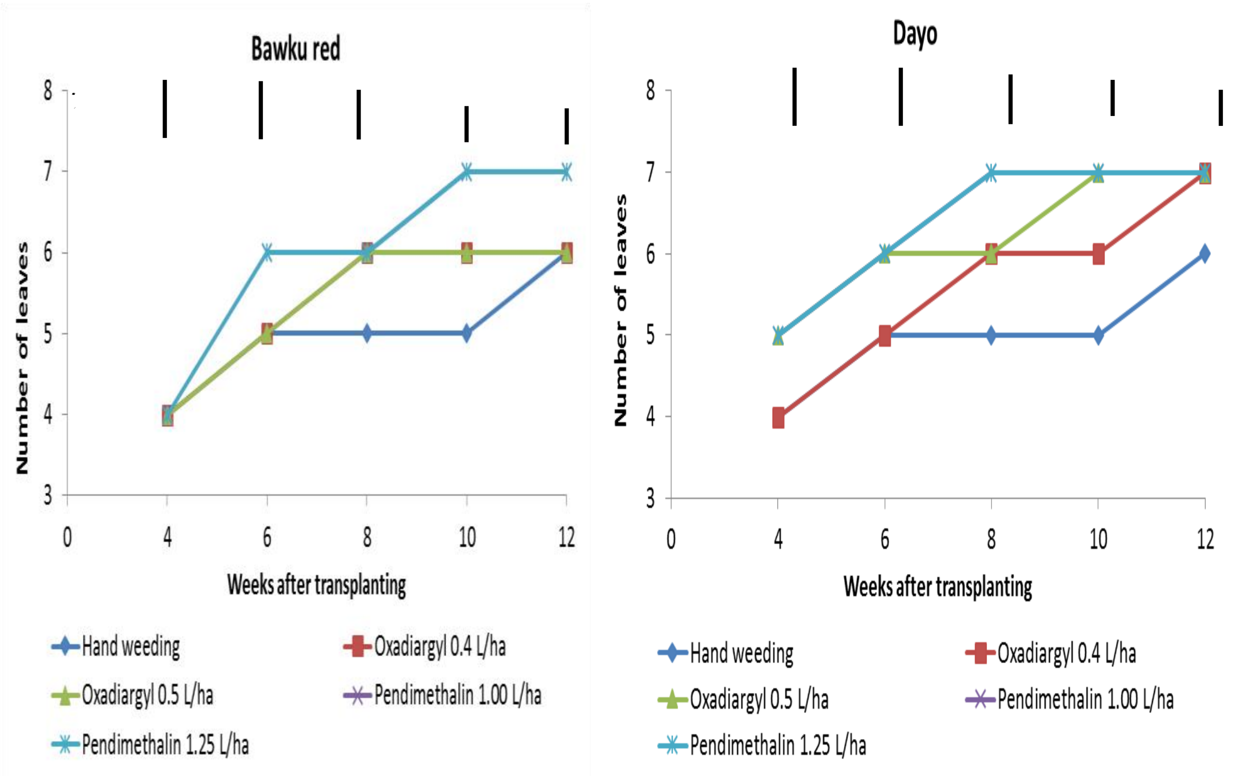


Vertical bars represent standard error bars

Figure 1 Plant height as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC).

4.2.2.2: Number of leaves of onion

There were significant differences (P<0.05) in the mean number of leaves of onion varieties (Bawku Red and Dayo) at 8, 10 and 12 WAT (Figure 2). Pendimethalin at 1.00 L/ha and at 1.25 L/ha with both varieties recorded the largest number of leaves (7.0) at 10 WAT with hand weeding for both varieties recording the least number of leaves (5.0). At 8WAT, Dayo under Pendimethalin (1.25 L/ha) and Pendimethalin (1.00L/ha) both recorded the highest number of leaves (7.0) with hand weeding for both varieties (Bawku Red and Dayo) recording the least number of leaves (5.0). All herbicides treated plots with Dayo recorded 7.0 leaves as the highest with hand weeding for both varieties recording 6.0 as the least at 12 WAT. There were no significant differences (P<0.05) between the interaction between herbicide and variety.



Vertical bars represent standard error bars

Figure 2: Number of leaves of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

4.2.2.3: Leaf length (cm)

With respect to leaf length, the interaction between herbicide and variety was not significant. Additionally, there were no significant differences (P<0.05) among the various herbicide treatments on leaf length of the onion plant. On the other hand, there was significant difference among the variety (sub plot effect) at 4, 8, 10 and 12 WAT. At 4 WAT Dayo under Pendimethalin (1.00 L/ha) recorded a significant leaf length of 29.4cm whiles Dayo under Oxadiargyl (0.4 L/ha) attained the least leaf length of 23.6cm (Figure 3). Pendimethalin (1.00L/ha) had a significant leaf length of 47.0 while Bawku Red under Oxadiargyl 0.4 L/ha recorded the least leaf length of 40.5cm. A significant leaf length of 49.2 cm (P<0.05) was recorded by Dayo under Pendimethalin 1.00 L/ha at 10 WAT whiles Bawku Red under Oxadiargyl 0.4 L/ha registered the least leaf length of 42.8cm. At 12 WAT, Dayo under Pendimethalin 1.00 L/ha recorded a significant leaf length of 30.0cm as the highest while Oxadiargyl 0.5 L/ha recorded the least leaf length of 25.0 cm

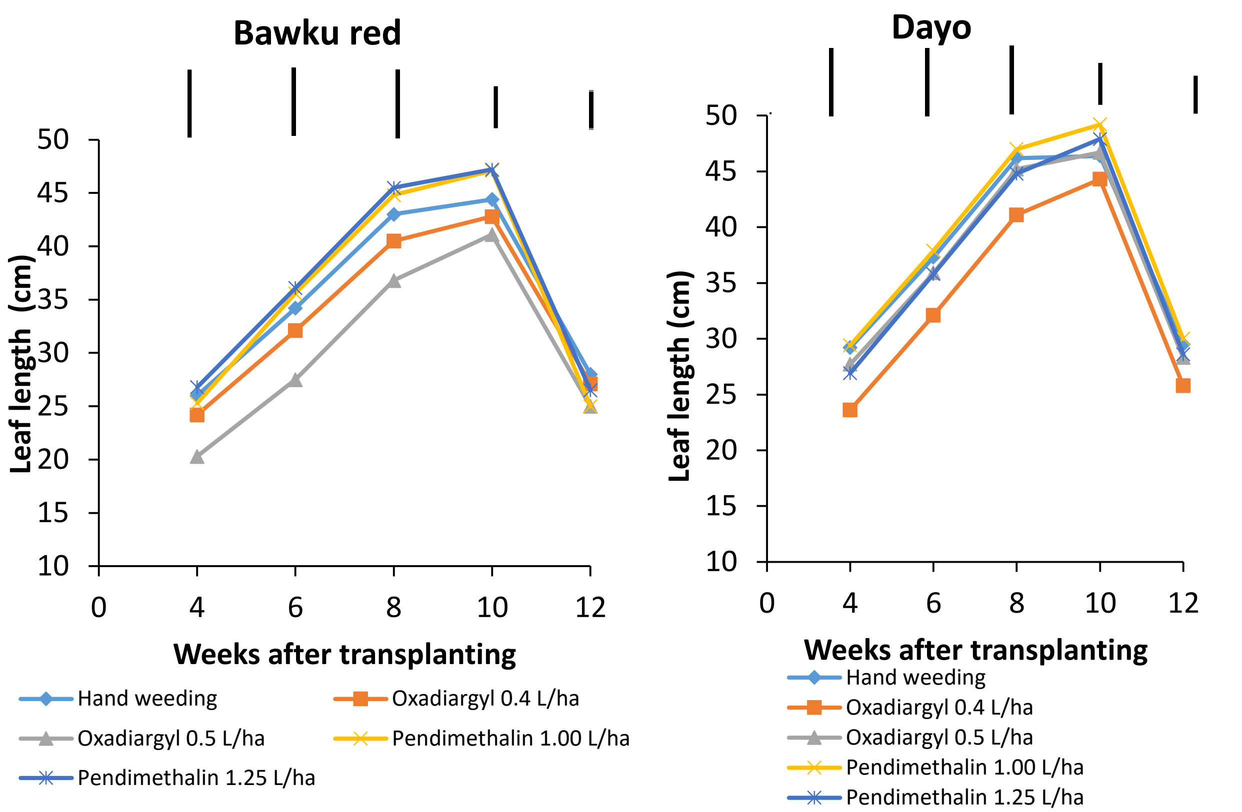


Figure 3: Leaf length of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

4.2.2.4: Leaf diameter (mm)

Figure 4 shows the leaf diameter of onion as influenced by the application of pre emergence herbicides (Pendimethalin and Oxadiargyl). No significant differences (P< 0.05) were observed for the interaction between the herbicide and variety. Additionally, there was no significant difference between the varieties on leaf diameter. Herbicides differed significantly (P< 0.05) on leaf diameter throughout the growth of the onion plant. At 4 WAT, leaf diameter of onion on Pendimethalin 1.25 L/ha and Pendimethalin 1.00L/ha differed significantly from all treatments. Again, hand weeding differed significantly (P< 0.05) from Pendimethalin treatment but not from

Oxadiargyl treated plots. Additionally, Oxydiargyl treated plots did not differ significantly (P< 0.05) from each other. Pendimethalin 1.00 L/ha (6.93mm) differed significantly (P< 0.05) from all treatments at 6 WAT. Pendimethalin treatments differed significantly (P< 0.05) from the hand weeding but not from each other. At 8WAT, Pendimethalin 1.00 L/ha (8.52mm) differed significantly from all treatment. Also, Pendimethalin treatments differed significantly from all other treatments. Hand weeding (6.91mm) differed significantly from Pendimethalin treatments but not from Oxadiargyl treatments. Oxadiargyl treatments did not differ significantly (P< 0.05) from each other. At 10 WAT, Pendimethalin 1.00 L/ha differed significantly (P< 0.05) from all other treatments. Again, Pendimethalin treatments differed significantly (P< 0.05) from all other treatments but not from each other. On the other hand, hand weeding (8.20mm) differed significantly (P< 0.05) from Pendimethalin treatments. Oxadiargyl treated plots did not differ significantly P<0.05 from each other. Same trend was observed at 12WAT.

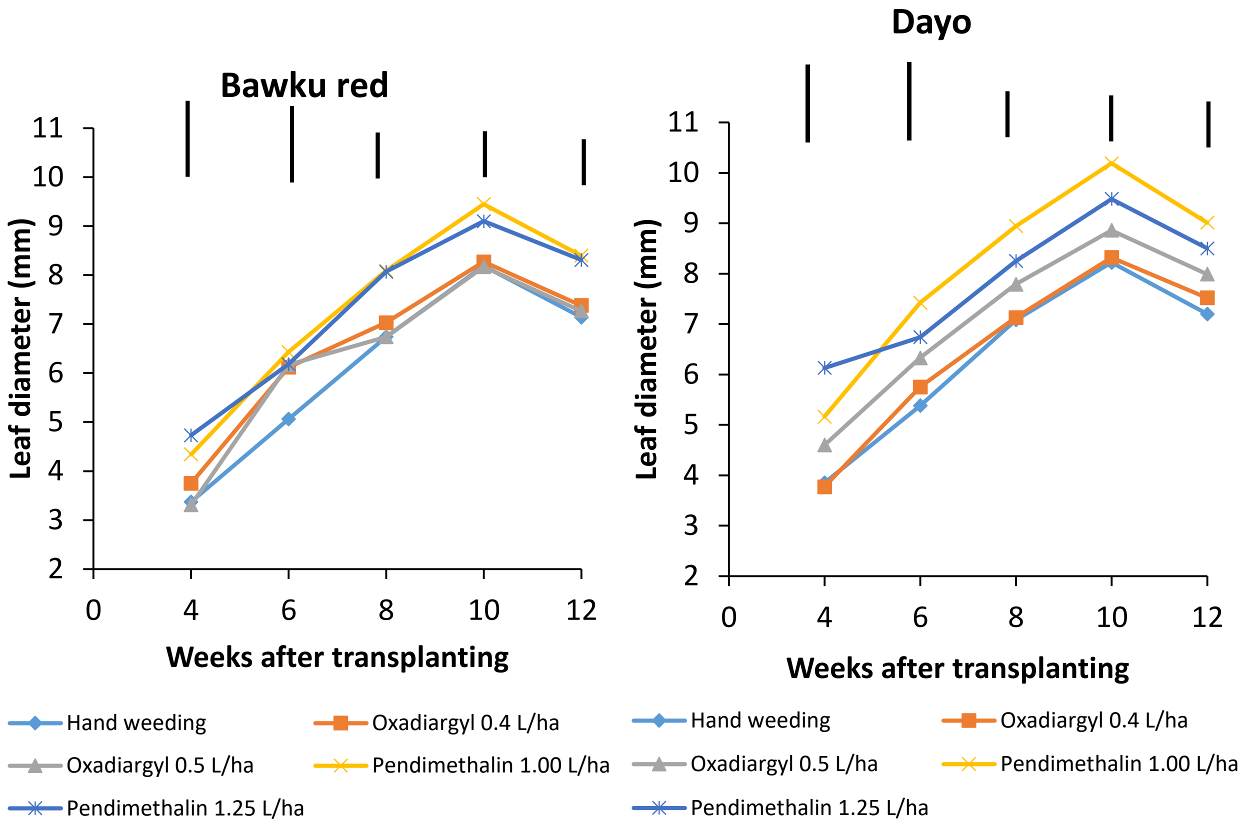


Figure 4: Leaf diameter of onion as influenced by pre-emergence herbicides (Oxadiargyl 400 g/L SC and Pendimethalin 456 g/L EC) application.

4.2.2.5: Chlorophyll content (spad)

There were significant differences (P< 0.05) between the interaction of herbicides and variety at 10 and 14 WAT but not at 5 WAT on chlorophyll content of onion plant leaves. At 5 WAT, Dayo under Pendimethalin (1.00 L/ha) attained the highest chlorophyll content of plant leaves whiles onion on oxadiargyl (0.5 L/ha) recorded 20.1 as the least chlorophyll content. Herbicide treated plots differed significantly from hand weeding. Pendimethalin treated plots differed significantly from Oxadiargyl treated plots but not among each other. Dayo under Pendimethalin 1.00 L/ha produced the highest leaf chlorophyll content of 47.5 and was significantly higher than all the other treatments whiles Bawku red at hand weeding registered the least leaf chlorophyll content of 35.6. Herbicide treated plots differed significantly from hand weeding. At 14 WAT, Dayo under

Pendimethalin (1.00 L/ha) produced the highest leaf chlorophyll (39.5) with Bawku Red at hand weeding registering 28.2 as the least plant chlorophyll content. Herbicide treated plots were significantly different from hand weeding. Pendimethalin (1.00 L/ha) also significantly different from the other herbicides.

Table 4.8: Chlorophyll content of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Chlorophyll content 5 WAP			Chlorophyll content 10 WAP			Chlorophyll content 14 WAP		
	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean	Bawku Red	Dayo	Mean
Hand weeding	20.5	21.1	20.8	35.6	37.7	36.3	28.2	28.5	28.4
Oxadiargyl 0.4 L/ha	20.5	21.9	21.2	39.1	44.0	41.6	31.7	35.1	33.4
Oxadiargyl 0.5 L/ha	20.1	22.0	21.0	39.8	43.2	41.5	32.3	34.9	33.6
Pendimethalin 1.00 L/ha	21.4	24.0	22.7	39.1	47.5	43.3	32.5	39.5	36.0
Pendimethalin 1.25 L/ha	21.9	23.7	22.8	38.9	43.5	41.2	31.2	36.1	33.7
Mean	20.9	22.6		38.5	43.1		31.2	34.8	
LSD ($P \leq 0.05$); Herbicide =	1.23			1.99			2.30		
Variety =	0.57			1.02			0.92		
Herbicide*Variety =	NS			2.44			2.61		

4.2.2.6: Neck girth of onion at harvest

Significant differences were observed between Bawku Red (8.90 mm) and Dayo (9.29) regarding stem girth at 14 WAT and also among the various herbicide treatments. Dayo at pendimethalin 1.00L/ha recorded the largest stem girth (11.06mm) with Dayo at hand weeding recording the least stem girth (7.45mm) (Table 4.9). Herbicide treated plots were significantly different ($P< 0.05$). There were no significant differences between interaction of herbicides and varieties at ($P<0.05$)

Table 4.9: Stem girth of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Plant girth (mm) at harvest		
	Bawku Red	Dayo	Mean
Hand weeding	7.69	7.45	7.57
Oxadiargyl (0.4 L/ha	8.96	9.44	9.20
Oxadiargyl 0.5 L/ha	8.12	8.33	8.22
Pendimethalin 1.00 L/ha	10.22	11.06	10.64
Pendimethalin 1.25 L/ha	9.52	10.18	9.85
Mean	8.90	9.29	

LSD ($P \leq 0.05$); Herbicide =1.39
Variety = 0.37
Herbicide*Variety = 1.47 NS

4.2.2.7: **Plant fresh weight (g)**

The interaction between herbicide and variety at 5WAT yielded a significant difference. On the other hand, the interaction between the two factors (herbicide and variety) did not differ significantly ($P< 0.05$) at ten 10 and 14 WAT (Figure 5). There was significant difference ($P< 0.05$) for herbicides by varieties at 5, 10 and 14WAT. After 5WAT, Bawku Red under Pendimethalin (1.00 L/ha) recorded a significantly highest plant fresh weight of 57.5g while Bawku red under Oxadiargyl (0.5 L/ha) recorded the least fresh weight of 29.5 (g). Herbicide treated plots differed significantly from hand weeding and also among themselves. Dayo under Pendimethalin (1.00 L/ha) at 10 WAT recorded the highest significant plant fresh weight of 34.7.0 (g) as against Bawku red at hand weeding which recorded the least plant fresh weight or 232.5 (g). Herbicide treated plots differed significantly from hand weeding. Within herbicide treated plots, pendimethalin differed significantly from oxadiargyl plots and among themselves. At 14 WAT, Dayo under Pendimethalin 1.00 l/ha attained the highest plant fresh weight of 362.8g with Bawku red at hand weeding recording the least plant fresh weight of 248.5 g. Herbicide treated plants differed significantly (P< 0.05) from hand weeding. Pendimethalin treated plots differed significantly among themselves and also significantly from Oxadiargyl treated plots.

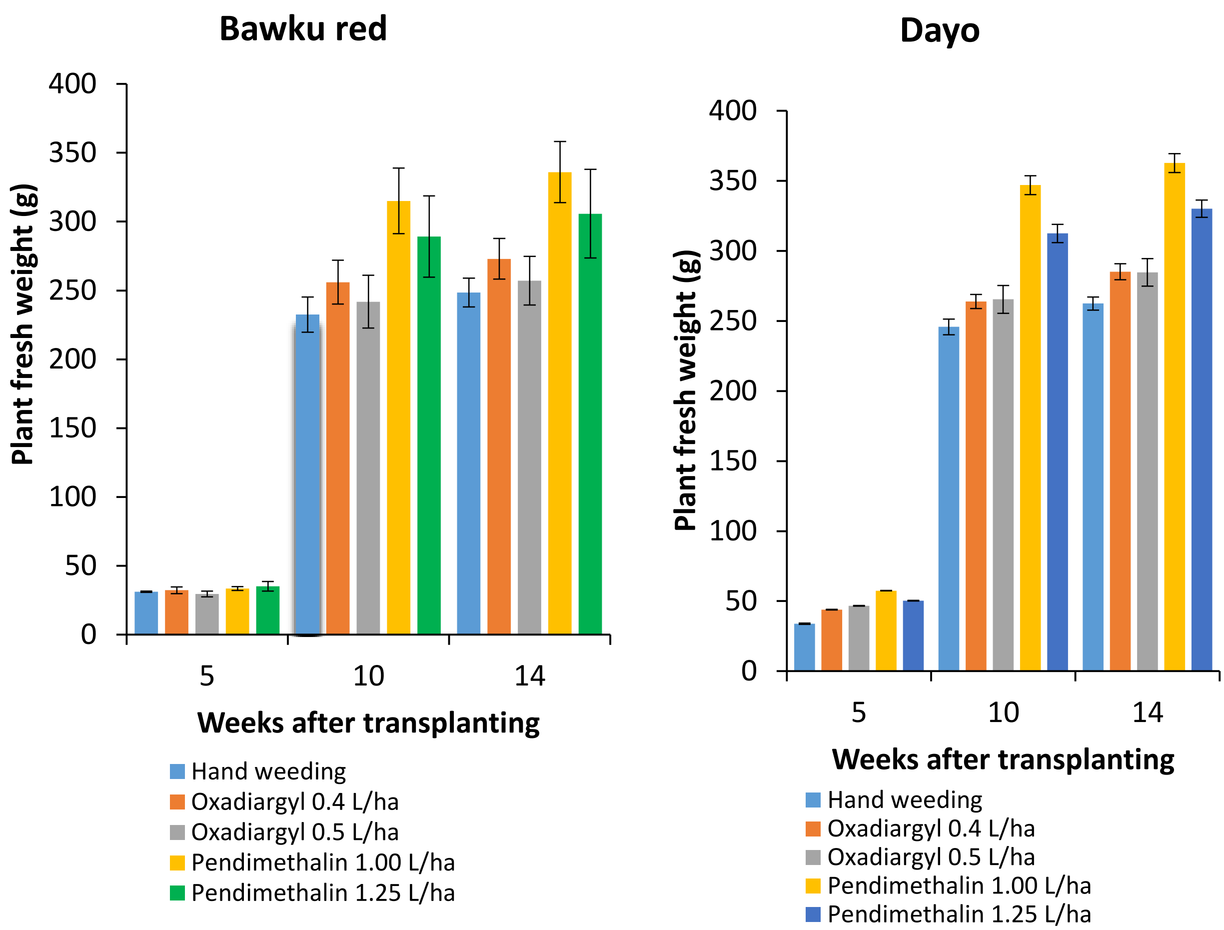


Figure 5: Plant (onion) fresh weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application

4.2.2.8: Plant dry weight (g)

The interaction between herbicide and variety yielded significant differences (P< 0.05) at 5 WAT. However, the interaction between herbicide and variety did not yield any significant differences (P< 0.05) at 10 and 14WAT.

On the other hand, there were significant difference ($P < 0.05$) among herbicides at 5, 10 and 14 WAT. Also, there were significant difference ($P < 0.05$) among varieties at 5, 10 and 14WAT. At 5 WAT, Dayo under Pendimethalin (1.00 L/ha) produced the highest plant dry weight of 5.5g whiles Bawku Red at Oxadiargyl (0.5 L/ha) recorded the least plant dry weight of 2.7 (g). Pendimethalin treated plots differed significantly among other treatments and among themselves. Dayo at Pendimethalin (1.00 L/ha) attained 109.7 (g) as the highest plant dry weight with hand weeding Bawku Red recording 73.5 (g) as the least plant dry weight. Pendimethalin treated plots differed significantly from hand weeding and Oxadiargyl but not among themselves. At 14 WAT, Dayo under Pendimethalin (1.00 L/ha) registered the highest plant dry weight of 115.7 (g) with Bawku Red at hand weeding registering 81.5 (g) as the least plant dry weight. Pendimethalin treated plots were significantly different from other treatments but not within themselves.

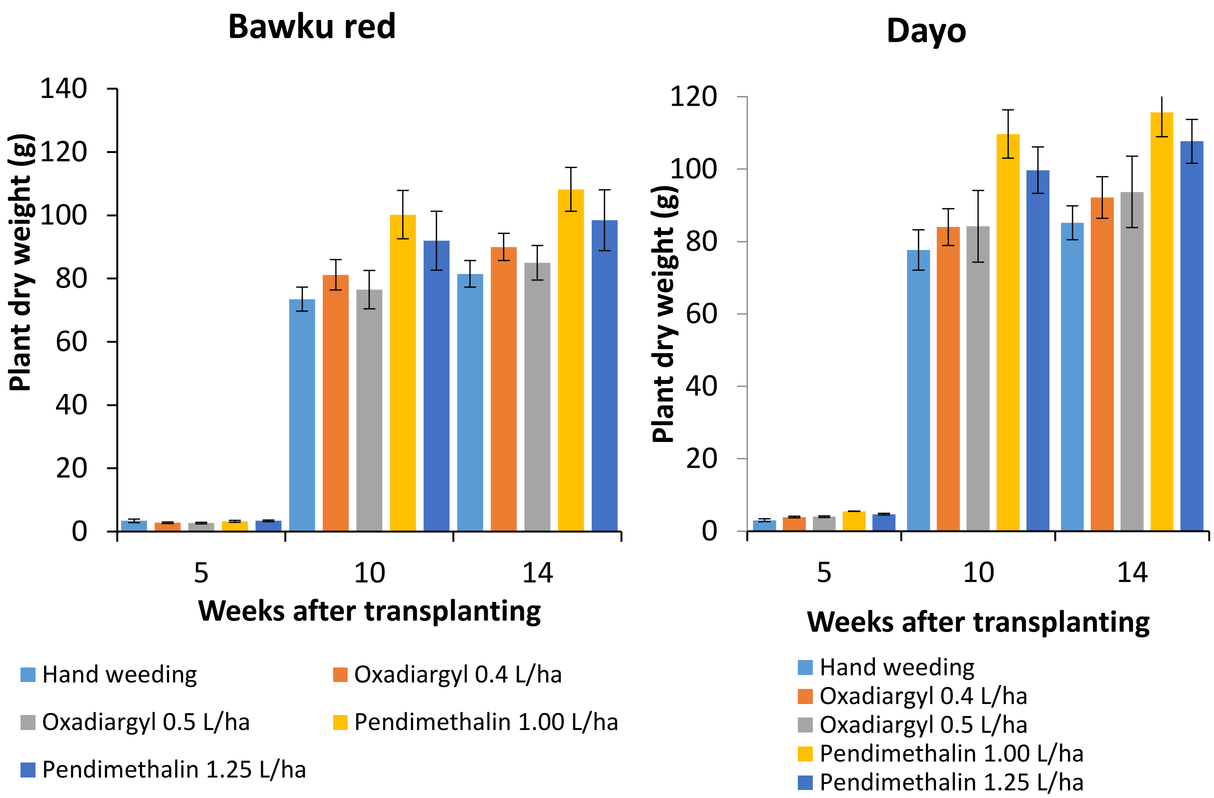


Figure 6: Plant (onion) dry weight as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application

4.2.2.9: Days to 50% bulbing of onion.

As indicated by Table 4.10, the interaction of herbicide and variety at days to 50% bulbing of onion was not significant

Additionally, there were no significant differences ($P< 0.05$) among the various herbicides at 50% bulbing of onion. At 50% bulbing, Dayo under hand weeding and Dayo under Pendimethalin treated plots recorded 78 days whiles Oxadiargyl treated plots recorded the least days of 70.

Table 4.10: Days to bulbing of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application

Herbicide	Days to 50 % Bulbing		
	Bawku Red	Dayo	Mean
Hand weeding	71	78	75
Oxadiargyl 0.4 L/ha	70	77	74
Oxadiargyl 0.5 L/ha	70	77	74
Pendimethalin 1.00 L/ha	70	78	74
Pendimethalin 1.25 L/ha	70	78	74
Mean	70	78	

LSD (P ≤ 0.05); Herbicide = NS
Variety = 0.23
Herbicide*Variety = NS

4.2.2.10: Days to physiological maturity.

There were significant differences (P< 0.05) between (varieties) Bawku Red (119) and Dayo (126) and among the various herbicide treatments regarding days to physiological maturity of onion. Hand weeding and Pendimethalin (1.25L/ha) differed significantly (P< 0.05) from other herbicide treatments by recording the longest days to physiological maturity. From Table 4 .11, Oxadiargyl 0.4L/ha, Oxadiargyl (0.5L/ha) and Pendimethalin 1.00L/ha treated plots matured earlier then hand weeding and Pendimethalin (1.25 L/ha). There were no significant differences (P< 0.05) for interaction of herbicides and varieties at (P≤0.05).

Table 4.11: Days to physiological maturity of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Days to maturity		
	Bawku Red	Dayo	Mean
Hand weeding	120.0	126.7	123.3
Oxadiargyl 0.4 L/ha	119.0	126.0	122.5
Oxadiargyl 0.5 L/ha	119.0	126.0	122.5
Pendimethalin 1.00 L/ha	119.2	126.0	122.6
Pendimethalin 1.25 L/ha	119.7	126.5	123.1
Mean	119.4	126.2	

LSD ($P \leq 0.05$); Herbicide = 0.32
Variety = 0.25
Herbicide*Variety = NS

4.2.2.11: Bulb diameter (mm) at harvest.

There was no significant difference (P< 0.05) on bulb diameter between varieties (Table 4.12). Bawku Red under Oxadiargyl 0.4L/ha recorded the largest bulb diameter (467mm) with hand weeding recording the least bulb diameter (41.1mm).

Significant differences (P< 0.05) were registered among the various herbicide treatments with Pendimethalin 1.00L/ha registering the largest bulb diameter (46.0mm) whiles hand weeding registered the least bulb diameter (41.1mm). Herbicide treatments differed significantly from hand weeding but not from each other. There were no significant differences for varieties and interaction between herbicides and varieties.

Table 4.12: Mean bulb diameter of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Bulb diameter (mm)		
	Bawku Red	Dayo	Mean
Hand weeding	41.1	41.2	41.1
Oxadiargyl 0.4 L/ha	46.7	44.6	45.7
Oxadiargyl 0.5 L/ha	46.1	45.2	45.6
Pendimethalin 1.00 L/ha	46.6	45.3	46.0
Pendimethalin 1.25 L/ha	44.2	42.4	43.3
Mean	44.9	43.7	

LSD (P ≤ 0.05); Herbicide = 3.56 Herbicide*Variety = NS Variety = NS

4.2.2.12: Bulb length (mm) at harvest

As depicted in Table 4.13, significant differences (P< 0.05) were not observed among the various herbicide treatments, varieties and interaction between varieties and herbicides.

Table 4.13: Mean bulb length of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Bulb length (mm)		
	Bawku Red	Dayo	Mean
Hand weeding	44.8	45.7	45.3
Oxadiargyl 0.4 L/ha	59.7	46.8	53.3
Oxadiargyl 0.5 L/ha	46.0	48.0	47.0
Pendimethalin 1.00 L/ha	47.2	49.7	48.4
Pendimethalin 1.25 L/ha	43.6	46.9	45.3
Mean	48.3	47.4	

LSD (P ≤ 0.05); Herbicide = NS Herbicide*Variety = NS
Variety = NS

4.2.2.13: Mean bulb weight (g)

The average bulb weight of both Bawku Red Dayo is shown in Table 4.14. There were no statistical differences between Bawku Red and Dayo, among herbicide treatments and between the interaction of herbicides and varieties.

Table 4.14: Mean bulb weight of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC)

Herbicide	Mean bulb weight (g)		
	Bawku Red	Dayo	Mean
Hand weeding	39.2	39.4	39.3
Oxadiargyl 0.4 L/ha	49.9	47.0	48.4
Oxadiargyl 0.5 L/ha	48.7	44.3	46.5
Pendimethalin 1.00 L/ha	49.4	48.6	49.0
Pendimethalin 1.25 L/ha	43.3	41.3	42.3
Mean	46.1	44.1	

LSD ($P \leq 0.05$); Herbicide = NS
Variety = NS
Herbicide*Variety = NS

4.2.2.14: Total bulb weight (tons/ha) of onion

There was no significant difference between the interaction of herbicides and varieties as indicated by Table 4.15. Additionally, herbicide treatments did not produce significant differences among themselves at $P<0.05$. Also, there were no significant differences ($P< 0.05$) between varieties (Bawku Red and Dayo)

Table 4.15: Total bulb weight (tons/ha) of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Total bulb weight (tons/ha)		
	Bawku Red	Dayo	Mean
Hand weeding	14.2	13.5	13.8
Oxadiargyl 0.4 L/ha	18.5	17.7	18.1
Oxadiargyl 0.5 L/ha	16.8	15.8	16.3
Pendimethalin 1.00 L/ha	19.2	17.3	18.3
Pendimethalin 1.25 L/ha	17.7	16.3	17.0
Mean	17.3	16.1	

LSD ($P \leq 0.05$); Herbicide = NS
Variety = NS
Herbicide*Variety = NS

4.2.2.15: Marketable yield (tons/ha) of onion

As indicated in Table 4.16, the interaction between herbicide and variety was not significant ($P<0.05$). Additionally, there was no significant difference ($P< 0.05$) between varieties regarding marketable yield of onion.

On the other hand, there were significant differences ($P< 0.05$) among the various herbicide treatments. Pendimethalin (1.00 L/ha) produced a highly significant marketable yield of onion of 17.7(tons/ha) whiles hand weeding recorded the least marketable yield of 13.3(tons/ha). Herbicide treated plots were significantly different ($P< 0.05$) from hand weeding but not with each other.

Table 4.16: Marketable yield of onion as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Marketable yield (tons/ha)		
	Bawku Red	Dayo	Mean
Hand weeding	13.6	13.0	13.3
Oxadiargyl 0.4 L/ha	17.7	16.8	17.2
Oxadiargyl 0.5 L/ha	16.3	15.0	15.6
Pendimethalin 1.00 L/ha	18.6	16.7	17.7
Pendimethalin 1.25 L/ha	17.3	15.6	16.5
Mean	16.7	15.4	

LSD ($P \leq 0.05$); Herbicide = 2.95
Variety = NS
Herbicide*Variety = NS

4.3: Soil quality as influenced by the application of pre-emergence herbicide (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC).

4.3.1: Soil pH

There was no significant difference in soil pH among the various treatments for pH after treatment application similarly, there was no significant difference in soil pH after harvest.

Table 4.17: Soil pH as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	pH after treatment application	pH after Harvest
Hand weeding	5.7	6.2
Oxadiargyl 0.4 L/ha	5.2	5.9
Oxadiargyl 0.5 L/ha	5.0	5.5
Pendimethalin 1.00 L/ha	5.3	5.9
Pendimethalin 1.25 L/ha	5.0	5.8
LSD ($P \leq 0.05$)	NS	NS

4.3.2: Microbial count

There was no significant difference P< 0.05 among the various treatments with regards microbial population one month after treatment application.

But hand weeded plots recorded 661500 with Oxadiargyl 0.5 L/ha recording 54500.

Additionally, microbial count after harvest showed no significant differences (P< 0.05) among the various treatments although the highest microbial population of 133000 was observed under Oxadiargyl (0.5L/ha). Microbial population for Oxadiargyl (0.5 L/ha), Oxadiargyl (0.4 L/ha) and pendimethalin (1.25 L/ha) increased at harvest as compared to one month after treatment application. On the other hand, microbial count for hand weeding and pendimethalin (1.00 L/ha) decreased at harvest as compared to one month after treatment application.

Table 4.18: Microbial count in soil samples one month after treatment application and after harvest as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Microbial count after treatment application	Microbial count after Harvest
Hand weeding	6.61×10^{5} (5.48 c)	106500.0 (4.93)
Oxadiargyl 0.4 L/ha	6.5×10^{4} ((4.80 ab)	129250.0 (4.94)
Oxadiargyl 0.5 L/ha	5.45×10^{4} ((4.72 a)	133000.0 (5.08)
Pendimethalin 1.00 L/ha	6.61×10^{5} ((5.47 bc)	91750.0 (4.87)
Pendimethalin 1.25 L/ha	5.6×10^{4} ((4.73 a)	307750.0 (5.13)
LSD ($P \leq 0.05$)	NS (0.67)	NS (NS)

4.4: Quantitative herbicide analysis of onion bulbs

4.4.1: **Pendimethalin**

Table 4.19, shows the samples of onion bulbs and the amount of residues of Pendimethalin present.

The herbicide was not detected in any of the samples used in the analysis

Table 4.19: Quantitative Residue analysis of compound Pendimethalin in onion bulbs after harvest.

Data file	Final conc.(ppb)	Accuracy
Reagent Blank	ND	
T1V1	ND	
T1V2	ND	
T2V1	ND	
T2V2	ND	
T3V1	ND	
T3V2	ND	
T4V1	ND	
T4V2	ND	
T5V1	ND	
T5V2	ND	
SPK T5V2	33.7905	70.96

T1= Oxadiargyl 0.5L/ha, T2= Oxadiargyl 0.4L/ha, T3= Pendimethalin 1.25 L/ha, T4= Pendimethalin 1.00 L/ha, V1= Dayo , V2= Bawku Red, SPK= Spike, ND= Not Detected

4.4.2: Oxadiargyl

The amount of residues of Oxadiargyl that were detected within samples from Oxadiargyl treated plots (Table 4.20). T1V2 recorded the highest residues of Oxadiargyl of 94.9404 ppb (equivalent to 0.94 ppm). Whiles T4 V2 recorded the least Oxadiargyl residue of 55.7868 (equivalent to 0.55ppm).

Table 4.20: Quantitative Residue analysis of compound Oxadiargyl in onion bulbs after harvest

Data file	Final conc.(ppb)	Accuracy
Reagent Blank	ND	
T1V1	78.0638	
T1V2	94.9404	
T2V1	86.6978	
T2V2	55.9180	
T3V1	ND	
T3V2	ND	
T4V1	ND	
T4V2	55.7868	
T5V1	ND	
T5V2	ND	
SPK T5V2	34.5420	72.54

T1=Oxadiargyl 0.5L/ha, T2= Oxadiargyl 0.4L/ha, T3= Pendimethalin 1.25 L/ha,

T4= Pendimethalin 1.00 L/ha, V1= Dayo , V2= Bawku Red, SPK= Spike, ND= Not Detected

4.5: Experiment Two

4.5.1: Percentage emergence of cowpea as a test crop as influenced by residual toxicity of pre-emergence herbicides (Oxadiargyl) 400g/l EC and Pendimethalin 456g/L SC.

There were significant differences (P< 0.05) among herbicides, varieties and interaction between herbicides and varieties on percentage emergence of cowpea at three (3) days after planting. At 3DAP hand weeding differed greatly from all herbicide treatments in terms of percentage emergence of cowpea. Dayo at hand weeding recorded the highest percentage emergence (27.5) as compared to Oxadiargyl 0.5L/ha which recorded the least (2.5). Both Bawku Red and Dayo hand weeded recorded higher emergence as compared to all herbicide treatments. At day 5, there was a significant difference (P< 0.05) between herbicide treatments with Pendimethalin 1.00 L/ha treated plots recording the highest (75.0) as compared to Oxadiargyl 0.5 L/ha which scored the least (50.6). Both Pendimethalin 1.25 L/ha and 1.00L/ha differed significantly from Oxadiargyl 0.5L/ha and 0.4 L/ha but not among themselves. There were no significant differences (P≤0.05) between varieties and interaction between herbicides and varieties. There was a significant difference (P≤0.05) at 7 DAP among herbicide means with pendimethalin 1.25L/ha, differing greatly from Oxadiargyl 0.5 L/ha, and oxadiargyl0.4 l/ha but not among each other. On the other hand, there was no significant difference (P< 0.05) for varieties and interaction between herbicides and varieties

Table 4.21: Percentage emergence of cowpea seeds as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	% Emergence 3 days after planting			% Emergence 5 days after planting		
	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean
Hand weeding	21.2 (24.0)	27.5 (27.9)	24.4 (26.0)	67.5 (55.5)	70.0 (57.2)	68.8 (56.3)
Oxadiargyl 0.4 L/ha	15.0 (19.8)	7.5 (13.1)	11.2 (16.5)	58.8 (50.1)	50.0 (45.0)	54.4 (47.5)
Oxadiargyl 0.5 L/ha	2.5 (6.5)	7.5 (11.2)	5.0 (8.9)	50.0 (45.0)	51.2 (45.7)	50.6 (45.3)
Pendimethalin 1.00 L/ha	7.5 (8.3)	10.0 (13.3)	8.8 (10.8)	70.0 (57.6)	80.0 (63.8)	75.0 (60.7)
Pendimethalin 1.25 L/ha	20.0 (23.2)	16.2 (20.7)	18.1 (22.0)	77.5 (61.7)	67.5 (55.5)	72.5 (58.6)
Mean	13.2 (16.4)	13.8 (17.2)		64.8 (54.0)	63.8 (53.4)	

LSD (P ≤ 0.05); Herbicide = NS — 13.06 (8.30)
Variety = NS — NS
Herbicide*Variety = NS — NS

Table 4.21: Percentage emergence of cowpea seeds as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	% Emergence 7 days after planting cowpea		
	Bawku Red	Dayo	Mean
Hand weeding	72.5 (59.0)	76.2 (62.2)	74.3 (60.6)
Oxadiargyl 0.4 L/ha	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Oxadiargyl 0.5 L/ha	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
Pendimethalin 1.00 L/ha	85.0 (73.4)	90.0 (74.1)	87.5 (73.7)
Pendimethalin 1.25 L/ha	90.0 (72.2)	83.7 (66.6)	86.8 (69.4)
Mean	49.5 (40.9)	50.0 (40.6)	

LSD ($P \leq 0.05$); Herbicide = 14.36 (12.99)
Variety = NS
Herbicide*Variety = NS

4.5.2: Chlorophyll content of cowpea (spad)

Different herbicides treatments affected chlorophyll content of cowpeas as there was significant differences ($P<0.05$) among various herbicides at 2 WAP and 4 WAP. At 2 WAP, the application of Pendimethalin 1.00 L/ha differed significantly ($P< 0.05$) from hand weeding and Oxadiargyl but not among each other. On the other hand, varieties and interaction between herbicides and varieties did not record any significant differences ($P< 0.05$) at 2 WAP. By the 4th week, herbicide means differed significantly. Pendimethalin 1.00l/ha registered the highest chlorophyll content (54.3) with hand weeding recording the least 40. 8. Both Pendimethalin 1.25 L/ha and Pendimethalin 1.00 L/ha differed significantly from Oxadiargyl and hand weeding but not among each other. There were no significant differences ($P< 0.05$) between both varieties (Bawku Red and Dayo) and interaction between herbicides and varieties.

Table 4.22: Chlorophyll content of cowpea plant as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Chlorophyll content 2 WAP (Cowpea)			Chlorophyll content 4 WAP (Cowpea)		
	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean
Hand weeding	37.0	37.5	37.3	40.4	41.1	40.8
Oxadiargyl 0.4 L/ha	0.00	0.00	0.00	0.00	0.00	0.00
Oxadiargyl 0.5 L/ha	0.00	0.00	0.00	0.00	0.00	0.00
Pendimethalin 1.00 L/ha	52.1	52.9	52.5	53.9	54.7	54.3
Pendimethalin 1.25 L/ha	48.6	50.1	49.3	51.4	52.0	51.7
Mean	27.5	28.1		29.1	29.5	
LSD ($P \leq 0.05$); Herbicide = 5.30				4.03		
Variety NS				NS		
Herbicide*Variety = NS				NS		

4.5.3: Number of weed emerged on plots 135 days after herbicide application

As indicated in Table 4.23, there was a significant difference (P< 0.05) among herbicide treated plots on number of weeds at both 2 and 4 WAP. At the 2WAP, hand weeded plots had the highest number of weeds (36.0) compared to Oxadiargyl 0.5L/ha which recorded the least (8.0). Pendimethalin 1.00L/ha and 1.25L/ha also had high weed count which differed significantly (P< 0.05) from the Oxadiargyl treated plots. Hand weeding at 4 WAP differed significantly against all herbicides treatments by recording 49.0 number of weeds with Oxadiargyl 0.5 L/ha recording the least number of weeds of 13.0. There were no significant differences (P< 0.05) among varieties and between herbicides and varieties at both 2 and 4 WAP.

Table 4.23: Number of weeds on cowpea plots as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

Herbicide	Number of weeds 2 WAP (Cowpea)			Number of weeds 4 WAP (Cowpea)		
	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean	Cowpea on Bawku Red plot	Cowpea on Dayo plot	Mean
Hand weeding	32.0 (5.7)	39.0 (6.2)	36.0 (6.0)	50.0 (7.0)	49.0 (7.0)	49.0 (7.0)
Oxadiargyl 0.4 L/ha	9.0 (2.7)	9.0 (2.9)	9.0 (2.8)	13.0 (3.7)	14.0 (3.7)	14.0 (3.7)
Oxadiargyl 0.5 L/ha	5.0 (2.1)	10.0 (3.1)	8.0 (2.6)	13.0 (3.5)	13.0 (3.7)	13.0 (3.6)
Pendimethalin 1.00 L/ha	23.0 (4.7)	30.0 (5.4)	26.0 (5.0)	33.0 (5.7)	37.0 (6.0)	35.0 (5.9)
Pendimethalin 1.25 L/ha	32.0 (5.6)	30.0 (5.5)	31.0 (5.5)	37.0 (6.1)	36.0 (6.0)	37.0 (6.1)
Mean	20.0 (4.1)	24.0 (4.6)		29.0 (5.2)	30.0 (5.3)	

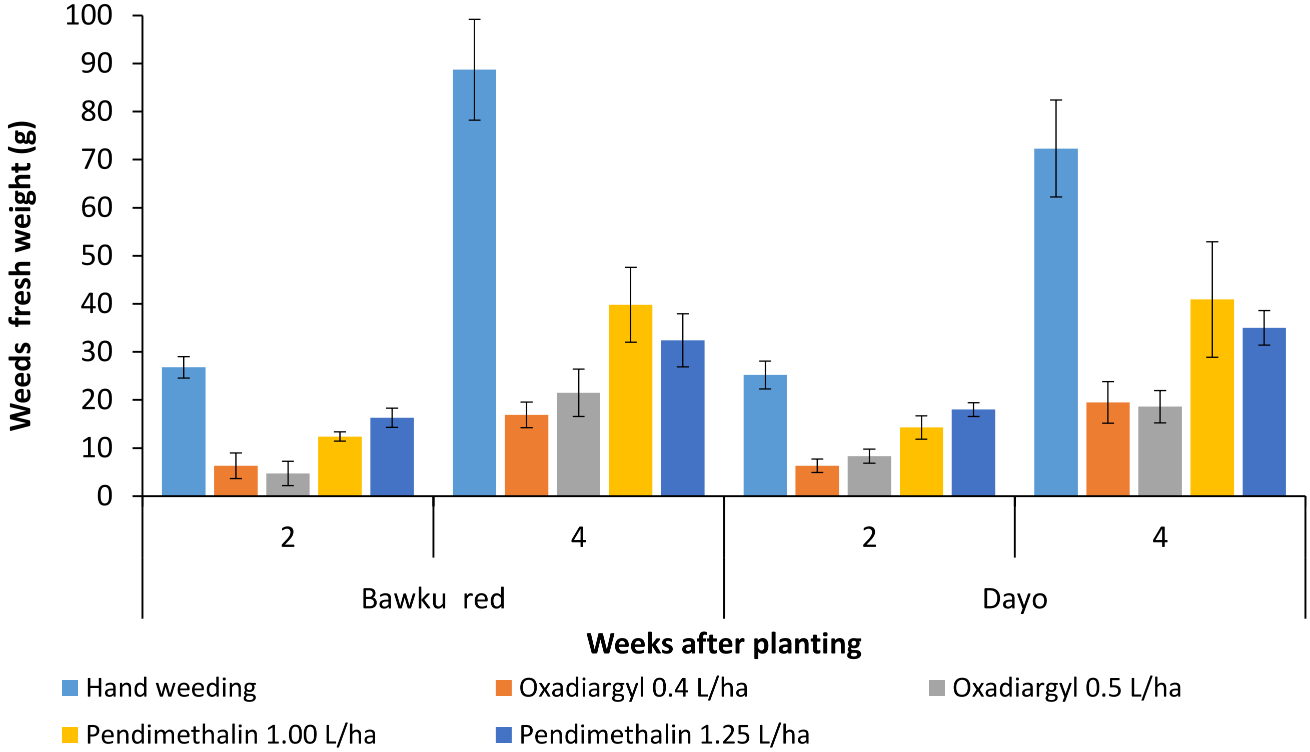
* Means in parenthesis are transformed values

	2 WAP	4 WAP
LSD ($P \leq 0.05$); Herbicide =	8.84 (1.04)	10.7
Variety =	NS	NS
Herbicide*Variety =	NS	NS

Numbers in parenthesis are transformed values

4.5.4: Weed fresh weight

Significant differences were observed among various herbicide treatments at (P<0.05). At 2 and 4WAP. At 2WAP, hand weeded plots recorded the highest fresh weed weight of 26.99g, whiles Oxadiargyl 0.4 L/ha recorded the least of 6.3 g. Hand weeding differed significantly (P< 0.05) from all herbicide treatments at 2WAP. At 4WAP, hand weeded plots recorded a significantly highest fresh weed weight of 80.5 g with Oxadiargyl 0.4L/ha recording the least of 18.2 (g). Hand weeding differed significantly (P< 0.05) from all herbicide treated plots. Statistically, there was no significant difference among varieties and interaction between herbicides and varieties.



Vertical bars represent standard error bars

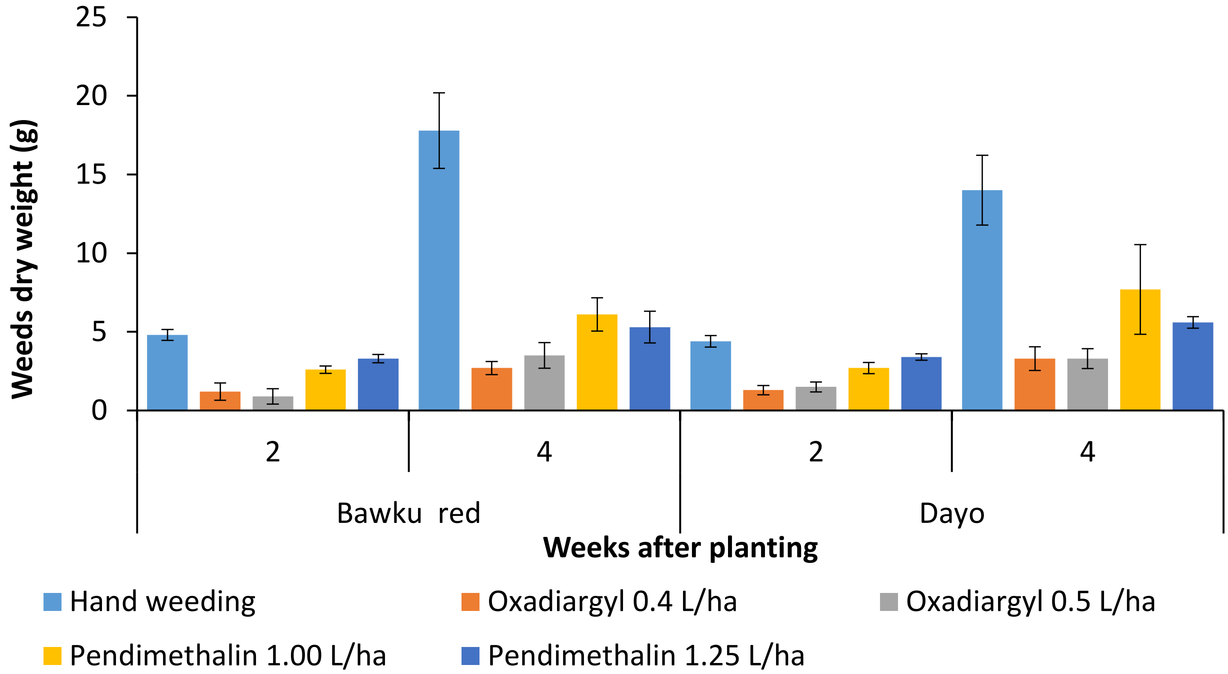
Figure 7: Weed fresh weight on cowpea plots as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

4.5.5: Weeds dry weight (g)

From figure 8, there was a significant difference among the various herbicide treatments. At both 2 and 4WAP. Hand weeding registered a significantly highest dry weeds weight (4.g) with Oxadiargyl 0.5 L/ha recording the least (1.2g) at 2WAP. Hand weeded plots differed significantly (P< 0.05) from all herbicide treatments at 2WAP.

Hand weeding at 4WAP recorded the highest dry weed weight of 15.9(g) compared to Oxadiargyl 0.4L/ha which recorded the least of 3.0(g). Hand weeded plots differed greatly to all herbicide treatments at 4WAP. It was also observed that Pendimethalin treated plots differed from

Oxadiargyl treated plots but not different with each other with regards to dry weeds weight. There was no significant difference herbicides and varieties at both 2 and 4 WAP.



Vertical bars represent standard error bars

Figure 8: Weeds dry weight on cowpea plots as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application.

4.6 Cost-Benefit Ratio Analysis for the Production of Onion.

Cost effectiveness of weed control methods as influenced by pre-emergence herbicides (Oxadiargyl 400g/L SC and Pendimethalin 456g/L EC) application and hand weeding

Table 4.24 indicates the cost benefit analysis of the production of onion using different rates of Oxadiargyl and Pendimethalin and hand weeding as control. There was a difference in the net revenue accrued resulting from the application of different pre emergence herbicides and hand weeding. The application of Pendimethalin (1.00L/ha) had the highest net revenue (34,035) followed by Oxadiargyl (0.4L//ha) (31,480) which was also followed by Pendimethalin (1.25L/ha) (30,775) and Oxadiargyl 0.5L/ha (28,340). Hand weeding had the lowest net revenue (21,470).

Table 4.24: Benefit Cost Ratio Analysis for the Production of Onion.

Treatments	**Total Cost (GHS)**	**Total Revenue (GHS)**	**Net Revenue (GHS)**	**Cost-Benefit ratio**
Oxadiagyrl @ 0.5 L/ha	12410.00	-	-	-
Oxadiagyrl @ 0.4 L/ha	12410.00	-	-	-
Pendimethalin @ 1.25 L/ha	12475.00	43,250	30,775	3.47
Pendimethalin @ 1.00 L/ha	12465.00	46,500	34,035	3.73
Hand weeding	12530.00	34,000	21,470	2.71

CHAPTER FIVE

5.0 DISCUSSION

A total of thirty weed species identified at the experimental site were dominated by broadleaved weeds followed by grasses and sedges.

Oxadiargyl at all rates used suppressed weed emergence over Pendimethalin and hand weeded treatment. Oxadiargyl 0.5 L/ha resulted in the longest number of days to weed re-emergence. Studies by Tetteh *et al.* (2011) however reported the use of Pendimethalin as one of the most effective method of weed control in onion. Generally, both herbicide applications in this study resulted in a more effective weed management compared to the hand weeding as the herbicides acted by killing the germinating weed seeds hence preventing emergence. These observations are in line with Sarkodie *et al.* (2014) who reported that manual weeding could not suppress weeds growth for long periods as it could not prevent germination of weed seeds and emergence.

Oxadiagyrl herbicide though recommended for weed control in vegetables, it is not widely adopted. In this study, the chemical was very effective in reducing weed re-emergence after tillage operations in the onion field. This finding agrees with those of McIntyre and Barbe (1995) who asserted that Oxadiargyl chemical weed control was superior to that of hand weeding in onion.

The results also conform to the findings of Nikolova and Baeva (2000) who also reported that Oxadiargyl was effective and efficient in controlling annual grasses and also broad-leaved weeds that grew on vegetable fields.

Like most herbicides Oxadiargyl 400 g/L and Pendimethalin 456 g/L become degradable with time therefore have their efficacy decreasing with time. This was evidenced in the general increase in the population of weeds on all herbicide treated plots especially Pendimethalin treated plots after a period of 20 weeks thereby requiring supplementary weeding. This observation is in line with reports by Rao (2000) that indicted that loss of efficacy of Pendimethalin herbicide over time which resulted in reduced weed control. Therefore, the use of pre-emergence herbicides need to be complemented with cultural weed management for instance to totally prevent the interference of weeds in onion cultivation.

Herbicide treatments did not have any phytotoxic effect on the growth and development of the onion plants. Chlorophyll content of the onion on plots treated with the herbicides were also higher than on hand weeded plots. This could be as a result of nutrient availability because of less competition from weeds. This agrees with reports by Patel *et al.* (2011), who recorded taller onion plants, neck thickness and dry matter in fields that were treated to Pendimethalin. The findings in this current study also agree with those of Sharma and Khandwe (2008) who reported that plant and number of leaves were found to be higher under weed free conditions and Pendimethalin treated plots.

Pendimethalin treated plot at (1.25 L/ha) and Pendimethalin (1.00 L/ha) were observed to have onions with the greatest number of leaves from fourth week through to the twelfth week compared to the other treatments as it effectively controlled weeds thereby reducing competition for light, water and space. The application of Pendimethalin also gave a significantly higher plant height, number of leaves and number of branches of cowpea (Usman, 2013).

Herbicide treated plots influenced growth characters such as plant height, number of leaves and leaf length due to conducive environment created in the root zone resulting in the taking up of water and plant nutrients from the soil. Also, better weed control throughout the growth stage helped in greater photosynthetic ability resulting in better vegetative growth (Verma and Singh, 1996)

Even though hand weeding is not phytotoxic to onion, it recorded the least onion yield. This finding is in contrast to the findings of Khan *et al.* (2005) and El-Metwally *et al*. (2010) who reported that effective weed control and high yield of onion was attained by hand weeding. The contrasting results of lowest bulb yield obtained from the hand weeded plots could be as a result of competition for essential resources from the high weed incidence since recommended handweeding appeared insufficient for effective control

Higher bulb yield from herbicide treatments could be due to the fact that weed growth and weed population remained at a lower rate especially during the critical period of onion bulb development. Similar findings were reported by Chopra (2007).

Soil microbial population increased under herbicide treated plots and decreased under hand weeded plots at harvest. This observation is in contrast with the finding of Ghosh *et al.* (2007) who affirmed that hand weeded treatments gave an increase in microbial population in soil. This could be attributed to clearing of weeds on the hand weeded plots exposing the soil to more evaporation and heat. The increased microbial population at hand weed decreased at harvest from its value a month after turning of soil during weeding which may have exposed the microbes to the direct sunlight thereby reducing their populations.

Herbicide residue analysis of onion bulbs did not show any traces of Pendimethaline in all the treated plots. Kaur *et al.,* (2010) also reported that samples of onion bulbs collected at 30, 60 and 90 days after spray and at uprooting stage showed no residues of Oxyfluorten and Pendimethaline. On the other hand, traces of Oxadiargyl were detected in onion bulbs from plots treated to Oxadiargyl. Bawku Red with Oxadiargyl at (0.5 L/ha) recorded a significantly higher residue of 0.094 more than the maximum residue limit of 0.01 mg/kg set by the European Union.

Additionally, traces of Oxadiargyl were detected in Bawku red at Pendimethalin (1.00 L/ha). This could be as a result of heavy down pour which could wash Oxadiargyl from treated plots close to the Pendimethalin plot. The nature of beds prepared could also facilitate the running of water from Oxadiargyl treated plots to this Pendimehthalin plot during watering. This was an indication that the use of Oxadiagyrl in vegetables could result in contamination of nearby fields if proper care is not taken.

In determining the impact of herbicide on succeeding crop, cowpea bioassay revealed that there were no traces of Pendimethalin in the soil as it did not affect germination and growth of cowpea negatively.

On the other hand, cowpea seeds that were sown on Oxadiargyl treated plots died just after emergence indicating possible residues of oxadiargyl. Oxadiargyl has a half-life of 120 days compared with pendimethalin which has a half-life of 90 days

For an efficient and effective weed control, one has to prudently select a weed control method that will help to minimize cost and maximize profit. Among all the pre--emergence herbicides applied, Pendimethalin at 1.00L/ha led to the highest net revenue. Oxadiargyl treated plots given no revenue as a result of the traces of the herbicide in onion bulbs making bulbs to be disposed of even though higher yield was attained from those plots which were more than hand weeded plots. Findings were in accordance with (Chikoye *et al*., 2007) who reported that chemical herbicides produce greater yield at less cost than hand weeding. However, findings were in contrast with Khan *et al*., 2005 who reported that effective weed control and high yield of onion was recorded by the application of hand hoeing. This could be due to cheap and available labour. Results however shown that Oxadiargyl at both 0.5 L/ha and 0.4 L/ha were more effective in controlling weeds over an extend period compared to Pendimethalin. Also, Dayo onion variety out performed Bawku Red onion variety in terms of growth and yield. In all, the application of pre emergence herbicides in general was more cost effective than hand weeding in this research.

CHAPTER SIX

6.0: CONCLUSIONS AND RECOMMENDATIONS

6.1: CONCLUSIONS

The results of the research done at the University of Ghana farm using pre emergence herbicides on two onion varieties revealed that:

- Oxadiargyl at both 0.5 L/ha and 0.4 L/ha were more effective in controlling weeds over an extend period compared to Pendimethalin. Hand weeding alone in onion resulted in high competition from weeds thereby affecting yield.
- Dayo onion variety out performed Bawku Red onion variety in terms of growth and yield and established very well within the first fourteen days after transplanting irrespective of herbicide treatments.
- The herbicides had no impact on soil properties except for significant residues recorded in Oxadiargyl treated plots.
- Traces of Oxadiargyl at both rates were present in more than the recommended maximum residue limit set by the European Union in both varieties of onion.
- High residues of Oxadiargyl were observed in harvested onion bulbs whiles bulbs from Pendimethalin treated plots contained no levels of residues
- The results on weed re-emergence after harvesting onion, percentage cowpea seedling emergence, weed biomass and plant biomass indicated that Oxadiargyl still existed in the soil after onion cultivation for 140 days and 105 days after application whiles Pendimethalin was not present.

- The application of pre emergence herbicides in general was more cost effective than hand weeding in this research.

6.2: RECOMMENDATIONS

- Further studies with regards to the time interval between application of Oxadiargyl and transplanting of onion should be conducted to ascertain if seedlings would still experience transplanting shock.
- Further studies to evaluate suitable rates of Oxadiargyl with minimal residual effects should be conducted to ascertain the safe use of this herbicide especially in short duration annual crops.

6.3 REFERENCES

Abbey, L. and Oppong-Konadu, E. (1997). Status of onion production in Ghana and prospects for improvement. *Ghana Journal of Science*. 37: 17 – 21.

Abbey, L., Danquah, A., O., Kanton, R., A., L. and Olympio, S., N. (2000). Characteristics and storage performance of eight onion cultivars. *Ghana Journal of Science*. 9-13.

Ado, P., O. (2001). Onion cultivation. *Onion newsletter*, 20: page 30 -34. *Advanced Agronomy* 23: 147-240.

Ageless (2015). Properties and therapeutic uses of onion. Available from:

Alexandratos, N. and Bruinsma, J. (2012). *World agriculture towards 2030/2050: the 2012 revision*. ESA Working paper No. 12-03. FAO, Rome.

Appearance of *Fusarium* Basal Rot Disease of Onion in the Kwahu Sought District of Ghana. *Asian-Pacific Weed Science Society*, 500-509.

Awuah, R.T., Kwoseh, C., Kuranteng, S. L., Okpala, R., O., C. and Amoako-Attah, I. (2009). Appearance of *Fusarium* Basal Rot Disease of Onion in the Kwahu South District of Ghana. *Ghana Journal of Horticulture* **7**: 84-88.

Baghizadeh, A., Baniasadi, F., Bonjar, G. H. S., Sirchi, G. R. S., Massumi, H., Jorjandi, M., Farokhi, P.R. and Aghighi, S. (2009). Biocontrol of B otrytis allii Munn the causal agent of neck rot, the post-harvest disease in onion, by use of a new Iranian isolate of Streptomyces. *America Journal of Agriculture and Biological Science., 4*: 72- 78.

Bautisa, Eulito, U. and Javier, E. F. (2008). Rice production practices. *Philippines Institute for Development Studies*, *Research Paper Series* No. 2008-02.

Benvenuti, S. (2007). Weed seed movement and dispersal strategies in the agricultural environment. *Weeds biology and management*, 7(3), page 141-157.

Blouin, M.,Hodson, M. E., Delgado, E. A., Baker, B., Brussaard, L., Butt, K. R., Dai J, Dendooven L,Peres, G., Tondoh, J. E., J.J and Cluzeau, D. (2013) . A review of earthworm impact on soil function and ecosystem services. *European Journal of soil science*, 64(2), 161-182.

Bond, W. and Burston, S. (1996). Timing of removal of weeds from drilled salad onions to prevent crop losses. *Crop protection.* 15: page 205-211.

Boydston, R.A., Mojtahedi, H., Crosslin, J. M., Brown, C.R. and Anderson, T. (2008). Effect of hairy nightshade (*Solanum sarrachoides*) presence on potato nematodes, diseases, and insect pests. *Weed science*, 56(1), 151-154.

Carlson, H., L., and Kirby, D. (2005). Effects of herbicide rate and application timing on weed control in dehydrated onions. *Intermountain Research and Extension Center*, Univ. of California, Tule Lake, C A. 334-335.

Carvalho, L. B, Bianco, S., Pitelli, R. A. and Bianco, M. S. (2017). Comparative study of the accumulation of dry mass and macronutrients by maize plant var. BR-106 and Brachiaria plantaginea. *Weed plant*, 25(2): 293-301.

Cheng F. and Cheng, Z. (2015). Research progress on the use of plant allelopathy in agriculture and the Physiological and ecological mechanism of allelopathy. *Frontiers in plant science*, http://doi.org/10.3389/fpls.2015.0120.

Chikoye, D., Udensi, U.E., 1um, A.F (2005). Evaluation of a new formulation of atrazine and metolachlor mixture for weed control in maize in Nigeria. *Crop protection*, 24(11), 1016-1020

Chikoye, D., Udensi, U.E., Ium, A. F. and Ekeleme, F. (2007). Rimsulfuron for postemergence weed control in corn in humid tropical environment of Nigeria. *Weed technology*, 21(4), 977-981.

Chopra, I., Kumari, B., Sharma S. K. (2010) Evaluation of leaching behavior of pendimethalin in sandy loam soil. *Environmental Monitoring and Assessment*. 160: 123–126. doi: 10.1007/s10661-008-0662-2.

Chopra, Nisha and Chopra, N., K. (2007**).** Production of weed free mother bulb of onion (*Allium cepa*) through integration of herbicides and weeding. *Indian Journal of Agronomy*, 52 (1): 80–82.

Cjhikoye, D., Schulz, S. and Ekeleme, F. (2004). Evaluation of integrated weed management practices for maize in the northern guinea savanna of Nigeria. *Crop protection*, 23(10), 895-900.

Corgan, J., Wall, M., Cramer, C., Samis, T., Lewis, B., and Schroeder, I. (2000). Bulb onion culture and management. *College of Agriculture and Home Economics*, New Mexico State Univ., Los Cruces, N M. 563.

Dickmann, R., Melgarejo, J., loubiere, P. and Montagnon, M. (1997). Oxadiargyl: novel herbicide for rice sugar cane In Brighton. *Crop Protection Council Conference weeds*, 1, 51-58.

Dinham, B. (2003). Growing vegetables in developing countries for local urban population and export market: problems confronting small scale producers. *Pest management science*. 59(5), 575-55

EEA. (2013). Late lessons from early warnings: science, precaution, innovation. *European Environment Agency*, Report No 1/2013. EEA, Copenhagen.

El-Metwally, I.M., Dawood, M. G., Messiha, N.K., - ELMasry, R. R. and Abdel –Moaty, M. S. (2010). Changes in minerals, carbohydrate, flavonoid, phenolic contents and yield of onion bulbs as affected by some herbicidal weed management. *Journal of Applied Science Research*, 8(2), page 930-936.

FAOSTAT (2004). Food and agricultural commodities production. Food and Agricultural organization Statistics. http://faostat.fao.org/site/339/default.aspx

FAOSTAT 2008. List of countries by onion production. Food and Agricultural Organization of United Nations, Rome, Italy.

FAO (2009) (United Nations, Food and Agriculture Organization), FAOStat (02/2001). World dry-bulb onion yield per hectare, 1990-2009.

FAOSTAT. (2013). The State of Food Insecurity in the World 2013. The multiple dimensions of food security. *World Soils Resource Report FAO*, Rome.

FOA/UNESSCO (1990). Soil map of the world revised legend. *World Soils Resource Report* 60. FAO, Rome, 41.

Forcella, F. (2000). Rotary hoeing substitutes for two-third rate of soil-applied herbicide. *Weed Technology*, 14(2) 298-303.

Francis, R., and Read, D., J. (1995). Mutualism and antagonism in mycorrhizal symbiosis with special reference to impact on plant community structures. *Canadian Journal of Botany*. 73 Suppl: S1301-S1309.

Gaikwad, C.B., Kolse, R. H. Yadav, S.T. and Jadhav, J. D. (2010). Nutrients uptake and phytotoxicity study of herbicides as influenced by different treatments in onion seed crop. *International journal of agricultural science*, 6(1), 333-336.

Gaskell, M., Cardwell, X., N., Faber, B., and Voss, R. (1998). Effects of transplant date and transplant size on production, quality and pungency of sweet onions. *Newsletter Articles, Small farms and Speciality Crops*. http://www.sbceo.k12.ca.us/-uccesb/sf_12.htm: Retrieved: 26/02/2019

Gazdag, M., Torma (1997). Competition between weeds and onion grown from seed bulbs. *Novenyvedelem* 33, 57-61.

Ghafoor, A., Huda, S., Hassan, G., Waseem, K. and Nadeem, M. A. (2000). Growth response of onion seedlings against various durations of weed competition sown by different planting methods. *Sarhad Journal of Agriculture*. 16 (5): 489-495.

Ghana-Made (2017). Onions production in Ghana. Ghana-made.org (Accessed 30/05/17, 4:49 pm).

Ghana Meteorological Agency, Mempeasem, Legon, Accra, Ghana.

Ghosh, P., Ghosh R. k., Saha, M. and Mandal, D. (2007). Effect of Clomazone + 2, 4 D on growth and productivity of rice and total bacteria in soil. *Journal of Crop and Weed Science*, 3(1) 18-23.

Hamma, I. L. and Ibrahim, U. (2013). Weed management techniques of horticultural crops in Nigeria. American-Eurasian Journal of Agricultural and Environmental Science, 13(3), page 362-366

Hatcher, P. E. and Melander, B. (2003) Combining physical, cultural and biological methods: prospects for integrated non-chemical weed management strategies. *Weed Research Society*. Weed Research 43,303

Helling, C., S., Kearney, P., C. and Alexander, M. (1971). Behavior of pesticides in soil.

Hutzinger, O. (1981). Environmental and toxicological chemistry at the University of Amsterdam: Five years of philosophy and practice of environmental health chemistry. *Environmental health chemistry*. J. D. McKinney, ed. Ann Arbor Science Publishers Inc., Ann Arbor, Michigan.

Jazwa, A., Szpyrka, E. and Sadło, S. (2009) Disappearance of Pendimethalin In Soil and Its Residue in Ripe Fennel. *Journal of Central European Agriculture* Vol 10(2) 153-158

Juraske, R., Anton, A., Castells, F., and Hujbergts, M., A., J. (2007). Human intake fraction of pesticide via greenhouse tomato consumption. *Chemosphere*, 67 (2007), page 1102-1107.

Kaur, S., M., Randhawa, S., K. and Walia, U., S. (2010). Analysis of herbicide residues in onion bulbs and soil under different planting patterns and straw management techniques. *Indian Journal of Weed Science* 42(1&2): page 77-81.

Kerle E. A., Jenlins J. J and Vogue P. A. (2007). Understanding pesticide persistence and mobility for ground water and surface water protection. *Oregon state university extension service*, EM8561-E.

Khan, B.M., Gul, B., Saeed, M. and Hussain, Z. (2005). Efficacy of different herbicides for controlling weeds in onion in higher altitudes. *Pakistan journal of science research*, 11(1-2), page 61-68.

Khuntia, A., Pradhan M. R., Jena, S. and Lenka P. C. (2013). Effects of Herbicides Soil on Microbial Population and Productivity of Rice in North Eastern Coastal Plain Zone of Odisha. *International Journal of Advanced Chemical Science and Application*, 51-53.

Knezevic, S., Z. and Datta, A. (2015). The critical period for weed control: Revisiting data analysis. *Weed science*, 63(1), page 188-202.

Kolo, M., G., M. and Daniya, E. (2006). Effects of variety and method of sowing on weed control and crop yield in sesame (*Sesamum Indicum* L.) In southern guinea savannah of Nigeria. Nigerian *Journal of Agricultural Research,* 22, 22-31.

Lamptey, S. (2007). Evaluation of the efficiency of weed control and crop response to herbicide in hot pepper (*Capsicum frutesscens*). M.Phil. (Crop Science) Thesis University of Ghana, Legon. 59-101.

Lancaster, J. E. Triggs, C. M., De Ruiter, J. M. and Gandar, P. W. (1996). Bulbing in onions: photoperiod and temperature requirements and prediction of bulb size and maturity. Annals of Botany 78: 423 - 430.

Liebman, M., and Gallandt, E., R. (1997). Ecological approach for management of crop weed interactions. In L.E Jackson (ed). *Ecology in agriculture*. Academic press, San Diego, C A. P291-343.

Management on the Prevalence of Pink Pineapple Mealybugs in Ghana. *Journal of Science and Technology*, 34(2), page 17-25.

McErlich, A. F. and Boydston, R. A. (2013). Current State of Weed Management in Organic and Conventional Cropping Systems. *USDA-ARS/UNL Faculty*. 1387. From http://digitalcommons.unl.edu/usdaarsfacpub/1387 Accessed on 20th march, 2015

McIntyre, G., and Barbe, C. (1995). Weed control in direct seeded and transplanted onion. *Revue agricole et sucriere de i'IleMaurice*. 74(3): 32-36.

Mercado, B. L. (1979). Introduction to weed science. *Southern Asian Regional centre for Graduate Study Research in Agriculture College*, Laguna and Philippines: 17-89.

Mettananda, K., A., and Fordham, R. (2001). The effects of plant size and leaf number on the bulbing of tropical short day onion cultivars (*Allium cepa* L.) under controlled environment. *Journal of Horticultural SScience*, 14 (5) 22-31.

Miller, R. O. And Bloese, P. (1999) Imazaquin And Pendimethalin Provide Safe and Effective Weed Control In 1st-Year Hybrid Poplar Plantations in Michigan. *Forest Biomass Innovation Center Research Report.* Vol. 54

Mirza- Hasanuzzaman, M. A., Alam M. H, Akther M. M, and Alam K.F., (2009). Evaluation of pre-emergence herbicide and hand weeding on the weed control efficiency and performance of transplanted Aus rice. *American –Eurasian journal of Agronomy*, 2(3), 138-143.

MOFA (2013). Ministry of Food and Agriculture. http://mofa.gov.gh/site/?pageid=13909. Accessed on 15th may, 2018.

Mohler, C., L. (2001). Weed life history: Identifying vulnerabilities. *Ecolocal management of agricultural weeds*. Cambridge University press, New York.

Moomaw, R., S., Klein, R. N., Martin, A., Roeth, F., Shea, P. J., Wicks, G. A. and Wilson, R. G. (1992). "G92-1081 Factors That Affect Soil-Applied Herbicides". *Historical Materials* from University of Nebraska-Lincoln Extension. 1220.

NARSP (National Agricultural Strategic Research Plan) Ghana (1994). Final Report.

Nikolova, V. and Baeva, G. (2000). Effect of oxadiargyl on the weeds of *Allium cepa* L. and soil biological activity. *Bulgarian J. Agriculture. Science.* v. 6(5), 533-537.

NOA (National Onion Association) (2011). How and where onions are grown. https://www.onions-usa.org/all-about-onions/ where-how -onions-are-grown.

Norman, J. C. (1992). Tropical Vegetable Crops. Arthur H. Stockwell Ltd. IIgracombe, Devon. 160-161.

Obeng-Ofori, D., Danquah, E., Y., Ofosu-Anim, J. (2007). Vegetable and Spice Crop Production in West Africa. *The City Publishers Limited*, Ghana. Page 77-79.

Oerke, E., C. (2006). Crop losses to pests. *Agriculture. Science*. V.144 Page 31-43.

Olorunmaiye, P. M, (2009). Effect of integrated weed management on weed control and yield components of maize and cassava intercrop in a southern Guinea savanna ecology of Nigeria. *Australian Jjournal of Crop Science, 3(3),* 129-136.

Opara, L., U. (2003). ONIONS: *Post-Harvest Operation*. *Pakistan journal of Botany*, 43, 2817-20. Palmerston North, New Zealand. 3.

Pandey, R. R., Sharma, G., Tripathi S. K. and Singh, A. K. (2007). Litter fall, litter decomposition and nutrient dynamics in subtropical natural forest and managed plantation in North-eastern India. Forest Ecological Management, 240:96-106.

Patel, T., U., Patel, C., L., Patel, D. D., Thanki, J. D., Patel, P. S. and Jat, R. A. (2011). Effect of weed and Fertilizer management on weed control and productivity of onion (*Allium cepa*). *Indian Journal of Agronomy*., page 56**:** 267-272.

Que Hee, S. S., and Sutherland, R. G. (1981). The phenoxyalkanoic herbicides. Vol 1, CRC series in pesticide chemistry. CRC Press, Boca Raton, Fla.

Raemaekers, H. R. (2001). Crop Production in Tropical Africa. DGIC Ministry of Foreign affairs, External Trade and International co-operation, Brussels, Belgium, 455.

Rahman, M., Juraimi, A. S., Jaya Sura, A. S. M., Azmi, B.M. and Anwar, P. (2012). Response of weed flora to different herbicides in aerobic rice system. *Scientific Research and Essays*, 70), 12-23.

Rana, S.S. and Rana, M. C., (2015). Advances in Weed Management. Department of Agronomy, College of Agriculture, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, 55

Rao, A. N. and Ladha, J. K. (2013). Economic weed management approaches for rice in Asia.

Rao, V. S. (2000). Principles of Weed Science, 2nd edition, Oxford and IBH Publishing CO. PVT. LTD. New Delhi. 23-42.

Rice, E., L. (1995). Biological control of weeds and plants diseases. Advances in applied allelopathy. University of Oklahoma press. Norman O K. Page 90-96.

Roca, E., D'Errico, E., Izzo, A., Strumia, S., Esposito, A. and Fiorentino, A. (2009). In vitro saprotrophic basidiomycetes tolerance to pendimethalin. *International Biodeterioration and Biodegradation*. 63: page 182–186. doi: 10.1016/j.ibiod.2008.08.004.

Rubin, B., Rabinowitch, H., D., and Brewster, J., L. (1990). Weed competition and weed control in Allium crops, onion and allied crops. *Agronomy, Biotic interaction, Pathology and Crop Protection. Boca Raton,* F L: CRC Press. Volume 11: 63 Page 84.

Sangha, J. K. and P. Baring. 2003. Efficacy of multiple dietary therapies in reducing risk factors for coronary heart disease. *Journal of Human Ecology*. 14(1): 33-36.

Sarkodie A., Techie J., Menson J. W. and Carlson A. G. (2014). Effects of weed management on the prevalence of pink pineapple Mealy Bugs in Ghana. *Journal of Science and Technology*, 34(2), 17-25.

Sebiomo, A., Ogundero, V. W. and Bankole, S. A. (2011). Effects of four herbicides on microbial population, soil organic matter and dehydrogenase activity. *African Journal of Biotechnology*. 10(5): 770-778.

Sharma, R.C. and Khandwe, R. (2008). Response of weed control measures in *kharif* onion. *Res. Crops*. 9: 348-349.

Sherwani, S. I., Arif, I. A. and Khan, H. A. (2015). Modes of Action of Different Classes of Herbicides, Herbicides, Physiology of Action, and Safety, Andrew Price, Jessica Kelton and Lina Sarunaite, IntechOpen, DOI: 10.5772/61779. Available from:

https://www.intechopen.com/books/herbicides-physiology-of-action-and safety/modes-of-action-of-different-classes-of-herbicides

Silva, A. A., Ferreira, F. A., Ferreira, L. R. and Santos, J. B. (2007). Biologia de plantas daninhas, In: Tópicos em Manejo de Plantas Daninhas, Silva, A. A. and Silva, J. F., (pp. 17-61). Universidade Federal de Viçosa, Viçosa, Brazil.

Singh, M., P. and Singh, K., P. (1994). Effect of crop weed competition on growth and yield of *kharif* onion. *Indian Jounal of Weed Sci*ence, 26: 18-21.

Singh, R. (2014). Weed management in major kharif and rabi crops. *National Training on Advances in Weed Management*. 31-40.

Sinnadurai, S. (1992). Vegetable cultivation. Asempa publication, Ghana, page 140-158.

Sinnadurai, S. (1992). Vegetable Cultivation. Asempa Publishers. Accra, Ghana, page. 83 - 96.

Sivesind, E. C., Leblanc, M. L, Cloutier, D. C., Seguin, P. and Stewart, K. A. (2009). Weed response to flame weeding at different developmental stages. *Weed Technology*, 23, page 438-443.

Smith, C. (2003). Genetic Analysis of Quercetin in Onion (*Allium cepa* L.) ‘Laddy Raider. *The Texas Journal of Agriculture and Natural Resource*, 16 page 24-28.

Smith, R., H., Oliver, J., E., and Lusby, W., R. (1997). Degradation of pendimethalin and its N-nitroso and N-nitro derivatives in anaerobic soil. *Chemosphere*. 8 page 855–867. doi: 10.1016/0045-6535(79)90017-1.

Sondhaia, S. (2007). Evaluation of leaching potential of Pendimethalin in clay loam soil. *Pesticide Research Journal*, 19(1), 119-121.

Sondhia, S. (2013). Herbicides residues in soil, water, palnt and non-targeted organisms and human health implications: *An Indian Journal of Weed Science,* 46(1), 66-85.

Subramanian, S., Ali, M. and Kumar, J. R. (1999). All about weed control. *Kalyon Publishers*, New Delhi, 30-38

Swinton, S. M., Buhler, D. D., Forcella, F., Gunsolus, J. L., and King R. P. (1994). Estimation of crop yield loss due to interference by multiple weed species. *Weed science*. 42: page 103-109.

Taylor, A. W., and Glotfelty. D. E. (1988). Evaporation from soils and crops. Chapter 4 in Environmental chemistry of herbicides, Vol I. R. Grover, ed. CRC Press, Boca Raton, Fla.

Taylor, M. D. Klaine, S. J., Carvalho, F. P., Barcelo, D. and Everaarts, J. (Eds). (2003). Pesticide residues in coastal tropical ecosystems. Distribution, fate and effects. Taylor & Francis Publ., CRC Press, London. 576

Tetteh, R., Norman J. C. and Amoatey, C. A (2011). Studies on Weed Management of tomato. *Ghana Journal of Horticulture,* 9, Page 66-76.

Tracchi, G., Loubiere, P. and Montagnon, M. (1997). Oxadiargyl: A novel herbicide for sunflower and vegetables, (2, 885-889). *In Proceedings of the Brighton Crop Protection Council Conference- Weeds.*

Tweneboah, C. K. (1998). Vegetables and Species in West Africa. Ghana: C.K. Tweneboah and Co-Wood Publishers, page 136 – 149.

TyurkanovA, G. K., Anan'eva, N. D. Shaly, A. and Kaluz, S. (1987). Effect of herbicides applied to sugar beets seedbeds on soil microorganisms. *Agrokhimiya*, 11, Page 93-97.

Upadhyay, U.C and Chaudhary, B.C. (1979). The effect of weed control methods on the growth and yield of rice under upland conditions, (pp. 289-291). *In proceedings of the 7th conference of the Asia Pacific, Weed Science Society Conference,* Sydney, Australia.

Usman, I. (2013). Effect of pre-emergence herbicides on weed control and performance of cowpea in Samaru. *The Journal of'Agricultural Sciences,* 8(2), 76-81.

Usoroh, M. J. (1979). Assessment of the critical period for weed competition in tomato (*Lycopersicon escuulentum* L.) under Nigerian conditions, (56, 151—154*). Proceedings on the 9th Annual Conference of Weed Science Society ofNigeria.*

Varshney, J. G. and Sondhia, S. (2008). Weed Management (introduction to herbicides*) National Research Centre for Weed Science* (Indian Council of Agricultural Research) Maharajpur, Jabalpur-482004 (M.P) India, 1-12.

Vatovec, C., Jordan, N., and Huerd, S. (2005). Responsiveness of certain agronomic weed species to arbuscular mycorrhizal fungal. Agriculture and food systems 20: page 181-189.

Verma, S. K. and Singh, S. B. (2008). Enhancing of wheat production through appropriate agronomic management. *Indian Farming.* 58(5), 15-18.

Verma, S. K. and Singh, S. B. (2008). Enhancing of wheat production through appropriate agronomic management. India farming.

Verma, S. K. and Singh, T. (1996). Weed control in kharif onion (*Allium cepa* L.). *India. Journal. Weed Science.*. 28: page 48-51.

Voos, G. and Groffman, P., M. (1997). Relationships between microbial biomass and dissipation of 2, 4-D and dicamba in soil. *Biological Fertilizer Soils* 24: page 106-110.

Voos, G. and Groffman, P.M. (1997). Relationship between microbial biomass and dissipation of 2, 4-D and discamba in soil. *Biology and Fertility of Soils*, 24,106-110.

Wapshere, A., Delfose, E., S., Cullen, J., M. (1989). Recent development in biological control of weeds. *Crop Protection*. 8: 227-250. www.ageless.co.za/herb-onion. htm Access date: 09/06/2018.

Zaman, S., Farrukh, H. L., and Muhammad, W. (2011). Floristic composition, communities and ecological characteristics of weed of wheat fields of labour, District Swabi Pakistan.

Zimdahl, R. L., Catizone, P., and Butcher, A. C. (1984). Degradation of pendimethalin in soil. Weed Science. 32: page 408–412.

6.4 APPENDICES

EXPERIMENT ONE: IMPACT OF PRE-EMERGENCE WEED MANAGEMENT USING PENDIMETHALIN AND OXADIARGYL ON THE GROWTH AND DEVELOPMENT OF TWO ONION VARIETIES.

APPENDIX 1: ANALYSIS OF VARIANCE
WEED DATA ANALYSIS

Variate: Days Weed Emergence

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	25.700	8.567	3.84	
Herbicide	4	8293.000	2073.250	928.32	<.001
Residual	12	26.800	2.233	1.72	
Variety	1	0.100	0.100	0.08	0.785
Herbicide.Variety	4	8.400	2.100	1.62	0.222
Residual	15	19.500	1.300		
Total	39	8373.500			

Variate: Number of weeds at week 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	669.9	223.3	0.98	
Herbicide	4	70956.0	17739.0	78.20	<.001
Residual	12	2722.0	226.8	0.45	
Variety	1	81.2	81.2	0.16	0.693
Herbicide.Variety	4	260.4	65.1	0.13	0.969
Residual	15	7523.9	501.6		
Total	39	82213.4			

Variate: Number of weeds at week 6

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	157.07	52.36	0.55	
Herbicide	4	14356.90	3589.23	37.61	<.001
Residual	12	1145.30	95.44	1.41	
Variety	1	119.03	119.03	1.76	0.204
Herbicide.Variety	4	309.60	77.40	1.15	0.373
Residual	15	1013.88	67.59		
Total	39	17101.77			

Variate: Number of weeds at week 9

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	76.00	25.33	1.76	
Herbicide	4	13497.40	3374.35	234.06	<.001
Residual	12	173.00	14.42	0.16	
Variety	1	28.90	28.90	0.32	0.579
Herbicide.Variety	4	41.60	10.40	0.12	0.975
Residual	15	1347.50	89.83		

Total	39	15164.40

Variate: Number of weeds at week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	115.27	38.42	2.14	
Herbicide	4	15793.60	3948.40	219.76	<.001
Residual	12	215.60	17.97	0.51	
Variety	1	55.22	55.22	1.58	0.229
Herbicide.Variety	4	38.40	9.60	0.27	0.890
Residual	15	525.87	35.06		
Total	39	16743.97			

Variate: Number of weeds at week 3 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.861	0.954	0.93	
Herbicide	4	503.079	125.770	123.24	<.001
Residual	12	12.246	1.021	0.68	
Variety	1	0.671	0.671	0.45	0.515
Herbicide.Variety	4	1.318	0.330	0.22	0.924
Residual	15	22.610	1.507		
Total	39	542.785			

Variate: Number of weeds at week 6 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.7164	0.9055	0.81	
Herbicide	4	219.5917	54.8979	49.16	<.001
Residual	12	13.4010	1.1167	1.87	
Variety	1	1.4649	1.4649	2.45	0.139
Herbicide.Variety	4	1.1328	0.2832	0.47	0.755
Residual	15	8.9783	0.5986		
Total	39	247.2851			

Variate: Number of weeds at week 9 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.5471	0.8490	4.74	
Herbicide	4	159.0211	39.7553	221.88	<.001
Residual	12	2.1501	0.1792	0.32	
Variety	1	0.3439	0.3439	0.62	0.444
Herbicide.Variety	4	0.4752	0.1188	0.21	0.927
Residual	15	8.3334	0.5556		
Total	39	172.8708			

Variate: Number of weeds at week 12 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.3290	0.4430	3.16	
Herbicide	4	160.0708	40.0177	285.15	<.001
Residual	12	1.6840	0.1403	0.58	
Variety	1	0.6971	0.6971	2.89	0.110
Herbicide.Variety	4	0.2932	0.0733	0.30	0.871
Residual	15	3.6235	0.2416		
Total	39	167.6977			

Variate: Weeds Fresh Weight at week 3					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	31951.	10650.	1.02	
Herbicide	4	456159.	114040.	10.97	<.001
Residual	12	124713.	10393.	0.63	
Variety	1	13319.	13319.	0.81	0.382
Herbicide.Variety	4	51776.	12944.	0.79	0.551
Residual	15	246499.	16433.		
Total	39	924417.			

Variate: Weeds Fresh Weight at week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	5052.5	1684.2	4.98	
Herbicide	4	110410.7	27602.7	81.63	<.001
Residual	12	4057.6	338.1	0.61	
Variety	1	99.2	99.2	0.18	0.678
Herbicide.Variety	4	288.0	72.0	0.13	0.969
Residual	15	8303.4	553.6		
Total	39	128211.4			

Variate: Weeds Fresh Weight at week 9					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	6268.6	2089.5	5.75	
Herbicide	4	62028.3	15507.1	42.68	<.001
Residual	12	4359.7	363.3	2.63	
Variety	1	10.9	10.9	0.08	0.783
Herbicide.Variety	4	89.0	22.2	0.16	0.955
Residual	15	2074.5	138.3		
Total	39	74831.0			

Variate: Weeds Fresh Weight at week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	10.07	3.36	0.19	
Herbicide	4	82037.58	20509.40	1175.03	<.001
Residual	12	209.45	17.45	0.77	
Variety	1	59.05	59.05	2.61	0.127
Herbicide.Variety	4	83.47	20.87	0.92	0.477
Residual	15	339.59	22.64		
Total	39	82739.22			

Variate: Weeds Dry Weight at week 3					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	76.142	25.381	1.42	
Herbicide	4	2519.804	629.951	35.13	<.001
Residual	12	215.168	17.931	6.34	
Variety	1	5.929	5.929	2.10	0.168
Herbicide.Variety	4	23.076	5.769	2.04	0.140
Residual	15	42.405	2.827		
Total	39	2882.524			

Variate: Weeds Dry Weight at week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	598.0	199.3	2.43	
Herbicide	4	1878.8	469.7	5.73	0.008
Residual	12	983.6	82.0	0.79	
Variety	1	118.3	118.3	1.14	0.302
Herbicide.Variety	4	349.6	87.4	0.84	0.519
Residual	15	1553.7	103.6		
Total	39	5482.0			

Variate: Weeds Dry Weight at week 9					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	102.184	34.061	4.63	
Herbicide	4	767.281	191.820	26.06	<.001
Residual	12	88.319	7.360	2.37	
Variety	1	1.764	1.764	0.57	0.463
Herbicide.Variety	4	4.259	1.065	0.34	0.845
Residual	15	46.597	3.106		
Total	39	1010.404			

Variate: Weeds Dry Weight at week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.8788	0.2929	0.76	
Herbicide	4	605.1875	151.2969	394.47	<.001
Residual	12	4.6025	0.3835	0.95	
Variety	1	0.9922	0.9922	2.47	0.137
Herbicide.Variety	4	1.7665	0.4416	1.10	0.393
Residual	15	6.0263	0.4018		
Total	39	619.4538			

LABORATORY SOIL ANALYSIS

Variate: pH After Treatment Application					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.5575	0.1858	0.88	
Treatment	4	1.3341	0.3335	1.57	0.244
Residual	12	2.5437	0.2120		
Total	19	4.4353			

Variate: pH After Harvest					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.1137	0.0379	0.25	
Treatment	4	1.0565	0.2641	1.76	0.201
Residual	12	1.7984	0.1499		
Total	19	2.9686			

Variate: Microbial Count After Treatment					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	6.319E+11	2.106E+11	1.17	
Treatment	4	1.744E+12	4.361E+11	2.43	0.105
Residual	12	2.153E+12	1.794E+11		
Total	19	4.529E+12			

Variate: Microbial Count After Harvest					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.085E+11	3.617E+10	0.71	
Treatment	4	1.233E+11	3.082E+10	0.60	0.668
Residual	12	6.138E+11	5.115E+10		
Total	19	8.456E+11			

Variate: Microbial Count After Treatment (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.8912	0.2971	1.54	

Treatment	4	2.5304	0.6326	3.28	0.049
Residual	12	2.3173	0.1931		
Total	19	5.7390			

Variate: Microbial Count After Harvest (Transformed)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.0512	0.3504	2.73	
Treatment	4	0.1904	0.0476	0.37	0.825
Residual	12	1.5406	0.1284		
Total	19	2.7822			

ONION GROWTH AND DEVELOPMENT DATA ANALYSIS

Variate: Percentage Crop Establishment at Day 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	81.453	27.151	3.88	
Herbicide	4	41.214	10.303	1.47	0.271
Residual	12	84.065	7.005	1.60	
Variety	1	171.396	171.396	39.23	<.001
Herbicide.Variety	4	32.207	8.052	1.84	0.173
Residual	15	65.537	4.369		
Total	39	475.871			

Variate: Percentage Crop Establishment at Day 14

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	70.235	23.412	2.97	
Herbicide	4	15.213	3.803	0.48	0.749
Residual	12	94.658	7.888	2.99	
Variety	1	42.849	42.849	16.22	0.001
Herbicide.Variety	4	42.339	10.585	4.01	0.021
Residual	15	39.623	2.642		
Total	39	304.915			

Variate: Percentage Crop Establishment at Day 7 (Transformed)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	278.26	92.75	5.35	
Herbicide	4	71.37	17.84	1.03	0.432
Residual	12	208.08	17.34	1.28	
Variety	1	506.59	506.59	37.30	<.001
Herbicide.Variety	4	56.43	14.11	1.04	0.420
Residual	15	203.74	13.58		
Total	39	1324.47			

Variate: Percentage Crop Establishment at Day 14 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	183.696	61.232	2.92	
Herbicide	4	25.689	6.422	0.31	0.868
Residual	12	251.494	20.958	2.35	
Variety	1	136.587	136.587	15.33	0.001
Herbicide.Variety	4	126.694	31.674	3.55	0.031
Residual	15	133.690	8.913		
Total	39	857.850			

Variate: Plant Height at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	17.21	5.74	0.32	
Herbicide	4	106.37	26.59	1.46	0.274
Residual	12	218.16	18.18	0.92	
Variety	1	88.89	88.89	4.48	0.051
Herbicide.Variety	4	90.04	22.51	1.14	0.377
Residual	15	297.30	19.82		
Total	39	817.98			

Variate: Plant Height at Week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	90.22	30.07	1.41	
Herbicide	4	207.48	51.87	2.43	0.104
Residual	12	255.75	21.31	1.12	
Variety	1	80.80	80.80	4.25	0.057
Herbicide.Variety	4	106.31	26.58	1.40	0.282
Residual	15	285.06	19.00		
Total	39	1025.63			

Variate: Plant Height at Week 8					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	176.61	58.87	2.80	
Herbicide	4	214.22	53.56	2.55	0.094
Residual	12	252.28	21.02	1.25	
Variety	1	86.88	86.88	5.15	0.038
Herbicide.Variety	4	100.16	25.04	1.48	0.256
Residual	15	252.95	16.86		
Total	39	1083.11			

Variate: Plant Height at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.74	1.58	0.02	
Herbicide	4	618.94	154.74	1.77	0.199
Residual	12	1046.57	87.21	1.16	
Variety	1	338.14	338.14	4.49	0.051
Herbicide.Variety	4	139.86	34.96	0.46	0.761
Residual	15	1130.31	75.35		
Total	39	3278.56			

Variate: Plant Height at Week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	85.745	28.582	5.41	
Herbicide	4	38.694	9.674	1.83	0.188
Residual	12	63.400	5.283	1.20	
Variety	1	50.176	50.176	11.44	0.004
Herbicide.Variety	4	38.959	9.740	2.22	0.116
Residual	15	65.785	4.386		
Total	39	342.759			

Variate: Number of leaves at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.0210	0.6737	3.06	
Herbicide	4	3.6800	0.9200	4.18	0.024
Residual	12	2.6440	0.2203	0.89	
Variety	1	1.0890	1.0890	4.41	0.053
Herbicide.Variety	4	0.9010	0.2252	0.91	0.481
Residual	15	3.7000	0.2467		
Total	39	14.0350			

Variate: Number of leaves at Week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.6328	0.2109	0.82	
Herbicide	4	6.2150	1.5537	6.05	0.007
Residual	12	3.0810	0.2568	1.04	
Variety	1	0.3803	0.3803	1.54	0.233
Herbicide.Variety	4	1.2560	0.3140	1.27	0.324
Residual	15	3.6987	0.2466		
Total	39	15.2637			

Variate: Number of leaves at Week 8					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.4140	0.4713	3.01	
Herbicide	4	8.4550	2.1138	13.48	<.001
Residual	12	1.8810	0.1568	1.21	
Variety	1	0.6250	0.6250	4.81	0.045
Herbicide.Variety	4	0.4550	0.1138	0.88	0.502
Residual	15	1.9500	0.1300		
Total	39	14.7800			

Variate: Number of leaves at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.77300	0.59100	5.66	
Herbicide	4	10.96600	2.74150	26.28	<.001
Residual	12	1.25200	0.10433	2.27	
Variety	1	0.52900	0.52900	11.50	0.004
Herbicide.Variety	4	0.28100	0.07025	1.53	0.245
Residual	15	0.69000	0.04600		
Total	39	15.49100			

Variate: Number of leaves at Week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.60893	1.20298	6.52	
Herbicide	4	11.49477	2.87369	15.57	<.001
Residual	12	2.21543	0.18462	7.95	
Variety	1	0.36523	0.36523	15.73	0.001
Herbicide.Variety	4	0.34344	0.08586	3.70	0.027
Residual	15	0.34824	0.02322		
Total	39	18.37604			

Variate: Leaf length at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	18.76	6.25	0.34	
Herbicide	4	107.66	26.92	1.48	0.269
Residual	12	218.13	18.18	1.11	
Variety	1	81.94	81.94	4.98	0.041
Herbicide.Variety	4	83.99	21.00	1.28	0.323
Residual	15	246.65	16.44		
Total	39	757.13			

Variate: Leaf length at Week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	94.89	31.63	1.62	
Herbicide	4	178.04	44.51	2.28	0.121
Residual	12	234.06	19.50	1.16	
Variety	1	73.44	73.44	4.35	0.054
Herbicide.Variety	4	98.78	24.70	1.46	0.262
Residual	15	253.12	16.87		
Total	39	932.32			

Variate: Leaf length at Week 8					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	154.86	51.62	2.78	
Herbicide	4	185.24	46.31	2.49	0.099
Residual	12	222.95	18.58	1.24	
Variety	1	76.18	76.18	5.06	0.040
Herbicide.Variety	4	96.23	24.06	1.60	0.226
Residual	15	225.63	15.04		
Total	39	961.09			

Variate: Leaf length at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	89.217	29.739	3.79	
Herbicide	4	139.211	34.803	4.43	0.020
Residual	12	94.243	7.854	1.30	
Variety	1	56.169	56.169	9.29	0.008
Herbicide.Variety	4	28.986	7.246	1.20	0.352
Residual	15	90.665	6.044		
Total	39	498.491			

Variate: Leaf length at Week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	72.331	24.110	4.42	
Herbicide	4	25.909	6.477	1.19	0.365
Residual	12	65.453	5.454	1.49	
Variety	1	44.732	44.732	12.26	0.003
Herbicide.Variety	4	42.869	10.717	2.94	0.056
Residual	15	54.734	3.649		
Total	39	306.028			

Variate: Chlorophyll Content at Week 5					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	58.2514	19.4171	15.05	
Herbicide	4	29.2700	7.3175	5.67	0.008
Residual	12	15.4810	1.2901	1.76	
Variety	1	27.7889	27.7889	37.92	<.001
Herbicide.Variety	4	4.2314	1.0578	1.44	0.268
Residual	15	10.9927	0.7328		
Total	39	146.0154			

Variate: Chlorophyll Content at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	81.989	27.330	8.18	
Herbicide	4	218.918	54.729	16.39	<.001
Residual	12	40.079	3.340	1.45	
Variety	1	207.754	207.754	89.94	<.001
Herbicide.Variety	4	51.351	12.838	5.56	0.006
Residual	15	34.647	2.310		
Total	39	634.738			

Variate: Chlorophyll Content at Week 14						
Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Reps stratum	3		15.493	5.164	1.16	
Herbicide	4		250.377	62.594	14.01	<.001
Residual	12		53.612	4.468	2.42	
Variety	1		131.384	131.384	71.25	<.001
Herbicide.Variety	4		50.388	12.597	6.83	0.003
Residual	14	(1)	25.816	1.844		
Total	38	(1)	503.498			

Variate: Plant Girth at Harvest					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	10.9395	3.6465	2.23	
Herbicide	4	48.2645	12.0661	7.39	0.003
Residual	12	19.5878	1.6323	5.27	
Variety	1	1.5398	1.5398	4.97	0.041
Herbicide.Variety	4	1.4195	0.3549	1.15	0.373
Residual	15	4.6442	0.3096		
Total	39	86.3953			

Variate: Leaf diameter at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F p
Reps stratum	3	5.414	1.805	2.43	
Herbicide	4	18.951	4.738	6.38	0.005
Residual	12	8.913	0.743	0.63	
Variety	1	6.443	6.443	5.43	0.034
Herbicide.Variety	4	2.590	0.647	0.55	0.705
Residual	15	17.793	1.186		
Total	39	60.103			

Variate: Leaf diameter at Week 6					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.757	1.252	1.57	
Herbicide	4	12.974	3.244	4.06	0.026
Residual	12	9.586	0.799	0.53	
Variety	1	1.092	1.092	0.72	0.408
Herbicide.Variety	4	2.015	0.504	0.33	0.851
Residual	15	22.651	1.510		
Total	39	52.076			

Variate: Leaf diameter at Week 8					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.3120	0.7707	1.19	
Herbicide	4	16.1256	4.0314	6.21	0.006
Residual	12	7.7876	0.6490	0.94	
Variety	1	2.5412	2.5412	3.68	0.074
Herbicide.Variety	4	1.4245	0.3561	0.52	0.726
Residual	15	10.3715	0.6914		
Total	39	40.5624			

Variate: Leaf diameter at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	2.1606	0.7202	1.42	
Herbicide	4	15.7766	3.9442	7.78	0.002
Residual	12	6.0830	0.5069	0.75	
Variety	1	1.4162	1.4162	2.10	0.168
Herbicide.Variety	4	0.9235	0.2309	0.34	0.846
Residual	15	10.1373	0.6758		
Total	39	36.4971			

Variate: Leaf diameter at Week 12					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3.0051	1.0017	2.45	
Herbicide	4	13.7053	3.4263	8.39	0.002
Residual	12	4.9002	0.4084	0.60	
Variety	1	1.2032	1.2032	1.78	0.202
Herbicide.Variety	4	0.7106	0.1777	0.26	0.897
Residual	15	10.1349	0.6757		
Total	39	33.6594			

Variate: Plant Fresh weight at Week 5					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	143.68	47.89	1.26	
Herbicide	4	793.48	198.37	5.21	0.011
Residual	12	457.02	38.09	2.28	
Variety	1	2009.31	2009.31	120.42	<.001
Herbicide.Variety	4	484.33	121.08	7.26	0.002
Residual	15	250.29	16.69		
Total	39	4138.11			

Variate: Plant Fresh weight at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	41947.7	13982.6	13.38	
Herbicide	4	46047.2	11511.8	11.01	<.001
Residual	12	12541.5	1045.1	4.26	
Variety	1	4020.0	4020.0	16.38	0.001
Herbicide.Variety	4	716.4	179.1	0.73	0.586
Residual	15	3682.1	245.5		
Total	39	108954.8			

Variate: Plant Fresh weight at Week 14					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	41595.4	13865.1	13.07	
Herbicide	4	46984.9	11746.2	11.07	<.001
Residual	12	12727.3	1060.6	3.23	
Variety	1	4410.0	4410.0	13.43	0.002
Herbicide.Variety	4	426.2	106.6	0.32	0.857
Residual	15	4923.8	328.2		
Total	39	111067.6			

Variate: Plant Dry Weight at Week 5					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.9230	0.6410	1.27	
Herbicide	4	8.1835	2.0459	4.04	0.027
Residual	12	6.0745	0.5062	2.52	
Variety	1	12.5440	12.5440	62.46	<.001
Herbicide.Variety	4	7.3735	1.8434	9.18	<.001
Residual	15	3.0125	0.2008		
Total	39	39.1110			

Variate: Plant Dry Weight at Week 10					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3942.87	1314.29	12.89	
Herbicide	4	4704.65	1176.16	11.53	<.001
Residual	12	1223.75	101.98	4.43	
Variety	1	403.22	403.22	17.50	<.001
Herbicide.Variety	4	64.65	16.16	0.70	0.603
Residual	15	345.62	23.04		
Total	39	10684.78			

Variate: Plant Dry Weight at Week 14					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	3550.40	1183.47	11.16	
Herbicide	4	4268.90	1067.22	10.06	<.001
Residual	12	1273.10	106.09	3.44	
Variety	1	396.90	396.90	12.86	0.003
Herbicide.Variety	4	78.10	19.53	0.63	0.647
Residual	15	463.00	30.87		
Total	39	10030.40			

Variate: Days 50% bulbing					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.8750	1.6250	3.90	
Herbicide	4	5.4000	1.3500	3.24	0.051
Residual	12	5.0000	0.4167	3.33	
Variety	1	525.6250	525.6250	4205.00	<.001
Herbicide.Variety	4	0.0000	0.0000	0.00	1.000
Residual	15	1.8750	0.1250		
Total	39	542.7750			

Variate: Days 75% bulbing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	4.2750	1.4250	3.05	
Herbicide	4	2.6000	0.6500	1.39	0.294
Residual	12	5.6000	0.4667	2.07	
Variety	1	555.0250	555.0250	2466.78	<.001
Herbicide.Variety	4	1.1000	0.2750	1.22	0.343
Residual	15	3.3750	0.2250		
Total	39	571.9750			

Variate: Days to 100% bulbing

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1.4750	0.4917	1.27	
Herbicide	4	2.1500	0.5375	1.39	0.296
Residual	12	4.6500	0.3875	2.74	
Variety	1	990.0250	990.0250	6988.41	<.001
Herbicide.Variety	4	0.3500	0.0875	0.62	0.657
Residual	15	2.1250	0.1417		
Total	39	1000.7750			

Variate: Days to Physiological maturity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	0.0750	0.0250	0.29	
Herbicide	4	5.1500	1.2875	14.71	<.001
Residual	12	1.0500	0.0875	0.62	
Variety	1	469.2250	469.2250	3312.18	<.001
Herbicide.Variety	4	0.1500	0.0375	0.26	0.896
Residual	15	2.1250	0.1417		
Total	39	477.7750			

YIELD DATA ANALYSIS

Variate: Average Bulb Diameter

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	41.398	13.799	1.29	
Herbicide	4	139.701	34.925	3.26	0.050
Residual	12	128.639	10.720	2.03	
Variety	1	14.322	14.322	2.71	0.121
Herbicide.Variety	4	6.072	1.518	0.29	0.882
Residual	15	79.338	5.289		
Total	39	409.470			

Variate: Average Bulb Length					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	226.87	75.62	1.22	
Herbicide	4	350.47	87.62	1.41	0.289
Residual	12	745.61	62.13	0.71	
Variety	1	7.12	7.12	0.08	0.779
Herbicide.Variety	4	367.56	91.89	1.05	0.414
Residual	15	1310.79	87.39		
Total	39	3008.41			

Variate: Average Bulb Weight					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	268.44	89.48	1.18	
Reps.Herbicide stratum					
Herbicide	4	555.85	138.96	1.84	0.186
Residual	12	906.42	75.54	1.47	
Variety	1	38.97	38.97	0.76	0.397
Herbicide.Variety	4	24.66	6.17	0.12	0.973
Residual	15	768.32	51.22		
Total	39	2562.65			

Variate: Total Bulb Weight (ton/hectare)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	85.466	28.489	2.02	
Herbicide	4	102.909	25.727	1.83	0.189
Residual	12	169.132	14.094	3.17	
Variety	1	13.678	13.678	3.08	0.100
Herbicide.Variety	4	1.749	0.437	0.10	0.981
Residual	15	66.623	4.442		
Total	39	439.557			

Variate: Marketable Yield (tons/hectare)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	83.432	27.811	1.99	
Herbicide	4	95.932	23.983	1.72	0.211
Residual	12	167.764	13.980	3.24	
Variety	1	16.602	16.602	3.85	0.069
Herbicide.Variety	4	2.423	0.606	0.14	0.964
Residual	15	64.649	4.310		
Total	39	430.802			

EXPERIMENT TWO: DATA ANALYSIS OF RESIDUAL TOXICITY ON SUCCEEDING CROP (COWPEA)

Variate: Percentage Emergence of Cowpea at Day 3

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1275.0	425.0	2.66	
Herbicide	4	1916.2	479.1	3.00	0.063
Residual	12	1918.8	159.9	1.48	
Variety	1	2.5	2.5	0.02	0.881
Herbicide.Variety	4	278.8	69.7	0.65	0.638
Residual	15	1618.8	107.9		
Total	39	7010.0			

Variate: Percentage Emergence of Cowpea at Day 5

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1207.50	402.50	2.80	
Herbicide	4	3896.25	974.06	6.78	0.004
Residual	12	1723.75	143.65		
Variety	1	10.00	10.00	0.15	0.708
Herbicide.Variety	4	558.75	139.69	2.03	0.141
Residual	15	1031.25	68.75		
Total	39	8427.50			

Variate: Percentage Emergence of Cowpea at Day 7

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	482.50	160.83	0.93	
Herbicide	4	66878.75	16719.69	96.17	<.001
Residual	12	2086.25	173.85	5.28	
Variety	1	2.50	2.50	0.08	0.787
Herbicide.Variety	4	153.75	38.44	1.17	0.364
Residual	15	493.75	32.92		
Total	39	70097.50			

Variate: Percentage Emergence of Cowpea at Day 3 (Transformed)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1742.9	581.0	2.61	
Herbicide	4	1678.9	419.7	1.89	0.177
Residual	12	2666.5	222.2	1.68	
Variety	1	7.8	7.8	0.06	0.811
Herbicide.Variety	4	221.5	55.4	0.42	0.793
Residual	15	1987.5	132.5		
Total	39	8305.1			

Variate: Percentage Emergence of Cowpea at Day 5 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	466.97	155.66	2.68	
Herbicide	4	1505.68	376.42	6.48	0.005
Residual	12	697.10	58.09	2.17	
Variety	1	3.25	3.25	0.12	0.733
Herbicide.Variety	4	209.11	52.28	1.95	0.154
Residual	15	402.24	26.82		
Total	39	3284.34			

Variate: Percentage Emergence of Cowpea at Day 7 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	320.61	106.87	0.75	
Herbicide	4	45056.16	11264.04	79.13	<.001
Residual	12	1708.26	142.35	4.61	
Variety	1	1.17	1.17	0.04	0.849
Herbicide.Variety	4	84.53	21.13	0.68	0.614
Residual	15	463.59	30.91		
Total	39	47634.32			

Variate: Chlorophyll content of Cowpea at Week 2					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	77.691	25.897	1.09	
Herbicide	4	21716.646	5429.161	228.57	<.001
Residual	12	285.038	23.753	7.74	
Variety	1	3.080	3.080	1.00	0.332
Herbicide.Variety	4	3.331	0.833	0.27	0.892
Residual	15	46.054	3.070		
Total	39	22131.840			

Variate: Chlorophyll content of Cowpea at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	28.563	9.521	0.69	
Herbicide	4	23828.981	5957.245	433.62	<.001
Residual	12	164.861	13.738	6.28	
Variety	1	1.806	1.806	0.83	0.378
Herbicide.Variety	4	1.245	0.311	0.14	0.964
Residual	15	32.824	2.188		
Total 39 24058.280					

Variate: Number of weeds at Week 2					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	1453.28	484.43	7.36	
Herbicide	4	5300.15	1325.04	20.13	<.001
Residual	12	789.85	65.82	1.63	
Variety	1	133.22	133.22	3.30	0.089
Herbicide.Variety	4	116.15	29.04	0.72	0.592
Residual	15	605.13	40.34		
Total	39	8397.78			

Variate: Number of Weeds at Week 4					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	705.28	235.09	2.4	
Herbicide	4	8027.65	2006.91	20.65	<.001
Residual	12	1166.35	97.20	2.91	
Variety	1	5.62	5.62	0.17	0.687
Herbicide.Variety	4	26.25	6.56	0.20	0.936
Residual	15	500.62	33.38		
Total	39	10431.77			

Variate: Number of weeds at Week 2 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	20.4175	6.8058	7.45	
Herbicide	4	80.0388	20.0097	21.92	<.001
Residual	12	10.9563	0.9130	1.60	
Variety	1	2.4434	2.4434	4.29	0.056
Herbicide.Variety	4	1.5496	0.3874	0.68	0.616
Residual	15	8.5459	0.5697		
Total	39	123.9514			

Variate: Number of Weeds at Week 4 (Transformed)					
Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	6.1050	2.0350	2.41	
Herbicide	4	74.9983	18.7496	22.23	<.001
Residual	12	10.1216	0.8435	3.06	
Variety	1	0.0601	0.0601	0.22	0.647
Herbicide.Variety	4	0.1764	0.0441	0.16	0.955
Residual	15	4.1309	0.2754		
Total	39	95.5923			

Variate: Weeds Fresh Weight at Week 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	184.67	61.56	4.33	
Herbicide	4	2151.12	537.78	37.80	<.001
Residual	12	170.74	14.23	1.27	
Variety	1	12.43	12.43	1.11	0.309
Herbicide.Variety	4	32.51	8.13	0.72	0.589
Residual	15	168.49	11.23		
Total	39	2719.96			

Variate: Weeds Fresh Weight at Week 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	456.3	152.1	1.47	
Herbicide	4	20340.0	5085.0	49.19	<.001
Residual	12	1240.6	103.4	0.34	
Variety	1	67.9	67.9	0.22	0.644
Herbicide.Variety	4	518.9	129.7	0.43	0.787
Residual	15	4565.3	304.4		
Total	39	27189.0			

Variate: Weeds Dry Weight at Week 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	6.4768	2.1589	4.66	
Herbicide	4	65.8315	16.4579	35.49	<.001
Residual	12	5.5645	0.4637	2.01	
Variety	1	0.1323	0.1323	0.57	0.460
Herbicide.Variety	4	1.1165	0.2791	1.21	0.347
Residual	15	3.4563	0.2304		
Total	39	82.5777			

Variate: Weeds Dry Weight at Week 4

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Reps stratum	3	17.75	5.92	1.33	
Herbicide	4	883.11	220.78	49.45	<.001
Residual	12	53.58	4.47	0.33	
Variety	1	1.00	1.00	0.07	0.790
Herbicide.Variety	4	34.28	8.57	0.63	0.647
Residual	15	203.27	13.55		
Total	39	1192.99			

APPENDIX 2

Determining soil pH

The pH of soil samples was measured using electrometric method by Peech, (1965). Soil samples of various treatments were added to distilled water at 1:1 ratio. Ten grams (10g) of sieved soil samples of each treatment was weight into a beaker.

Ten mils (10mls) of distilled was added to the soil samples to form a supervision. The suspensions were stirred vigorous with a glass rod for 30minutes and then allowed to stand for 1 hour. Glass electrodes of the PL700 AL pH meter were carefully and gently immersed into the suspension and the pH was read.

APPENDIX 3

Plate 2. Onion Plants at Week 6

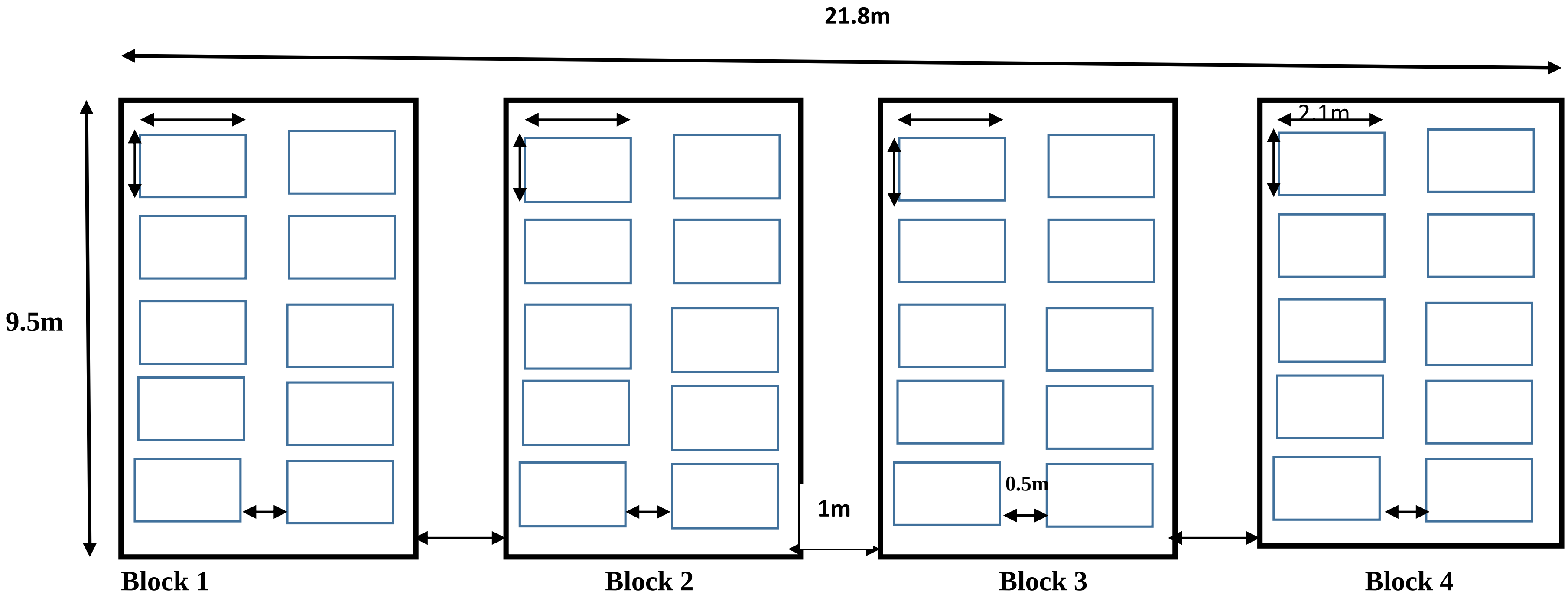


Figure 9. Experimental Layout