Efficacy evaluation of selected soil applied herbicides on Okra (*Abelmoschus esculentus)* seedlings under thermoperiods simulating Mutale magisterial area.

by

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DECLARATION

I, **Dzivhuluwani Mashamba** hereby declare that the above work in this master's dissertation in Agriculture which is entitled **"Efficacy Evaluation of Selected Soil Applied Herbicides on *Abelmoschus esculentus* (Okra) Seedlings under Thermoperiods Simulating Mutale Magisterial Area**" submitted at the University of South Africa is the original work that was conducted by me under the mentorship of my supervisors mentioned on the cover page of my dissertation. Furthermore, I hereby declare that the work presented herein has not been conducted nor submitted or rather published at any other institutions as part of any degree requirement. All sources and literature that have been used or quoted throughout my dissertation which is part of the research work that was done by other individuals have been indicated, acknowledged, and listed as complete references as part of acknowledgement.

18 December 2023

SIGNATURE

DATE

Dzivhuluwani Mashamba

University: University of South Africa

Date: 18 December 2023

DEDICATION

I dedicate my master's dissertation to the Almighty God for making it possible throughout even when things seem impossible, for Knowledge and Wisdom, and for being vigilant. He is God who starts and finishes everything, God of Light and new beginnings. God made it possible. **Jeremiah Chapter 29 verse 11.**

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LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
cm	Centimeter
°	Degree
°C	Degree Celsius
CPWC	Critical Period for Weed Competition
CS	Clemson Spineless
CV	Coefficient of
VariationCv	Cultivar
DAS	Days After Sowing
30^{0}80.39E	30^{0}80.39 East
et al	And others
g	gram
g/plant	gram per plant
H1-H4	Herbicide 1 to Herbicide 4
i.e	that is
kg/ha	Kilogram per hectare
LAI	Leaf Area Index
LSD	Least Significant Difference
mm	Millimeter
R	South African Rand
RB	Red Burgundy
RCBD	Randomized Complete Block
DesignS 22^{0}20.17	22^{0}51.08 South
t/ha	Ton per hector
Tukey's HSD	Tukey's Honestly Significant Difference Test
UNISA	University of South Africa
WAS	Weeks After Sowing
WCE	Weed Control Efficiency

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ABSTRACT

Okra (*Abelmoschus esculentus* L.) Moench is an essential vegetable globally, but in the past decade, a reduction in yield per hectare has been noted. Amongst various reasons for its low yield, weeds are the most important. These weeds reduce crop growth by competing for resources and by allelopathic effects. In this research, we investigated the influence of pendimethalin and alachlor on the plant height, leaf length, leaf width, stem diameter, number of leaves, root length and root diameter of okra plants.

The results reveal that pendimethalin was found to exert an influence on the plant height of okra; okra treated with pendimethalin grew faster than that treated with alachlor. With pendimethalin, a gradual increase was recorded in the leaf length, leaf width, stem diameter and number of leaves. A significant influence of alachlor was observed on the plant height, leaf width and stem diameter in okra plants as the measured parameters were high. In summary, the stem diameter of okra treated with pendimethalin at rate 5 and the leaf width were positively increased to 253% at week 4. It is concluded that the use of pendimethalin and alachlor soil-applied herbicides will enhance production and farmers’ livelihood in the Mutale district involving mainly okra plants.

In this research, we also investigated the influence of metolachlor and trifluralin on the agronomic parameters of okra plants. The results show that the herbicide metolachlor had an impact on okra plant height compared to okra plants treated with trifluralin. Trifluralin recorded a gradual increase in leaf length.

TSHIVENDA ABSTRACT

Mandane (*Okra Moench*) (*Abelmoschus esculentus* L.) ndi muroho wa wa ndeme kha ḽifhasi. Fhedzi kha miṅwaha yo fhiraho, ho thoma u vhonala u fhungudzea kha khaṋo yawo nga hekithara. Zwiṅwe zwa zwiitisi zwa u vha na khaṋo i re fhasi zwo fhambanaho, ho vha tsheṋe. Tsheṋe i thivhela nyaluwo nga u ḽa zwiḽiwa na ngauri ndizwimela zwine zwa vha na mulimo. Kha ṱhoḓisiso iyi, ri khou ḓa u ṱoḓulusa ṱhuṱhuwedzo ya tshumiso ya mushonga wa *pendimethalin* na *alachlor* u itela uri tshimela tshi aluwe, vhulapfu ha maṱari, vhuphara ha maṱari, vhudenya ha tsinde, tshivhalo tsha maṱari, vhulapfu ha midzi na vhudenya ha midzi kha zwimela zwa

mandande.

Mvelelo dzo sumbedza uri mushonga wa *pendimethalin* wo vha wone u ṱuṱuwedzaho nyaluwo kha vhulapfu ha tshimela tsha mandande; arali vha tshi khou shumisa *pendimethalin* kha tshimela tsha mandande tshi hula nga u ṱavhanya u fhira arali vha tshi khou shumisa mushonga wa *alachlor*. Musi hu tshi khou shumiswa mushonga wa *pendimethalin*, ho vhonala nyaluwo kha vhulapfu ha maṱari, vhudenya ha tsinde na tshivhalo tsha maṱari. Ho vhonala na ṱhuṱhuwedzo i khulwane ya musi hu tshi khou shumiswa mushonga wa *alachlor* kha vhulapfu ha tshimela na vhuphara ha maṱari na vhudenya ha tsinde kha zwimela zwa muroho wa mandande ngauri tshikhala tsha mikano yo elwaho tsho vha tshi nṱha. Nga u pfufhifhadza, vhudenya ha tsinde ḽa mandande ḽo shelwaho *pendimethalin* tshi kha phimo ya 5 na vhuphara ha ṱari zwo aluwa u swika kha 253% nga vhege ya vhu 4. Ho khunyeledzwa uri u shumisa mushonga wa *pendimethalin* na *alachlor* kha mavu zwi ḓo engedzedza mbuelo ya khaṋo kha vhalimi vhane vha lima mandande kha tshiṱiriki tsha Mutale.

Kha ṱhoḓisiso iyi ro do vha ra ṱoḓulusa ṱhuṱhuwedzo ya mushonga wa metolachlor na trifluralin kha saintsi ya zwa zwimela kha mikano ya tshikhala vhukati ha zwimela zwa okra. Mvelelo dzo sumbedza uri mushonga wa metolachlor u na ṱhuṱhuwedzo khulwane kha vhulapfu ha tshimela tsha okra zwi tshi vhambedzwa na tshimela tsha okra tsho shumiselwaho trifluralin. Trifluralin yo sumbedza u shuma kha nyaluwo kha vhulapfu ha ṱari.

KAKARETŠO

Okra (*Abelmoschus esculentus* L.) Moench ke morogo wo bohlokwa lefaseng ka bophara, eupša mo mengwageng ye lesome ye e fetilego, go lemogilwe gore mo go hekethara ye nngwe le ye nngwe puno e fokotšegile. Gare ga mabaka a go fapafapana a puno ya fase ya okra, dikoro le lengwe la mabaka a magolo a go hlola se. Dikoro tše di fokotša kgolo ya dibjalo ka go bakišana methopo le dikhuetšo tša alelophati. Mo nyakišišong ye, re nyakišišitše khuetšo ya pendimethalin le alachlor go botelele bja sebjalo, botelele bja matlakala, bophara bja matlakala, bophara bja kutu, palo ya matlakala, botelele bja medu le bophara bja medu bja dibjalo tša okra.

Dipoelo di utolla gore pendimethalin e hweditšwe e na le khuetšo go botelele bja sebjalo sa okra; okra yeo e bego e hlokomelwa ka pendimethalin e gotše ka lebelo go feta yeo e hlokometšwego ka alachlor. Ka pendimethalin, go begilwe koketšego ye e nanyago go botelele bja matlakala, bophara bja matlakala, bophara bja kutu le palo ya matlakala. Khuetšo ye bohlokwa ya alachlor e lemogilwe go botelele bja sebjalo, bophara bja matlakala le bophara bja kutu ka dibjalong tša okra ka ge magomo a a metilwego a be a le godimo. Ka boripana, bophara bja kutu ya okra ye e hlokometšwego ka pendimethalin ya kelo ya 5 le bophara bja matlakala di okeditšwe gabotse go fihla go 253% ka beke ya 4. Go phethilwe ka gore tšhomišo ya dibolayasekoro tše di tsenywago mmung tša pendimethalin le alachlor e tla oketša tšweletšo le letseno la balemi ka seleteng sa Mutale seo se akaretšago kudu dibjalo tša okra.

Mo nyakišišong ye, re nyakišišitše gape khuetšo ya metolachlor le trifluralin go magomo a temo ya dibjalo tša okra. Dipoelo di bontšha gore sebolayasekoro sa metolachlor se bile le khuetšo go botelele bja sebjalo sa okra ge se bapetšwa le dibjalo tša okra tšeo di hlokometšwego ka trifluralin. Trifluralin e laeditše koketšego ye e nanyago ya botelele bja matlakala.

CHAPTER ONE

ORIENTATION AND OVERVIEW OF THE STUDY

1.1 Okra *(Abelmoschus esculentus* L.) Moench food plant

Okra (Abelmoschus esculentus L.) Moench is a green vegetable crop grown throughout the country during the warm seasons. During this warm season, annual weeds also grow in the fields, possibly leading to the reduction in production of the crop. *A. esculentus* is a traditional annual commercial vegetable that is believedto originate from both Africa and Asia (Asawalam and Chukwu, 2012). In 1753, Linnaeus included Okra in the genus of *Hibiscus* in the division of *Abelmoschus* in thefamily Malvaceae which by then comprised approximately 50 species in Malesia (VanBorssumWaalkes, 1966).

In 1968, Bates revised the taxonomical which fully documented studies of the genus *Abelmoschus*. *Okra (Abelmoschus esculentus* L.) Moench leaves (Figure 1A) are generally heart-shaped and highly toothed,three to five-lobed, while its flowers are creamy white to yellowish with a crimson center (Figure 1C). The fruits which appear like pods (Figure 1B) are hairy at the base,tapering like capsules of about 10 to 25 cm in length in many varieties (Hager *et al.,* 2002).

Figure 1. Okra crop in the field, A-leaves, B-pod or fruit, C-flower.

The production of Okra over a decade ago was estimated at 6 million tons per hectare which is for fresh vegetables (Iyagba *et al.,* 2012). According to Asawalam and Chukwu (2012), *Okra (Abelmoschus esculentus* L.) Moench is regarded as an indigenous crop and its productivity is growing throughout the world. Its production is basically for its fibrous fruits which are pods that contain round seeds that are white. The fruits are harvested

when immature and eaten as a vegetable while it is a good source of vitamins (A, B, and C), protein, and carbohydrates (Schippers (2000).

Besides its nutritive value, Okra is an important vegetable as it serves as an alternative when vegetables are scanty in the market (Akintoye *et al.,* 2011). According to Chauhan (1972), *Okra (Abelmoschus esculentus* L.) Moench is well known as "Mandande", "Delete", and "Gusher" in South Africa, "Lady's finger" in England, "Gumbo" in the United States of America, "Guino-gombo" in Spanish, "Guibeiro" in Portuguese and "Bhindi" in India.It is very popular in many countries because of its easier cultivation, dependable yield,and adaptability to varying moisture conditions (Kumar *et al.,* 2010).

Efficacy evaluation refers to the assessment or review of the effectiveness of a certain herbicide product, against a certain weed target, which may consist of an assessment of its agronomic sustainability and economic benefits (EPPO, 2004). Weed interference and their competition with Okra is one of the major problems that usually reduce the yield and quality of Okra (Govindra *et al.,* 1982; Adejonwo *et al.,* 1989, Hager *et al*., 2002). Adejonwo et al. (1987), advised that weeds need to be successfully controlled for up to nine weeks following planting. If weed growth is managed throughout the life cycle of the okra plant, fruit yield loss of up to 88 and 90 percent can be avoided (Singh *et al.,* 1981). In Brazil, 63% of crop loss was recorded by William and Warren (1975).

Herbicides sprayed on the soil are frequently used as a pre-plant treatment, either before the seed is planted or before the seedlings appear. The herbicide is typically absorbed by the emerging seedlings' roots or shoots (Vats, 2015). In addition to pre-emergence and pre-planting incorporated herbicides, post- emergence herbicides are also approved for the control of weeds in okra. However, there is a need to conduct a study on the effectiveness of pre-emergence herbicides on Okra. The purpose of this study is to assess the effects of four pre-emergence herbicides such as metolachlor, alachlor, pendimethalin, and trifluralin. on seedlings

of a single cultivar of okra (Clemson spineless): These herbicides were selected due to their usage on different okra cultivars, some of which were combined with other herbicides but were not applied to the Mutale magisterial area or the Clemson spineless cultivar.

1.2 Study area Simulation

Simulation in research simply refers to a way of research or technique that reproduces actual events and processes under test conditions or rather controlled environments. This may specifically describe the daytime and or night temperature variation when the temperature and period are at or close to the ideal values for inducing different activities, like growth or flowering (Adeola *et al.,* 2017). Approximately 681mm of rainfall is received in Mutale per year, with most precipitation occurring mostly during midsummer.

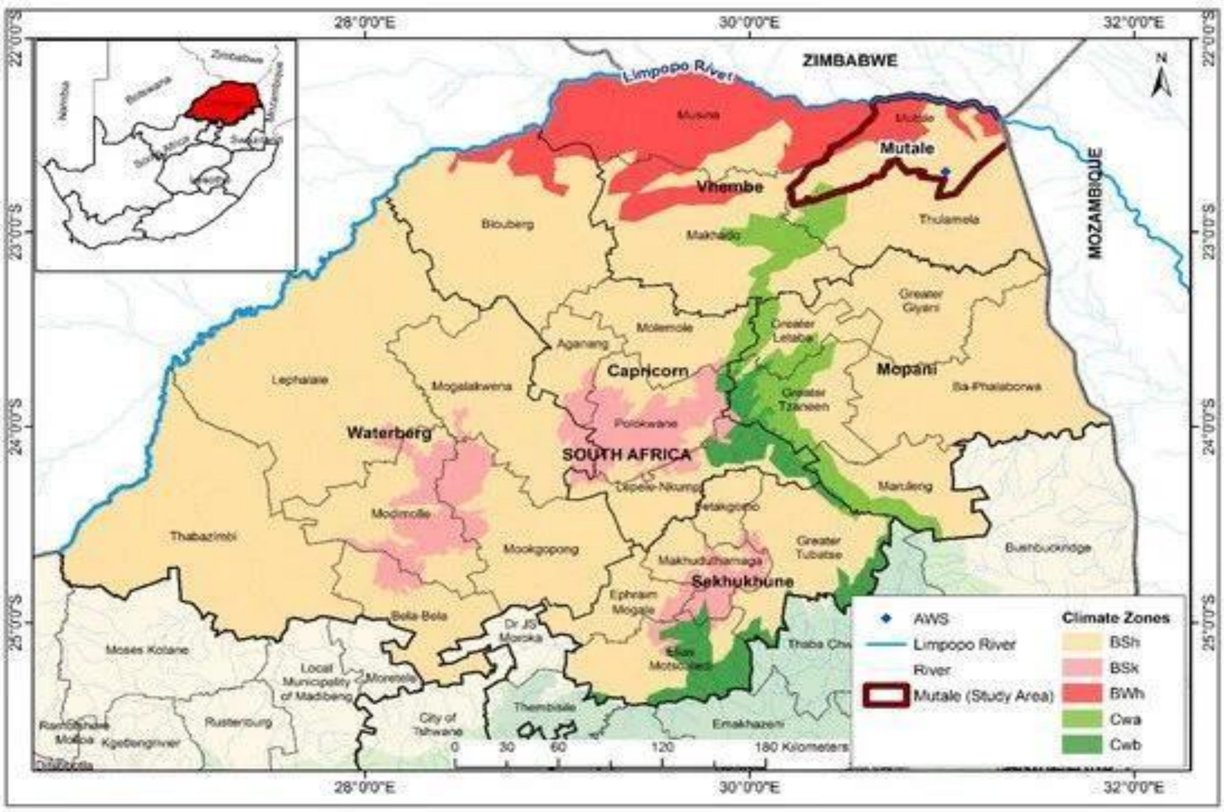

Figure 2. Map showing Limpopo Province locating Mutale municipality in South Africa.

The chart below shows the average rainfall values for Mutale per month. It receives the lowest rainfall (2mm) in July and the highest (137mm) in January (Maponya and Mpandeli, 2015). The monthly distribution of average daily maximum temperatures (Centre chart below) shows that the average midday temperatures for Mutale range from 22.1°C in June to 29.2°C in January. The region is the coldest during July when the mercury drops to 7.7°C on average during the night (Adeola *et al.,* 2017). In a fully automated greenhouse where okra will be planted, these thermoperiods of the Mutale magisterial area will be replicated.

Banks *et al.,* (2001) described simulation as the process of gradually replicating how a system or process would work in the real world. To simulate something,a model must first be created, one that captures the essential traits or actions of the chosen physical or abstract system or procedure. According to Banks *et al.,* (2001),the simulation depicts the system's operation over time, while the model represents the system itself.

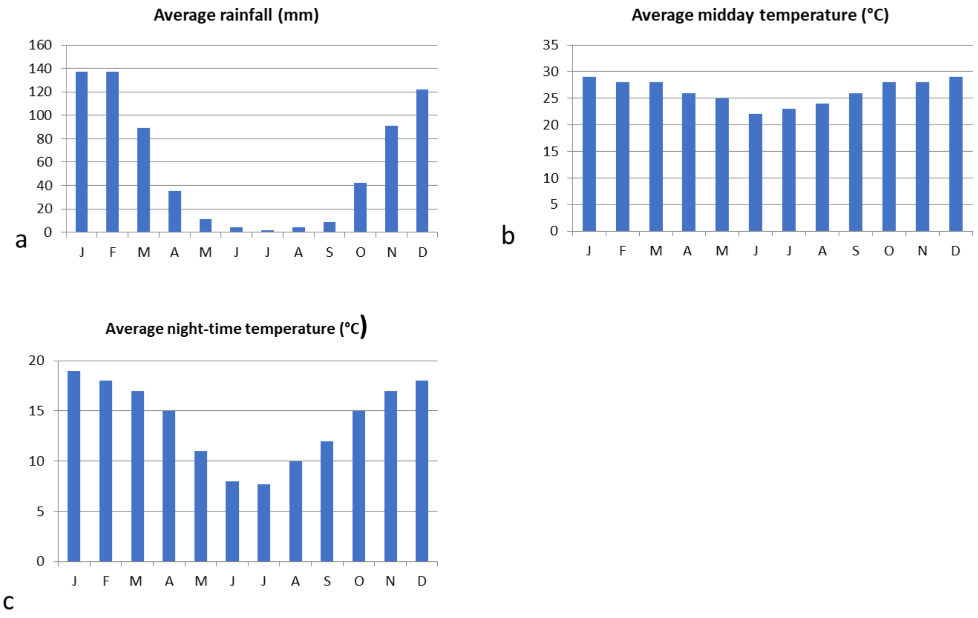

Figure 3. Thermoperiods of Mutale municipality (a) depict the average rainfall(mm), (b) the average midday temperatures (◦c), (c) depicts the average night-time temperature (◦c). (Adeola *et al.,* 2017).

Mutale magisterial area is characterized by the farmers who use mechanical weed control using hand, hoes, or removing the weeds by hand (Wilding *et al.,* 1986). In some areas, commercial farmers use post-emergence herbicides to control weeds in the field whereas the use of pre-emergence herbicides is very scanty (Sutton and Burgis, 1966).

1.2 Problem statement

Okra is one of the vegetable crops grown by most farmers in the Vhembe District especially in the Mutale Magisterial area. The production of okra is increasing among most of the emerging farmers around the Mutale Magisterial area but the yields of okra are very low because of the weeds. Nandwani, (2013), concluded that herbicides can benefit small farmers by reducing the amount of labor required for weeding, and land preparation and extending the critical period of weed competition. The most problematic weeds are the ones that emerge with the seedlings while post-emergence weeds can be controlled at a later stage of crop development (Brathwaite, 1981).

Farmers have been using mechanical control of weeds that is controlling weeds after they have emerged by either using post-emergence herbicides by using hoes or removing the weeds by hand. Mechanical control of weeds in the rows of Okra disrupts the roots and sometimes causes injuries to the leaves or stems.

Soil-applied herbicides can be used to trim down the emergence of weeds that emerge with the seeds (Brathwaite, 1981). Americanos and Vouzounis (1995) conducted a study on herbicides used for Okra growth and found that the application of pre-emergence herbicides to direct seeded okra results in substantial diminution in weeding using hand saves time and reduces labor costs. Due to the high costs of herbicides, some emerging and commercial farmers choose to use mechanical control of weeds in Okra. Most farmers in rural areas that are cultivating okra commercially consider using manpower to remove weeds in the field by either using hoes or by handpicking the weeds.

Montelaro and Maryel (1966) indicated that since okra is a seeded crop, during its early stages of development is when the crop is most vulnerable to the competition of weeds. Weeds must be controlled during the critical periods for weed competition to prevent yield losses. The critical period of weed control (CPWC) in a particular crop is the minimum period during which weeds must be well suppressed to prevent yield losses (Stefanic *et al.,* 2023). Knowing the CPWC is useful in making decisions on the need for and timing of weed control and in achieving efficient herbicide use (Knezevic, 2000). Herbicide use on okra is very low, even though it may provide a valuable alternative. Where drip irrigation is utilized, mechanical weeding is not feasible and is not feasible in the broadcast crop due to the high cost of hand labor (Wascom and Fontenot, 1967). Pre-emergence herbicide use is the subject of very little literature worldwide, and there are also very few documented cases.

1.3 Justification of the study

In addition to having several health benefits in humans, okra requires careful management when it is still in the seedling stage of growth and development. Weed management must be implemented when the crop is still in the seedling stage; otherwise, yields will be lost due to unmanaged weeds in the early stages of crop development. Even though most farmers use mechanical weed removal later after planting their crop, it is already late, and most seedlings cannot compete with weed infestation.

To prevent weeds from germination and produce healthy seedlings, it is necessary to carry out a study in which various herbicides are applied to the seedlings. Since no research has been done on the herbicides that will be used in this study, a successful conclusion to this research will contribute to the solution of growing okra seedlings free of weeds.

1.4 Aims and objectives of the study*.*

This study's main objective was to assess the impact of four herbicides applied to the soil—Metolachlor, Alachlor, Pendimethalin, and Trifluralin—on *Okra (Abelmoschus esculentus* L.) Moench cultivar seedlings (*Abelmoschus esculentus* L.) (Clemson spineless) on weedcontrol in a Mutale Magisterial Area simulated by thermoperiods.

1.6 Objectives of the study

Objective 1: To evaluate the effect of Metolachlor, Alachlor, Pendimenthalin and Trifluralin on seedling growth of Clemson Spineless *Okra (Abelmoschus esculentus* L.) Moench cultivar grown under Thermoperiods Simulating Mutale Magisterial Area.

1.5 Research Hypotheses

Hypothesis 1: The selected herbicides do not affect seedling growth of Clemson spineless *Okra (Abelmoschus esculentus* L.) Moench cultivar grown under term periods simulating Mutale Magisterial area.

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CHAPTER TWO

LITERATURE REVIEW

2.1. Taxonomy and Botany of *Okra (Abelmoschus esculentus* L.) Moench

2.1.1. Taxonomy of Okra

Okra or Lady's finger (*A. esculentus*) plant is one the crops that was previously encompassed in the genus of *Hibiscus.* It was then later selected to *Abelmoschus* which is differentiated from the genus *Hibiscus* (Aladele 2008). In 1787, Medikus consequently suggested that *Abelmoschus* be raised to the rank of a distinct genus.

The taxonomic and contemporary literature subsequently acknowledged the broader usage of the genus *Abelmoschus* (Hochreutiner, 1924). *Abelmoschus* and Hibiscus are distinguished by the physiognomies of the calyx, spathulate, with five short teeth, connate to the corolla, and caducous after flowering (Kundu and Biswas 1973; Terrell and Winters 1974). Okra falls under the kingdom of*Plantae* since it is a vegetable (plant) whereas it is in the division and class of *Magndiophyta* and *Magnoliopsida* respectively.

It belongs in the order of *Malvalese* because it produces flowers that give rise to the fruit which is called the pod. Okra was earlier included in the genus of *Hibiscus*, *Abelmoschus* section in the family of *Malvaceae,* and the species being called *esculentus* leading to the crop(okra) being called Abelmoschus *esculentus*. Below in Table 1 is the table classifying the taxonomy of okra.

Table 1. Taxonomy of *Okra (Abelmoschus esculentus* L.) Moench

Name	**Okra**
Kingdom	*Plantae*
Division	*Magnoliophyta*
Class	*Magnolipsida*
Order	*Malvales*
Genus	*Abelmoschus*
Species	*Esculentus*

The taxonomists have portrayed approximately 50 species of okra. The taxonomical revision undertaken by van Borssum Waalkes (1966) and its continuation by Bates (1968) undertook the taxonomical revision which comprises the most fully documented studies of the genus *Abelmoschus*. Below is the classification of van BorssumWaalkes the classification that was adopted at the International Okra Workshop held at the National Bureau of Plant Genetic Resources (NBPGR) in 1990 (IBPGR 1991) as given in Table 2.

Table 2. The classification adopted by IBPGR, 1991.

Species Number	Species
1	*A.moschatus Medikus- subsp. Moschatus var moschatus-subsp. Moschatus var betulifolius (Mast) Hochr- subsp biakensis (Hochr) Borss- subsp tuberosus (Span) Borss*
2	*A. manihot (L) Medikus- subsp tetraphyllus (Roxb ex Hornem) Borss var tetraphyllus - var pungent*
3	*A. esculentus (L) Moench*
4	*A. tuberculatus Pal and Singh*
5	*A. ficulneus (L) W and A.ex. Wight*
6	*A. crinitus Wall*
7	*A. angulosus Wall ex. W, and A*
8	A. caillei (A. Chev) Stevels

2.1.1. Botany of Okra *(Abelmoschus esculentus* L.) Moench

Okra has the physical attributes of being an upright annual crop, falling under the category of herbaceous plant with a height that ranges between 100 to 200cm feet tall plant with a hibiscus-like flower (Kundu and Biswas 1973; Terrell and Winters 1974). It is a tropical vegetable which is sown directly to the soil. The color of the flower petals ranges from blue to purple, white, and yellow. Depending on varieties grown in certain areas, okra generally has a duration that varies between 90-100 days. Some morphological features of okra are discussed below:

Okra *(Abelmoschus esculentus* L.) Moench is cultivated throughout the tropical and warm temperate regions of the world, it is cultivated for its fibrous fruits or pods containing round, whiteseeds (Van BorssumWaalkes 1996). Okra is among the most common crops that fallsunder heat and drought-tolerant vegetable species in the world, and they do tolerate soils with heavy clay and intermittent moisture but conditions such as frost can damage the pods. In cultivation, the seeds of okra are soaked overnight before planting to a depth of 1-2 cm.
Germination of Okra *(Abelmoschus esculentus* L.) Moench occurs between six days (for the soaked seeds) and three weeks (Van BorssumWaalkes 1996). Seedlings require sufficient water to grow strong and with better vigor. The seed pods rapidly become fibrous woody, and edible (Kundu and Biswas 1973; Terrell and Winters 1974). The seed podsmust be harvested within a week of the fruit having been pollinated. The fruits are harvested when immature and eaten as a vegetable.

2.1.1.1 Roots

Okra is categorized under the crops that have deep taproot systems. The deep taproot system is the one that allows it to utilize all the nutrients in the soil making it a good crop that is planted even in areas with warm weather conditions (Bates 1968)
. It also survives in dryland production whereby even smallholder farmers can plant commercially.

2.1.1.2 Stem

The stem of Okra *(Abelmoschus esculentus* L.) Moench is categorized as semi-woody and is sometimespigmented with a green or reddish tinge colour. The stems are erect, variable in branching, with many short branches being attached to thick semi-woody stem. It consists of the flowering stem which has circular foam or lots of small angles so that it is roughly circular (Bates 1968). The stem is also characterized by the hairs between the nodes. In every stem, there is at least one available full leaf that is above the base of the flowering stem. The tendrils are not present in okra plants (Van BorssumWaalkes 1996).

2.1.1.3 Leaves

Since Okra *(Abelmoschus esculentus* L.) Moench has a woody stem, it bears leaves that are lobed andare generally hairy, the underside and upper side of the leaves are fuzzy and hairy. The leaves are alternate meaning that there is one leaf per node along the stem. Theleaf consists of a distinct leaf stalk called the petiole (Bates 1968). The base of the leafblade is cordate (having heart-shaped and rounded lobes at the base). It consists of the lobes at the edge of the leaf blade with both teeth and lobes. The okra leaves consist of blades that have simple hairs without glands, and they are not twisted (VanBorssumWaalkes 1996). The length of the leaf blades ranges between 50 to 350mm(Bates 1968).

The shape of the leaf blades is distinguished by being elliptic (they are broadest near the middle while narrowing at both ends), oblong (they have a rectangular shape however with rounded ends), ovate (having a shape that is broadest below the middle and broadly narrowing at both ends) and spatulate (they are like spoon-shaped, tempered near the base, then suddenly spreading to a rounded tip). The color of the leaf blades on the surface is comparatively uniform on the upper side (Van BorssumWaalkes 1996).

The leaf of okra normally falls off during the winter season. The colour of leaves is generally dark green consisting of an expanded blade and resembles a maple leaf, a texture that is leaf-like. The leaf edges do not have spines (Bates 1968). The leaves consist of the leaf stalk whereby the petiole is attached at the basal margins of the leaf blade. The base of the petiole becomes narrow where it attaches itself to the stem (Bates 1968). The leaf blade has external-pointing or outward-pointing teeth. The type of okra leaves is simple, meaning that they are either lobed or unlobed, but they are not alienated into leaflets. The node which is along the stem has only one leaf. The okra plant has stipules.

2.1.2.3. Growth form

Okra plant falls under the plants that are herbs with self-supporting stems. The plant has a lifespan of only a single year or less depending on the variety planted (Bates 1968). Okra does not have the ability or characteristics of parasitism therefore it is not parasitic. The young stems and leaves of the plant are green. The plant consists of the spines.

2.1.2.4. Flowers

The flower of okra has an anthers whereby the anthers have narrow slits or furrows that run lengthwise along the anthers. Unlike anthers of other crops, okra anthers do not have spurs on them (Bates 1968). It consists of carpels that are fused. The flower consists of an epicalyx which has a number parts of about 7 to 12.
The flower of okra is described by its superior ovary and with the absence of hypanthium. The petal color of the flower differs from variety; it can either be blue to purple, white, or even yellow (Bates 1968). The flower comprises both reproductive parts (the flower consists of pollen and seed-producing parts).

Flowers of okra are symmetry, meaning that they have two or more ways to equally divide the flower (Van BorssumWaalkes 1996). The style of the flower is branched above the base whereas stamen clusters are joined (there is one cluster of fused stamens) (Bates 1968). The sepals or petals are fused into a cup or tube. The hypanthium is not present on the flower. The petals have marks or spots or streaks on them whereas its flower does not have the nectar spur. Okra flowers have carpels of about five and a number of pistils which are one to five. The flower consists of five petals, sepals with one style.

The position of the ovary is above the point of the petal or sepal attachment. A petal and sepal color differs from blue to purple, white, and yellow (Bates 1968). The appearance of petals is usually thin delicate and pigmented; they are coloured other than green or brown. The petals do not have folds or plaits, they are longer than the sepals and they are five (Van BorssumWaalkes 1996). All the flowers have both reproductive systems (synoecious), both carpels and stamens. There is no scale inside the corolla. Sepals are different from petals; sepals do not have appendages on them, and their length is about 20 to 30 mm.

2.1.2.5. Fruit or Seed

The pod is the edible portion of the crop okra. The pods which are the fruits are the ones that are normally harvested while they are still tender or immature when the fruit is still soft (Bates 1968). The length of the fruit ranges between 60-250mm depending on the type or variety of okra cultivated. The fruits grow very fast with a tip that is either pointed like a beak or blunt. It consists of the fruit locules which are five and when the fruit is dry; it splits open which can result in some seeds being dispersed on the ground (Van BorssumWaalkes 1996).

The fruit type is capsule meaning that the fruit will rapture along two or more joints or pores when they are dry to release two or more seeds (Bates 1968). The seed or fruit of okra is smooth or does not have clear markings. The okra fruit contains numerous seeds that are oval, green to dark brown. The wings are not present on the fruit. The fruit do not have prickles meaning that they do not have a thorn-like defensive structure.

2.2. Weeds in general

2.2.1. Critical Period of Crop-Weed Competition

Battling with weeds in crops is always associated with agriculture. In a field crop, unless weeds are controlled in the right manner and moment; the plenty of time and money that are spent by the soil scientists, agronomics, pathologists, entomologists, and genetics in improving and increasing the productivity of crops will be just a waste (Nieto *et al.,* 1968). These unwanted plants in the cultivated field cause two types of losses.

The most losses arise when weeds compete with the desired cultivated plants for available resources such as light, water, and nutrients (Kasassian and Seeyave 2009). The other losses caused by weeds occur indirectly whereby they hamper harvesting because of the infest, some of examples include wheat in cases where weed seeds are found in wheat seeds**,** in some cases, weeds may harbor things such as insects, fungi, or even viruses which may negatively affect the crop (Nieto *et al.,* 1968).

In the world, farmers usually have land that have weeds and they witness the fact that they use only elementary methods to keep them down as they generally sow the area that they can cultivate (Roberts 1976). In some parts of the world where agriculture is categorised by a high degree of technology (equipment), farmers invest a good deal of money on continuous weed control. It is done over the impression that the further cultural care is taken in the production, the higher production will be. Farmers tend to forget that yield is a matter of genetics, which cannot be altered by further weeding, which consequently only results in high production costs (Kasassian and Seeyave 2009).

It has been indicated by (Nieto *et al.,* 1968) that research workers usually make one of the principal mistakes in their studies on weed control is ignorance when it comes to the critical period for completion. (Nieto *et al.,* 1968) reported that it has been discovered by other researchers how most farmers deplore the presence of weeds between their crops but that, is not the main reason, There are periods when weeds must be eliminated and other periods where they can be allowed to grow because they do not cause the slightest harm to the crop.

2.2.2. **Weed Management in** Okra *(Abelmoschus esculentus* L.) Moench

Furthermore, the leaves are removed from the plant when the crop is harvested after ripening. The sun can easily reach the surface soil and may increase the late-season weed interference (Roberts, 1976). The harvesting of okra will continue as okra will produce more fruits until a killing frost occurs; this type of late-season interference can be considerable.

Through the research conducted by Nieto *et al.,* it is found that the critical weed-free period; is the period during which no loss of yield is incurred if the field is kept weed-free for many (Nieto *et al.,* 1968; Roberts, 1976). From the research conducted by

Iremire (1988) on okra, it has been shown that there is no weed-free period that occurs. Few herbicides are registered for the control of weeds in okra.

Consequently, the production of okra will still heavily depend on cultivation supplemented with hand weeding to preserve high yields (Nieto *et al.,* 1968). For better cultivation of okra, shallow cultivation can benefit in controlling weeds just afterthey emerge between crop rows. Cultivation must be done along the row middles between the rows of okra crops.

When weed control is properly timed, cultivation becomes more effective (Roberts 1976). On the other hand, cultivating very early could reduce the benefits of any pre-emergence herbicides. Weeds may be very large to kill or control with shallow cultivation, nevertheless, that's if cultivation occurs late (Iremiren, 1988). As soon as weeds emerge, the control of weeds with hand hoeing within the rows should begin.

2.2.3. Weed and Crop Competition

Weed control has become an essential role of all crop production systems. Weeds tend to reduce yields thereby competing with crops for available factors such as water, nutrients, and sunlight (Iremiren, 1988). They also reduce profits directly by hindering harvest operations and reducing the quality. Some weeds are allelopathy, meaning that they have the ability to produce chemicals which are detrimental to crop plants (Kasassian and Seeyave, 2009). If weeds are left uncontrolled in a field crop, they may harbor insect pests and diseasesand be able to produce seeds or rootstocks which invade the field and affect future crops (Adejonwo *et al.,* 1987, 1991). Uncontrolled weeds result in loss of expenditure (costs encountered for preparation of planting until harvest) since researchers have shown that uncontrolled weeds can reduce yield by up to 80% in a field. Through manyyears of research, it has been shown that good weed control must be done within thefirst 4 to 6 weeks after crops are planted (Roberts, 1976). That is the critical period forweed control which must be taken into consideration to avoid a yield reduction from weeds.

2.2.4. Impact of climatic change factors on weed management and herbicide efficacy.

Weeds have been declared to cause extensive damage especially to cropland and noncropland areas and to public health. The primary focus for farmers and weed scientists around the world now has become weed management on crops. Several options for weed control are available (Aruna Varanasi *et al.,* 2015). Those weed control options include cultural, mechanical, chemical, and biological methods (Aruna Varanasi *et al.,* 2015).

The most discovered economical and widely used alternative weed control measure is chemical weed management which uses herbicides though it is mostly in developed countries such as the United States (Gianessi, 2013). There is increased use of herbicides in parts of the world, including India, China, and Sub-Sarahan Africa; all interested because of their potential for better results in weed control such as saving labor and energy, yield crop improvement leading to cost reduced in farming (Gianessi, 2013).

The use of herbicides remains the backbone of weed control due to their ease of application and cost-effectiveness in production Though the focus of weed management is shifting towards integrated strategies to reduce the impact of herbicide use on the environment and the development of herbicide-resistant weeds (Gianessi, 2013).

It becomes necessary to understand climatic changes that influence the efficacy of herbicides to control weeds in the future since the use of herbicides in sustainable crop production is essential (Aruna Varanasi *et al.,* 2015). There are several studies conducted that have focused on the impact of climate change on crop productivity although less attention has been given to the impact on weed management, mostly herbicide efficacy and its subsequent effects on the development of herbicide-resistant weeds (Gianessi, 2013). Certain things such as a change in herbicide susceptibility due to environmental stress could have major consequences for crop weed competition and may contribute to higher production losses in the future (Aruna Varanasi *et al.,* 2015).

2.2.5. Environmental factors that affect herbicide activity

On herbicide efficacy, it is important to understand how environmental conditions affect herbicide performance and to realize the impact of climate change (Aruna Varanasi *et al.,* 2015). Environmental conditions before, during, and after herbicide application also determine the successful use of the herbicide (Aruna Varanasi *et al.,*2015). The growth and physiology of the plants are not only factors influenced by theenvironment but also the interaction between the plant and herbicide (Gianessi, 2013).

In the previous sections by Aruna Varanasi *et al.,* 2015, there was a review of how climate change influences things such as weed physiology and growth. In this chapter by Aruna Varanasi *et al.,* 2015, the effects of environmental factors such as CO2, Temperature, soil moisture, relative humidity, rainfall, and wind on herbicide mode of action will be discussed (Aruna Varanasi *et al.,* 2015).

The above-mentioned factors can influence herbicide efficacy directly by altering the penetration and translocation of herbicides inside the plant or indirectly by changing the growth and physiological characteristics of the plants (Aruna Varanasi *et al.,* 2015). On the other hand, foliar-applied herbicides are influenced by many environmental factors while soil-applied herbicides are mainly influenced by soil moisture and temperature (Gianessi, 2013).

2.2.5.1. Light

The most important environmental factor that influences plant growth anddevelopment is light. Certain difference in light intensities changes the anatomy, morphology, and growth of plants, which further influence herbicide performance (Devine, 1989). Light is known as the source of energy for photosynthesis, and the rate of photosynthesis determines the rate of phloem translocation of assimilates (Devine, 1989).

The efficacy of clethodim and tralkoxydim was reduced in ultraviolet light, which indicates that spraying these grasses with herbicides later in the day when light intensity is higher may improve their efficacy due to the net photosynthetic rate that typically increases with light intensity, and higher photosynthesis and subsequent phloem translocation increased the movement of foliar-applied systemic herbicides (McMullan, 1996).

According to Ohadi *et al.,* 2010, light is very essential for seed and leaf development. Light is positively correlated with stomatal conductance and leaf cuticle development (Hull *et al.,* 1975; Raschke *et al.,* 1978). At high light intensity, stomata remain open at a high light intensity, therefore improving tissue penetration for foliar-applied herbicides (Matos *et al.,* 2009). Moreover, plant branching and leaf thickness increase to reduce the damage caused by extreme light energy and to ensure the proceeding of photosynthesis (Matos *et al.,* 2009; Wentworth *et al.,* 2006).

On the contrary, where there is low light intensity, even the plants will tend to produce thinner leaves with greater specific leaf area and plant height to capture available light and meet the demand for photosynthesis (Steinger *et al.,* 2003). These adaptations in plant growth and leaf anatomy influence the amount of herbicide that is absorbed and retained by the plant. They are influenced by these adaptations in plant growth and leaf anatomy, for example, higher plant branching increases surface coverage and absorption of post-emergent (POST) herbicides, while thicker leaves slow the diffusion of herbicides giving rise to reduced herbicide activity (Riederer and Schonherr, 1985).

2.2.5.2. Carbon Dioxide

The significance of CO_2 about influence on herbicide efficacy has come into consideration in recent years because of the stable rise in atmospheric CO_2 since the Industrial Revolution (Bunce, 1993). High CO_2 concentrations in the atmosphere are likely to have prominent effects on weed biology, subsequently fluctuating herbicide performance on weeds. The most projecting effects of elevated CO_2 levels give rise to the reduction in stomatal conductance, which could result in up to 50% increase in some plants (Bunce, 1993).

The efficacy of both foliar- and soil-applied herbicides can be altered by reduced stomatal conductance. The leaf thickness increases, and the number of open stomata decreases at projected CO_2 levels; thus, reducing the amount of foliar-applied herbicide that is directly absorbed into the plants, by that weeds will be protected from damage by post herbicides (Ziska, 2008). If the stomatal conductance is decreased therefore, it will also result in reduced transpiration flow, which further decreases the uptake of soil-applied herbicides (Bunce and Ziska, 2000; Ziska, 2008).

In addition, an increase in the net photosynthetic rates at high CO_2 levels, particularly in C3 weeds, could result in rapid seedling growth (Ziska *et al.,* 1999). Since the seedling stage is the most susceptible stage for effective weed control, the timing of POST herbicide application could be altered an example of a C3 weed that has shown higher tolerance to glyphosate because of increased growth and biomass at elevated CO_2 is common lamb squatters (Ziska *et al.,* 1999).

The efficacy of glyphosate at elevated CO_2 concentrations was also reported to reduce C4 invasive weeds such as Rhodes grass (*Chloris gayana*), weeping lovegrass (*Eragostis curvula*), and dallisgrass (*Paspalum dilatatum*) owing to increased biomass and leaf area (Manea *et al.,* 2011). While greater CO_2 concentrations may promote rhizome or tuber (below-ground) growth relative to aboveground growth in most perennial weeds, which may render herbicide control of such weeds more problematic (Patterson *et al.,* 1999). It has been reported by Ziska *et al.,* (2004) that increased growth and root: shoot ratio of field-grown Canada thistle (*C. arvense*) under elevated CO_2 levels, resulted in the reduced efficacy of glyphosate because of the dilution effect caused by large stimulation of below-ground growth.

2.2.5.3. Temperature

The effects that temperature has on herbicide efficacy are both direct and indirect. On plant growth and development, temperature has compound effects. The temperature-dependent physiological processes include photosynthesis, phloem, translocation, respiration, and protoplasmic streaming (Hull *et al.,* 1975). These changes in terms of the rate of this process will indirectly affect herbicide penetration and translocation.

According to Hull *et al.,* 1975, germination, seedling growth rate, and leaf anatomy (leaf area, leaf shape, and cuticle development) can be influenced by air and soil temperature, which, in turn, determine the time when plants are most susceptible to herbicides (Hull *et al.,* 1975). While Guo and Al-Khatib (2003) have shown that seedling growth rates of weeds such as redroot pigweed, common water hemp, and palmer amaranth increased at high temperatures and suggested that the amount of time for post herbicide applications to be most effective (when the seedling are younger) decreases at high temperatures (Price,1983).

Temperature can directly affect herbicide performance can be through its effects on the rate of herbicide diffusion, viscosity of cuticle waxes, and physicochemical properties of spray solutions (Price,1983). Higher temperatures may lower the viscosity of cuticular lipids, thereby increasing the permeability and diffusion of herbicides through the cuticle; for example, uptake and translocation of ^{14}C-glyphosate was found to be higher at 22°C than at 16 °C in Desmodium tortuosum (Sharma and Singh, 2001).

Similarly, Roundup Ready Soybean translocated more 14C-glyphosate to meristematic issues at 35°C than at 15°C, indicating potentially increased glyphosate injury at higher temperatures (Pline *et al.,* 1999). Flumiclorac also showed higher activity on common lamb squarters (sevenfold) and redroot pigweed (threefold) as temperatures increased from 10°C to 40 °C (Fausey and Renner, 2001).

Although high air temperatures tend to speed both the absorption and translocation of most foliar-applied herbicides, in some cases high temperatures also may induce rapid metabolism, which subsequently reduces herbicide activity on target plants (Kells *et al.,* 1984; Johnson and Young, 2002). A threefold increase in the absorption and translocation of mesotrione in velvetleaf and common cocklebur was observed at 32°C. In contrast, mesotrione efficacy on common water hemp and large crabgrass sanguinalis) decreased by six and sevenfold at the same temperature (Johnson and Young, 2002). Similarly, mesotrione efficacy on palmer amaranth decreased significantly with an increase in temperature from 25°C to 40 °C, indicating a possible increase in the metabolism of mesotrione at higher temperatures (Godar *et al.,* 2015).

Warmer temperatures usually may also result in reduced herbicide uptake due to rapid drying of spray droplets to solid deposits (Devine *et al.,* 1993). Temperature may also affect the volatility of some herbicides, such as synthetic auxins resulting in vapour drift and possible injury on non-target broadleaf plants (van Rensburg and Breeze, 1990; Strachan *et al.,* 2010). Visual symptoms of injury due to dicamba drift on soybeans increased from 0% to 40% as temperature increased from 15°C to 30 °C (Behrens and Lueschen, 1979).

Although these effects are observed mainly with foliar-applied herbicides, soil temperature affects the movement and permeability of soil-applied herbicides within the plant. High soil temperatures may lower the efficacy of soil-applied herbicides by increasing volatility and microbial breakdown. According to Atienza *et al.,* 2001, high temperatures had a profound effect on the volatilization of the triallate herbicide from soils. Triallate losses increased from 14% to 60% in sandy soil and 7% to 41% in loamy soil when temperatures increased from 5°C to 25°C.

2.2.5.4. Relative Humidity

It primarily influences the activity of foliar-applied herbicides (herbicides that are applied directly on the part of the plant) through its effects on herbicide uptake. Whereas relative humidity could influence the efficacy of foliar-applied herbicides through interactions between the herbicide droplet, leaf cuticle, and availability of water in or around droplets (Devine *et al.,* 1993).

2.2.6. Impact of Climate Change Factors on Weeds and Herbicide Efficacy

Air temperature and relative humidity also influence the flow of transpiration; thus, affecting chemical absorption and movement. High temperature and low humidity increase evaporation, which, in turn, reduces droplet size and increases herbicide drift (Devine *et al.,* 1993). At high humidity, nevertheless, the effects of high temperature on droplet drying are reduced due to increased leaf retention time, thus increased herbicide absorption. Plants that are grown at high humidity usually develop softer cuticles than plants that are grown at low humidity, which tend to have thicker cuticles and thus less herbicide penetration.

Overall, humidity has a greater effect on herbicide uptake than temperature. The efficacy of glufosinate ammonium conducted on green foxtail (Setariafaberi) and barley was greater at high humidity than at high temperatures (Anderson *et al.,* 1993). In general, humidity typically affects herbicide uptake through its impact on cuticle hydration and the rate of droplet drying after herbicide application (Muzik, 1976; Price, 1983). Consequently, humidity is considered more important at the time of spraying than during the post-spraying period.

Increased herbicide uptake at high relative humidity may lead to greater translocation of herbicides. The effects of humidity are much higher on water-soluble herbicides than on lipophilic herbicides. At high humidity, cuticle hydration and stomatal opening increases, which further increases the permeability of water-soluble herbicides into the leaf surface (Kudsk *et al.,* 1990).it has been found that the susceptibility of common waterhemp and large crabgrass to mesotrione was four and two-fold higher at 85% relative humidity compared with 30%, respectively (Johnson and Young, 2002).

While wild oat plants grown at high (>95%) relative humidity demonstrated significantly increased glufosinate ammonium efficacy compared with those grown at low (40%) relative humidity; furthermore, uptake of 14C-glufosinate ammonium was higher when wild oat plants were exposed to high relative humidity for 30 min before and after treatment compared with those left at continuously low relative humidity (Ramsey *et al.,* 2002). Uptake and efficacy of most herbicides were generally found to be higher when plants were exposed to high humidity after spraying than before, suggesting that delayed droplet drying could be the mechanism for higher efficacy at high humidity levels rather than cuticle hydration (Ramsey *et al.,* 2005).

2.2.6.1. Precipitation and Soil Moisture

Precipitation can directly influence herbicide uptake by washing the spray droplets off leaf surfaces or by diluting the herbicide to a less effective form. Precipitation can directly influence herbicide uptake by washing the spray droplets off leaf surfaces or by diluting the herbicide to a less effective form (Spillman, 1984). This effect is more pronounced if precipitation occurs shortly after herbicide application. Herbicide applications are generally not recommended immediately after rainfall because wet leaf surfaces have a higher tendency to bounce off the spray droplets (Spillman, 1984).

The intensity and duration of precipitation determine the rain fastness of the herbicide. Rain fastness is simply the ability of an herbicide to quickly dry and penetrate the leaf tissues, so it remains effective after rainfall. Herbicides with lipophilic properties usually have better rain-fast properties than water-soluble herbicides (Kudsk and Kristensen, 1992). Ester formulations of auxinic herbicides are absorbed more quicklythan amine and salt formulations, which are more susceptible to wash-off. Low levels of precipitation or dew may improve leaf retention and herbicide efficacy by rewetting spray droplets on the surface Olesen and Kudsk, 1987).

On the other hand, lower precipitation amounts throughout the season may result in water stress conditions that affect both plant growth and herbicide efficacy (Zanatta *et al.,* 2008). Soil temperature and moisture directly influence soil-applied herbicides by affecting herbicide concentration, solubility, and movement in the soil and through the plant via transpiration (Moyer, 1987). Low soil moisture content may result in increased adsorption of herbicides to the soil particles, thus reducing their availability for uptake by plant roots (Dao and Lavy, 1978).

Adequate soil moisture is particularly necessary for pre-emergent herbicides for movement into the zone of weed seed germination and effective weed control. Soil moisture effects on foliar-applied herbicides are related to herbicide absorption, translocation, and metabolism (Hinz and Owen, 1994; Peregoy *et al.,* 1990). Cheatgrass and spring wheat were injured more from sulfonylurea herbicides applied when soil moisture was at saturation compared with one-third of moisture content (Olson *et al.,* 2000).

The study conducted, it was found that the efficacy of imazamethabenz on blackgrass (*Alopecurus myosuroides*) increased with increasing soil moisture (Malefyt and Quakenbush, 1991). Corn injury by EPTC and butylate was higher at 33% than at 15% soil moisture (Burt and Akinsoratan, 1976). Plants grown under moisture stress develop leaves with an upright orientation to minimize leaf surface area that intercepts light and temperature. This orientation has negative consequences for foliar absorption because upright leaves cannot retain spray droplets for a long time (Levene and Owen, 1995).

Prolonged periods of moisture stress reduce photosynthesis due to stomatal closure and cause leaf thickening, tissue dehydration, and greater leaf senescence which, in turn, reduces herbicide diffusion and subsequently lowers herbicide absorption and translocation (Kogan and Bayer, 1996). Pereira *et al.,* (2011) found that the efficacy of sethoxydim was lower in goosegrass (indica) plants grown under water-deficit conditions. Similarly, plantain signal grass (Urochloaplantaginea)plants grown under water stress were not effectively controlled by ACCase-inhibiting herbicides when applied during the later growth stages (Pereira, 2010).

2.6.2. Wind

Wind may have a less pronounced influence on herbicide performance. Nonetheless, windy conditions can interfere with surface application and cause spray drift, thereby reducing spray application efficiency (Combellack, 1982). Wind reduces herbicide retention by moving spray off and away from plants and particularly affects the deposition of smaller droplets on the leaf surface (Nordbo and Taylor, 1991). Furthermore, spray deposits tend to dry rapidly under windy conditions, with a subsequent reduction in herbicide uptake.

Wind can also cause cuticle damage through leaf collisions and abrasions from soil particles (Thomson, 1974). Wind also affects evapotranspiration from the leaf surface; thus, altering herbicide absorption from soil. However, in the case of contact herbicides, wind may increase herbicide action, especially at high temperatures and low humidity (Muzik, 1976).

2.2.7. Types of weeds competing with okra

In general, weed species diverge greatly in their ability to compete with crops for available resources and reduce yields. It is necessary to have 100% control of weeds, particularly in a field with weeds that are competitive, persistent, or difficult to control (Kembie *et al.,* 1914). Certain crops can tolerate a certain threshold number of weeds without suffering a yield reduction. Kembie *et al.,* (1914) have mentioned a few weeds that compete with okra both broadleaf, annual, and perennial weeds.

Table 3. Weeds competing with okra.

Common name	**Botanical name**
Goosegrass	*Eleusine indica (*L.) Gaertn.
Crabgrass	*Digitaria spp*
Morningglory	*Ipomoea purpurea* (L.) Roth
Bermudagrass	*Cynadon dactylon* (L.) pers
Sicklepod	*Cassia obtusifolia*
Common cocklebur	*Xanthium* L.

Nutsedge	*Cyperus esculentus* L. var. esculentus

Some weed species that are a threat to okra production include annual grasses such as crabgrass and goose grass; perennial grasses such as Bermuda grass; broadleaf weeds such as Sicklepod, annual morning glory, and common cocklebur; and nutsedge (Franklin, 1982). When the okra and weeds are small, tilling with a rolling cultivator will kill most small weeds. Later, use sweep cultivators or rolling cultivators set to cover small weeds within the row. Avoid throwing too much soil directly against the okra stems because doing so can increase the incidence of stem rot (Kembie *et al.,* 1914). Few herbicides are registered for weed control in okra fields. Using them improperly can damage your crop. Carefully follow the instructions printed on the label and apply herbicides at exactly the right rate and time. Contact your county Extension agent for up-to-date recommendations on herbicides for use on okra (Kembie *et al.,* 1914).

Weed species infesting okra include annual grasses such as crabgrass and goose grass; and perennial grasses such as Bermuda grass; and broadleaf. Weeds such as sicklepod, annual morning glory, common cocklebur, and nutsedge. When the okra and weeds are small, tilling with a rolling cultivator will kill off most small weeds. Later, use sweep cultivators or rolling cultivators set to cover small weeds within the row. Avoid throwing too much soil directly against the okra stems because doing so can increase the incidence of stem rot. Few herbicides are registered for weed control in okra fields. Using them improperly can damage your crop. Okra is harvested over a long period, so full-season weed control is usually required. A preplant application of Tre flan is recommended for the control of grasses. There are no herbicides labeled for broadleaf weed control in okra.

2.3. Types of weed control in okra.

2.3.1. Mechanical Control

Mechanical cultivation should be used as often as necessary to control broadleaf weed species. Care should be taken to cultivate as shallowly as possible to avoid root damage to the okra. Producers may want to avoid fields with known heavy infestations of broadleaf weeds.

2.3.2. Chemical control

Weed control depends largely upon one factor - timeliness. There are many weed control practices such as cultural, mechanical, and chemical methods that are effective if applied at the correct time, type of weeds, and type of crop. When the fields are kept free of weeds for the first four to six weeks after the crop has been planted, it gives the crop a “head start” which enables it to shade out and out-compete weeds that emerge later in the season.

Herbicide options in okra Pre-plant and Pre emergence Glyphosate (roundup and other trade names) may be applied before crop emergence to kill emerged weeds. It will non-selectively kill these weeds and will translocate in the plant to help control large weeds as well as perennials. Apply at a rate of 0.5 to 1.5 pounds of active ingredient per acre. The rate of product per acre will change based on the formulation being used. Perennial weeds may require higher rates of glyphosate. Add surfactant to brands of glyphosate requiring surfactant by the product label.

2.3.2.1. Trifluralin (tre flan 4eC and other names)

Trifluralin is one of the herbicides labeled for pre-plant incorporated use in okra crops usually for annual grasses and small-seeded broadleaf weeds. The application rates for the herbicides on weeds range from 0.5 to 1 pound of active ingredient per acre (1 to 2 pints per acre) (Americanos and Vouzounis, 1991). For best results andmaximum activity of the herbicide, the pre-plant application needs to be incorporated for about 4 to 5cm deep within 24 hours of application (thus before planting the okra).

2.3.2.2. Metolachlor (dual)

Metolachlor falls under one of the herbicides that have been previously labeled for use as a pre-plant incorporated lot pre-emergence herbicide in okra. When the U.S. Environmental Protection Agency (EPA) categorized okra with pod crops, this label was in place (Americanos and Vouzounis, 1991). Okra was categorized withother crops such as peas and beans. Subsequently, the use of metolachlor was discontinued and remains prohibited just when the classification was changed during the mid-1990s.

2.3.2.3. Post-emergence Glyphosate (roundup WeatherMax 5.5l).

Hooded or shielded spray or wiper application may be used to apply glyphosate to row middles between the rows of okra crop or as a post-harvest nonselective spray (Americanos and Vouzounis, 1991). Glyphosate must not come into contactwith the crop, and it must be made a priority that such mistakes be avoided during mixing and applying. Apply at 0.5 to 0.94 pounds of active ingredient per acre or 11 to22 ounces of product per acre. With this brand of glyphosate, surfactant is not needed. Metolachlor must not be applied within 14 days of harvest.

2.3.2.4. Carfentrazone (aim 1.9 EW, 2.0 EC)

On small or emerged weeds, sulfentrazone may be applied in okra fields as a hooded or shielded application to row middles between rows of okra crops (Americanos and Vouzounis, 1991). Up to 2 ounces per acre may be applied at any one application, with a seasonal limit of 6.1 ounces per acre for okra. Crop injury may resultif there is contact of herbicide with okra foliage during an application (see Figures 1 and 2). Good weed coverage with Aim is essential, and it is recommended that a cropoil concentrate (1 percent of spray volume) or nonionic surfactant (0.25 percent of spray volume) be used.

2.3.2.5. Sethoxydim (post 1.5 EC)

The herbicide can be applied as post-emergence to okra for the control of emerging grass species. Application of the herbicide must be 1.5 pints of the product per acre with a seasonal maximum of 5.5 pints per acre (Americanos and Vouzounis, 1991). Like Carfentrazone, Sethoxydim must not be applied within 14 days of harvest.Weeds that have already emerged such as nutsedge, broadleaf weeds, or grasses willnot be controlled by Sethoxydim.

2.3.2.6. Recent findings on prometryn (Caparol 4 l, Cotton-pro 4 l)

The use of prometryn in okra has been researched in recent years. There are replicated trials that have been carried out in North Carolina and Georgia that have shown Cotton-Pro applied pre- or post-emergence at 1.5 pints per acre did not cause significant injury to okra (Batts and Culpepper, unpublished data) (Americanos and Vouzounis, 1991). The registration of prometryn was presently being followed through the USDA IR-4 program; the data was to be submitted to the U.S. EPA expected in summer 2008.

2.3.2.7. Pre-plant incorporated: Trifluralin

The recommended pre-plant incorporated herbicide for weed control in okra crops is trifluralin. Whereas for post-emergence control of weeds in okra crops are achieved by cultivation and hand-hoeing in combination with glyphosate or carfentrazone, or it could be a combination of both, herbicide must be applied to row middles between crop rows (Americanos and Vouzounis, 1991).

2.4. Physiology of selected soil-applied herbicides.

2.4.1 Physiology of trifluralin

Trifluralin is one of the herbicides that belong under the group of dinitroanaline. It is an emulsifiable concentrate containing 480g/L and contains 557g/L hydrocarbon liquid (Americanos and Vouzounis, 1991). Trifluralin is categorized under selective,pre-plant soil incorporated herbicide used for control of a wide range of broadleaf weeds and annual grasses in a diversity of crops.

2.4.1.1. Mode of action.

Trifluralin controls weeds as they germinate but will not control established weeds. The active ingredient in trifluralin is broken down by ultraviolet light, so it must be incorporated into the soil immediately after application.

2.4.1.2. Crops in which trifluralin is used to control weeds.

Trifluralin is used as pre-plant in the following crops whereby the herbicide is incorporated into the soil: Carrots, choumoellier, celery, haricot beans, kale, linseed, French beans, lucerne, okra, parsnips, peas, oilseed rape, rape, soybeans, turnips, sunflowers, swedes and. The herbicide (trifluralin) can also be applied as a pre-transplant by incorporating herbicide solution into the soil before transplanting the seedlings (Americanos and Vouzounis, 1991). The crops include the following: Brassicas (cauliflower, Brussels sprouts, okra, broccoli, and cabbage), peppers, tomatoes, and celery.

Trifluralin can also be used post-emergent through incorporating the solution on the soil on the inter-rows of the planted crops. The crops include Cucurbits (squash, cucumbers, okra, melons, pumpkins, and zucchini). Trifluralin can be used on okra crops for the control of weeds as pre-plant, pre-transplant, and post emergent (Americanos and Vouzounis, 1991). The above-mentioned crops can be sown or planted at any time after the herbicide solution has been applied and preferably it must be within 14 days.

2.4.1.3. Safety of crop applied with Trifluralin for weed control.

Trifluralin that is applied according to the given directions that are found on the label of the herbicide and under normal growing conditions will not distract, or destroy the treated crop. Certain things such as seedling disease, cold weather, deep planting, excessive moisture, high salt concentration, or drought may result in weakened crop seedlings and it may also increase the probability of crop damage (Americanos and Vouzounis, 1991). On that note, if such conditions happen, deferred crop development, or reduced yields may result.

Planting linseed deeper such as deeper than 3cm may give rise to some linseed stand. Under protracted dry conditions or protracted cold and wet conditions, certain crops are susceptible to damage when planted in soil that was previously treated with trifluralin (Americanos and Vouzounis, 1991). To avoid such injury every farmer, is advised not to plant sensitive grasses, such as ryegrass or wheat, for about12 months following the application of trifluralin.

2.4.1.4. Application and incorporation of trifluralin on the soil.

The soil where herbicide is going to be applied must be flat, free of debris, large clods, and not be disproportionately wet. Alien material such as plant residues or stones that could be on, or in the soil can reduce or downgrade herbicide effectiveness. For trifluralin to be effective always, it should be equally applied to the soil surface in a spray volume of about 100400 liters of water per hectare and at pressures of 200- 300kPa. Boom overlaps must be avoided in most cases to decrease the risk of crop injury in the field.

The herbicide must be incorporated thoroughly since it is very essential for weed control (Americanos and Vouzounis, 1991). During the normal seedbed preparation, incorporation can be carried out provided that the implements are used as per the recommendations as follows:

- Power-driven rotary implements set to cut to a depth of 5-10 cm.
- Lely Roterra may be used only if the spray boom is mounted on the implement.
- Tandem discs set to cut 8-15cm deep and operated at a speed of not less than 6-10km/h.
- Heavy spike or diamond harrows or Dutch harrows operated at 10-13km/h. Trailing harrows must be weighted 20-30kg per section.
- Chain harrows are not recommended.

For thorough incorporation, it is advisable to allow a minimum of two workings in different directions (i.e. at 90o to each other) is fundamental (except with rotary hoe). In terms of the soil surface, it should be left comparatively clod-free that means a maximum clod size of about 4 cm diameters. Weed control will not be reduced by shallow cultivation during the growth development of the crop.

2.5. Review of previous studies done on soil-applied herbicides on okra Mutale magisterial area.

Although the use of soil-applied herbicides in emerging farmers can be useful, save time and reduce costs of producing okra, most of them do not use it as they recommend hand labor. On the other side hand, labor can disturb the growth and development of the crop. Registered pre-emergence herbicides for okra are very few and trifluralin is the one registered (Elmore and Dale, 1982) which limits its use in most of the farmers around the Mutale Magisterial area.

There are very few studies that have been carried out to test the efficiency of pre-emergence herbicides on cultivars of okra. Most commercial farmers use post-emergence herbicides but no documented evidence of study has been done to test the efficiency of Trifluralin, Metolachlor, Alachlor, and Pendimethalin used on Clemson spineless okra cultivar (Pandet *et al.,* 2014).

2.6. Theoretical statement comprising similar studies done on soil-applied herbicides and other hybrids/cultivars of okra.

2.6.1. Effect of trifluralin on Okra *(Abelmoschus esculentus* L.) Moench

Trifluralin is one of the dinitroanaline herbicides and is a pre-plant or pre-emergence herbicide used commercially for the control of grasses and broadleaf weeds. It functions by preventing weed growth by inhibiting the development of roots by interrupting the process of mitosis. Nandwani (2012) conducted research at the Albert A. Sheen campus of the University of the Virgin Islands Agricultural Experiment Station in the summer. Sandy loam soil with 2% organic matter and a pH of 8.0 was used.

Clemson Spineless' (CS) and 'Red Burgundy' (RB) were the two seeds of okra cultivar that were used in the experiment. Trifluralin was applied at a rate of 2 kg/ha a day before transplanting okra plants into the field with Scythe (Pelargonic acid) sprayed at an application rate of 5% volume of water.

In the results, Trifluralin controlled weeds in all plots treated within two weeks as there was no emergence of weeds recorded. A slight injury of 2% in okra plants was recorded from two weeks after transplanting until four weeks but recovered as they grew. Nandwani 2013 reported the Marketable yield of okra was significantly higher in plots that were treated with trifluralin. A weight of 393g/plant was recorded in 'Clemson Spineless' and 329.4/plant was recorded in 'Red Burgundy'.

2.6.2. Response of Okra *(Abelmoschus esculentus* L.) Moench to Metolachlor.

Metolachlor is a pre-emergence herbicide classified as a derivative of aniline and a member of chloroacetanilide herbicides. It is highly recommended to be effective in the control of grasses and sometimes broad leaves. Patel *et al.,* 2004 reported effective weed control in Metolachlor at 1.0 kg/ha and increased fruit yield of 11.41 t/ha. In a report by Sharma and Sharma (2000), metolachlor at 1.0 kg/ha plus one hand weeding at 40DAS recorded the highest seed yield of 17.06 g/ha in Punjab-t cultivar. In 1985, the application of metolachlor at 2.0 kg/ha followed by supplementary hoe weeding resulted in significant weed reduction and increased fruit yield of okra cultivars (V35 and TAE-38) (Adejonwo *et al* 1991).

2.3.3. Sensitivity of Okra *(Abelmoschus esculentus* L.) Moench to Alachlor

Alachlor is one of the pre-emergence herbicides that belong to the chloroacetanilide family. Its greatest use is mostly known for the control of broadleaves and grasses. In 1981, Americanos P.G and Vouzounis N.A reported that the application rate of Alachlor at 3.0 kg/ha and 2.0 kg/ha did not affect the germination percentage also the establishment of Okra *(Abelmoschus esculentus* L.) Moench as all seeds in all pots practically germinated and young plants were produced. The slight symptoms of toxicity startedto emerge when the plants were developing. Application of Alachlor at a high rate resulted in stunting of plants while the lowest rate resulted in growth being slowed down (Pandey *et al.,* 2014).

Alachlor at an application rate of 3.0 kg/ha significantly reduces yield. Americanos P.G and Vouzounis N.A, 1981 did not recommend the application rate of alachlor at 3.0 kg/ha due to the slight symptoms of toxicity that were observed and reduced yield. Alachlor at 2.50 kg/ha significantly decreases weed population and increases seed yield (Sandhu and Randhawa, 1976)**.**

The results of a study conducted by Pandey *et al* in 2014 showed that the application rate of Alachlor at 1.5 kg/ha plus one hand weeding at 45 days after sowing (DAS) resulted in a high percentage of weed control efficiency (WCE) and significantly increase the fruit yield of Okra *(Abelmoschus esculentus* L.) Moench. Promising herbicide treatment for reducing weed population and increasing fruit yield of okra should be when alachlor is applied at 1.5 kg/ha supplemented by one-hand weeding.

In an investigation that was carried out in 2016 by Jalendhar *et al* on the Effect of Integrated Weed Management practices on Growth, Yields, and its attributes in Okra (*Abelmoschus esculentus* L. Moench Cv. Arka Anamika), two treatments of alachlor were included, alachlor as pre-emergence herbicide was used at the rate of 1.0 kg/ha and alachlor at 1.0 kg/ha plus one hand weeding at 30 days after sowing (DAS). Okra Cv. Arka Anamika seeds were sown on ridges at a spacing of 50x25cm. Parameters recorded include Plant height (cm) at the final harvest stage, Initial plant population **(**lakh ha-1), Final plant population (lakh ha-1), Days to 50 percent flowering, Leaf area index (LAI) at final harvest stage, Number of pods per plant, Pod yield per plant (g/plant) and Total pod yield (kg/ha).

Effect of alachlor at 1.0 kg/ha resulted in a plant height of 78.27cm, decreased plant population which was recorded from 0.8 to 0.77, leaf area index (LAI) of 1.057, Days to 50% flowering recorded was 37.33%, number of pods per plant was 15.66, pod yield per plant of 82.26g and total pod yield of 8203 kg/ha. The above-mentioned parameters were significantly higher in the treatment of alachlor at 1.0 kg/ha plus one hand weeding at 30 days after sowing (DAS).

Sharma and Sharma (2000) reported the highest seed yield of 17.40 g/ha that was obtained from a treatment of alachlor at 1.0 kg/ha plus one hand weeding at 40 DAS in Punjab-t cultivars. A yield loss was recorded in a weedy control resulting in a conclusion that alachlor at 1.0 kg/ha significantly increase seed yield.

2.6.4 Influence of Pendimethalin on Okra *(Abelmoschus esculentus* L.) Moench**.**

Herbicide pendimethalin belongs to the class dinitroanaline and is used in pre-emergence and post-emergence application to control annual grasses and certain broadleaf weeds. It inhibits the growth of shoots and roots of a particular weed. The weed population is controlled by preventing weeds from emerging, especially during the critical period for development. From the results that were found by Bagudo *et al.,* (2016) on the Evaluation of pre-emergence herbicides for weed control in Okra *(Abelmoschus esculentus* L.) Moench. Six treatments of herbicides were used (Pendimethalin atthe rates of 1.0 and 1.5 kg/ha, diuron at the rates of 1.0 and 1.5kg/ha, and Butachlor at the rates of 1.5 and 2.0 kg/ha) and two treatments of (one hoe weeding at 3, 6 and9 WAS and a weedy check).

Pendimethalin at the application rates of 1 kg/ha and 1.5 kg/ha resulted in taller plants throughout the crop cycle, this means Pendimethalin influences the growth of okra throughout the growing season. The leaf area index (LAI) was significantly high which resulted in better leaf size growth. The effect of pendimethalin at 1.5 kg/ha resulted in the okra plant producing 19.46 pods per plant. It was concluded that the figure could be attributed to the larger leaves that were produced by the plant which enables the crop to manufacture greater assimilates during their photosynthetic activities and suppress the weeds by denying them growth resources sunlight. Higher fresh pod weight per plant of 573.49g/plant was recorded on pendimethalin at 1.5 kg/ha and supplementary hoe-weeding at 6WAS.

This was achieved due to controlled weeds, and it also supports the findings of Iyagba *et al.,* (2012) who reported that in plots where weeds were controlled, maximum pod weight per plant was recorded. For effective weed control, Ademiluyi *et al.,* (2013) recommended the application of Pendimethalin at the rate of 1.0 and 1.5 kg /ha + manual weeding. Pendimethalin at 1.5 kg/ha resulted in a high fresh pod yield of 6.56t/ha which was high among other treatments (Bagudo *et al.,* 2016). Baguio *et al.,* 2016 recommended the application of Pendimethalin at the rate of 1.5 kg/ha.

The highest fruit yield of okra was reported by Patel *et al.,* (2004) when conducting a study on the Effect of Methods of Herbicide Application on Weeds and Okra *(Abelmoschus esculentus* L.) Moench Gujarat hybrid Okra-I was chosen as the hybridof choice. Pendimethalin was among the twelve treatments at the application rate of 1.0 kg/ha. The highest fruit yield recorded was 12.40 t/ha which was significantly higher than the other treatments.

In a study conducted by Jalendhar *et al.,* 2016 evaluating the effect of integrated weed management practices on growth, yield, and its attributes on Okra *(Abelmoschus esculentus* L.) Moench) Cv Arka Anamika. Among 12 treatments that were used, two treatments were of Pendimethalin at the rate of 0.6 kg/ha and 0.6 kg/ha plus one hand weeding when the crop is 30DAS.

Jalendhar *et al.,* 2016 reported that all crop parameters were significantly higher in the treatment of pendimethalin at 0.6 kg/ha plus one hand weeding at 30DAS than in treatment of pendimethalin at 0.6 kg/ha. Plant heights of 80.23 cm and 84.63 respectively. There was no significant difference between the initial plant population and the final plant population of the crop that was observed throughout the crop cycle. The leaf area index was increased from 1.113 to 1.189.

The results also showed 50 percent flowering was recorded when okra was about 37 to 39 days after sowing (37.33% and 38%) whereas early 50 percent flowering resulted in a weedy check treatment (control) by 2 to 4 days before. There was no significant difference in the number of pods per plant between the above-mentioned treatment and that is 16.88 and 17.99 pods per plant respectively. A significant difference in pod yield per plant recorded was 91.84g and 103.47g. Pod yield per plant was increased when pendimethalin at 0.6 kg/ha plus one hand weeding at 30DAS.

The highest total pod yield recorded was 102.13 kg/ha which was obtained from the treatment of pendimethalin at 0.6 kg/ha plus one hand weeding at 30DAS while 90.23 kg/ha was recorded in a treatment of pendimethalin at 0.6 kg/ha. From the results above, it can be concluded that for effective weed management in okra, pendimethalin should be applied at the application rate of 0.6 kg/ha plus one hand weeding at 30 DAS.

2.7. Gross Margins determination for Trifluralin, Metolachlor, Alachlor and Pendimethalin sprayed on seedlings of Okra *(Abelmoschus esculentus* L.) Moench.

No literature was found on the efficacy evaluation of selected soil-applied herbicides on the Okra *(Abelmoschus esculentus* L.) Moench cultivar that was conducted in the Mutale magisterialarea in which the four selected soil-applied herbicides have been used on Clemson

Spineless or other cultivars. Therefore, there was no literature to demonstrate the existence of empirical data about Gross Margin comparisons among the four pre-emergence herbicides for weed control and production of Okra *(Abelmoschus esculentus* L.) Moench.

Gross margin is defined by Anonymous (2016c) as net sales of produced goods, less the production cost of goods sold. Anonymous (2016c) explained that Gross Margin is frequently expressed as a percentage, called the Gross Margin Percentage, and is calculated using the following formula where estimated figures will be used:

Gross Margin Percentage =	Estimated Net Sales of Okra – Estimated Input Costs of Okra x 100. Estimated Net Sales of Okra

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CHAPTER THREE

MATERIALS AND METHODS

3.1. Introduction

Okra *(Abelmoschus esculentus* L.) Moench is a traditional annual commercial vegetable thatusually requires warm growing conditions, and it is also believed that its production originated in Africa and Asia (Asawalam and Chukwu, 2012). In 1753, Linnaeus included Okra in the genus *Hibiscus* in the division of *Abelmoschus* in the family Malvaceae. Taxonomists have portrayed almost 50 species (Van BorssumWaalkes, 1966). Van BorssumWaalkes (1966) and its continuation by Bates (1968) have undertaken a revision of the taxonomical which comprises the most fully documented studies of the genus Abelmoschus. The production ofOkra *(Abelmoschus esculentus* L.) Moench is estimated at 6 million tons per hectare which is for fresh fruit and vegetables (Iyagba *et al.,* 2012; Pandey *et al.,* 2014). According to Kumar *et al.,* (2010), Okra *(Abelmoschus esculentus* L.) Moench is regarded as an indigenous crop of which its productivity is growing throughout the world. Its production is basically for its fibrous fruits which are pods that contain round seeds that are white (Jahan *et al.,* 2012).

The fruits are harvested when immature and eaten as a vegetable while it is a good source of vitamins (A, B, and C), protein, and carbohydrates (Van Rensburg *et al.,* (2007); Osawaru and Dania-Ogbe, 2010). It is an important summer and annual vegetable because of its nutritive value since it plays an important role in meeting the demand for vegetables in the country when vegetables are scanty in the market (Singh *et al.,* 2016).

Global crop yields are impacted by weeds, which lower yield, and climate change, which can have a positive or negative impact on both crop and weed species (Vila *et al.,* 2021). Global demand for food production is rising in tandem with the growth of the human population. A changing set of factors is also affecting the availability of food (Colbach *et al.,* 2019). Weed species are spreading more widely and weeds resistant to herbicides are more common. Global crop losses due to weeds are already higher than those caused by pathogens or insect pests (Shivalingaswamy *et al.,* 2002; Fried *et al.,* 2017); yield losses resulting from non-native weeds can reach 42% of crop production (Vila *et al.,* 2004).

3.2. Materials and Methods

3.2.1. Experimental Site and Design

Mutale magisterial area is located within the Vhembe District of Limpopo province (Figure 2) and is selected as the study site with GPS readings Latitude: -22° 34' 59.99" S Longitude: 30°39'59.99"E. "Thermoperiod" refers to the time a plant spends exposed to a specific temperature regime. This may specifically describe the daytime and or night temperature variation when the temperature and period are at or close to the ideal values for inducing different activities, like growth or flowering (Adeola *et al.,* 2017). Approximately 681mm of rainfall is received in Mutale per year, with most precipitation occurring mostly during midsummer.

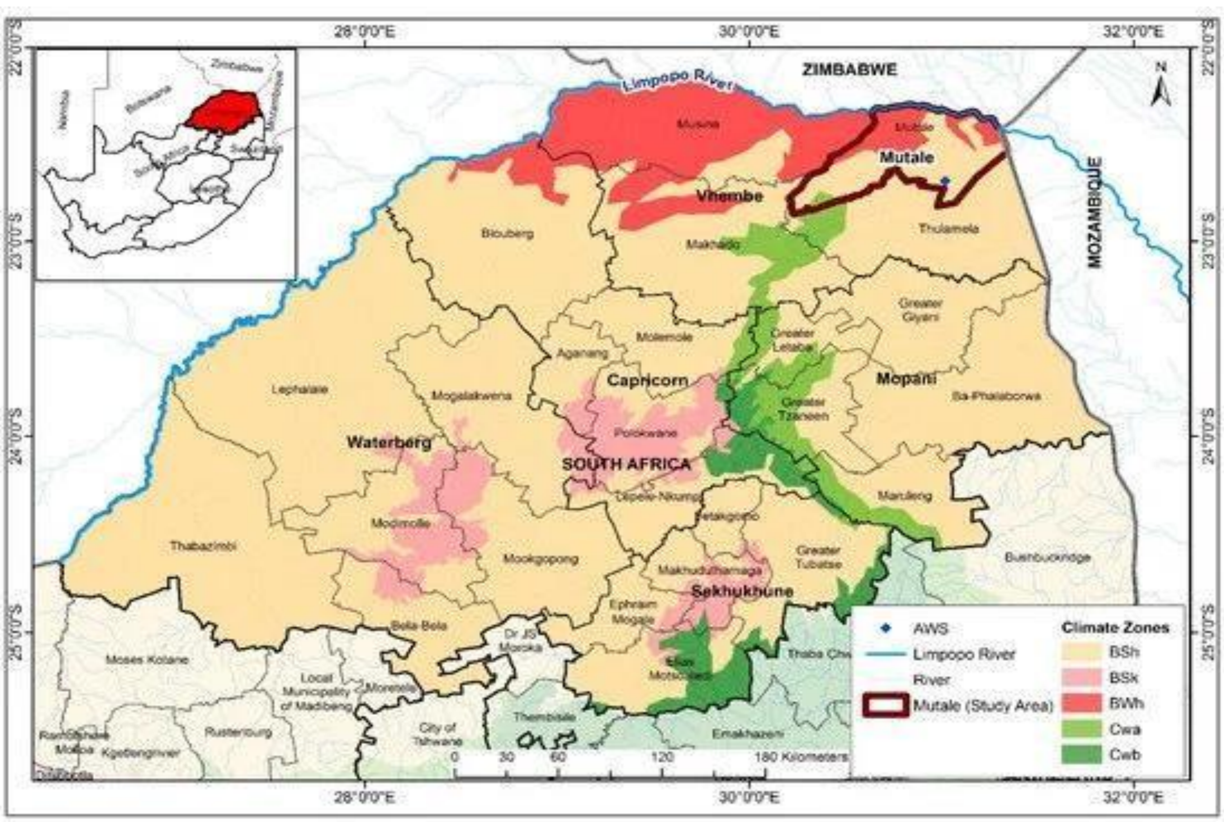

Figure 2. Map showing Limpopo Province locating Mutale municipality in South Africa.

The chart below shows the average rainfall values for Mutale per month. It receives the lowest rainfall (2mm) in July and the highest (137mm) in January (Maponya and

Mpandeli, 2015). The monthly distribution of average daily maximum temperatures (Centre chart below) shows that the average midday temperatures for Mutale range from 22.1°C in June to 29.2°C in January. The region is the coldest during July when the mercury drops to 7.7°C on average during the night (Adeola *et al.,* 2017). In a fully automated greenhouse where okra will be planted, these thermoperiods of the Mutale magisterial area will be replicated.

Banks *et al.,* (2001) described simulation as the process of gradually replicating how a system or process would work in the real world. To simulate something,a model must first be created, one that captures the essential traits or actions of the chosen physical or abstract system or procedure. According to Banks *et al.,* (2001),the simulation depicts the system's operation over time, while the model represents the system itself.

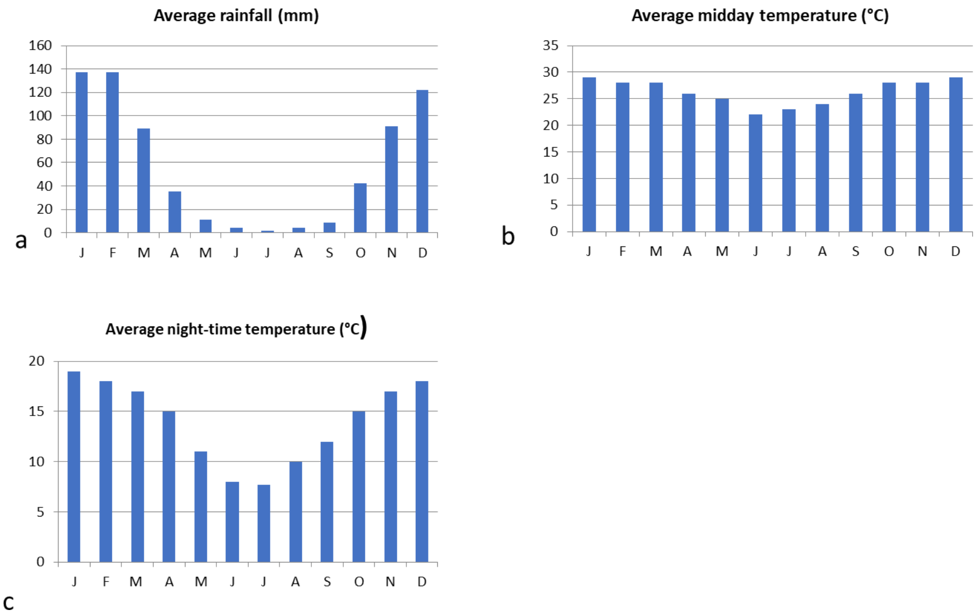

Figure 3. Thermoperiods of Mutale municipality (a) depict the average rainfall (mm), (b) the average midday temperatures (◦c), (c) depicts the average night-time temperature (◦c). (Adeola *et al.,* 2017).

Mutale magisterial area is characterized by the farmers who use mechanical weed control using hand, hoes, or removing the weeds by hand (Wilding *et al.,* 1986). In some areas, commercial farmers use post-emergence herbicides to control weeds in the field whereas the use of pre-emergence herbicides is very scanty (Sutton and

Burgis, 1966).

Trials for Efficacy Evaluation of Selected Soil Applied Herbicides on Okra *(Abelmoschus esculentus* L.) Moench seedlings were carried out in a fully automated Greenhouse at UNISAFlorida Campus Horticultural Centre simulating Mutale thermoperiods. Mutale magisterial area is in the Vhembe District of Limpopo province with the coordinates: 22.5108° S and 30.8039° E. A factorial experiment was laid out in acompletely randomized block design in a glasshouse at the Florida campus, University of South Africa (UNISA), Johannesburg, Gauteng Province (26° 10' 30'S, 27° 55' 22.8' E). There was a total of 5 treatments per herbicide and 1 control which was deployed to a single factor Randomized Complete Block Design (RCBD) with three replications. They were employed by Gomez and Gomez (1984). There was a total of 5(five) treatments per herbicide and 1 control. The treatments were replicated 3 times. After replication, the total number of treatments per herbicide was 15 with 3 replicated treatments of control.

Note that the 5 treatments/ rates (0.25ml, 0.75ml, 1ml, 1.25ml, and 1.75ml per liter) were each randomly assigned to different 20cm diameter pots planted at 2 seeds, 2cm apart in autoclaved washed sand. Note that the only variables in this experiment will be the different levels of herbicides (i.e. application rates). This means that all other factors were employed as per standard agronomic recommendations for okra cultivar production. Spraying of the herbicide treatments was done using a hand sprayer that was calibrated according to Sumner (1997) and Patel *et al.,* (2017).

Plant height (measured in cm): The plant height was measured with a meter ruler from the base top of the plant (at the soil surface) to the main shoot of the plants. The mean of the plant height was determined and expressed in centimeters per pot. It was taken at 7, 14, 21 and 28 days after planting (DAP)

The stem diameter at about 5 cm above the stem base was measured using a digital Vernier caliper (Model DC – 515) while the height was measured in cm. The root diameter was also measured using a digital Vernier caliper. The plant height, number of leaves, leaf width leaf length, and root length were measured using a standard ruler in mm and cm.

3.3. Statistical analysis

The nutritional composition data were subjected to analysis of variance (ANOVA) using Statistix v. 10. All parameters (plant height, leaf length, leaf width, stem diameter, number of leaves, root length, and root diameter) were compared. All parameters were tested at $P \leq 0.05$ according to Fisher's Least Significance Difference (LSD) test was used for the separation between treatment means.

3.4. Results and discussion

According to Table 4, the soil-applied pendimethalin herbicide had no significant difference when the herbicide was applied at different ratios measured in weekly intervals. The samples treated with 0% herbicide showed a significant difference at week 4 witha mean of 1.10, while week 1 showed a mean of 0.96, for week 2 and week 3 with means of 1.02 and 1.09 respectively meaning that application of pendimethalin didn't give any significant difference on the measured parameters.

For rate 1, week 4 showed a slightly significant difference with a mean of 0.83 when compared to weeks 1, 2, and 3 with means of 0.49, 0.60, and 0.77 respectively. The Relative impact (%) for stem height was negatively noted between 49 and 79 between the control and the other 5 different soil-applied herbicide. For rate 1, the negative values state that the herbicide had reduced the stem hence 74 at week 1 and 50 for week 4 in percentage. There was no significant difference when the soil was treated with other rates of Pendimethalin.

Table 4. The effect of different concentrations of Pendithenthalin on agronomic traits of Okra (Continued).

Rate	Weeks	Height	RI (%)	Leaf length	RI (%)	Leaf width	RI (%)	Stem diameter	RI (%)	Leaves number	RI (%)
0	1	0.96(8.1)^{c}	-	0.41(1.6)^{efg}	-	0.39(1.43)^{ef}	-	0.08(0.19)^{n}	-	0.48(2)^{e}	-
0	2	1.02(9.6)^{ab}	-	0.56(2.63)^{d}	-	0.52(2.33)^{d}	-	0.11(0.21)^{kl}	-	0.63(3.33)^{d}	-
0	3	1.09(11.27)^{a}	-	0.68(3.8)^{ab}	-	0.65(3.47)^{ab}	-	0.17(0.50)^{defg}	-	0.75(4.67)^{bc}	-
0	4	1.10(11.53)^{a}	-	0.72(4.23)^{a}	-	0.66(3.53)^{ab}	-	0.18(0.54)^{cdef}	-	0.80(5.33)^{ab}	-
1	1	0.49(2.13)^{ij}	-74	0.39(1.43)^{efgh}	-10	0.31(1.07)^{fg}	-26	0.12(0.31)^{jk}	65	0.48(2)^{e}	0
1	2	0.60(3)^{g}	-69	0.45(1.83)^{of}	-30	0.42(1.63)^{e}	-30	0.16(0.46)^{fgh}	59	0.63(3.33)^{d}	0
1	3	0.77(5)^{cde}	-56	0.62(3.2)^{bcd}	-16	0.59(2.9)^{cd}	-16	0.21(0.64)^{ab}	28	0.75(4.67)^{bc}	0
1	4	0.83(5.8)^{c}	-50	0.67(3.67)^{ab}	-13	0.63(3.27)^{ABC}	-8	0.23(0.68)^{a}	30	0.86(6.33)^{a}	19
2	1	0.51(2.23)^{hij}	-72	0.35(1.23)^{gh}	-23	0.32(1.1)^{fg}	-23	0.12(0.32)^{jk}	68	0.48(2)^{e}	0
2	2	0.61(3.1)^{fg}	-68	0.42(1.67)^{efg}	-37	0.37(1.37)^{efg}	-41	0.15(0.42)^{ghi}	44	0.63(3.33)^{d}	0
2	3	0.81(5.47)^{cd}	-51	0.62(3.13)^{bcd}	-18	0.55(2.6)^{cd}	-25	0.20(0.57)^{bcde}	15	0.75(4.67)^{bc}	0
2	4	0.84(5.93)^{c}	-49	0.66(3.53)^{abc}	-17	0.62(3.13)^{abc}	-11	0.21(0.61)^{abc}	16	0.82(5.67)^{a}	6
3	1	0.43(1.7)^{j}	-79	0.34(1.17)^{h}	-27,	0.31(1.03)^{g}	-28	0.09(0.21)^{lmn}	16	0.48(2)^{e}	0
3	2	0.55(2.57)^{ghi}	-73	0.43(1.7)^{ef}	-35	0.37(1.37)^{efg}	-41	0.13(0.35)^{ijk}	22	0.60(3)^{d}	-10
3	3	0.69(3.87)^{ef}	-66	0.58(2.83)^{cd}	-25	0.55(2.53)^{cd}	-27	0.17(0.49)^{efg}	-1	0.73(4.33)^{c}	-7
3	4	0.72(4.23)^{e}	-63	0.63(3.3)^{bcd}	-22	0.60(2.97)^{abcd}	-16	0.18(0.52)^{cdef}	0	0.82(5.67)^{a}	6
4	1	0.48(2)^{ij}	-75	0.34(1.17)^{h}	-27	0.31(1.03)^{g}	-28	0.08(0.21)^{mn}	9	0.48(2)^{e}	0
4	2	0.56(2.67)^{ghi}	-72	0.43(1.7)^{ef}	-35	0.39(1.47)^{ef}	-37	0.14(0.39)^{hij}	36	0.63(3.33)^{d}	0
4	3	0.74(4.87)^{de}	-60	0.62(3.13)^{bcd}	-18	0.59(2.9)^{abcd}	-16	0.19(0.56)^{bcde}	13	0.73(4.33)^{c}	-7

4	4	0.77(4.87)^{cde}	-58	0.66(3.53)^{abc}	-17	0.64(3.37)^{ab}	-5	0.21(0.61)^{abc}	17	0.80(5.33)^{ab}	0
5	1	0.46(1.9)^{j}	-77	0.37(1.37)^{fgh}	-15	0.34(1.2)^{efg}	-16	0.10(0.27)^{klm}	44	0.48(2)^{e}	0
5	2	0.60(2.97)^{gh}	-69	0.46(1.9)^{e}	-28	0.42(1.67)^{e}	-29	0.15(0.42)^{ghi}	46	0.63(3.33)^{d}	0
5	3	0.72(4.33)^{e}	-62	0.64(3.43)^{bcd}	-10	0.59(2.97)^{bcd}	-14	0.20(0.59)^{abcd}	19	0.73(4.33)^{c}	-7
5	4	0.77(4.9)^{cde}	-56	0.69(3.97)^{ab}	-6	0.67(3.77)^{a}	7	0.21(0.63)^{ab}	21	0.80(5.33)^{ab}	0
P value		0.2204		0.9923		0.9278		0.9115		0.9714	
F value		1.34		0.31		0.50		0.53		0.40	
LSD0.05		2.013		2.013		2.013		2.013		2.013	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). *****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in the bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100

According to Table 4, in week 1, the control (0% herbicide) showed high significant difference at week 4 with a mean of 0.72 compared to weeks 1, 2, and 3 with means of 0.41, 0.56, and 0.68 respectively. Moreover, rate 1; showed high leaf length in week 4 with a mean of 0.67, followed by week 3 then week 2, and lastly week 1 with means 0.62, 0.45, and 0.39 respectively. Rate 2, week 4 has shown the highest mean for leaf length; the same results were observed for control in week 4 compared to weeks 1, 2, and 3. The means for the weeks are as follows; 0.35, 0.42, 0.62, and 0.66 respectively for 4 weeks. On the other hand, rate 3; week 4 showed the highest leaf length whereas week 1 recorded the least. Week 4 had a mean of 0.63, whilst week 1 had the lowest mean of 0.34.

The same findings were observed for rate 4. Furthermore, rate 5; also shows similar results compared to the other 4 rates. Week 4 showed the highest leaf length with a mean of 0.69 which was the highest compared to the other 3 weeks. The means for weeks 1, 2, and 3 were 0.37, 0.46, and 0.69 respectively. The Relative impact (%) for leaf length was negatively noted between 6 and 37 between the control and other 5 different pendimethalin soil-applied herbicide. For rate 5, the negative values state that the herbicide had reduced the leaf length hence 15 for week 1 and 28, 10 and 6 for week 4 in percentages respectively.

According to Table 4, the leaf width did not show a significant difference when the treatment was compared. The results show that the highest leaf width was observed at week four with a mean of 0.66 for control followed by week three with a mean of 0.65. Week two on the other hand had the second lowest compared with week one, the means were 0.52 and 0.39 for weeks 1 and 2, respectively. The same trend has been observed for leaf width as well, rate one; week four showed the highest leaf width with a mean of 0.63. Week three did not show a significant difference when compared to week four.

The recorded means for week three were 0.59. Nonetheless, the lowest leaf width was observed in week one for control. Followed by week two with means of 0.39 and 0.52, respectively. The leaf width was significantly different for rates 2, 3, 4, and 5 when week one was compared to week four. The Relative impact (%) for leaf width was negatively noted between 5% and 41% between the control and other 5 different Pendimethalin soil-applied herbicide. Nonetheless, rate 5 at week 5 has positively affected the leaf width and the relative impact was 7%. For rate 1, the herbicide had negatively reduced the leaf width with 26, 30, 16, and 8 for weeks 1 to 4 respectively. Rate two has also negatively affected the leaf width for weeks 1 to 4 with percentages of 23, 41, 25, and 11% respectively.

Furthermore, rate three also had a significant negative impact on the leaf width for all 4 weeks with percentage values of 28, 41, 27, and 16% respectively. Moreover, rate four has also negatively affected the leaf width with percentages of 28, 37, 16, and 5 % for weeks 1 to 4, respectively. Lastly, the same results were observed for rate five; with negative impact percentages of 16, 29 and 14% respectively. Nonetheless, when the Okra was treated with pendimethalin at rate five, the leaf width was positively increased to 7 % at week four.

The stem diameter showed a significant difference when Okra was treated with control and five other levels of the soil-applied herbicide. The stem diameter had means of 0.08, 0.11, 0.17, and 0.18 respectively for weeks 1 to 4. There was a significant difference at week four when the soil was treated with rate one with a mean of 0.23, followed by week three then two lastly week one with means of 0.16 and 0.12, respectively. Rate two has positively increased the stem diameter for weeks 1 to 4 with percentages of 65, 59, 28, and 30% for weeks to four, respectively.

The highest stem diameter was observed when rate five was applied compared to the control, followed by rates 2, 3, and 4, respectively. Week four had a mean of 0.21, followed by 0.20, 0.15, and 0.10 for weeks 3, 2, and 1, respectively. The results also showed an increased stem diameter when the Okra was subjected to rate five, the percentage was as follows: 44, 46, 19, and 21% respectively for weeks 1-4. The number of leaves was not significantly different for all different rates when applied in all 4 weeks.

Table 5. The effect of different concentrations of Pendithenthalin on length and root diameter was measured after 4 weeks of Okra.

Rate	**Root length**	**RI (%)**	**Root diameter**	**RI (%)**
0	1.91(79.68)[a]		0.37[a]	
1	1.54(33.79)[c]	-58	0.38[a]	3
2	1.61(40.01)[bc]	-50	0.40[a]	7
3	1.67(46.35)[b]	-42	0.39[a]	5
4	1.55(34.91)[c]	-56	0.40[a]	6
5	1.86(72.25)[a]	-9	0.46[a]	23
P value	0.0000		0.5364	
F Value	34.60		0.86	
LSD0.05	2.179		2.179	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). *****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in the bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

Table 5 depicts the root length and diameter of Okra treated with the control and five rates of soil-applied herbicide for a month. The results show that there was no significant difference in root length in all the different rates of the soil-applied herbicide. Nonetheless, there was a high significant difference in root diameter when the control was compared with five rates of soil-applied pendimethalin herbicide.

Table 6. The effect of different concentrations of Alachlor on agronomic traits of Okra (Continued).

Rate	Weeks	Plant height (cm)	RI (%)	Leaf length(cm)	RI (%)	Leaf Width (cm)	RI (%)	Stem diameter (cm)	RI (%)	Number of leaves	RI (%)
0	1	$4,67^{jklm}$		-	-	-	-		-	$0,48(2,00)^{h}$	-
0	2	$9,80^{cdefg}$		$0,58(2,83)^{abcd}$	-	$2,60^{abc}$	-	$0,08(0,22)^{b}$	-	$0,60(3,00)^{ef}$	-
0	3	$11,87^{abc}$		$0,62(3,20)^{ab}$	-	$2,80^{ab}$	-	$0,12(0,31)^{b}$	-	$0,67(3,67)^{cde}$	-
0	4	$13,37^{ab}$		$0,65(3,53)^{a}$	-	$2,90^{a}$	-	$0,11(0,28)^{b}$	-	$0,73(4,33)^{gabc}$	-
1	1	$3,27^{lm}$	-30	-	-	-	-		-	$0,48(2,00)^{h}$	0
1	2	$7,80^{fghi}$	-20	$0,56(2,67)^{brief}$	-6	$2,27^{abcd}$	-13	$0,09(0,23)^{b}$	5	$0,52(2,33)^{gh}$	-22
1	3	$9,23^{cdefg}$	-22	$0,59(2,93)^{abcd}$	-8	$2,20^{bcde}$	-21	$0,12(0,32)^{b}$	4	$0,63(3,33)^{de}$	-9
1	4	$9,13^{defg}$	-32	$0,60(2,97)^{abcd}$	-7	$2,50^{abc}$	-14	$0,14(0,37)^{b}$	35	$0,78(5,00)^{a}$	15
2	1	$3,37^{lm}$	-28	-	-	-	-	-	-	$0,48(2,00)^{h}$	0
2	2	$8,30^{defgh}$	-15	$0,52(2,33)^{defg}$	-18	$2,13^{cde}$	-18	$0,10(0,25)^{b}$	14	$0,52(2,33)^{gh}$	-22
2	3	$9,93^{cdef}$	-16	$0,56(2,67)^{bcdef}$	-17	$2,23^{bcd}$	-20	$0,14(0,31)^{b}$	2	$0,60(3,00)^{of}$	-18
2	4	$10,63^{cde}$	-20	$0,60(2,8)^{abcd}$	-21	$2,37^{abcd}$	-18	$0,12(0,33)^{b}$	19	$0,63(3,33)^{de}$	-23
3	1	$4,10^{klm}$	-12	-	-	-	-	-	-	$0,48(2,00)^{h}$	0
3	2	$8,07^{efghi}$	-18	$0,54(2,43)^{cdef}$	-14	$2,13^{cde}$	-18	$0,54(8,50)^{a}$	3823	$0,56(2,67)^{fg}$	-11
3	3	$10,97^{bcd}$	-8	$0,60(3,00)^{abcd}$	-6	$2,63^{abc}$	-6	$0,12(0,31)^{b}$	1	$0,63(3,33)^{de}$	-9
3	4	$13,90^{a}$	4	$0,64(3,33)^{ab}$	-6	$2,90^{a}$	0	$0,14(0,37)^{b}$	35	$0,75(4,67)^{ab}$	8
4	1	$3,50^{klm}$	-25	-	-	-	-	-	-	$0,48(2,00)^{h}$	0
4	2	$7,20^{ghij}$	-27	$0,49(2,10)^{efgh}$	-26	$1,80^{def}$	-31	$0,10(0,26)^{b}$	20	$0,48(2,00)^{h}$	-33
4	3	$9,17^{cdefg}$	-23	$0,57(2,73)^{abcde}$	-15	$2,33^{abcd}$	-17	$0,11(0,28)^{b}$	-9	$0,67(3,67)^{cde}$	0
4	4	$10,30^{cdef}$	-23	$0,61(3,07)^{abc}$	-13	$2,37^{abcd}$	-18	$0,12(0,32)^{b}$	17	$0,69(4,00)^{bcd}$	-8

5	1	2,53^{m}	-46	-	-	-	-	-	-	0,48(2,00)^{h}	0
5	2	5,40^{ijkl}	-45	0,41(1,67)^{h}	-41	1,33^{f}	-49	0,10(0,26)^{b}	0	0,48(2,00)^{h}	-33
5	3	6,20^{hijk}	-48	0,44(1,87)^{gh}	-42	1,57^{ef}	-44	0,11(0,28)^{b}	-10	0,52(2,33)^{gh}	-36
5	4	6,20^{hijk}	-54	0,48(2,10)^{fgh}	-41	1,73^{def}	-40	0,10(0,25)^{b}	-11	0,60(3,00)^{ef}	-31
P at 0.05		0,3858		0,9755		0,9583		0,49		0,0141	
F value		1,1		0,3		0,35		0,97		2,33	
LSD = 0.05		2,013		2,032		2,032		2,032		2,013	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). *****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in the bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

According to Table 6, the plant height was not significantly different when the control was compared to the rates of the soil-applied herbicide. The plant height was higher at week four compared to all other weeks regardless of the rate of soil-applied herbicide applied. Week four had a mean of 1.18 followed by week two and then week one with means of 1.04 and 0.63, respectively. The same results were observed in all other rates of the soil-applied herbicide, where week four in all rates showed a significant difference compared to weeks 1, 2, and 3, respectively.

The leaf width did not show a significant difference when the control was compared to the rates of the soil-applied herbicide. There are only untransformed means presented for alachlor soil-applied herbicide because the means were normally distributed. There was a slight difference when week four was compared to weeks 3 and 2. The mean for the leaf width for week four was 3.07 followed by week three with a mean of 2.87 and lastly a mean of 2.5 for week two, respectively. There were no results for week one because the plant had no leaves. The same pattern was observed for all treatments. There were no leaves for week therefore week 4 was compared with weeks 3 and 2 respectively (Table 6). The number of leaves was individually counted from the Okra plant. The different rates of soil-applied herbicide did not show a significant difference when compared to the control in all 4 weeks.

The leaf length did not have a significant difference when the rates of soil-applied herbicide when compared to the control in all 4 weeks. No results were recorded for week one due to the slow germination of the Okra plant. There was a slight difference when results for week four were compared to weeks 3 and 2. The mean for week four was 0.66, followed by week three with a mean of 0.64 and week two with a mean of 0.58, respectively. The means for all rates except control were normally distributed hence only the untransformed means were presented in table 3. Rate one, week four had a mean of 2.57, followed by week three with a mean of 2.43, and lastly week one with a mean of 2.13, respectively. The Relative impact (%) for leaf length was negatively noted between 6 and 32 between the control and other 5 different pendimethalin soil-applied herbicide. For rate 2, the negative values states that the herbicide had reduced the leaf length hence 14 for weeks 2 and 13, and 8% for weeks 3 and 4 respectively (Table 3).

The stem diameter showed a highly significant difference when the different rates of soil-applied herbicide were compared to the control. Nonetheless, the stem diameter of Okra treated with pendimethalin at rate five, and the leaf width was positively increased to 253% at week four.

Table 7. The effect of different concentrations of Alachlor on length and root diameter was measured after 4 weeks of Okra.

Rate	**Root length (cm)**	**RI (%)**	**Root diameter (cm)**	**RI (%)**
0	9.40[a]	-	0.11[a]	-
1	6.50[ab]	-31	0.12[a]	3
2	5.40[b]	-42	0.13[a]	12
3	8.77[a]	-7	0.15[a]	29
4	4.20[b]	-55	0.13[a]	12
5	4.93[b]	-48	0.13[a]	18
P value	0.1399		0.8021	
F value	2.07		0.45	
$LSD_{0.05}$	2.179		2.179	

***Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). ***Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. ***Values in the bracket are normally distributed while the values outside the bracket are untransformed. ***RI = Relative impact (%) = [Treatment/control 1]X100.

The root length and diameter were measured after 4 weeks (Table 7). Nonetheless, the root length did not show a significant difference at week 4. The root diameter did not show a difference when the control was compared with all 5 rates of soil-applied herbicide (Alachlor). The relative impact (%) shows positive values meaning that the herbicide had increased the root diameter positively with percentages of 3, 12, 29, 12, and 18% for all 5 rates respectively. Nonetheless, the root length has been affected negatively by the rate of the soil-applied herbicide with the RI (%) values of 31, 42, 7, 55, and 48% respectively.

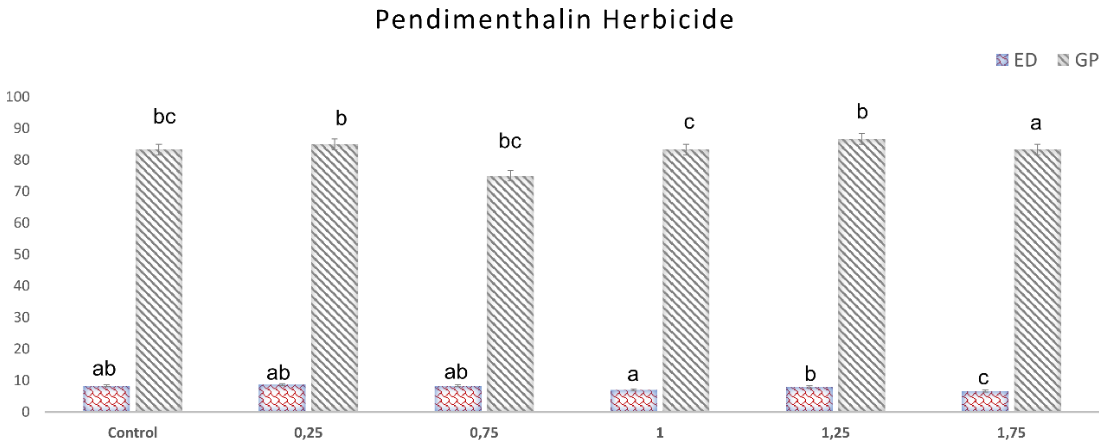

Figure 4. The effect of different concentrations of pendimethalin on emergence days (red); GP germination percentage (grey)of Okra. The mean followed by the same letters is not significantly different from each other at P≤0.05 according to Fisher's LSD.

According to Figure 4, pendimethalin did not have any significant difference. The critical T value was 2.179. There were 3 groups (a, ab, and c), in which the means were not significantly different from one another. The highest number of emergences was high at rate 3 with a mean of 9,33, followed by a rate of 1 with a mean of 8,66, followed by control with a mean of 8,33, control had lower emergences compared to rate 3 and 1 respectively. Nonetheless, control was higher at the rates 2, 4, and 5 respectively. Rate 2 recorded 8.33, rate 4 had a mean of 8,00 and lastly, rate 5 recorded the lowest number of emergences with a mean of 6,66. Pendithenthalin soil-applied herbicide had no significant difference in the germination percentage.

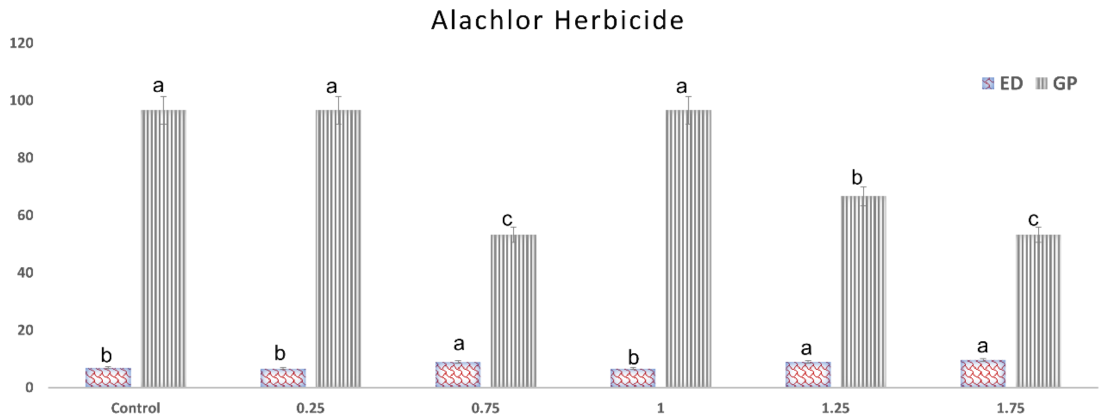

Figure 5. The effect of different concentrations of alachlor on emergence days (red); GP- germination percentage (grey)of Okra. The mean followed by the same letters is not significantly different from each other at P≤0.05 according to Fisher's LSD.

According to Figure 5, alachlor showed a significant difference when control is compared to 5 different rates of soil-applied herbicide. The critical T value was 2.179. There were 2 groups (a and b), in which the means were not significantly different from one another. The highest number of emergences was high at rate 5 with a mean of 9,66, followed by a rate of 4 with a mean of 9,00, followed by a rate of 2 with a mean of 8,66, control had lower emergences compared to rate 5, 4 and 2 respectively.

Nonetheless, the mean for control was 7,00, which was higher than rate 1 and 3 respectively. Rate 1 recorded 6,66, and lastly rate 3 recorded the lowest number of emergences with a mean of 6,66. Alachlor soil-applied herbicide had no significant difference in the germination percentage.

Regarding the effect of pendimethalin soil-applied herbicide on the production of Okra, some studies have suggested that different rates of soil-applied herbicide increase the stem height.

Some researchers Narayan *et al.,* (2020) used pendimethalin as a soil applied herbicideon Okra. According to their results, it was revealed that treatment T4 = (Pre-emergence application of pendimethalin at 6ml/lt + one hand weeding) indicated maximum plant height (104.41cms), no of leaves per plant (33.01) and pod length (14.65 cm) which was significantly greater to rest of other treatment but at equivalence with treatment T5 in case of plant height and pod length whereas no. of leaves were at par with treatment T2.Their results further indicated that a maximum number of pods per plant (17.00) was observed with treatment T3 (Pre-emergence application of pendimethalin at 6ml/lt) whichwas significantly higher with to rest of all treatments but at par with treatment T2 moreover maximum average pod weight (11.97 g) and pod yield (156.66 q ha-1) were found with treatment T2 (Weed free check (two to three hand weeding) which was greaterto rest of all treatments in case of pod yield whereas the values were at parity with rest of all other treatments except treatment T-1.

These results agree with Mekki *et al.,* (2010). The plant height varied significantly due to different treatments and rates of the soil-applied herbicide. Pendimethalin application at 1.0 kg/ha pre-emergence + single-handed weeding (T4) showed better performance in plant height than all other treatments tested except the weed-free test (T2). A plant height of (146.43 cm) indicates that pre-emergence application of pendimethalin + hand weeding had a positive effect on the growth and development of okra, followed by a weed-free test T3 (143.80 cm).

Chukuka and Wasiu (2020) in their research examined the growth of okra using pendimethalin, metolachlor + atrazine (2:1), and pre-emergence atrazine. Treatments and controls were designed in a randomized complete block design (RCBD) and replicated three times. Each plot was 2.0 × 2.0 m in size with a spacing of 1 m between plots within a replicate. Adjacent blocks were separated by 1.5 m. Significant phytotoxic effects were observed on okra plants grown in plots treated with pendimethalin, metolachlor + atrazine, and atrazine.

Okra grew in plots where 2 kg of pendimethalin was sprayed before emergence ¯ha showed no phytotoxic effect on the okra plants. Okra is grown in plots treated with 2.64 kg a.i. ha¯1 and atrazine at 3 kg a.i. ha¯1 showed phytotoxic effects; In each of the years, atrazine was significantly more phytotoxic to okra than metolachlor + atrazine. Atrazine had a phytotoxic rate of 6.8 and 4.2 on okra seedlings three weeks after sowing in the first and second years, respectively; These were well above 5.5 and 2.9 phytotoxicity values for okra caused by metolachlor + atrazine in 2013 and 2014, respectively. Atrazine in an amount of 3 kg of active ingredient per hectare was more phytotoxic in okra than metolachlor

+ atrazine in an amount of 2, 64 kg of active ingredient per hectare by Chukuka and Wasiu (2020).

Primextra (metolachlor + atrazine, used in this study at the rate of 2.64 kg API/ha, was less harmful to the okra plant than atrazine, which was used in this study at the rate of 3 kg API/ha. Okra showed sensitivity to the pre-emergence application of atrazine. On average, the phytotoxicity ratings of the herbicides were atrazine > metolachlor + atrazine > pendimethalin. Plots treated with atrazine had 4.93 and 7.91 leaves per plant in 2013 and 2014, respectively, the plots treated with atrazine had the lowest number of leaves per plant in the first year. However, in 2014, the value (7.91) in metolachlor + atrazine was comparable to the number of leaves per plant in Plots treated with pendimethalin (8.92) or metolachlor + atrazine (8.58) grew (Chukuka and Wasiu, 2020).

The number of leaves per plant in 2014 was between 7.91 (atrazine) and 9.12 (hoe-weed plots). The hoe weed-treated plots had a significantly higher number of leaves per plant than those grown in atrazine-treated plots. The average number of leaves per plant was in the order hoe weeding (10.02) = pendimethalin (9.32) > weeds (7.82) = metolachlor + atrazine (7.38) = atrazine (6.42). Okra grown in pendimethalin-treated plots was the highest (63.8 cm) in both 2013 and 2014 (65.6 cm). The height of okra grown in the other plots ranged from 19.7 cm to 58.1 cm in both years (Chukuka and Wasiu, 2020).

The shortest okra stems were found in weed-free plots; However, okra plants in plots treated with metolachlor + atrazine in 2014 did not differ significantly in height from okra plants in untreated plots. On average, okra plants growing in pendimethalin-treated plots were highest, while those growing in atrazine-treated plots were lowest. The thickest stems (3.10 cm) were produced in plots treated with weeding in 2014, and the thinnest stems (0.87 cm) were produced in plots treated with atrazine in 2013. Okra plants grown in pendimethalin-treated plots had similar stem diameters to those grown in weeded plots in both years. Each of them had an average trunk thickness of more than 2.60 cm. Okra plants grown in plots treated with metolachlor atrazine and atrazine were like those of the weed-free control; Their trunk diameter was between 0.87 and 1.17 cm (Chukuka and Wasiu, 2020).

Pendimethalin did not have a phytotoxic effect on okra over two years in this study. Okra stand survival, number of leaves per plant, stem diameter, and shoot dry weight in pendimethalin-sprayed plots were comparable to those obtained in plots weeded three and six weeks after sowing. Chukuka and Wasiu (2020) reported that pendimethalin did not affect okra seed germination at all doses tested.

Similar results were reported by Sah *et al.,* (2018) showed that all weed control treatments and weed-free control except pendimethalin at a dosage of 0.50 kg/ha (pendimethalin at a dosage of 0.5, 1.0, and 1.5 kg a.i. ha^{-1} were in this Study involved) significantly improved the growth parameters compared to weed control. Similarly, Saleh and Oyinbo (2017) suggested that farmers who weed and use agricultural technologies should be encouraged to adopt pendimethalin technology, among others, to earn more profit.

More studies have been conducted where pendimethalin for weed control in vegetable crops (Peterson, 2018). In green peppers before transplanting, this chemical has good weed control when applied at 3 or 5 L/ha (Palczynski and Anyszka, 1996). When applied before emergence at a rate of 5 l/ha, a yield was between 379.9 and 628.8 kg/ha without any significant phytotoxic damage to the crop. On the other hand, Sinha *et al.,* (1996) also obtained effective control of broadleaved weeds in onion when pendimethalin was applied post-transplanting to onion seedlings at 1.0-2.0 kg/ha on moderately fertile soil.

Other observations recorded included okra plant height and leaves/plant at 8 and 10 weeks after treatment, as well as cumulative pod production and fresh yield after the last pod harvest. All recorded data were subjected to ANOVA and the means were separated using the LSD test at $P \leq 0.05$. On the other hand, no significant differences were found in the effect of both cultivars on plant height, crop leaves/plant, and pod cumulative fresh yield or the effect of weed control method on plant height and leaves/plant.

Canopy formation, number of leaves per plant 8 weeks after treatment, and pods/plant were significantly influenced by crop variety and variety NHAE performed better than Jokoso. Similar observations were made regarding the effects of the weed control method on both stand establishment and pods/plants (Smith et al, 2009).

Moreover, Franca *et al.,* (2019); researched groundnut and okra subjecting the plants to Prim-Extra-Gold herbicides. Their results showed a progressive height gain over time. Okra experienced slow height growth with an increase in herbicide concentration of 1.0-2.0 kg active treatment/pot, especially 7-14 days after treatment. But 21 days after treatment there was an increase. The number of leaves in the tested crop showed the number of leaves in groundnut and okra plants under the different concentration treatments with Prim-Extra-Gold herbicides. The number of leaves in the treated pots was significantly ($p \leq 0.05$) lower than in the untreated (control) pots of groundnut and okra plants. It was also observed that the decrease in leaf number was dependent on herbicide concentration and the day after treatment.

More work by Dash *et al.,* (2020) has been conducted; four herbicides (treatments) namely nitenpyram, justicia, neemix, mugwort, and control were used for the study. Nitenpyram recorded the highest plant height and was significantly ($P<0.05$) better than Justicia, Neemix, mugwort, and control. Justicia was very different from control and mugwort. Neemix and Justicia were comparable, but Mugwort was only found to be non-significant and on par with the control. In a study by Zhang *et al.,* (2015), nitenpyram was found to increase plant height, which may improve plants' defenses against outside disturbances. According to Preetha and Stanley (2012), okra plants treated with neonicotinoid pesticides reached their maximum height, which accounts for the highest plant height in the plot treated with nitenpyram.

Furthermore, Smith (2004) has conducted some research on pendimethalin phytotoxicity and seedling weed control in Indian spinach. Applying pendimethalin at doses of 40.75 kg ai ha^{-1} to certain vegetable crops has proven to be effective in controlling dominant weed species with a wide range of growth forms in addition to providing good weed control. growing *Basella alba* L. in pots. Over time, weed emergence was reduced by 54.5% at higher doses especially above 0.99 kg ai ha^{-1} in comparison to lower doses.

Another work was carried out by Smith (2006) in which okra and tossa jute seedlings were exposed to different concentrations of pendimethalin. The emergence of tossa jute seedlings from the control (untreated soil) and the soil treated with 0.99 kg ai ha^{-1} pendimethalin was comparable, but the emergence of seedlings from the control was significantly ($P \leq 0.05$) higher than that from herbicide treatments.

In contrast to tossa jute, okra emergence was similar in control and herbicide-treated soils, indicating greater tolerance to pendimethalin in okra. However, the shoot lengths of okra seedlings in the control group and soil treated with 0.33–0.99 kg ai ha^{-1} pendimethalin were similar, and these were significantly higher than in soil treated with 1.32 kg ai ha^{-1} pendimethalin were treated. Moreover, Patel *et al.,* (2017) have also confirmed that pendimethalin had a significant difference when compared to untreated soil results in their research.

The root growth of crops from the control and soil treated with 0.33, 0.66, and 1.32 kg ai ha^{-1} pendimethalin was similar and significantly higher than that of soil treated with 0.99 kg ai ha^{-1} was treated with pendimethalin. Crop root growth in the herbicide-treated soil was like that of the control and the soil treated with 0.33, 0.66, and 1.32 kg ai ha^{-1} pendimethalin. Nevertheless, okra germination from herbicide solutions varied less widely with herbicide concentration. Due to superior weed control during the critical growth stage of the crop and reduced crop weed competition, this treatment demonstrated superior growth and development throughout the crop growth period, ultimately yielding higher yields than all other treatments (Smith, 2006).

Parween *et al.,* (2016) also did research on okra and cotton treated with thiamethoxamat herbicide. Throughout the experiment, the average height of each treatment group from the okra and cotton increased. Following a seven-day treatment period, thiamethoxamat caused the highest average height of cotton plants (16.94 cm), followed by imidacloprid (15.22 cm). Following a 14-day treatment period, plants treated with thiamethoxam had the highest average height of 22.82 cm, which was statistically superior to plants treated with imidacloprid, acetamiprid, and thiacloprid, all of which had average heights of more than 20 cm. After 21 days of treatment, the thiamethoxam-treated cotton plants reached a height of 26.30 cm, while the untreated check plants stood at 18.84 cm.

More studies have been conducted by Adebooye and Oputa (1996); in comparison to the 1.5 kg ai ha^{-1}, untreated, and two weeding at 3 and 6 weeks after planting (WAP) plants, respectively, the average plant height under 2.0 kg ai ha^{-}1was decreased by 94.7 %, 80.9 %, and 94.3 %. The inhibition of enzyme activity, protein metabolism, photosynthesis, and the arrest of root growth and ion uptake caused by metolachlor and metobrornuron on susceptible plant species could all be contributing factors to the growth retardation seen at 2.0 kg ai ha^{-1}.

Nandwani (2012 and 2013) researched the yield and weight of okra. The results show that yield and weight were greatly affected. At 1 kg ai ha^{-1}, the post-emergence oxadiazon yielded the highest yield; in the first and second years, the increase over the control plots was 44 and 40 percent, respectively. The pre-planting of alachlor at a rate of 2.5 kg ai ha^{-1} was the next treatment combination to be performed in addition to 1.8 kg ai ha^{-1} of post-emergence propanil. Oxadiazon following emergence at 2 kg ai ha^{-1} and putting 1.25 kg ai ha^{-1} of nitro fen in advance plus 1.25 kg ai ha^{-1} of post-emergence nitrogen per hectare was well-performing. Along with decreasing plant height and mean bulb, the phytotoxic treatments had the opposite effect on the crop. More research has been done on various crops subjected to soil-applied herbicide (Weaver, 1983).

The excellent range of efficacy of fluchloralin against weeds has also been demonstrated in sesame (Punia *et al.,* 2001); cole crops (Leela, 1985); jute (Mukherjee *et al.,* 2011); soybean (Singh *et al.,* 2014); onion (Patel *et al.,* 1987); peas (Ram *et al.,* 2011); chickpea (Kachhadiya *et al.,* 2009); cumin (Yadav *et al.,* 2005); rapeseed mustard (Singh *et al.,* 2013); potato (Sing *et al.,* 2001); maize (Praveen and Murthy, 2005); mungbean (Aktar *et al.,* 2015); chili (Rajput *et al.,* 2003); fenugreek (Kumar *et al.,* 2005) and brinjal (Chakrabarti, M., 2000).

Studies by Wascom and Fontenot, (1967); Burnside *et al.,* (1971); Singh *et al.,* (1981); Burch (1983), and Sharma*et al.,* (2000) confirmed that excellent weed control was achieved in field beans with EPTC plus alachlor at 3.36 + 3.36 kg a.i ha^{-1}. No phytotoxic effect on the culture was observed under the influence of herbicide treatment. All herbicide treatments resulted in increased plant weight and seed yields compared to the weed-free control. Using Fluchloralin, EPTC + Alachlor, and Alachlor alone (at 2.50 kg a.i ha^{-1}), the seed yields achieved were statistically like those of the weed controls, but in the case of fluchloralin, the yield was higher than that at 2.20 kg a.i. ha-1, which was achieved manually. Plant height achieved with these treatments, the lower dose of alachlor (1.94 kg a.i ha^{-1}), and both nitrofen treatments were also statistically like that achieved with the hoe controls.

Further research was carried out by Jadhao *et al.,* (1999). In their results, it was confirmed that the effectiveness of Alachlor (1.5 and 2.0 kg/ha), Anilofos (1.0 and 1.5 kg/ha), Alachlor + Glyphosate (1.5 + 1.0, 2.0 + 1.0 and 1.0 + 1.0 kg/ha) and farmers' practice (weeding at 20, 40 and 60 DAS) to control weeds of okra cv. Parbhani Kranti was evaluated in 1998 in Maharashtra, India.

In addition, farmers' practices recorded the lowest weed counts and weed dry matter accumulation, as well as the highest weed control effectiveness. It also produced the tallest (96.23 cm) plants, the longest (17.92 cm) and heaviest (11.13 g) fruits and seeds (24.65 g), and the highest yield (13.59 q/ha). The application of alachlor + glyphosate (2.0 + 1.0 kg/ha) significantly increased the seed yield and its properties, with the results being very close to those of agricultural practice. The higher alachlor rate was significantly superior to the lower rate.

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CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1. Introduction

The efficacy of soil-applied herbicide.

The term efficacy evaluation describes the process of evaluating an herbicide product's performance against a specific weed target. This evaluation mayinclude a review of the product's economic and agronomic sustainability (EPPO,

2004). A common issue that lowers okra's yield and quality is weed interference and its competition with the crop (Tufaro *et al.,* (2002)). Adejonwo *et al.,* (1991) advised that up to nine weeks following planting, weeds need to be effectively controlled. Dash *et al.,* (2020) noted a decrease as a result of uncontrolled weeds.

Due to the lack of an effective control method, weeds have been identified as a problem for most okra growers (Adejonwo *et al.,* 1991). The Mutale Magisterial Area is in the province of Limpopo's Vhembe District (Anonymous 2016a). Mutale's monthly average rainfall is displayed in the chart on the lower left of the figure below (Figure 2). The months with the least amount of rainfall (2 mm) are July and January with the most (137 mm). The average midday temperature for Mutale ranges from 22.1°C in June to 29.2°C in January, according to the monthly distribution of average daily maximum temperatures (center chart below). When the mercury averages 7.7°C at night in July, the area experiences its coldest temperatures (Anonymous 2016b).

4.2. Materials and Methods

The materials and method used are outlined in Chapter 3 at 3.2.1.

4.2.1. Statistical analysis

The statistical analysis used is outlined in Chapter 3 at 3.3.

4.3. Results and discussions.

Plant height (cm): The plant height was measured with a meter rule from the base of the plant (at the soil surface) to the tip of the main shoot of the plants. The mean of plant height was determined and expressed in centimeters per pot. It was taken at 7, 14, 21 and 28 days after planting (DAP). According to Table 3, the soil applied metolachlor herbicide had no significant difference when the herbicide was applied at different ratios measured in weekly intervals. The samples treated with 0% herbicide showed a significant difference at week 4 with a mean of 13.37, while week 1 shown a mean of 9.80, for week 2 and week 3 with means of 11.87 and 13.37 respectively.

For rate 1 (0.25ml), week 4 showed a slightly significant difference with a mean of 19.13 when compared to weeks 1, 2, and 3 with means of 3.27, 7.80, and 9.23 respectively. The Relative impact (%) for plant height was negatively noted between 8% and 54% between control and other 5 different rates of soil-applied herbicide. For all rates, the negative values state that the herbicide had reduced the stem height in percentage. The was no significant difference when the soil was treated with other rates of metolachlor.

According to Table 8, in week 1, the control (0% herbicide) for leaf length showed high significant difference at week 4 with a mean of 0.65 compared to weeks 1 and 2 with means of 0.58 and 0.65 respectively. Moreover, in rate 1 (0.25ml); there was no significant difference on leaf length in week 1 with a mean of 0.56, followed by week 3 and then week 2 with means of 0.59 and 0.60 respectively. Rate 2 (0.75ml), week 4 has shown the highest mean for leaf length; the same results were observed for control in week 4 compared to weeks 2 and 3. The means for the weeks are as follows; 0.52, 0.56, and 0.60 respectively for 4 weeks.

On the other hand, in rate 3 (1ml); week 4 showed the highest leaf length whereas week 1 recorded the least. Week 4 had a mean of 0.60, whilst week 1 had the lowest mean of 0.52. The same findings were observed for rate 4 (1.25) in all weeks. Furthermore, rate 5 (1.75ml); also shows similar results compared to the other 4 rates. Week 4 showed the highest leaf length with a mean of 0.48 which was the highest compared to other weeks. The means for weeks 2 and 3 were 0.41 and 0.44 respectively. The Relative impact (%) for leaf length was negatively noted between 6% and 42% between the control and other 5 different metolachlor soil-applied herbicide. Table 8 shows that the treatment has negatively affected the leaf length and none of the treatments affected the leaf length positively.

According to table 8 results, the leaf width did not show a significant difference when the treatment was compared. The results show that the highest leaf width was observed at week 4 with a mean of 2.90 for control followed by week 3 with a mean of 2.80. Week 2 on the other hand had the second lowest leaf width with a mean of 2.60. No results were recorded for week 1 due to the slow germination of the Okra plant. The same trend has been observed for leaf width as well, rate 1 (0.25ml); week 4 showed the highest leaf width with a mean of 2.50.

Week 3 did not show a significant difference when compared to week 4. The recorded means for week 3 were 2.20. Nonetheless, the lowest leaf width was observed in week 2 for control with a mean of 2.27. The leaf width was significantly different for rates 2, 3, 4, and 5 when week 1 was compared to week 4. The Relative impact (%) for leaf width was negatively noted between 6% and 49% between the control and other 5 different metolachlor soil-applied herbicide.

The stem diameter did not show a significant difference when Okra was treated with control and five other levels of the metolachlor soil-applied herbicide. The stem diameter had means of 0.08, 0.12, and 0.11 respectively for weeks 2 to 4 for control. There was no significant difference at week 4 when the soil was treated with rate 1 with a mean of 0.14, followed by week 3 then lastly week 2 with means of 0.12 and 0.09 respectively.

Furthermore, for rate 2 (0.75ml); no significant difference was observed in all weeks when compared to the control. The highest stem diameter was observed at week two with a mean of 0.14 followed by week 4 then lastly week 2, the means for all the weeks 4 and 2 were0.12 and 0.10 respectively. Rate 2 (0.75ml) has positively increased the stem diameter for weeks 2 to 4 with percentages of 14%, 2%, and 19% respectively.

There was a highly significant difference when the Okra was treated with rate 3 (1ml). The highest stem diameter was observed when rate 3 was applied compared to the control, followed by rate 4, 3, and 1 respectively. Week 2 had a mean of 0.54, followed by 0.14 and 0.12 for weeks 3 and 2 respectively. The Relative impact (%) for stem diameter was positively noted between 1% and 3823% between control and other 5 different metolachlor soil-applied herbicide. Table 8 shows that the treatment has negatively affected the stem diameter. The relative impact (%) was positively noted between 1% and 3823%, whereas the treatment has negatively affected the stem diameter between 9% and 11%. The highest relative impact was noted when okta was treated with rate 3 of metolachlor herbicide at week 2.

The number of leaves was not significantly different for all different rates when applied in all 4 weeks compared to the control. The Relative impact (%) for a number of leaves was negatively noted between 8% and 36% between the control and other 5 different metolachlor soil-applied herbicides. Table 8 shows that the treatment has positively affected the number of leaves between the percentage ranges of 8% and 15%.

Table 8. The effect of different concentrations of Metolachlor on agronomic traits of Okra (Continued).

Rate	Weeks	Plant height (cm)	RI (%)	Leaf length(cm)	RI (%)	Leaf Width (cm)	RI (%)	Stem diameter (cm)	RI (%)	Number of leaves	RI (%)
0	1	4,67^{jklm}		-	-	-	-		-	0,48(2,00)^{h}	-
0	2	9,80^{cdefg}		0,58(2,83)^{abcd}	-	2,60^{abc}	-	0,08(0,22)^{b}	-	0,60(3,00)^{ef}	-
0	3	11,87^{abc}		0,62(3,20)^{ab}	-	2,80^{ab}	-	0,12(0,31)^{b}	-	0,67(3,67)^{cde}	-
0	4	13,37^{ab}		0,65(3,53)^{a}	-	2,90^{a}	-	0,11(0,28)^{b}	-	0,73(4,33)^{gabc}	-
1	1	3,27^{lm}	-30	-	-	-	-		-	0,48(2,00)^{h}	0
1	2	7,80^{fghi}	-20	0,56(2,67)^{bcdef}	-6	2,27^{abcd}	-13	0,09(0,23)^{b}	5	0,52(2,33)^{gh}	-22
1	3	9,23^{cdefg}	-22	0,59(2,93)^{abcd}	-8	2,20^{bcde}	-21	0,12(0,32)^{b}	4	0,63(3,33)^{de}	-9
1	4	9,13^{defg}	-32	0,60(2,97)^{abcd}	-7	2,50^{abc}	-14	0,14(0,37)^{b}	35	0,78(5,00)^{a}	15
2	1	3,37^{lm}	-28	-	-	-	-	-	-	0,48(2,00)^{h}	0
2	2	8,30^{defgh}	-15	0,52(2,33)^{defg}	-18	2,13^{cde}	-18	0,10(0,25)^{b}	14	0,52(2,33)^{gh}	-22
2	3	9,93^{cdef}	-16	0,56(2,67)^{bcdef}	-17	2,23^{bcd}	-20	0,14(0,31)^{b}	2	0,60(3,00)^{ef}	-18
2	4	10,63^{cde}	-20	0,60(2,8)^{abcd}	-21	2,37^{abcd}	-18	0,12(0,33)^{b}	19	0,63(3,33)^{de}	-23
3	1	4,10^{klm}	-12	-	-	-	-	-	-	0,48(2,00)^{h}	0
3	2	8,07^{efghi}	-18	0,54(2,43)^{cdef}	-14	2,13^{cde}	-18	0,54(8,50)^{a}	3823	0,56(2,67)^{fg}	-11
3	3	10,97^{bcd}	-8	0,60(3,00)^{abcd}	-6	2,63^{abc}	-6	0,12(0,31)^{b}	1	0,63(3,33)^{de}	-9
3	4	13,90^{a}	4	0,64(3,33)^{ab}	-6	2,90^{a}	0	0,14(0,37)^{b}	35	0,75(4,67)^{ab}	8
4	1	3,50^{klm}	-25	-	-	-	-	-	-	0,48(2,00)^{h}	0
4	2	7,20^{ghij}	-27	0,49(2,10)^{efgh}	-26	1,80^{def}	-31	0,10(0,26)^{b}	20	0,48(2,00)^{h}	-33

4	3	9,17^{cdefg}	-23	0,57(2,73)^{abcde}	-15	2,33^{abcd}	-17	0,11(0,28)^{b}	-9	0,67(3,67)^{cde}	0
4	4	10,30^{cdef}	-23	0,61(3,07)^{abc}	-13	2,37^{abcd}	-18	0,12(0,32)^{b}	17	0,69(4,00)^{bcd}	-8
5	1	2,53^{m}	-46	-	-	-	-	-	-	0,48(2,00)^{h}	0
5	2	5,40^{ijkl}	-45	0,41(1,67)^{h}	-41	1,33^{f}	-49	0,10(0,26)^{b}	0	0,48(2,00)^{h}	-33
5	3	6,20^{hijk}	-48	0,44(1,87)^{gh}	-42	1,57^{ef}	-44	0,11(0,28)^{b}	-10	0,52(2,33)^{gh}	-36
5	4	6,20^{hijk}	-54	0,48(2,10)^{fgh}	-41	1,73^{def}	-40	0,10(0,25)^{b}	-11	0,60(3,00)^{ef}	-31
P at 0.05		0,3858		0,9755		0,9583		0,49		0,0141	
F value		1,1		0,3		0,35		0,97		2,33	
LSD = 0.05		2,013		2,032		2,032		2,032		2,013	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). *****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in the bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

Table 9. The effect of different concentrations of Metolachlor on length and root diameter was measured after 4 weeks of Okra (Continued).

Rate	Root length	RI (%)	Root diameter	RI (%)
0	6,50^{bc}	-	0,133^{b}	-
1	3,50^{bc}	-46	0,32^{a}	138
2	6,73^{ab}	4	0,16^{b}	23
3	7,33^{a}	13	0,17^{b}	30
4	5,87^{abc}	-10	0,19^{b}	45
5	3,20^{c}	-51	0,17^{b}	28
P at 0.05	0.0687		0,0577	
F value	2,77		2,95	
LSD = 0.05	2,179		2,179	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml).
*****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in the bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

Table 9 depicts the root length and diameter of Okra treated with the control and 5 rates of soil-applied herbicide for a month. The results show that there was no significant difference in root length in all the different rates of the soil-applied herbicide. Nonetheless, there was a high significant difference in root diameter when the control was compared with 5 rates of soil-applied metolachlor herbicide. The Relative impact (%) for root length was negatively noted between 10% and 51% between the control and other 5 different metolachlor soil-applied herbicides. Whereas the same rates have also positively affected the root length noted between 4% and 13% when compared to the control. On the other side, the relative impact (%) for root diameter has shown that the different rates have positively affected the root diameter with the control.

Table 10. The effect of different concentrations of Trifluralin on agronomic traits of Okra (Continued).

Rate	**Weeks**	**Plant height (cm)**	**RI (%)**	**Leaf length(cm)**	**RI (%)**	**Leaf width (cm)**	**RI (%)**	**Stem diameter (cm)**	**RI (%)**	**Number of Leaves**	**RI(%)**
0	1	3,24^{lmn}	-	0,34(1,21)^{m}	-	0,32(1,11)^{i}	-	0,10^{i}		0,48(2,00)^{d}	-
0	2	4,47^{hijk}	-	0,39(1,48)^{jkl}	-	0,37(1,32)^{ghi}	-	0,20^{cdefgh}		0,60(3,00)^{c}	-
0	3	5,64^{cdefg}	-	0,44(1,76)^{ghi}	-	0,41(1,59)^{efgh}	-	0,24^{abcd}		0,73(4,33)^{b}	-
0	4	6,40^{bcd}	-	0,51(2,23)^{cde}	-	0,44(1,80)^{cdef}	-	0,26^{abcd}		0,80(5,33)^{a}	-
1	1	2,49^{mn}	-23	0,36(1,30)^{klm}	7	0,33(1,13)i	2	0,12^{hi}	23	0,48(2,00)^{d}	0
1	2	4,40^{ijk}	-2	0,40(1,54)^{ij}	5	0,37(1,32)^{ghi}	0	0,19^{defgh}	-7	0,60(3,33)^{c}	0
1	3	5,21^{efghi}	-8	0,44(1,78)^{fghi}	1	0,39(1,46)^{fghi}	-8	0,22^{bcdef}	-8	0,73(4,33)^{b}	0
1	4	6,57^{bc}	3	0,57(2,76)^{b}	24	0,58(2,79)^{ab}	55	0,29^{ab}	13	0,82(5,67)^{a}	6
2	1	3,60^{klmn}	11	0,41(1,61)^{hij}	33	0,41(1,55)^{efgh}	40	0,13^{ghi}	33	0,48(2,00)^{d}	0
2	2	4,69^{ghijk}	5	0,46(1,87)^{fgh}	26	0,44(1,75)^{defg}	32	0,18^{defgh}	-8	0,63(3,00)^{c}	11
2	3	6,03^{cdef}	7	0,50(2,18)^{cde}	24	0,47(2.00)^{cde}	26	0,23^{abcde}	-4	0,73(4,33)^{b}	0
2	4	7,55^{ab}	18	0,64(3,38)^{a}	51	0,61(3.11)^{a}	73	0,29^{ab}	14	0,82(5,67)^{a}	6
3	1	3,95^{jkl}	22	0,36(1,27)^{lm}	6	0,34(1,19)^{hi}	8	0,15^{fghi}	50	0,48(2,00)^{d}	0
3	2	5,41^{defghi}	21	0,42(1,62)^{hij}	9	0,41(1,55)^{efgh}	17	0,20^{cdefg}	2	0,60(3,33)^{c}	0
3	3	6,56^{cde}	13	0,47(1,95)^{efg}	10	0,44(1,73)^{efg}	9	0,25^{abcd}	1	0,70(4,00)^{b}	-8
3	4	7,98^{a}	25	0,54(2,46)^{bc}	10	0,51(2,28)^{bc}	26	0,28^{ab}	10	0,78(5,00)^{a}	-6
4	1	2,47^{n}	-24	0,35(1,24)^{lm}	3	0,33(1,13)^{i}	2	0,13^{ghi}	27	0,48(2,00)^{d}	0
4	2	3,75^{kl}	-16	0,40(1,53)^{ijk}	4	0,37(1,34)^{ghi}	2	0,19^{defgh}	-5	0,63(3,00)^{c}	11
4	3	5,04^{fghij}	-11	0,44(1,78)^{fghi}	1	0,43(1,70)^{efg}	7	0,23^{abcde}	-5	0,73(4,33)^{b}	0
4	4	5,59^{cdefgh}	-13	0,49(2,08)^{def}	-7	0,47(1,96)^{cde}	9	0,31^{a}	19	0,80(5,33)^{a}	0
5	1	2,47^{n}	-24	0,34(1,18)^{m}	-2	0,23(0,76)^{j}	-31	0,16^{efghi}	57	0,48(2,00)^{d}	0

5	2	3,62^{klm}	-19	0,42(1,62)^{hij}	9	0,41(1,58)^{efgh}	19	0,20^{defgh}	-2	0,60(3,00)^{c}	0
5	3	5,37^{defghi}	-5	0,45(1,82)^{fgh}	3	0,43(1,66)^{efg}	5	0,24^{abcd}	-3	0,70(4,00)^{b}	-8
5	4	5,70^{cdefg}	-11	0,53(2,39)^{bcd}	7	0,51(2,24)^{bcd}	24	0,28^{abc}	8	0,78(5,00)^{a}	-6
P at 0.05		0.9471		0.1835		0.0489		0.9969		0.974	
F value		0.46		1.41		1.90		0.26		0.39	
LSD = 0.05			2.013		2.013		2.013		2.013		2.013

***Rates/Treatments:** (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml). *****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

According to Table 10, the plant height was not significantly different p-value of 0.05 when the control was compared to the rates of the trifluralin soil applied herbicide. The plant height was higher at week 4 compared to all other weeks regardless of the rate of soil-applied herbicide applied. Week 4 had a mean of 6.40 followed by week 3, week 2 then week 1 followed by means of 5.64, 4.47, and 3.24 respectively.

The same results were observed in all other rates of the soil-applied herbicide, where week 4 in all rates showed a significant difference compared to week 1, 2, and 3 respectively. For rate 3 (1ml) week 4, the treatment showed a highly significant difference when compared to the control. The mean for week 4 was 7.98 while weeks 1, 2, and 3 recorded the following means 3.95, 5.41, and 6.566 respectively. The Relative impact (%) for plant height was negatively noted between 2% and 24% between control and other 5 different rates of soil-applied herbicide. The relative impact (%) also shows that the plant height was positively affected when all 5 rates were compared to the control with the percentage of 3% to 25%. It can be summarized that the different rates show that the plant height was increased by 3% to 25%.

The leaf length did not have a significant difference at p-value 0.05 when the rates of soil-applied herbicide when compared to the control in all 4 weeks. For control, week 4 showed the highest leaf length compared to 5 rates of the soil-applied herbicide. There was a slight difference when results for week 4 were compared to weeks 1, 2, and 3. The mean for week 4 was 0.51, followed by week 3 with a mean of 0.44, week 2 with a mean of 0.39, and week 1 with a mean of 0.34 respectively (Table 10).

Rate 1, week 4 had a mean of 0.57, followed by week 3 with a mean of 0.44, week 2 with a mean of 0.40, and lastly week 1 with a mean of 0.36 respectively. Rate 2 (0.75ml), week 4 has shown a high significant difference at a p-value of 0.05 the highest mean for leaf length; the same results were observed for control in week 4 compared to weeks 1, 2, and 3. The means for weeks 1, 2, 3, and 4 are as follows; 0.41, 0.46, 0.50, and 0.64 respectively for 4 weeks. The Relative impact (%) for leaf length was negatively noted between 2% and 7% between the control and other 5 different trifluralin soil-applied herbicide. Moreover, the leaf length of okra has been positively affected by the different rates of the soil-applied herbicide with percentages ranging from 1% to 51%. For rate 2, the negative values state that the herbicide had increased the leaf length hence 33 for week 1, 26% for week 2, 24% for week 3, and 51% for week 4 respectively (Table 10).

The leaf width did not show a significant difference at a p-value of 0.05 when the control was compared to the rates of the trifluralin soil-applied herbicide. There was a slight difference when week 4 was compared to week 3, 2, and 1. The mean for the leaf width for week 4 was 0.44 followed by week 3 with a mean of 0.41, 0.73, and 0.32 for week 2 and 1 respectively. The same pattern was observed for all treatments. The leaf width was highest in week 4 compared to all other weeks regardless of the treatment applied.

The leaf width of okra has been positively affected by the different rates of the soil-applied to herbicide with percentages ranging from 2% to 73%. Nonetheless, the okra plant was negatively affected when different rates of soil-applied herbicide were applied with percentages ranging from 8% to 31%. The relative impact (%) was highly recorded when the okra was treated with rate 2 (0.75ml) at week 5 with a relative impact of 73%. The negative values state that the herbicide had decreased the leaf width while the positive relative impact (%) shows that the treatments had positively increased the leaf width.

The stem diameter did not show a significant difference when Okra was treated with control and five other levels of the trifluralin soil-applied herbicide. The stem diameter for control had means of 0.10, 0.20, 0.24, and 0.26 respectively for weeks 1 to 4. There are only untransformed means presented for trifluralin soil-applied herbicide because the means were normally distributed. There was no significant difference at week 4 when the soil was treated with rate 1 with a mean of 0.29, followed by week 3 then week 2 then lastly week 1 with means of 0.22, 0.19, and 0.12 respectively. Furthermore, for rate 2 (0.75ml); no significant difference was observed in all weeks when compared to the control.

The highest stem diameter was observed at week 4 with a mean of 0.29 followed by week 3 then week 2 and lastly week 1, the means for all weeks 3, 2, and 1 were 0.23, 0.18, and 0.13 respectively. The relative impact (%) was highly recorded when the okra was treated with rate 3 (0.75ml) at week 1 with a relative impact of 50%. The negative values state that the herbicide had decreased the leaf width while the positive relative impact (%) shows that the treatments had positively increased the stem diameter. The soil-applied herbicide has negatively affected the stem diameter with percentages ranging between 2% and 8%.

Nonetheless, the different rates of soil-applied herbicide have also positively affected the stem diameter with the percentages ranging between 1% and 57%. The number of leaves was individually counted from the Okra plant. The different rates of soil-applied herbicide did not show a significant difference when compared to the control in all 4 weeks. The Relative impact (%) for a number of leaves was negatively noted between 6% and 8% between the control and other 5 different trifluralin soil-applied herbicide. The same different treatments had positively affected the number of leaves and recorded 6% and 11%.

Table 11. The effect of different concentrations of Trifluralin on length and root diameter was measured after 4 weeks of Okra.

Rate	**Root length**	**RI (%)**	**Root diameter (cm)**	**RI (%)**
0	0,53[a]	-	0,33[ab]	-
1	0,51(2,21)[a]	-9	0,42[a]	25
2	0,48(2,01)[a]	-17	0,25[bc]	-25
3	0,49(2,10)[a]	-13	0,23[bc]	-31
4	0,41(1,72)[a]	-29	0,22[bc]	-33
5	0,44(1,82)[a]	-25	0,20[c]	-39
P at 0.05	0,6148		0,0265	
F value	0,73		3,82	
LSD = 0.05	2,179		2,179	

*****Rates/Treatments: (Control, Rate 1 (0.25ml), Rate 2 (0.75ml), Rate 3 (1ml,), Rate 4 (1.25ml) and Rate 5 (1.75ml).
*****Columns mean followed by the same letters are not significantly different from each other at P≤0.05 according to Fisher's LSD. Values in brackets are untransformed ([Log (x+1)]. *****Values in bracket are normally distributed while the values outside the bracket are untransformed. *****RI = Relative impact (%) = [Treatment/control 1]X100.

The root length and diameter were measured after 4 weeks (Table 11). Nonetheless, the root length showed a significant difference for rate 1 at a p-value of 0.05. However the root diameter did not show a difference when the control was compared with all 5 rates of soil-applied herbicide (trifluralin). The relative impact (%) for root length shows negative values meaning that the herbicide had decreased the root length negatively with percentages of 9%, 17%, 13%, 29%, and 25% respectively for all 5 rates of the soil-applied herbicide. Nonetheless, the root diameter has been affected negatively by the rate of the soil-applied herbicide with the RI (%) values of 25%, 31%, 33%, and 39% respectively. While rate 1 (0.25ml) has positively affected the roof diameter with a relative impact (%) of 25%.

According to Figure 6, metolachlor did not have any significant difference in the emergence days (ED); or germination percentage (GP) of Okra. There were 3 groups (a, ab, and c), in which the means were not significantly different from one another. The highest number of emergences was high at rate 5 with a mean of 9,00, followed by a rate of 4 with a mean of 8,66, followed by control with a mean of 8,33, control had lower emergences compared to rate 3 and 1 respectively. Nonetheless, control was higher than rate 2, 3, and 4 respectively. Lastly, rate 1 and 3 recorded the lowest number of emergences with a mean of 3.33. Overall, metolachlor soil-applied herbicide had no significant difference in the germination percentage.

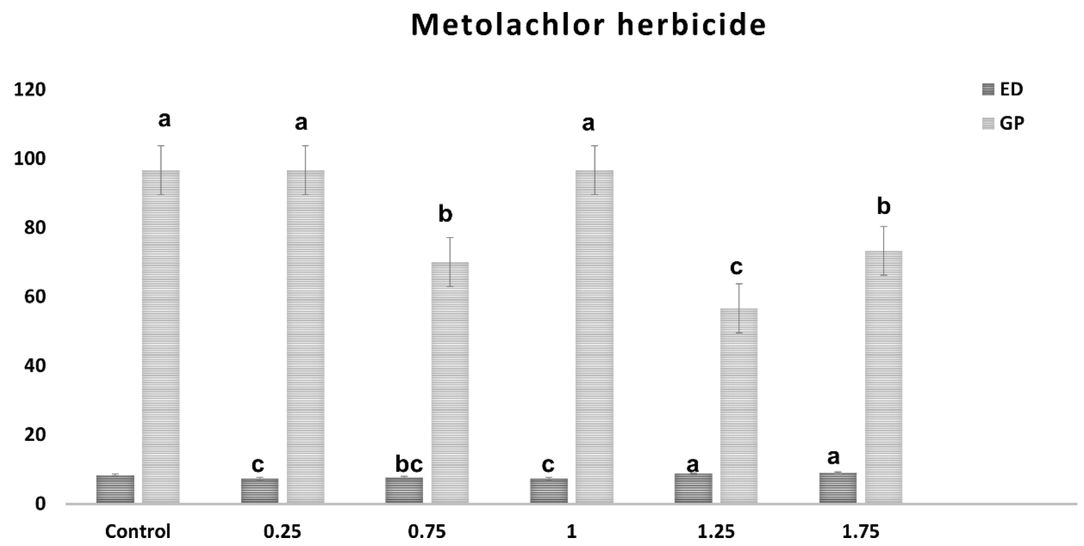

Figure 6. The effect of different concentrations of metolachlor on emergence days (dark grey); GP germination percentage (light grey) of Okra. The mean followed by the same letters is not significantly different from each other at P≤0.05 according to Fisher's LSD.

Figure 7, did not show a significant difference when the control was compared to 5 different rates of trifluralin soil-applied herbicide. There were 2 groups (a and b), in which the means were not significantly different from one another. The highest number of emergences was high in control with a mean of 7,33, followed by a rate of 5 with a mean of 7,00, followed by a rate of 1 and 3 with a mean of 6,66 respectively. Trifluralin soil-applied herbicide had no significant difference in the germination percentage.

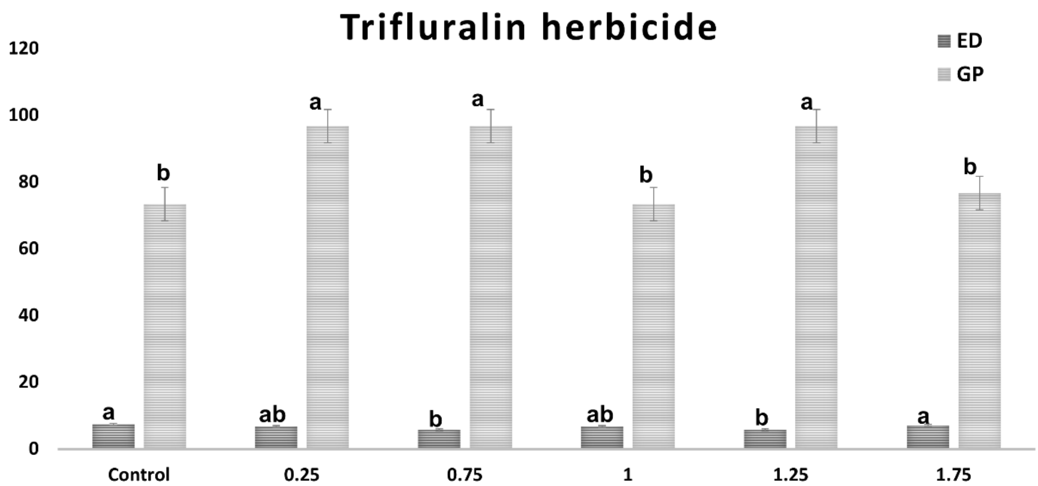

Figure 7. The effect of different concentrations of trifluralin on emergence days (dark grey); GP- germination percentage (light grey) of Okra. The mean followed by the same letters is not significantly different from each other at P≤0.05 according to Fisher's LSD.

It can be seen from the current study that the herbicide was effective at keeping the weeds under control. A study conducted in 2016 by Janak and Grichar supports the findings. According to Janak and Grichar's (2016) research, we can therefore, conclude that P. *Gonzoacantha*. physiology was unaffected by the herbicide trifluralin. Additionally, their findings indicate that P. *gonoacantha* shoots dry mass and leaf count were more prevalent at 890 g a. i. ha^{-1} and lower when the maximum herbicide dosage (1335 g a. i. ha^{-1}). Moreover, the chlorophyll content of P. Gonoacantha was unaffected by the herbicide trifluralin.

Based on research conducted by Iqbal *et al.,* (2012) herbicides' impact on weed control in saffron. Crocus weeding was found to be the most effective way to manage weeds regarding morphological characteristics, corm-related traits, and saffron yield without leaving any residues in the saffron product; however, it is an expensive, labor-intensive, and time-consuming process that could hurt producer returns. The research verified that when compared to the control group (no weeding), herbicides, including manual weeding, demonstrated noteworthy variations in terms of fresh flower weight (g), saffron yield (kg. ha-1), number of radical leaves/hills, radical leaf length (cm), corm yield (g m-2), number of daughter corms/mother corm, and weight of daughter corms/mother corm (g).

Ferreira (2018) researched to examine the effects of six weed control treatments, three hill spacings (5, 10, and 15 cm), and associated weeds on soybean plant growth, yield, and quality. Trifluralin, linuron, pendimethalin, bentazon, and hand hoeing were used as weed control treatments; an unweeded treatment served as the control. It is verified that the dry weight of weeds was significantly impacted by each weed control treatment. Plant height, weight of pods and seeds/plant, number of plants at harvest, and seed yield/ha were among the study's characteristics on which the weed control treatments had a significant impact. The application of pendimethalin increased the number of pods/plants, but hand hoeing decreased the height of the first pod; on the other hand, linuron application produced the highest values for the number of branches/plants, seed index, oil, and protein contents.

Samunder *et al.,* (2012) studied weed control efficacy of trifluralin in cotton. From their results, it can be confirmed that trifluralin provided more than 75% control of weeds over untreated plots. Compared to other techniques that used flat fan nozzles, the effectiveness of weed control was significantly lower when trifluralin was sprayed using a local tractor sprayer equipped with hollow cone nozzles. The efficacy of trifluralin was 5-15% better than pendimethalin though none was effective against *D. arvensis, Convolvulus arvensis, C. rotundus,* and Ipomoea species. At 1.0 and 1.5 kg. ha^{-1}, respectively, pendimethalin offered 60 to 85% control; however, its efficacy was inferior to that of trifluralin. Furthermore, 150 days following spraying, plant height showed a significant impact from trifluralin incorporation techniques (DAS). The outcomes align with the findings of Muthusankaranarayanan *et al.,* (1998).

Maghsoudi *et al.,* (2020) studied the effects of applying imazethapyr, which reduced chickpea injuries and halted their growth. Chickpea yield was considerably enhanced by the application of wood-shaving mulch and trifluralin alone, which also reduced weed biomass and density. The trifluralin-mulch mixture produced the highest chickpea seed yield (1450 kg. ha^{-1}) as well as biomass (3700 kg. ha^{-1}), despite the combination of wood shaving mulch and trifluralin showing two distinct results. While mulching after pre-emergence trifluralin treatment greatly reduced weeds and provided longer weed control throughout the growing season, it also hurt chickpeas, reduced their appropriate density, and showed the lowest biomass and seed yield of chickpeas.

It is possible to conclude that trifluralin application, which raises chickpea yields considerably and reduced biomass and weed density, lessens the sensitivity of chickpeas to trifluralin. However, it appears that the trifluralin-mulch combination is appropriate, increases the effectiveness of weed control, and lowers costs in this regard when applied beneath the mulch; however, it also caused crop damage and decreased chickpea yield. Finally, compared to applying trifluralin underneath the mulch, the pre-mixed combination of trifluralin and mulch reduced the efficacy of trifluralin.

Sarbout *et al.,* (2023) research was done on the use of herbicides on cowpea and sorghum plants. Treatment with trifluralin at the label rate increased biological yield by 86.46 % and seed production by 74.19 % in comparison to the control.

The yield component metrics were higher for the label rate of herbicide application when compared to the control. Incorporating sorghum wastes into the field soil increased the number of seeds per pod, the number of plants per plant, and the weight of 500 seeds by 22, 48.1, and 2.7 %, respectively, above control. However, combining a lower dosage of herbicide with sorghum residues at 800mg/m-2 resulted in larger numbers of seeds per pod, pods per plant, and 500-seed weight, which were 11, 2.2, and 42.7 % higher than using the label rate of herbicide alone. The plant height was decreased when compared to the control, all treatments dramatically reduced cowpea plant height. However, there were significant differences between all the treatments.

Sardana *et al.,* (2006) have completed more work in which one hand hoeing at the 30-day mark combined with pre-emergence application of trifluralin at 0.50 kg. ha^{-1} effectively controlled weeds and markedly increased blackgram seed yield compared to weedy check, one-hand hoeing, or herbicide application alone. When compared to their lower dose, higher herbicide doses alone did not further improve seed yield or weed control. Pendimethalin produced lower yields and less profit because the herbicide was more expensive.

Works by Kaur *et al.,* (2013) investigated the effects of various weed control methods on the growth and yield of rapeseed conducted in Ludhiana, Punjab, between 2009 and 2010. The study focused on weeds, growth, and yield of toria. Eight different herbicide applications, namely. The following treatments were used: two-hand weeding (25 and 45 days after sowing), unweeded control, and pendimethalin at 0.56 kg. ha^{-1} and 0.75 kg. ha^{-1} (preemergence), trifluralin at 0.48 kg. ha^{-1} and 0.60 kg. ha^{-1} (pre-plant and pre-emergence), and oxyfluorfen at 0.25 kg.ha^{-1} (pre-emergence). The dry weight of related weeds was considerably reduced by two-hand weeding, and preplant application of trifluralin at 0.60 kg. ha^{-1}, and pre-plant and pre-emergence application of pendimethalin at 0.70 kg. ha^{-1} when compared to the unweeded control.

In line with the trend of weed dry matter, weed control efficiency was also observed. The application of these weed control treatments increased, in conclusion. According to the research, herbicides are effective at controlling weeds and boosting toria plant yields.

Chowdhury *et al.,* (2020) investigated the herbicide sensitivity of trifluralin and atrazine to a range of cereal and legume crops. As trifluralin concentrations in the soil increased, shoot dry weight decreased significantly. At the lowest concentration (0.075 $mg.kg^{-1}$), there was a reduction of as much as 60–70% compared to the control, and at the highest concentrations, plant death occurred. When compared to other crops, lucerne exhibited the highest sensitivity to significantly lower trifluralin concentrations ($P < 0.001$) than those of other crops (0.01 $mg.kg^{-1}$).

Chaudhari *et al.,* (2019) observed a significant decrease in shoot dry weight (up to 89 percent) in turnip plants exposed to trifluralin at doses of about 170 mg/kg soil. Nosratti *et al.,* (2017) determined that a decrease in plant height, chlorophyll content, and shoot dry weight are among the toxic symptoms of trifluralin. Their findings indicate that the plant height decreased as the rates and concentrations increased. On the other hand, the presence of trifluralin in the soil had asignificant impact on the measured root parameters of nodulation, root length, and root dry weight.

All species' roots, however, had a 60–80% reduction in length even at the lowest levels of trifluralin in the soil. Roggenbuck and Penner (1987) as well as Vencill (2002) support the findings. It can also be concluded that the roots of wheat, oat, and lucerne died at a concentration of 0.30 mg/kg, whereas the roots of lentils showed their maximum mean root diameter (2 points14 mm) at a concentration of 0.30 mg/kg soil, which is four times that of the control. In contrast, the root dry weight of all crop species was significantly reduced by trifluralin, even at the lowest concentration of 0.075 $mg.kg^{-1}$ soil; reductions ranged from 95% in oat to 69% in lucerne.

Work done by Singh *et al.,* (2009) investigated how herbicides affected radish *(Raphanus sativus* L.) yield, quality, and herbicide residue. A field experiment was carried out at Ludhiana during the winter of 2007-2008 to find effective and safe herbicides for radish (*Raphanus sativus* L.). Pre-emergence herbicides viz., pendimethalin (0.37, 56 and 0.75 kg/ha), trifluralin (0.6, 0.9 and 1.2 kg. ha^{-1}), alachlor (1.25, 1.87 and 2.5 kg/ha), oxyfluorfen (0.117, 0.147 and 0.176 kg/ha), vis-a-vis, two hand hoeing (20 and 40 days after sowing) and unweeded control were evaluated. Uncontrolled weeds reduced the radish root yield by 10.7 to 27.1%.

Additionally, there was little to no detectable herbicide residue in the crop roots. Although the increase was not statistically significant when compared to the unweeded control, herbicides were also found to lengthen roots. It is concluded that when radish was treated with alachlor, pendimethalin, trifluralin, oxyfluorfen, butachlor, and metolachlor before emergence, there was a significant increase in leaf area index, total chlorophyll content, photosynthetic rate, and nitrate reductase activity when compared to the unweeded control.

Patel and Meisuriya (2008) investigated various dosages of herbicide applied to the soil for cumin. Their findings indicate that the application of different herbicides had no discernible effect on plant height at 30 days after spraying (DAS) or plant density at 15 days after spraying (DAS). The current study's results corroborate the same findings. Furthermore, the weed-free treatment had a considerably higher number of branches/plants at 30 DAS compared to all other herbicidal treatments.

However, compared to other weed control treatments, trifluralin at 0.75 kg. ha^{-1} produced a low cumin yield, most likely because the weeds were not well controlled at this dose. Prior research on these same findings was published by Mustafee (1991) and Patel and Mehta (1989). However, in areas where pendimethalin or fluchloralin was applied at a rate of 1.0 kg. ha^{-1} in the previous crop, there was a significant decrease in germination, plant height, the number of tillers per plant, and grain yield

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CHAPTER FIVE

CONCLUSIONS ANDRECOMMENDATIONS

In this research, we investigated the influence of pendimethalin, trifluralin, metolachlor and alachlor on plant height, leaf length, leaf width, stem diameter, number of leaves, root length, and root diameter in okra plants. Our results showed that pendimethalin exerts an influence on the plant height of okra compared ti alachlor, trifluralin and metolachlor-treated okra plants.

Pendimethalinrecorded a gradual increase in leaf length, leaf width, stem diameter, and leaf number on okra leaves. A significant influence of alachlor on plant height, leaf width,and stem diameter in okra plants. Alachlor herbicide was monitored by leaf number,root length and diameter, and weed control effectiveness. It is concluded that the use of pendimethalin and alachlor soil herbicides improves the production and livelihood of farmers in the Mutale district who mainly grow okra crops. In summary,the stem diameter of Okra treated with pendimethalin at rate 5, and the leaf width was positively increased to 253% at week 4.

The use of pre-emergence metolachlor and trifluralin herbicides significantly gave higher mean values of stem diameter when the okra plant was treated with rate 2. The herbicide further did not have any significant effect on the plant height, leaf length, leaf width, number of leaves, root length, and root diameter respectively. Competition between weeds and crops starts right from germination of the crop up to harvest affecting both growth and yield parameters adversely. It is therefore recommended that farmers should employ the use of pre-emergence for okra production. In conclusion, the trifluralin soil-applied herbicide did not show any significant difference at a p-value of 0.05.

ANNEXURES

APPENDIX I: ETHICS APPROVAL

UNISA university of south africa

CAES RESEARCH ETHICS REVIEW COMMITTEE

National Health Research Ethics Council Registration no: REC-170616-051

Date: 25/11/2016

Ref #: **2016/CAES/124**
Name of applicant: **Ms D Mashamba**
Student #: **58548947**

Dear Ms Mashamba,

Decision: Ethics Approval

Proposal: Efficacy evaluation of selected soil applied herbicides on *Abelmoschus esculentus* (okra) seedlings under thermoperiods simulating Mutale magisterial area

Supervisor: Dr R Awumey

Qualification: Postgraduate degree

Thank you for the application for research ethics clearance by the CAES Research Ethics Review Committee for the above mentioned research. Approval is granted for the project.

Please note that the approval is valid for a one year period only. After one year the researcher is required to submit a progress report, upon which the ethics clearance may be renewed for another year.

Due date for progress report: 30 November 2017

The application was reviewed in compliance with the Unisa Policy on Research Ethics by the CAES Research Ethics Review Committee on 24 November 2016.

The proposed research may now commence with the proviso that:

1) *The researcher/s will ensure that the research project adheres to the values and principles expressed in the UNISA Policy on Research Ethics.*
2) *Any adverse circumstance arising in the undertaking of the research project that is relevant to the ethicality of the study, as well as changes in the methodology, should*

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be communicated in writing to the CAES Research Ethics Review Committee. An amended application could be requested if there are substantial changes from the existing proposal, especially if those changes affect any of the study-related risks for the research participants.

3) *The researcher will ensure that the research project adheres to any applicable national legislation, professional codes of conduct, institutional guidelines and scientific standards relevant to the specific field of study.*

Note:

The reference number [top right corner of this communiqué] should be clearly indicated on all forms of communication [e.g. Webmail, E-mail messages, letters] with the intended research participants, as well as with the CAES RERC.

Kind regards,

Signature
CAES RERC Chair: Prof EL Kempen

Signature
CAES Executive Dean: Prof MJ Linington

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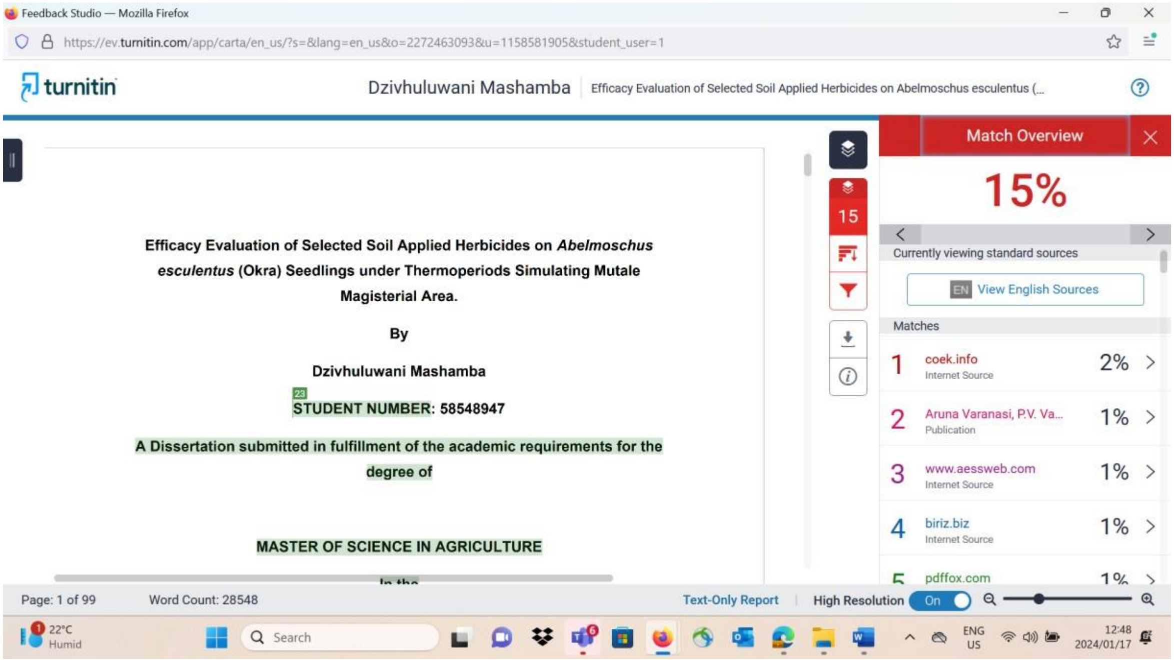
APPENDIX II: TURNITIN ORIGINALITY REPORT



APPENDIX III: MANUSCRIPTS PROOF OF SUBMISSION (ARTICLE 1)

Submission Confirmation

Print

Thank you for your submission

Submitted to	Plant-Environment Interactions
Manuscript ID	PEI3-2023-0104
Title	Efficacy Evaluation of Selected Soil Applied Herbicides (Pendimethalin and Alachlor) on Abelmoschus esculentus (Okra) Seedlings under Thermoperiods Simulating Mutale Magisterial Area.
Authors	Mashamba, Dzivhuluwani Molele, Piet Khashane Makhubu, Fikile Nelly Mongalo, Nkoana Ishmael Raletsena, Maropeng Vellry
Date Submitted	20-Nov-2023

APPENDIX IV: ARTICLE NUMBER 2 (SUBMITTED)