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Effects of Restoration Techniques on Plant Diversity and Forage Biomass in Areas Invaded by *Prosopis juliflora*

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ABSTRACT

Prosopis juliflora, an invasive plant worldwide causes major threats by destructing natural ecosystem and limits provisioning of ecosystem services in the invaded areas. Attempts to manage the species and restore invaded lands have landed countries to adopt and implement different restoration options. This study tested three restoration options namely Diveting, Mulching and Seeding and their combination to assess their effectiveness in enhancing plant diversity and forage biomass. The study cleared invaded lands in Kahe Ward, Northern Tanzania and laid two blocks, each designated to address livestock pasture and conservation challenges. Experimental blocks were laid in a complete randomized design in 10mx10m plots. Data on plant species and forage biomass were collected in each 10mx10m whereby plants were identified with the support of a botanist; their number recorded, and grass samples green and dry weight determined. The Shannon–Wiener Diversity Index was used to estimate diversity of plant species and the average values in each restoration treatment. One way ANOVA showed that, diversity of native plants was higher in control (Mean±SE =1.239±0.937) than diveting (Mean±SE =1.105±0.56) and diveting-mulching (Mean±SE =0.7703±0.55). Forage biomass was higher in control (Mean±SE =65.917±10.083) than in diveting (Mean±SE =52.425±11.15), diveting-mulching (Mean±SE =42.067±8.751) and diveting-seeding-mulching (Mean±SE =57.625±10.02) implying that restoration interventions have no positive influence on forage biomass. It is recommended that, clearing the land and leave it without restoration is enough because the restoration options do not have positive influence on plant diversity and forage biomass.

Key Words: Restoration, Diveting, Mulching, Seeding, Diversity, Biomass.

1. INTRODUCTION

Prosopis juliflora is recognized as an invasive plant affecting agropastoral and landscapes worldwide [1]. The species express high capability to establish, invade and outcompete native species outside its natural habitat [2]. Following its introduction from America in the 1800s, it has widely spread across arid and semi-arid regions of Africa, [1, 3], reducing biodiversity and changing vegetation to unproductive thickets [4]. *Prosopis juliflora* also negatively affects human and animal health. Thorns of *Prosopis juliflora* cause inflammation when penetrating human or animal skin [5]. Ingestion of *Prosopis juliflora* pods over a long period of time can result to death of livestock [4]. Stomach poisoning by *Prosopis juliflora* pods results in permanent incapacity of animal to digest cellulose. *Prosopis juliflora* also impairs agricultural production [6] and can act as breeding site for malaria vector mosquitoes [7].

In Eastern Africa, *Prosopis juliflora* was intentionally introduced in Kenya and Ethiopia around 1960s and 1970s in attempt to promote energy self-sufficiency and environmental stabilization [8]. Since then, the species has invaded more than a million hectares of agricultural land (crop fields, grasslands) in both Kenya and Ethiopia, forming dense thorny thickets which hinder growth of other plants species, reduce water availability, and affect livestock health by causing tooth decay and obstructing movement [9]. In Ethiopia, *Prosopis juliflora* invasion has accelerated degradation of pasturelands as it flourishes in overgrazed and denuded grassland ecosystems, and subsequently turning pasture lands to unusable bush lands [10]. Management measures that have been implemented such as complete mechanical removal and maximizing utilization are not practical eradicating *Prosopis juliflora* at large scale due to high costs [11].

In Tanzania, *Prosopis juliflora* was unintentionally introduced in Tanzania by traders between Taveta County (Kenya) and Mwanga District in Kilimanjaro Region around 1988 [12]. Since then, *Prosopis juliflora* has spread significantly, invading valuable agricultural and pastoral lands in the Northern part of the country including Kilimanjaro, Arusha and Manyara regions, leading to challenges in agricultural and grazing lands [13],[14]. Attempts to solve problems associated with *Prosopis juliflora* are implemented by the "Woody Weeds" project since 2017. The project produced species management policy insights [12], and established restoration trial plots in Kahe Ward, Moshi Rural District to address conservation and livestock pasture challenges in areas invaded by *Prosopis juliflora*. The Woody Weeds project, established two restoration blocks comprising four restoration treatments which were diveting (DIV), diveting-seeding-mulching (DSM), diveting-mulching (DIM) and control (CON). In Diveting, shallow hollows of about 50 x 50 cm size were made to retain water and seed run-off during rainfall, whereas in seeding, seed of grasses native to Kahe were sown for restoration purposes. In mulching, grasses native to the study area were used as mulch and no restoration was done in the control treatment. Yet, three years later, information about the effects of these restoration options on plant diversity, forage biomass and crop growth performance remained elusive. This paper therefore unveils the effectiveness of the restoration options, and best practices toward successful *Prosopis juliflora* management.

2. MATERIALS AND METHODS

2.1 Description of the study area

This study was conducted in Kahe ward located in Moshi Rural, Kilimanjaro Region, Northern Tanzania. The two main ethnic groups in Kahe are Chagga and Pare, whose main livelihood strategies in agriculture and livestock keeping [15]. Soils of this area are derived from volcanic and alluvial deposits [16]. They range from dark reddish brown to dark brown sandy loam or heavy clays [16]. Annual precipitation ranges between 275 mm and 500 mm, with most rain occurring between March and May [17]. The annual air temperature ranges from 15−36 °C, with June − August being the coldest months (15−23 °C) and January−February being the hottest months (32−35 °C) [18]. Within Kahe Ward, the study concentrated in Oria village which is highly invaded by *Prosopis juliflora*. This village has an area of 42.5ha whereby 50% of its area is invaded.

2.2. Study design and sampling strategy

The total area invaded in Oria village was 21.25 ha, of which an area of 0.425 ha equivalent to 2% was sampled for establishment of trial plot. The study adopted sampling strategy established by FAO [19] to obtain the number of research trials plots.

$$\text{Number of research trial plots} = \frac{\text{Area of the study (ha) x Sampling intensity}}{\text{Area of the plot (ha)}}$$

2.3. Trial plot establishment and designing

The 0.425 ha sampled area for establishment of trial plot was cleared by cutting and uprooting all *Prosopis juliflora* plants, and ploughed to soften the soil. In order to accommodate the interest of the community social economic activities (pastoralism and conservation), the area was divided into two parts for establishing research plots. The first part was designed to comply with conservation and the other part for pastoralists. The research employed the following restoration techniques through randomization design; i) Diveting (DIV): This involved digging of shallow hollows of about 50 x 50 cm size in order to retain water run-off during rainfall, ii) Diveting-mulching (DIM): This involved digging of shallow hollows to retain water and seed run-off during rainfall as well as the use of grasses (*Digitaria velutina*) native to Kahe as mulches to prevent water loss during dry seasons, iii) Diveting-sowing-mulching: This involved digging of shallow hollows, seeding of native grasses (*Digitaria velutina*) for livestock and the use of mulches to prevent water loss during dry seasons and, iv) Control (CON): This did not involve any intervention; it was left as a baseline of the study.

2.3.1. Research plot design for plant diversity

Restoration trial by using three treatments which are Diveting (DIV), Diveting-mulching (DIM) with their control (CON) was established by using complete randomized design technique. The area composed of 1,200 m^2 was divided into three 10m X 10m parts to accommodate the mentioned treatments separately and replicated four times (Table 2.3.1).

Table 2.3.1: Complete randomized design treatment plot for plant diversity

DIV	CON	DIM	CON
DIM	DIV	CON	DIV
CON	DIM	DIV	DIM

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2.3.2. Research plot design for forage biomass

Restoration trial by using four treatments which are Diveting (DIV), Diveting-mulching (DIM) and Diveting-seeding-mulching (DSM) with their control (CON) was established by using complete randomized design technique. The area composed of 1,600 m^2 was divided into four 10m X 10m parts to accommodate the mentioned treatments separately and replicated four times (Table 2.3.2). Then seeds of Velvet finger-grass (*Digitaria velutina*), a grass species native to Kahe and which is more preferred by livestock were sown for the sake of increasing forage biomass for pastoralists.

Table 2.3.2: Complete randomized design treatment plot for forage biomass

DIV	CON	DIM	DSM
DIM	DIV	DSM	CON
CON	DSM	DIV	DIM
DSM	DIM	CON	DIV

2.4. Data collection

2.4.1 Plant diversity

To understand how diveting and mulching affect plant community and diversity parameters such as plant species richness and abundance, both native tree species and grasses were identified and counted in the 10m x 10m plots in DIV, DIM and CON. A botanist was employed to identify plant species in all plots. Names and number of the identified native plant species were recorded. A checklist of all surveyed plant species was prepared in order to keep records of the conservation status in the area.

2.4.2. Forage biomass

48 grass samples were collected in DIV, DIM, DSM and CON treatments of 10m x 10m size each, making a total area of 4,800 m^2 which was the area having grasses during the period of data collection. In each 10m x 10m plot, 3 grass samples were taken in 3 random 1m x 1m plots. The 3 grass samples taken in each restoration treatment were weighed to obtain their total initial green weights. Then 50% of the total initial weight per plot was taken to represent the whole treatment making a total of 48 grass samples for all treatments [20]. Thereafter, the samples were oven dried at 60^0 C for 6 hours to obtain the final dry weights which were regarded as biomass.

2.5. Data analysis

The Shannon–Wiener Diversity Index (SDI) was used to estimate species diversity and the average values in DIV, DIM and CON. One-way analysis of variance (ANOVA) was used to test whether there is a difference in means among all treatments on plant diversity and forage biomass. Post-hoc test using Tukey's honest significance difference (Tukey's HSD) was done to show which treatment differed from others.

3. RESULTS AND DISCUSSION

3.1 Results

3.1.1 Effects of diveting and mulching on plant diversity for conservationists

Diveting and mulching had no significant effect on diversity of the native plants in the area which was previously invaded by *Prosopis juliflora* ($F = 0.195$, $df = 3$, $P = 0.828$). However, plant diversity in diveting and mulching was lower compared to the control (CON) area which appeared to have higher diversity (Figure 3.1.1).

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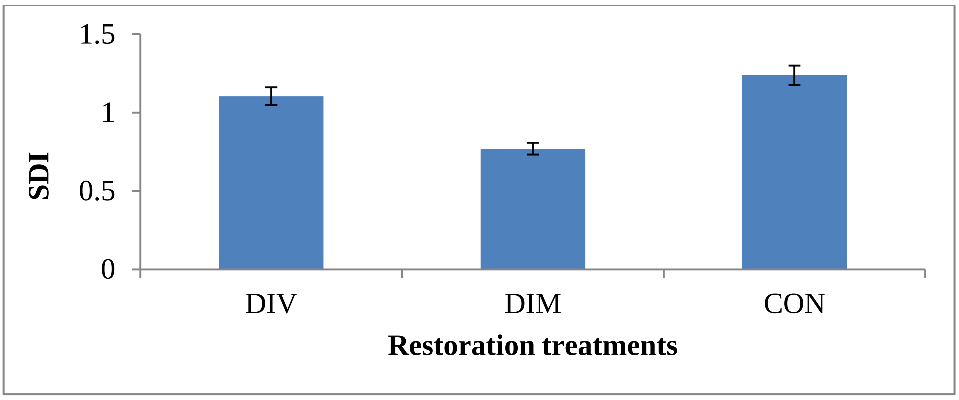

Figure 1.1.1: Diversity of plants across restoration treatments

The maximum and minimum values for SDI in the diveting treatment were 1.873642 and 0.0266 (M = 1.105442, SD = 0.56 and Median = 1.416084). Further, the DIM treatment had the maximum and minimum SDI values of 1.8516 and 0.093746 (M = 0.770334, SD = 0.55 and Median = 0.365656). The control (CON) had the maximum and minimum SDI value of 2.305615 and 0.548883 (M = 1.239197667, SD = 0.94 and Median = 0.863095) as shown in Table 3.1.1. The mean values in the control and DIM treatments are greater than their median values. This implies that the distribution of native plant species in the treatments is positively skewed. However, the mean value in DIV treatment is less than the median value indicating that the distribution of native plant species in the treatment is negatively skewed.

Table 3.1.1: Maximum value, minimum value, mean SDI (±SE) and median value per treatment

Treatment	Maximum value	Minimum value	Mean±SE	Median value
DIV	1.873642	0.0266	1.105±0.56	1.416084
DIM	1.8516	0.093746	0.7703±0.55	0.365656
CON	2.305615	0.548883	1.239±0.937	0.863095

3.1.2. Effect of diveting, seeding and mulching on forage biomass for pastoralists

The amount of forage biomass did not differ significantly across Diveting (DIV), Diveting-mulching (DIM), Diveting-sowing-mulching (DSM) and Control (CON) since df = 3, F = 0.837and P = 0.481. But, forage biomass was found to be higher in the control (CON) treatment than in DIV, DIM and DSM treatments (Figure 3.1.2).

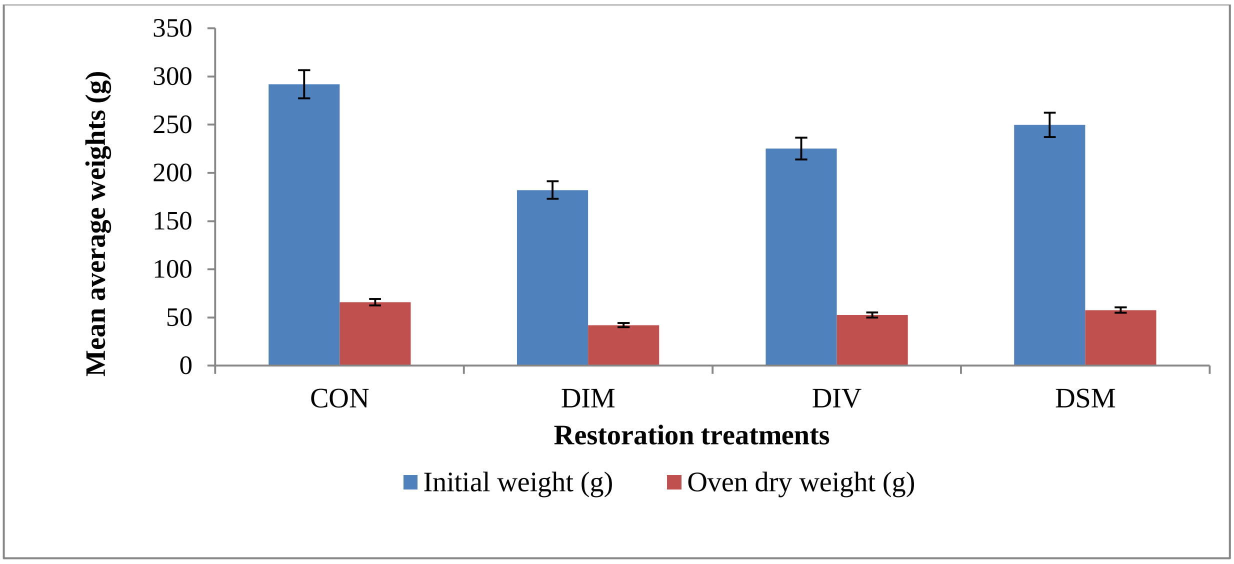

Figure 3.1.2: Forage biomass across restoration treatments

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The mean average values of initial and oven dry forage weights in the CON were 291.875±45.098 and 65.917±10.083 respectively while for DIV were 225.36±46.97 and 52.425±11.15 respectively. The mean average values of initial and oven dry weights in DIM were 182.117±40.677 and 42.067±8.751 respectively while for DSM were 249.792±36.35 and 57.625±10.02 respectively. The median values for oven dry weights in CON, DIV, DIM and DSM were 65.917, 51.1, 40.3 and 57.625 respectively (Table 3.1.2).

Table 3.1.2: Mean values (±SE), median and mode values of forage biomass across restoration treatments

Treatment	Mean±SE	Median	Mode
DIV	52.425±11.15	51.1	48.45
DIM	42.067±8.751	40.3	36.766
DSM	57.625±10.02	57.625	57.625
CON	65.917±10.083	65.917	89

3.2. Discussion

3.2.1 Effects of diveting and mulching on plant diversity for conservationists

Both diveting and mulching seem to have no significant effect on diversity of the native plants in the study area. Diversity of native plant species indicated no significant difference among the treatments in which diveting and mulching were applied. However, diversity increased in control (CON) plot (Mean±SE =1.239±0.937) compared to DIV (Mean±SE =1.105±0.56) and DIM (Mean±SE =0.7703±0.55). The higher diversity of native plant species in CON might be attributed to factors such as availability of more free spaces for emergence of plants not blocked by the mulches. Clearing, ploughing and leaving the land uncovered increase the chances of plants to emerge compared to where mulches may act as a barrier. The results from this study are however contrary to a study by [21] who concluded that application of mulching increases plant diversity because mulches improve soil conditions which facilitate the growth of other plant species. Grass mulches take more than one growing season to decompose and release nutrients and open up spaces for plants to emerge [22].

3.2.2 Effect of diveting, seeding and mulching on forage biomass for pastoralists

Diveting, seeding and mulching observed to be not effective in restoration of native grasses for pastoralists in the study area ($p>0.05$) compared to the area that was only cleared and left without any restoration intervention (i.e. CON) which had more forage biomass (Mean±SE =65.917±10.083). The higher forage biomass in the control area might be attributed to the absence of mulches that could act as a barrier that prevented emergence of grasses in DIM and DIV treatments. Mulches physically prevent the emergence of native grasses by obstructing sunlight and air flow. The same reason explains why block with only diveting (DIV) was found to have larger forage biomass compared to the area with diveting-mulching (DIM). The findings in study are in line with a study by [23] who showed that mulches block the germination stimuli of grass seeds by stopping light, decreasing soil temperature, and significantly reducing the day to night temperature fluctuations leading to germination of fewer grass seeds under the mulches than in uncovered soil. Although more water was conserved in the areas where diveting, seeding and mulching were applied but the major challenge was presence of mulches that acted as a barrier preventing the germination of grass seeds and emergence of grasses. Studies show that, diveting, seeding and mulching when combined together could support more grasses than diveting and mulching [24], [25]. In this study, larger amount of forage biomass was also observed when diveting, seeding and mulching were simultaneously compared to areas where only diveting and mulching were applied. Also, [26] show that mulches conserve moisture in soils and enhance the nutrients, hence contributing to growth of grasses and increases forage biomass. However, in this study forage biomass was low despite the application of diveting; mulching and sowing of the native grass seeds promote regeneration. This demonstrate that application of restoration techniques such as diveting, seeding and mulching can only be effective in enhancing grass productivity and forage biomass when removal of *Prosopis juliflora* is combined with long-term fallowing to allow mulches to decompose [27].

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4. CONCLUSION

This study aimed at assessing the effects of restoration techniques on plant diversity and forage biomass in areas invaded by *Prosopis juliflora*. The results show that restoration techniques had no positive influence on plant diversity and forage biomass. The diversity of native plants differed across DIV (Mean±SE =1.105±0.56) and DIM (Mean±SE =0.7703±0.55) were low compared CON (Mean±SE =1.239±0.937). Forage biomass was low in DIV (Mean±SE =52.425±11.15), DIM (Mean±SE =42.067±8.751) and DSM (Mean±SE =57.625±10.02) compared to CON (Mean±SE =65.917±10.083) implying that restoration interventions have not been successful in enhancing forage biomass productivity. This study therefore, concludes that application of restoration interventions after mechanical removal of *Prosopis juliflora* does not enhance plant diversity and forage biomass in the first production cycle. Long-term monitoring is therefore required to determine production required to make the restoration options effective.

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