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Rangeland rehabilitation using micro-catchments and native species in Turkana County, Kenya

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Turkana County is prone to perturbations and famine owing to the prevailing climatic conditions. Due to degradation through natural and anthropogenic activities such as charcoal burning; over time, existing woodlands have been degraded, necessitating rehabilitation. Several drylands adapted plant species studied over the years for the response to the needs of the communities were identified and isolated through a survey. The species identified to be most useful to the communities included *Cenchrus ciliaris, Tamarindus indica, Salvadora persica, Moringa oleifera, Aloe turkanensis, Acacia senegal, Acacia tortilis, Acacia mellifera, Cordia sinensis, Adenia obesum, Dobera glabra, Parkinsonia acuelata* and *Balanites aegyptiaca.* The final species planted were *A. mellifera; A. senegal; A. tortilis; Adenium obesum; B. aegyptiaca; C. sinensis; D. glabra; P. aculeata, S. persica* and *Melia volkensii* were introduced for observation on performance. This study's objectives were to determine the effectiveness of micro-catchments in rangeland rehabilitation and to compare species performance to appraise the species highly adaptable to the environment. This offered an opportunity to demonstrate climate-smart technologies regarding rangeland rehabilitation. The methodology was adapted from proving phase provenance trials using nested intensity design to give the best measurements that measure native and exotic plant species. The site was in Ekalees 10 km off Lodwar -Kerio road, Lodwar. Micro-catchment was used as a treatment where a similar number of species of the same age were grown with micro catchments and others without micro-catchments. The major result of this study was found in the site with micro-catchments having higher mean heights and root collar diameters for each species tested. The results indicated the usefulness of micro-catchments, especially in arid and semi-arid areas, as well as showing the performance of selected native species performance in the natural ecosystem.

Key words: Water harvesting, land restoration, climate-smart technology, native species.

INTRODUCTION

Land degradation and deforestation in the rangelands is a serious challenge, currently recognized as a major threat to the wellbeing of range inhabitants and the environment (Yirdaw et al., 2017). According to the report

by the Millennium Ecosystem Assessment (2005), 10-20% of the drylands globally are highly degraded. This degradation is mainly caused by natural and anthropogenic factors resulting in loss of biodiversity, soil degradation, increased greenhouse gases, and periodic stresses of extreme and persistent climatic events (World Meteorological Organization, 2005). In lieu of climate change, the arid and semi-arid lands (ASALs) of Kenya are highly characterized by scattered vegetation, low and erratic rainfall, high evapotranspiration, and shallow soils with low water holding capacity (Mwamburi and Musyoki, 2010), thus favouring pastoral production systems. According to Kigomo and Muturi (2013), rangeland degradation and deforestation continue to threaten the survival of indigenous plant communities, which entirely depend on the scarce and diminishing natural resource base.

Pastoralists in ASALs of Kenya continue to face myriad challenges due to rangeland degradation, unpredicted weather patterns, and land mismanagement, thus threatening the sustainability of land-based production systems (Mganga et al., 2015). Turkana County, which is one of Kenya's driest counties, experiences low and unpredictable rainfall, frequent droughts and flooding, and in most instances, prone to perturbations and famine (CIDP, 2018). Despite the challenges, Turkana pastoralists have used traditional land management practices such as delineation of seasonal grazing areas and periodic movement, which facilitated the resilience of range resources to conserve natural resource bases (Barrow and Mlenge, 2003; Kidake et al., 2016). Nonetheless, these practices have currently collapsed owing to the changing dynamics of land use and socio-economic factors (Gaur and Squires, 2017).

Seventy percentage of the inhabitants of Turkana County are pastoralists depending largely on livestock and livestock products for their livelihood (CIDP, 2018; Watson and Binsbergen, 2008). These pastoralists have over the years sustainably used woodland resources through traditional practices and laws (Barrow and Mlenge, 2003; Muturi et al., 2014a), as the region is largely endowed with a diversity of native species. However, indigenous practices on natural resource management are breaking down as current policies favour sedentarization as an avenue of accelerated development in drylands. Afforestation and re-afforestation as an avenue of reversing land degradation in the ASALs faces several challenges, including moisture stress, termite infestation, animal damage, and competition from weeds (Mwamburi and Musyoki, 2010). The available woodland resources cannot sustainably meet the increasing demand for fuelwood, charcoal, and construction poles, thus exacerbating woodland degradation and reduction of both plant species diversity and density (Muturi et al., 2014a). This study also showed that degradation is even more serious around settled areas where the population has continued to grow

drastically. Forest cover in Turkana County is estimated to be 4.06% far below the recommended 10% forest cover, and about 50% of the landscape is highly degraded (CIDP, 2018). The vegetation cover is influenced by climate, topography, and soil structure, as rainfall increases with elevation (Wang et al., 2016). The vegetation cover comprises of scattered *Acacia tortilis, Salvadora persica, Dobera glabra, Cordia sinesis, Balanites orbicularis, Acacia senegal* and *Acacia reficiens*, which at the moment have decreased significantly paving the way for the succession of invasive species such as *Prosopis juliflora* (Turkana County Government, 2015). Most indigenous grasses such as *Cenchrus ciliaris* have disappeared, leaving most grazing areas bare (Mganga et al., 2015). Among the contributing factors to the loss of vegetation cover is the increased overgrazing and human pressure on the woodland vegetation for charcoal production and construction (Muturi et al., 2014a), thus creating conditions conducive to soil degradation, deforestation and desertification of the fragile environment (GoK, 2016; Lal, 2012). Muturi et al. (2014a) argue that woodlands have been degraded necessitating rehabilitation; hence such areas cannot be left for the natural regeneration process. There is, therefore, the need to beef up forestry in designated settlement areas to act as a buffer zone during dry season and cushion pastoralists from extreme weather conditions.

Forest and woodland restoration play a vital role in rehabilitating degraded and over-exploited areas (M'aty'as et al., 2013; Yirdaw et al., 2017). The government of Kenya and several non-governmental organizations have invested great effort and resources in afforestation and conservation of forests in the drylands to stabilize water supply and reduce soil erosion and desertification (GoK, 2016; Okeyo et al., 2020). However, water scarcity and high evapotranspiration rates in the rangelands have constrained these afforestation and re-afforestation measures. According to M'aty'as et al.(2013), the man-made forest has a high water consumption, which may lead to water scarcity and aridification, thus the need of well-thought technologies to achieve the goal environmental protection. Some rehabilitation measures to combat degradation and improve vegetation cover has successfully been undertaken in some areas (Kigomo and Muturi, 2013; Muturi et al., 2014a; Wairore, 2015), with most rehabilitation strategies being the establishment of the enclosure.

The use of water harvesting infrastructures and tree with high water use efficiency has not been exploited fully in re-afforestation of Kenya's drylands despite its documented importance in capturing and storing run-off water, thus improving soil moisture, speeding up tree establishment and deep root development (Ali et al., 2003; Glotzbach et al., 2011). Most native trees are well adapted to adverse climatic conditions with high

water use efficiency. However, water use efficiency can reduce if infiltration and water holding capacity is not addressed (Hatfield and Dold, 2019; Stroosnijder et al., 2012). A combination of these native species and the use of water harvesting technologies in Turkana County as a strategy for rehabilitation can significantly provide a platform for promoting regeneration of native plant species to improve forest and ground cover as well as improving communities' livelihoods (Castruita-Esparza et al., 2019; Jama and Zeila, 2005). Micro-catchments are rainwater harvesting structures that collect rainfall run-off and direct it to the planting hole, thus improving soil moisture and plant vigour (Haruna, 2014; Rahman et al., 2020). Thus, water harvested is made available to the tree long after the rains have stopped. There are different types of micro-catchments: V-shaped, W-shaped, circular, and semi-circular (Mullah et al., 1995; Mwamburi and Musyoki, 2010; Reijntjes, 1896). Thus, semi-circular micro-catchments were used in trials to rehabilitate some areas with much success and various community adaptation. In order to put the issue into a wider perspective, this paper sought to determine the effectiveness of micro-catchments and native tree species in rangeland rehabilitation and to compare species performance to appraise the species highly adaptable to the environment. This offered an opportunity to demonstrate climate smart technologies regarding rangeland rehabilitation.

MATERIALS AND METHODS

Study site

The experiment was conducted in a public plot of land in Ekalees (3.08465N 35.63903E), Turkana County, 10km off Lodwar-Kitale road. The area selected had deep sandy soils. The vegetation was scarce on the site, with only two species visible: *Balanites aegyptiaca* L. Drel and *A. tortilis*. The entire site was fenced with metal bars and barbed wire to secure the site from browse species and had security round the clock to secure the site.

Establishment of research plots

Within the Ekalees plot, a 38 m × 29 m experimental plot was established and fenced. Semi-circular micro-catchments with a spacing of 4 m × 4 m were then constructed within the fenced plot. Seedlings of mixed species that were propagated at Kenya Forestry Research Institute (KEFRI) tree nursery, Lodwar were planted in the plot with micro-catchment and adjacent area without micro-catchment. The treatment of the site was with micro-catchments, while control site was without micro-catchments. Trees were chosen based on their importance to the Turkana Community and their adaptations to arid and semi-arid environments. A similar number of species of the same age were planted. The tree species planted were: *A. tortilis, A. senegal, Acacia mellifera, D. glabra, Salvadora persica, Adenium obesum, Melia volkensii, C. sinesis,* and *Parkinsonia aculeata.* The site had received 4 mm of rain immediately before planting in August 2015 and only 9 mm in 6 months (August 2015 - January 2016) was received at the site. Monitoring was subsequently undertaken to estimate the extent of regeneration.

Data collection

Baseline and monitoring data were collected from each experimental site. The height and the root collar diameter of all the trees planted were taken after six months, using the height pole and vernier calipers, respectively. The species count was done for the two sites, and also vegetation counts in the two sites according to Muturi et al. (2014). The design of a micro-catchment is a 1.5 m arc (Figure 1 and Plates 1 and 2).

Data analysis

Data on tree height and root collar diameter was keyed in and summarized in R statistical software where mean and percentages were generated and results illustrated in graphical charts. Differences were analysed with ANOVA and post-hoc Tukey HSD.

RESULTS

The boxplot shows the median height of species planted in micro-catchment and outside micro-catchment. Tree species planted in the micro-catchment shows a median height of 67.5 cm, while tree species planted outside micro-catchment show a median height of 35 cm. Most trees in the micro-catchment had height between 36 and 90 cm; and height as low as 10 cm and as high as 115 cm. Most tree species outside the micro-catchment had a height of between 24 and 56 cm; and height as low as 9 cm Figure 2.

The boxplot results show the median root collar diameter (RCD) of tree species planted inside the micro-catchment and outside micro-catchment. The median RCD of tree species inside the micro-catchment was 13.6 mm, while the median RCD of tree species planted outside micro-catchment was 5.5 mm. Most trees in the micro-catchment had RCD between 10 and 18.1 mm; and RCD as low as 3.5 mm and as high as 21.5 mm. Most tree species outside the micro-catchment had RCD of between 5 and 7 mm; and RCD as low as 3.5 mm and as high as 8.2 mm (Figure 3). The results of the assessment of the tree species planted using micro-catchments and without micro-catchment showed significant differences. The results showed that the mean height of trees planted with micro-catchment was higher (57.9 cm) compared to those planted without micro-catchments (39.6 cm). *A. senegal, A. mellifera, D. glabra* and *C. sinensis* in the micro-catchments had a higher mean growth in the heights of 95, 66.5, 31, and 79.4 cm respectively than those planted without micro-catchment at six months old. *Adenium obesum, Melia volkensii*, and
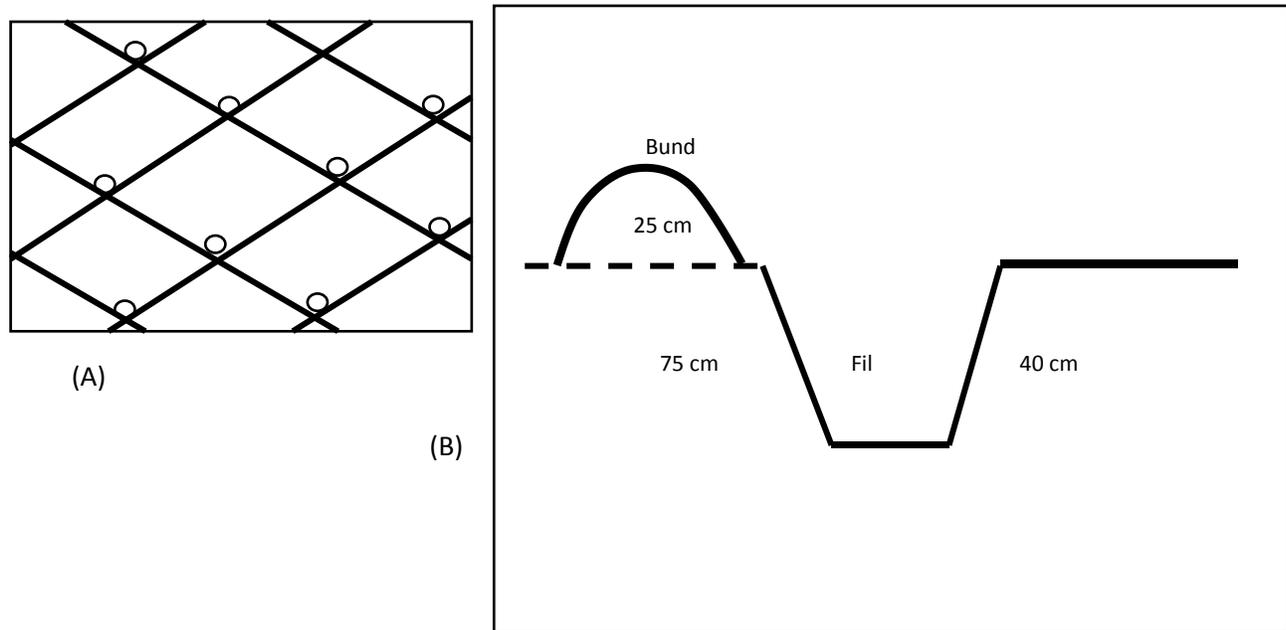
Figure 1. Micro-catchments in a plot (A) and a side view of bund and hole for trapping water in a micro-catchment (B).

Plate 1. Plant species in the micro catchment of fenced (A) and non-fenced (B) plots.

P. aculeata did not survive in sites without micro-catchments. *A. senegal* and *C. sinensis* in the site without micro-catchment were taller than other species because the species are well adapted to the environment (Figure 4). From the results in Figures 5 and 6, the percent increase in tree height of most species was directly proportional to the increase in DBH. Salvadora persica had the highest percent increase in height and the lowest increase in DBH. The heights of Adenium obesum, Cordia sinensis, and Parkinsonia aculeate increased by over 50% in the period between 6 months old and 2 years old. While the increase in DBH of *A. obesum* was slightly above 50%, the other species *S. persica, A. melifera, C. sinensis, A. senegal* and *P. aculeata* ranged between 7 and 32%.

The micro-catchment site had a higher species density compared to sites without micro-catchment. In the micro-catchment sites, *Cordia sinensis* had the highest density while *Acacia senegal* and *M. volkensii* had the lowest density. *M. volkensii, A. obesum* and *P. aculeata* were present in the micro-catchment and absent *in site* without micro-catchment (Table 1). The herbaceous density was

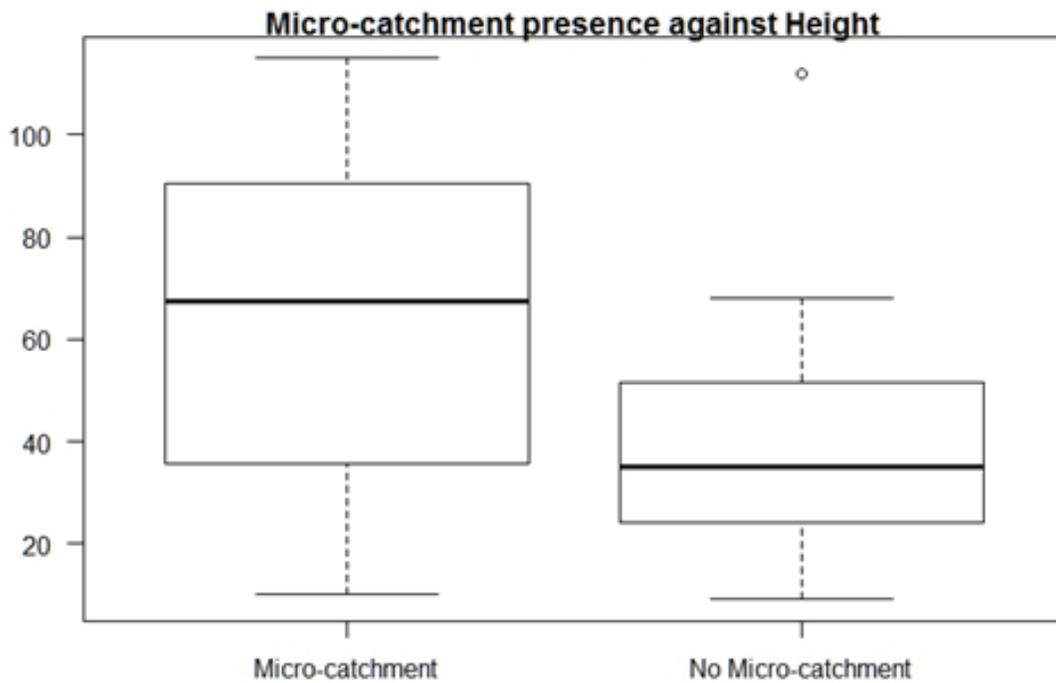**Plate 2.** Area with micro-catchment and the abundance of vegetation.

Figure 2. Boxplots showing tree species height comparison in micro-catchment and non-micro-catchment plots.

higher in sites with micro-catchment compared to sites without micro-catchment with 520,000 and 120,000 species per hectare. Sites without micro-catchment had only one herbaceous species (*Indigofera spinosa*) (Table 2).
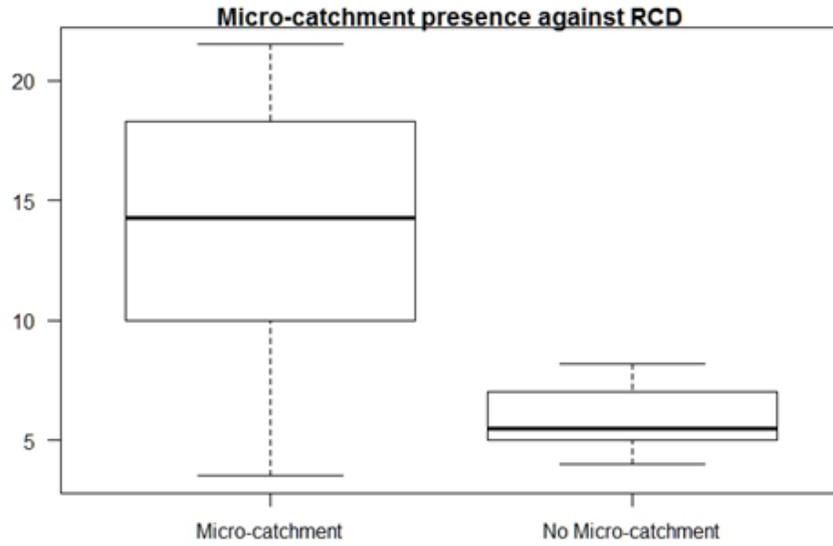
Figure 3. Boxplots showing tree species root collar diameter comparison in micro-catchment and non-micro-catchment plots.
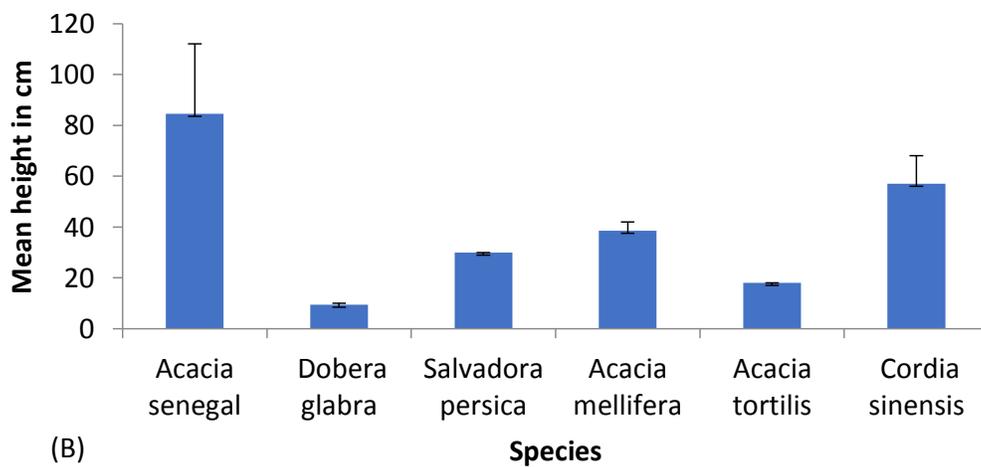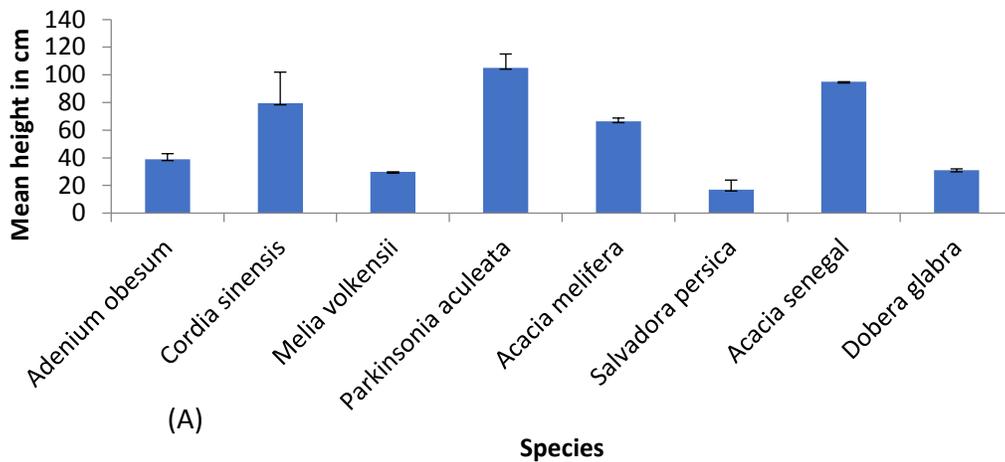

Figure 4. Mean heights of the plant species in (A) micro-catchment and (B) non- micro-cathment plots after six months of planting.
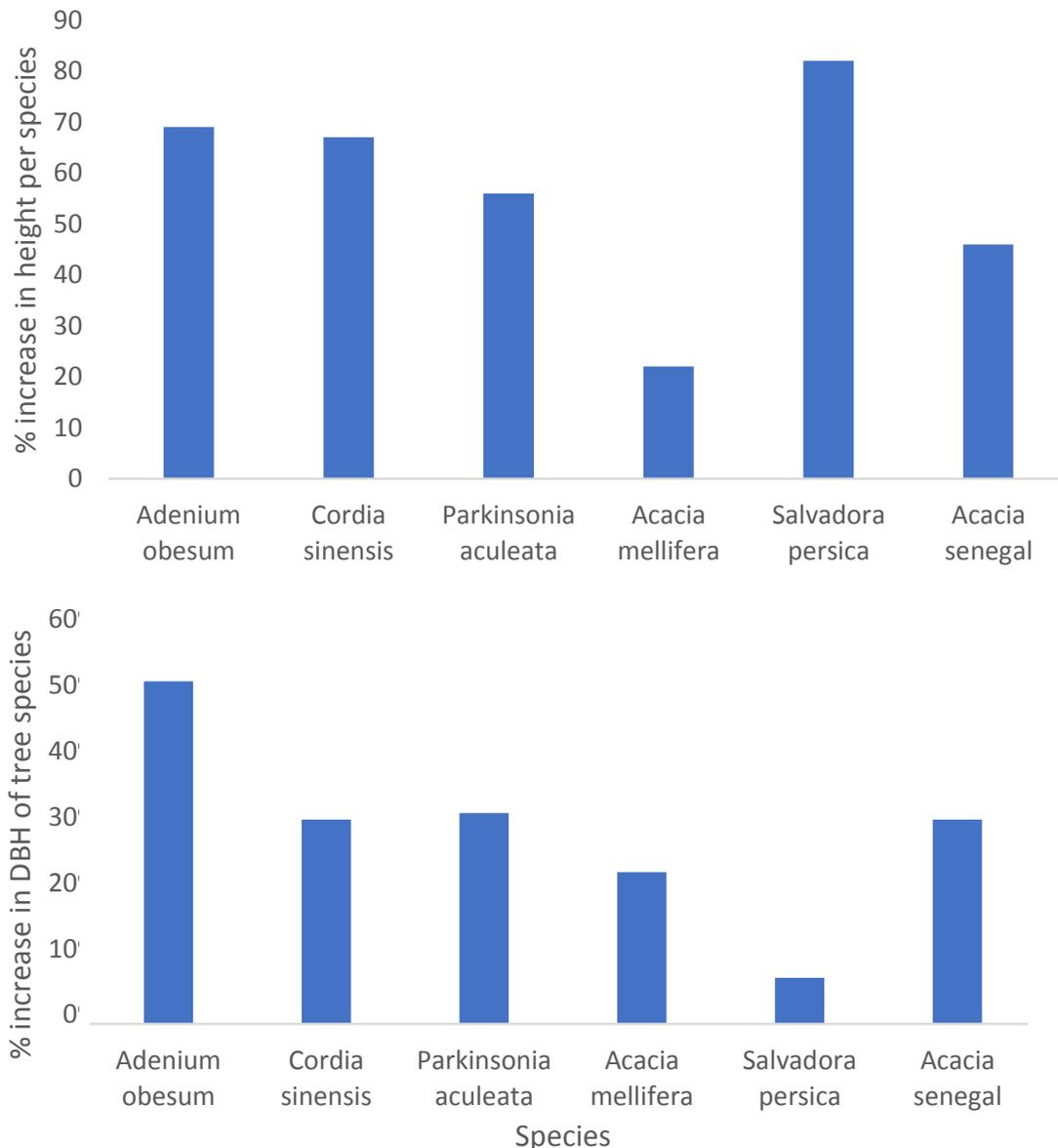
Figure 5. The percent increase in mean height and DBH of species in the site with micro-catchment after two years of establishment.

DISCUSSION

Effectiveness of micro-catchment in rangeland rehabilitation

The use of micro-catchment technology has been utilized to be able to increase the survivability of various afforestation initiatives in the drylands as it ensures speedy growth of trees and deep root development, thus minimizing mortality rate (Ali and Yazar, 2007; Haruna, 2014). This results from the fact that rainfall in arid and semi-arid areas is unreliable, hence trees planted for afforestation or re-afforestation must have some drought-tolerant ability and tree properties for their sustainability (Muturi et al., 2014b).

The contrasting tree species height and presence in the site with and without micro-catchments attest to the effectiveness of micro-catchments in range rehabilitation. These results show proof of the technology to various afforestation initiatives that can be adopted by the local community to improve tree cover and livelihoods. The absence of some tree species planted in the site without
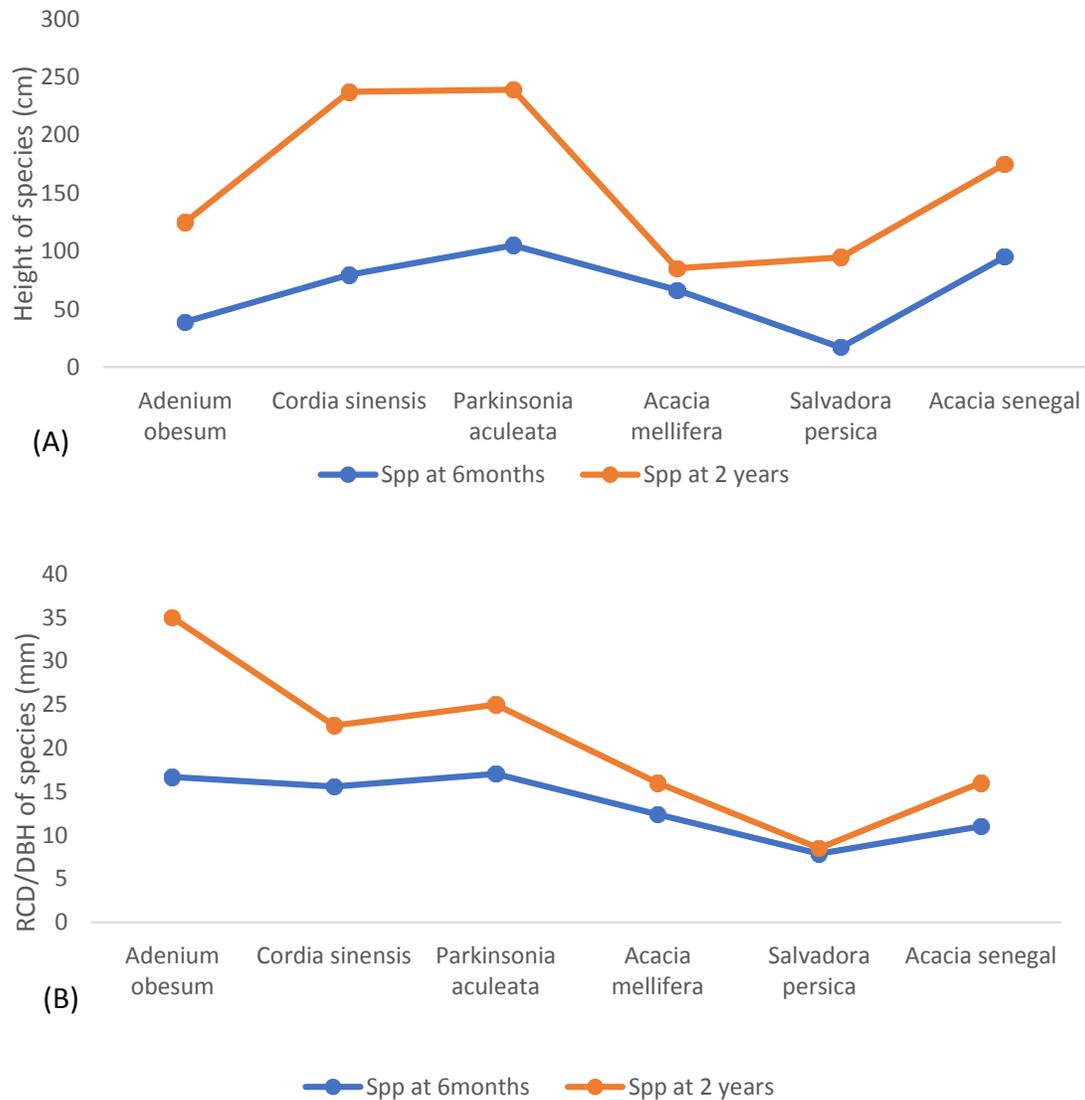
Figure 6. (A) Mean height of spp in micro-catchment, (B) Mean RCD/DBH of spp in micro-catchment at 6 months and 2 years old.

Table 1. Showing species counts in Ekaales with micro-catchments and without micro-catchments. This is total survival after 6 months.

Species	Micro-catchment	
	Yes	No
Acacia mellifera	4	2
Acacia senegal	1	2
Acacia tortilis	0	1
Balanites aegyptiaca	0	1
Cordia sinensis	18	2
Adenium obesum	4	0
Dobera glabra	2	2
Melia volkensii	1	0
Parkinsonia aculeata	2	0
Salvadora persica	4	1

Table 2. Species count in the quadrats in sites with and without micro-catchment.

	Species density/ m^2	Species /ha
Micro-catchment	52	520,000
No micro-catchment	12	120,000

micro-catchment shows the importance of water harvesting structures in areas with low and unpredictable rainfall. This is because the micro-catchment has a higher water collection efficiency and retains water, which could have been lost through run-off and made available to the tree long after the rains have stopped (Haruna, 2014). This technology can be applied in areas with an annual rainfall of 200 to 750 mm. The position of planting the tree should also be determined according to characteristics of the tree species and the soil type (Muturi et al*.,* 2014a).

Species performance in the arid environment

The vegetation data shed light on the influence of micro-catchment on tree growth and survival in the harsh environment of Turkana County. Tree survival in the arid area under natural conditions is usually poor (Haruna, 2014). However, the use of micro-catchment proved to improve the successful establishment of indigenous tree species despite the limited amount of rainfall accompanied by high daily temperature (Mohammed and Mohamed, 2016). The survival rate of trees grown in micro-catchment was recorded to be high, hence the need to advocate for the use of micro-catchment to enhance water infiltration rate. The native plant species outperformed the exotic species in growth and survival. This is because the native species are well adapted to the local environmental conditions. The study also revealed poor long-term survival of exotic species, which in the course of experiment exhibited much stress, and the majority of them dying especially in sites without micro-catchment.

Plant growth occurs as a result of the mutual interaction of genetic structure and environmental conditions (Hrivnák et al*.,* 2017; Yigit et al*.,* 2016a). External factors prevail in the environment in which the plant is grown, this means, climatic and edaphic conditions play an extremely important role in plant growth. Morphological, anatomical, and phenotypic characteristics of plants come up as a result of the interaction of genetic structure and environmental conditions (Sevik et al*.,* 2020a,b; Yucedag et al*.,* 2019). Plants' reaction to environmental factors is closely related to their genetic structures (Yigit et al*.,* 2016b). Since plants of the same species have different genetic structures, they can react to the same

growing conditions and stress conditions at different levels (Topacoglu et al*.,* 2016; Guney et al., 2017; Sevik et al., 2019a,b,c). It is stated as a fact that there may be significant differences between the morphological and micro-morphological characteristics of plants grown in the same environment and belonging to the same species, as well as their growth performances (Sevik et al., 2017; Turkyilmaz et al., 2018a,b).

Morphological characteristics of plants, and hence their growth rate, are also under the influence of environmental factors. There are many factors such as precipitation, temperature, stress factors, light, air pollution, and soil structure which affect the morphological characteristics and development of plants (Cetin et al., 2018a,b; Aricak et al., 2020). In addition to ecological conditions, the studies conducted reveal that the factors such as pruning, hormone applications, spraying, shading, and fertilizing factors are also effective on plant morphological characteristics and development (Guney et al*.,* 2016; Sevik and Cetin, 2016; Yigit et al*.,* 2019). However, the reactions given to these conditions by plants are also shaped under the influence of genetic structure. Therefore, the first step of growing high-quality seedlings is the selection of suitable species and provenances with quality and suitable genetic material.

Herbaceous density

In areas with limited water resource availability, conservation of soil, and water to increase water availability is the only option to improve biomass production (Singh et al*.,* 2013). Water harvesting technologies have a positive role in enhancing soil organic components, nutrients mobility, vegetation population, evenness, and growth (Singh et al*.,* 2017). This is because water harvesting structures help in the conservation of soil and water, and promote herbaceous growth, thus facilitating the land restoration process. The high density of herbaceous species in sites with micro-catchment shows the importance of enclosing a rehabilitated area to allow vegetation to establish. High infiltration rate and low grazing pressure could be a contributing factor to high herbaceous species density. The presence of a single species in sites without micro-catchment (*I. spinosa*) is as a result of high grazing pressure; leading to suppression of decreased species

as well as low infiltration rate during the rainy season.

CONCLUSION AND RECOMMENDATIONS

Rehabilitation of degraded ASAL areas is possible if effective measures and technologies are employed. The results from the study show that the use of native species with proper water harvesting technologies can enhance tree survival and contribute to the rehabilitation of degraded areas. The use of micro-catchment can be adopted by the local communities in Turkana to improve forest and ground cover, thus improving livestock production and environmental conservation. The correct choice of plant species and domestication of young seedlings from domestic browsing species is important. Native species such as *A.senegal, A. mellifera, C. sinensis,* and *P. aculeata* are highly recommended for this region because of their fast growth, drought-tolerant ability and properties for their sustainability. Community training is necessary so as to encourage the practice of planting native plant species using micro-catchments as a rehabilitation strategy (Muturi et al., 2014a,b; Mwamburi and Musyoki, 2010).

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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