The effects of mechanical removal and herbicide application on the resprouting patterns of several woody plant species in the Marikana thornveld, South Africa

by

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submitted in accordance with the requirements for

the degree of

MASTER OF SCIENCE

in

AGRICULTURE

at the

University of South Africa

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September 2026

ABSTRACT

The benefits of controlling woody plants, such as increased grass production, are often temporary since many species can resprout from cut stems after felling. Combining tree cutting with immediate herbicide application to stumps is essential, as it greatly reduces resprouting in woody species. However, there is limited information on how factors such as woody species age, herbicide type, concentration, and application timing affect the efficacy of the control methods. We conducted a field experiment to determine: (1) the effects of mechanical removal alone (control) and stem treatment at herbicide concentration of 1%, 2%, and 3%; (2) type of herbicide (i.e. picloram and triclopyr amine); (3) plant age (measured by stem diameter); and (4) season of treatment application (dry versus wet season) on shoot production and vigour of seven woody species. Seven tree species were selected for the study: *Combretum apiculatum*, *Euclea undulata*, *Peltophorum africanum*, *Searsia lancea*, *Vachellia karroo*, *V. nilotica*, and *V. tortilis*. Systematically, 140 trees were selected for each woody species that were subjected to removal per season (i.e. 70 trees removed during the wet season and another 70 removed during the dry season), with the selection process ensuring that the herbicide application was consistent across the tree species. These 70 trees were further divided into seven groups of 10. The first group served as the control, receiving no herbicide treatment. The second, third and fourth groups were treated with Scrubber 240 SL (picloram) applied to the stem at a concentration of 1%, 2% and 3%, respectively. Similarly, the fifth, sixth and seventh groups were treated with Garlon™ 480 EC (triclopyr amine) applied at concentrations of 1%, 2% and 3%, respectively. Trees were cut with a chainsaw in February 2022 (wet season) and July 2022 (dry season). The findings indicate that mechanical removal alone effectively controlled woody species like *E. undulata* even 24 months after removal, especially when stems were removed during the dry season. However, this study indicated a substantial variance regarding the impact of picloram and triclopyr amine on shoot production and vigour of the study species in both

seasons of treatment application. Some of the woody species were better controlled by chemical treatment during the dry season, whereas others were better controlled during the wet season. However, for most species treated with triclopyr amine, higher concentrations were needed to substantially reduce the resprouting ability of the study plants. Nonetheless, no cut stem resprouted for *V. karroo* in this study regardless of treatment or season, including the control group (no herbicide application). Failure to resprout by *V. karroo* trees suggests that other unknown factors beyond the scope of the present study may have played a role. Nonetheless, the study findings imply that it would be more economically beneficial for land managers to consider the timing of treatment application when controlling woody plants in savanna landscapes. Moreover, the current study findings imply that when cutting and using herbicides to control undesirable trees in savannas, consideration must be given to herbicide selection, which is based on efficacy on target species while minimizing costs.

Key words: Herbicide efficacy, resprouting ability, seasonal application, woody plant control

PREFACE

The research contained in this thesis was completed in the School of Agriculture and Life Sciences, College of Agriculture and Environmental Sciences, University of South Africa, under the supervision of Dr. Piet Monegi. This thesis was co-supervised by Prof. Khanyisile R. Mbatha and Prof. Julius Tjelele. The research was financially supported by the National Research Foundation and the Agricultural Research Council.

This thesis represents original work by the author and the contents of this work have not been submitted in any form to another University. Proper acknowledgement has been given where other people's work has been used.



Nchaupa Johannes Rasekgokga

Date: September 2026

DECLARATION 1: PLAGIARISM

I, Nchaupa Johannes Rasekgokga, declare that:

(i) the research reported in this thesis, except where otherwise indicated or acknowledged, is my original work;

(ii) this thesis has not been submitted in full or in part for any degree or examination to any other university;

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ACKNOWLEDGMENTS

I am deeply grateful for the leadership, patience, support, feedback, and suggestions offered by Prof. Mbatha, Prof. Tjelele, and Dr. Monegi throughout this study. Dr. Monegi has been a mentor and a pillar of support, without whom this MSc would not have been possible. My sincere thanks!

I also appreciate the financial support from the National Research Foundation and the Agricultural Research Council (ARC). Special thanks to ARC (Animal Production, Irene) for providing the research facilities.

The success of data collection relied heavily on the assistance of Dr. Mthunzi Mndela, Mr. Mziwanda Mangwane, and Ms. Nothando Ngcobo. I am extremely thankful for their help.

I am deeply grateful to Dr. Piet Monegi and Ms. Nothando Ngcobo for their unwavering support throughout this study. Their encouragement and motivation were instrumental in helping me persevere during fieldwork.

Lastly, I dedicate this MSc to my mother, Albertina Rasekgokga, and my siblings, Derrick and Sabina Rasekgokga. I also remember my late father, Magari Rasekgokga, whose lessons on discipline and perseverance were instrumental in achieving my goals. Thank you.

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Chapter 1: Introduction

1.1. Background

Savannas are widely described as biomes where grasses dominate the understorey with scattered trees and shrubs. These ecosystems occupy about 20% of the global land surface (Scholes and Archer, 1997), with nearly half of Africa's landmass classified as savannas (Osborne et al., 2018). The structure and function of savanna ecosystems are underpinned by ever-changing interactions among climate, soil properties, and biotic factors (Backeus, 1992). The key drivers include seasonal changes in temperature and precipitation, which regulate plant growth and spatial distribution (Sankaran et al., 2005). Additionally, the interaction between fire, herbivores and soil nutrients is essential in defining plant community composition and density. For instance, regular fire events assist in maintaining the open canopy of savannas by suppressing tree growth while promoting grass productivity (Archer, 2017).

Transformation in savanna ecosystems, including modifications to fire regimes and herbivore grazing intensity, has contributed to the increase in woody vegetation into grassland areas (Luvuno et al., 2018). This encroachment, driven by alterations in vegetation dynamics, can cause savannas to be densely vegetated systems, which affects habitat structure and reduces biodiversity (Ding and Eldridge, 2019) among others. As a result, woody plant encroachment is a crucial challenge for ecosystem management and conservation, which has an impact on ecological balance and resilience of savanna landscapes (Wilcox et al., 2018). Reduction in grass biomass, often driven by anthropogenic factors such as poor rangeland management, which is

associated with land degradation and the increase in woody plants (Belayneh and Tessema, 2017; Mohammed et al., 2017; Venter et al., 2018).

1.2. Problem statement

Woody plant encroachment constitutes of a globally widespread phenomenon across grasslands and savanna ecosystems, exerting substantial effects on rangeland productivity, biodiversity, and ecosystem functioning (Ding and Eldridge, 2019). In southern African savannas, including the Marikana Thornveld, the proliferation of woody species poses a major challenge for land managers seeking to maintain grass production for livestock and wildlife (Monegi et al., 2023). Management strategies such as mechanical removal and herbicide application are commonly used to control woody plants. However, their long-term effectiveness, in relation to resprouting patterns of different woody species, remains an area requiring further investigation (Monegi, 2023; Bansal et al., 2016). Most research still focuses on the effects of herbicide type, concentration, and timing in isolation. This creates a gap in our understanding of how these factors work together to affect different woody plant species (Barbieri et al., 2022). Furthermore, there is a lack of research on integrating mechanical control with herbicide application for optimal results in the Marikana Thornveld, and insufficient data on cost-benefit analysis of herbicide versus mechanical control in local contexts.

1.3. Rationale

Mechanical removal alone is often insufficient because many woody species can resprout from cut stems. This study aimed to investigate whether combining mechanical cutting with herbicide application can effectively control the resprouting of encroaching

woody plant species in the Marikana Thornveld. The research shows how the type of herbicide, how much is used, and when it is applied can affect the control of specific woody species. This information can help improve rangeland management practises.

1.4. Aims and objectives

This study aimed to determine whether combining mechanical cutting with herbicide application can effectively control the resprouting of encroaching woody plant species in the Marikana Thornveld.

The objectives of the study were: (1) to measure how the selected woody species resprout and how vigorously they grow after being cut and treated with herbicide, (2) compare how two herbicide with different ingredients (picloram and triclopyr amine) affect the resprouting patterns of these species, (3) determine if different herbicide concentrations (1%, 2%, and 3%) affect woody plants to resprout, (4) evaluate if the time of year when treatment is applied (wet season versus dry season) affects how the herbicide results, (5) explore the relationship between stem diameter and the resprouting ability of woody plants.

To achieve these objectives, a field experiment was carried out. The following predictions were made: (1) all cut stems treated with herbicide, regardless of the species, will resprout less compared to the untreated stems, (2) both picloram and triclopyr amine will reduce resprouting and shoot growth, regardless of whether they are applied in the wet or dry season, (3) stems cut and treated during dry season will produce less shoots and lower growth than those treated in the wet season, this is because of below ground energy reserves are lower during the dry season (Enloe et al.,

2018), (4) there will be a negative relationship between stem diameter and resprouting ability, with larger trees showing less resprouting ability (Neke et al., 2006).

1.5. Hypotheses and expected outcomes

1.5.1. Positive and negative hypotheses

Null hypotheses (H_0): Changing the herbicide concentration will not result in a significant difference in the amount of woody plant resprouting.

Alternative hypotheses (H_1): Using higher concentrations of herbicide (picloram and triclopyr amine) will greatly reduce the resprouting of woody species, and this effect will be seen regardless of the time of year the treatment is applied.

1.5.2. Expected outcomes

It is expected that tree species treated with higher herbicide concentrations, such as 3%, will show lower rates of resprouting compared to those treated with lower concentrations (1% and 2%) or no herbicide at all. The reduction in resprouting is predicted to be greatest when the herbicide is applied during the dry season. This is because the carbohydrate reserves stored in the stumps are at their lowest during this time (Baillie, 2016).

Chapter 2: Literature review

2.1. Woody plant encroachment

Experimental research has identified woody plant encroachment as a primary driver of degradation in savanna rangelands (Yassin, 2019). In addition, climate change can better woody encroachment processes by altering temperature regimes, precipitation variability and through extreme weather events (Venter et al., 2018). Higher temperatures and irregular rainfall patterns can create favorable conditions for woody plants to germinate and dominate, potentially reducing the herbaceous layer (Devine et al., 2017). Moreover, long-term droughts can weaken grasses, leaving them more vulnerable to competition from woody plant seedlings, while increased rainfall in some areas can promote tree seedling establishment (February et al., 2013). Severe floods can disrupt the balance between grasses and trees by changing soil moisture and nutrients levels (Szejgis et al., 2024). Woody cover usually reaches its highest point when annual rainfall is around 650 mm (Kulmatiski and Beard, 2013). Above this level, woody plants can form dense thickets (Archer et al., 2017). More rainfall can increase the amount of water that reaches deep soil layers, which may encourage tree growth. When several wet years occur in a row, it can lead to a large increase in the number of woody plants (February et al., 2013; Brandt et al., 2019).

2.1.1. The role of fire in savanna dynamics

Fire plays a key role in keeping the balance between grasses and woody plants in savanns (Accatino et al., 2016). When fires occur regularly, they regulate plants from taking over by destroying young seedlings and saplings that are sensitive to fire

(Nefabas and Gambiza, 2007). Additionally, when fire is kept out of an area, woody plants are able to establish and grow more easily (Bond and Midgley, 2012). Without fire, young trees can mature into larger ones, which leads to woody thickening (Rachamose, 2022). This change in the plant community can happen in ecosystems that depend on fire, such as savannas, because the lack of fire allows tree cover to increase (Peris-Llopis et al., 2024).

2.1.2. The impact of rising CO_2 levels

Rising levels of CO_2 in the atmosphere are connected to increases in woody plant densities (Ward et al., 2014; Stevens et al., 2017). Higher CO_2 levels tend to favor C3 woody species over C4 grasses, since C4 grasses are adapted to the lower CO_2 levels that existed in the past (Devine et al., 2017). Research from southern Africa indicates that certain encroaching leguminous trees, like those in the *Vachellia* genus, send a large portion of the CO_2 they absorb down to their root systems (Martinez et al., 2016). Leguminous species generally respond more strongly to higher CO_2 levels compared to C4 grasses and non-leguminous plants (Singer et al., 2020; Nackley et al., 2018). Because of this, climate change together with rising CO_2 levels is expected to encourage the spread of woody plants, particularly leguminous ones. The increase in tree numbers, along with other factors that cause land degradation, presents difficulties for those managing these areas. For this reason, it is crucial to put in place management strategies that are both effective and practical to prevent further damage to savanna ecosystems (Slayi et al., 2024). Approaches that focus on maintaining or increasing grass production for livestock and wildlife farming are important (Yusuf et al., 2016; Slayi et al., 2024).

2.2. Resprouting in woody plants

In woody plants, new shoots frequently emerge from dormant buds after damage, leading to the development of multiple stems that can suppress the herbaceous vegetation necessary for pastoralism (Bond and Midgley, 2003). This approach enhances survival after natural disturbances like fire or grazing and is a widespread characteristic among many encroaching and invasive woody plants (Pausas and Keeley, 2023). Waters et al. (2010) suggested that the resprouting ability of woody plants as influenced by plant age is related to bud senescence. Therefore, thick bark in older trees may inhibit resprouting abilities through hindering bud emergence (Pausas and Lamont, 2022), which supported the results in this study. According to recent studies, tree bark thickens with size, creating a mechanical barrier that stops epicormic bud activation (Clarke et al., 2010). Additionally, smaller non-structural carbohydrate (NSC) reserves may result in a reduced ability of larger stems to resprout, as larger trees invest more resources in maintenance than storage (Piper and Paula, 2020). The observed decline in resprouting vigour as stem size increases is corroborated by recent studies showing that mature trees ability to mobilise energy for resprouting after disturbance is limited due to NSC depletion (Rosell et al., 2025; Sandoya et al., 2021).

2.3. Mechanical removal

Woody plant encroachment disrupts important ecosystem functions such as grass production, and restoring these rangelands becomes a key priority (Ding and Eldridge, 2019). Restoration can be achieved by using different management approaches, including mechanical and chemical control methods together with prescribed burning. This becomes important when ecosystems have reached a critical point, for example

when low fuel loads during dry seasons mean that natural fires are unlikely to occur (Furlaud et al., 2023). In such cases, effective restoration may require direct actions such as mechanically removing trees (Smiley et al., 2017). Mechanical removal lowers the number of trees in areas affected by encroachment, and research has shown that this can benefit savannas by increasing grass production, which in turn raises fuel loads for future fires (Monegi et al., 2022, 2024; Mndela et al., 2022).

2.4. Chemical control

Across the globe, government-led restoration programs are working to restore rangeland productivity in areas where woody encroachment has lowered economic returns (Ding and Eldridge, 2019). An important factor in these efforts is the choice of herbicide, as different chemicals can be effective on different types of woody plants (Waryszak et al., 2018). Picloram and triclopyr amine are commonly applied herbicides, usually directed to stumps after mechanical cutting (Enloe et al., 2018). These selective herbicides are formulated to control woody plants with minimal impact on herbaceous plants (Palai, 2010). Picloram and triclopyr amine are particularly effective in controlling woody plants by acting through their roots and cut surfaces, ensuring that the resprouting of stumps is minimized after tree cutting (Howard and Parker, 1991). In southern Africa, studies have documented the use of herbicides such as glyphosate and tebuthiuron to control woody encroachment (O'Connor et al., 2014; Puttick et al., 2020).

2.4.1. Picloram

Picloram is a systematic auxin-mimic herbicide that disrupts normal growth regulation by overstimulating auxin-responsive pathways, which results in unmanaged growth and plant death. Whereas it moves down to the roots, it helps stop regrowth, particularly in perennial plants (Sen et al., 2023). However, the efficacy of picloram against woody plants stems from its systemic, auxin-mimetic mode of action

and its adaptability to multiple application methods, establishing it is an important herbicide for controlling invasive and undesirable woody vegetation, especially when applied as cut stump or basal treatment (Braz et al., 2026).

2.4.2. Triclopyr amine

Triclopyr amine stops cell division in growing tissues, which leads to the death of the target woody species (Dias et al., 2017). Similar to picloram, triclopyr amine is selective. Triclopyr amine mainly target broadleaf plants, including both trees and non-woody species, but they cause little harm to grasses. This is because grasses and woody plants differ in how they take in and process chemicals (Yu and Powles, 2014). Turner et al. (2021) indicated that the effectiveness of triclopyr herbicide in controlling woody plants is species-specific. In another case, Enloe et al. (2015) reported that a 25% concentration of triclopyr amine did not work on the invasive tree *Triadica sebifera* in the southeastern United States. However, the same concentration was associated with reduced efficacy against another invasive plant, *Ligustrum sinense*, in the same area (Enloe et al., 2016).

2.5. Herbicide concentration

The selection of herbicide treatments can depend on a number of factors. These include the type of woody species being targeted, the type of herbicide used, how much is applied, and when it is applied (Badalamenti et al., 2015; Enloe et al., 2016, 2018). Often, these factors are examined separately rather than together. For example, Monegi et al. (2023) found that applying picloram at a rate of 6 mL per liter of water only reduced resprouting in four out of the twelve tree species they studied.

2.6. Seasonality of application

When herbicide is applied also matters a great deal. Treatments carried out during the wet season, when plants are growing actively, usually lead to better uptake of the chemical. However, applying herbicide during the dry season may not work because plant activity slows down (Enloe et al., 2016). Getting the timing right helps the herbicide to be taken up more effectively, lowers the chance of regrowth, and cuts down on the need for repeat treatments. This saves money and labour and also reduces harm to the environment (Norsworthy et al., 2012). In addition, management actions tend to work better when they are timed to match periods when woody plants have low carbohydrate reserves. This is because their ability to grow and survive after a disturbance depends on the energy stored in their roots (Bisikwa et al., 2020).

2.7. Plant size and stem diameter

Carbohydrate levels rise and fall with the seasons and are affected by stress and by management activities (Palacia et al., 2014; Wiley et al., 2017). Because of this, applying treatments during the dry season, when carbohydrate reserves are usually low,

can greatly reduce a plant's ability to resprout (Enloe et al., 2018). However, most research still focuses on the effects of herbicide type, concentration, and timing in isolation. The size of the stem, or stem diameter, is another important factor that affects how a plant can resprout (Monegi et al., 2023). Whether stem diameter has a positive or negative effect on resprouting can differ and often depends on the species (Syampungani et al., 2017). Additionally, it is important to study how specific species respond to cutting based on their stem diameter. Even though this is important, there are not many studies that have documented how herbicide concentration, timing of application, and type of herbicide all together affect the resprouting of particular woody species. Having this kind of information would help land managers create better and more targeted plans for controlling woody plants in savannas.

2.8. Synthesis of literature and research gaps

The management of woody plant encroachment has been widely studied, with various control methods such as mechanical treatment and herbicide application being tested for their efficacy in different ecosystems (O'Connor et al., 2014). While both mechanical and chemical methods have demonstrated varying degrees of success, their long-term efficacy, particularly in relation to the resprouting patterns of woody species remains an area requiring further investigation (Monegi, 2023; Bansal et al., 2016). Nevertheless, savanna woody species are highly resilient to disturbances and can regenerate by resprouting after losing their above-ground structures (Monegi et al., 2023).

Studies further indicates that herbicide treatments are generally more cost-effective for large-scale management, but their success depends heavily on the

appropriate choice of herbicide concentration and timing of application (Nath et al., 2024). The key gaps identified from the reviewed literature are: (1) limited studies comparing effects of herbicide versus mechanical control on resprouting patterns of woody plants species, (2) lack of research on integrating mechanical control with herbicide application for optimal results in the Marikana Thornveld, and (3) insufficient data on cost-benefit analysis of herbicide versus mechanical control in local contexts. The current study addresses these gaps by comparing the effects of herbicide application and mechanical control on the resprouting patterns of woody plant species in the Marikana Thornveld, and by determining the optimal herbicide concentration and timing for effective control of resprouting.

Chapter 3: Materials and methods

3.1. Study area description

This study was conducted at the Roodeplaat experimental farm (25° 56'S 28° 35'E), which is managed by the Agricultural Research Council and is located in Gauteng, South Africa. The site covers about 2100 hectares of natural vegetation that has not been disturbed (**Figure 1**). According to the vegetation classification system developed by Rutherford et al. (2006), the area is part of the Marikana Thornveld biome. The most common woody plants in this area include *Vachellia* species, *Senegalia caffra, Ziziphus mucronata*, and *Euclea* species. The herbaceous layer in the study area comprises of *Digitaria eriantha*, *Megathyrsus maximus,* and *Setaria sphacelate*, *Eragrostis curvula*, *Themeda triandra*, and *Heteropogon contortus* (Van Rooyen, 1983). The area receives an average rainfall of 646 mm each year, between November and March. Temperatures, range from 20° to 29℃ in summer and between 2 and 16℃ during winter (Monegi et al., 2024). The soils in the area are mainly Valsriver, Arcadia, and Hutton types, located on the Roodeplaat Igneous Complex (Panagos et al., 2015).

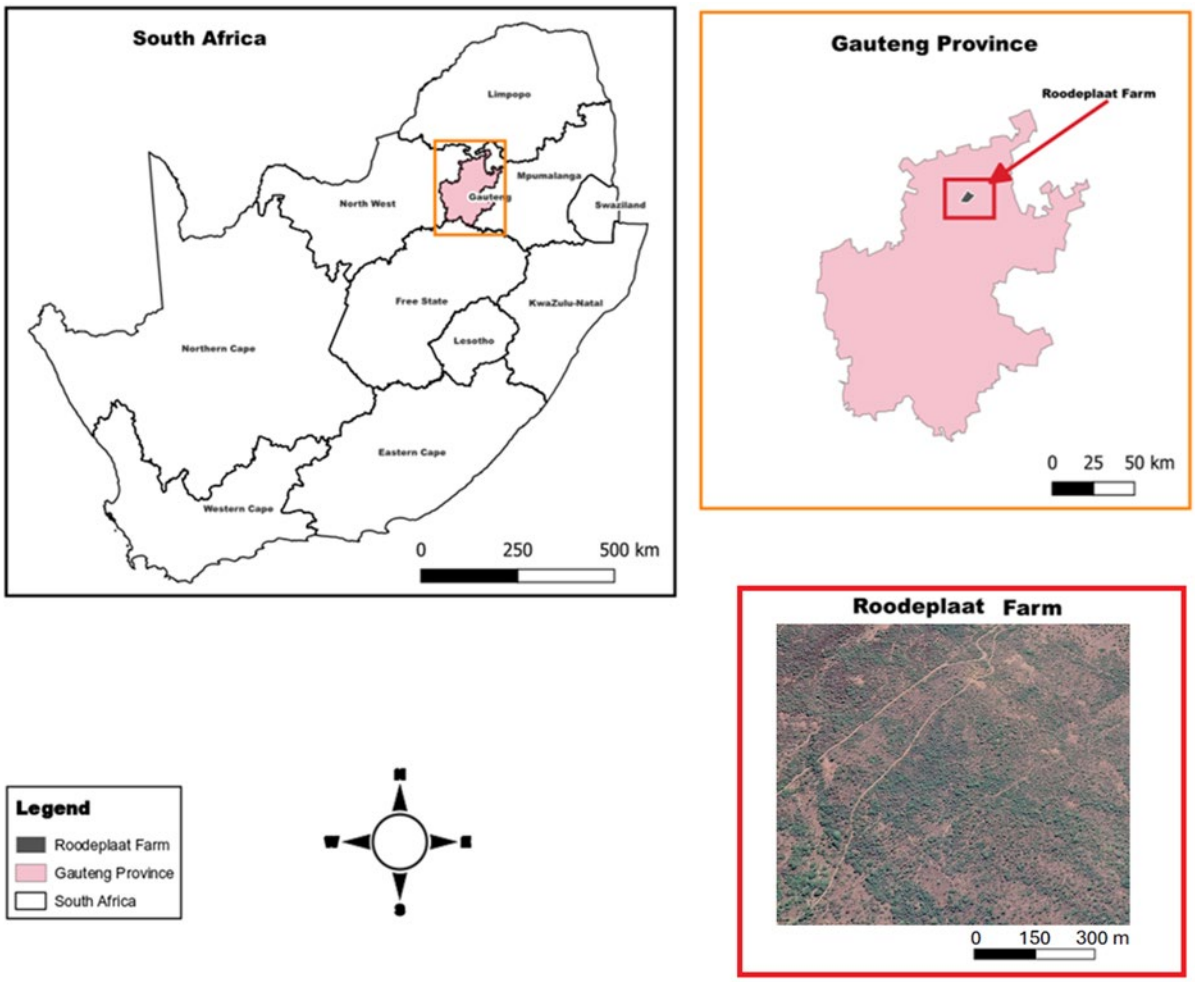


Figure 1: Map showing the study area, South Africa, Gauteng Province (Monegi, 2025).

3.2. Study design

In this study, seven tree species that are common in the area were selected. These were *Combretum apiculatum, Euclea undulata, Peltophorum africanum, Searsia lancea, Vachellia karroo, V.nilotica*, and *V.tortilis* (**Table 1**). These species represent the main woody plants found in the study area. For each species, a total of 140 trees were chosen to be cut down. Half of these (70 trees) were removed during the wet season, and the other half (70 trees) were removed during the dry season (**Figure 2**). Care was taken to make sure that the herbicide was applied in the same way across all

tree species. The 70 trees for each species were then split into seven groups of 10 trees each. The first group was the control, meaning no herbicide was applied to the stumps. The second, third, and fourth groups were treated with Scrubber 240 SL (picloram), which was applied to the cut stems at concentrations of 1%, 2%, and 3% respectively. In the same way, the fifth, sixth, and seventh groups were treated with Garlon^{TM} 480 EC (triclopyr amine), also at concentrations of 1%, 2%, and 3%. Both picloram (Scrubber 240 SL) and triclopyr amine (Garlon^{TM} 480 EC) were mixed with water at these three concentrations for every 100 liters of spray solution. For all treatment groups (groups two through seven), 0.5 Actipron Super, which is a mineral oil, was added to every 100 liters of the spray mixture (Weimer et al., 2015). The different herbicide concentrations used in this study follow the rate recommended by the manufacturer.

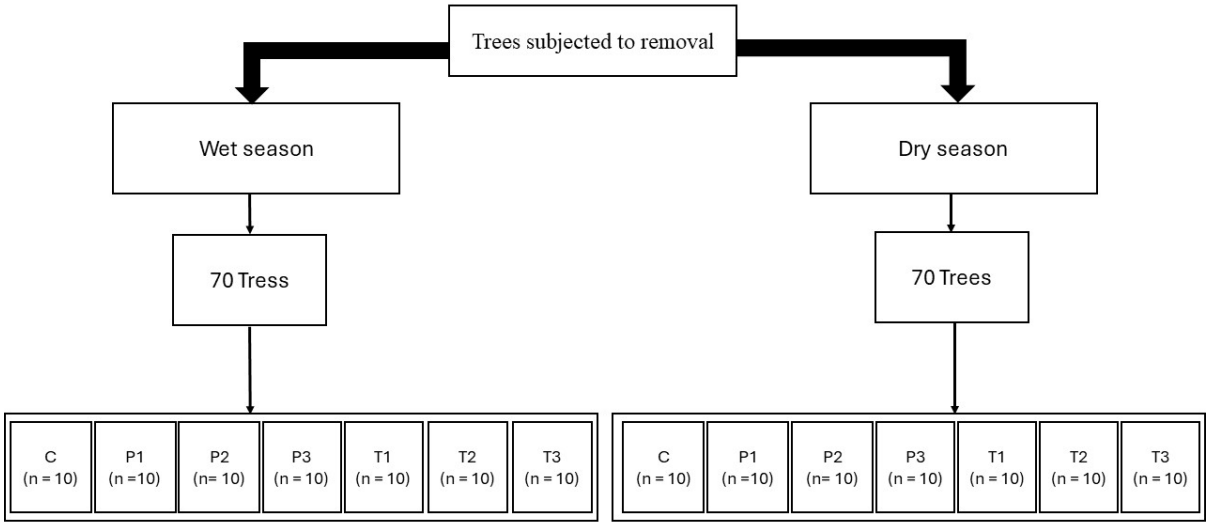


Figure 2: Schematic representation of the experimental design. Key to treatments:

C = control, P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

Table 1: Growth form, description, and resprouting ability of selected woody species.

Species	**Growth form**	**Description**
Combretum apiculatum	Small to medium	Deciduous, often multi-stemmed, found in savanna and woodland regions.
Euclea undulata	Shrub to small tree	Evergreen often forms dense thickets, commonly found in bushveld and arid regions
Peltophorum africanum	Medium tree	Deciduous, drought-resistant, often used for shade and fodder
Searsia lancea	Small to medium tree	Evergreen, hardy species found on a variety of soil types, commonly occurring near water.
Vachellia karroo	Small to medium tree	Deciduous, fast-growing, nitrogen-fixing, widespread grassland and savanna ecosystems.
Vachellia nilotica	Medium to large tree	Deciduous, thorny, commonly found near watercourses, valued for timber and fodder
Vachellia tortilis	Small to medium tree	Deciduous, drought-tolerant, commonly occurring in arid savannas and semi-deserts

Trees were selected based on the same species, similar stem diameters, and being easy to reach. This was done to make sure the experimental conditions were as uniform as possible. The selected trees were then cut down using a chainsaw in February 2022 (wet season) and again in July 2022 (dry season). Any sawdust or loose material left on the cut stems from cutting was cleaned off. To avoid any confusing effects that could result from cutting trees at different heights (Greenland et al., 2016), all trees were cut at a standardized height of 25 cm above ground level.

The cut stems were treated with herbicide within 15 minutes after cut (DiTomasso and Kyser, 2007). Each stem that received herbicide was treated for about one minute to make sure the same amount was applied to all of them. A knapsack sprayer (Spraying Systems TG-1, Delavan CE 1) with a single solid-cone nozzle was used to apply the herbicide. Tree cutting and herbicide application were done on clear days when there was no rain. This helped ensure that the weather conditions were good for the herbicide to work and reduced the chance of rain or high humidity interfering. To make sure the entire cut surface was covered, each stem was sprayed until the point of run off (Weimer et al., 2015). A 40 cm cylinder was placed around the stem during spraying to protect it from the wind. This step was taken to prevent accidentally harming other plants in the area that were not meant to be treated.

To measure how each stem resprouted and how vigorously it grew after being cut, the following information was recorded for every stump: (1) the total number of shoots from the stump, and (2) the length of the longest shoot. Shoot production was worked out by counting how many shoots for each unit of stump area (Moyo et al., 2015). For both the wet and dry season treatments, data were collected 24 months after the trees were cut down.

3.3. Data analysis

Two-way ANOVA was conducted using general linear models (GLMs) to examine the main effects of different herbicide concentrations and the season of application and their interactions on mean shoot production and shoot length of the tree species. Stem diameter was used as a covariate. Treatments were considered significant at 95% confidence level. When ANOVA indicated significant effects, a Bonferroni *post hoc* tests were conducted to identify differences among treatments. In addition, linear regression was used to examine the relationship between shoot production and stem diameter. The data were analysed separately for each species. All data analyses were executed in IBM SPSS statistics for windows, version 29.0. Armonk, New York: IBM Corporation (SPSS, 2024).

Chapter 4: Results

4.1. Results

4.1.1. *Vachellia karroo*

In this study, *V. karroo* did not resprout from cut stems under any condition, regardless of the treatment, season, or even in the control group where no herbicide was applied.

4.1.2. *Vachellia nilotica*

Herbicide treatment ($F = 5.838$; $p < 0.001$), season of application ($F = 5.304$; $p = 0.026$) substantially influenced shoot production of *V. nilotica* except for their interaction ($F = 1.214$; $p = 0.317$) (**Figure 3A**). *Vachellia nilotica* shoot production was significantly enhanced in the control group compared with the herbicide treatment for both seasons, except for stems treated with triclopyr amine at 1% and 2% concentrations, specifically in the dry season. Picloram significantly reduced shoot production and length in both seasons ($p < 0.05$). Moreover, there was a significant negative relationship between shoot production and stem diameter of *V. nilotica* ($p = 0.031$) (**Figure 4**).

Vachellia nilotica shoot length was significantly affected by herbicide treatment ($F = 4.541$; $p < 0.001$), season of application ($F = 4.758$; $p = 0.034$), but not by their interactions ($F = 1.553$; $p = 0.183$) (**Figure 3B**). The post hoc test indicated that the control treatment recorded a significantly greater shoot length compared to the herbicide treatment with triclopyr amine at 1% and 2% concentrations, particularly during the dry season. Shoot length was substantially reduced by picloram application in both seasons ($p < 0.05$).

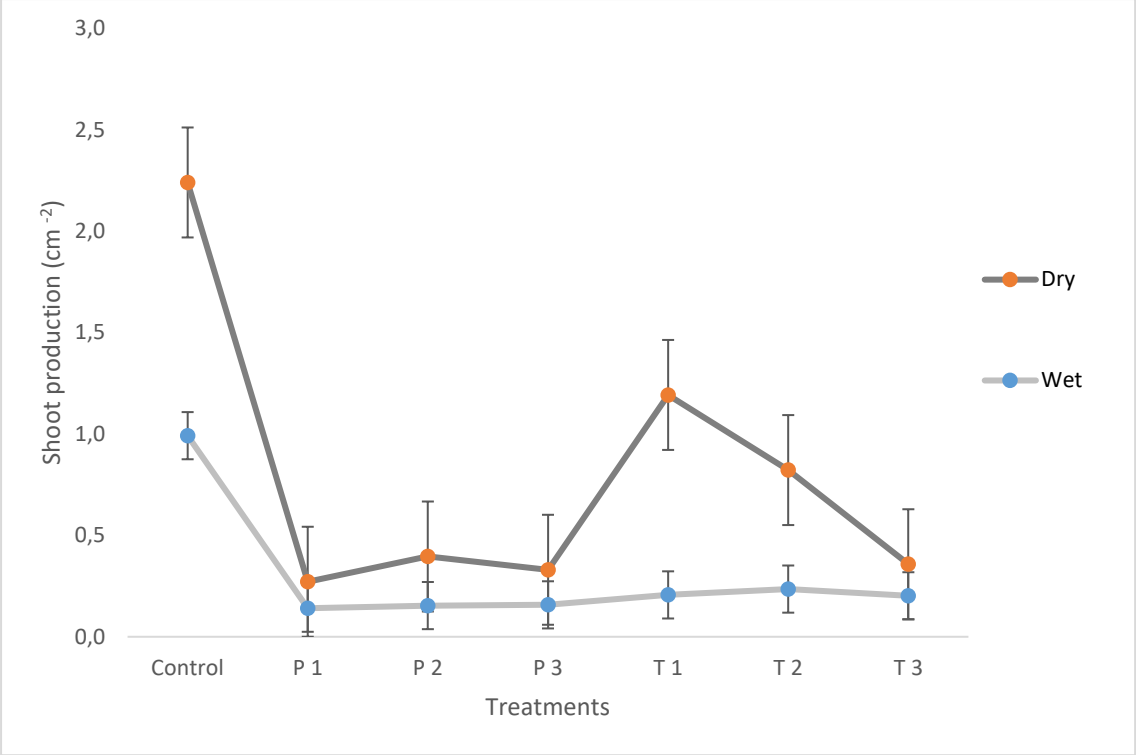


Figure 3A: Shoot production of *V. nilotica* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

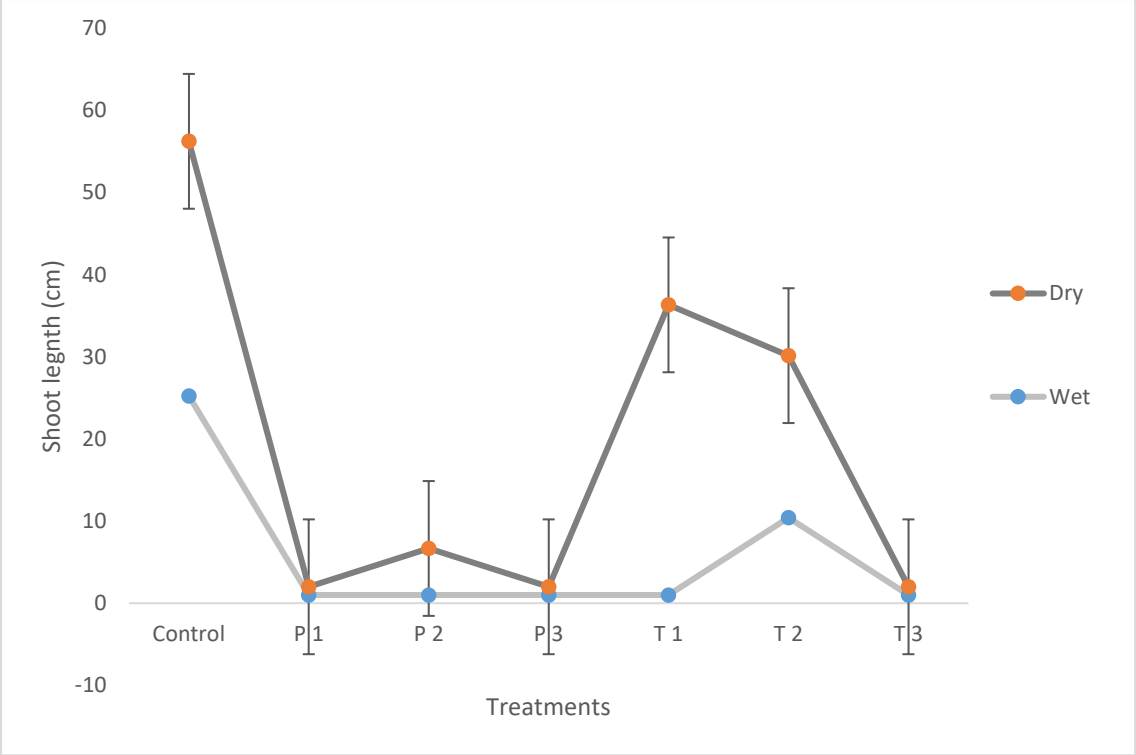


Figure 3B: Shoot length of *V. nilotica* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

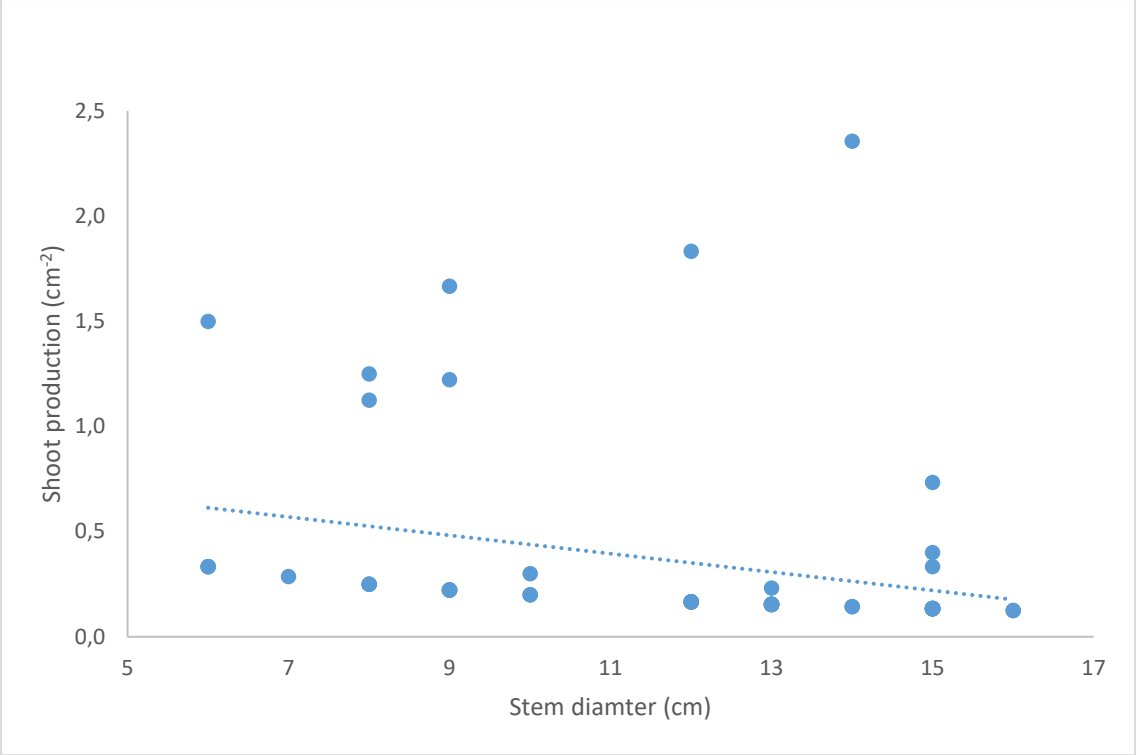


Figure 4: The relationship between stem diameter and shoot production of *V. nilotica*.

4.1.3. *Vachellia tortilis*

Herbicide application ($F = 7.442$; $p < 0.001$), season of application ($F = 11.680$; $p < 0.001$) but not their interactions ($F = 0.970$; $p = 0.455$), substantially affected shoot production of *V. tortlilis*. The findings indicated no significant differences in shoot production between the control treatment and stems treated with picloram at 1% concentration ($p > 0.05$). However, when applied at 2% and 3%, picloram substantially reduced shoot production substantially reduced shoot production in both seasons compared to the control group (**Figure 5A**). Moreover, shoot production was comparable between the control group and stems treated with triclopyr amine when applied at 1% and 2% concentrations ($p > 0.05$). Significant reductions in shoot production were noticed only when triclopyr amine was applied at 3% concentration ($p < 0.05$), specifically during the dry season. Nonetheless, there was a significant negative

relationship between shoot production and stem diameter of *V. tortilis* ($p = 0.011$) (**Figure 6**).

Vachellia tortilis shoot length was significantly influenced by herbicide treatment ($F = 11.139$; $p < 0.001$), season of application ($F = 20.853$; $p < 0.001$), and their interactions ($F = 4.950$; $p < 0.001$). There was a significant difference in shoot length between the control stems that were cut during the dry and wet seasons ($p = 0.021$), with the control stems cut during the wet season recording the highest shoot length. During the dry season, there were no significant differences in shoot length between the control group and stems treated with picloram at all levels of application ($p > 0.05$) (**Figure 5B**). However, during the wet season, stems treated with picloram at 1% had a significantly greater shoot length than stems treated with picloram at 2% and 3% concentrations ($p < 0.05$). In addition, no significant differences in shoot length were recorded between the control treatment and stems treated with all concentrations of triclopyr amine ($p > 0.05$), particularly in the wet season.

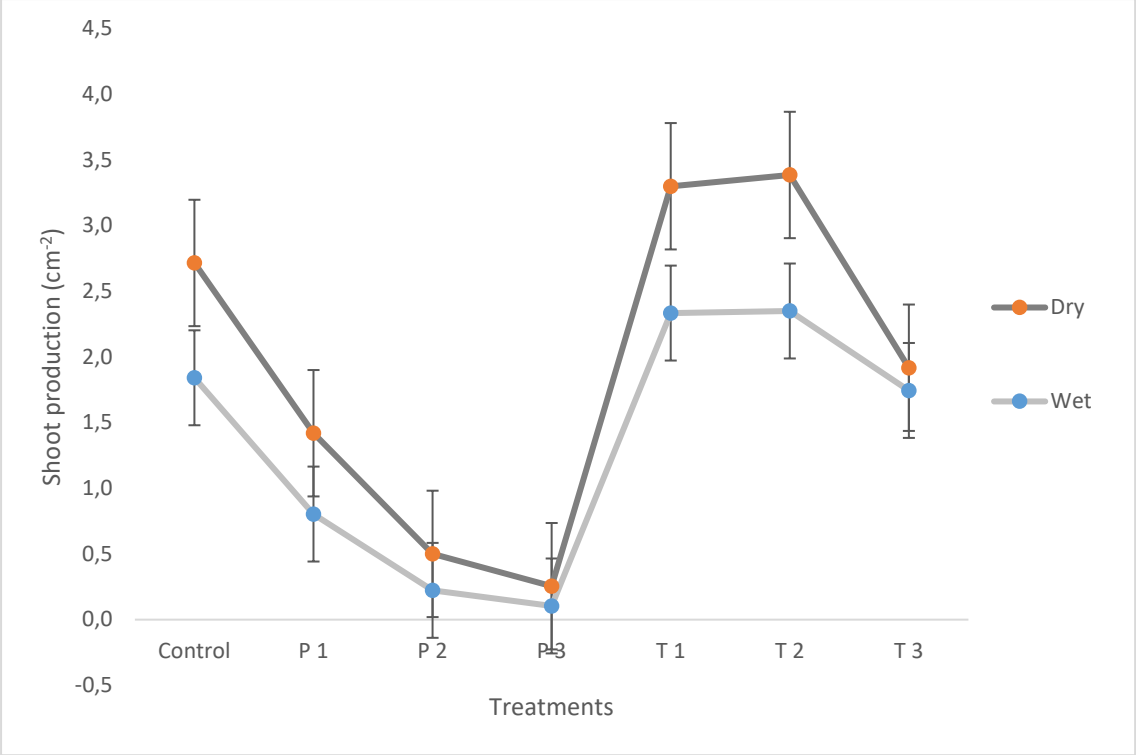


Figure 5A: Shoot production of *V. tortilis* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

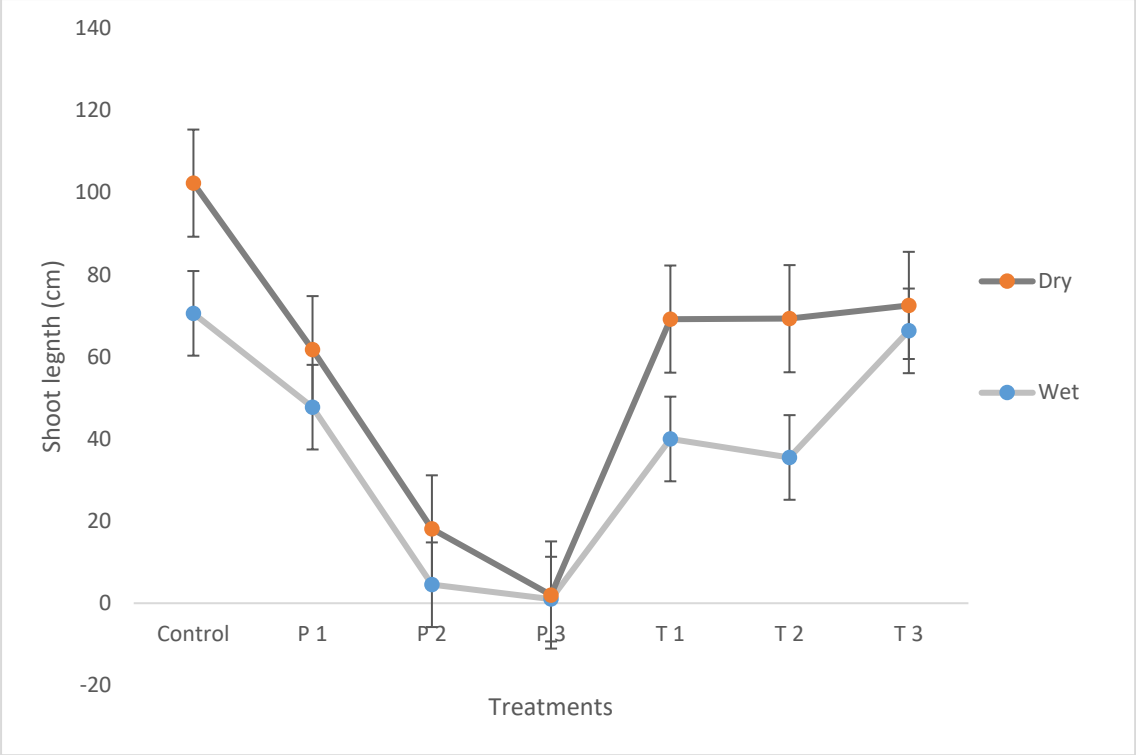


Figure 5B: Shoot length of *V. tortilis* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

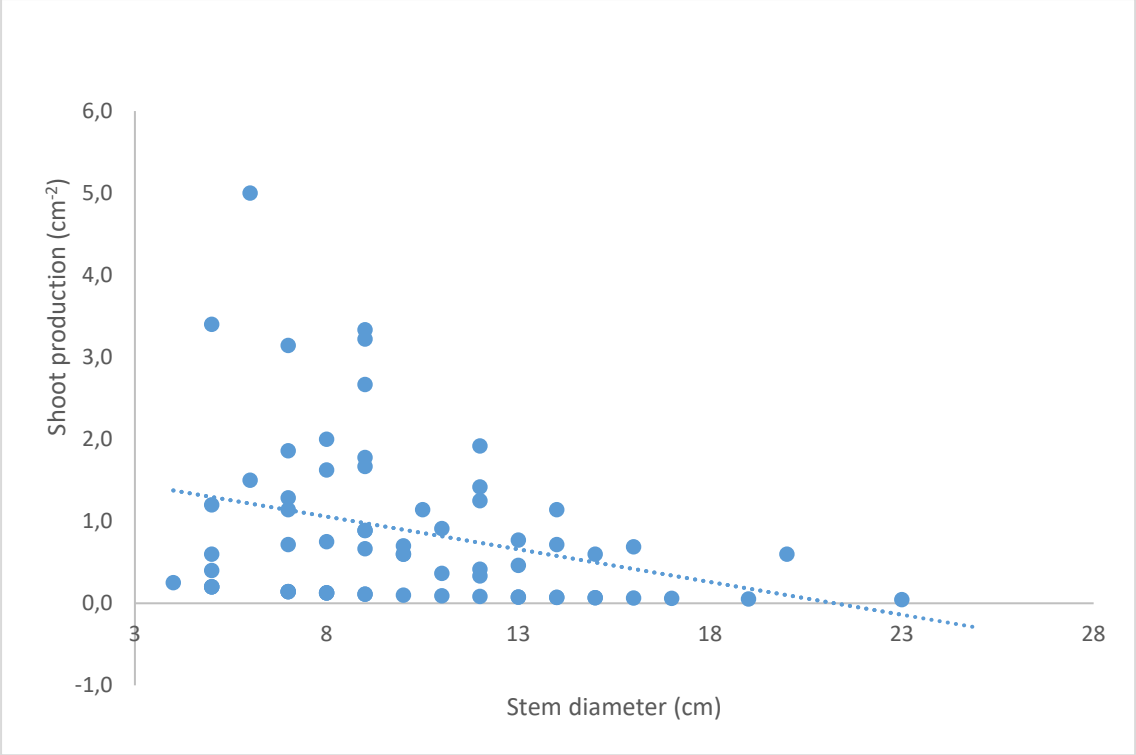


Figure 6: The relationship between stem diameter and shoot production of *V. tortilis*.

4.1.4. *Combretum apiculatum*

Shoot production of *C. apiculatum* was significantly affected by the herbicide treatment ($F = 22.381$; $p < 0.001$) but not the season of application ($F = 0.189$; $p = 0.666$). However, there was a significant interaction between herbicide concentration and season of application on shoot production of *C. apiculatum* ($F = 0.083$; $p = 0.006$). The control group had a significantly greater shoot production than the other treatments for both seasons, except for stems treated with triclopyr amine when applied at 1% concentration during the dry season (**Figure 7A**). Shoot production was comparable between the control group and stems treated with triclopyr amine when applied at 1% concentration ($p > 0.05$). In addition, no significant relationship was found between shoot production and stem diameter of *C. apiculatum* ($p = 0.297$) (**Figure 8**).

Herbicide treatment ($F = 12.798$; $p < 0.001$), season of application ($F = 4.902$; $p = 0.031$), and their interactions ($F = 5.624$; $p < 0.001$) significantly affected the shoot length of *C. apiculatum* (**Figure 7B**). The control treatment had a substantially greater shoot length compared to the herbicide treatments, except for stems that were treated with triclopyr amine when applied at 1% concentration during the dry season. The study findings indicated that stems treated with triclopyr amine at 1% concentration had a significantly greater shoot length compared to picloram herbicide treatment, particularly during the dry season.

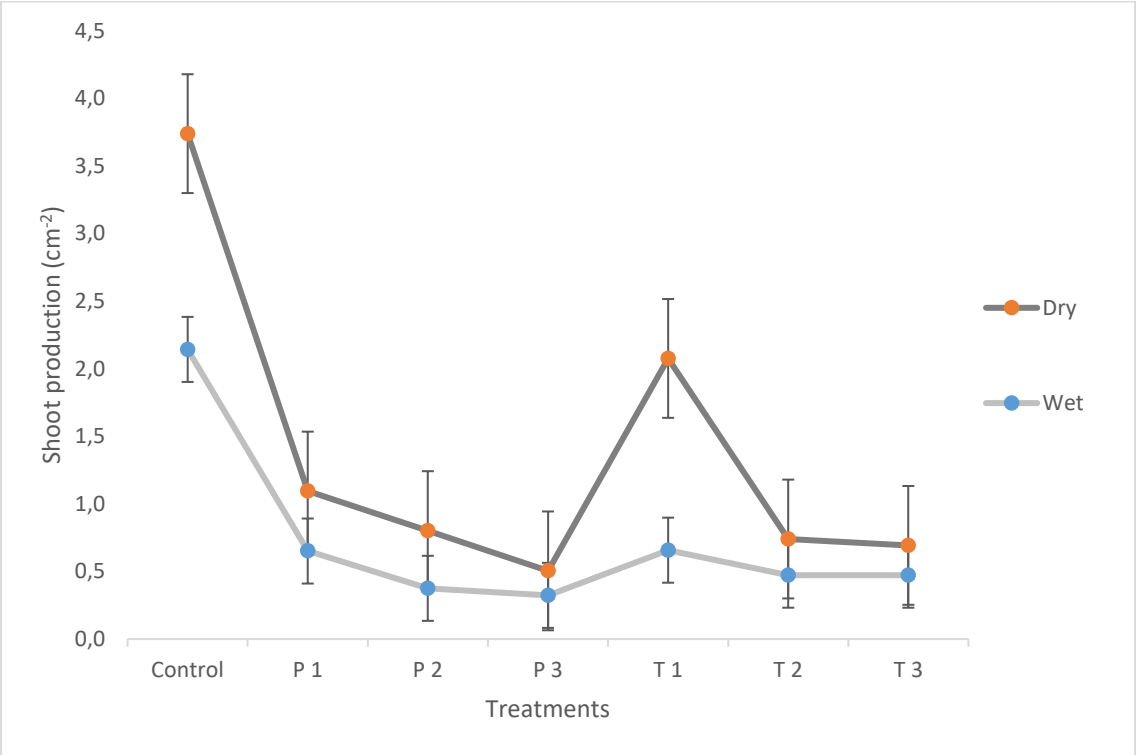


Figure 7A: Shoot production of *C. apiculatum* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

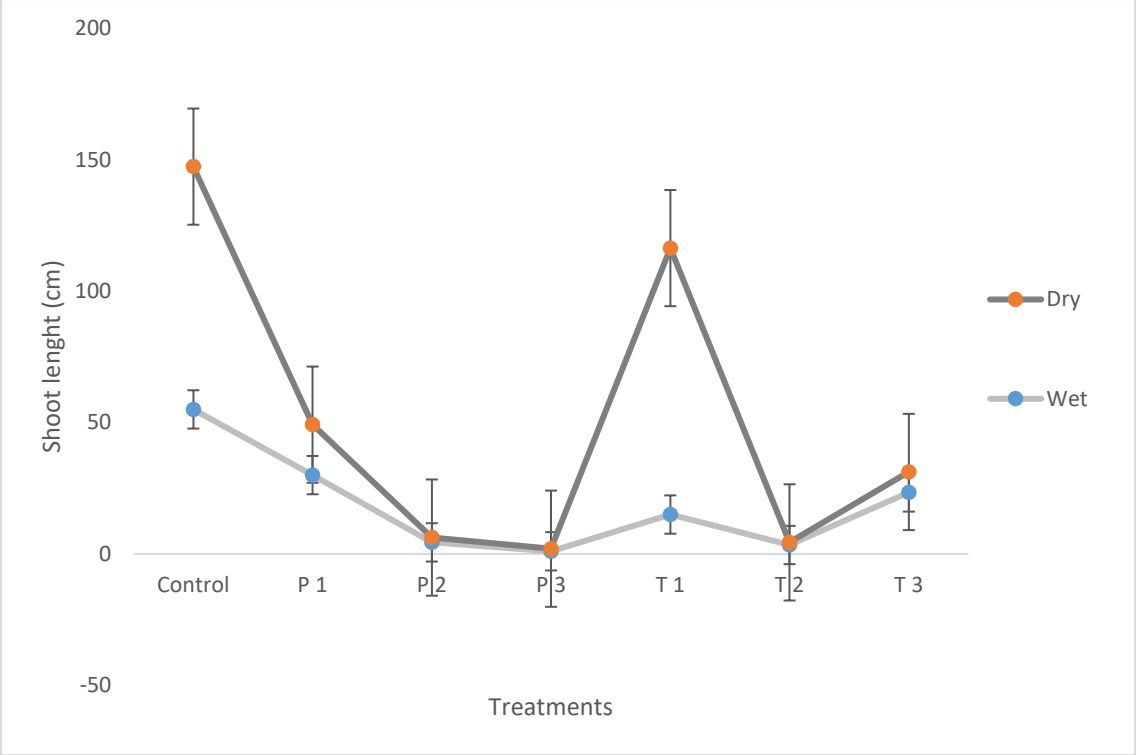


Figure 7B: Shoot length of *C. apiculatum* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

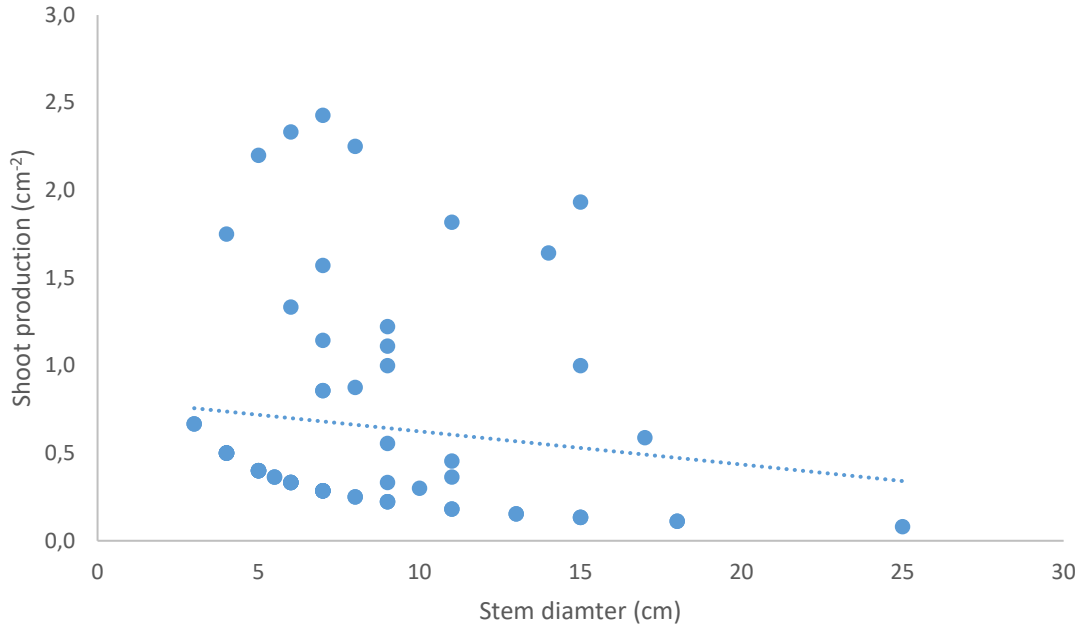


Figure 8: The relationship between stem diameter and shoot production of *C. apiculatum*.

4.1.5. *Euclea undulata*

Herbicide treatment (F = 1.442; p = 0.216), season of application (F = 1.073; p = 0.35), and their interactions (F = 1.178; p = 0.332) did not significantly affect shoot production of *E. undulata*. Shoot production of *E. undulata* showed a declining trend regardless of treatment, especially in the dry season (**Figure 9A**). Nonetheless, there was a significant negative relationship between shoot production and stem diameter of *E. undulata* (p = 0.018) (**Figure 10**). In addition, shoot length of *E. undulata* was significantly affected by herbicide treatment (F = 10.658; p < 0.05), season of application (F = 5.054; p = 0.029), and their interactions (F = .107; p = 0.011) (**Figure 9B**). The control stems cut during the wet season had significantly greater shoot length compared to the control

stems cut during the dry season and stems treated with all levels of herbicide application ($p < 0.001$). However, no significant differences in

shoot length were recorded between the control stems cut during the dry season and stems treated with herbicides regardless of season ($p > 0.05$).

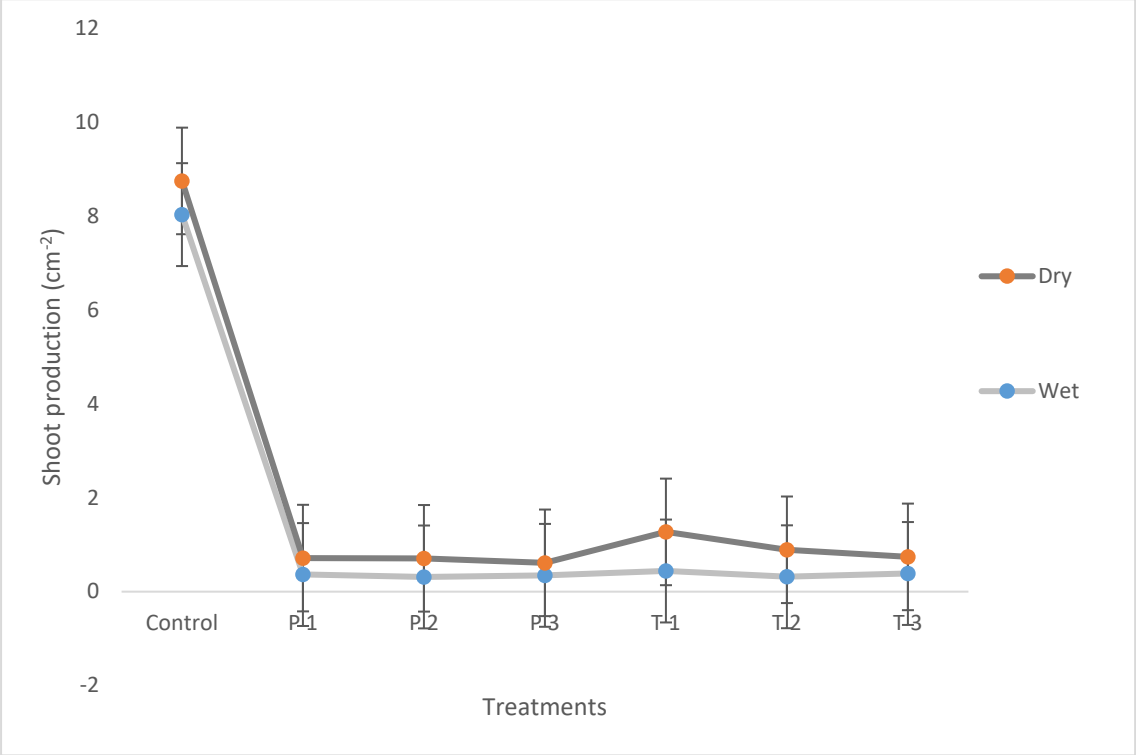


Figure 9A: Shoot production of *E. undulata* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

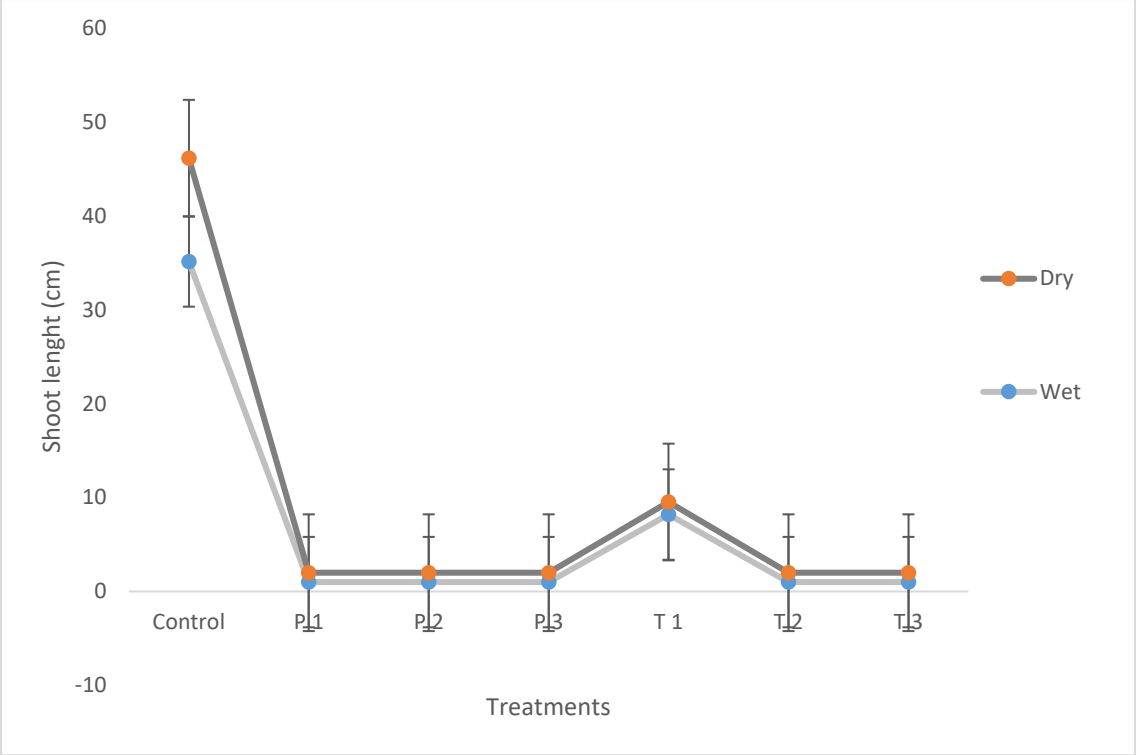


Figure 9B: Shoot length of *E. undulata* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

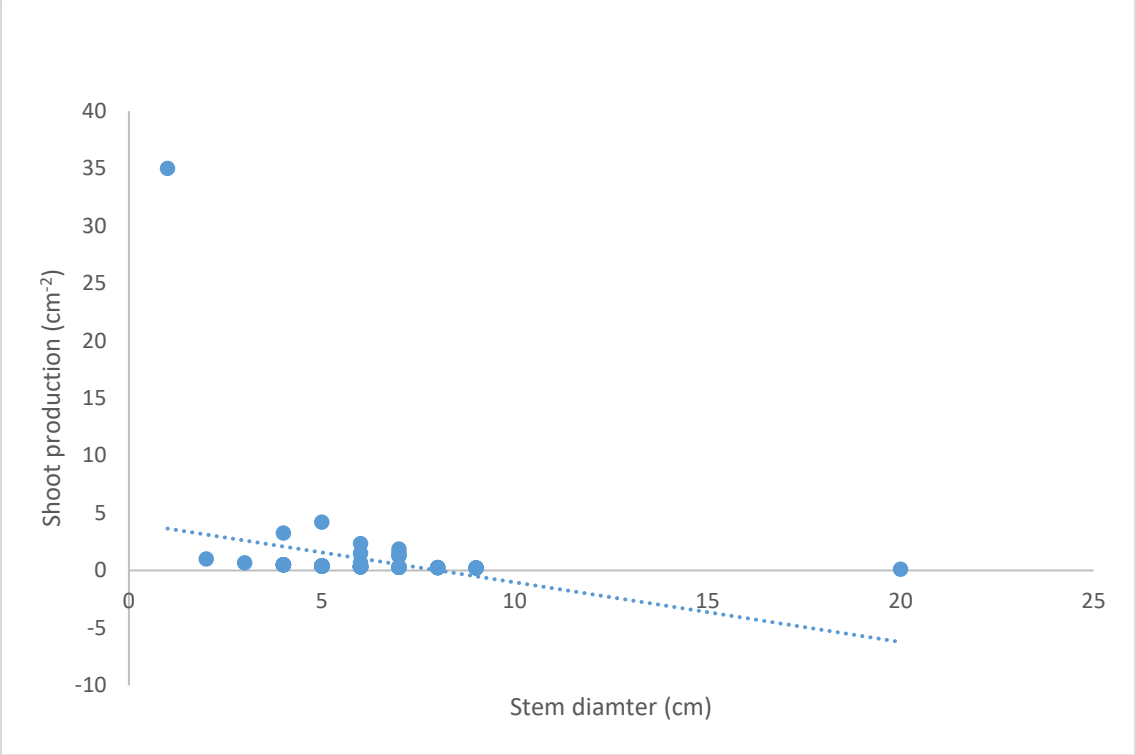


Figure 10: The relationship between stem diameter and shoot production of *E. undulata*.

4.1.6. *Peltophorum africanum*

Shoot production of *P. africanum* was significantly affected by herbicide treatment ($F = 23.245$; $p < 0.001$), season of application ($F = 4.134$; $p = 0.047$) but not their interactions ($F = 1.854$; $p = 1.854$). Shoot production from the control treatment was significantly greater than that of picloram treatments, except for when picloram was applied at 1% concentration during the dry season (**Figure 11A**). Additionally, shoot production between the control treatment and all levels of triclopyr amine applied during the dry season was comparable ($p > 0.05$). When comparing the control treatments with triclopyr amine applied during the wet season, only 2% and 3% concentrations recorded a significantly low shoot production but not 1% concentration.

No significant relationship was found between shoot production and stem diameter for *P. africanum* ($p = 0.081$) (**Figure 12**).

Herbicide treatment ($F = 21.653$; $p < 0.001$), season of application ($F = 5.769$; $p = 0.020$), but not their interactions ($F = 1.592$; $p = 0.168$) significantly affected shoot length of *P. africanum*. Shoot length was significantly greater in the control treatment compared to stems treated with picloram ($p < 0.05$) (**Figure 11B**). However, no significant differences were recorded between the control treatment and stems treated with picloram at 1% concentration during the dry season. In addition, there were no significant differences in shoot length between the control treatment and all levels of triclopyr amine concentrations in both seasons ($p > 0.05$).

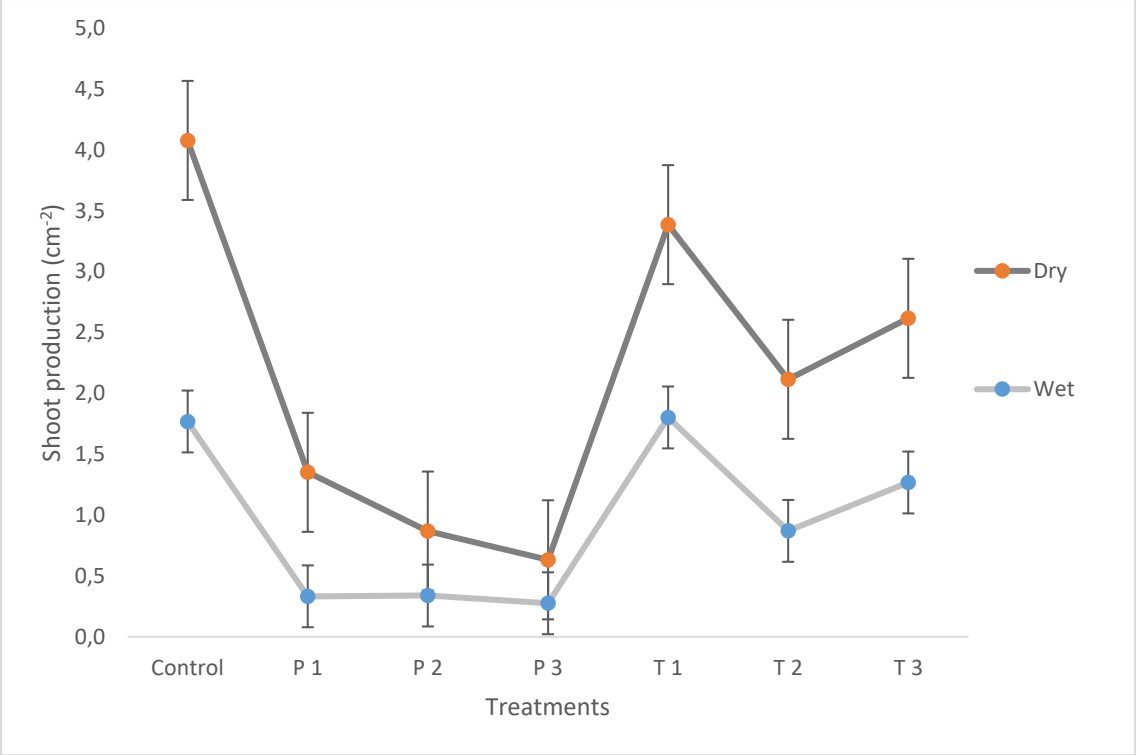


Figure 11A: Shoot production of *P. africanum* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

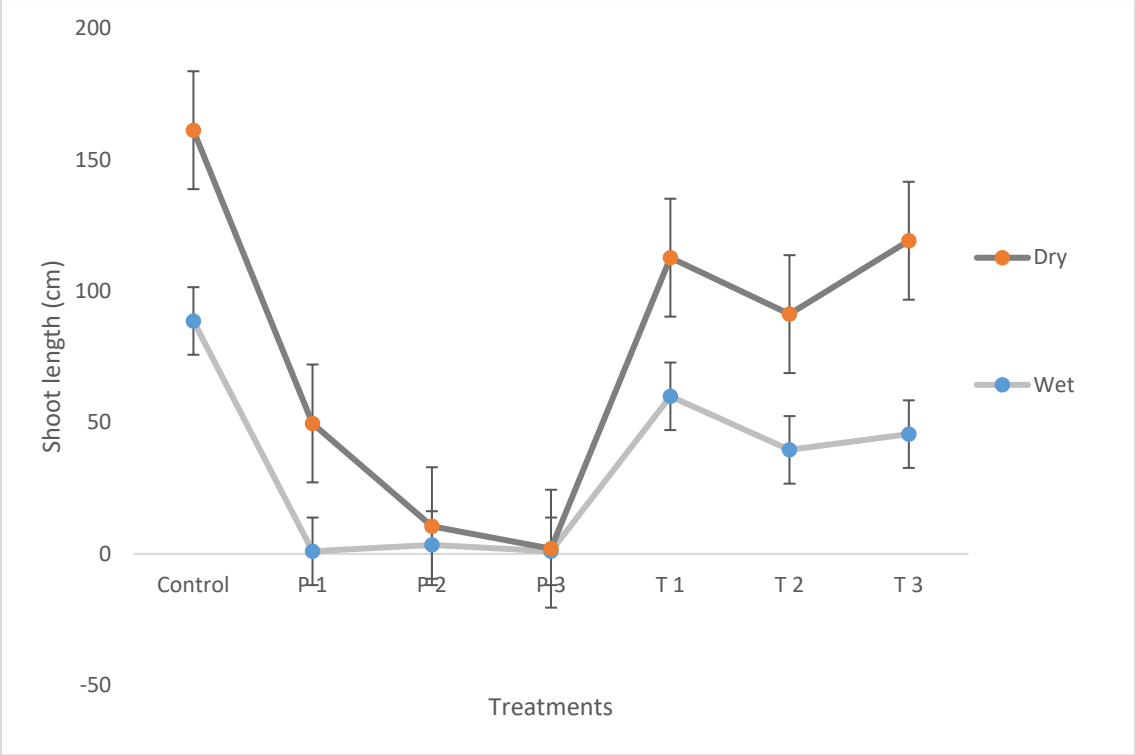


Figure 11B: Shoot length of *P. africanum* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

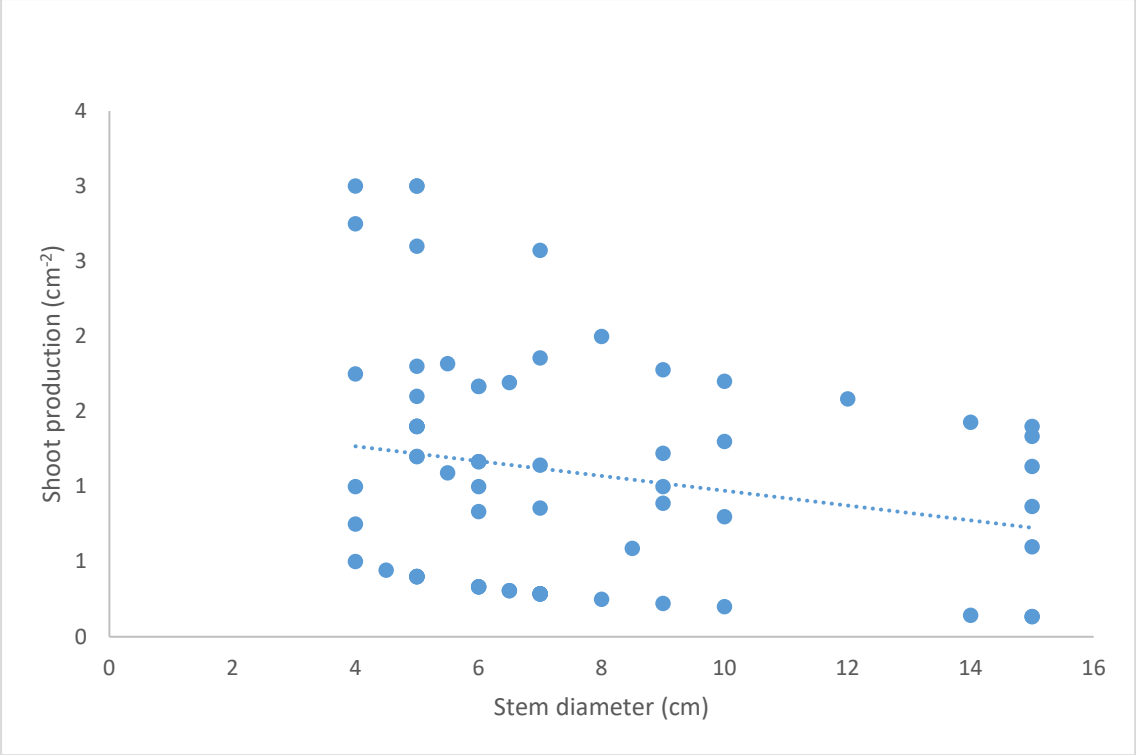


Figure 12: The relationship between stem diameter and shoot production of *P. africanum*.

4.1.7. *Searsia lancea*

Herbicide application ($F = 16.439$; $p < 0.001$), season of application ($F = 9.758$; $p = 0.003$), and their interactions ($F = 5.048$; $p < 0.001$) substantially affected shoot production of *S. lancea*. The control treatment during the wet season recorded a significantly greater shoot production than all treatments including the control group during the dry season and all levels of herbicide application ($p < 0.001$) (**Figure 13A**). However, no significant differences in shoot production were observed between the control stems that were cut during the dry season and herbicide treatments in both seasons ($p > 0.05$). Moreover, shoot production was comparable between the control stems cut during the wet season and stems treated with triclopyr amine at 1% concentration during the wet season ($p > 0.05$). In addition, there was no significant

relationship between shoot production and stem diameter of *S. lancea* in this study (p = 0.464) (**Figure 14**).

Searsia lancea shoot length was significantly affected by herbicide treatment (F = 30.447; p < 0.001), season of application (F = 5.398; p = 0.024), and their interactions (F = 6.560; p < 0.001) (**Figure 13B**). Shoot length was significantly enhanced in the control group for both seasons compared to the herbicide treatments (p < 0.05). Shoot length of stems treated with triclopyr amine at 1% concentration during the wet season was comparable with shoot length of the control group for both seasons (p > 0.05).

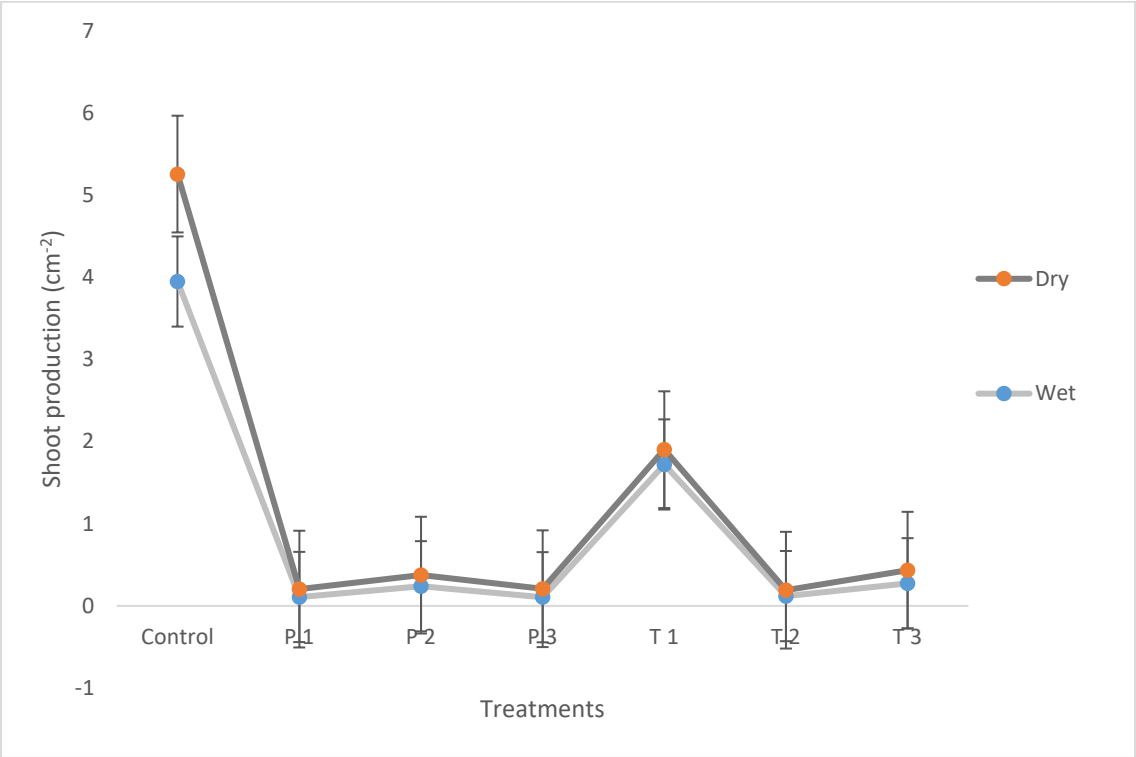


Figure 13A: Shoot production of *S. lancea* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

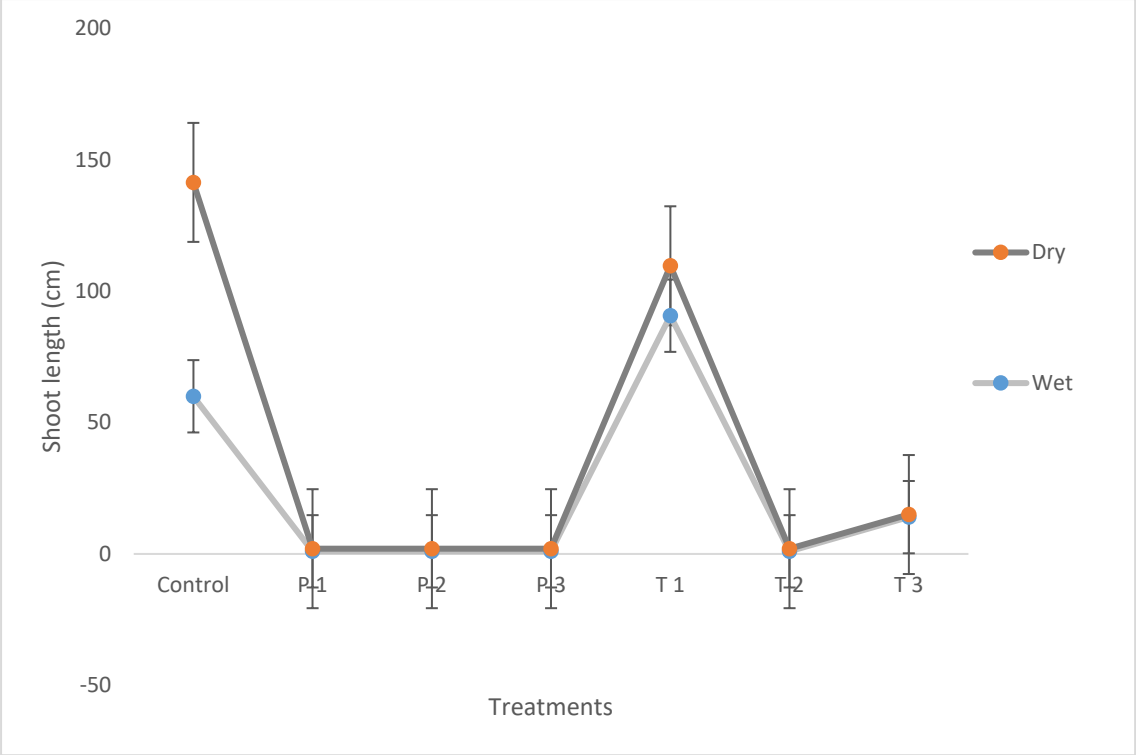


Figure 13B: Shoot lenght of *S. lancea* 24 months after treatment application in the wet and dry seasons. Key to treatments: P1 = picloram applied at 1%, P2 = picloram applied at 2%, P3 = picloram applied at 3%, T1 = triclopyr amine applied at 1%, T2 = triclopyr amine applied at 2% and T3 = triclopyr amine applied at 3%.

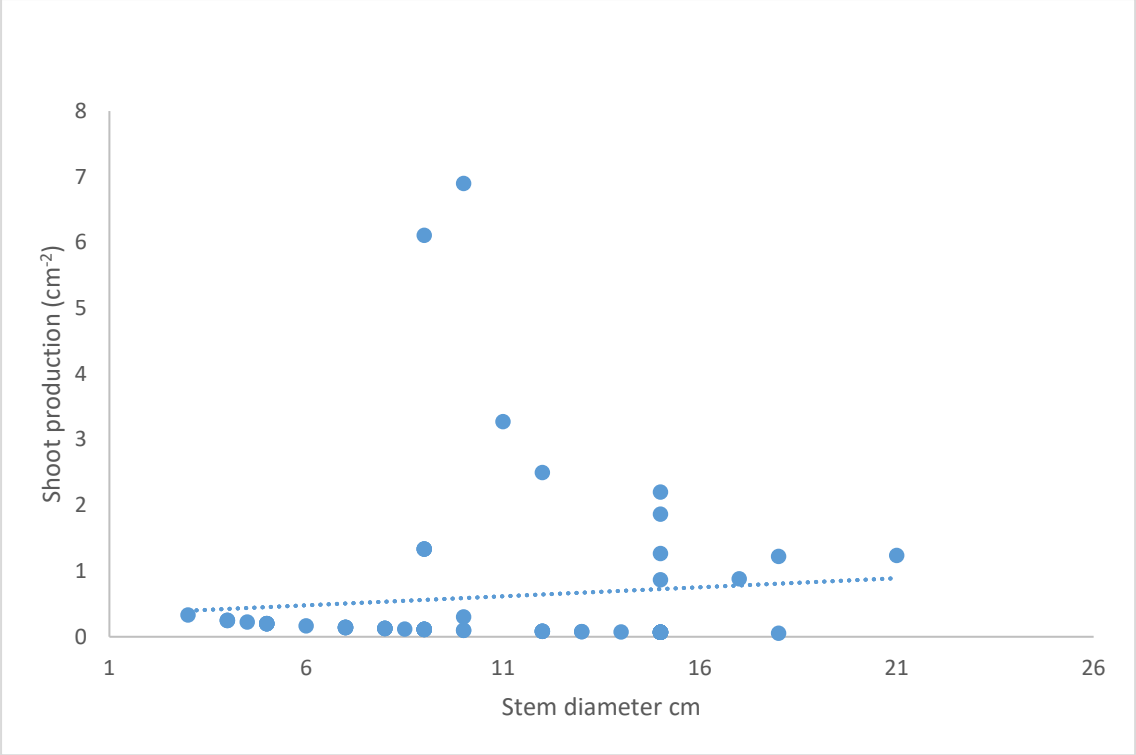


Figure 14: The relationship between stem diameter and shoot production of *S. lancea*.

Chapter 5: Discussion

5.1. *The efficacy of mechanical removal, and different concentrations of picloram and triclopyr amine on resprouting ability and vigour of woody species*

Contrary to the prediction that all cut stems subjected to herbicide treatment will show reduced or no resprouting compared to mechanical treatment alone (control), the study findings demonstrated that the impact of mechanical and herbicide treatment depends on the type of woody species and the control method used. For instance, in this study, picloram had a greater efficacy in controlling shoot production and vigour of all the study plants than triclopyr amine. However, it is important to note that herbicide identity and concentration were combined into a single treatment factor; therefore, overall herbicide level effects were not formally tested in this study. At low concentrations, triclopyr amine was most effective in controlling only shoot production and vigour of *E. undulata* compared to other tree species. The study findings suggest that higher concentrations (i.e. 3% in this study) of triclopyr amine are required to substantially reduce shoot production and vigour of savanna woody plants. Nonetheless, in the current study, increased triclopyr amine concentrations were associated in reduced shoot production and vigour of *C. apiculatum*, *S. lancea*, *V. nilotica* and *V. tortilis*. However, increased triclopyr amine concentrations were not effective in controlling shoot production and vigour of *P. africanum* and *V. tortilis*. Thus, it might not be economical for land users to consider triclopyr amine as a first-choice herbicide for controlling the study species, particularly in resource-constrained communities.

In contrast to the prediction that mechanical removal alone (control) would show a significantly greater shoot production and vigour than stems treated with herbicides, *V.*

karroo stems did not regenerate after cutting regardless of treatment or season. This result was surprising because (Monegi et al., 2023) demonstrated that *V. karroo* trees have the ability to resprout after cutting in the same study area. We postulate that plant age, measured by stem diameter, may have contributed to the resprouting failure of *V. karroo* trees in the present study. For example, *V. karroo* trees had a stem diameter of < 7 cm, whilst in the present study, *V. karroo* trees had a mean stem diameter of 15 cm, almost two folds that of *V. karroo* plants in Monegi et al.'s (2023) study. The assertion that resprouting failure in *V. karroo* trees could be because of plant age needs to be tested. The current findings indicate that chemical treatment after cutting of *V. karroo* trees is redundant, particularly for large trees.

5.2. *Resprouting ability and vigour of woody plants subjected to mechanical removal and herbicide treatment are season and species-specific*

The study findings also demonstrated that triclopyr amine was associated in reduced shoot production and vigour of *C. apiculatum* when applied at 1% concentration during the dry season. In addition, triclopyr amine was not associated in reduced shoot production and vigour of *V. nilotica* during the dry season when applied at 1% and 2% concentrations, whereas during the wet season, both concentrations were associated with reduced shoot production and vigour. Picloram was also not associated in shoot production and vigour of *P. africanum* when applied at 1% concentrations during the dry season. Nonetheless, *S. lancea* shoot production and vigour were controlled by triclopyr amine during the dry season; however, during the wet season, higher concentrations were required.

In addition, *V. tortilis* shoot production and vigour were reduced during the dry season by triclopyr amine when applied at 3% concentration. However, during the wet season, all concentrations of triclopyr amine were not associated in reduced *V. tortilis* shoot production and vigour. The reduced ability to resprout and lower vigour observed in *E. undulata* individuals that were removed during the dry season have been documented in other species such as *Quercus ilex* and *Q. cerrioides* (Resco de Dios et al., 2020). This phenomenon is linked to deteriorating water conditions for the plants and the use of stored resources to maintain metabolic functions during the dry season (Xu et al., 2022; Dralle et al., 2016). In accordance, Enloe et al. (2018) showed that herbicides are more effective at controlling *Ligustrum sinense* (an invasive shrub) during the dry season in the southeastern United States. Other studies have shown that stem treatment for *Rhamnus cathartica* trees with herbicides during autumn was associated with reduced regrowth (Roth, 2015). In contrast, Kochenderfer et al. (2013) suggested that the best time for herbicide application is when trees are actively growing. But the herbicide efficacy for controlling the resprouting ability of *Fagus grandifolia* during a time when trees are actively growing was less consistent. Consequently, the efficacy of mechanical and chemical control of woody plants depends on the type of species, herbicide and the timing of treatment application. Therefore, the findings from the current study suggest that some woody species are controlled better with herbicide treatment during the dry season when they are not actively growing, whereas some are better controlled during the wet season when trees are actively growing.

5.3. *The effect of stem diameter on shoot production of woody species*

In line with the study prediction, shoot production of *E. undulata*, *V. nilotica* and *V. tortilis* declined with increasing stem diameter. However, the findings for *C.*

apiculatum, *P. africanum* and *S. lancea* were not in accordance with the prediction that shoot production will decline with increasing stem diameter. Contrary to predictions, shoot production in *C. apiculatum, P. africanum, and S. lancea* did not decline with increasing stem diameter. This pattern is consistent with studies showing that resprouting capacity is often greater in juvenile trees than in mature individuals, likely due to age-related shifts in resource allocation, bark thickness, or meristematic activity (Clarke et al., 2013; Chiminazzo et al., 2023). The reasons behind this resprouting pattern in woody species are not well understood but are often assumed to arise from a combination of genetic, physiological and related anatomical changes that take place as trees mature (Li et al., 2025; Waters et al., 2010; Clarke et al., 2013). The lack of a relationship between stem diameter and shoot production of *C. apiculatum*, *P. africanum* and *S. lancea* are in accordance with (Nzunda and Griffiths, 2014) who found no relationship between stem diameter and resprouting ability in coastal dunes trees of South Africa, a result consistent with Mostacedo et al. (2009). Nonetheless, the findings from the current study suggest that tree species such as *E. undulata*, *V. nilotica* and *V. tortilis* are likely to resprout and survive disturbances as juveniles than as adults. Additionally, the findings imply that stem diameter is an important determinant of resprouting success in some tree species but not all.

The findings from the current study did not support the prediction that shoot production and vigour will be significantly low when treatments are applied during the dry season because stored carbohydrates are expected to be low during this period. In the current study the impact of the season of treatment application was species-specific. For instance, mechanical removal alone was enough to substantially reduce shoot production and vigour of *E. undulata* during the dry season, but not during the wet season. Peguero and Espelta, (2011) showed that the resprouting ability and vigour of

V. pennatula declined when trees were clipped during the dry season, a result consistent with the findings of *E. undulata*.

5.4. *Limitation of the study*

A limitation of the study was quantity of trees ($n=10$) per treatment combination, specifically, when responses were considered separately across different woody species and seasons. The limited sample size for individual species × treatment may have restricted the statistical power to identify subtle treatment effects and higher-order interactions. In addition, herbicide identity and concentration were considered as combined treatment categories. Therefore, the independent effects of herbicide type and concentration, including formal dose-response relationship could not be evaluated separately. Future research should look into increasing the number of trees per treatment and use factorial design that allows herbicide identity and concentration to be evaluated as independent factors. Such approach would enhance the capability to detect species-specific responses and the interactions between herbicide type, concentration, and season.

Chapter 6: Conclusion and recommendations

The findings from this study demonstrated that both mechanical removal and herbicides treatment are both associated in reduced resprouting ability and vigour of woody plants. However, the impact of mechanical removal and herbicides treatment on shoot production and vigour of woody plants are species- and season-specific. The findings from the current study did not support the prediction that cut stems subjected to herbicide treatment will show less or no resprouting regardless of species compared to the control group.

Therefore, the findings demonstrated that mechanical removal alone was sufficient for the control of woody species such as *E. undulata*, particularly if the stems were removed during the dry season. In addition, the findings did not support the prediction that both picloram and triclopyr amine herbicides will result in reduced resprouting ability and vigour regardless of season of application. The study results indicated a substantial variance regarding the impact of picloram and triclopyr amine on shoot production and vigour of the study species in both seasons of treatment application. Some of the woody species, such as *S .lancea* and *V. tortilis*, were better controlled by chemical treatment during the dry season, whereas others, such as *V. nilotica*, were controlled better during the wet season. However, for most species treated with triclopyr amine, higher concentrations were needed to substantially reduce resprouting ability of the study plants.

Consequently, picloram was associated with reduced resprouting ability of the study species compared to triclopyr amine, although for *P. africanum* higher concentrations were needed, specifically during the dry season. Reducing herbicide

use is a global goal (Enloe et al., 2018), thus, the study findings suggest picloram should be the preferred option for controlling the woody species, as lower concentrations effectively reduce resprouting. Failure to resprout by *V. karroo* trees suggests that other factors beyond the scope of the present study may have played a role.

Thus, further studies to understand the resprouting dynamics of *V. karroo* trees are needed. Nonetheless, the study findings imply that it would be more economically beneficial for land managers to consider the timing of treatment application when controlling woody plants in savanna landscapes. Furthermore, the results indicate that employing cutting and herbicides to control undesirable trees in savannas, consideration must be given to herbicide selection, which is based on efficacy on target species while minimizing costs. However, further research is needed to assess potential differences among these control methods across various field conditions and target species. Nonetheless, the study findings suggest that stem diameter could be a key factor in determining resprouting success in certain woody plants (Monegi et al., 2023). However, in some species, it may have little to no impact. The aim is to provide a comprehensive overview that informs future management strategies for woody plant encroachment, with a specific focus on the Marikana Thornveld. **Table 2** below summarizes key concepts, including treatment effects, research gaps, the aims and objectives of the current study, the implications of the results and recommendations.

Table 2: Synthesis of literature, research findings, and management implications.

Concept	Summary
1. Treatment effects (Mechanical control and herbicides)	• Mechanical control (e.g. bush clearing) and herbicides (e.g. picloram and triclopyr amine) are commonly used to control woody plant encroachment in southern Africa. These methods aim to reduce tree density and manage invasive species. • Herbicide treatments tend to be more cost-effective and efficient for larger areas compared to mechanical control, though they require careful application timing. • Mechanical control is more labour-intensive but may be necessary in sensitive areas. • Herbicides affect resprouting differently depending on type, concentration, and application timing.
2. Gaps	• Limited studies comparing long-term effects of herbicide versus mechanical control on resprouting patterns of woody plant species. • Knowledge gaps in how herbicide type and concentration interact with specific environmental factors such as

	soil type and rainfall patterns. • Lack of research on integrating mechanical control with herbicide application for optimal results in the Marikana Thornveld. • Insufficient data on cost-benefit analysis of herbicide versus mechanical control in local contexts.
3. Aims and objectives of this study	• To compare the effects of herbicide application and mechanical control on the resprouting patterns of woody plant species in the Marikana Thornveld. • To determine the optimal herbicide concentration and timing for effective control of resprouting.
4. Results	• Herbicide application was more effective at reducing resprouting compared to mechanical control, with varying results depending on concentration and timing. • Mechanical control showed an initial reduction in woody plant density, but resprouting rates were higher over time. • Herbicide treatments at higher concentrations led to almost complete suppression of

	resprouting for a longer duration. • Timing of application was a critical factor in achieving effective results for both methods.
5. Management implications	• Herbicide treatments may be more cost-effective in the long term for large-scale woody plant control, but their effectiveness is highly dependent on proper timing and concentration. • Mechanical control can be useful for smaller or sensitive areas, but it may require frequent follow-ups to manage resprouting. • Integrated management using both herbicides and mechanical control could provide a more sustainable approach to woody plant management. • Effective monitoring of treatment efficacy and post-treatment management is essential to prevent regrowth.
6. Conclusion and recommendations	• Herbicide application, when used appropriately, is the most effective treatment for controlling woody plant resprouting, especially when timed well.

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