# RESIDUAL EFFECTS OF SOIL APPLIED ATRAZINE ON POTATOES (*SOLANUM TUBEROSUM*)IN SELECTED SOUTH AFRICAN SOILS

by

**Mashibihli Dineo Phasha**

**63359987**

Submitted in accordancewith the requirements

for the degree

**Master of Science in Agriculture**

in the

**COLLEGE OF AGRICULTURE AND ENVIRONMENTAL SCIENCES**

**DEPARTMENT OF AGRICULTURE AND ANIMAL HEALTH**

**at the**

**UNIVERSITY OF SOUTH AFRICA**

**Supervisor: Prof IIC Wakindiki**

**Co-supervisor: Prof FN Mudau**

**February 2022**

**DECLARATION**

I Mashibihli Dineo Phasha hereby declare that the dissertation/thesis Title:Residual effects of soil applied atrazine on follow-up bioassay vegetable crop in selected South African soils, which I hereby submit for the degree of Master of Science in Agriculture at the Universityof South Africa, is my own work and has not previously been submitted by me for a degree at this or any other institution.

I declare that the dissertation /thesis does not contain any written work presented by other persons whether written, pictures, graphs or data or any other information without acknowledging the source.

I declare that where words from a written source have been used the words have been paraphrased and referenced and where exact words from a source have been used the words have been placed inside quotation marks and referenced.

I declare that I have not copied and pasted any information from the Internet, without specifically acknowledging the source and have inserted appropriate references to these sources in the reference section of the dissertation or thesis.

I declare that during my study I adhered to the Research Ethics Policy of the University of South Africa, received ethics approval for the duration of my study prior to the commencement of data gathering, and have not acted outside the approval conditions.

I declare that the content of my dissertation/thesis has been submitted through an electronic plagiarism detection program before the final submission for examination.

Student signature: MD Phasha Date: February 2022

**DEDICATION**

To my parents Mr S.W & Mrs T.S Phasha who opened the doors to my academic achievement

To my brothers and sisters who have hung in there when the going got rough and for their moral support and always being there for me

Above all, to almighty God for paving the way for me to do this MSc research work and for the grace and mercy which he showered towards me

## ACKNOWLEDGEMENT

The completion of this study was made possible by a number of people and organisations. I wish to express my profound thanks to the following people and organisations:

- Thanks to God the Almighty for the ability and wisdom to further my studies
- To my supervisor Prof Wakindiki and Co-supervisor Prof FN Mudau for their intellectual advice, guidance and supervision during the period of my studies
- The seed company (Potato Seed Production) for providing the potato seeds used in the course of this study
- The DSF Post Graduate Bursary for providing the necessary funding for my study
- To my beloved family and friends for their patience, prayers and encouragementthroughout the journey
- Additionally, I wish to acknowledge Mr. Udoka Ogugua my mentor for his untiring encouragement, advice and guidance during the entire period of my research

**LIST OF ABBREVIATION**

ANOVA........................................................................... Analysis of Variance

CV ............................................................................... Coefficient of variation

DF ...................................................................................Degree of freedom

LS........................................................................................Least significant

NS ........................................................................................ Not significant

SOM ..................................................................................Soil organic matter

**ABSTRACT**

The residual effect of Atrazine [2-chloro-4-(ethylamino)-6-isopropylamino)-s-triazine] has emerged as a concern because of the possibility of carryover. A study was conducted at the Florida campus of the University of South Africa (Unisa) to determine the residual effect of atrazine on follow-up bioassay vegetable crops. Potato cultivar (Moonlight) as a bioassay crop was grown separately in three soils (Sandy, Clay loam and Sandy loam soil) with four atrazine rates (0.0. 0.1, 0.2 and 0.3 mg/l) applied in each pot. The experiment was laid out as a Randomised Complete Block Design with three (3) replicates based on a fully automated greenhouse. Sandy loam soil increased plant height, number of leaves, dry weight and tuber number all at an application rate of 0.3 mg/l in comparison with Sandy and Clay loam soils. Sandy soil reduced fresh tuber weight at an application rate of 0.2 mg/l. An increase in the growth of potato parameters was caused by an increase in the application rate. The residual effect of atrazine was found to delay emergence of potatoes on Clay loam soil. Sandy loam soil proved to have performed better than Sandy and Clay loam soil for the growth of potatoes. The findings implied that the herbicides showed a reduction in efficacy as regards the emergence and growth of potato plants.

**Key words:***Atrazine, Carryover*

**Setsopolwa**

Seabe sa mašaledi a Atrazine [2-chloro-4-(ethylamino)-6-isopropylamino)-s-triazine] se tšweletše bjalo ka tlhobaboroko ka lebaka la kgonagalo ya kgogolego. Dinyakišišo di dirilwe ka khamphaseng ya Florida ya Yunibesithi ya Afrika Borwa (Unisa) go nyaka go tseba seabe sa mašaledi a atrazine go dibjalo tša merogo tšeo go nyakišišitšwego gore di amilwe ke seabe sa dibolayadibokwana. Mohuta wa sebjalo sa matsapane (Moonlight) bjalo ka sebjalo seo se angwago ke dibolayadibokwana se bjetšwe se arogane ka mebung ye meraro, mobu wa seloko, Letsopa le wa Santa (wa go hlakana le letsopa) wo o nago le dikelo tše nne tša atrazine (0.0. 0.1, 0.2 le 0.3 mg/l) o ile wa tsenywa ka pitšeng ye nngwe le ye nngwe. Tekolo ye e ile ya beakanywa ka go šomiša Tlhamo ya Sewelo ye e Feleletšego ya Poloko gomme ya ba le dikekišo tše tharo (3) go

dirišwa ntlo ya bomedišetšo yeo e sepetšwago ka maitirišo. Mobu wa santa le wa seloko wo o hlakanego le letsopa o ile wa oketša botelele bja dimela, palo ya matlakala, boima bja go oma le palo ya go ntšha digwere ka moka ga yona ka ge go dirišitšwe kelo ya 0.3 mg/l ge go bapetšwa le mebu ya Santa le wa seloko wa go hlakana le letsopa. Mobu wa santa o fokoditše o boima bja digwere tše foreše ge go dirišwa kelo ya 0.2 mg/l. Koketšego ka go kgolo ya bogolo bja matsapane e bakilwe ke go oketšega ga kelo ya go e diriša. Seabe sa atrazine go hweditše gore se ditela go ba gona ga matsapane ka go mobu wa santa wa go hlakana le seloko le letsopa. Mobu wa santa wa go hlakana le seloko le letsopa o laeditše gore o šoma bokaone go phala mobu wa Santa le wa Seloko wo o hlakanego le letsopa go godiša matsapane. Dikutollo di laeditše gore dibolayadibokwana di baka go fokotšega ga go šoma gabotse ga go ba gona le kgolo ya dimela tša matsapane.

**Mantšu a bohlokwa:***Atrazine, Kgogolego*

**Ingqikithi Yocwaningo**

Umphumela wensalela ye-Atrazine [2-chloro-4-(ethylamino)-6-isopropylamino)-s-triazine] uvele njengento ekhathazayo ngoba kungenzeka ukuthi uyinto esukela kwenye. Ucwaningo lwenziwa ekhempasini yeNyuvesi yaseNingizimu Afrika (i-Unisa) eseFlorida ukuze kutholakale umphumela wensalela ye-atrazine ezitshalweni zemifino ezishubile. Izambane elibomvana elimhlophe ngaphakathi (i-Moonlight) njengesitshalo esishubile latshalwa lahlukaniswa enhlabathini eyayihlukene kathathu (Umhlabathi, Inhlabathi egcwele ubumba kanye neNhlabathi enobumba oluncane) enezilinganiso ze-atrazine ezine (0.0. 0.1, 0.2 kanye no-0.3 mg/l) eyayifakwe ebhodweni ngalinye. Kwahlolwa kusetshenziswa uHlelo Lokucwaninga Kwezolimo Olubeka Izinto Ezifanayo Ngokwamaqoqo Ahlukahlukene kusetshenziswa izicucu ezintathu (3) ezifanayo ezazibekwe endlwaneni eyakhelwe ukuvikela izithombo kungqoqwane. Inhlabathi enobumba oluncane yakhulisa ubude bezitshalo, inani lamaqabunga, isisindo sokomile kanye nesibalo sezithombo ezimila ngaphansi komhlaba uma kufakwa isilinganiso esingu-0.3 mg/l uma kuqhathaniswa nomhlabathi kanye nenhlabathi egcwele ubumba.

Umhlabathi onobumba oluncane wanciphisa isisindo sezithombo ezimila ngaphansi komhlaba uma kufakwa isilinganiso esingama-0.2 mg/l. Ukwanda kokukhula kwemingcele yamazambane kwadalwa ukwanda kwezinga lokufakwa kwe-atrizine. Kwatholakala ukuthi umphumela wensalela ye-atrazine ubambezela ukuvela kwamazambane enhlabathini egcwele ubumba. Inhlabathi enobumba oluncane yabonakala yenza kangcono kunomhlabathi kanye nenhlabathi egcwele ubumba ekukhuleni kwamazambane. Okwatholakela kwaveza ukuthi imithi yokubulala izimila ayinamandla maqondana nokuvela nokukhula kwezitshalo zamazambane.

**Amagama asemqoka:***I-Atrazine, Okusukela Kokunye*

## TABLE OF CONTENTS

**LIST OF TABLES**

**LIST OF FIGURES**

## CHAPTER 1

### 1.1 INTRODUCTION

Atrazine [2-chloro-4-(ethylamino)-6-isopropylamino)-s-triazine] is one of the used herbicides in agriculture and forestry (Mahia *et al.,* 2011).Atrazine is a photosynthetic inhibitor and is activated by light which then causes chlorosis and desiccation of green tissues (Burhan & Shaukat, 2000). It is mainly applied to corn crops to control broadleaf weeds (Graziano *et al.*, 2006). Atrazine can also be used to control weeds in the cultivation of sugarcane, sorghum, wheat, and residential and recreational turf grass (Lesan & Bhandari, 2004). Atrazine belongs to the Triazine group, which has contributed significantly to improvements in crop yields around the world since the late 1950s (LeBaron *et al*., 2008). Other s-triazines include simazine, ametryne and propazine (Mudhoo & Garg, 2011).

Generally, atrazine is applied for soil pre-planting or pre-emergence and to the foliage post emergence (Graziano *et al.,* 2006). Atrazine is usually applied before weeds emerge in a water spray at concentrations of 2.2 to 4.5 kg/ha and is only slightly soluble in water but soluble at 360 to 183 000 mg/L in many organic solvents (Mudhoo & Garg, 2011). Atrazine is available as a technical material at 99.9% active ingredient and as a manufacturing use product containing 80% atrazine for formulation of wettable powders, pellets, granules, flowable concentrates, emulsifiable concentrates and tablets (Du Preez *et al.,* 2005). Atrazine can be compatible with some fertilizers when used at recommended rates as it has been discovered that the application of lime proved beneficial when it markedly improved the herbicidal efficacy of atrazine and resulted in positive growth and yield responses in maize (Aladesanwa & Akinbobola, 2008). In South Africa it is used in combination with various other herbicides including terbuthylazine, S-metolachlor and simazine (Du Preez *et al.,* 2005).

Atrazine was first introduced in the twentieth century and became the second most widely used herbicide in the world (Singh *et al.,* 2018). Atrazine is registered in more than 70 countries worldwide and is still by far most widely used for weed control in maize (Aladeswa & Akinbobola, 2008). Atrazine is used in many countries including the

United States and Australia (Stipicevic *et al.,* 2015). Because of its residues and potential to persist in fields it was banned in few countries like Germany, Italy, Denmark and Finland in 1991 and 1992 in Europe (Singh *et al.,* 2018). Atrazine administration covers most areas of developing countries. In recent years, it has become one of the most serious environmental problems as its residue is persistent in soils, and many crops such as rice were reported to take up atrazine from the environment (Yi Chen Lu *et al.,* 2013). During 1990-1993, an average of 28 million kg of atrazine was applied annually to crops in the continental United States. In Indiana, 3 million kg of atrazine was applied in 1993 (Mudhoo & Garg., 2011).

In South Africa pesticides are one of the many technologies commonly used to improve agricultural production. In the sub-Saharan Africa region, South Africa has the largest agricultural pesticide market with a variety of pesticides registered during the year 2010 and 2013 by the South African National Department of Agriculture, Forestry and Fisheries (Machete & Shadung, 2019). In 2015 more than 3 000 pesticides were registered for use by the agricultural sector in South Africa (Machete & Shadung, 2019). South Africa has more than 500 registered pesticides and is one of the four largest importers of pesticides in sub-Saharan Africa (Ntombela & Mahlambi, 2019). In South Africa, most pesticides that are used are triazines and acetanilide-derived herbicides, specifically atrazine and metolachlor, respectively (Mosotho, 2014). Historically, South Africa is the 9th biggest corn producer in the world using 88% of atrazine on corn fields and in combination with other triazine herbicides (Rimayi *et al.,* 2018). In South Africa, the persistence of atrazine under field conditions is often longer than 12 months, which may seriously affect rotational crops. On the other hand, limited atrazine persistence or follow-up crops do not distinguish between soil types. Therefore, atrazine is invasive and waiting periods might be shortened on certain soil types (Reinhardt & Nel, 1990).

The availability of atrazine for uptake by certain crop species can be influenced by several soil and climatic factors (Reinhardt & Nel, 1993). Not all atrazine can be taken up by their target and the residues accumulate in the soil to exert secondary detrimental effects on crops. However, factors including soil type, soil pH, organic matter, soil temperature and moisture influence herbicide persistence (Aladesanwa & Akinbobola, 2008). Soils showing a potential for rapid mineralization of atrazine have been identified throughout the world in recent years. However, residues of both the patent compound and its degradation products have been detected in soils years after application (Mahia, 2011). Seed size as one of the factors has also been linked to differences in tolerance to atrazine (Reinhardt & Nel, 1993).

## 1.2 PROBLEM STATEMENT

Atrazine due to its large quantity of use and potential for transport and accumulation has become a special concern (Yu-Hong *et al*., 2005). The residual activity is also important since this could relate to phytotoxic effects that may prove injurious to succeeding crops reducing their productivity (Novais *et al*., 2019). For example, it has been established that atrazine at 1.5 kg/ha may damage soybeans grown in the year following maize. In contrast, atrazine at the usual application dose of 3.0 kg/ha was no longer phytotoxic to tomato seedlings 8 weeks after application in the humid tropical environment in Southwestern Nigeria (Aladeswana, 2005).

The widespread use of atrazine has created possibilities of the risk of phytotoxicity on the plant species which are not direct object of the treatment. Furthermore, there is less flexibility in re-cropping options due to changing market demands. The persistence of atrazine in South Africa is often much longer than 12 months under field conditions (Nel & Reinhardt, 1984). Since the persistence of atrazine over long periods has become an issue, a series of field trials must be conducted to determine the persistence of the herbicide in different soils. A study by Novais *et al*. (2019), reported that atrazine provided a higher residual effect in clayey soil compared to sandy soil which caused a higher percentage of dry matter reduction and lower chlorophyll content of sunflower and soybean bioindicators. Robinson (2008), reported a 66.6% reduction in the dry weight of carrot shoots 12 months after application in sandy loam soil.

(Brighenti *et al*., 2002) found out that sunflower is sensitive when sown shortly after application of atrazine to the predecessor crop while Khorommbi & Reinhard (2002), observed a 45% reduction in shoot fresh mass at the 2-leaf growth stage. Other researchers have reported an effect of atrazine on crop. Andersen (1970), examined approximately 2,700 strains of soybeans for response to atrazine whereby tolerance of soybean to atrazine increased as seed size increased. Le Court De Billot & Nel (1985), evaluated 67 maize cultivars to tolerance of atrazine and found that atrazine affected shoot dry mass of only two cultivars of maize which were reduced by more 40% and another 14 reduced by more than 30%. Werner & Putnam (1980), also reported that most cultivars of cucumber were killed by 0.14kg/ha of atrazine. Robinson (2006), who determined the effect of foramsulfuron post, isoxaflutole pre and isoxaflutole plus atrazine pre to the four market class of dry bean (cranberry, black, kidney and white bean) reported visual injury across the four market classes which varied from 30 to 54% one year after application of isoxaflutole plus atrazine. More work needs to be done on the persistence of atrazine before suggestions for the alteration of present guideline for waiting periods can be made.

Since agricultural soil is a major reservoir of pesticides and a secondary source of the pollutants to water and air, it is necessary to explore the levels of atrazine and its effect on the soil microbial community in agricultural soils (Dou *et al*., 2020). Since several research on the effect of atrazine has been done on different crops and soil, limited research was done potatoes, that is the reason the crop was chosen for this study. The nature of soil changes in time, also with modern technology and modification of agricultural practices, new developments in agriculture are being implemented which may change the nature of soil.

Cultivars that were not yet in existence are now in use and it is very important to test herbicides on different crops and soil from time to time as time goes by regardless of how many times it was done. That is the purpose of the present study to discover new information that will benefit agricultural farmers that move with time and new developments. Another purpose of the study is that the same herbicide may be used but different results will always be discovered because people use herbicides on different locations which differ in soil fertility and quality, that is why the three soils from Limpopo were selected for this study because it is very important for herbicides to be tested in different ways, different localities and time after time.

The present study will benefit farmers with similar soil and crops as they will use the herbicide based on what was done already to be assured of the end results and to avoid loopholes for the benefit of their farm and safety of their crops. The present study seeks to contribute to this knowledge by providing an insight that will assist in the choice of the re-cropping options and guideline for waiting periods. The knowledge will help minimize the restrictions on the choice of follow-up crops in the future and in preventing an injury to follow up crops because the toxic response of some plants to different levels of atrazine in soils has been reported.

### 1.3 JUSTIFICATION

Since the persistence of atrazine over long periods has become an issue, a series of field trials must be conducted to determine the persistence of the herbicide in different soils. The quality and fertility of the soil can be implicated by the residues of atrazine in the soil (Dou *et al*, 2020). When the herbicide preserves the integrity of its molecule in the environment for longer, it is considered residual (Hinz, 2001). It has been reported by several researchers on the effect of atrazine on different soils. Reinhardt & Nel (1993), discovered that in all crops tested, the reduction in growth caused by atrazine generally increased with increasing herbicide rates, and the damage caused by a particular atrazine rate varied from soil to soil because the significant differences in tolerance between dry bean and sunflower to atrazine varied between all the soils tested.

(Bontempo *et al*., 2016) evaluated the effect of tembotrione and atrazine residues on carrot planted in succession to corn and found that the presence of atrazine in the soil decreased carrot shoot dry mass. In another study by Novais *et al*. (2019), an application of atrazine to clay soils at a dose of 2,500 g/ha reduced dry matter of sunflower at 15 and 30 days between application by 70.97% and 75.51% respectively whereas an accumulation of approximately 100% at 0 and 15 days between application was observed in soybean for the doses applied in the clay soil and in the sandy soil, the same value was only observed at 0 days between application. Cornelius and Bradley (2017), also found that atrazine residues reduced dry ryegrass biomass by 37% to 51%. The present study involves the use of atrazine on potatoes as a bioassay crop on three different soils to provide more information on the residual effect of atrazine on follow-up crops for farmers that use crop rotation systems to understand how residual effect of atrazine damage follow-up crops grown in soils previously treated with atrazine and to prove if it is safe to grow crops on soils containing atrazine residues. The present study will also clarify on how to determine to what extent does the nature of soil influence the residual effect of atrazine on the growth and yield of succeeding crops. This would assist in making suggestions regarding follow-up crops, soil types, application rates and waiting periods to be adopted when using the atrazine herbicide.

## 1.4AIM AND OBJECTIVES

### 1.4.1 AIM

Demonstrate the effect of residual soil applied atrazine on follow-up bioassay vegetable crop in selected South African soils.

### 1.4.2 OBJECTIVES

1) To determine the residual effect of soil applied atrazine on emergence of seedpotatoes

2) To establish the extent the nature of soil influences residual effect of soil applied atrazine on emergnce of seedpotatoes

## 1.5 HYPOTHESIS

1) Soil applied atrazine does not affect emergence of seed potatoesand potato parameters (plant height, number of leaves, fresh weight, dry weight, fresh tuber weight, dry tuber weight and tuber number)

2) The nature of soil does not influence residual effect of atrazine on the growth of potatoes.

**CHAPTER 2 LITERATURE REVIEW**

Weed control is a major component in agricultural production in South Africa and has been accomplished using different methods including the use of herbicides like atrazine. Pesticides have been used in the development of modern agriculture for several decades to ensure the quality, safety and yield of agricultural products but some pesticides can impose a negative impact on the soil quality and microbial community structure as can be stable and persistent in the soil (Dou et al,).The soil applied herbicide can remain in the soil long enough to give acceptable period of weed control but the duration can be long enough that the soil residues limit the range of subsequent crops that will be grown afterwards (Vouzounis, Americanos, 2002).

Residual effects of atrazine can be reduced when atrazine is applied with a combination of other herbicides than when applied alone due to the breakdown of atrazine induced by tank mixtures as this was proved by Chikutuma, Lovejoy &Wisdom (2015), which treated cowpea with atrazine alone and with a combination of atrazine + glyphosate and metolachlor and found that atrazine applied alone had caused the lowest yield of 0.9 t/ha on cowpea compared to a combination of the three herbicides which had the highest yield of 1.2 t/ha.

Atrazine can also be used to control volunteer potatoes in South Africa. Results byBoydston (2001), demonstrated that atrazine reduced tuber weight by more than 90% through an application of atrazine at 1.1 kg/ha.However, the application of atrazine at 1.25 kg/ha was found to have no significant effect on plant growth, tuber production or tuber mass (Allemann, 2016). When atrazine is used to control weeds on the field where potatoes follow up, atrazine residues may have an effect on the growth and yield of potatoes, and also if used for controlling volunteer potato plants, it can be phytotoxic to other plants in the rotation system since the incorporation of atrazine, however can carry-over to the next season under certain climate and soil conditions (Steiner *et al.,* 2005). Therefore, this study will determine how does the nature of soil influence the residual effect of atrazine on the gowth and yield of potatoes.

It is very important to understand how the residual effect of atrazine affect emergence and the growth of potatoes because the concentration of the herbicide does not necessarily influence the amount of herbicide in the plant system or determine the plant response to the compound. There are many factors influencing the uptake of the herbicide by the plant and several such factors include absorption, translocation,and dissimilarity in metabolic degradation rates, discrepancies in the ability of atrazine molecules to inhibit photosynthesis electron transport, seed size and soil conditions.

**2.1 Chemical and physical properties of atrazine**

Chemical and physical properties of herbicides influence their bioavailability, degradation and residual activity in a specific area or to specific plants (Ramakrishnan *et al.,* 2019). Each chemical has unique physical and chemical properties. Chemical and physical properties of atrazine are as follows:

| | | |
|---|---|---|
| Physical state | : | colorless powder and colerless crystals |
| Molucular weight | : | 215.69 unit |
| Color | : | white colorless |
| Melting point | : | 173-175 $^{0}$C |
| Density | : | 1.23 g/cm$^3$ (22 $^{o}$C) |
| Vapour pressure | : | 2.89x10$^{-7}$ mmHg at 25 $^{o}$C |
| Odor | : | odorless |
| Solubility | : | soluble in water (34.7 mg/L) at 22 $^{o}$C |
| Chemical stucture | : | |

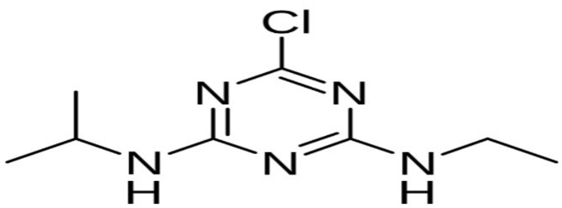


Figure 1: Chemical structure of atrazine [2-chloro-4-(ethylamino)-6-isopropylamino)-s triazine]. Source: Wikipedia, the free encyclopedia

**2.2 Mode of action**

Herbicides can either be selective or non-selective in their mode of action (Varshney *et al.,* 2012). The mode of action of herbicides is very helpful in understanding the management, classification, organization, and hierarchy of the herbicides (Sherwani *et al.*, 2015). The mechanism of the action of herbicides for killing a weed is effective when the herbicide undergoes the following processes, in the sequential order: Contact-Absorption- Movement- Toxicity- and Death (DeBoer *et al.,* 2011). The mode of action of herbicides includes inhibition, interruption, disruption, or mitigation of the regular plant growth.

The herbicide may interrupt and cause an injury or disrupt the regular plant growth and development causing eventual plant death depending on the specific mode of action at work which may involve a plant enzyme or a biological system (Sherwani *et al*., 2015). Herbicides that belong to a specific group may have the same mode of action even though they may belong to a different chemical family. There are different modes of mechanism such as Lipid biosynthesis inhibitors, Amino acid biosynthesis inhibitors; Plant growth regulators; Photosynthesis inhibitors; Nitrogen-metabolism inhibitors; Pigment inhibitors; Cell-membrane disruptors; and Seedling-growth inhibitors.

Atrazine is a photosynthesis inhibitor (Diana *et al*., 2000).The mode of action of atrazine herbicide is the inhibition of the photosynthetic pathway, specifically the Photosystem II (PSII) (Muoni *et al*., 2014). Atrazine inhibits photosystem II (PSII) by binding to the D1 protein thus blocking the electron transfer to the plastoquinone pool (Muoni *et al*., 2014), hence with a resultant production of triplet chlorophyll and reactive oxygen species.

Therefore, plants suffer oxidative stress as a result of reactive oxygen species (ROS) generated at the cellular level such as singlet oxygen, superoxide radicals, hydroxyl radical and hydrogen peroxide. Then in plant cells, these ROS are mainly produced in the chloroplasts, mitochondria and peroxisomes (Erinle *et al.*, 2016).

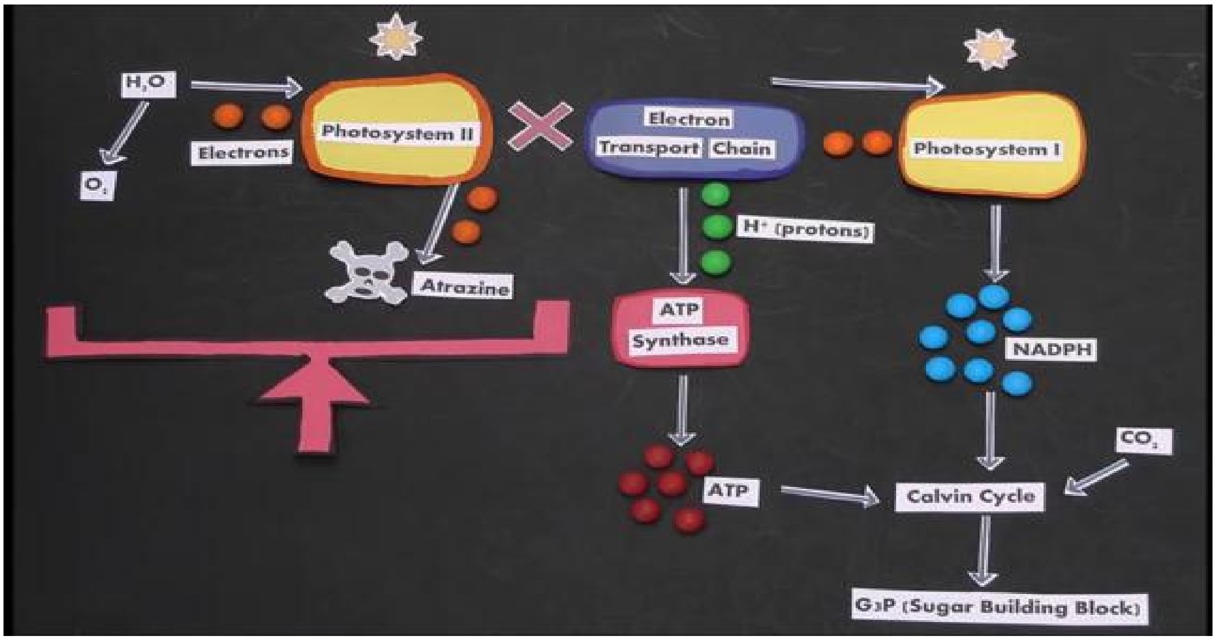


Figure 2:Photosynthesis cycle/process (Angela Hartsock; Wikimedia, public domain)

**2.3 Toxicity and residual effect of atrazine**

Atrazine is known worldwide as the herbicide with the characteristic of broad-spectrum toxicity (Lin *et al.*, 2018). It has a half-life ranging from days to years depending on the soil properties, environmental factors, and microorganism species (Wang *et al.*, 2018). It is resistant to degradation in water and is relatively stable in soil which may cause phytotoxicity on non-target plant species (Gao *et al.*, 2018). Due to its long persistence in soil,it has a high potential to contaminate soil and become toxic to plants (James & Singh, 2018).

The toxicity of atrazine can result in lower growth and crop productivity in situations of low herbicide concentration in the soil. This can occur even when the toxicity is not visible resulting in problems like intoxication in species cultivated in succession when the residual effect exceeds the crop growing season which is known as carryover (Bontempo *et al.,* 2016). Atrazine can still be detected in low concentrations in agricultural soils after decades (Douglass *et al*., 2017) with the highest detected residual amounts reaching 1mg/kg of soil (Ivanov *et al*., 2004). Because triazines are considered as a potential risk, toxic and accumulate in the environment they need to be monitored to ensure that their concentrations do not exceed safe levels (Ntombela & Mahlambi, 2019). This study seeks to contribute to this by determining the residual levels of atrazine in selected South African soils.

### 2.4 Factors affecting selectivity and residual activity of atrazine

Selectivity is the capacity of the herbicide to kill a target plant without harming or killing the non-target plants. The selectivity of herbicides depends upon various factors, such as plant physiology, soil topography, environment, timing of application, rate of application, and application technique (Varshney *et al.*, 2012). Selective herbicides are highly specific herbicides which controls specific weeds associated with a specific crop. Selective herbicides act by getting absorbed and translocated into the xylem or the phloem of the weeds to inhibit or disrupt the metabolic machinery or other biosynthetic pathways, and by injuring or killing the weeds (Varshney *et al.*, 2012).

Atrazine is a selective herbicide that controlsgrassy and broadleaf weeds in sugarcane, sorghum, nuts and corn crops (Singh *et al.*, 2018). It is absorbed by the roots and leaves then translocated acropetally in the xylem and accumulated in the apical meristems. It is a photosynthetic inhibitor that is activated by light causing chlorosis and desiccation of green tissues (Burhan & Shaukat, 2000).

Many cultures use herbicides with residual effects on soil. When the herbicide preserves the integrity of its molecule in the environment for long, it is considered residual (Janaki *et al.,* 2012). When using herbicides, crop injury can be experienced from time to time even if full spectrum weed control is often not achieved and carry-over to follow-up crops may also occur (Saayman-du Toit, 2002). This is because when certain herbicides are applied to the soil in large amounts, they accumulate leading to herbicide residues that can be absorbed by plants (Wolmarans & Swart, 2014).

When the residual effect exceeds the crop growing season it can cause problems such as intoxication in species cultivated in succession. Biotic factors, the microbial flora in soil, and abiotic factors such as soil pH, sunlight, soil humic acid, and metal oxide content, can trigger chemical reactions. These reactions such as hydrolysis, photolysis, and redox in these compounds determine the persistence and leaching of pesticides in the soil (de Paulaa *et al.*, 2016). Atrazine is highly persistent in soil withreported half-life ranging between 10 and 5824 days (Salazar-Ledesmaa *et al.*, 2018). The availability of atrazine for uptake by certain crop species is influenced by several soil and weather factors but crop species may show variable tolerance to atrazine in different localities (Reinhardt & Nel, 1993).

### 2.4.1 Plant factors

Plants can be exposed to a complex of stress factors which can be divided into two groups. Natural factors include extreme temperatures, water shortage, or lodging. Anthropogenic factors include pesticides, heavy metals and air pollutants (Ivanov, Alexieva, & Karanov, 2005). Pesticides though beneficial, can pose serious risks to non-target plants (Ntombela & Mahlambi, 2019). The uptake of atrazine by plants is influenced by several physiochemical and biochemical mechanisms (Mudhoo & Garg, 2011). Crop species may be tolerant to atrazine in different localities. This is because soil and weather conditions may differ between them resulting in differential availability of atrazine for uptake by plants (Reinardt & Nel, 1993).

The only way plants respond to the herbicide is when the molecules of the compound reach the site of action (Reinhardt & Nel, 1993). A herbicide absorbed by the plant reaches its site of action usually located within an organelle in the plant cell. To elicit a phytotoxic effect, it must be present in a toxic form for a sufficient time and concentrations prior to phytotoxic action (Ferreira *et al*., 1999). Different plant mechanisms control the accumulation of atrazine in target and non-target plants because plants accumulate atrazine differently. Sensitive grass crops such as oats accumulate atrazine at the tip of the lamina with a progressive decrease towards the base. In dicotyledons such as soybeans accumulation occurs along the margins of the lamina and the development of phytotoxic symptoms follows this distribution pattern (Nel & Reinhardt, 1984).

Exposure of atrazine to target and non-target plants results in oxidative stress (Singh *et al.*, 2018).Atrazine exposed and accumulated by maize can cause oxidative toxicity and antioxidant response. Exposure to rice triggers specific GT genes and enzyme activities (Singh *et al.*, 2018). Plants use different mechanisms to prevent oxidative stress for instance through reactive oxygen species scavenging (Singh *et al.*, 2018). Plants can use multiple sophisticated strategies that are based on the glycosyltransferase detoxified pathway to withstand the adverse impact of atrazine and alleviate its phytotoxicity via an enzymatic or nonenzymatic degradation system (Yi Chen Lu, 2013).

Plants detoxify herbicides through enzymes such as cytochrome 450, peroxidases, aryl acylamidases, esterases, lipases, proteases, amidases, oxygenases and reductases (Jiang *et al.*, 2016). Resistant species such as corn and sorghum are able to use *N*-dealkylation, 2-hydroxylation, and glutathione conjugation to rapidly metabolize and detoxify atrazine (Mudhoo & Garg, 2011). Rice uses cytochrome P450 monooxygenase genes to modify and detoxify atrazine (Singh *et al.*, 2018).Bhullar *et al.* (2015), reported that atrazine applied at 2 kg/ha in maize seeded in the first week of September affected wheat crop seeded in the first half of November; with an interval of <75 days between atrazine application and seeding wheat.

The studies above found that the exposure of plants to pesticides results in oxidative stress. The authors further indicated that plants accumulate pesticides differently and at different concentrations. Few studies have been done on the effect of atrazine on emergence of potatoes and the accumulation of atrazine by potatoes in South Africa. A positive outcome from the present study seeks to contribute to this by providing an additional knowledge on the effect of atrazine on emergence of potatoes. The study will also provide knowledge on the different levels of atrazine concentrations to determine how much is accumulated in such a way that is toxic to the plant and the amount of atrazine to be adjusted to concentrations desirable to crop uptake.

### 2.4.2 Soil factors

When agricultural chemicals are either applied directly to soil or to the aerial parts of the plants, soil is the final destination (Inoue *et al.*, 2004). Therefore, it is important to identify and understand the interactions between soil and herbicides (de Paula *et al.*, 2016). The presence of different reaction sites in soils in terms of their nature and accessibility to herbicides determine the rate of sorption of the chemical (Inoue *et al.*, 2004). Atrazine, like many other herbicides enter the environment in a variety of ways and remain in the soil through adsorptive processes.

Persistence, fate and eco-toxicological impacts of pesticide residues are determined by the adsorption of the chemical to soil components (Gongora-Echeverria *et al.*, 2019). Atrazine has a high mobility in soil (Reis *et al.*, 2018). It is expected that different crops and cultivars are bound to respond differently to atrazine residues in the soil. Atrazine contaminate soils at the highest detected residual amounts that reach 1mg/kg soil. Inagricultural areas atrazine has been detected in 1-100g/kg soil. Thesame atrazine concentrations have been reported to result in cytokinin-like properties in some plants (Ivanov *et al*., 2004).Zabermawi & El-Bestawy, (2017), detected an atrazine residue of 0.232 ppm in soil after 25 days of application which decreased to 0.140 ppm 50 days after herbicide application.

Soil pH, organic material, temperature and soil layer can influence herbicide degradation rates (Nousiainen *et al.*, 2015). Atrazine is degraded at higher concentrations in topsoil than in subsoil where its degradation is considerably slower. Soil pH has greater effect than organic matter and other soil properties (Shaner & Henry, 2007). Reinhardt & Nel, (1993) demonstrated that soils with high organic matter content of 3% C and a clay content of 31% showed no response to atrazine for dry bean and sunflower except for the grain sorghum which was treated with relatively high doses. Similarly, Reinhardt, (1995) demonstrated that atrazine persisted long in Warmbaths soils with 35% total clay, 80% montmorillonite, 0.5% C and pH 7.8.In this study, atrazine residues caused total failure on both sunflower and dry beans and on soils which kaolinite clay mineral predominated sunflower yield was reduced by 13% and 21% (Reinhardt, 1995).

#### 2.4.2.1 Soil texture

Migration of atrazine in soil occurs through soil microporous structure and adsorption of atrazine on soil particles. This is because atrazine residues can be identified even after several months of its application on soil particles (Janaki *et al.*, 2012). Soil texture influences atrazine residues more especially clay soils that have a higher capacity to retain the molecule in colloids (Novais *et al.,* 2019). Catalytic and adsorption properties of clay soils make them important for retention and transport of organic and inorganic chemicals through the environment.

Particles made of clays are frequently carriers of atrazine and other pollutants (Bilanovic *et al*., 2007). Clay minerals can also form the last barrier to avoid translocation of chemicals by soil leachates because clay minerals are the most reactive inorganic constituents of soil (Salazar-Ledesma *et al.*, 2018). Movement of atrazine to ground water is related to its propensity to leach in coarse texture soils which are low in clay content (Reinhardt & Hugo, 1997). Soils with high clay content binds herbicides such as imazapyr (Campbell *et al*., 2019).

Clay content of the soil can change the adsorption behavior of atrazine which affects atrazine removal efficiency (Mecozzi *et al*., 2006).Salazar-Ledesma *et al*. (2018) studied soils having a clay content of 28% that increases with depth and medium total carbon contents. He found thatthe soil had a moderate adsorption capacity for atrazine. In soils with less than 30% clay under conventional tillage, the use of atrazine at application rate greater than 50 g/ha active ingredient is not recommended (Muoni *et al.*, 2014).

Some producers observed phytotoxicity after the application of pre-emergence graminicides or graminicide mixtures used in South Africa such as acetochlor-atrazine-propazine mixture, alachlor, atrazine-s-metholachlor mixture, and smetolachlor-terbuthylazine mixture in soils with less than 10% clay (Saayman-du Toit, 2002).

Atrazine is persistent in some types of soils and its half-life in sandy soils is 125 days (Oladele *et al*., 2017). In unsaturated zone of agricultural soils microbial attenuation of atrazine takes place and is most active in the top 15 cm layer. Only a fractional atrazine residue can reach the saturated zone and drainage of atrazine in this zone is enhanced in sandy soils (Douglass *et al*., 2017).

#### 2.4.2.2 Soil pH

Soil pH is one of the factors that have a greater effect on the rate of degradation than OM and other soil properties (Yale *et al*., 2017). Soil fertility for crop production is determined by soil acidity as indicated by pH. Changes in soil pH affects herbicide persistence in soil (Kotze & du Preez, 2008). Atrazine is a weak base pKa 1.7 and adsorbs less as soil pH increases and the rate of degradation decreases (Shaner & Henry, 2007). Atrazine as a weak base protonates when the pH of the soil is close to 1.7, further increasing its solubility (Salazar-Ledesma *et al.,* 2018). Additionally, atrazine degradation is faster in soils with a pH of 6.5 than with soils with a pH of 6.0 due to the bioavailability of the herbicide to soil microbes (Shaner & Henry, 2007).

Reinhardt & Hugo (1997), pointed out that soil pH and organic matter are the indicators of atrazine persistence in the soil. In addition, they reported that atrazine would have a higher propensity to leach in neutral or alkaline soils low in organic matter content (Reinhardt & Hugo, 1997). Similarly, Yale *et al*. (2017), showed that soil pH affected degradation of atrazine. Soil pH is one of the factors that are very important for herbicide degradation and sorption and associated microbial activity. It controls sorption of glyphosate more than soil organic carbon (Wolmarans & Swart, 2014).

#### 2.4.2.3 Soil temperature

Soil temperature has an effect on atrazine. Research has demonstrated that in several soils, atrazine half-life varied from about one month in warm, wet soil with 25°C to about a year in cool, dry soil with 5°C (Reinhardt & Nel, 1993). Soil temperature decreases with depth during daytime in summer and affect the sorption and microbial rate processes of the herbicide (Paraiba & Spadotto, 2002). Tilled soils are warmer at the surface but cooler below a certain depth because soil temperature decreases with depth more steeply in tilled than untilled soil (Paraiba *et al.*, 2003). Under the modified environmental conditions, the rate of pesticide degradation is faster than in temperate climates. This is due to higher microbial populations and activities as a result of higher soil temperature (Paraiba *et al.*, 2003).

Janaki *et al*. (2012) showed that soil temperature and distribution of rainfall plays a key role on the degradation of atrazine in the soil.The susceptibility of plants to the herbicide is affected by factors that influences the amount of herbicide absorbed such as cultivar, herbicide placement, temperature, soil moisture and other soil factors (Allemann & Ceronio, 2009). Atrazine residues in soil depends on the soil composition, temperature, pH and soil humidity and that its persistence is increased by cool and dry soil conditions (Janaki *et al.*, 2012).

#### 2.4.2.4 Soil microorganisms

Atrazine and its residues persist long in soil posing a threat to non-target plants. Various methods to remove atrazine from the environment have been tested. These includes adsorption by various materials and biodegradation by microorganisms (Tao *et al.*, 2019). Bioremediation is a more preferred method for atrazine removal from the environment because it can completely remove organic contaminants with low operation costs (Gao *et al.*, 2018). Microorganisms are well known for their bio-degradative capabilities against a wide range of recalcitrant environmental pollutants. On repeated and long application of atrazine, enhanced degradation due to microbial adaptation to atrazine takes place leading to a reduction in herbicidal effectiveness (Zabermawi & El-Bestawy, 2017).

Atrazine degradation in soil is usually caused by the action of microbes like bacteria, fungi, and actinomycetes. The best characterized organisms that degrade atrazine are of *Pseudomonas spp* and *Bacillus spp* (Zabermawi & El-Bestawy, 2017). *Penicillium sp.* also has a great potential in bioremediation because of its cytochrome P450 enzyme that can degrade organic matter by dealkylation and dehalogenation (Yu *et al.*, 2018). In previous studies, it has been found that several species of *Penicillium* sp. like *Penicillium documbens, Penicillium janthinellum* and *Penicillium luteum* are able to degrade atrazine (Yu *et al.*, 2018). Other microbial species such as Agrobacterium radiobacter, Alcaligenes sp., Enterobacter cloacae, Nocardia sp., and Rhodococcus spcan exhibit atrazine metabolism (Singh *et al.*, 2018).

Degradation by microorganisms occurs when the herbicide is broken down by microorganisms present in the soil. The microorganisms use the herbicide molecule as a food source, to derive their energy and other nutrients for their cellular metabolism (Oladele & Ayodele, 2017). Agricultural soils have become the new hotspot for microorganisms degrading pesticides as these soils receive pesticides year after year (Ramakrishnan *et al.*, 2019). However, the presence and activity of microorganisms in the soil depends on the conditions favorable for their growth and survival. These include warm temperatures, favorable pH levels, adequate soil moisture, oxygen and nutrient availability (Rao, 2000).

Atrazine degradation in the environment takes place in three processes which includes dechlorination, dealkylation, and deamination (Yu *et al.,* 2018). A mechanism of hydrolytic dechlorination is used by some bacteria to initiate degradation of atrazine involving the enzyme atrazine chlorohydrolase (Singh *et al.*, 2018). Bacterial and fungal species dechlorinate atrazine molecule leading to the formation of hyroxyatrazine, deisopropylatrazine and deethylatrazine (Singh *et al.*, 2018). Biodegradation of atrazine by microorganisms has been reported by many researchers with the formation of metabolites like hydroxyatrazine, deethylatrazine, or deisopropylatrazine being proposed (Kolekara *et al.*, 2019). Gao *et al.* (2018), used Arthrobacter sp. strain HB-5, a degrading bacterial strain to remove atrazine from soil in a lab incubation experiment. The strain degraded of added atrazine 100%, withthe degradation half-life three times less than the natural soil.

#### 2.4.2.5 Soil moisture

Moisture and temperature are the two main environmental factors affecting the behavior of pesticides in soil with moisture having a more significant relative weight than soil temperature (Paraiba & Pulino, 2003). Soil moisture is an important factor in management of water resources, especially in arid and semi-arid regions (Moller *et al.*, 2018). Soil moisture is also a key variable in the water and energy cycles and is essential for adequate development of crops (Tamfuh *et al.*, 2018). Overall biological activity of atrazine is limited by soil moisture below field capacity during at least 15 days between irrigation events (Salazar-Ledesma *et al.,* 2018). Increased moisture retention promotes the build-up of microorganisms of which some of them contribute in atrazine degradation (Muoni *et al.*, 2014).

#### 2.4.2.6 Soil organic matter

Soil organic matter is crucial for agricultural productivity because it is important for soil structure, water holding capacity, and release and retention of plant nutrients (Martinsen *et al.*, 2019). It is also a key indicator for soil quality (Paul *et al.*, 2013). Soil ecosystem functions can be affected by synthetic fertilizers through the impact on primary productivity and reduction in the quantity of soil organic matter input (Zabermawi & El-Bestawy, 2017). Soil organic matter helps the soil to rebound against soil compaction (Cheong *et al*., 2009). The adsorption of s-triazines to organic matter determines the vertical distribution of herbicides in the soil (Reinhardt & Hugo, 1997). It is one of the most important factors of atrazine adsorption and bioactivity (Reinhardt *et al*., 1990).

Atrazine has been detected as an organic contaminant in agricultural soils with the sorption controlled by soil organic matter (Wu *et al.*, 2015). Sorption of atrazine to soils correlates positively with organic carbon content. Sorption of the herbicide to organic matter lowers its bioavailability increasing its persistence despite its susceptibility to abiotic and biotic degradation (Mudhoo & Garg, 2011). Atrazine does not adsorb strongly to soil particles therefore it is moderately to highly mobile in soils with low organic matter content (Paraiba & Pulino, 2003). Sorption of atrazine is slow in a well-structured soil with high organic matter (Inoue *et al.*, 2004).

Organic matter content is the main regulator of atrazine binding and residue formation (Novais *et al.*, 2019). Depending above all on the molecular structure of the natural organic matter atrazine can bind to soil humic substances (Gongora-Echeverria *et al.*, 2019). Humus-fixed atrazine persists long in the soil and is recalcitrant to degradation. This is since it is strongly bound with soil organic matter or it is trapped within the soil micropores and it has an extremely low accessibility by microorganisms (Lin *et al.*, 2019).Soil organic matter content in South Africa is naturally very low with an estimation of 60% of the soils containing less than 0.5% of soil organic matter (Swanepoel *et al*, 2018).

Soil organic matter was reported by numerous studies to be the most important soil factor concerning atrazine adsorption and bioactivity. Soil organic matter and P-reversion are better predictors of the biological activity of atrazine in South African soils than clay content (Reinhardt & Hugo, 1997). Wu *et al.*(2015) investigated the sorption characteristics of atrazine on SOM fractions. The study quantified the relative contribution of SOM fractions to the overall sorption of atrazine in Vertisols.The study found that the amounts of atrazine sorbed onto the extracted SOM fractions increased sharply in the first 10 hours attained 75% of the equilibrium sorption amounts within 48 hours followed by much slower progress toward an apparent equilibrium during the next 120 hours after which the maximum sorbed amount was observed. The studies above found that crops respond differently to atrazine residues in the soil and that soils differ in their characteristics and influence to herbicides. The presentstudy will provide knowledge on the interaction of soil type and atrazine to determine the type of soils that influence the activity and effect of atrazine on potatoes.

## CHAPTER 3:MATERIALS AND METHODS

### 3.0 Material and Methods

This chapter presents the material and methods employed in this study. Also, the statistical procedures that were employed were detailed.

### 3.1 Ethical Considerations

Ethics Clearance was received before proceeding with the study under Ethics Approval number 2019/CAES/071 from the UNISA Ethics Committee of the College of Agriculture and Environmental Sciences (CAES). A research proposal was presented before the CAES panel for post-graduate students prior to application for ethics approval.

### 3.2 Experimental Site

The study on bioassay of Potato (*Solamum Tuberosum*) cultivar (Moonlight), using three different types of soils (Table 1) named sandy, clay loam, and sandy loam soil from Thohoyandou, Mphephu Limpopo was conducted in a fully automated greenhouse at the Horticultural Centre UNISA Florida Campus, South Africa. The coordinates are latitude S26° 9.501 and Longitude: E27° 54.113 in Johannesburg Gauteng Province. Temperatures ranged between 18 and 30°C (AccuWeather Inc, online). Supplemental lighting was not provided, and humidity was increased from ambient by an evaporative cooling system. The temperature in the greenhouse was set to a 28°/18°C day/night temperature regime. The trials were conducted under natural daylight conditions, with a day length of approximately 12 hours.

The three soils used were collected from Thohoyandou, Mphephu Limpopo (Table 1). For each soil, sampling was done by collecting soil from a depth of 60cm using a spade. The 1$^{st}$ 30cm soil was top soil and the 2$^{nd}$ subsoil. The soil was taken several times at other randomly chosen spots. The top soils were then mixed together as well as the sub soils which were then put in containers marked top and subsoil. A sample of 1 kg soil was obtained and then sent to ARC for soil analysis.

Table 1: Characteristics of selected Soils

| Soil Type | Clay % | Silt % | Sand % | pH $H_2O$ | CEC $cmol(+)kg^{-1}$ |
|---|---|---|---|---|---|
| Clay loam soil | 37.70 | 22.0 | 34.45 | 5.56 | 6.2552 |
| Sandysoil | 12.0 | 8.0 | 72.67 | 6.70 | 6.4335 |
| Sandy loam soil | 22.0 | 10.6 | 68.0 | 6.49 | 7.3587 |

**3.3 Experimental Design**

Three soils were harvested namely sandy, clay loam, and sandy loam soils. The soils were used in the study as a factor, and different application rates of atrazine were applied as a second factor. The experiment was laid out using Randomized Complete Block Design with three (3) replicates based on the fully automated greenhouse. The study trial constituted three (3) blocks with thirty-six (36) pots spaced at 30 cm inter-row and 15 cm intra row spacing. Four different atrazine rates namely: 0.1, 0.2, 0.3 mg/L, and 0 control were soil administered into a 30 cm plastic pot having the soils (1 kg/pot).

A 20 ml spray bottle was used, 19.9 ml of tap water was make-up with 0.1 ml of atrazine solution to apply in a pot for treatment 1, 19.8 ml of tap water was make-up with 0.2 ml of atrazine solution to apply in a pot for treatment 2, and 19.7 ml of tap water was make-up with 0.3 ml of atrazine solution to apply in a pot for treatment 3. The soil after atrazine administration was homogenized and the process was replicated accordingly. The atrazine levels were determined in accordance with the reports by Sharma *et al*. (2004). Prior to this, white plastic bags were placed inside the pots before filling the pots with soil to avoid herbicide leaching.

Two seed potatoes (cultivar Moonlight) were planted into the pots a day after the application of herbicide. The seed tubers were at bud breaking stage and of equal size of approximately 2 - 4 g. The pots received overhead sprinkler water irrigation 48 hours after planting. As recommended by ARC, MAP (110 kg/h MAP of 10:48:0), KCL (510 kg/h KCl (50), and Zn (40 kg/h of 2:3:4 (30) + 0.50%) were applied pre-planting, thereafter fertigation was done at 3 to 4 weeks using LAN (350 kg/h LAN (28) based on the soil analysis. The fertilizer was applied in a ring band and allowed to dissolve as the plants receive water. After 12 weeks of planting, the experiment was terminated then the soil was used further for the $2^{nd}$ planting of potato seed without application of the herbicide to determine the residual effect of atrazine on emergence.

### 3.4 Data Collection

The number of days to emergence of the first seeds to emerge and the number of seedlings that emerged (establishment count) were recorded within 1 to 3 weeks after planting. Plant height per plant was measured from the base of the stem to the tip using a meter rule and the number of leaves per plant was counted and recorded weekly. The plants were uprooted 12 weeks after planting and washed off any loose soil using tap water before the fresh weight was weighed and recorded using a sensitive weighing balance.

For the dry weight, the plants were dried in a well-labeled paper bag according to the different treatments, with the date of sample collection and replicate number. Thereafter, they were placed in the oven at $60^0$C for 48 hours. After oven drying the samples were weighed and recorded. The number of potato tubers per plant was counted and recorded respectively. After harvesting all the potatoes from the plant, the fresh and dry potato tubers were weighed and recorded. Data were expressed as percentage damage, i.e. percentage reduction in the emergence and shoot dry mass compared with the number planted in each experiment.

### 3.5 Data Analysis

Analysis of variance (ANOVA) was achieved using Statistica and SAS Version 9.4 at 95% confidence level (i.e. ≤0.05 significance) which explains that, if P values are ≤0.05;

the null hypothesis will be rejected which says that soil applied atrazine has no effect on growth parameters of potato plant (Steel & Torrie, 1980).

## CHAPTER 4: RESULTS

### 4.0 INTRODUCTION

Two experiments were carried out. The 1st experiment was carried out with atrazine application and potato seeds planted immediately. The effect of atrazine on potato parameters (days to emergence, number of seedlings emerged, plant height, number of leaves and fresh weight, dry weight, fresh tuber weight, dry tuber weight and tuber number) was observed. The soil was used further for 2nd planting where the application of atrazine was not included but all other planting conditions kept constant. The residual effect of atrazine was determined only on emergence (number of seedlings emerged (establishment count)and days to emergence).

### 4.1 Effect of atrazine on days to emergence of seed potatoes for Sandy, Clay loam and Sandy loam soil for 1$^{st}$ planting

The present study found atrazine significantly ($P \leq 0.05$) affected potato seed days to emergence of the three soils.

Table 2: The effect of soil type and atrazine application rate on days to emergence of seed potato

| **Atrazine (mg/l)** | **Days to Emergence** |
|---|---|
| **Soil Type** | |
| Sandy soil | 8.19 b |
| Clay loam soil | 9.58 a |
| Sandy loam soil | 8.75 b |
| Least Significance | * |
| **Atrazine application rate** | |
| Control | 7.03 a |
| 0.1 | 8.89 c |

| | |
|---|---|
| 0.2 | 9.56 bc |
| 0.3 | 9.89 b |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

The effect of the soils on the mean number of days to emergence was significant (P≤ 0.05) (Table 2). Clay loam soil produced the highest (9.58) mean number of days to emergence (Table 2). Sandy soil and Sandy loam soil resulted in similar number of days to emergence (Table 2). Atrazine application rate significantly (P≤ 0.05) affected the number of days to emergence (Table 2). The control had the lowest (7.03) number of days to emergence than all atrazine applied treatments and the highest (9.89) was observed on applying 0.3 mg/l atrazine (Table 2). The control was significantly (P≤ 0.05) different from all atrazine applied treatments (Table 2).

Results indicated that the interaction of soil type and atrazine application rate was significant (P≤ 0.05) (Figure 3,4,5). This indicated that days to emergence from different soil types responded differently at different atrazine rates. In the Sandy soil, applying 0.3 mg/l atrazine resulted in the highest (10.33) number of days to emergence (Figure 3). In this soil, the control (without application) had the lowest (7.10) number of days to emergence (Figure 3). The control was significantly (P≤ 0.05) similar to applying 0.1 mg/l atrazine and significantly (P≤ 0.05) different from 0.2 and 0.3 mg/l atrazine applied treatments (Figure 3).

For the Clay loam soil, the control (without herbicide) had the lowest number of days to emergence (7.00) compared to all atrazine applied treatments (Figure 4). In this soil, the control was significantly (P≤ 0.05) different from all atrazine applied treatments and insignificant (P≤ 0.05) difference was observed between applying 0.2 and 0.3 mg/l (Figure 4). In the Sandy loam soil, the control had the lowest number of days to emergence compared to all other atrazine applied treatments (Figure 5). In this soil, the highest (10.00) was at applying 0.3 mg/l atrazine (Figure 5).

The three soils had similar number of days to emergence on the control (treatment without) compared to all atrazine applied treatments. The highest (11.00) number of days to emergence was observed on applying 0.1 and 0.2 mg/l atrazine on Clay loam soil relative to the other soils (Figure 4).

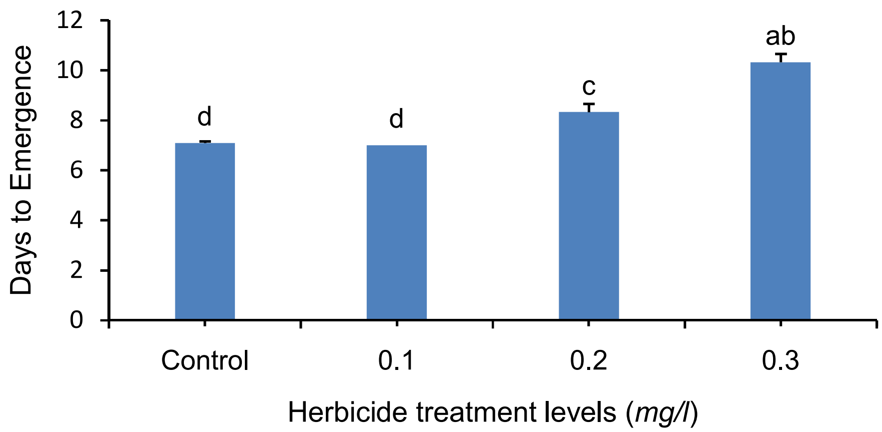


Figure 3: Days to emergence of seed potatoes treated with atrazine on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

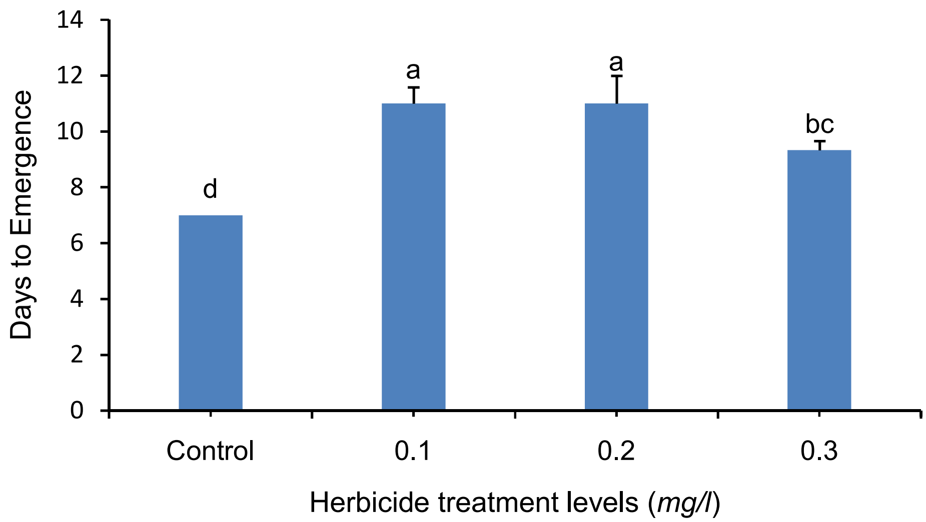


Figure 4: Days to emergence of seed potatoes treated with atrazine on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

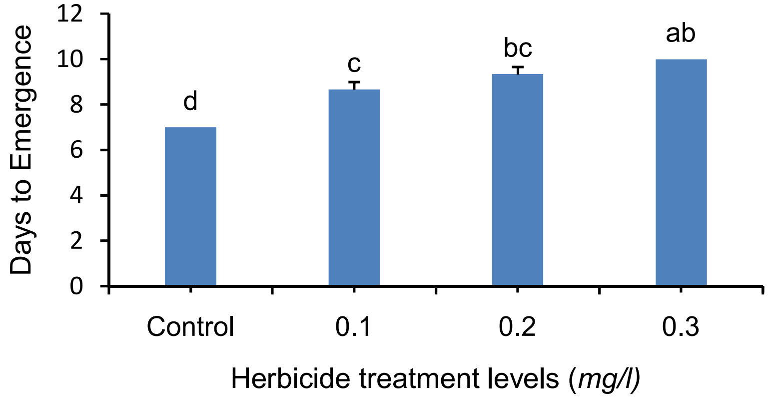


Figure 5: Days to emergence of seed potatoes treated with atrazine Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.2 Effect of atrazine on the number of potato seedlings emerging (establishment count)for Sandy, Clay loam and Sandy loam soil of 1st planting**

The effect of atrazine on the number of potato seedlings that emerged was significant (P≤ 0.05) for Sandy loam soil. There was no statistically significant (P≤ 0.05) effect for Sandy and Clay loam soils.

Table 3: The effect of soil type and atrazine application rate on number of seedlings emerged of seed potato

| Atrazine (mg/l) | Number of seedlings emerged |
|---|---|
| **Soil type** | |
| Sandy soil | 2.58 a |
| Clay loam soil | 2.67 a |
| Sandy loam soil | 2.58 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 2.00 c |
| 0.1 | 2.78 ab |
| 0.2 | 2.33 bc |
| 0.3 | 3.33 a |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

The effect of the soils on mean number of potato seedlings emerged was not significant (P≤ 0.05) (Table 4). The three soils resulted in similar mean number of potato seedlings emerging (Table 4). Atrazine application rate significantly (P≤ 0.05) affected the number of potato seedlings that emerged (Table 4). Treatment level 0.3 mg/l resulted in the highest mean number of seedlings emerged (3.33) relative to the other treatments including the control (without herbicide treatment) (2.00) (Table 4). The control is significantly (P≤ 0.05)similar to applying 0.2 mg/l and significantly different from 0.1 and 0.3 atrazine applied treatments (Table 4).

Results indicated that the interaction of soil type and atrazine application rate was significant (P≤ 0.05) (Figure 6,7,8). In the Sandy soil, the highest (3.33) number of seedlings emerging was observed at applying 0.3 mg/l atrazine (Figure 6). In this soil, the control was significantly (P≤ 0.05) similar to applying 0.2 mg/l atrazine and significantly (P≤ 0.05) different from 0.1 and 0.3 mg/l atrazine applied treatments (Figure 6). For the Clay loam soil, the control had the lowest (2.00) number of potato seedlings emerging compared to all atrazine applied treatments (Figure 7). The highest (3.33) number of potato seedlings emerging was observed at applying 0.1 mg/l atrazine (Figure 7). The control was significantly (P≤ 0.05) different from all atrazine applied treatments (Figure 7).

In the Sandy loam soil, the control (without herbicide) had similar mean number of potato seedlings emerging with applying 0.1 gm/l atrazine (Figure 8). The highest (4.00) number of potato seedlings emerging was observed on applying 0.3 mg/l atrazine. Sandy loam soil resulted in the highest number of potato seedlings emerging compared to all other soils (Figure 8). For control (without herbicide treatment) the three soils had similar number of potato seedlings emerging. Applying 0.1 mg/l atrazine on Sandy loam soil and 0.2 mg/l on Sandy soil had similar number of seedlings emerged with the control (without application).

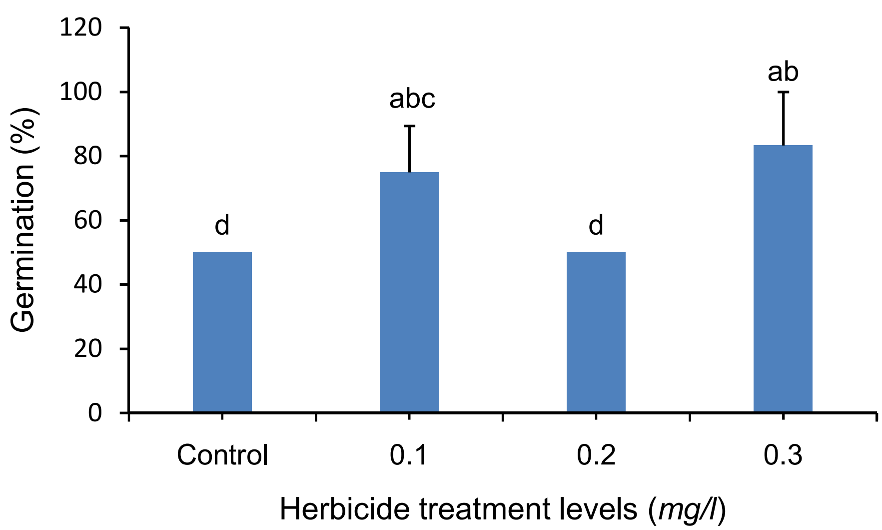


Figure 6: Effect of atrazine on germination percentage of seed potatoes on Sandy soil.
*Means with the same letter are not significantly different at P≤ 0.05

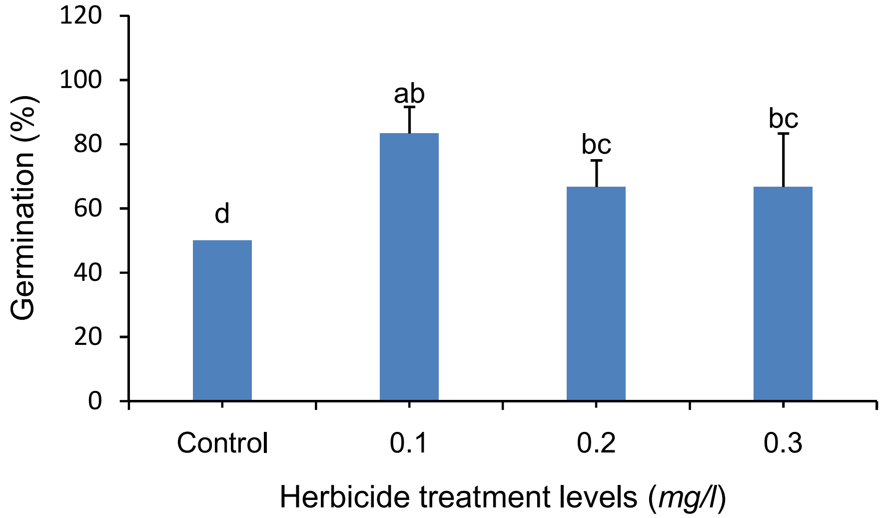


Figure 7: Effect of atrazine on germination percentage of seed potatoes on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

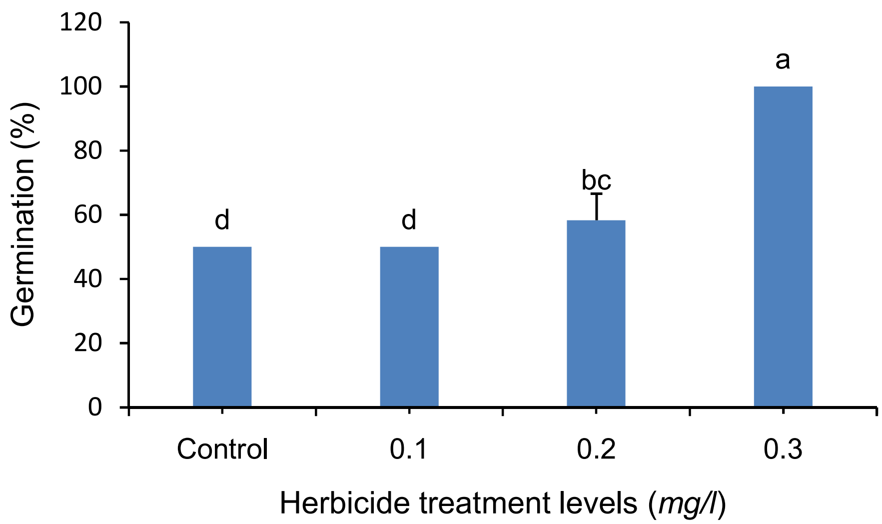


Figure 8: Effect of atrazine on germination percentage of seed potatoes on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.3 Effect of atrazine on potato height for Sandy, Clay loam and Sandy loam soil**

The effect of atrazine on potato height was significant (P≤ 0.05) for Sandy and Sandy loam soil and insignificant (P≤ 0.05) for Clay loam soil.

Table 4: Effect of soil type and atrazine application rate on potato height (cm)

| Atrazine (mg/l) | Plant Height (cm) |
|---|---|
| **Soil Type** | |
| Sandy soil | 47.00 a |
| Clay loam soil | 35.17 c |
| Sandy loam soil | 44.42 b |
| Least Significance | * |
| **Atrazine application rate** | |
| Control | 42.88 b |
| 0.1 | 37.22 a |
| 0.2 | 43.00 b |
| 0.3 | 45.66 b |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

The effect of the soils on mean potato height was significant (P≤ 0.05) (Table 6). All the means of the potato height were significantly (P≤ 0.05) different (Table 6). Sandy soil produced the highest mean of potato height (47.00) compared to Clay loam soil (35.00) and Sandy loam soil (44.42). Clay loam soil resulted in significantly (P≤ 0.05) lower mean potato height (35.00) than the other soils. Atrazine application rate significantly(P≤ 0.05) affected potato height (Table 6). Applying atrazine at 0.1 mg/l resulted in the lowest mean potato height compared to all other treatments including the control (without herbicide treatment). The control is significantly (P≤ 0.05) similar toapplying 0.2 and 0.3 mg/l atrazine (Table 6).

Results indicated significant (P≤ 0.05) interaction of soil type and application rate (Figure 9,10,11). Sandy soil had the highest mean potato height (54.00) for the control (without herbicide) compared with treatments treated with atrazine (Figure 9). The lowest potato height of 39.67 was on application rate of 0.1 mg/l atrazine (Figure 9). The Clay loam soil had the lowest potato height (32.00) in the control (without herbicide) compared with the treatments treated with atrazine, with the highest height observed on applying atrazine at 0.3 mg/l (38.67) (Figure 10).

For the Sandy loam soil, the lowest potato height was on applying atrazine at 0.1 mg/l (36.33) compared to the control (Figure 11). However, the control also had a lower potato height than on applying 0.2 and 0.3 mg/l atrazine with the tallest potato plants recorded on applying 0.3 mg/l (52.00) atrazine (Figure 11). The shortest potato plants among all the soils were in the control treatment for the Clay loam soil (32.00) (Figure 10) while the tallest were on the Sandy soil (54.00) (Figure 9).

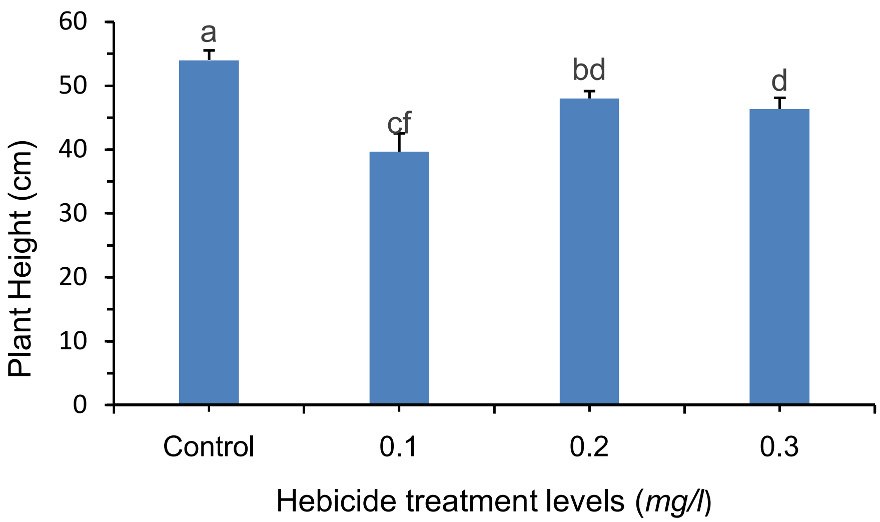


Figure 9: Effect of atrazine on plant height of potato plant on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

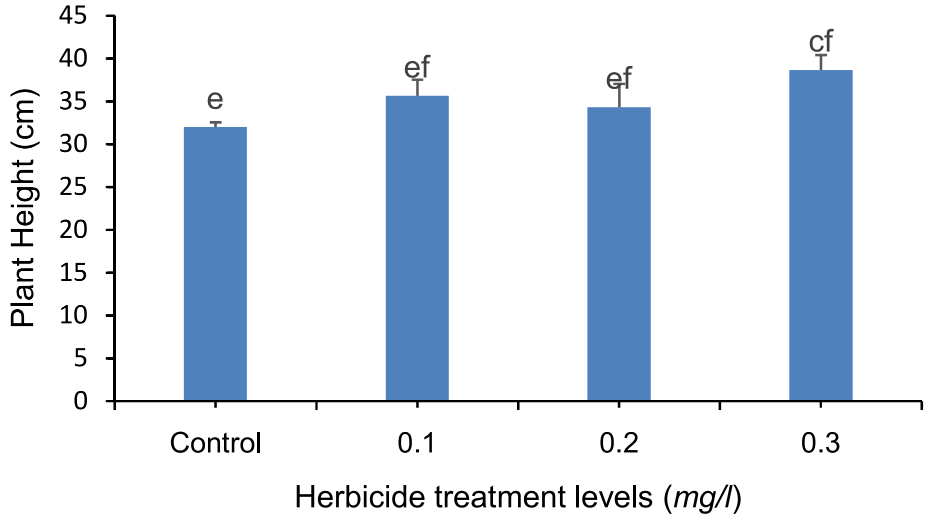


Figure 10: Effect of atrazine on plant height of potato plant on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

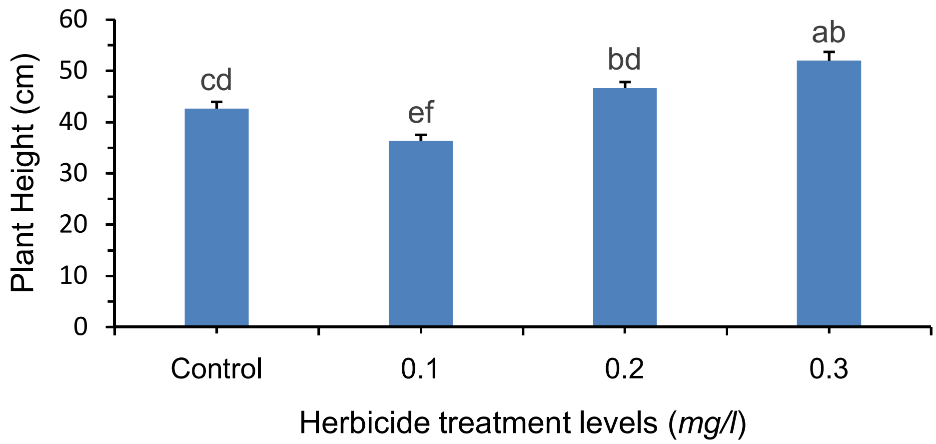


Figure 11: Effect of atrazine on plant height of potato plant on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

### 4.4 Effect of atrazine on the number of potato leaves for Sandy, Clay loam and Sandy loam soils

The effect of atrazine on the number of potato leaves was significant (P≤ 0.05) for Sandy loam soil. There was no statistically significant (P≤ 0.05) effect for Sandy and Clay loam soils.

Table5: Effect of soil type and atrazine application rate on the mean number of potato leaves

| Atrazine (mg/l) | Number of leaves |
|---|---|
| **Soil type** | |
| Sandy soil | 29.5 b |
| Clay loam soil | 24.92 a |
| Sandy loam soil | 30.67 b |
| Least Significance | * |
| **Atrazine application rate** | |
| Control | 27. 66 b |
| 0.1 | 27.22 b |
| 0.2 | 28.00 b |
| 0.3 | 30.55 a |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

The effect of the soils on mean number of potato leaves formed was significant (P≤ 0.05) (Table 8). Clay loam soil had significantly (P≤ 0.05) fewer leaves (24, 94) than Sandy soil (29,5) and Sandy loam soil (30.67) (Table 8). There was no significant (P≤ 0.05) difference between Sandy soil and Sandy loam soil (Table 8). Atrazine application rate significantly (P≤ 0.05) affected the number of potato leaves formed by potato plants (Table 8). Application rate of 0.3 mg/l atrazine resulted in the highest number of potato leaves than all other treatments (Table 8). There was no significant (P≤ 0.05) difference between the control and applying 0.1 and 0.2 mg/l atrazine (Table 8).

The results indicated that the interaction of soil type and atrazine application rate is significant (P≤ 0.05) (Figure 12,13,14). This indicated that the number of leaves formed per plant from different soil types responded differently at different atrazine rates. Sandy soil had the highest number of potato leaves (31.67) in the control (without herbicide treatment) compared to the other treatments (Figure 12). For Clay loam soil, the control (without application) had similar number of potato leaves with applying 0.2 mg/l atrazine of 23.67 (Figure 13). The highest number of potato leaves were observed on applying atrazine at 0.3 mg/l (27.00) (Figure 13).

In the Sandy loam soil, the control (without herbicide) had fewer potato leaves (27.67) compared to the treatments treated with atrazine (Figure 14). The highest (36.33) number of leaves were observed on applying 0.3 mg/l atrazine (Figure 14). Applying 0.3 mg/l atrazine resulted in significant ($P \leq 0.05$) difference from all other treatments for the Sandy loam soil (Figure 14).

On comparing the three soils, the control (without herbicide) had fewer leaves on Clay loam and Sandy loam soils (23.67 and 27.67 respectively) compared to the Sandy soil (31.67). For the treatments treated with atrazine the highest number of potato leaves were observed on applying 0.3 mg/l (36) atrazine in the Clay loam soil (Figure 13).

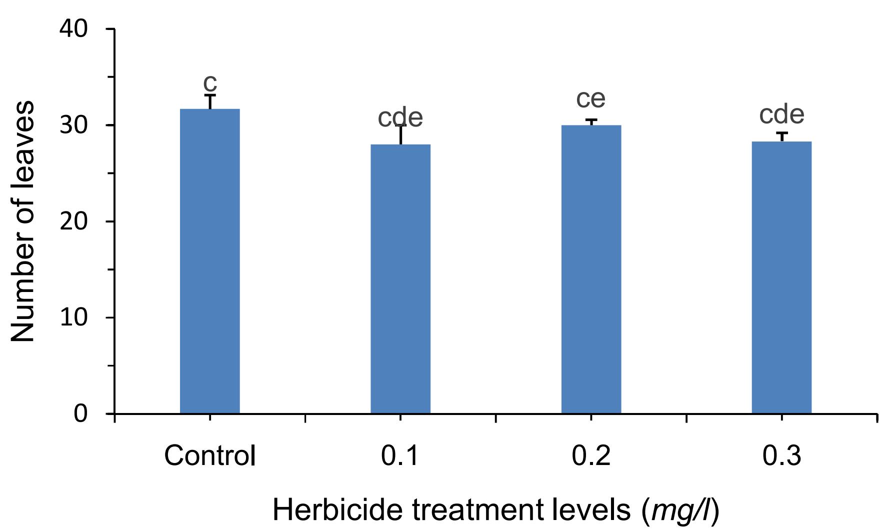


Figure 12**:** Effect of atrazine on the number of potato leaves on Sandy soil. *Means with the same letter are not significantly different at $P \leq 0.05$

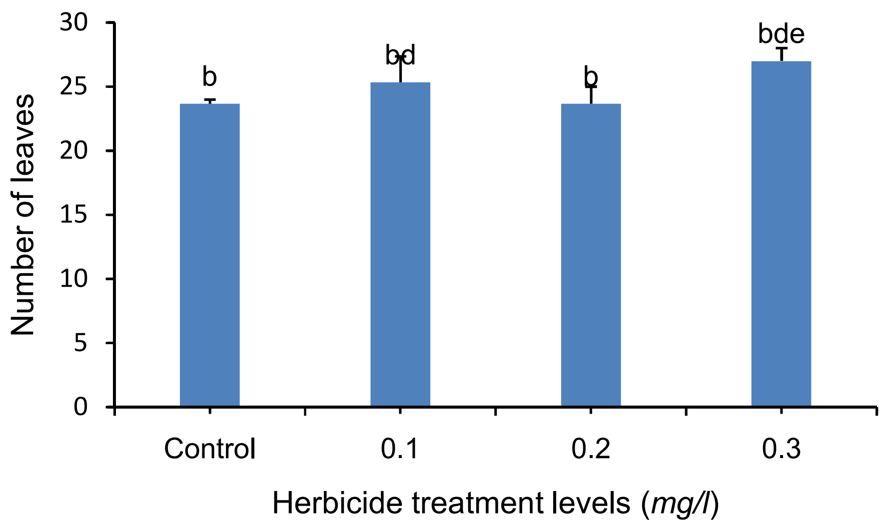


Figure 13**:** Effect of atrazine on the number of potato leaves on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

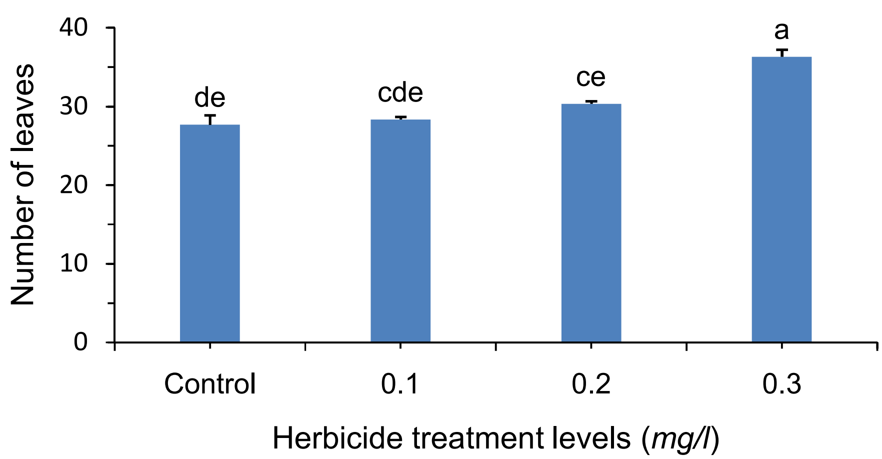


Figure 14**:** Effect of atrazine on the number of potato leaves on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

### 4.5 Effect of atrazine on potato fresh weight for Sandy, Clay loam and Sandy loam soil

This study found atrazine application not significantly (P≤ 0.05) affecting potato fresh weight in the three soils.

Table 6: Effect of soil type and atrazine application rate on potato fresh weight (g)

| **Atrazine (mg/l)** | **Fresh weight (g)** |
|---|---|
| **Soil Type** | |
| Sandy soil | 365.85 a |
| Clay loam soil | 354.94 a |
| Sandy loam soil | 360.46 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 328.64 b |
| 0.1 | 349.35 ab |
| 0.2 | 360.44 ab |
| 0.3 | 403.25 a |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | Ns |

*Means with the same letter are not significantly different at P≤ 0.05

Soils had a statistically (P≤ 0.05) insignificant effect on potato fresh weight (Table 10). Potato fresh weight was similar in the three soils (Table 10). The atrazineapplication rate significantly (P≤ 0.05) affected the potato fresh weight (Table 10).Applying 0.3 mg/l atrazine resulted in the highest potato fresh weight (403.25) (Table 10). There was no significant (P≤ 0.05) difference between applying 0.1 and 0.2 mg/l atrazine (Table 10). The control is significantly (P≥0.5) different from applying atrazine at 0.3 mg/l and statistically (P≥0.5) similar to applying atrazine at 0.1 and 0.2 mg/l (Table 10).

The interaction of soil type and atrazine application rate on potato fresh weight of potatoes was statistically insignificant (P≤ 0.05) (Figure 15,16,17). This indicated that the fresh weight of potatoes from different soil types did not respond differently to different atrazine application rates (Figure 15,16,17).

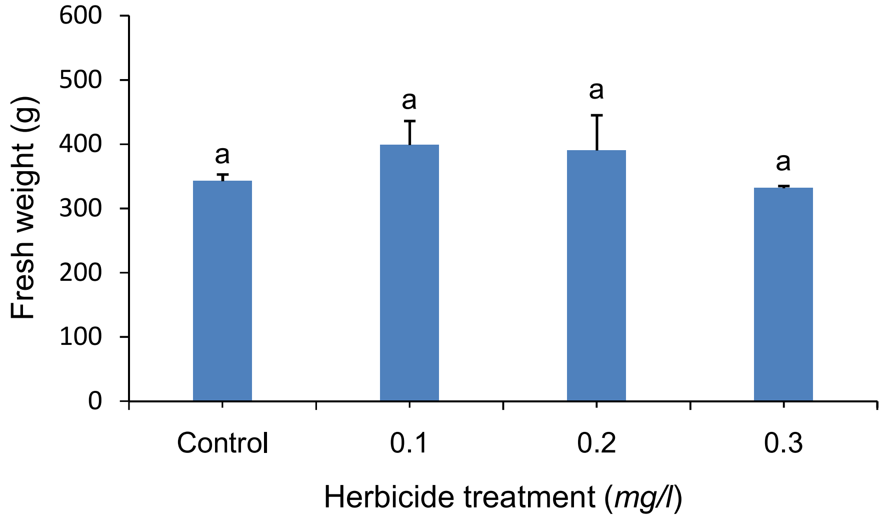


Figure 15: Effect of atrazine on potato fresh weight on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

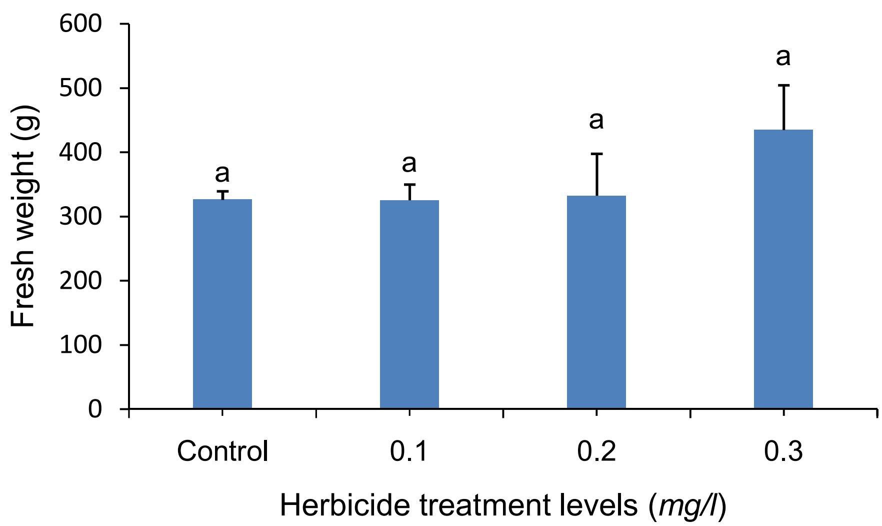


Figure 16: Effect of atrazine on potato fresh weight on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

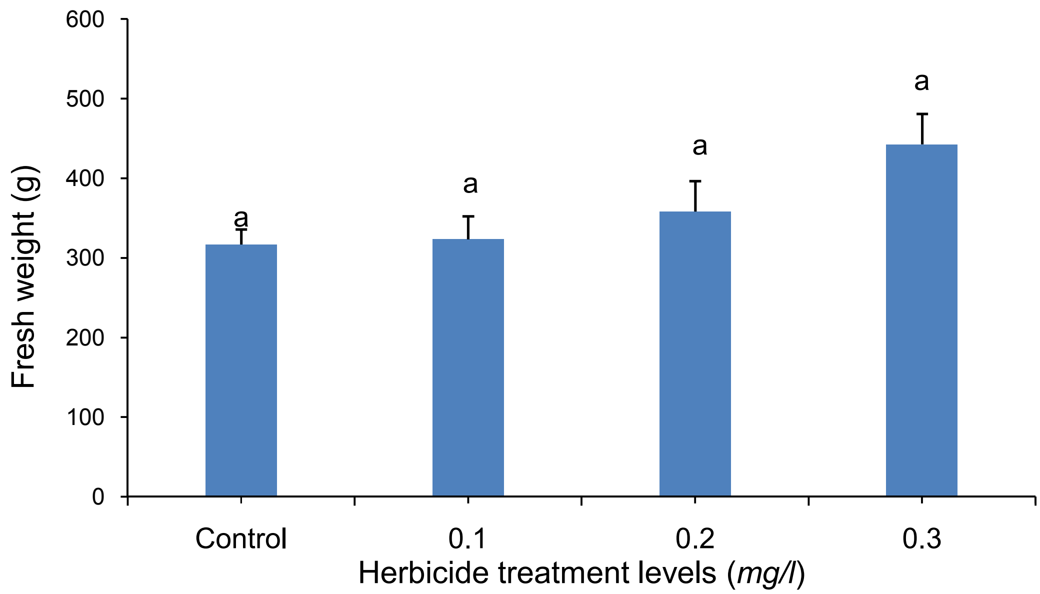


Figure 17**:** Effect of atrazine on potato fresh weight on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.6 Effect of atrazine on dry potato above ground biomass for Sandy, Clay loam and Sandy loam soils**

The current study found statistically (P≤ 0.05) insignificant effects of applying atrazine on dry potato above ground biomassin the three soils.

Table 7: Effect of soil type and atrazine application rate on the potato dry above ground biomass (g) of potato plants

| **Atrazine (mg/l)** | **Dry above-ground biomass (g)** |
|---|---|
| **Soil Type** | |
| Sandy soil | 64.99 a |
| Clay loam soil | 64.74 a |
| Sandy loam soil | 69.99 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 58.45 b |
| 0.1 | 61.33 ab |
| 0.2 | 67.47 ab |

| | |
|---|---|
| 0.3 | 79.05 a |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at $P \leq 0.05$

The three soils resulted in similar dry potato above ground biomass (Table 12). Atrazine application rate significantly ($P \geq 0.5$) effected the dry potato above ground biomass weight of potato plants (Table 12). Applying atrazine at 0.3 mg/l resulted in the highest mean of dry weight (79.05). (Table 12).

The control produced the lowest mean of dry weight (58.45) compared to all the atrazine applied treatments (Table 12). Applying atrazine at 0.1 and 0.2 mg/l, resulted in statistically ($P \geq 0.5$) similar dry potato aboveground biomass (Table 12). The control is significantly ($P \geq 0.5$) different from applying atrazine at 0.3 mg/l and statistically ($P \geq 0.5$) similar to applying atrazine at 0.1 and 0.2 mg/l (Table 12).

The present study found statistically significant ($P<0.05$) interaction between soils and atrazine application rate on dry aboveground potato biomass (Figure 18,19,20). The highest (95.15) dry potato aboveground biomass weight was recorded in the Sandy loam soil (Table 13). In this soil, the control had the lowest weight (57.96) compared to the atrazine applied treatments (Table 13). The highest dry weight of 95.15 g was observed on applying 0.3 mg/l atrazine (Table 13).

In the Clay loam soil, the control (without herbicide) had the lowest dry weight (54.67 g) compared to the atrazine applied treatments (Table 13). The highest (82.26) dry potato aboveground biomass was observed on applying 0.3 mg/l atrazine in this soil (Table 13). The Sandy soil had the lowest mean (59.73) on applying 0.3 mg/l atrazine compared to the control (62.72) (Table 13).

For the three soils, Clay loam soil had the lowest dry weight (54.67 g) on control (Table 13). Applying atrazine at 0.1 mg/l resulted in the lowest dry weight (56.24 g) and the highest (95.15 g) was observed on applying 0.3 mg/l atrazine (Table 13).

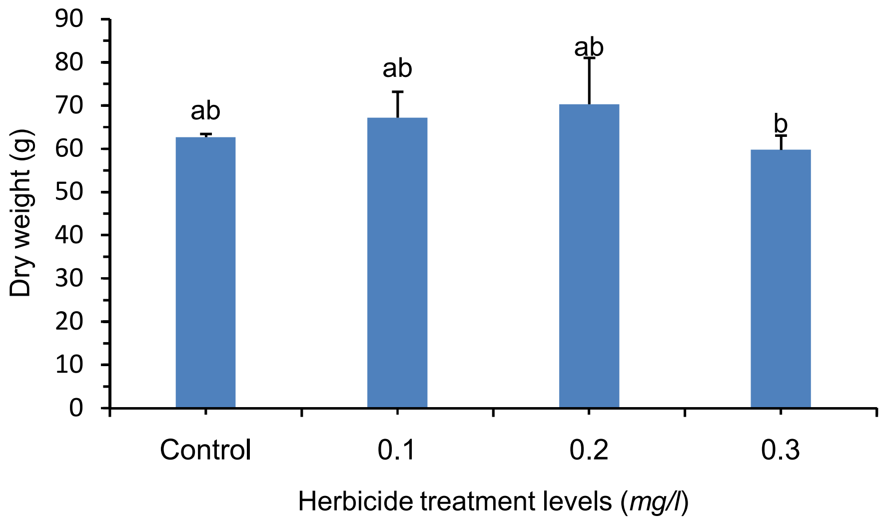


Figure 18: Effect of atrazine on dry potato above ground biomass on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

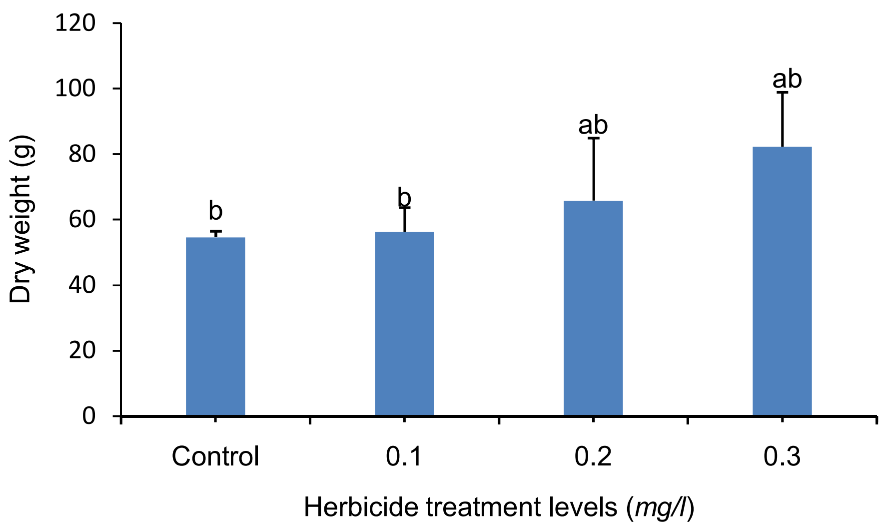


Figure 19: Effect of atrazine on dry potato above ground biomass on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

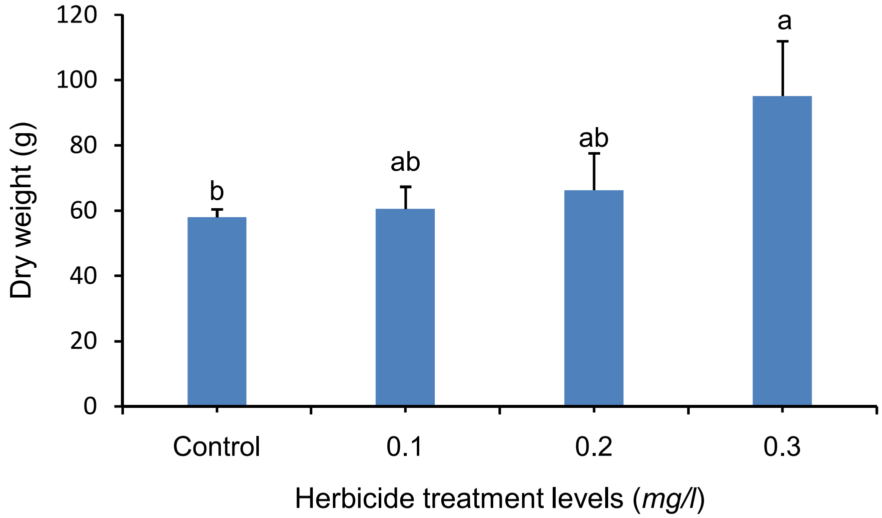


Figure 20: Effect of atrazine on dry potato above ground biomass on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.7 Effect of atrazine on fresh potato tuber weight for Sandy, Clay loam and Sandy loam soil**

The effect of atrazine on potato fresh tuber weight was significant (P≤ 0.05) for Clay loam and Sandy loam soil andinsignificant (P≤ 0.05) for Sandy soils.

Table 8: Effect of soil type and atrazine application rate on potato fresh tuber weight (g)

| Atrazine (mg/l) | Fresh tuber weight (g) |
|---|---|
| **Soil Type** | |
| Sandy soil | 148.83 a |
| Clay loam soil | 141.00 a |
| Sandy loam soil | 146.83 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 173.89 a |
| 0.1 | 135.78 b |
| 0.2 | 139.78 b |
| 0.3 | 132.78 b |
| Least Significance | * |

| | |
|---|---|
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

The three soils statistically (P≤ 0.05) resulted in similar potato dry tuber weight (Table 14).Atrazine application rate significantly (P≤ 0.05) affected the potato fresh tuber weight (Table 14). The control produced the highest potato fresh tuber weight (173.89) compared to all atrazine applied treatments (Table 14). The control was significantly (P≤ 0.05) different from all other atrazine applied treatments (Table 14).

The interaction of soil type and atrazine application rate on fresh tuber was significant (P≤ 0.05) (Figure 21,22 &23). The highest (186.67) fresh potato tuber weight was recorded in the Sandy soil (Figure 21). In this soil, the control had the highest mean of fresh tuber weight (186.67 g) compared to the atrazine applied treatments (Figure 21). In the Clay loam soil, the control had the highest potato fresh tuber weight (167.67 g) compared to the atrazine applied treatments (Figure 22). In this soil, applying atrazine at 0.2 and 0.3 mg/l resulted in similar fresh tuber weight of potatoes (Figure 22). For the Sandy loam soil, the control was significantly (P≤ 0.05) similar to all atrazine applied treatments (Figure 23).

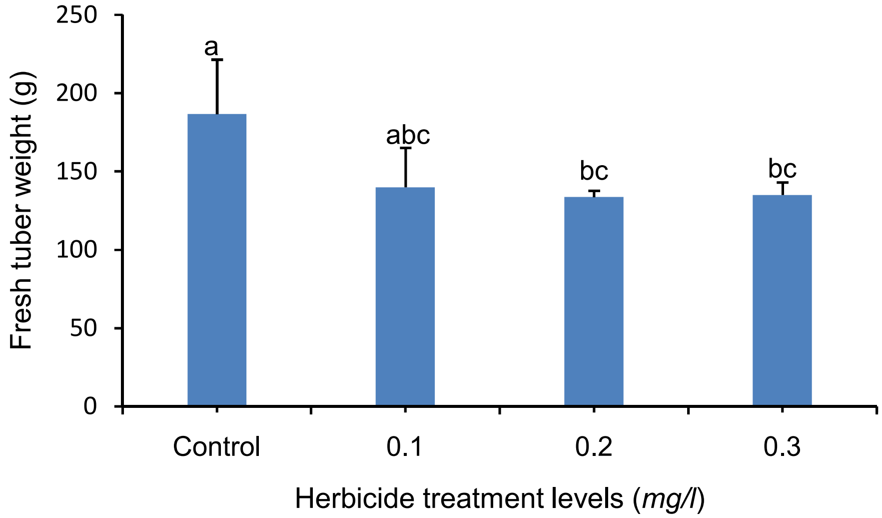


Figure 21: Effect of atrazine on fresh potato tuber weight on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

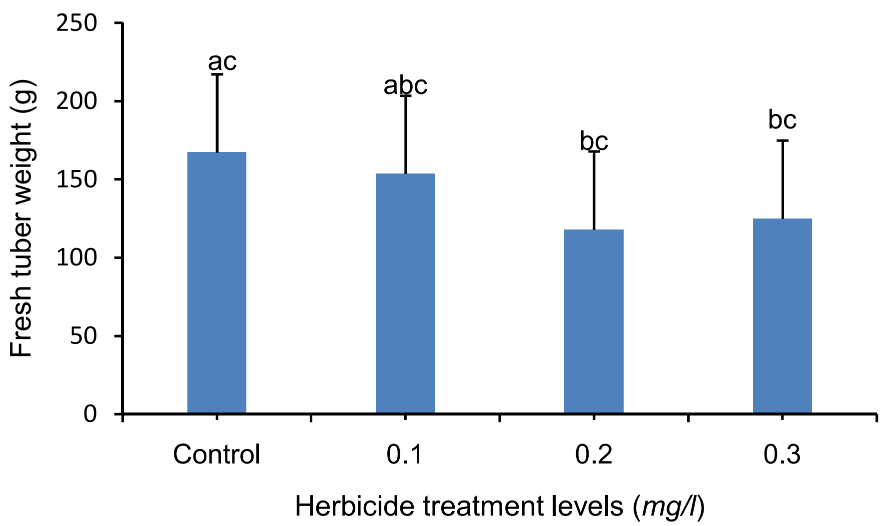


Figure 22: Effect of atrazine on fresh potato tuber weight on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

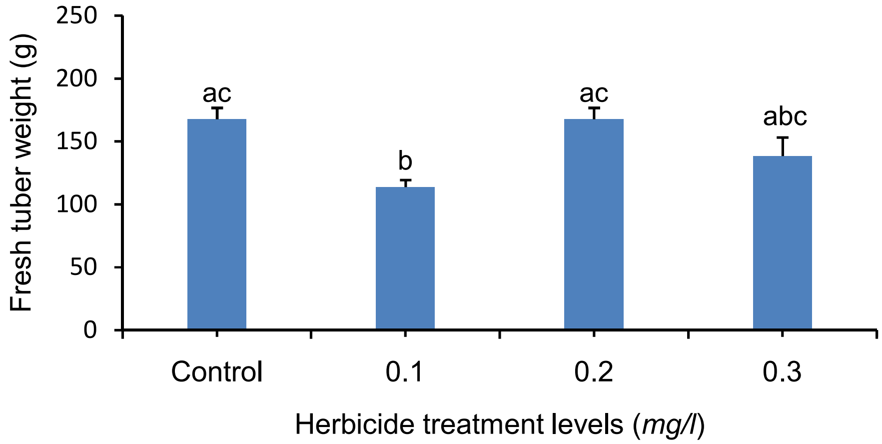


Figure 23**:** Effect of atrazine on fresh potato tuber weight on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.8 Effect of atrazine on dry potato tuber weight for Sandy, Clay loam and Sandy loam soil**

The current study found statistically (P≤ 0.05) insignificant effects of applying atrazine on dry potato tuber weight in the three soils.

Table 9: Effect of soil type and atrazine application rate on potato dry tuber weight (g)

| **Atrazine (mg/l)** | **Dry tuber weight (g)** |
|---|---|
| **Soil Type** | |
| Sandy soil | 94.92 a |
| Clay loam soil | 92.58 a |
| Sandy loam soil | 89.42 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 95.89 a |
| 0.1 | 92.22 a |
| 0.2 | 88.78 a |
| 0.3 | 92.33 a |
| Least Significance | Ns |
| **Interaction** | |
| Soil X Atrazine | Ns |

*Means with the same letter are not significantly different at P≤ 0.05

Soils had a statistically (P≤ 0.05) insignificant effect on dry potato tuber weight (Table 16). Potato dry tuber weight was similar in the three soils (Table 16). The atrazine application rate had a statistically (P≤ 0.05) insignificant affect the dry potato tuber weight (Table 16). The control was significantly (P≤ 0.05) similar to all atrazine applied treatments (Table 16).

The interaction of soil type and atrazine application rate on potato dry tuber weight was statistically insignificant (P≤ 0.05) (Figure 24, 25 &26). This indicated that the dry tuber weight of potatoes from different soil types did not respond differently to different atrazine application rates (Figure 24, 25 &26).

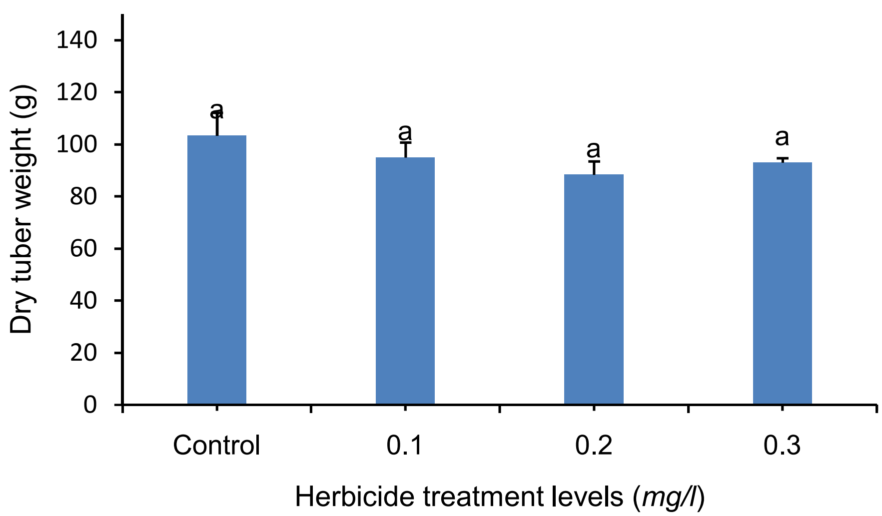


Figure 24: Effect of atrazine on potato dry tuber weight on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

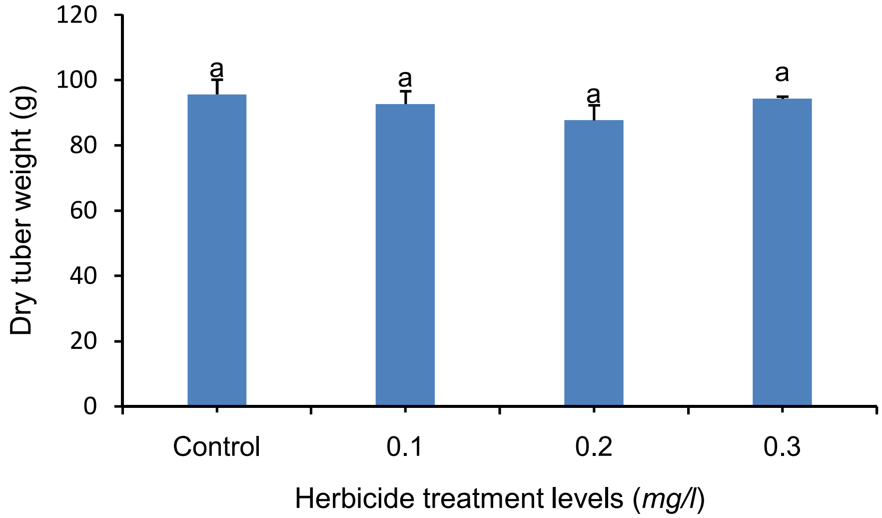


Figure 25**:** Effect of atrazine on potato dry tuber weight on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

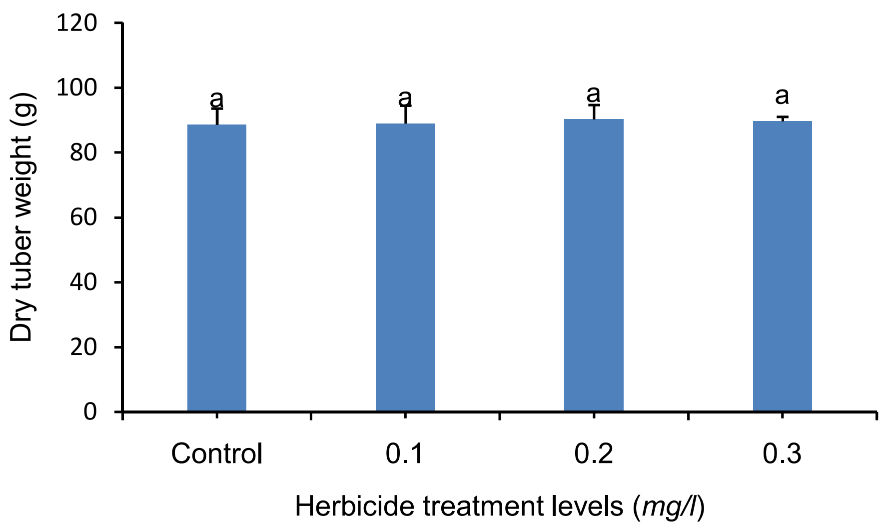


Figure 26**:** Effect of atrazine on potato dry tuber weight on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.9 Effect of atrazine on potato tuber number for Sandy, Clay loam and Sandy loam soil**

The effect of atrazine on potato dry tuber weight was significant (P≤ 0.05) for Sandy soil and insignificant (P≤ 0.05) for Clay loam and Sandy loam soil.

Table 10: Effect of soil type and atrazine application rate on the mean number of tubers per potato plant

| Atrazine (mg/l) | Tuber number (per plant) |
|---|---|
| **Soil Type** | |
| Sandy soil | 2.33 b |
| Clay loam soil | 2.75 ab |
| Sandy loam soil | 3.25 a |
| Least Significance | * |
| **Atrazine application rate** | |
| Control | 3.00 a |
| 0.1 | 2.44 a |
| 0.2 | 2.67 a |
| 0.3 | 3.00 a |
| Least Significance | Ns |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

Sandy loam soil resulted in significantly (P≤ 0.05) higher number of tubers (Table 18). The atrazine application rate had a statistically (P≤ 0.05) insignificant effect on the number of tubers produced (Table 18). The control was significantly (P≤ 0.05) similar to all atrazine applied treatments (Table 18).

The interaction of soil type and atrazine application rate on potato tuber number was significant (P≤ 0.05) (Figure 27, 28 &29).In the Sandy soil, the control was significantly (P≤ 0.05) different from all atrazine applied treatments (Figure 27). In this soil the control had higher (3.33) number of tubers compared to all atrazine applied treatments (Figure 27). In the Clay loam soil, applying 0.3 mg/l atrazine resulted in the highest (3.33) number of tubers produced by potatoes (Figure 28).

For the Sandy loam soil, the highest (3.67) was observed on applying 0.3 mg/l atrazine compared to the control (3.00) which was similar to applying 0.1 and 0.2 mg/l atrazine (Figure 29). Comparing the three soils, Sandy loam soil had the highest mean number of tubers (Figure 29).

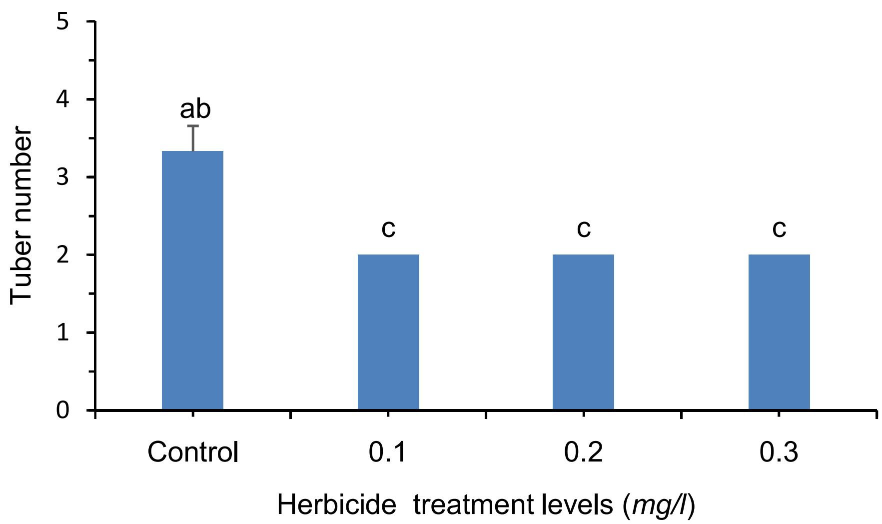


Figure 27: Effect of atrazine on potato dry tuber weight on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

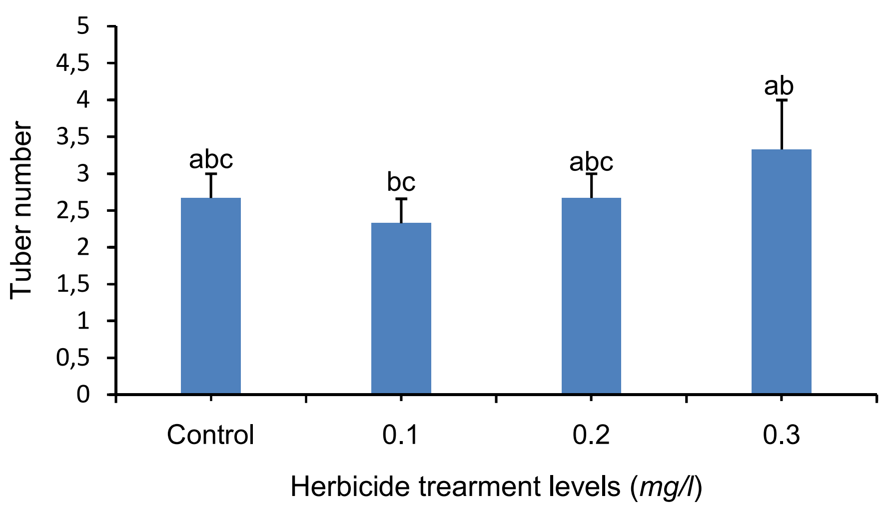


Figure 28: Effect of atrazine on potato dry tuber weight on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

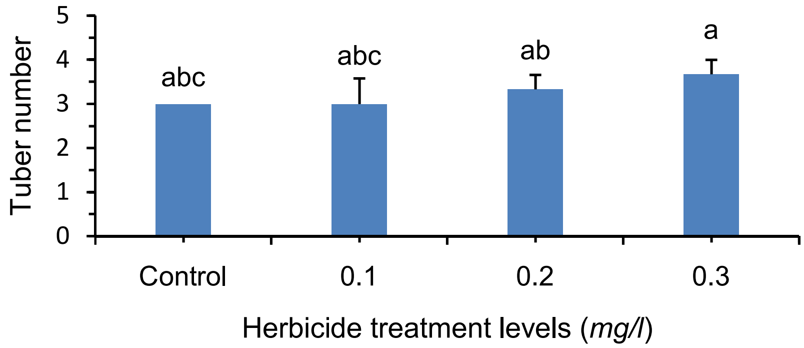


Figure 29**:** Effect of atrazine on potato dry tuber weight on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.10 Residual effect of atrazine on days to emergence of seed potatoes for Sandy, Clay loam and Sandy loam soil of 2nd planting**

The soil was used further for 2$^{nd}$ planting and only emergence was measured to determine the residual effect of atrazine on emergence of seed potatoes. The study found atrazine significantly (P≤ 0.05) different on Days to emergence for Sandy and Clay loam soils andinsignificant (P≤ 0.05) for Sandy loam soil.

Table 11: Effect of soil type and atrazine application rate on the number of days to emergence of seed potatoes

| **Atrazine (mg/l)** | **Days to Emergence** |
|---|---|
| **Soil Type** | |
| Sandy soil | 7.50 a |
| Clay loam soil | 8.17 b |
| Sandy loam soil | 8.33 b |
| Least Significance | * |
| **Atrazine application rate** | |
| Control | 7.33 a |
| 0.1 | 8.00 b |
| 0.2 | 8.22 b |
| 0.3 | 8.44 b |
| Least Significance | * |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

Sandy soil was more affected than Clay loam and Sandy loam soil (Table 20). Sandy soil resulted in significantly (P≤ 0.05) lower mean number of days to emergence compared to the three soils (Table 20).Except for the Sandy loam and Clay loam soil, the atrazine residues tended to reduce the number of days to emergence for Sandy soil (Table 20). Clay loam and Sandy loam soils resulted in similar mean number of days to emergence (Table 20).

Atrazine application rate significantly (P≤ 0.05) affected the number of days to emergence of potato plant (Table 20). The control had the lowest (7.33) number of days to emergence compared to all atrazine applied treatments (Table 20). The control is significantly (P≤ 0.05) different from all atrazine applied treatments (Table 20).

The interaction of soil type and atrazine application rate significantly (P≤ 0.05) affected the three soils (Figure 30, 31 & 32). An increase in the application rate by 0.3 mg/l resulted in the highest number of days to emergence being on the Sandy soil compared to the three soils (Figure 30).The control resulted in differences being insignificant for only Sandy and Clay loam soil compared to Sandy loam soil. However, residues of atrazine reduced the number of days to emergence for Sandy soil followed by Clay loam soil (Figure 30 & 31).

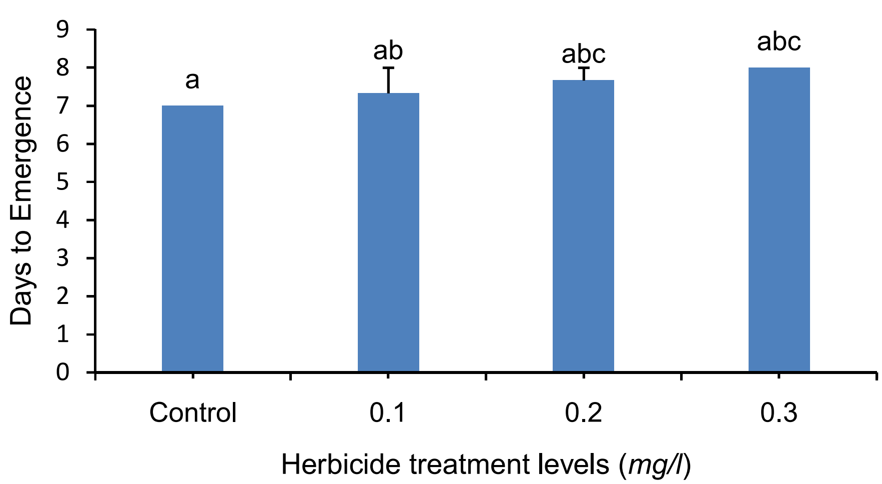


Figure 30**:** Residual effect of atrazine on days to emergence of seed potatoes on Sandy soil. *Means with the same letter are not significantly different at P≤ 0.05

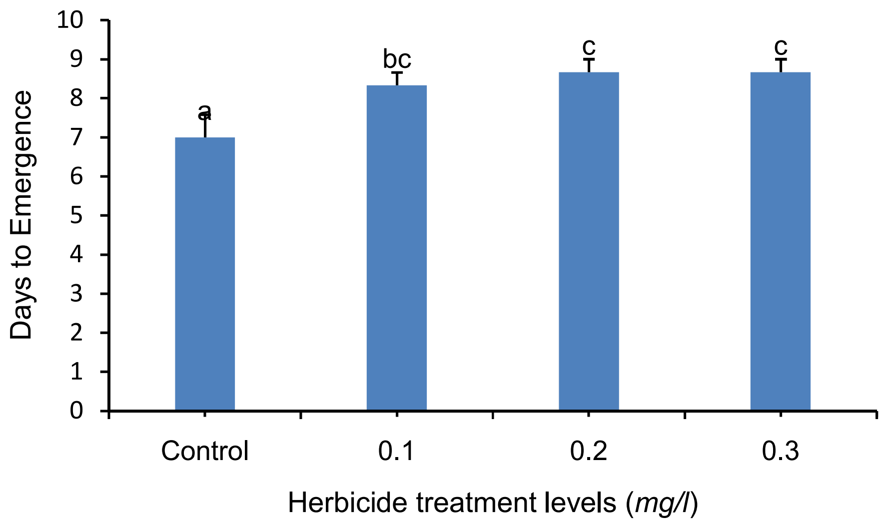


Figure 31**:** Residual effect of atrazine on days to emergence of seed potatoes on Clay loam soil. *Means with the same letter are not significantly different at P≤ 0.05

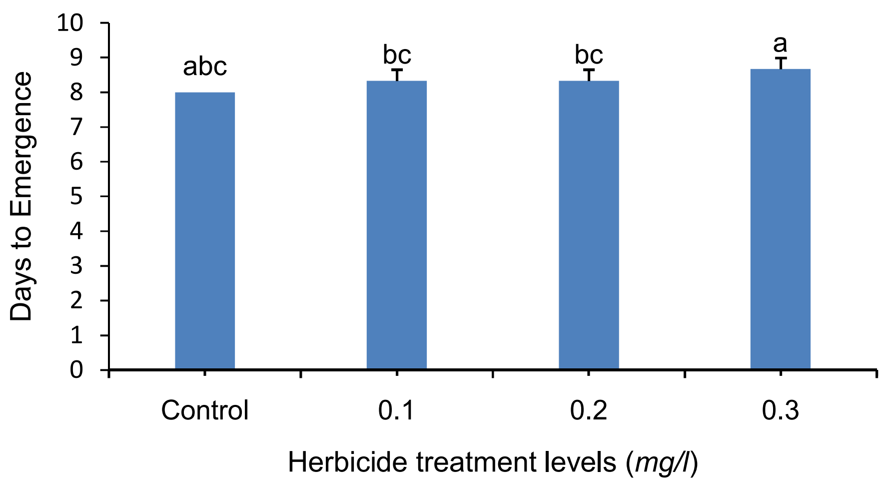


Figure 32**:** Residual effect of atrazine on days to emergence of seed potatoes on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 0.05

**4.11 Residual effect of atrazine on the number of seedlings emerged for Sandy, Clay loam and Sandy loam soil of 2nd planting**

This study found atrazine application not significantly (P≤ 0.05) affecting potato fresh weight in the three soils.

Table 12: The effect of soil type and atrazine application rate on the mean number of seedlings emerging

| Atrazine (mg/l) | Number of seedlings emerged |
|---|---|
| **Soil Type** | |
| Sandy soil | 3.17 a |
| Clay loam soil | 3.17 a |
| Sandy loam soil | 3.50 a |
| Least Significance | Ns |
| **Atrazine application rate** | |
| Control | 3.11 a |
| 0.1 | 3.56 a |
| 0.2 | 3.56 a |
| 0.3 | 2.89 a |
| Least Significance | Ns |
| **Interaction** | |
| Soil X Atrazine | * |

*Means with the same letter are not significantly different at P≤ 0.05

Soils had a statistically (P≤ 0.05) insignificant effect on the number of seedlings emerging (Table 22). Potato fresh weight was similar in the three soils (Table 22). The atrazine application rate was statistically (P≤ 0.05) insignificant to the number of seedlings emerging(Table 22). The control was significantly (P≤ 0.05) similar to all atrazine applied treatments (Table 22).

The interaction of soil type and application rate was significant (P≤ 0.05) (Figure 23, 24 & 35). An increase in the application rate of 0.3 mg/l resulted in the lowest mean number of seedlings emerging on Sandy soil except for the Sandy loam soil which resulted in the highest. Decreasing atrazine by 0.1 mg/l and 0.2 mg/lresulted in the highest number of seedlings emerging for Sandy and Clay loam soil respectively. Therefore, Sandy and Clay loam soils resulted in the lowest number of seedlings emerging than Sandy loam soil (T). The residues of atrazine affect the soils except Sandy loam soil.

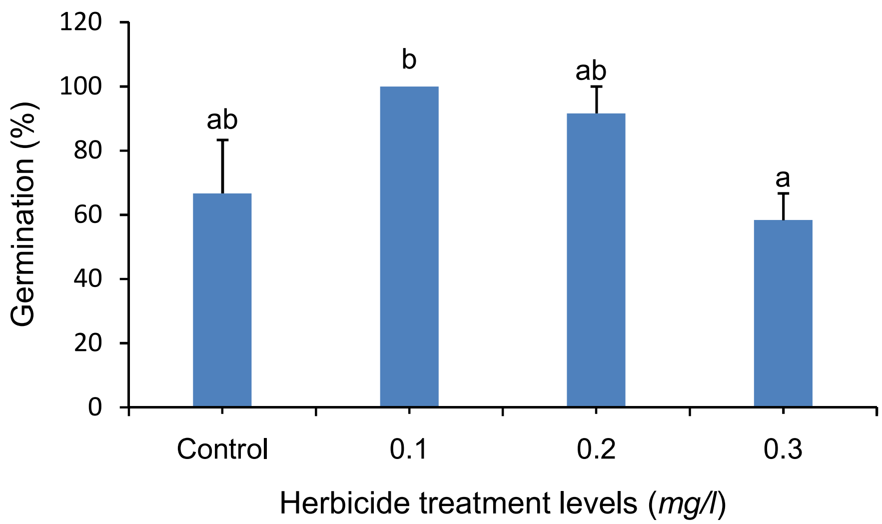


Figure 33**:** The effect of atrazine on the number of seedlings emerging on Sandy soil. *Means with the same letter are not significantly different at P≤ 05

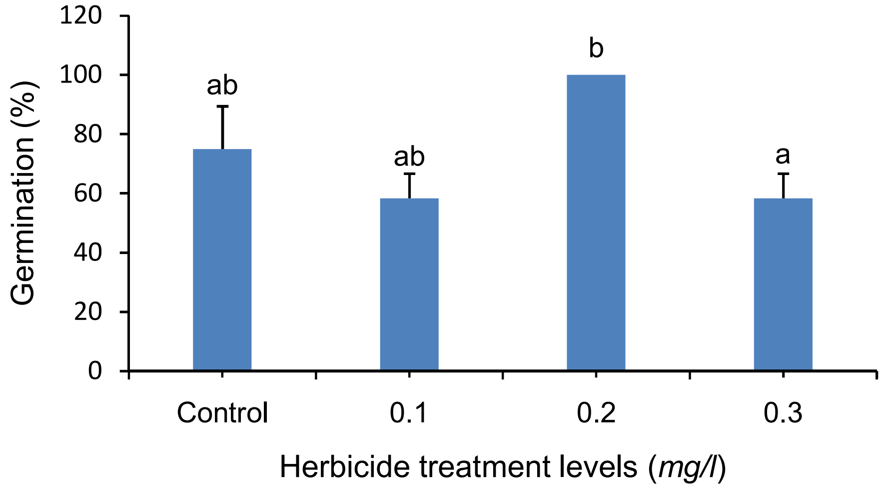


Figure 34**:** The effect of atrazine on the number of seedlings emerging on Clay loam soil. *Means with the same letter are not significantly different at P≤ 05

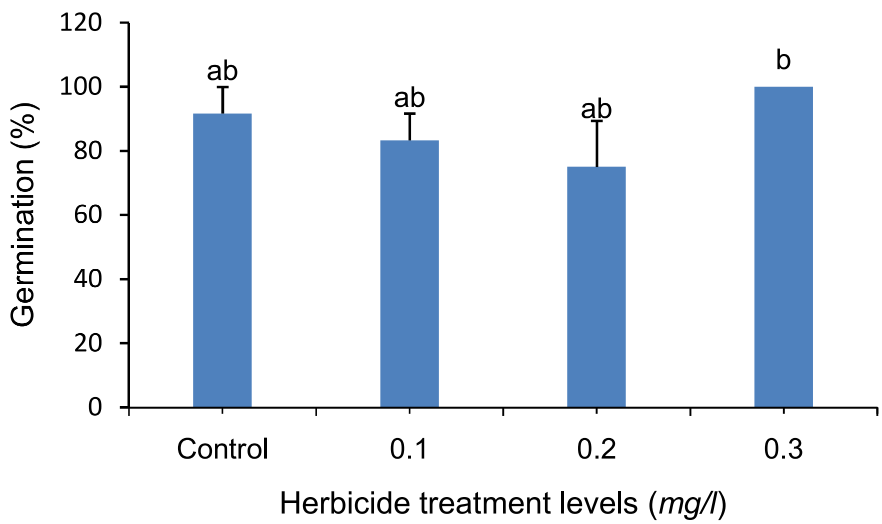


Figure 35**:** The effect of atrazine on the number of seedlings emerging on Sandy loam soil. *Means with the same letter are not significantly different at P≤ 05

# CHAPTER 5: GENERAL DISCUSSION

## 5.1 Effect of atrazine on potato growth parameters

The results of the present study indicated that a relationship exists between atrazine application in the three soils and on potato growth. The Clay loam soil had earlier germination compared to the Sandy and Sandy loam soils. The number of days to emergence was delayed to 11 when the herbicide increased to 0.2 mg/l atrazine. Sandy loam soil had higher mean number of seedlings emerged than Sandy and Clay loam soil. The number of seedlings emerged increased to 4 when atrazine increased to 0.3 mg/l. The results are in conformity with Deshi *et al.* (2019), who reported a significant effect of atrazine and paraquat on potato establishment count (emergence).

Atrazine affected plant height as it was also confirmed by Deshi *et al.* (2019), who reported that atrazine resulted in higher mean plant height than the control. In the present study, increasing atrazine application rate by 0.3 mg/l increased potato height by 52 cm. Plant height increased with an increase in application rate. This variation may be due to the characteristics of the different soils and atrazine degradation that might have occurred at different application rates (Fayinminnu *et al.,* 2017). Potato height was higher on Sandy and Sandy loam soil than on Clay loam soil. The results are consistence with the findings by Kumar *et al*. (2017), who also recorded maximum plant height in weed free followed by the treatment with atrazine at 250 g/ha applied as pre-emergence.

Sandy loam soil produced the highest number of potato leaves than Sandy and Clay loam soils. A report by Carneiro *et al.* (2019), revealed that atrazine residues between 0.20 and 0.30 mg/kg caused extensive leaf chlorosis on all species except potatoes but between 0.30 and 0.40 mg/kg caused chlorotic injury to potato foliage. Atrazine had no effect on potato fresh weight. Sandy loam soil produced the highest dry potato above ground biomass than Sandy and Clay loam soil, and this was also observed when atrazine application rate was increased to 0.3 mg/l.

Atrazine reduced fresh tuber weight for all atrazine applied treatments compared to the control. Sandy soil had the lowest potato fresh tuber weight with a reduction in atrazine application rate. The results are in conformity with Boydston *et al*. (2008), who reported that tuber weight was reduced by the highest rate of atrazine alone at 1.1 kg/ha as they have increased atrazine rate from 0.3 to 1.1 kg/ha.

No significant effect was observed on dry tuber weight of potatoes. Atrazine may not cause an effect on potatoes considering soil microflora population and soil physical and chemical properties. Bera & Ghosh (2014), that herbicidal treatments did not show any long run adverse effect on the field soil of the experimental field of potato and was safe in comparison to untreated control. Reis *et al.* (2018), recorded that potato tuber yield was not affected by atrazine in the soil and when applied alone did not reduce yield nor promote cracks in tubers.

Tuber number was higher on Sandy loam soil than on Sandy and Clay loam soil. The number of potato tubers was increased to 3.67 on Sandy loam soil when atrazine application rate was increased to 0.3 mg/l. Results are in conformity with Kebede *et al*. (2016), who reported an increase in the number of marketable tubers per plant with an increases in herbicide application rates of isoproturon, smetolachlor and atrazine. Rana *et al*. (2005), also reported that plants in atrazine treated plots produced more number of tubers per plants.

**5.2 Residual effect of atrazine on potato emergence**

Increasing atrazine application rate, increased days to emergence of seed potatoes. Atrazine residues affected the number of days for Sandy soil. Clay loam and Sandy loam soils had higher mean number of days to emergence of seed potatoes than Sandy soil. The interaction was insignificant ($P \leq 0.05$) with both soils resulting in similar control mean and having the highest number of seeds emerging on applying 0.1, 0.2 and 0.3 mg/l atrazine for Sandy, Clay loam and Sandy loam soils respectively, compared to the control.

### 5.3 Summary

It has been proved that soil type and application rate played a major role in the effect of atrazine on potatoes. Sandy loam soil was the highest on the growth of potato parameters than Sandy and Clay loam soils. This may be due to the soil physical and chemical properties that plays a major role in the activity of herbicides because soil decompose organic wastes and detoxify certain hazardous compounds in the soil (Antonious *et al.,* 2001). These compounds in the soil could be leached down and if immobile, would persist on the top soil then accumulate to toxic levels in the soil and become harmful to the plants (Bera & Ghosh, 2014). Sandy loam soil increased plant height, number of leaves, dry weight and tuber number than Sandy and Clay loam soils whereas Sandy soil reduced fresh tuber weight.

The effect of atrazine to potato growth parameters varied from one soil to another. The cation exchange capacity of the soil from Sandy loam soil was the highest (7. 356 cmol(+)$kg^{-1}$), and this property probably contributed to the effect of atrazine on potato parameters combined with a of pH 6.49. This is because atrazine degradation is faster in soils with a pH of 6.5 than with soils with a pH of 6.0 due to the bioavailability of the herbicide to soil microbes (Shaner & Henry, 2007). A research by Frank *et al*. (1983), reported that crops such as Alfalfa, barley, oats, soybeans and tomatoes died when added atrazine levels reached 0.20 mg/kg in the sandy loam and loam soils, but were little affected on the organic loam soil.

The results proved that atrazine application rate played a major role. Increasing atrazine application rate resulted in an increase in potato growth parameters and a reduction in application rate reduced growth of potato parameters. It has been found that an increase in atrazine application rate to 0.3 mg/l increased growth especially on Sandy loam soil and a reduction in potato fresh tuber weight occurred with a reduction in atrazine application rate on Sandy soil. Herbicides such as atrazine may cause visible injury to the crop, although visible crop injury may not be apparent, persistent herbicides may result in reduced growth and this can happen even in conditions of low herbicide concentrations in soil (Carneiro *et al.*, 2019). Atrazine applied on sandy loam soil showed visible injury on cereals, legumes, solanaceous crops, cucumbers and grasses grown on soils containing 0.10-0.30 mg/kg I-atrazine and only potatoes showed no injury at these levels but were also injured above 0.30 mg/kg (Frank *et al,* 1983).

The residual effect of atrazine on the number of days to emergence of potatoes was delayed on Clay loam soils and no significant effect on the number of seedlings emerged. This means that the residual effect of atrazine did not have an effect on the number of seedlings emerged although the number of days to emergence was delayed on Clay loam soil.

# CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

## 6.1 Conclusions and Recommendations

Results confirm that response of potato growth and emergence was based on the nature of soil. The growth performance and emergence of potato seeds varied from soil to soil. It can be concluded that Sandy loam soil was the highest in the growth performance of potatoes than Sandy and Clay loam soil. When atrazine is used and potatoes are planted in rotation on Sandy loam soil, there might be less effect to the crop than when planted on Sandy and Clay loam soil.

Atrazine residues was found to delay emergence of potatoes on Clay loam soil. The findings in this study provided important information for producers who grow potatoes in rotation on soils where atrazine had been used and for future research work. It is recommended that producers should use the appropriate concentrations of the herbicides to avoid any effect of herbicides because emergence was delayed as application rate was increased. Furthermore, studies regarding the interaction between atrazine and soil types especially Clay loam and Sandy soils are also recommended for future research work because an injury may occur a year following atrazine when Sandy and Clay loam soils are used in crop rotation of potato production.

**References**

Akinnuoye-Adelabu DB, Mabhaudhi T, Modi AT. 2019. Interactive effect of planting date and fertiliser application on maize growth and yield under dryland conditions. *South African Journal of Plant and Soil*, 36(3):189-198

Aladesanwa RD. 2005. Screenhouse evaluation of atrazine for soil residual activityon growth, development and nutritional quality of okra (Abelmoschus esculentus Moench) in Southwestern Nigeria. *Journal of Crop Protection*, 24:927 -931

Aladesanwa RD, Akinbobola TN. 2008. Effects of lime on the herbicidal efficacy of atrazine and yield response of maize (Zea mays L.) under field conditions in southwestern Nigeria. *Journal of Crop Protection*, 27:926-931

Allemann J, Ceronio GM. 2009. Effect of microencapsulated alachlor on South African sunflower (Helianthus annuus L.) cultivars. *South African Journal of Plant and Soil*, 26(2):110-118

Allemann J, Molomo JM. 2016. Sensitivity of selected dry bean (Phaseolus vulgaris L.) cultivars to mesotrione in a simulated carry-over trial. *South African Journal of Plant and Soil*, 33(3): 229-235

Andersen RN. 1970. Influence of soybean seed size on response to atrazine. *Journal of Weed Science*, 18:162-164

Antonious GF, Lee CM, Snyder JC. 2001. Sustainable soil management practices and quality of potato grown on erodible lands. *Journal of Environmental Sciences and Health, Part B,* 36(4):435-444

Bera S, Ghosh RK. 2014. Microflora Population and Physico-Chemical Properties of Soil of Potato as Influenced by Oxyfluorfen 23.5%EC. *Universal Journal of Agricultural Research*, 2(4):135-140

Bilanovic DD, Kroeger TJ, Spigarelli SA. 2007. Behaviour of humic-bentonite aggregates in diluted suspensions. *Journal of Water SA*, 33(1):111-116

Bhullar MS, Kaur S, Kaur T, Jhala AJ. 2015. Integrated Weed Management in Potato Using Straw Mulch and Atrazine. *Journal of Horticultural Technology*, 25(3): 335-339

Bontempoa AF, Carneiroa GDP, Guimar~aesb FAR, Dos Reisa MR, Silvac DV, Rochad BH, Souzaa MF, Sediyama T. 2016. Residual tembotrione and atrazine in carrot. *Journal of Environmental Science and Health, Part B*, 51(7): 465-468

Boydston RA. 2001. Volunteer potato (Solanum tuberosum) control with herbicides and cultivation in field corn (Zea mays). *Weed Technology,*15:461-466

Boydston RA, Collins HP, Alva AK. 2008. Control of Volunteer Potato (Solanum tuberosum) in Sweet Corn with Mesotrione Is Unaffected by Atrazine and Tillage. *Journal of Weed Technology*, 22:654-659

Brighenti AM, Moraes VJ, Oliveira Junior RS, Gazziero DLP, Barroso ALL, Gomes JA. 2002. Persistence and phytotoxicity of soybean herbicide on successive sunflower crop. *Journal of Planta Daninha*, 20(2):291-297

Burhan NS, Shaukat S. 2000. Effects of Atrazine and Phenolic Compounds on Germination and Seedling Growth of Some Crop Plants. *Journal of Biological Sciences*, 3(2): 269-274

Campbell PL, Beckett RP, Leslie GW. 2019. Weed management in sugarcane using a combination of imazapyr followed by velvet bean as a break crop. *South African Journal of Plant and Soil*, 36(2): 83-90

Carneiro GDOP, Bontempo AF, Guimaraes FAR, Reis MR, Silva DV, Souza MF, Lins HA. 2019. Carryover of tembotrione and atrazine in sugar beet. *Journal of Ciencia Investigacion Agraria*, 46(3):319-324

Chakandinakira AT, Mwedzi T, Tarakini T, Bere T. 2019. Ecological responses of periphyton dry mass and epilithic diatom community structure for different atrazine and temperature scenarios. *Journal of Water SA*, (45)4:580-591

Chikutuma M, Lovejoy T, Wisdom K. 2015. The effect of Herbicide on Residual Effect of Atrazine under Conservation Agriculture. Greener journal of Agricultural Sciences 5 (2), 062-075

Cornelius CD, Bradley KW. 2017. Carryover of common corn and soybean herbicides to various cover crop species. *Journal of Weed Technology*, 31:21-31

DeBoer GJ, Thornburgh S, Gilbert J, Gast RE. 2011. The impact of uptake, translocation and metabolism on the differential selectivity between black-grass and wheat for the herbicide pyroxsulam. *Journal of Pest Management Science*, (67):27-286

de Paulaa RT, de Abreub ABG, de Queiroza MELR, Nevesa AA, da Silvac AA. 2016. Leaching and persistence of ametryn and atrazine in red-yellow latosol. *Journal of Environmental Science and Health, Part B*, 51 (2):90-95

Deshi KE, Nanbol KK, Dawang SN, Gushit JS. 2019. Response of two potato (Solanum tuberosum L.) plant varieties to different types of herbicides under field conditions. *Direct Research Journal of Agriculture and Food Science*, 7(8):208-214

Diana SG, Resetarits WJ, Schaeffer DJ, Beckmen KB, Beasley VR. 2000. Effects of atrazine on amphibian growth and survival in artificial aquatic communities. *Journal of Environmental Toxicology and Chemistry*, 19 (12): 2961-2967

Dou R, Sun J, Deng F, Wang P, Zhou H, Wei Z, Chen M, He Z, Lai M, Ye T, Zhu L. 2020. Contamination of pyrethroids and atrazine in greenhouse and open-field agricultural soils in China. *Journal of Science of the Total Environment*, 701:1-10

Douglass JF, Radosevich M, Tuovinen OH. 2017. Microbial attenuation of atrazine in agricultural soils: Biometer assays, bacterial taxonomic diversity, and catabolic genes. *Journal of Chemosphere*, 176:352-360

Du Preez LH, Jansen van Rensburg PJ, Jooste MA, Carr JA, Giesy JP, Gross TS, Kendall RJ, Smith EE, Van Der Kraak G, Solomon KR. 2005. Seasonal exposures to traizine and other pesticides in surface waters in the Western Highveld corn-production region in South Africa. *Environmental Pollution,* 135:131-141

Erinle KO, Jiang Z, Mengyuan Li, Guangxia Su, Bingbing Ma, Yuheng Ma, and Ying Z. 2016. Oxidative stress response induced in an atrazine phytoremediating plant: Physiological responses of Pennisetum glaucum to high atrazine concentrations. *International Journal of Phytoremediation*, 18 (12) 1187-1194

Fanadzo M, Chiduza C, Mnkeni PNS. 2010. Reduced dosages of atrazine and narrow rows can provide adequate weed control in smallholder irrigated maize (Zea mays L.) production in South Africa. *African Journal of Biotechnology*, 9(45):7660-7666

Fayinminnu OO, Odewale MO, Adebayo A, Thomas KA, Omobusuyi DO. 2017. Atrazine residues in irish potatoe (Solanum tuberosum L.) varieties from three selected areas in plateau state, Nigeria. *Journal of Tropical Agricultural Research and Extension*, 20(3 & 4):66-75

Ferreira MI, van der Merwe CF, Reinhardt CF. 1999. Ultrastructural changes caused by post-emergence herbicides in leaves of Bengal wandering jew (Commelina henghaiensis L.). *South African Journal of Plant and Soil*, 16(1):18-23

Frank R, Sirons GJ, Anderson GW. 1983. Atrazine: the impact of persistent residues in soil on susceptible crop species. *Canadian Journal of Soil Science*, 63:315-325

Gao J, Song P, Wang G, Wang J, Zhu L, Wang J. 2018. Responses of atrazine degradation and native bacterial community in soil to Arthrobacter sp. strain HB 5. *Journal of Ecotoxicology and Environmental Safety*, 159:317-323

Gongora-Echeverria VR, Martin-Laurent F, Quintal-Franco C, Lorenzo-Flores A, Giacoman-Vallejos G, Ponce-Caballero C. 2019. Dissipation and Adsorption of 2,4-D, Atrazine, Diazinon, and Glyphosate in an Agricultural Soil from Yucatan State, Mexico. *Journal of Water Air Soil Pollution*, 230 (131):1-15

Hinz C. 2001. Description of sorption data with isotherm equations. Journal of *Geoderma*, 99:225-243

Inoue MH, Oliveira Jr. RS, Regitano JB, Tormena CA, Constantin J, Tornisielo VL. 2004. Sorption Kinetics of Atrazine and Diuron in Soils from Southern Brazil. *Journal of Environmental Science and Health, Part B*, 39(4): 589-601

Ivanov SV, Alexieva VS, Karanov EN. 2004. Cumulative Effect of Low and High Atrazine Concentrations on Arabidopsis thaliana Plants. *Russian Journal of Plant Physiology,* 52 (2):213-219

James A, Singh DK. 2018. Assessment of atrazine decontamination by epiphytic root bacteria isolated from emergent hydrophytes. *Journal of Annals of Microbiology*, 68:953-962

Janaki P. Meena S, Chinnusamy C, Arthanari PM, Nalini K. 2012. Field Persistence of Repeated Use of Atrazine in Sandy Clay Loam Soil under Maize. *Madras Agriculture Journal*, 99 (7-9): 533-537

Jiang Z, Ma B, Erinle KO, Cao B, Liu X, Ye S, Zhang Y. 2016. Enzymatic antioxidant defense in resistant plant: Pennisetum Americanum (L.) K. Schum during long term atrazine exposure. *Journal of Pesticides Biochemistry Physiology*, 133:59-66

Kebede G, Sharma JJ, Dechassa N. 2016. Evaluation of Chemical and Cultural Methods of Weed Management in Potato (Solanum tuberosum L.) in Gishe District,North Shewa, Ethiopia. *Journal of Natural Sciences Research*, 6(5):28-47

Khorommbi NGR, Reinhard CF. 2002. Factors influencing the tolerance of maize to atrazine and terbuthylazine applied post-emergence. *South African Journal of Plant and Soil*, 9(1):8-11

Kolekara PD, Patilc SM, Suryavanshid MV, Suryawanshi SS, Khandaree RV, Govindwarc SP, Jadhava JP. 2019. Microcosm study of atrazine bioremediation by indigenous microorganisms and cytotoxicity of biodegraded metabolites. *Journal of Hazardous Materials*, 374:66-73

Kotze E, du Preez CC. 2008. Influence of long-term wheat residue management on acidity and some macronutrients in an Avalon soil. *South African Journal of Plant and Soil*, 25(1):14-21

Kumar R, Bhatia AK, Singh D. 2017. Efficiency of Different Herbicides Alone and their Combination with Optimum time of Application to Control Weeds in Potato (Solanum tuberosum L.) in Haryana. *Journal of Biosciences Biotechnology Research Asia*, 14(1):453-460

Lebaron HM, Mcfarland JE, Burnside OC. 2008. The Triazine Herbicides: A Milestone in the Development of Weed Control Technolog. New York

Le Court De Billot MR, NEL PC. 1985. Tolerance of South African maize cultivars to atrazine. *South African Journal of Plant and Soil*, 2:101-106

Lesan HM, Bhandari A. 2014 Contact-time-dependent atrazine residue formation insurface soils. *Journal of Water Research*, (38):4435-4445

Lim Tung OJ. 2018. Drought-tolerant GM maize as a climate-smart measure in South Africa: Promises, Perils and Precaution. *SA Journal of Environmental Law and Policy*, 24:119-154

Lin SZ, Zhen Z, Chen C, Li Y, Luo C, Zhong L, Hu H, Li J, Zhang Y, Liang Y, Yang J, Zhang D. 2018. Rhizospheric effects on atrazine speciation and degradation in laterite soils of Pennisetum alopecuroides (L.). *Journal of Environmental Science and Pollution Research*, 25:12407-12418

Lin Z, Zhen Z, Liang Y, Li J, Yang J, Zhong L, Zhao L, Li Y, Luo C, Ren L, Zhang D. 2019. Changes in atrazine speciation and the degradation pathway in red soil during the vermiremediation process. *Journal of Hazardous Materials*, 364:710-719

Machete M, Shadung JM. 2019. Detection of selected agricultural pesticides in river and tap water in Letsitele, Lomati and Vals–Renoster catchments, South Africa. *Journal of Water SA*, 45(4):716-720

Mahia J, González-Prieto SJ, Martin A, Baath E, Díaz-Raviña. 2011. Biochemical properties and microbial community structure of five different soils after atrazine addition. *Journal of Biological Fertilizer Soils* 47:577-589

Malan C, Visser JH, van de Venter HA. 1987. Atrazine metabolism in field-grown maize and the effect of atrazine phototoxicity on yield. *Journal of South African Journal of Plant and Soi*l, 4(1):7-11

Mapanda S, Chitja JM, Duffy K. 2016. Indigenous strategies and empirical models for adaptability of the maize-bean intercropping system to climate change. *Indilinga African Journal of Indigenous Knowledge Systems*, 15(3):328-347

Martinsen V, Munera-Echeverri JL, Obia A, Cornelissen G, Mulder J. 2019. Significant build-up of soil organic carbon under climate-smart conservation farming in Sub Saharan Acrisols. *Journal of Science of the Total Environment*, 660:97-104

Mecozzi R, Palma L, Merli C. 2006. Experimental in situ chemical peroxidation of atrazine in contaminated soil. *Journal of Chemosphere*, 62:1481-1489

Moller J, Jovanovic N, Garcia CL, Bugan RDH, Mazvimavi D. 2018. Validation and downscaling of Advanced Scatterometer (ASCAT) soil moisture using ground measurements in the Western Cape, South Africa. *South African Journal of Plant and Soil*, 35(1):9-22

Mosotho JG. 2014. Monitoring of Herbicides in Aquatic Environments using the Bubble in-Drop Single Drop Micro-Extraction (BID-SDME) Method. *South African Journal of Chemistry*, 67:56-60

Mudhoo A, Garg VK. 2011. Sorption, Transport and Transformation of Atrazine in Soils, Minerals and Composts: A Review. *Journal of Pedosphere*, 21(1):11-25

Muoni T, Rusinamhodzi L, Mabasa S, Rugare JT, Thierfelder C. 2014. Does the Use of Atrazine in Maize Grown Under Conservation Agriculture Adversely Affect Soybean Productivity in Maize-Soybean Rotation in Zimbabwe? *Journal of Agricultural Science*, 6(7):294-302

Nel PC, Reinhardt CF. 1984. Factors affecting the activity of atrazine in plants and soil. *South African Journal of Plant and Soil*, 1(2):67-72

Ng Cheong LR, Ng Kee Kwong KF, Du Preez CC. 2009. Soil compaction under sugar cane (Saccharum hybrid sp.) cropping and mechanization in Mauritius. *South African Journal of Plant and Soil*, 26(4):199-205

Nousiainen AO, Bjorklof K, Sagarkar S, Nielsen JL, Kapley A, Jorgensen KS. 2015. Bioremediation strategies for removal of residual atrazine in the boreal groundwater zone. *Journal of Applied Microbiology Biotechnology*, 99:10249-10259

Novais J, Mendes KF, Inoue MH, Maciel CDG, Helvig EO, Stanieski CM. 2019. Use of sunflower and soybean as bioindicators to detect atrazine residues in soils. *Journal of Planta Daninha*, (37):1-8

Ntombela SC, Mahlambi PN. 2019. Method development and application for triazine herbicides analysis in water, soil and sediment samples from KwaZulu-Natal. *Journal of Environmental Science and Health*, Part B, 54(7):569-579

Oladele S, Ayodele O. 2017. Glyphosate, 1,1'- dimethyl-4,4' bipyridinium dichlorideand Atrazine induces changes in Soil organic carbon, bacterial and fungal communities in a tropical alfisol. *Eurasian Journal of Soil Sciences*, 6(3):238-248

Paraiba LC, Cerdeira AL, da Silva EF, Martins JS, da Costa Coutinho HL. 2003. Evaluation of soil temperature effect on herbicide leaching potential into groundwater in the Brazilian Cerrado. *Journal of Chemosphere*, 53:1087-1095

Paraiba LC, Pulino P. 2003. Pesticide dispersion–advection equation with soil temperature effect. *Jounal of Environmetrics*, 14:323-337

Paraiba LC, Spadotto CA. 2002. Soil temperature effect in calculating attenuation and retardation factors. *Journal of Chemosphere*, 48:905-912

Paul BK, Vanlauwe B, Ayuke F, Gassner A, Hoogmoed M, Hurisso TT, Koala S, Lelei D, Ndabamenye T, Six J, Pulleman MM. 2013. Medium-term impact of tillage and residue management on soil aggregate stability, soil carbon and crop productivity. *Journal of Agriculture, Ecosystems and Environment*, 164:14-22

Ramakrishnan B, Venkateswarlu K, Sethunathan N, Megharaj M. 2019. Local applications but global implications: Can pesticides drive microorganisms to develop antimicrobial resistance? *Journal of Science of the Total Environment*, 654:177-189

Rana MC, Rana SS, Singh M. 2005. Influence of weed control and fertility levels on the productivity of seed potato under Lahaul valley conditions of Himachal Pradesh. *Indian Journal of Weed Science*, 37(3 & 4):228-230

Refatti JP, de Avila LA, Camargo ER, Ziska LH, Oliveira C, Salas-Perez R, Rouse CE, Roma-Burgos N. 2019. High [CO2] and Temperature Increase Resistance to

Cyhalofop Butyl in Multiple-Resistant Echinochloa colona. *Journal of Frontiers in Plant Science*, 529(10):1-11

Reinhardt CF. 1995. Residual effect of atrazine on field-grown dry beans and sunflower. *South African Journal of Plant and Soil,* 12(2):82-85

Reinhardt CF, Ehlers JG, Nel PC. 1990. Persistence of atrazine as affected by selected soil properties. *South African Journal of Plant and Soil*, 7(3):182-187

Reinhardt CF, Hugo KJ. 1997. Simple regression models for the qualitative prediction of atrazine and terbuthylazine leaching. *South African Journal of Plant Soil*, 14(2):58-62

Reinhardt CF, Nel PC. 1993. The influence of soil type, soil water content and temperature on atrazine persistence. *South African Journal of Plant and Soil*, 10(1):45-49

Reinhardt CF, Nel PC. 1993. Variable tolerance of some crop species to atrazine in various soils. *South African Journal of Plant and Soil*, 10 (4):183-187

Reis MR, Aquino LA, Melo CAD, Silva DV, Dias RC. 2018. Carryover of tembotrione and atrazine affects yield and quality of potato tubers. *Journal of Acta Scientiarum Agronomy*, 40:1-6

Rimayi C, Odusanya D, Weiss JM, de Boer J, Chimuka L. 2018. Seasonal variation of chloro-s-triazines in the Hartbeespoort Dam catchment, South Africa. *Journal of Science of the Total Environment*, 613-614:472-482

Robinson DE. 2008. Atrazine accentuates carryover injury from mesotrione in vegetable crops. *Journal of Weed Technology*, 22:641-5

Robinson DE, Soltani N, Sikkema PH. 2006. Response of four market classes of dry bean (Phaseolus vulgaris) to foramsulfuron, isoxaflutole, and isoxaflutole plus atrazine applied in previous years. *Journal of Weed Technology*, 20:558-563

Saayman-du Toit AEJ. 2002. Phytotoxicity of seven graminicides on Maize. *South African Journal of Plant and Soil*, 19(2):111-113

Saayman-du Toit AEJ. 2006. Phytotoxicity resulting from pre-emergence graminicides in sorghum. *South African Journal of Plant and Soil*, 23(1):54-57

Salazar-Ledesmaa M, Pradob B, Zamorab O, Siebeb C. 2018. Mobility of atrazine in soils of a wastewater irrigated maize field. *Journal of Agriculture, Ecosystems and Environment*, 255:73-83

Shaner DL, Henry WB. 2007. Field History and Dissipation of Atrazine and Metolachlor in Colorado. *Journal of Environmental Quality*, 36(1):128-134

Sharma JJ, Sharma GD,Sood S. 2004. Weed management in potato under dry temperate agro-ecosystem (HP). *Journal of Potato*, 31:55-58

Singh S, Kumar V, Chauhan A, Datta S, Wani AB, Singh N, Singh J. 2018.Toxicity, degradation and analysis of the herbicide atrazine. *Journal of Environmental Chemistry Letters*, 16:211-237

Steiner CM, Newberry G, Boydston R, Yenish J, Thornton, R. 2005. Volunteer potato management in the Pacific Northwest rotational crops. Washington State University Extension Bulletin EB1993

Stipicevic S, Galzina N, Udikovic-Kolic N, Jurina T, Mendas G, Dvorscak M, Petric I, Baric K, Drevenkar V. 2015. Distribution of terbuthylazine and atrazine residues in crop-cultivated soil: The effect of herbicide application rate on herbicide persistence. *Journal of Geoderma,* 259-260:300-309

Swanepoel CM, Swanepoel LH, Smith HJ. 2018. A review of conservation agriculture research in South Africa. *South African Journal of Plant and Soil*, 35(4):297-306

Tamfuh PA, Woumfo ED, Temgoua E, Boukong A, Bitom D. 2018. Moisture content, moisture-related properties and agricultural management strategies of the Benue floodplain vertisols in North Cameroon. *African Journal of Agricultural Research*, 13(33):1730-1746

Tao Y, Hu S, Han S, Shi H, Yang Y, Li H, Jiao Y, Zhang Q, Akindolie MS, Ji M, Chen Z, Zhanga Y. 2019. Efficient removal of atrazine by iron-modified biochar loaded Acinetobacter lwoffii DNS32. *Journal of Science of the Total Environment*, 682:59-69

Taylor TS, Titshall LW, Hughes JC, Thibaud GR. 2012. Effect of tillage systems and nitrogen application rates on selected physical and biological properties of a clay loam soil in KwaZulu-Natal, South Africa. *South African Journal of Plant and Soil*, 29(1):47-52

van Dam JW, Negri AP, Mueller JF, Altenburger R, Uthicke S. 2012. Additive Pressures of Elevated Sea Surface Temperatures and Herbicides on Symbiont Bearing Foraminifera. PLoS one, 7(3)

van Eeden TE. 1988. The effect of simulated rain on the efficiency of herbicides in the presence of maize stubble. *South African Journal of Plant and Soil*, 5(4):212 214

van Rensburg LD. 2008. Advances in soil physics: Application in irrigation and dry land crop production. *South African Journal of Plant and Soil*, 27(1):9-18

van Rensburg E, van Dyk LP. 1986. The persistence in soil and phytotoxicity on dry beans of alachlor and metolachlor as affected by climatic factors. *South African Journal of Plant and Soil*, 3(3):95-98

van Rensburg E, van Dyk LP, de Swardt GH. 1988. Role of temperature in the activity of acetanilide herbicides on three Phaseolus taxa. *South African Journal of Plant and Soil*, 5(3):131-133

Varshney S, Hayat S, Alyemeni MN, Ahmad A. 2012. Effects of herbicide applications in wheat fields: is phytohormones application a remedy? *Journal of Plant Signaling and Behavior*, 7(5):570-575

Wang H, Cao X, Li L, Fang Z, Li X. 2018. Augmenting atrazine and hexachlorobenzene degradation under different soil redox conditions in a bioelectrochemistry system and an analysis of the relevant microorganisms. *Journal of Ecotoxicology and Environmental Safety*, 147:735-741

Werner GM, Putnam AR. 1980. Differential atrazine tolerance within cucumber (Cucumis salivus). *Journal of Weed Science*, 28:142-148.

Wolmarans K, Swart WJ. 2014. Influence of glyphosate, other herbicides and genetically modified herbicideresistant crops on soil microbiota: a review. *South African Journal of Plant and Soil*, 31(4):177-186

Woyessa YE, Bennie ATP. 2004. Factors affecting runoff and soil loss under simulated rainfall on a sandy Bainsvlei Amalia soil. *South African Journal of Plant and Soil*, 21(4):203-208

Wu Q, Yan Q, Zhou W, Zhu L. 2015. Sorption characteristics and contribution of organic matter fractions for atrazine in soil. *Journal of Soils Sediments*, 15:2210-2219

Yale RL, Sapp M, Sinclair CJ, Moir JWB. 2017. Microbial changes linked to the accelerated degradation of the herbicide atrazine in a range of temperate soils. *Journal of Environmental Science Pollution Res*, 24:7359-7374

Yi Chen Lu AB, Sheng Ning Yang C, Jing Jing Zhang A, Jia Jun Zhang A, Li Rong Tan AB, Hong Yang A. 2013. Collection of glycosyltransferases from rice (Oryza sativa) exposed to atrazine. *Journal of Gene*, (531):243-252

Yu-Hong SU, Yong-Guan ZHU, Ai-Jun Lin A, Xu-Hong Zhang. 2005. Interaction between cadmium and atrazine during uptake by rice seedlings (Oryza sativa L.). *Journal of Chemosphere* (60):802-809

Yu J, He H, Yanga WL, Yang C, Zeng G, Wu X. 2018. Magnetic bionanoparticles of Penicillium sp. yz11-22N2 doped with Fe3O4 and encapsulated within PVA-SA gel beads for atrazine removal. *Journal of Bioresource Technology*, 260:196-203

Zabermawi N, El-Bestawy E. 2017. Microbial Degradation and Residue Analysis of Atrazine in Open Field and Indoor Cultures. *Merit Research Journal of Agricultural Science and Soil Sciences,* 5(7): 128-141