

COMPARING THE EFFECTS OF TWO TYPES OF MULCHES ON SOIL
PROPERTIES AND THE PERFORMANCE OF SELECTED WOODY SPECIES
ON A DEGRADED LAND IN KUNENE REGION, NAMIBIA

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ABSTRACT

Land degradation in arid and semi-arid regions has put tremendous pressure on rangelands, reducing their ability to provide important ecosystem services and sufficient forage for livestock. Given the increasing pressures on rangelands, it is of utmost importance to find ways to restore degraded rangelands. Incorporating mulching treatments into ecological restoration plans could aid in establishing diverse and resilient plant communities and enhance the long-term success of restoration projects. The present study sought to determine the effects of two types of mulching materials (leaf litter and straw) on the soil's temperature, moisture content, and pH as well as the cumulative stem length, seedling survival, and leaf chlorophyll content of the selected species (*Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba*, and *Senegalia galpinii*) during three watering periods (once-daily, twice-weekly and once-weekly). A 5 x 5 block grid was used with treatments (control, 5cm leaf litter, 10cm leaf litter, 5cm straw, and 10cm straw) assigned randomly and within each treatment the species were assigned randomly to holes. Mulching significantly reduced soil temperatures and retained soil moisture content but did not influence soil pH during the course of the study. Amongst the various treatment combinations tested, both 10 cm mulch depths (straw and leaf litter) appeared to be the most effective in terms of optimizing soil conditions, seedling growth, and survival for *Senegalia galpinii*, *Catophractes alexandri*, and *Faidherbia albida*. During the twice-weekly watering period, *Vachellia erioloba* seedlings grew much better in the control blocks than in the two 5 cm mulch depths (leaf litter and straw), but their seedling survival rate was unaffected by mulching throughout the study period, indicating that mulching had no positive effect. These findings could be attributed to the fact that *Vachellia erioloba* is a phreatophyte, which means that it can access groundwater in water-

stressed environments (possibly very early on) and that mulching has a lower impact on its survival and growth, making the shallow effect of mulching on it less noticeable. Mulching had no effect on the leaf chlorophyll content of *Senegalia galpinii*, *Catophractes alexandri*, or *Faidherbia albida* but significantly increased chlorophyll content of *Vachellia erioloba* at both straw mulching depths, suggesting a positive species-specific response in *V. erioloba*'s photosynthetic rate towards mulching with straw. This study concludes that using leaf litter or straw mulch at 10 cm depths can improve soil conditions for plant growth and help restore degraded regions, and that some of the plant responses to the different mulching treatment combination may be species specific.

Keywords: Land degradation, ecological restoration, vegetation establishment, organic mulch, leaf litter, straw, Kunene Region, Namibia.

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DEDICATION

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DECLARATIONS

I, Simon N Kristof, hereby declare that this study is my own work and is a true reflection of my research and that this work or any part thereof has not been submitted for a degree at any other institution.

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CHAPTER 1: INTRODUCTION

1.1 Background of the study

Land degradation in arid, semi-arid, and dry sub-humid regions as a result of anthropogenic and natural activities is considered as one of the most severe environmental and socio-economic problem of recent times (Abdi *et al.*, 2013; Toor *et al.*, 2020). Land degradation is defined as a negative trend in land condition, caused by direct or indirect human-induced processes including anthropogenic climate change, expressed as long-term reduction or loss of at least one of the following: biological productivity, ecological integrity, or value to humans (Tilahun & Zewide, 2021). This definition also applies to rangeland degradation, which is the focus of this study. Rangeland degradation is the term used to describe the decline of vegetation and land cover in a particular area, often brought on by grazing and climate change (Olsson *et al.*, 2022).

The combined effect of natural and anthropogenic factors on land degradation has led to reduced production of the rangelands. Natural causes include those that determine the ecosystem's inherent capacity to generate biomass, provide goods and services, ground cover, and biodiversity (Global Environment Facility (GEF), 2019). In addition to that, some other natural causes are water and wind erosion, and it is exacerbated by a number of factors such as loss of vegetation cover, which results in a state of vulnerability (Mahata & Sharma, 2021). The anthropogenic or human-induced causes such as land-use changes and unsustainable land management practices are the primary drivers of land degradation, with the agricultural sector serving as the dominant driver (Saturday, 2018). Overall, land degradation has a negative impact on a significant portion of the Earth's arable lands, resulting in a temporary or permanent decline in

land productivity at all spatial scales (Mosier *et al.*, 2021). On a global scale, land degradation has led to a decline in ecosystem services, food insecurity, species extinction and climate change (Papanastasis, 2009). At a regional scale, it has led to a decrease and loss of vegetation cover, soil erosion, reduced soil fertility and a reduction in the ecosystem's resilience (Zeberio & Pérez, 2020), subsequently threatening the livelihoods of many residing in drylands (Yirdaw *et al.*, 2017). This has a direct impact on the ability of the rangeland to support grazing animals and provide a sustainable income to the landowner (Beukes & Cowling, 2018).

In Namibia, land degradation has become a significant problem with detrimental effects on the locals, notably in the Kunene region where the majority of the population depend on livestock production for subsistence (Eisold, 2010; Ministry of Environment & Tourism (MET), 2014). The Ovahimba, a Namibian ethnic group that comprises the majority of the pastoral villages in the north-western Kunene region, are particularly affected (Schwieger, Kiaka and Schnegg, 2022). In addition to land degradation (driven, *inter alia*, by overgrazing and overstocking), resource scarcity has exacerbated the problem (Inman, 2020), resulting in ecological and economic losses. The continued effects of the aforementioned factors on the environment, severely hamper the ability of the land to passively recover. In order to protect the ecosystem's integrity and restore ecosystem services, it is imperative to address this issue (Integrated Environmental Consultants Namibia (IECN), 2011). Ecological restoration may be a viable option for combating land degradation.

Ecological restoration is the exercise aimed at restoring an ecosystem that has been disturbed, degraded, or impaired to as close to its original state as possible (Dagar & Singh, 2018). In cases where returning the ecosystem to its original state in terms of species composition is not possible, restoring ecosystem functioning (rehabilitation)

(Cooke, 2005) or, in extreme cases, replacing the system with a completely different one (reclamation) are considered under ecological restoration (Albert, 2015). An important goal in ecological restoration is to restore soil health. Soils provide essential ecosystem services, such as providing habitats for animals that live in the soil, carbon sequestration and water purification (Nkonya *et al.*, 2016). Several soil treatments can be used to improve soil health, including mulching, the use of compost and manure, among others (Havrilla *et al.*, 2020). Although much research has been carried out on soil improvement, there is a need to identify locally appropriate strategies for treatment application (Leger, 2020).

The use of mulch to cover the soil surface where seeds have been sown or seedlings transplanted is a common method used in the establishment of plant species in areas that receive minimal care, such as restoration sites and also in crop production (Chalker-Scott, 2016; Breton *et al.*, 2016). Mulches are broadly classified into three types: organic, inorganic, and living mulches (Rahmani *et al.*, 2021). Organic mulches are derived from plant and animal materials such as straw, hay, leaf litter, compost, sawdust, wood chips and animal manure to mention a few (Bhardwaj, 2013). While inorganic mulches involve gravel, bricks, and cobblestones made of polyethylene clover. Dwarf lily turfs, white clover, and vining crops (e.g. watermelon plant) are examples of living mulches (Qian *et al.*, 2015).

In general, mulching improves soil conditions by inhibiting weed growth, encouraging the growth of beneficial soil micro-organisms, minimizing soil erosion and retaining soil moisture (Sathiyamurthy *et al.*, 2017). Using locally available material to ameliorate soil conditions in order to improve vegetation establishment at degraded sites, could be an appropriate method in the rural area of the Kunene Region, where

the majority of the people (51%) are considered living below the poverty line (Inman, Hobbs, & Tsvuura, 2020a). Additionally, it is essential to select the type of mulch and depth that yields the best results because different mulches and depths/thicknesses have been shown to have variable impacts on soil physical attributes and plant growth (Ni *et al.*, 2016). Since little is known about how native Kunene species respond to mulching in terms of growth, chlorophyll, and survival, as well as how mulching affects soil temperature, moisture, and pH or how mulching influences the beneficial effects of mulching on plant performance in the Kunene region, this study aimed to provide an insight on the aforementioned variables. *Senegalia galpinii*, *Vachellia erioloba*, *Catophractes alexandri*, and *Faidherbia albida* were the species chosen for this investigation.

1.2 Statement of the problem

The Kunene Region is an inherently arid region with a low carrying capacity for livestock (IECN, 2011). With an increase in human (and livestock) populations, coupled with seasonal fluctuations in rainfall and prolonged droughts, the effects of land degradation are bound to be more severe for rural communities with no or limited adaptive capacity. The manifestation of land degradation in the Kunene includes vegetation loss, leaving the soil surface bare and the soil prone to erosion of fertile topsoil, the latter being evident in the fissures and gullies observed in some areas of the region (Vallejo Orti *et al.*, 2024). Furthermore, land degradation has led to the poor condition of livestock and animal losses, in turn, negatively affecting the livelihood of the residents, who are mainly dependent on agro-pastoral farming (Eisold, 2010). Land degradation is a source of great concern to the farmers, the government and non-governmental organizations involved in rural development, thereby necessitating the

need to combat this problem. The current study seeks to contribute to an improved understanding of restoration of degraded areas in drylands, such as Kunene.

1.3 Aim of the study

The purpose of this study was to determine whether combinations of locally sourced organic mulches and stepped watering regimes can improve first-year survival, growth, and chlorophyll status of four selected woody species (*Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba*, and *Senegalia galpinii*) in the arid rangelands of Kunene, Namibia, thereby providing practical guidance for restoration efforts in similar drylands.

Specific objectives

The specific objectives of the study were to:

- a) Determine the extent to which each mulch × depth combination improves the temperature, moisture and soil pH under three watering periods and relate these changes to seedling survival and growth.
- b) Compare the growth (cumulative stem length) and survival of *Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba* and *Senegalia galpinii* seedlings under the five treatment combinations (control, 5cm leaf litter, 10 cm leaf litter, 5cm straw and 10cm straw) during three watering periods (once-daily, twice-weekly and once-weekly watering periods); and
- c) Compare leaf chlorophyll contents of *Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba* and *Senegalia galpinii* under the five treatment combinations (control, 5cm leaf litter, 10 cm leaf litter, 5cm straw and 10cm straw) at the end of the study period.

1.5 Research hypotheses

The following were the research hypotheses for the study:

- i. Applying organic mulch (leaf litter and straw) on the surface of the soil will lower the average diurnal soil temperature compared to bare soil (control blocks) due to increased shading and insulation.
- ii. Different depths of mulch will have varying effects on diurnal soil temperature, with thicker or denser mulches potentially having a greater impact on temperature regulation by buffering against temperature extremes.
- iii. Straw mulch is expected to provide stronger surface cooling for three complementary reasons. First, its lighter colour and smoother surface reflect more incoming short-wave radiation than the darker, irregular leaf litter, raising surface albedo by about 8–11 % (Che Soh *et al.*, 2023). Second, the large air pores between straw pieces promote convective heat loss, an effect that lowered mid-day soil temperatures by roughly 4–6 °C in dry-orchard trials (Ni *et al.*, 2016). Third, straw's coarse architecture intercepts sunlight while still allowing air flow, whereas fine, compacted leaf litter may hold more surface heat under calm conditions (Chalker-Scott, 2007). Collectively, these traits justify the prediction that straw, particularly at a 10 cm depth, will yield the coolest soil profiles.
- iv. Field research indicates that, although minor treatment-specific trends do occur, organic mulches rarely result in significant, rapid shifts in the pH of bulk soil during the first season because the localized production of acids from decomposing mulch will be minimal. In a semi-arid, rain-fed orchard on the Chinese Loess Plateau, an 8 t ha⁻¹ wheat-straw layer raised the 0–10 cm soil

pH by +0.15 units after 12 months, apparently through leaching of exchangeable Ca^{2+} and K^{+} (Ni *et al.*, 2016).

- v. The soil moisture content of the seedlings grown in both 10 and 5 cm blocks of leaf litter is expected to be higher than that of straw at the same depths due to a higher soil water retention property of leaf-litter.
- vi. Plants that are mulched at depths of 5 cm regardless of mulch type are expected to grow and survive better than plants that are mulched at 10 cm depths because shallow mulches (3 – 5 cm) are generally beneficial for moisture retention and soil temperature regulation without causing oxygen deprivation or nutrient imbalances.
- vii. Applying mulch is expected to increase seedling chlorophyll content relative to the bare-soil (control), with leaf-litter mulch producing the highest levels, straw mulch an intermediate increase, and the un-mulched (control) the lowest. Organic covers reduce evaporative demand and heat stress, improving plant water status and sustaining stomatal opening during midday; higher tissue hydration in turn maintains chlorophyll integrity and photosynthetic protein turnover. Leaf-litter mulch is expected to give the largest chlorophyll boost because its C:N ratio (generally ranges from 15:1 to 30:1) is well below that of straw (ranges from 48:1 to 150:1) decomposing rapidly leading to nitrogen enrichment and increased photosynthetic rate (van der Sloot *et al.*, 2022).

1.6 Significance of the study

Many parties, including farmers, government departments involved in rural development, NGOs, and the ecological scientific community, are interested in solutions to address land degradation and its consequences. Adopting appropriate land degradation mitigation strategies/techniques can help to reduce land degradation and

improve livelihoods in drylands. Constraints to restoring degraded lands include a lack of knowledge about appropriate plant species to employ, and management of soil moisture and fertility. Land productivity in the Kunene region has declined, soil fertility has decreased due to both direct (amount of organic matter, moisture, and field aeration) and indirect (soil biota activity, tillage method, etc.) factors, and people's livelihoods have suffered as a consequence of land degradation. To mitigate some of these challenges, I investigated a method that has been shown to improve both soil water conditions and nutrient levels, while utilizing easily accessible, naturally occurring material for prospective use in restoration/rangeland improvement interventions in degraded areas. Because different mulch depths/thicknesses have been shown to have variable effects on soil physical properties and plant growth, it is critical to assess the effects of different mulch depths of locally available soil amendments on both soil and plant performance in order to choose the mulch and depth that yields the best results. This study will provide insight into which of the two locally accessible materials is better to utilize and at what depth to improve soil conditions and plant establishment. The findings of this study can potentially be used to identify a cost-effective method that could be implemented by the local people for the restoration of the degraded land in the Kunene Region and other similar ecosystems in Namibia or elsewhere in the world.

1.7 Limitations of the study

The experimental site is in a naturally arid environment. This being a hot and dry area, the environmental conditions were a limitation such that the amount of working hours per day were drastically reduced as work was limited to early mornings and late afternoon, which delayed the transplanting date from the 10th to 16th December 2022. This delay was addressed by increasing the duration of the experiment/period of data

collection. Water for irrigation was pumped from the Kunene River using a solar pump; but, on overcast days, the pump did not provide enough water, so we used a water pump generator as a backup.

1.8 Delimitation of the study

The study was carried out in Otjamaungu, a small village in the Epupa constituency of the Kunene Region. As a result, the results obtained are not a representative of the entire region or the country as a whole. Only seedlings of four woody tree species were used in the study. The experimental site was identified and assigned by the local community based on what they considered a degraded area.

CHAPTER 2: LITERATURE REVIEW

2.1 Land degradation and its impacts

Land degradation gained significant global recognition in the twentieth century due to its negative impacts on the global environment, income, and food chain (Mahata & Sharma, 2021). It still remains a high priority discussion in the twenty-first century. The literature defines land degradation in a variety of ways. According to a review by Tilahun & Zewide, (2021)), land degradation is defined as a negative trend in land condition caused by direct or indirect human-induced processes combined with anthropogenic temperature change, expressed as a long reduction or loss of at least one of the following: biological productivity, ecological integrity, or human price. Furthermore, the United Nations Convention to Combat Desertification (2019) defined land degradation as the result of human-induced acts that exploit land, reducing its utility, biodiversity, soil fertility, and overall health.

Land degradation is occurring in almost all terrestrial biomes and agro-ecologies (Erkossa *et al.*, 2022), in both low and high income countries, although its impacts are more severe on the livelihoods of the poor who heavily depend on natural resources (Nkonya *et al.*, 2016). Globally, 23% of arable land is no longer productive, 75% has been transformed (92 % is due to mismanagement and 38 % of that is due to overgrazing of animals), and the annual degradation cost is about USD 40 billion (United Nations Convention to Combat Desertification (UNCCD), 2019; Nkonya *et al.*, 2016). It has become an environmental problem with approximately 18.1 million km² of degraded land globally, and it has consequences for critical livelihood aspects such as food security, ecosystem services, water security and climate change mitigation, particularly in Africa and Asia (Baartman *et al.*, 2007). Hussain *et al.* (2021) emphasized that the cost of action against land degradation has a higher

economic return than the cost of inaction, with a one US dollar investment in the restoration of a degraded land returning five US dollars, which they cited as a strong incentive for taking action against land degradation.

2.2 Strategies to address land degradation

Several authors have emphasized the importance of implementing sustainable management practices or strategies that prevent or reverse land degradation in African drylands (Inman, 2020, Inman, Hobbs, & Tsvuura, 2020b). Similarly, Hussain *et al.* (2021) emphasized the importance of adopting appropriate and sustainable management practices for preventing the degradation process and restoring the already degraded lands that are prevalent worldwide. Measures such as cover crops, compost, mulching, green manures, and conservation tillage (Barman *et al.*, 2013), are the most important in increasing soil fertility since they satisfactorily assist the restoration of damaged soils (Bartman, 2007). Land degradation can be managed through dedicated policies (Akhtar-Schuster *et al.*, 2017), ground cover, organic and inorganic soil amendments and agroforestry (Saturday, 2018; Toor *et al.*, 2020). Furthermore, the restoration of degraded agricultural lands and rangelands requires agronomic (Iqbal *et al.*, 2020) and biological techniques (Mesene, 2017) such as crop rotation, agroforestry, buffers, mulching or manure and drip irrigation in order to protect the soil from soil erosion, indirectly contributing to the reduction of land degradation (Havrilla *et al.*, 2020; Toor *et al.*, 2020). Despite the expanding body of literature, ecological restoration of degraded areas as a means of addressing the current issues of land degradation in Namibia has received little attention. There is, therefore, a need for studies that will address this research gap, which includes identifying restoration strategies suited to our local environments and available resources. To prevent, reduce, and mitigate the causes of degradation and restore degraded lands, Meena (2022)

suggested feasible solutions. Soil and water conservation (SWC) technologies such as mixed cropping, mulching, and vegetative barriers are typically used in restoration to maintain soil fertility (Mosier *et al.*, 2021) and agronomic productivity (Apfelbaum, 2014, Mesene, 2017, Meena 2022). This strategies improve restoration or rehabilitation efforts while also eradicating poverty, achieving land degradation neutrality (Scholes *et al.*, 2018), and constructing climate-resilient agriculture (Chazdon, 2008).

2.3 Success and failure of restoration initiatives

The absence of systematic, predefined criteria for evaluating success and strategies to spot possible failures early on is a common problem with ecological restoration projects (Höhl *et al.*, 2020). Major obstacles to successful restoration projects are but not limited to a lack of local stakeholder involvement and a mismatch between goals of local communities and restoration managers, as well as environmental, anthropogenic, and technical barriers to tree regeneration (Fragoso *et al.*, 2017, Höhl *et al.*, 2020). When local communities, their goals, and needs are disregarded in project planning and implementation, there is a risk of project failure (Santini & Miquelajauregui, 2022). Coupling the goals of ecological restoration with the participation of local communities is needed for successful, long-term restoration of ecosystems (Inman, Hobbs, & Tsvuura, 2020a). These communities often directly rely on the ecosystem services for their livelihood and are particularly vulnerable to land degradation. Therefore, restoring degraded habitats is often critical for the well-being of these communities, who are well-positioned with an interest in restoring the land upon which their livelihood depends.

2.4 The use of mulch in degraded areas and restoration projects

Ecological restoration is the process of assisting the recovery of an ecosystem after it has been damaged, destroyed, or degraded (Gann *et al.*, 2019; Martin 2017). Restoration ecology is the scientific discipline of ecology that underpins the practice of ecological restoration (Martin, 2017) and aims to put a degraded ecosystem on a path towards recovery that allows adaptation to local (Venditto *et al.*, 2022) and global changes, as well as persistence and evolution of its constituent species (Gann *et al.*, 2019).

Mulching is a technique defined as the addition of an artificial or natural layer of materials to the soil surface (Chalker-scott, 2016). This technique is well known among green space managers and the agricultural world because, in addition to providing a nutrient rich soil amendment and being low-cost, it influences the soil's physio-chemical parameters (Leclercq-dransart *et al.*, 2020). For instance, the presence of mulch in an arid region significantly increased soil moisture (4.70-12.50%), decreased water infiltration rate (15.35-18.40%), increased plant growth (12.30-26.90%), and reduced soil erosion (70.0-85.0%) (Bhardwaj, 2013). In particular, Breton *et al.* (2016) found the use of wood chips as a mulch to result in an overall improvement in plant survival of up to 50%.

According to Khoramizadeh *et al.* (2021), organic mulches can speed up the restoration of soil properties, which can take a few years to several decades without mulching, as well as compensate for the loss of the litter layer on degraded soils. The ability of various organic mulches (leaf litter, straw, and sawdust) to improve the soil conditions in the Hyrcanian Forests, Northern Iran Azadeh, was evaluated by Khoramizadeh *et al.* (2021). They discovered that treatments with litter, straw, and

sawdust significantly improved the values of soil's physical and chemical properties when compared to those of untreated soil. Additionally, they also discovered that leaf litter offered more nutrients than mulches made of sawdust and straw. Mollard *et al.* (2016), discovered that mulching (straw and hay) the soil surface in degraded areas improved plant recruitment and early vegetation development in water-limited areas while reducing soil erosion. Additionally, a comparative study by Chalker-scott, (2016) found that using leaf material as mulch rather than incorporating the same leaf material directly into the soil was more effective at conserving water. These findings emphasize the value of mulching and the need to compare the efficiency of various types of mulches when used to restore degraded areas in arid and semi-arid environments.

Surface mulching is widely acknowledged as sound practice in arid and semi-arid agriculture (Yirdaw *et al.*, 2017a; Chalker-Scott, 2007; Bhardwaj, 2013). Yet the supporting evidence is drawn almost entirely from annual crops, exotic shade trees grown under uninterrupted irrigation, or irrigated vineyards and frequently relies on synthetic films rather than readily available organic materials such as straw or leaf litter. Apart from a quartz pebble-mulch experiment on *Acacia mellifera* seedlings in Namibia's Highland Savanna which used a single, inorganic cover at one thickness, no published Southern-African study has yet tested factorial combinations of two locally available organic mulches (leaf litter and cereal straw) at different depths on indigenous woody seedlings. No studies of these natures have also focused on the four selected species in this study (*Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba*, and *Senegalia galpinii*), most of which are regarded as highly important by the Himba communities in Kunene. Furthermore, many existing experiments are run under fixed irrigation, whereas FAO guidelines for dry-zone planting explicitly call

for frequent light watering during germination, followed by a staged reduction as roots establish, mulch performance under such step-down watering is unknown. The present study addresses these gaps by testing mulch type \times depth under a stepped irrigation regime on those four priority species, moving the discourse from generic claims that “mulching helps” to an evidence-based, locally actionable recommendation

3.1.2 Climate

The Kunene region is an arid area, with a sporadic annual rainfall increasing from the west to the east, mostly occurring in the summer, between November and April, ranging from 50 mm to 415 mm per annum (IECN, 2011; Inman, Hobbs, & Tsvuura, 2020; Menestrey Schwieger *et al.*, 2022). Summer day temperatures can reach up to 35 °C, with typical lows of 14 °C, and winter temperatures can range from 5 to 26 °C (Kunene Regional Council, 2015). The landscape is often subject to protracted dry spells with devastating impacts on livestock and wildlife (Inman, *et al.*, 2020).

3.1.3 Geology, Soils, and Physical features

The Kunene landscape is divided into the interior highlands and the pro-Namib plains. It has six agro-ecological zones, namely the Mountainous areas, Plateaus, Riverine, Lacustrine and Karst areas, Coastal desert and Etosha region (Dieckmann, 2014). The soils are mainly described as sandy to loamy sand, characterized by low organic matter content and their depth varies from shallow to deep (Clarke, 2021).

3.1.4 Vegetation

The vegetation of this landscape is predominantly Mopane Savanna (*Colophospermum mopane*), mixed with several other woody species such as *Terminalia prunioides*, *Vachellia erioloba*, *Catophractes alexandri*, *Faidherbia albida*, *Diospyros mespiliformis*, *Combretum imberbe*, *Ximenia americana*, *Boscia foetida*, *Hyphaene petersiana*, *Commiphora glaucescens*, *Ziziphus mucronata* and the succulent *Euphorbia* species (*E. damarana*, *E. verosa* and *E. mauritanica*) (Kabajani, 2021; Teshirogi *et al.*, 2017). Grass species found in the area include *Antheophora schinzi*, *Enneapogon cenchroides*, *Enneapogon desvauxi*, *Chloris virgata* and *Antheophora*

pubescens (Klaassen & Craven, 2003), as well as *Schmidtia pappophoroides*, *Aristida adscensionis*, *Stipagrostis uniplumis* and *Stipagrostis ciliata* (Eisold, 2010).

3.2 Study species

For this study, four woody species that are indigenous to Namibia were selected, including three species occurring locally in the study area namely *Faidherbia albida*, *Catophractes alexandri*, *Vachellia erioloba*, and *Senegalia galpinii* that does not occur locally in study area. The woody seedlings were selected for this study rather than perennial grasses because of:

1. Restoration priority in Kunene.

Rapid-assessment data from north-western Kunene record <10 % herbaceous cover and >60 % bare ground, but very low natural recruitment of long-lived woody species (Pringle, 2021). Re-introducing structurally dominant trees and large shrubs therefore tackles the most persistent vegetation gap, while grasses can recolonize once micro-climate and soil stability improve (Bayen *et al.*, 2020).

2. Multi-functionality of selected species valued by Himba communities.

The four chosen species supply dry-season browse (*Catophractes*, *Faidherbia pods*), shade for livestock (*Vachellia erioloba*), soil nitrogen (all are legumes) and fuelwood (*Senegalia galpinii*). Goats and cattle owners interviewed in Epupa and Opuwo ranked these functions above additional grass biomass (Inman *et al.*, 2020). The research species' seeds were also easily accessible, making them ideal candidates for local restoration efforts with low seed collecting input, allowing the local people to replicate the study with low-income input.

3.2.1 *Faidherbia albida*

Faidherbia albida is a leguminous tree from the family Fabaceae and it is well known for its benefits on soil fertility (Spevacek, 2011). It is a widely distributed species, which is believed to be indigenous to the arid and semiarid zones of Africa, but it is also found in Israel, Syria, and Cyprus (Spevacek, 2011; Tougiani *et al.*, 2021). When conditions are favorable, *F. albida* can reach more than 30m in height and 1.5m in diameter at breast height (Tougiani *et al.*, 2021). The crown is pyramidal when the tree is young and becomes hemi-spherical with age. It also has a special (reverse) phenology as it sheds its leaves during the rainy season and keeps them during the dry season, (Tougiani *et al.*, 2021). The reversed leaf phenology of *F. albida* sets it apart from other tree species that also increase soil nutrients, because it sheds its nitrogen-rich foliage during the cropping season, thus it hardly competes for light and water during the growing season of the crop which is beneficial to crop farmers (Hadgu & Kooistra, 2009). This tree species was chosen for this study because it is an ideal multipurpose agroforestry tree that grows in a wide range of ecological conditions, either scattered or gregarious, along the banks of seasonal and perennial rivers and streams on sandy alluvial soils, and thrives in climates characterized by long summers or a dry season with long days (Tsegu, 2019a), similar to those found in the Kunene region. It has nitrogen-fixing properties and has a positive effect on the microclimate, soil fertility, and soil moisture for associated crops, which can help farmers with their annual crops like pearl millet when intercropped with them, increasing food security during dry periods (Akpalu *et al.*, 2020). Its leaves and protein-rich fruits (pods) that fall from the tree in large quantities during dormancy in the early rainy season enrich the soil with nitrogen, phosphorus, and exchangeable calcium, aiding in the restoration of soil health, and also serve as a source of fodder for livestock in the dry season when

herbage is scarce (Akpalu *et al.*, 2020; Githae & Mutiga, 2021). The tree has strong and fast spreading tap roots that can reach aquifers of up to 80 m below the surface to assure permanent water supply (Tsegu, 2019a). Access to groundwater permits *F. albida* to thrive in an otherwise desert or water scarce environment.

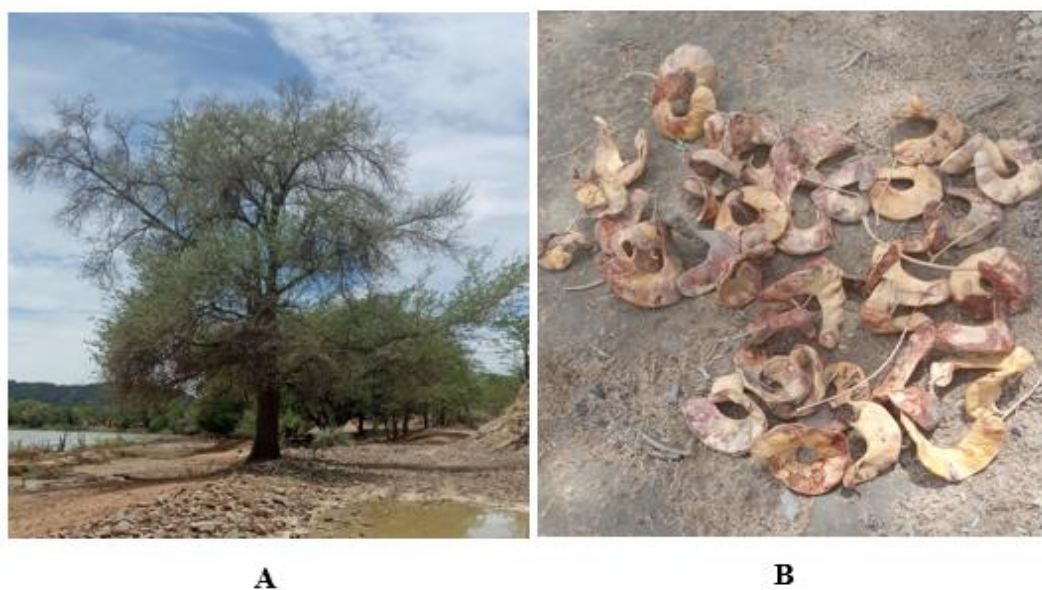


Figure 2. A photo of *Faidherbia albida*, showing (A) a whole plant and (B) pods with seeds.

3.2.2 *Catophractes alexandri*

Catophractes alexandri is a branched spiny shrub with greyish green foliage (figure 3), it is the only species in the genus *Catophractes* and belongs to the family Bignoniaceae (Lori *et al.*, 2019). The roots of this widely distributed plant are used to make tea, while the bark is used to treat coughs and stomach ache (Teshirogi, 2010). In the Kunene region, *C. alexandri* is also regarded as one of the most sought after plants, as a browse preference for goats, as well as wildlife such as zebra and springbok

(Rothauge, 2022), hence it is a valuable plant to both the people and animals in the region.

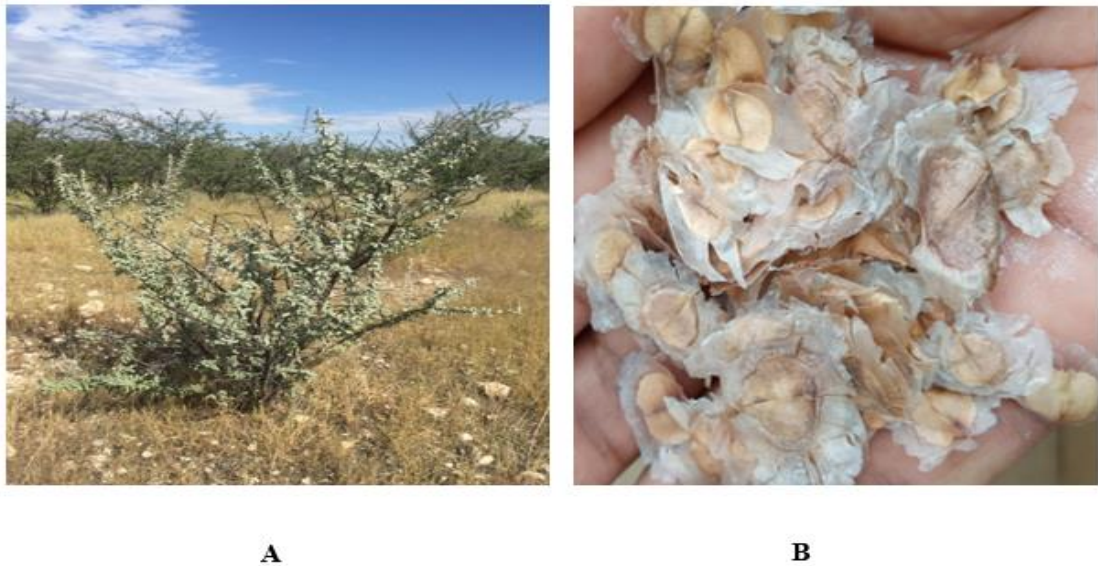


Figure 3. A photo of *Catophractes alexandri*, showing (A) a whole plant and (B) seeds.

3.2.3 *Vachellia erioloba*

V. erioloba belongs to the family Fabaceae and subfamily Mimosoideae (Orwa *et al.*, 2009; Toivo, 2021). It was previously known as *Acacia erioloba* (Seigler & Ebinger, 2010). It is a long-lived tree with a lifespan in excess of 240 years (van der Merwe *et al.*, 2019). It is widely distributed in Namibia, occurring in different habitats such as on grass plains, along riverbeds, in rocky areas and its preferred habitat, sandy soils (Toivo, 2021). Its canopy shape varies from circular to semicircular (Moustakas *et al.*, 2008) and it can reach up to 22m in height (Hassan & Hamdy, 2021). Its flowers are bright golden-yellow and the pods are greyish-green (Hassan & Hamdy, 2021). The pods are useful fodder for goats, cattle, and wild animals, especially during the dry season, and are highly nutritious, with a feeding value comparable to legume hay; cows that have eaten them have shown a significant increase in their milk quantity (Marius

et al., 2018). This will greatly benefit Kunene's local communities, as a large portion of its population rely on cattle products like milk for their daily subsistence (Inman, Hobbs, & Tsvuura, 2020b). Dry powdered pods can be used to treat ear infections, gum to treat gonorrhoea, burned bark to treat headaches and roots are used as a cough remedy (Tsegu, 2019b). Mature trees are drought resistant and are not easily affected by short-term climatic variations, because they have one of the deepest roots of any known species (68 m), which allows them to access deep underground water sources (Moustakas *et al.*, 2006), making them ideal for an arid area like the Kunene region. *V. erioloba* is regarded as a keystone species because it provides food e.g. cattle, shelter, perches, nests and roost sites to many types of animals and harbors a distinct assemblage of plant species below its canopy (Moustakas *et al.*, 2008).



Figure 4. A photo of *Vachellia erioloba*, showing (A) whole plant with pods and (B) treated seeds for the current study.

3.2.4 *Senegalia galpinii*

Senegalia galpinii belongs to the family of Fabaceae and it was previously known as *Acacia galpinii* (Seigler & Ebinger, 2010). This tree species grows very fast, reaching 25-30 m and it is an excellent candidate for establishing planted forests (Botumile *et al.*, 2020). *Senegalia galpinii* is one of the trees that can survive harsh conditions (hot and dry) (Hassan & Hamdy, 2021), a characteristic that can enable it to thrive and possibly be a viable self-sustaining population in the Kunene region with minimal care once it establishes. It can sequester carbon, rehabilitate degraded areas, aid in landscape restoration, and protect watersheds and agricultural soils (Botumile *et al.*, 2020). Naturally, it grows on open, wooded grassland, open woodland and near streams (Kyalangalilwa *et al.*, 2013). It is deciduous, losing its leaves during the southern African winter from April to July and it has creamy to light yellow flowers appearing during the growing season from September to October (Botumile *et al.*, 2020). The pods are reddish to purplish brown. Furthermore, the roots are burnt and used to cure headaches while dried and crushed pods are used for ear infections, heated pods are used for swellings, wood ash is used to sooth wounds, and the root infusions are used as cough medicine (Botumile *et al.*, 2020). Bees and wasps visit the flowers, and giraffes, kudus and elephants' brows on the plant and also use it for shade during the hot summer.



Figure 5. A photo of *Senegalia galpinii*, showing (A) seedlings and (B) treated seeds used in the current study.

3.3 Seed collection, treatment & sowing

The seeds of *F. albida*, *V. erioloba* and *C. alexandri* were collected along the Kunene River and the surrounding areas of the experimental site by hand from their respective tree branches or from the ground, in the Kunene Region. While the seeds of *S. galpinii* were collected from trees at the University of Namibia, Windhoek main campus, by hand. All the seeds were collected from March to August 2022, and they were stored in brown paper bags until seed treatment. The seeds of *F. albida*, *V. erioloba* and *S. galpinii* were treated with sulphuric acid for 45 minutes (Fig. 6) and were also left in hot water over night to break seed dormancy depending on the toughness of their seed coat. No seed treatment was done for the seeds of *C. alexandri*, as the seeds do not have a hard seed coat that can prevent the seeds from germinating readily. The seeds were sown in black polythene growing bags filled with river sand to maximize germination (Inman, 2020). Three seeds were sown per bag for each species and, after germination, the seedlings were raised in a nursery at the experimental site in the

Kunene Region for a period of 10 weeks before they were transplanted. The seedlings were watered daily in the nursery. Before transplanting, the seedlings were thinned to one seedling per bag and hardened for two weeks, by slowly exposing them to the elements of the environment before full sun exposure. Seedlings were transplanted to the field on the 16 December 2022 at 10 weeks old (Fig. 7).



Figure 6. Seed treatment with sulphuric acid (A) and (B) seeds after treatment.



Figure 7. Seedling transplant preparations (A), (B) application of lifer litter as per required treatment depth and (C) transplanting of a seedling.

3.4 Collection of mulching material

The collection of leaf litter and straw material was carried out in September 2022. The collected leaf litter and straw material was kept in black refuse bags to prevent it from being damaged by insects and it was stored in a storage room at the experimental site until it was required for application. Leaf litter was collected from the surrounding

areas of the experimental site, using a rake and a wheel barrow. There was insufficient straw material in the surrounding areas of the experimental site due to the aridity of the environment and the limited vegetation in the area, which translated into the low supply of plant material. The straw material used in this study was, thus, collected from a research site in a nearby village (Otjimbundu), which was fenced off to prevent grazing.



Figure 8. Collection of (A) leaf litter from the surroundings of the experimental site and (B) straw from a research site in Otjimbundu village, Kunene region.

3.5 Experimental design

In this study, 10-week-old seedlings of four woody plant species were transplanted on an experimental site in Otjamaungu village, Kunene region. We compared the effects of two mulches, 1) leaf litter and 2) straw, applied at two different depths/thicknesses, a) 5 cm (as recommended by Breton *et al.*, 2016) and 10 cm (Ni *et al.*, 2016). A 5 x 5 block grid was used to simplify the application and monitoring of the various treatment

combinations (control, 5cm leaf litter, 10cm leaf litter, 5cm straw, and 10cm straw) (Fig. 9). To ease treatment application, treatments were applied randomly in blocks and within each block the species were assigned randomly to holes, with each of the five treatment combinations being represented by five randomly placed blocks (Fig. 9a). Within each block, the study species were replicated five times and each of the 20 seedlings (5x4 species) were planted at a distance of 1m apart at random (Fig. 9b). This study used 500 seedlings, with 125 seedlings from each species. Fig. 10 shows the digging of seedling holes at 1 m distance apart.

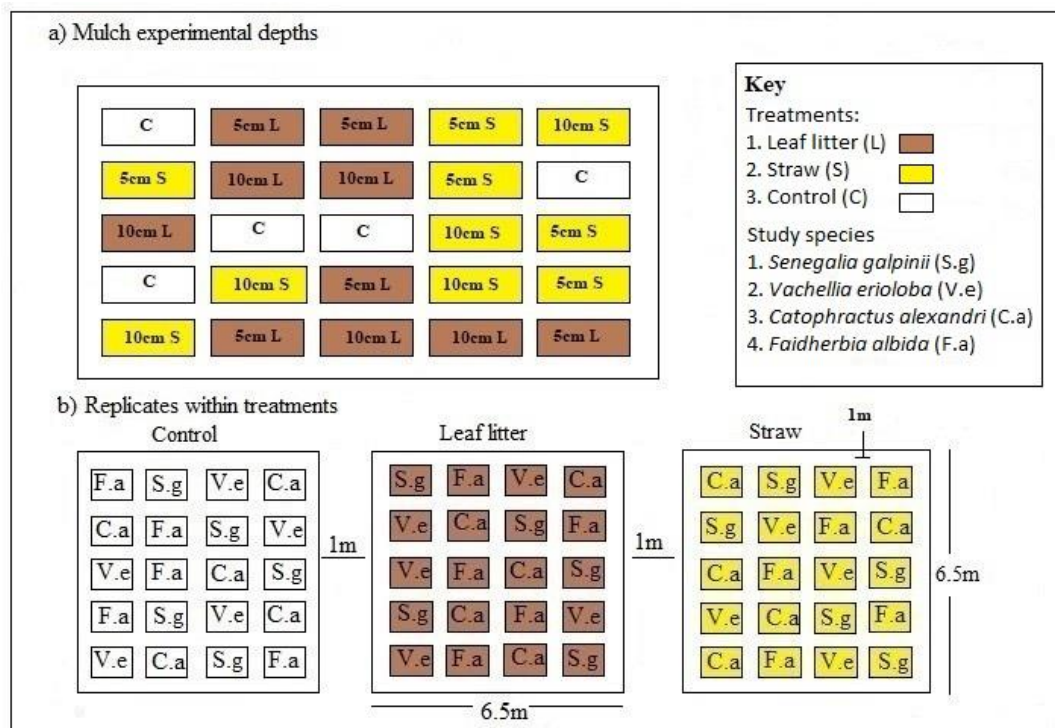


Figure 9. A graphical representation of the experimental design, showing an example of a) a layout of the different treatments (mulch + depth combinations) per block, and b) an example of the distribution of the different species' replicates within a treatment block.



Figure 10. Digging of the seedling holes at 1m apart at the experimental site.

3.7 Treatment application and data collection

Seedlings of all species were transplanted into 0.5 x 0.5 x 0.5 m holes on December 16, 2022. The seedlings were initially watered daily from 16 December 2022 to 28 February 2023 to allow for establishment. Watering was then reduced to twice weekly from 01 March – 31 May, 2023 and then finally once weekly from 01 June – 21 August, 2023.

A sprinkler system (micro sprinklers) was used to ensure that the seedlings received equal amounts of water at all stages of watering and watering was done for one during the respective watering period. No watering was applied if it had rained within the last 24 hours or if the soil was still saturated from earlier severe rainfalls. Leaf litter and straw were spread by hand on the surface after seedling transplantation as per the experimental design (Fig. 9). The depths of leaf litter and straw were measured using a 30 cm ruler. Surface applications of leaf litter and straw were replenished after rainy or windy days to maintain the experimental depths constant throughout the study. Shrubs and any recruitments growing within 1 m of seedlings were cut off at the base

and weeding was carried out throughout the experiment, removing all emerging grasses and forbs within the treatment blocks.

As response variables to the treatment combinations, diurnal soil temperature, moisture content, and pH were assessed and measurements were recorded from 12pm to 14pm daily. Daily measurements were taken from 5 points per treatment combination, which were assigned at random throughout the study's duration. These readings were pooled and averaged to provide a monthly diurnal temperature, moisture content and pH reading. The daily temperature, moisture content, and pH readings were measured using a soil thermometer and a Resun RM31MLS 3-way soil meter plunged into the soil at a depth of 10 cm.

The cumulative stem length of seedlings of each of the species was measured with a tape measure by measuring the length of individual branches/stems (ignoring the leaves), and in cases where the plant had multiple stems, they were all measured, and their value pooled (Fig. 11a) (Verma *et al.*, 2009). Since each watering period lasted for 3 months, the measurements were done 3 times per watering period. In each treatment combination, seedling survival (%) was calculated by dividing the number of seedlings that survived by the total number of seedlings initially transplanted multiplied by 100. Seedling survival was recorded 3 times per watering period. The soil plant analytical development (SPAD)-502Plus meter was used to measure the chlorophyll content of the leaves of all four study species in all treatment combinations (Fig. 11b) at the end of the study. Three seedlings were selected at random from each treatment block and chlorophyll content was measured from three leaves with five replicates per leaf. In total 15 seedlings were measured for chlorophyll content from each treatment combination at the end of the study.



Figure 11. Measuring the cumulative stem length (growth) (A) and taking chlorophyll readings (B).

3.8 Data processing and analysis

Data analyses were carried out using the IBM Statistical Package for the social Sciences (SPSS) version 29.0.0.0 (241) and the graphs were created with SigmaPlot 14.0. The Shapiro-Wilk test was performed to test for normality in the diurnal soil temperature, moisture content, pH, cumulative stem length, seedling survival and chlorophyll content data, which advised the type of statistical test used. Before using nonparametric tests, data were first log (10) transformed and tested for normality again. If the data were still not normally distributed, the original data was subjected to a non-parametric test. A parametric test was applied to the transformed data when the data were found to be normally distributed after transformation. The data for soil temperature, moisture content, pH, cumulative stem length and seedling survival were not normally distributed, thus a Kruskal Wallis test was applied to those data among the five different treatment combinations (control, 5cm leaf litter, 10cm leaf litter, 5cm

straw, and 10cm straw) during the study period. Where the Kruskal Wallis test revealed a significant difference, the Dunn's post hoc tests using a Bonferroni-adjusted alpha level of 0.05 was used for pair-wise comparisons of the different treatment combinations. The chlorophyll content data were normally distributed after log (10) transformation; thus, a one-way ANOVA was performed to test for differences in the leaf chlorophyll content among the five different treatment combinations and four species. The Tukey's honestly significant difference (HSD) test was used as a post-hoc test where significant differences were found with the one-way ANOVA.

CHAPTER 4: RESULT

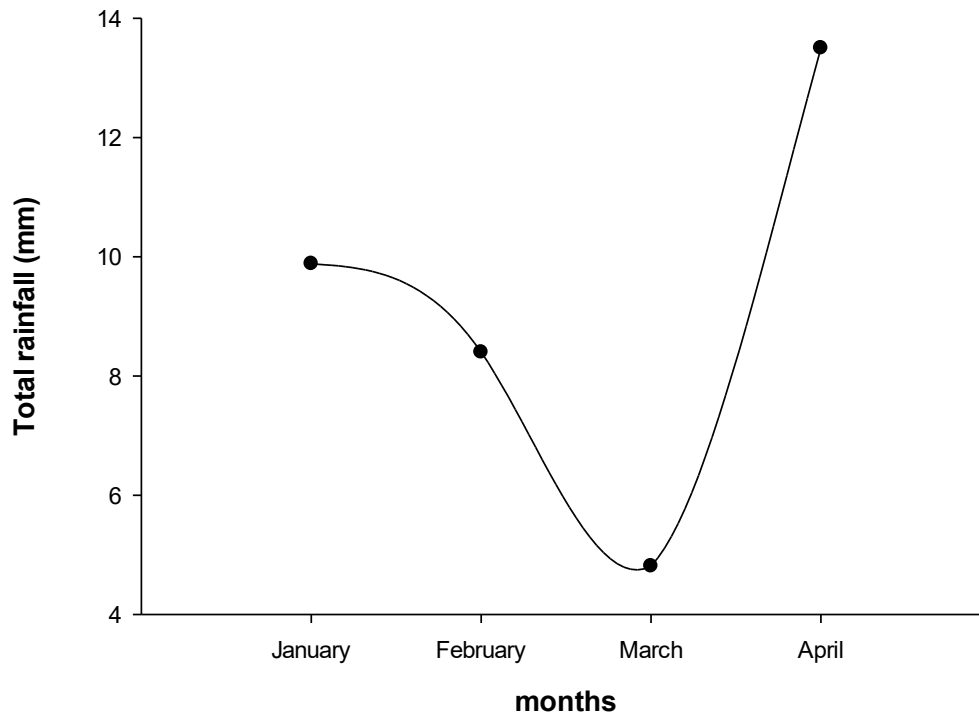


Figure 12. Total mean rainfall (mm) readings throughout the study period from January to April 2023 at Otjamaungu village, Kunene region.

During the study period, rainfall began in January 2023 and continued until April 2023. The month with the least rainfall was March, and the month with the most rainfall was April (Figure 12). On days when it rained, no watering was applied, and if the rain was severe, causing the seedlings' holes to be saturated the next day/days, no watering was applied as well. The rain may have had an effect on soil moisture readings, especially when it rained heavily, resulting in higher moisture readings on those days.

4.1 Effects of mulching treatments on soil temperature (°C), soil moisture content (%) and soil pH under three watering periods.

4.1.1 Soil Temperature (°C)

Once-daily watering period

There was a statistically significant difference in the median soil temperature amongst treatment combinations (control, 5cm leaf litter, 10cm leaf litter, 5cm straw, and 10cm straw) during the once-daily watering period, ($H(4) = 104.710, p < 0.001$) (Fig. 13). The soil temperature in the control blocks (33°C) was significantly higher than the soil temperature in the 10 cm leaf litter blocks (30°C), 5 cm leaf litter blocks (30°C), 10 cm straw blocks (29°C), and 5 cm straw blocks (30°C) ($p < 0.001$ for all the comparisons) (Fig. 13). All other pairwise comparisons were not significantly different ($p > 0.05$).

Twice-weekly watering period

The median soil temperature differed significantly between treatment combinations ($H(4) = 68.789, p < 0.001$) during the twice-weekly watering period (Fig. 13). Soil temperature in the control blocks (33°C) was significantly higher than in 10 cm leaf litter (30°C), 5 cm leaf litter (31°C), 10 cm straw (29°C), and 5 cm straw blocks (31°C) ($p < 0.001$ for all comparisons). Soil temperature was significantly lower in 10 cm straw blocks (29°C), compared to 5 cm straw and 5 cm leaf litter blocks (31°C for both) ($p < 0.01$). The other pairwise comparisons showed no statistical difference ($p > 0.05$).

Once-weekly watering period

During once-weekly watering period, treatment combinations had significantly different median soil temperatures ($H(4) = 59.094, p < 0.001$) (Fig. 13). Fig. 13 shows

that the control blocks (30°C) had significantly higher soil temperature than the 10 cm straw (27°C) ($p < 0.001$) and 5 cm leaf litter blocks (28°C) ($p < 0.01$). The 10 cm straw blocks had significantly lower soil temperatures than the 5 cm straw blocks (29°C) ($p < 0.001$), 10 cm leaf litter blocks (29°C) ($p < 0.01$), and 5 cm leaf litter blocks (28°C) ($p < 0.01$).

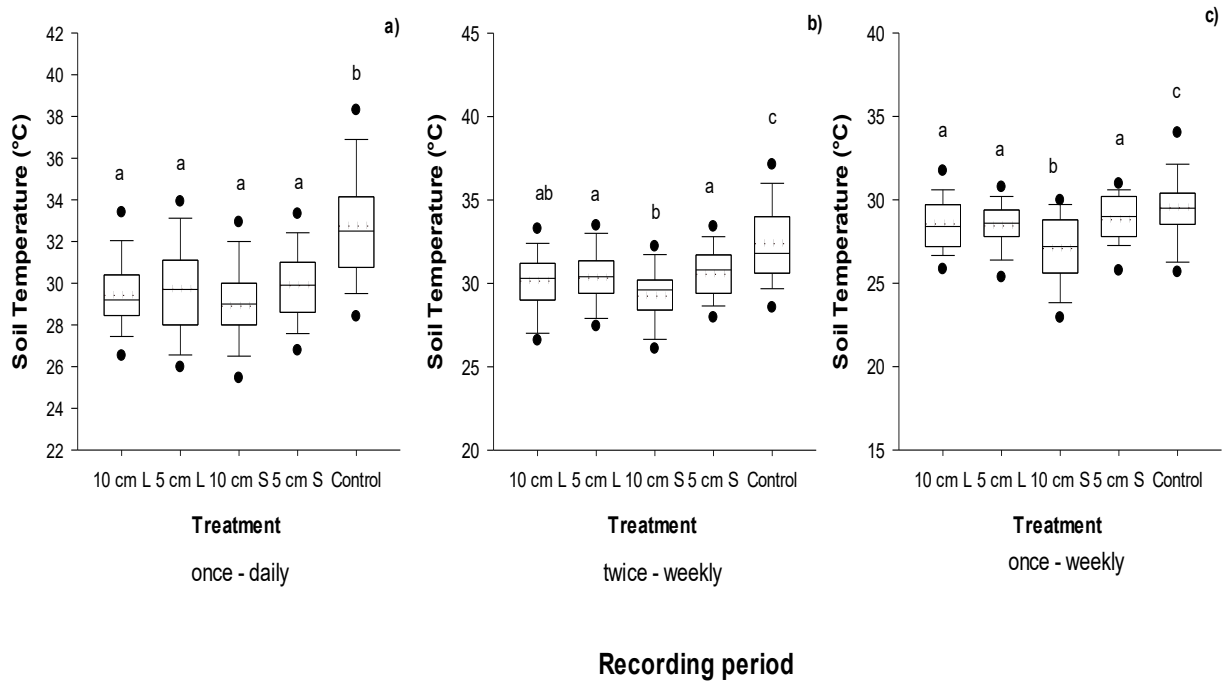


Figure 13. Soil temperature under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

4.1.2 Soil moisture (%)

Once-daily watering period

During the once-daily watering period, the treatment combinations showed a significant difference in median soil moisture content ($H(4) = 46.577, p < 0.001$) (Fig. 14). Control blocks had significantly lower soil moisture contents (63%) compared to other treatment combinations: 10 cm leaf litter blocks (78%) ($p < 0.001$), 5 cm leaf litter (73%) ($p < 0.001$), 10 cm straw blocks (73%) ($p < 0.01$), and 5 cm straw blocks (71 %) ($p < 0.05$). Fig. 14 shows that soil moisture content was significantly higher in 10 cm leaf litter blocks compared to 5 cm leaf litter ($p < 0.01$), 10 cm straw blocks ($p < 0.01$) and 5 cm straw ($p < 0.05$). No other significant differences were observed among treatment combinations.

Twice-weekly watering period

The median soil moisture content differed significantly among treatment combinations ($H(4) = 116.543, p < 0.001$) (Fig. 14), with control blocks having the lowest soil moisture content (55%) compared to 10 cm leaf litter blocks (78%), 5 cm leaf litter blocks (76%), 10 cm straw blocks (76%), and 5 cm straw blocks (75%), ($p < 0.001$ for all comparisons). No other significant differences were observed among treatment combinations.

Once-weekly watering period

During the once-weekly watering period, the median soil moisture content differed significantly among the treatment combinations ($H(4) = 143.793, p < 0.001$) (Fig. 14). The control blocks (40%) had the lowest soil moisture content compared to the 10 cm leaf litter blocks (74%), 5 cm leaf litter blocks (74%), 10 cm straw blocks

(71%), and 5 cm straw blocks (71%) ($p < 0.001$ for all the comparisons). The other pairwise comparisons were not statistically different ($p > 0.05$).

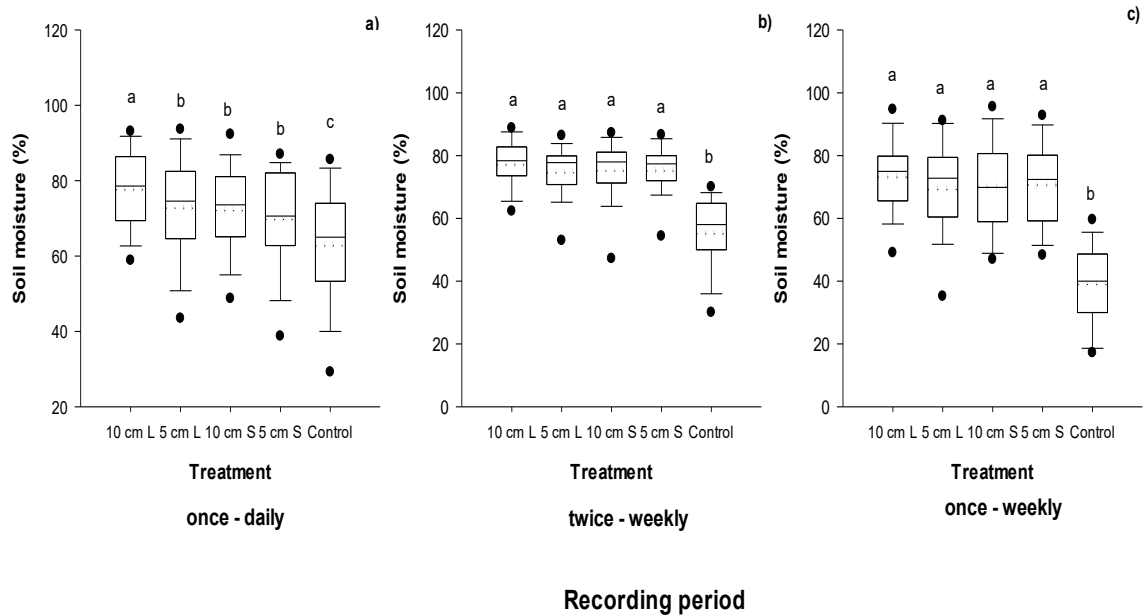


Figure 14 Soil moisture under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

4.1.3 Soil pH

The median soil pH did not differ significantly amongst treatment combinations throughout the three watering periods: once-daily ($H(4) = 9.484$, $p > 0.05$), twice-weekly ($H(4) = 5.601$, $p > 0.05$), and once-weekly ($H(4) = 3.268$, $p > 0.05$) (Fig. 15).

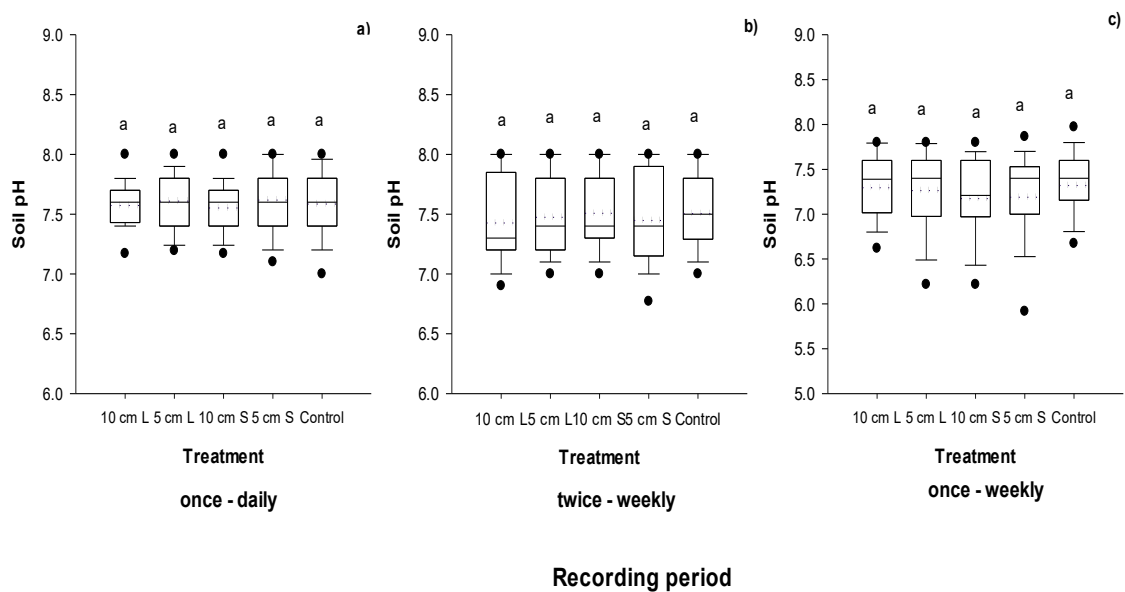


Figure 15. Soil pH under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

4.2 Effects of mulching treatments on the cumulative stem length (cm) under three watering periods.

Senegalia galpinii

During the once-daily watering period, there was no significant difference in the median cumulative stem length of *Senegalia galpinii* amongst treatment combinations ($H(4) = 2.594, p > 0.05$) (Fig. 16).

During the twice-weekly watering period, the median cumulative stem length of *Senegalia galpinii* differed statistically among treatment combinations ($H(4) = 13.261$, $p < 0.01$) (Fig. 16). *Senegalia galpinii* had a longer cumulative stem length in 10 cm leaf litter blocks (1315 cm) compared to 5 cm straw (675 cm) ($p < 0.05$). The other pairwise comparisons were not statistically significant ($p > 0.05$).

During the once-weekly watering period, there was a significant difference in the median cumulative stem length of *Senegalia galpinii* among treatment combinations ($H(4) = 13.044$, $p < 0.05$), as shown in Fig. 16. *Senegalia galpinii* had a significantly longer cumulative stem length in 10 cm leaf litter (2624 cm), 5 cm leaf litter (2457 cm), 10 cm straw (1860 cm) and control (1774 cm) blocks compared to 5 cm straw blocks (1177 cm) ($p < 0.01$) (Fig. 16). There were no other differences observed in pairwise comparisons ($p > 0.05$).

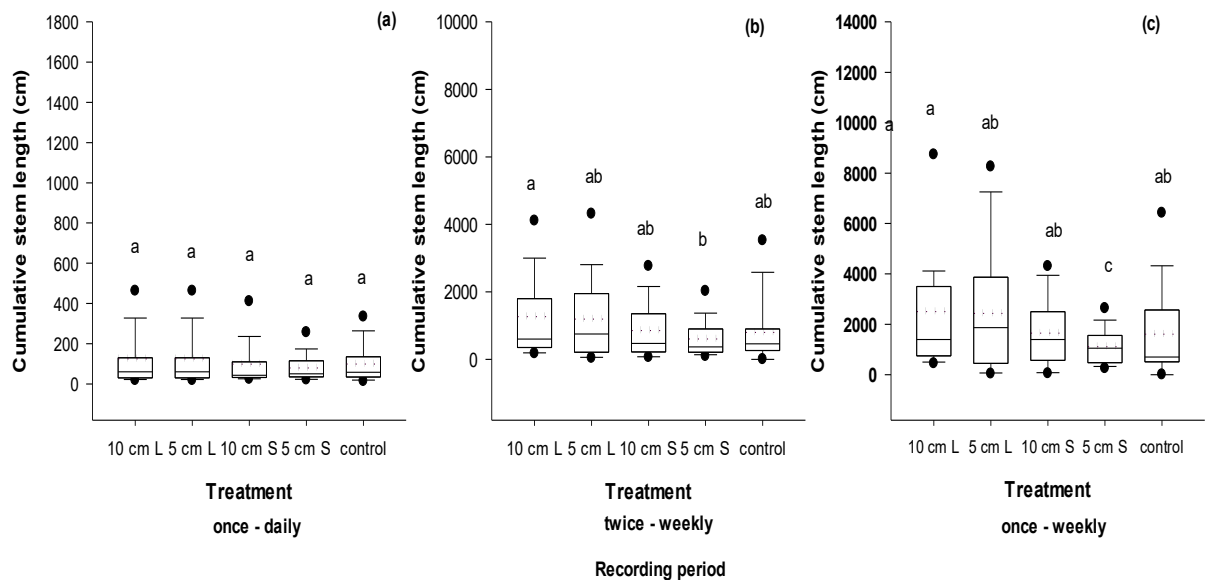


Figure 16. Cumulative stem length of *Senegalia galpinii* under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly

watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

Vachellia erioloba

The median cumulative stem length of *Vachellia erioloba* did not differ statistically among treatment combinations during the once-daily watering period, ($H(4) = 4.561$, $p > 0.05$) (Fig. 17).

During the twice-weekly watering period, the median cumulative stem length of *Vachellia erioloba* was statistically different among treatment combinations ($H(4) = 15.675$, $p < 0.01$) (Fig. 17). *Vachellia erioloba*'s cumulative stem length was significantly longer in control blocks (208 cm) compared to 5 cm leaf litter blocks (160 cm) ($p < 0.01$) and 5cm straw blocks (104 cm) ($p < 0.05$). No other significant differences were observed in the pairwise comparisons ($p > 0.05$).

During the once-weekly watering period, the median cumulative stem length of *Vachellia erioloba* was not statistically different among treatment combinations ($H(4) = 7.767$, $p > 0.05$) (Fig. 17).

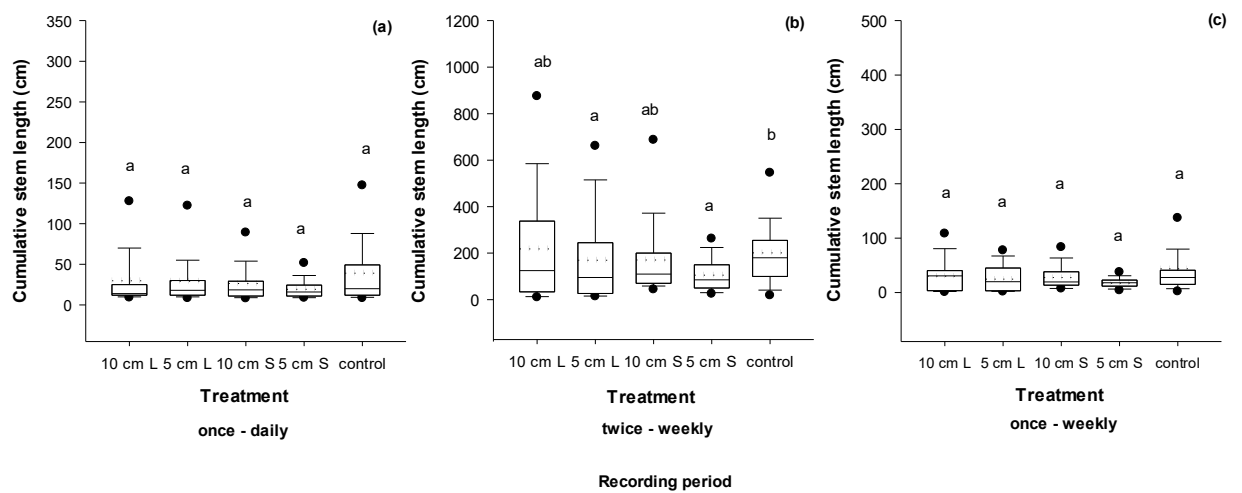


Figure 17. Effects of mulching treatment combinations on Cumulative stem length of *Vachellia erioloba* under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

Catophractes alexandri

The median cumulative stem length of *Catophractes alexandri* did not differ statistically among treatment combinations during the once-daily watering period, ($H(4) = 1.816, p > 0.05$) (Fig. 18).

During the twice-weekly watering period, the median cumulative stem length of *Catophractes alexandri* was statistically different among treatment combinations

($H(4) = 13.282, p < 0.05$) (Fig. 18). The cumulative stem length of *Catophractes alexandri* was significantly longer in 10 cm leaf litter blocks (1163 cm) compared to 5 cm straw blocks (681 cm) ($p < 0.01$). No other significant differences were observed in the pairwise comparisons ($p > 0.05$).

During the once-weekly watering period, the median cumulative stem length of *Catophractes alexandri* was statistically different among treatment combinations ($H(4) = 10.303, p < 0.05$) (Fig. 18). The cumulative stem length of *Catophractes alexandri* was significantly longer in the 10 cm straw blocks compared to 5 cm straw blocks and 5 cm leaf litter blocks ($p < 0.05$ for all comparisons) (Fig. 18). There were no other significant differences in the pairwise comparisons ($p > 0.05$).

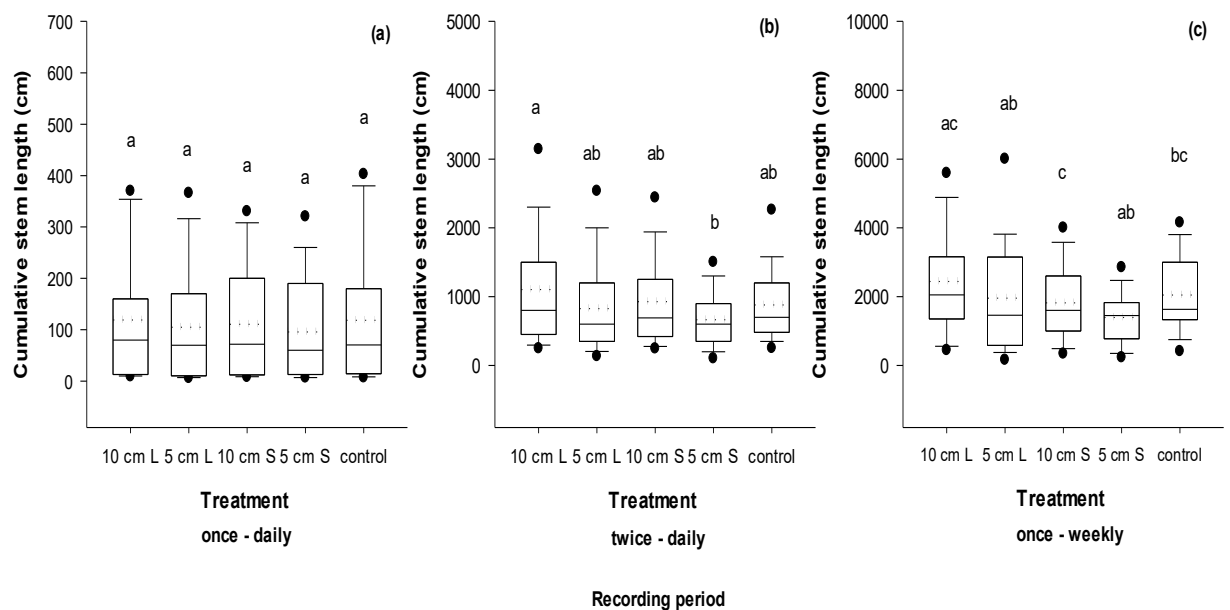


Figure 18. Effects of mulching treatment combinations on Cumulative stem length of *Catophractes alexandri* under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and

c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

Faidherbia albida

The median cumulative stem length of *Faidherbia albida* did not differ statistically among treatment combinations during the once-daily watering period, ($H(4) = 1.903$, $p > 0.05$) (Fig. 19).

During the twice-weekly watering period, the median cumulative stem length of *Faidherbia albida* was statistically different among treatment combinations ($H(4) = 15.503$, $p < 0.01$) (Fig. 19). *Faidherbia albida* had significantly shorter stem lengths in 5 cm leaf litter blocks (380 cm) compared to 10 cm leaf litter blocks (564 cm) and 10 cm straw blocks (555 cm) ($p < 0.01$ respectively) (Fig. 19). There were no other significant differences in the pairwise comparisons ($p > 0.05$).

During the once-weekly watering period, the median cumulative stem length of *Faidherbia albida* was statistically different among treatment combinations ($H(4) = 16.255$, $p < 0.01$) (Fig. 19). *Faidherbia albida* stem length was significantly longer in 10 cm straw blocks (1131 cm) and 10 cm leaf litter blocks (1155 cm) than in 5 cm leaf litter blocks (732 cm) ($p < 0.001$) (Fig. 19). There were no other significant differences in the pairwise comparisons ($p > 0.05$).

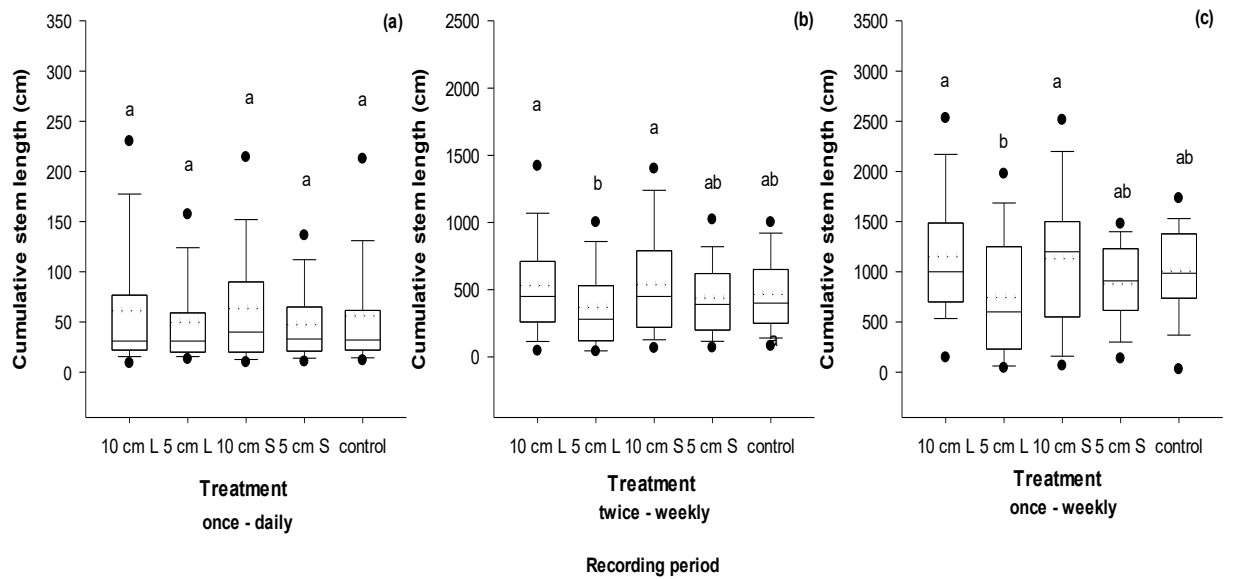


Figure 19. Effects of mulching treatment combinations on Cumulative stem length of *Faidherbia albida* under different mulching treatment combinations during three watering periods. Note: 10 cm L= 10 cm leaf litter; 5 cm L= 5 cm leaf litter; 10 cm S=10 cm straw; 5 cm S= 5 cm straw and control= no mulch. A) Once-daily watering (16 Dec 2022 – 28 Feb 2023), b) Twice-weekly watering (01 Mar – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). Different letters (superscript) denote significant differences (Kruskal-Wallis; Pairwise comparison, $p \leq 0.05$). The dotted line indicates the mean. Whiskers show the minimum and maximum values (quantile range) of the data excluding outliers.

4.3 Effects of mulching treatments on seedling survival (%) under three watering periods.

Senegalia galpinii

The median survival rate of *Senegalia galpinii* was not significantly different amongst treatment combinations during the once-daily watering period ($H(4) = 5.481, p > 0.05$) (Fig. 20). At the start of the experiment, 125 seedlings were transplanted into each

treatment block; 99% survived in the 10 cm leaf litter, 100% in the 5 cm leaf litter, 10 cm straw, and 5 cm straw, and 97% in the control.

The median survival rate of *Senegalia galpinii* differed significantly between treatment combinations during the twice-weekly watering period ($H(4) = 35.343, p < 0.001$) (Fig. 20). *Senegalia galpinii* survival rates were significantly lower in the control blocks (89%) compared to the mulched blocks (10 cm leaf litter, 5 cm leaf litter, 10 cm straw, and 5 cm straw, all with 100% survival rate) ($p < 0.001$ for all pairwise comparison). There were no other significant differences in the pairwise comparisons ($p > 0.05$).

Senegalia galpinii survival rates differed significantly between treatment combinations during the once-weekly watering period ($H(4) = 40.364, p < 0.001$) (Fig. 20). Survival rates of *Senegalia galpinii* were significantly lower in the control blocks (88%) than in the mulched blocks (10 cm leaf litter, 5 cm leaf litter, 10 cm straw, and 5 cm straw, all with 100% survival rate) ($p < 0.001$ for all pairwise comparison). There were no other significant differences observed in the pairwise comparisons ($p > 0.05$).

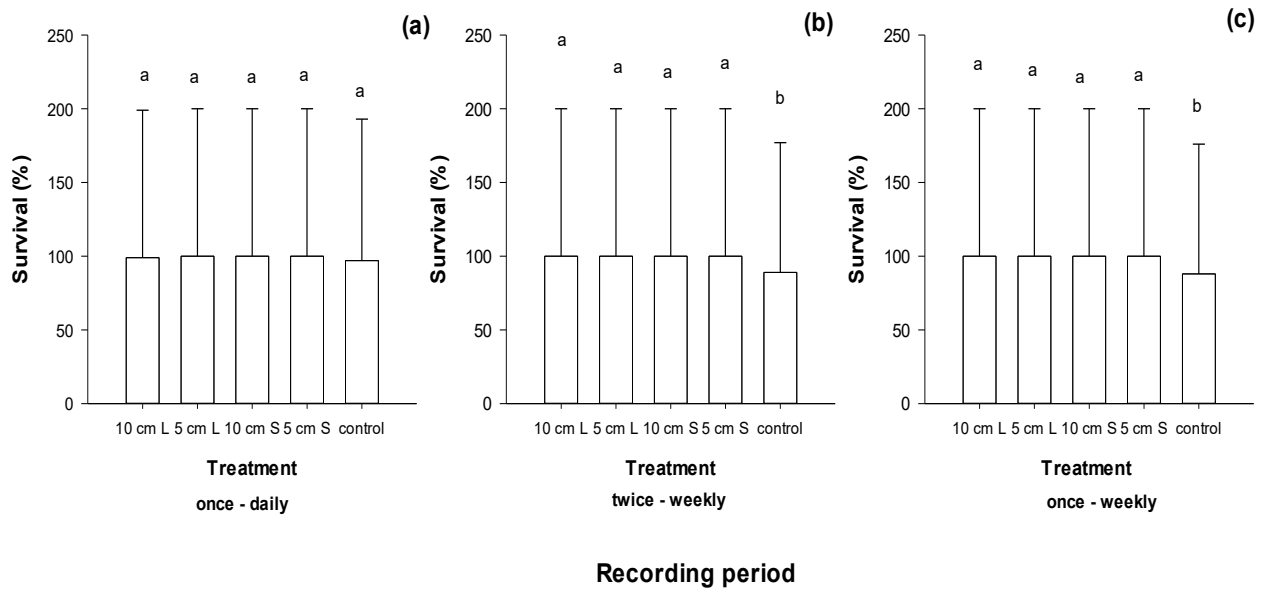


Figure 20. Effects of mulching treatment combinations on seedling survival rate of *Senegalia galpinii* during the three recording periods. A) Once-daily watering (16 December 2022 – 28 February 2023), b) Twice-weekly watering (01 March – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). The treatments were: 10 cm leaf litter (10 cm L), 5 cm leaf litter (5 cm L), 10 cm straw (10 cm S), 5 cm straw (5 cm S) and control (unmulched soil).

Vachellia erioloba

Throughout the study period, the median survival rate of *Vachellia erioloba* did not differ significantly amongst treatment combinations: once-daily watering ($H(4) = 1.077, p > 0.05$), 10 cm leaf litter (92%), 5 cm leaf litter (95%), 10 cm straw (92%), 5 cm straw (97%) and control (95%). Twice-weekly watering period ($H(4) = 1.188, p > 0.05$), 10 cm leaf litter (85%), 5 cm leaf litter (88%), 10 cm straw (88%), 5 cm straw (88%) and control (80%); and once-weekly weekly watering period ($H(4) = 1.456, p > 0.05$), 10 cm leaf litter (84%), 5 cm leaf litter (88%), 10 cm straw (88%), 5 cm straw (88%) and control (80%) (Fig. 21).

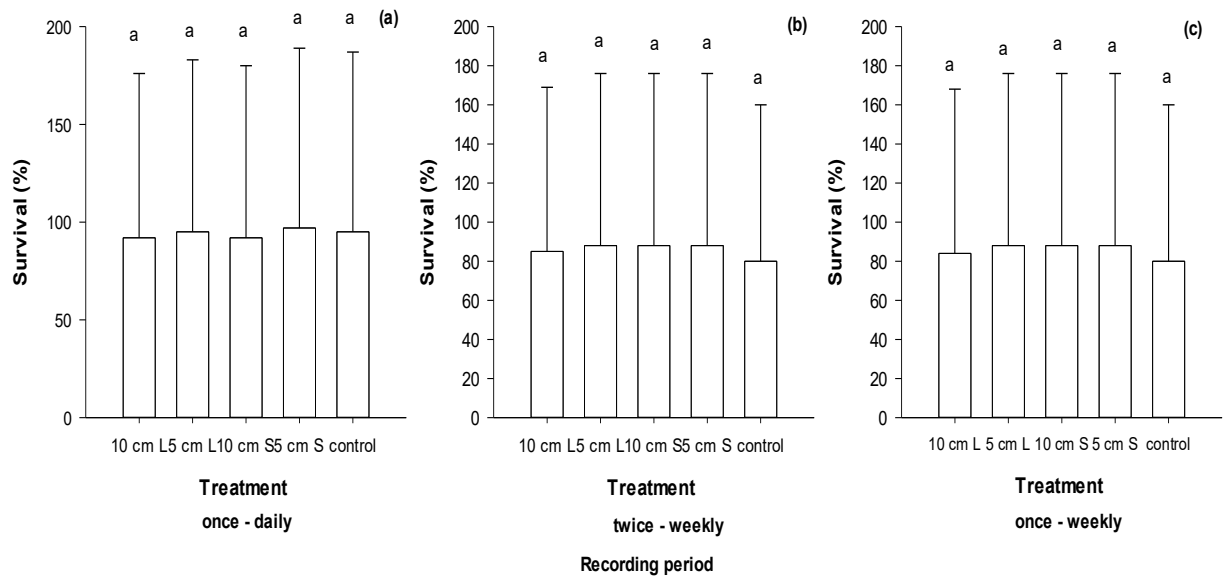


Figure 21. Effects of mulching treatment combinations on seedling survival of *Vachellia erioloba* during the three recording periods. A) Once-daily watering (16 December 2022 – 28 February 2023), b) Twice-weekly watering (01 March – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). The treatments were: 10 cm leaf litter (10 cm L), 5 cm leaf litter (5 cm L), 10 cm straw (10 cm S), 5 cm straw (5 cm S) and control (unmulched soil).

Catophractes alexandri

The median survival rate of *Catophractes alexandri* did not differ significantly amongst treatment combinations during the once-daily watering period ($H(4) = 8.706$, $p > 0.05$) (Fig. 22). 10 cm leaf litter and 10 cm straw both had a 100% survival rate, 5 cm leaf litter (97%), 5 cm straw (95%) and control (99%).

The median survival rate of *Catophractes alexandri* differed significantly amongst treatment combinations during the twice-weekly watering period ($H(4) = 12.486$, $p < 0.05$) (Fig. 22). *Catophractes alexandri* had higher survival rates in both 10 cm leaf litter and 10 cm straw blocks (100% in both) than in 5 cm straw (92%) blocks ($p <$

0.05 for both comparisons). There were no other significant differences identified by the pairwise comparisons ($p > 0.05$).

During the once-weekly watering period, there was a significant difference in the median survival rate of *Catophractes alexandri* amongst the different treatment combinations ($H(4) = 11.661$, $p < 0.05$) as shown in Fig. 22. The survival rate of *Catophractes alexandri* was higher in 10 cm leaf litter and 10 cm straw blocks (100% in both) compared to 5 cm straw blocks and control (92%) ($p < 0.05$ in both cases). There were no more significant differences found in the pairwise comparisons ($p > 0.05$).

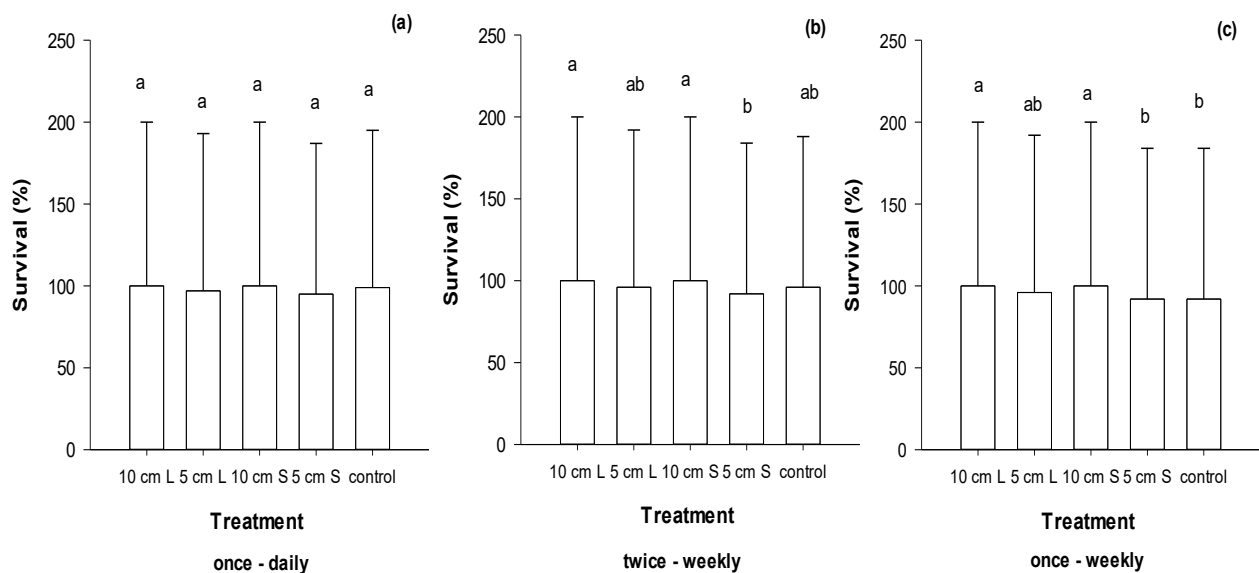


Figure 22. Effects of mulching treatment combinations on seedling survival of *Catophractes alexandri* during the three recording periods. A) Once-daily watering (16 December 2022 – 28 February 2023), b) Twice-weekly watering (01 March – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). The treatments were: 10 cm leaf litter (10 cm L), 5 cm leaf litter (5 cm L), 10 cm straw (10 cm S), 5 cm straw (5 cm S) and control (unmulched soil).

Faidherbia albida

Throughout the study period, there was no significant difference in the median survival rate of *Faidherbia albida* between the treatment combinations of once-daily ($H(4) = 4.229, p > 0.05$): 10 cm leaf litter (99%), 5 cm leaf litter (100%), 10 cm and 5 cm straw (97%), and control (100%). Twice-weekly ($H(4) = 4.554, p > 0.05$): 10 cm leaf litter, 10 cm and 5 cm straw (96%), 5 cm leaf litter (100%) and control (99%); and once-weekly ($H(4) = 3.524, p > 0.05$) watering: 10 cm leaf litter, 10 cm straw, 5 cm straw and control all recorded 96% survival rate, while 100% survival rate was recorded in 5 cm leaf litter (Fig. 23).

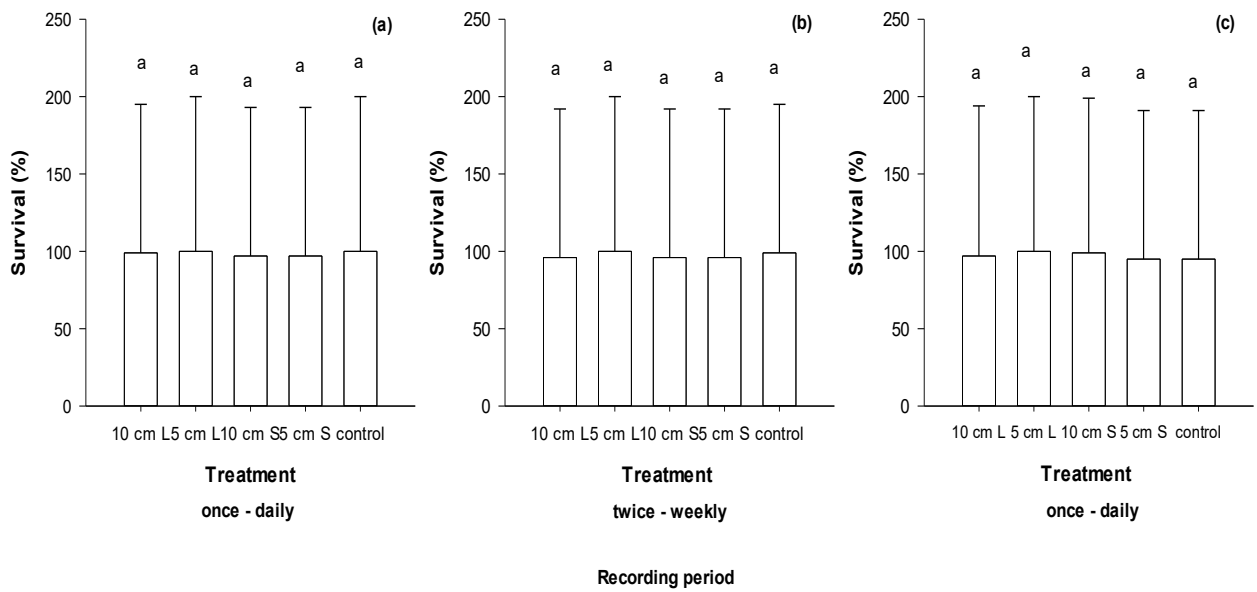


Figure 23. Effects of mulching treatment combinations on seedling survival of *Faidherbia albida* during the three recording periods. A) Once-daily watering (16 December 2022 – 28 February 2023), b) Twice-weekly watering (01 March – 31 May 2023) and c) Once-weekly watering (01 June – 21 August 2023). The treatments were: 10 cm leaf litter (10 cm L), 5 cm leaf litter (5 cm L), 10 cm straw (10 cm S), 5 cm straw (5 cm S) and control (unmulched soil).

4.4 Effects of mulching treatments on the chlorophyll content of the seedlings at the end of the study.

The chlorophyll content of *Senegalia galpinii* ($F(4) = 1.725, p > 0.05$) (Fig. 24a), *Catophractes alexandri* ($F(4) = 0.174, p > 0.05$) (Fig. 24c), and *Faidherbia albida* ($F(4) = 0.970, p > 0.05$) (Fig. 24d) did not significantly differ amongst treatment combinations. *Senegalia galpinii* recorded: 32 mg/g m² in the 10 cm leaf litter, 22 mg/g m² in both 5 cm leaf litter and 10 cm straw, 30 mg/g m² in 5 cm straw and 28 mg/g m² in the control) (Fig. 24a). *Catophractes alexandri* recorded: 49 mg/g m² in the 5 cm leaf litter, 47 mg/g m² in both 10 cm leaf litter and control, 50 mg/g m² in 10 cm straw and 48 mg/g m² in 5 cm straw) (Fig. 24c). *Faidherbia albida* recorded: 21 mg/g m² in the 10 cm leaf litter, 22 mg/g m² in both 5 straw and control, 31 mg/g m² in 5 cm leaf litter and 18 mg/g m² in the 10 cm straw) (Fig. 24d). However, there were significant differences in *Vachellia erioloba*'s chlorophyll content amongst treatment combinations ($F(4) = 4.456, p < 0.01$). *Vachellia erioloba*'s chlorophyll content in the control blocks (22 mg/g m²) was significantly lower than that of the 10 cm straw (35 mg/g m²) ($p < 0.05$) and 5 cm straw blocks (39 mg/g m²) ($p < 0.01$) (Fig. 24b). There were no other significant differences identified by the pairwise comparisons ($p > 0.05$).

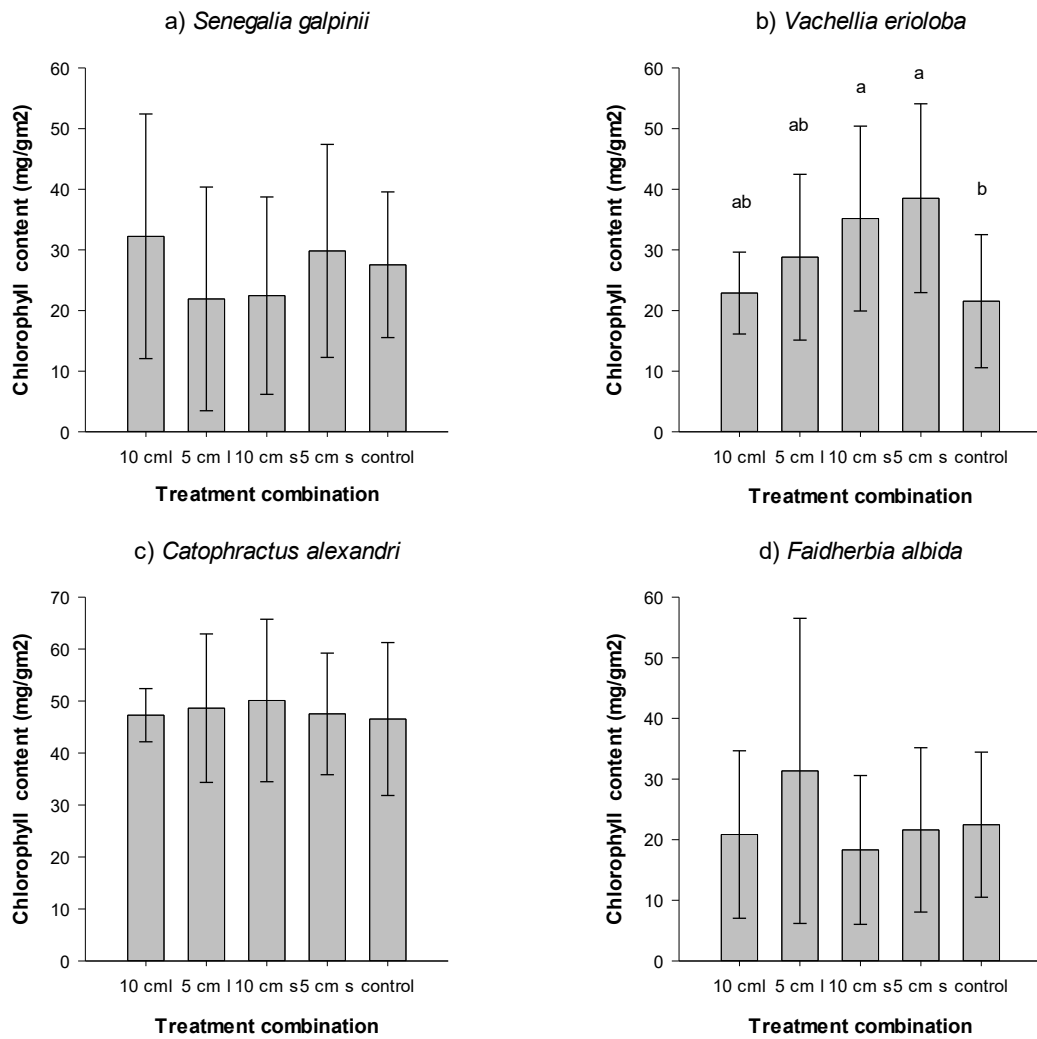


Figure 24. Effects of mulch treatment combination on the chlorophyll content of the seedlings, where a) represents the chlorophyll content of *Senegalia galpinii*; b) *Vachellia erioloba*; c) *Catophractes alexandri*; d) *Faidherbia albida*. Superscripts denote significant differences (one-way ANOVA, Tukey post hoc tests, $p \leq 0.05$). Error bars indicate standard error (\pm SE).

CHAPTER 5: DISCUSSION

5.1 Effects of mulching treatment on soil temperature (°C), soil moisture content (%) and soil pH

As hypothesized, mulching generally lowered soil temperature, with the greatest effect occurring under the twice-weekly and once-weekly watering periods, with the lowest soil temperature reported in the 10 cm straw blocks during both watering periods. I attribute this finding to the heat insulation effect of straw, which lowers the direct influence of sunlight while allowing for air and heat circulation. Although both straw and leaf litter were tested at the same depths (10 and 5 cm), the 10 cm straw depth had the greatest influence on lowering soil temperature, indicating that while both mulches can reduce soil temperature, the 10 cm straw had the greatest effect of the two, implying that depth has a greater influence on the effect of straw mulch on the soil than leaf litter. This may indicate that straw mulch may have a higher albedo and lower thermal conductivity than leaf litter, preventing soil water evaporation, enhancing water use efficiency, reducing the amount of solar radiation reaching the soil and, as a result, reducing temperature increases during warm environments (Liu *et al.*, 2014). This argument is also supported by a study by Du *et al.*, (2022) on the effects of straw mulching and reduced tillage on crop production and the environment, which found that straw mulching significantly reduced soil temperature when ambient temperature was high and that the temperature of the soil surface improved with the thickness of the straw mulch layer. Similarly, Zhang *et al.*, (2015) found that straw mulching had a heat insulation effect that reduced soil temperature, with mulch thickness playing an important role, and that this could help mitigate the effects of extreme weather conditions such as heatwaves, implying that straw mulch can help maintain more stable soil temperatures that are beneficial for plant growth.

The 10 cm leaf litter blocks maintained high soil moisture contents compared to the 5 cm and 10 cm straw blocks during the once-daily watering period, but as the study progressed to twice-weekly and once-weekly watering periods, all of the mulched blocks had significantly higher soil moisture contents than the control blocks (no mulch). The findings of this study shows that leaf litter at a depth of 10 cm had a high-water retention effect on soil moisture during the once-daily watering period, whereas the effects of the other mulch treatment depths on soil moisture was only apparent during the later watering periods (twice and once weekly). Although the effects of the other mulch treatment depths were only noticeable in later watering periods, our findings are consistent with previous studies, which found that mulching, regardless of mulch type or depth, significantly preserves soil moisture content when compared to control blocks (no mulch) (Sharma & Bhardwaj, 2017).

Our findings highlight that mulching (especially at 10 cm depths) helped to block out excessive heat while maintaining moisture (essential in a dry environment like the Kunene). This has the potential to benefit the local community by adopting a low-cost technique that lowers water loss via soil evaporation, which is especially beneficial in creating favorable conditions for plant development and effective plant production in water-stressed areas. Moreover, the low soil temperatures found in this study for mulched blocks (straw) and high moisture contents for leaf litter blocks were consistent with the findings of Pou *et al.* (2021) and Pramanik, *et al.* (2015), who reported that mulches with different thermal and optical properties contribute to varying degrees of soil warming and moisture retention. Pramanik, *et al.* (2015) found that surface application of straw reduced maximum soil temperatures from 37.1 to 28.6 °C. Retention of soil moisture and lowering of soil temperature in the top few layers of the soil by leaf litter mulching was reported by Tóth *et al.* (2011). Soil temperatures

in the current study ranged from 33.3 to 27.5 °C depending on the treatment combination. These soil temperature findings were slightly within the appropriate range (20-30 °C) for improved rate of metabolism by soil microorganisms, resulting in higher organic matter decomposition and adequate supply of nutrients for plant growth (Onwuka, 2016). Also, the high soil temperatures and low soil moisture contents observed in the control blocks compared to the mulched blocks could be attributed to the significant temperature difference between bare soil and soil with a mulch layer, as soil temperature is directly influenced by how much heat reaches the soil surface. The control blocks received the most sunlight because there was no mulch cover to minimize the amount of heat attained, resulting in higher soil temperatures and increased soil water evaporation, which significantly lowered soil water content in the control blocks (Wight & Macbr, 2018).

The pH of the soil was similar among treatment combinations throughout the three watering periods. These findings indicate that mulching (regardless of type and depth) had no significant influence on soil pH. Other studies have also found that mulching has no effect on soil pH (Chen *et al.*, 2022; Ni *et al.*, 2016). Ni *et al.* (2016) studied the effects of mulching with inorganic (round gravel), organic (wood chips), and living (manila turf grass) materials on the soil parameters and growth of Tea Olive (*Osmanthus fragrans*) at 0-5 cm and 5-10 cm depths. Mulching showed no effect on soil bulk density, pH, or total nitrogen concentration, but it consistently improved soil organic matter. In contrast, Rahmani *et al.* (2021) discovered that both organic and inorganic mulching enhanced soil pH. Olusegun *et al.*, (2020) also observed that the pH changed depending on the type of mulch used. Takase *et al.* (2011) found that differences observed in the soil pH are treatment-specific. Our results agreed with those of Ni *et al.* (2016) and Chen *et al.* (2022). Although our results showed that the

pH was similar among treatment combinations throughout the experiment, the pH values were within a biologically acceptable range (7.7 to 7.3) for optimal nutrient availability for promoting seedling growth and development (Rahmani, *et al.*, 2021). Jackson *et al.* (2018) reported that different pH ranges correspond to different nutrient availability for plants, and plant nutrients are broadly classed as macro-nutrients and micro-nutrients based on the plant's requirements. With the exception of phosphorus, macronutrients such as nitrogen, calcium, potassium, magnesium, and sulfur are more readily available in a pH range of 6.5-8, while micronutrients are available in slightly acidic pH ranges of 5-7, which are the optimal ranges in which nutrients are available to plants in favorable quantities.

5.2 Effects of mulching treatment combinations on the cumulative stem length (cm) and seedling survival (%) of the four study species under three watering periods.

The application of different mulching treatments has been shown to have varying effects on tree survival and growth responses depending on the tree species, growing environment, and mulching material (Mechergui *et al.*, 2019). Mulching also helps plants by minimizing or preventing soil water loss, nutrient leaching, soil compaction and weed growth. Throughout the nine months of this study, mulching had an effect on both (direct) response variables (growth and survival). While there were occasions when straw or leaf litter was preferable, the effect was generally greater with thicker mulch. Although there were no consistent differences between leaf litter and straw, I felt that leaf litter was slightly more effective overall. Statistically, there were no significant differences in growth (cumulative stem length) and seedling survival between treatment combinations in the studied species during the once-daily watering period. This could have been because the seedlings were still acclimating to the

experimental site's conditions, and the effects of mulch on their cumulative stem lengths and survival were still not apparent. During the twice-weekly and once-weekly watering periods, *Senegalia galpinii* had significantly longer cumulative stem lengths in the 10 cm leaf litter blocks and 10 cm straw blocks than in the 5 cm straw blocks, while seedling survival was higher in all the mulched blocks than the control. The results suggest that both 10 cm depths of leaf litter and straw provided ideal growing conditions for this species, while mulching (regardless of type or depth) improved seedling survival.

On the other hand, although mulching raised soil moisture throughout the experiment, the mean cumulative stem length of *Vachellia erioloba* in the mulched treatments was sometimes comparable to and on a few measurement dates slightly lower than that in the bare-soil (control) during the twice-weekly watering period, but as the study progressed to the once-weekly watering period, there were no significant differences in the cumulative stem lengths of *Vachellia erioloba* among treatment combinations. Three interrelated processes could account for this result. First, selective mortality in the control plots likely removed the least vigorous individuals, leaving a survivorship pool skewed toward faster growers and thereby elevating the average height (Likoski *et al.*, 2022). Second, cooler soil under the mulch may have curtailed shoot elongation: the 10 cm litter layer reduced peak soil temperatures by approximately 3–5 °C, and root-growth studies on *Acacia* species indicate that extension is optimal near 30 °C and slows at lower temperatures (Wight & Macbr, 2018). Third, short-term nitrogen immobilisation is expected under fresh leaf litter with a C:N ratio above 45, temporarily restricting shoot growth until mineralisation commences (van der Sloot *et al.*, 2022). Taken together, these mechanisms explain why enhanced moisture did not automatically translate into greater early height, underscoring the importance of

balancing water availability, temperature, and nutrient dynamics when specifying mulch type and depth. Another explanation could be that *Vachellia erioloba*, also known as camel thorn, is a phreatophyte (Herrmann & Bucksch, 2014), which means that it can accumulate groundwater in water-stressed environments (possibly very early on) and that mulching has a lower impact on its survival and growth, making the shallow effect of mulching on it less noticeable. All treatment combinations showed no statistically significant influence on seedling survival, implying that neither mulch type nor depth had a positive or negative effect on the species' survival rate. The results indicate that *Vachellia erioloba* may favor unmulched soils for maximum growth. This also may suggest that different tree species have different responses to soil treatments and that different environmental factors have variable effects on growth and may interact with the presence of mulch in complex ways, highlighting the importance of considering multiple factors in understanding plant responses to environmental conditions.

For *Catophractes alexandri*, the seedlings had a better cumulative stem length in the 10 cm leaf litter and 10 cm straw blocks than in 5 cm leaf litter blocks during the twice-weekly and once-weekly watering periods. Seedling survival was higher in 10 cm leaf litter and straw blocks than in 5 cm straw blocks during the twice-weekly and once-weekly watering periods, respectively. The findings suggest that both 10 cm depths of leaf litter and straw provided suitable growing conditions for *Catophractes alexandri*, resulting in higher seedling survival at both depths. And for *Faidherbia albida*, the cumulative stem lengths were longer in both 10 cm leaf litter and straw blocks during the twice weekly and once weekly watering periods. Seedling survival was not significantly different amongst treatments throughout the study period. The findings of this study showed that mulching significantly improved the cumulative stem lengths

of all the study species during the study period, with the exception of *Vachellia erioloba* which grew better in the control (unmulched) blocks. Additionally, mulching improved seedling survival in both *Senegalia galpinii* and *Catophractes alexandri*, while having no significant effect on the seedling survival rate of *Vachellia erioloba* and *Faidherbia albida*. We also noticed that the seedlings in control blocks were not the shortest, indicating that mulching effect was not the only factor contributing the growth of the seedlings, soil nutrient availability and other soil properties may need to be assessed to provide clarity. The findings also revealed that growth and seedling survival were species and treatment-dependent. The findings of the study on the cumulative stem length and survival rate of the four study seedlings affected by mulching treatment are in line with the findings of other similar research studies (Chalker-scott, 2016; Frezghi *et al.*, 2021; Rahmani *et al.*, 2021). Those researchers reported that mulching improved early growth of transplanted seedlings by improving seedling survival and root establishment, as mulches provide improved soil moisture conservation, reduced soil temperature, reduced weed infestation, and increased nutrient availability due to reduced nutrient leaching.

5.3 Effects of mulching treatment combinations on the chlorophyll content of the seedlings at the end of the study.

The chlorophyll contents of *Senegalia galpinii*, *Catophractes alexandri*, and *Faidherbia albida* were similar across treatment combinations, and neither mulch type nor depth had a significant effect on these species' chlorophyll contents. In contrast, the chlorophyll content of *Vachellia erioloba* varied significantly between treatment combinations. The highest chlorophyll content of *Vachellia erioloba* was found in the leaves of seedlings grown in both 10 and 5 cm straw blocks, with the lowest in the control blocks. This demonstrates that both 10 and 5 cm straw mulch depths were

beneficial in improving the chlorophyll content of *Vachellia erioloba*'s seedlings in an arid environment, resulting in a faster photosynthetic rate and better plant performance. These findings may aid in the identification of a local mulching material that improves plant performance in this species. Similarly, Zhang *et al.* (2015) found that straw mulching significantly increased chlorophyll content of maize when compared with the no mulching treatment. They also stated that straw mulching can improve chlorophyll content and photosynthetic rate because straw mulching not only improves soil physical and chemical characteristics in the maize rhizosphere (such as soil water content, heat energy, bulk density, and nutrient status), but also crop growth and development. Yousaf *et al.*, (2022) reported that, in comparison to the control, applying various organic mulches greatly increased the chlorophyll contents and gas exchange parameters for *Vachellia nilotica* and *Dalbergia Sissoo*. Another study investigated the impact of intercropping and straw mulching. Mulching with straw increased the chlorophyll content of *Gossypium hirsutum* by up to 41.9% when compared to no mulching at all (Adil *et al.*, 2023). As a result, we can deduce that the response of a plant's chlorophyll content to different treatment combinations is species-specific and treatment specific. Although both depths of straw significantly increased the leaf chlorophyll content of *V. erioloba*, it prompts a question as to why neither *erioloba*'s survival nor growth was responding to mulching, which improves moisture, as water stress affects photosynthesis and chlorophyll content but it did respond in terms of chlorophyll. With this odd outcome, I suggest that the gas exchange of *V. erioloba* be investigated for further clarity.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

In the present study, the effects of mulching treatments (leaf litter and straw) on soil properties (temperature, moisture content and pH), seedling growth (cumulative stem length), and seedling survival were tested at 10 and 5 cm depths during three watering periods on a degraded land in the Kunene region in an attempt to select the better locally sourced material for the improvement of soil condition as well as the possible revegetation of this area. The study found that both mulching materials significantly improved soil temperature and moisture content under 10 cm depths, while soil pH was not affected by either mulch at any depth during the study period. Seedling growth (cumulative stem length) and survival differed between treatment combinations and species during the three watering periods with most species performing better in terms of growth and survival in both the 10 cm depths of straw and leaf litter. Leading to the conclusion that, in this study, it was the mulching depth rather than the type of mulching material that was the main driver behind the mulching effect. Mulching had no effect on the chlorophyll content of *Senegalia galpinii*, *Catophractes alexandri*, or *Faidherbia albida*, but it did have significant effect on *Vachellia erioloba*, with the leaves of seedlings grown in both 10 and 5 cm straw blocks having higher chlorophyll contents than the other treatments. Based on the findings of this study, we can conclude that mulching with either leaf litter or straw, at 10 cm depths/ mulch layer, would be an effective soil improvement and plant growth/performance boosting intervention in the study area because it acts as a protective layer over the soil, retaining moisture, managing temperature, supplying nutrients, preventing erosion, increasing seedling growth, and ensuring plants produce to their full capacity, which is particularly

important in the restoration of degraded drylands such as the Kunene region of Namibia.

6.2 Recommendations

In recent years, Namibia's Kunene region has seen a number of research activities focusing on rehabilitation efforts of degraded areas using various methodologies, but the need for more study is apparent. This was, for example, the first study to detail the effect of various soil treatment combinations (leaf litter and straw) at two different depths (10 and 5 cm) on soil temperature, moisture content, pH, cumulative stem length and seedling survival on a degraded land in Otjamaungu village, Kunene region. Based on the findings of this study, we recommend that using leaf litter or straw mulch at 10 cm depths can significantly improve soil properties (temperature, pH, and moisture), which are required for basic plant nutrition, resulting in the establishment of a healthy plant population and improved survival rates of transplanted seedlings in degraded areas. This will also assist local people to establish plant communities in degraded areas in a cost-effective manner. Further research can focus or test the interaction effect of watering frequency and mulch treatment combinations on soil properties and the performance of indigenous species in order to determine whether the amount or frequency of watering has a significant effect on enhancing these variables. The amount of water used in restoration projects should be quantified and reported for replication of the experiment. Since we noticed in this study that plants from the control were not the shortest, further studies should investigate differences in plant growth. The C:N ratio of the local mulch (litter and straw) should be investigated to identify which gives more nutrients to the soil during early seedling development stages and how it influences chlorophyll content and growth.

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CHAPTER 7: APPENDICES

Appendix 1: Ethical clearance certificate issued by the University of Namibia Ethics Committee to conduct the study.



ETHICAL CLEARANCE CERTIFICATE

Ethical Clearance Reference Number: SOS-0114 Date: 12 October 2022

This Ethical Clearance Certificate is issued by the University of Namibia Ethics Committee (REC) in accordance with the University of Namibia's Research Ethics Policy and Guidelines. Ethical approval is given in respect of undertakings contained in the Research Project outlined below. This Certificate is issued on the recommendations of the ethical evaluation done by the ethics committee.

Title of Project: **COMPARING THE EFFECTS OF TWO TYPES OF MULCHES ON SOIL PROPERTIES AND THE PERFORMANCE OF SELECTED WOODY SPECIES ON A DEGRADED LAND IN KUNENE REGION, NAMIBIA**

Student: **KRISTOF NDATIPO SIMON**

Student Number: **201509902**


Supervisor(s): **DR. WELLENCIA NESONGANO
DR. EMILIA INMAN**

Centre for Research Services

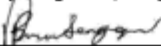
Take note of the following:

1. Any significant changes in the conditions or undertakings outlined in the approved Proposal must be communicated to the ethics committee. An application to make amendments may be necessary.
2. Any breaches of ethical undertakings or practices that have an impact on ethical conduct of the research must be reported to the ethics committee
3. The Principal Researcher must report issues of ethical compliance to the ethics committee (through the Chairperson) at the end of the Project or as may be requested by the ethics committee
4. The ethics committee retains the right to:
 - i) Withdraw or amend this Ethical Clearance if any unethical practices (as outlined in the Research Ethics Policy) have been detected or suspected,
 - ii) Request for an ethical compliance report at any point during the course of the research.

The ethics committee wishes you the best in your research.





Dr. Zivayi Chiguvare (Chairperson Ethics Committee)



Prof. Davis Mumbengegwi (Head, Multidisciplinary Research)

Appendix 2: Research permission letter

CENTRE FOR RESEARCH SERVICES <i>Office of the Pro-Vice Chancellor: Research, Innovation & Development</i> University of Namibia, Private Bag 13301, Windhoek, Namibia 340 Mandume Ndamutayo Avenue, Pioneers Park, Office F223 - Block, Second Floor ☎ +264 61 206-4673; E-mail: mkribulu@unam.na ; URL.: http://www.unam.edu.na	 UNAM UNIVERSITY OF NAMIBIA					
RESEARCH PERMISSION LETTER						
Date: 06/03/2023						
Student Name:	KRISTOF NDATIPO SIMON					
Student Number:	201509902					
Programme:	Master of Science					
Approved Research Title:	COMPARING THE EFFECTS OF TWO TYPES OF MULCHES ON SOIL PROPERTIES AND THE PERFORMANCE OF SELECTED WOODY SPECIES ON A DEGRADED LAND IN KUNENE REGION, NAMIBIA					
TO WHOM IT MAY CONCERN:						
I hereby confirm that the above-mentioned student is registered at the University of Namibia for the programme indicated. The proposed study met all the requirements as stipulated in the University guidelines and has been approved by the relevant committees.						
The proposal adheres to ethical principles as per attached Ethical Clearance Certificate. Permission is hereby granted to carry out the research as described in the approved proposal.						
Best Regards						
 Dr. AEE Shikongo Head: Postgraduate Research Support Services Tel: +264 61 206 3129 E-mail: aeshikongo@unam.na	<table border="1"><tr><td>CENTRE FOR RESEARCH SERVICES</td></tr><tr><td>Office of the Director</td></tr><tr><td style="text-align: center;">2023 -03- 06</td></tr><tr><td>University of Namibia</td></tr><tr><td style="text-align: center;">UNAM</td></tr></table>	CENTRE FOR RESEARCH SERVICES	Office of the Director	2023 -03- 06	University of Namibia	UNAM
CENTRE FOR RESEARCH SERVICES						
Office of the Director						
2023 -03- 06						
University of Namibia						
UNAM						

Appendix 3: Screenshot of the data entry form for the study.

1				Environmental variables			Cumulative stem length (cm)				Survival %				Chlorophyll content mg/gm ²			
	2 Treatment	month	Watering intens	Temperatur	Moisture %	pH	S.g	Ve	Ca	F.a	S.g	Ve	Ca	F.a	S.g	Ve	Ca	F.a
3	1	1	1	28.9	96.2	7.3	43	14	10	22	1	1	1	1	6.8	26.4	60.7	7.9
4	1	1	1	33.5	85.6	7.0	29	12	12	28	1	1	1	1	30.1	24	48.2	33.4
5	1	1	1	32.2	86.2	7.0	65	14	16	25	1	1	1	1	30.8	18.5	51.5	9.3
6	1	1	1	32.8	78.6	7.0	30	25	17	25	1	1	1	1	16.6	20	52.8	14.8
7	1	1	1	33.4	63.4	7.2	58	12	11	35	1	1	1	1	30.4	19.4	43.3	8.1
8	1	1	1	30.8	71.6	6.9	23	17	9	18	1	1	1	1	51.3	20.6	42.7	10.5
9	1	1	1	29.5	82.4	6.7	24	11	8	25	1	1	1	1	17	31.2	49.3	9.6
10	1	1	1	29.1	91.8	7.2	20	15	10	26	1	1	1	1	38.9	35.1	43.6	5.5
11	1	1	1	29.0	95.2	7.0	30	13	10	32	1	1	1	1	21.4	21.1	48.8	11.4
12	1	1	1	30.1	88	7.2	18	18	11	20	1	1	1	1	15.7	25.5	45.7	22.3
13	1	1	1	29.1	89.6	7.2	28	10	14	21	1	1	1	1	39.1	33.2	41.1	35.1
14	1	1	1	30.7	86.4	7.3	26	13	10	19	1	1	1	1	40.1	23.5	45.8	24.4
15	1	1	1	30.2	91.8	7.1	30	14	10	31	1	1	1	1	89.8	8.8	48.8	34
16	1	1	1	29	78	7.4	18	13	10	22	1	1	1	1	40.1	18.3	41.7	48.8
17	1	1	1	30.2	57	7.3	18	16	9	14	1	1	1	1	15.5	17.8	45.2	37.6
18	1	1	1	31.8	69	7.2	32	11	12	17	1	1	1	1	24.1	43.3	72.1	5.9
19	1	1	1	29.8	80.6	7.3	25	13	13	30	1	1	1	1	7.3	13.3	33.6	18.9
20	1	1	1	27.6	87	7.4	16	12	12	12	1	1	1	1	12.1	7.8	58.6	26.7
21	1	1	1	30.4	68	7.4	20	9	9	15	1	1	1	1	20	44.2	61.8	29.1
22	1	1	1	31.0	59	7.3	31	10	8	30	1	1	1	1	5.2	45.3	21.1	3
23	1	1	1	33.5	92	7.3	28	11	9	27	1	1	1	1	20.4	19.3	62.7	21.1
24	1	1	1	32.2	51	7.3	39	12	13	18	1	1	1	1	24.4	31.1	23.6	24.5
25	1	1	1	32.8	81.4	7.2	35	14	13	24	1	1	1	1	18.5	30.1	53	27.9
26	1	1	1	33.4	63	7.5	33	10	13	21	1	1	1	1	12	12.1	59	18.1
27	1	1	1	30.8	83	7.3	40	10	11	25	1	1	1	1	33.7	19	50.6	37.7