Below ground benefits of cactus *Opuntia stricta* under rangeland conditions in Laikipia, Kenya

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Abstract

Cactus *Opuntia stricta* primarily invades arid and semi-arid lands (ASALs), which form more than 80% of Kenya's landmass. The ability of the plant to tolerate poor soils and accumulate biomass under low precipitation has resulted in studies into its potential use by pastoral communities for biofuel and livestock feed. However, few studies have assessed the below-ground benefits associated with cactus under rangeland conditions. In this study, we evaluated the root contributions of the invasives cactus *Opuntia stricta* under rangeland conditions in Laikipia, Kenya. The experiment was laid out in a randomized complete block design with ten (10) replicates, each measuring 30 × 30 m. Each block was further subdivided into three plots of 10 x 30m Three clusters were randomly selected from each plot for roots and soil samples starting from the center of the cluster (C) to the outside in a gradient of three radii, R1, R2 and R3. Data was collected for root (dry root biomass, % carbon and % nitrogen) and soil (pH, bulk density, % moisture and % nitrogen) characteristics. Significant differences in total root mass, root carbon, and root nitrogen were observed under varying cluster gradients. Root mass ranged from 4527.0 to 9242.0 kg/ha for the outermost radius (R3) and the cluster's center, respectively. Similarly, except for the soil nitrogen, statistical differences were observed for soil bulk density, percent soil moisture and percent nitrogen along the different cluster gradients. The soil bulk density ranged from 1.2±0.02 (center) to 1.5±0.01 g cm^3 (radius 2). Findings from this study demonstrate the important contribution of the invasive cactus species in sustaining the ecological functions of rangeland soils such as those found in Laikipia, Kenya

Keywords: Biodiversity, carbon stock, invasive, sustainability, soil ecological benefits

Introduction

Arid and Semi-arid Lands (ASALs) occupy about 80% of the total land area in Kenya and offer livelihoods to millions of people who practice pastoralism and reside on these lands (Nyariki & Amwata, 2019). However, these areas are faced with an increasing number of challenges, such as drought, overgrazing, deforestation for fuelwood, and encroachment by invasive plant species, all of which compromises their ecosystem functionality (Mganga et al., 2015). Cactus *O. stricta* is one of the most problematic invasive plant species that threaten the existence of rangelands in Laikipia (Witt et al., 2020). However, the plant is drought tolerant with yield potentials in less fertile soils where traditional crops such as corn and soybean would fail. However, most studies have focused on the above-ground potential of cactus for biomass with little attention to their below-ground contribution. For example, in Morocco, planting cactus-rehabilitated denuded lands with the net benefit of soil protection and increased productivity (Mazhar et al., 2002). In similar studies, De León-González et al. (2018) indicated an increase in total soil organic carbon under cultivated cactus. In this study, we sought to evaluate the root contribution of the invasives cactus *Opuntia stricta* under rangeland conditions in Laikipia, Kenya.

Methods

The experiment was laid out in a randomized complete block design with ten (10) replicates in the rangelands of Laikipia county, Kenya (Figure 1). Each block measured 30 × 30 m, and further was subdivided into three plots of 30 m × 10 m. Scouting was conducted to identify suitable sites to maximize on homogeneity among the experimental plots. Root samples were obtained from four different gradients (distance at the center of the cluster) previously determined based on the average cluster density for all the blocks. The gradients were C=center of the cluster, R1= first radius (inner most), R2= second radius, and R3=third radius (outer most) (Figure 2). A total of three clusters were sampled from each plot using a golf hole cutter, and soil was obtained at a depth of 20 cm from each of the distances.

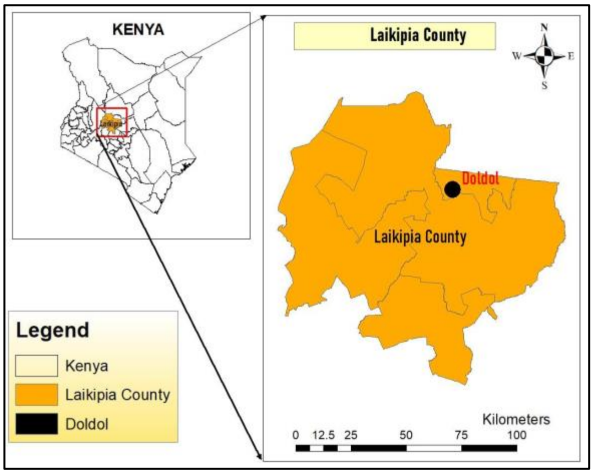


Figure 1: Map of the study area

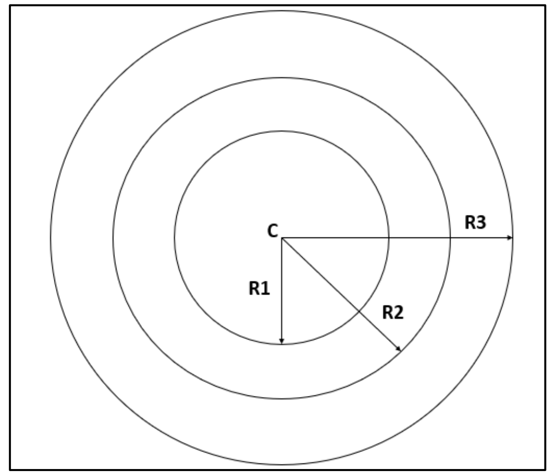


Figure 2: Cluster Sampling points

Eventually, soils from similar gradients but within the same plot were composited, resulting in 120 soil samples (4 sampling points per cluster x 3 clusters per plot x 10 blocks). To determine the soil dry weight, samples were weighed and dried at 55^0C for 48 hours. The soils were then washed, passing through an 850-mm mesh to obtain the roots, which were later dried at 55^0C for 48 hours. Dry weight was recorded, and samples were grounded and kept in vials for subsequent analysis. Similarly soil samples were obtained along the same gradients but at a depth of 15 cm using a soil sampler for analysis of pH, % soil moisture and % Nitrogen. Samples were composited in a similar way as the roots. To determine bulk density, soils were obtained along the cluster gradient using core rings of 100 cm^2. However, soils from each sampling point were kept in separate bags and were not composited. The soils were then oven-dried at 105^0C for 48 hours, and dry weights were recorded. To analyze the data, we used the model; $Y= \mu + block + \beta_n + Error$, where Y=response is the response variable, μ= overall mean, β_n= n different gradients. Significant means were separated using Tukey's HSD $P \leq 0.05$.

Results and discussion

Root mass

The total root mass significantly varied along the cluster gradient and ranged between 4527.0 to 9242.0 kg/ha for the outermost radius and at the center of the cluster, respectively (Figure 1). However, no differences were observed between R1, R2 and R3 for this response variable. Studies by Fonseca et al. (2022) reported similar results where the highest roots concentration were observed at 0.15 meters from the center of the row in cultivated cactus. This could be attributed to high carbon stocks in older roots at the center of the cluster as well as the competitive advantage for moisture as observed in this study.

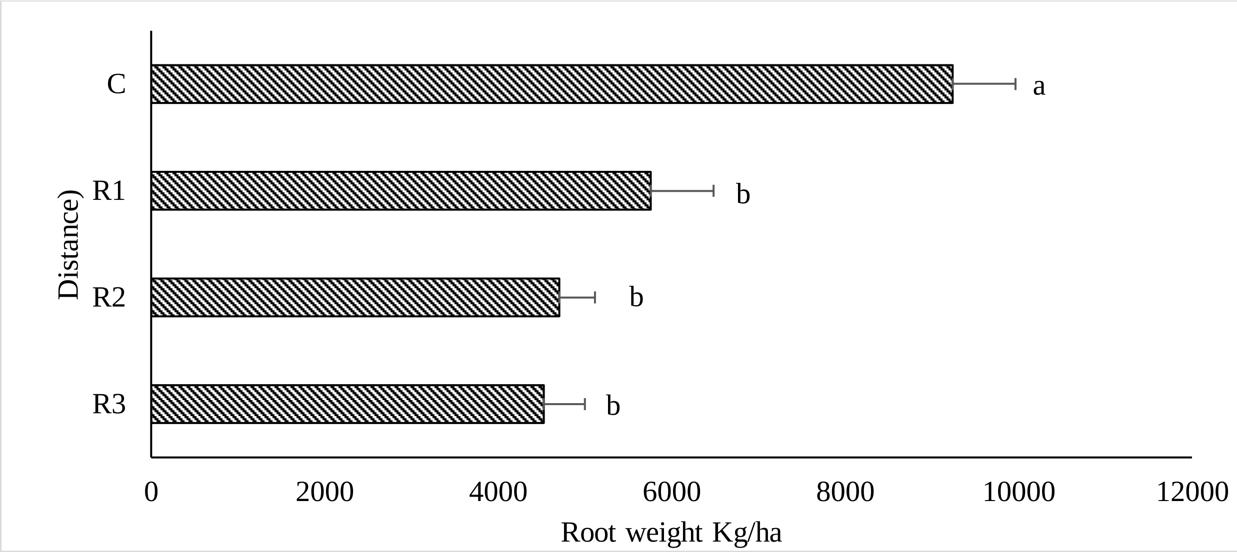
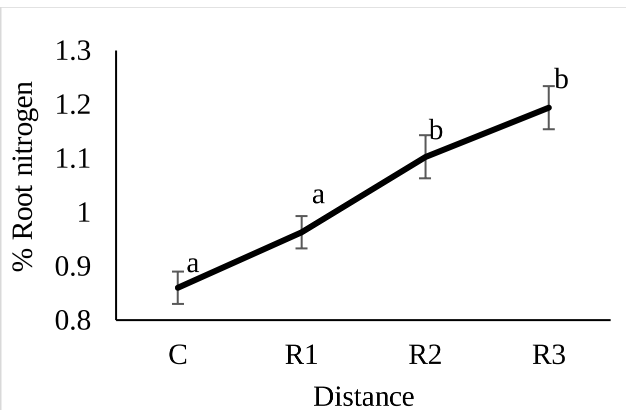


Figure 3: Root mass from different gradients in clusters of cactus.

Root nitrogen and carbon

Increasing gradient from the center of the cluster had a significant effect on the percent nitrogen and carbon of the root samples (Figures 4a and 4b).



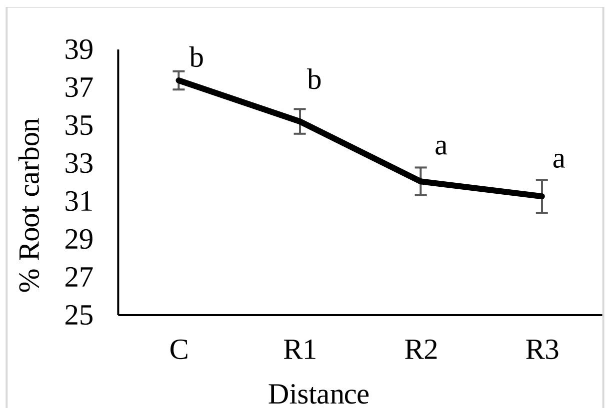


Figure 4a: Root nitrogen (%) in different distances

Figure 4b: Root carbon (%) in different distances

The percent nitrogen ranged from 0.86±0.03 for the centre of the cluster to 1.20±0.04 for the outermost radius (R3). On the contrary, carbon was highest for roots at the center of the cluster recording 37.37±0.48 percent and the least for samples from the outermost radius (31.26±0.87). Similar findings for nitrogen and carbon were reported by Li et al. (2022); in their study, young roots recorded higher nitrogen levels compared to older ones. On the contrary, older roots exhibited carbon stocks than young roots. The authors indicated that young sites had a higher substrate quality than old sites. Typically, young roots are located furthest from the base of the plant with tips to explore water and nutrients with the older ones at the base. Similarly, soil contamination of the root samples could potentially result to carbon overestimation and the need to correct this on organic matter basis.

Soil properties

Except for the percent soil nitrogen, statistical differences were observed for soil bulk density, percent soil moisture, and percent nitrogen along the different cluster gradients (Table 1). Soil pH values ranged from 6.71± to 7.08± at the center of the cluster and the outermost radius respectively. The soil bulk density was lowest at the center of the cluster 1.25± gcm^3 and did not differ among the other gradients. Soil moisture at the center of the cluster and at the innermost radius (R1) were not statistically different, however, they were different from radius 2 and radius 3.

Table 1: Soil properties along different gradients of cactus clusters

	Distance from the center of the cluster					
Variables	**C**	**R1**	**R2**	**R3**	**SEM**	**P-value**
pH	6.71a	6.88ab	7.04bc	7.08c	0.077	<.001
Bulk density (gcm^3)	1.25 a	1.4 b	1.46 bc	1.47 c	0.025	<.001
% Soil moisture	4.03b	3.49 ab	3.28 a	3.02 a	0.225	<.001
% Nitrogen	0.15	0.13	0.11	0.11	0.024	NS

*Averages followed by the same letter do not differ by the Tukey test ($P \leq 0.05$)

Typically, the presences of bicarbonates impose alkaline conditions in dryland soils as reported by Stavi et al. (2021). The authors attribute this condition to presence of bicarbonate (HCO_3^-) following an evaporation of water containing HCO_3^-. The slightly acidic soil pH at the center of the cluster and at the innermost most gradient could be attributed to roots exudates from cactus given their CAM pathway. Notably, the root mass in this region is also high compared to other gradients. The soil bulk density in cactus fields has been reported to be 1.3 g cm^{-3} by Coêlho et al. (2022) and 1.39 g cm^{-3} by Barigabre et al. (2016) closely corresponding to the values in this study. Typically, soil bulk density is closely linked to soil texture and could be influenced by soil aggregation. The observed differences in bulk density along the cluster gradient could be explained by the effect of cactus roots on soil aggregation influencing the proportions of sand, silt and clay particles. Similarly, accumulation of organic matter under the canopy of cactus could lead to improved soil structure enhancing porosity and eventually decreasing compaction. Our findings on soil moisture corroborates with those of Pugnaire et al. (2011), who observed higher values of moisture under canopy of cactus. The authors attribute this to reduced thermal stress and water loss through evaporation. The decline in moisture levels from the center of the cluster to the outside radius could be attributed to differences in bulk density, reduced vegetation cover as well as compaction by animals which tend to access grass within the cactus clusters.

Conclusion

The roots of invasive cactus *Opuntia stricta* play an important biological role in sustaining the ecological functions of rangeland soils such as those in Laikipia, Kenya. The ability to accumulate root biomass under harsh conditions in drylands offers a great potential for use of cactus as an alternative crop for carbon storage in drylands. Similarly, the ability of this plant to improve the physical and chemical properties of soils could potentially be tapped into to reclaim marginal lands in ASAL regions. These benefits have the potential to improve the livelihoods of pastoral communities.

Acknowledgements

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