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Estimation of *Prosopis juliflora* pod production in the drylands of Magadi region, Kajiado, Kenya

[1*]KYUMA R.K., [2]KINAMA J.M., [3]WAHOME R.G., [1]MWENDWA S.M

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, Kenya, P.O Box 29053-00625, Nairobi.
[2]Department of Plant Science and Crop Protection, University of Nairobi, Kenya, P.O. Box 29053-00625, Nairobi.
[3]Department of Animal Production, University of Nairobi, Kenya, P.O Box 29053-00625, Nairobi.
***Corresponding author**: kavilakyuma@gmail.com

Abstract

Prosopis juliflora was introduced in Baringo County in the Rift valley, Kenya as a shrub species to rehabilitate the denuded dry lands. It became invasive and spread to other pastoralist areas in Kenya, including Magadi region thereby competing and replacing other vegetation types. Past research has however shown that its pods have proven qualities for use as animal feedstuff. This study was undertaken with the objective of establishing whether *Prosopis juliflora* pods in the drylands of Magadi area in Kajiado County was in sufficient quantities for production of animal feeds. Pods were collected and weighed once a week in randomly selected and fenced 30 x 30-meter plots in the Nguruman escarpment and the Olkiramatian floodplains. Three categories of plots based on plant density were marked out as dense, moderate and sparse respectively. Half of the dense plots had their Prosopis trees pruned and thinned to allow spacing of five meters (managed dense). Weekly collection and weighing of pods was carried out for a period of ten months including one wet season and two dry seasons. The managed dense, unmanaged dense, moderate and sparse plots yielded 44.3 tonnes per hectare (tha-1,) 24.5 tha-1, 15.4 tha-1 and 1.3 tha-1 in Nguruman escarpment and 9.3 tha-1, 17.6 tha-1, 1.5 tha-1 and 0.2 tha-1 in the Olkiramatian floodplains respectively. The management practice of pruning and spacing increased pod yield production in the well-watered escarpment landscape. The lowest and highest pod yields were recorded during the dry season and the rainy season respectively. The results showed that the dense unmanaged plots in the lowland landscapes had higher pod yields when compared to the managed dense plots in the escarpment landscape. Variation in pod yields was analyzed using Genstat 14th edition. The results from this study found that the managed Prosopis stands located in the escarpment landscape could sustain commercial Prosopis based animal feeds production.

Keywords: *Animal feeds; Drylands; Management; Prosopis, Pods, Yields*

Introduction

Human-wildlife conflict (HWC) is one of the critical challenges facing conservation across the globe, and as a result, it has captured the attention of many stakeholders including researchers, policy makers, managers and practitioners (Glikman, *et al.*, 2019). Traditionally, HWC has been more intense in developing world where people depend largely on livestock and agriculture for subsistence and income (Eniang *et al*, 2011). However, according to Messmer (2019) communities living in urban neighbourhoods are also increasingly affected by HWC. This can be attributed to the encroachment of wildlife habitats by human settlements as population continue to grow across the globe.

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The seeds are normally dispersed through dung excretions of livestock and wildlife that feed on the pods (Mwangi and Swallow, 2005; Koech *et al.,* 2010). The seeds spread through runoff especially along riparian courses during periods of rainy periods and then spreads laterally from these water courses. It is a difficult tree to eradicate and has been used successfully and profitably for timber, human food and animal feed (Choge and Pasiecznik, 2006; Wahome *et al.,* 2008). *Prosopis juliflora* has been known to thrive in a variety of soils including those that are rocky, sandy, infertile and saline within an elevation ranging from 300 to 1900 meters above sea level. One of its major adaptations is its very deep taproots that enables it to access sub-surface waters.

The plant's beneficial qualities include the control of soil erosion, provision of shade, fuelwood, source of building materials, and pods for animal and human consumption in arid and semi-arid areas. Additionally, *P. juliflora* has been known to enhance soil fertility (Singh and Shukla, 2012) and serves as a cheap source of firewood, human food, animal feed, medicine, timber, honey, among other benefits in Kenya (Sato, 2013). These clear economic uses are contrasted by the negative consequences which *Prosopis juliflora* invasion poses, which results to a conflict of interest in the view of the species.

Some of the negative implications include casting of shade which changes composition, abundance, richness, and diversity of understorey plant species and poses threats to ecosystem services (El-Keblawy and Al-Rawai, 2007). The aggressiveness of *Prosopis juliflora* in its invasion replaces native vegetation very absurdly, thereby dominating rangeland landscapes. The key negative impacts associated with the plant include loss of pasture and rangeland vegetation for both domestic and wild herbivores, destruction of fishing nets in adjacent water bodies by *Prosopis* thorns, livestock diseases and death due piercing by *Prosopis juliflora* thorns after ingesting the pods. Other negative effects include loss or reduction of cropping land, high cost of repairing punctured vehicle tyres due to roadside thorns, and increased hospital bills associated with the treatment of thorn wounds. Dense stands of *Prosopis juliflora* sometimes can block irrigation channels completely affecting access to pasture, croplands, water sources and fishing areas.

Prosopis juliflora are known to tolerate saline soils and drought conditions, with the deep roots enabling the plants to also tolerate waterlogged conditions. The plant is characterized by very prolific seed production which enables it to very quickly form dense and thorny thickets that affect overall biodiversity (Weber, 2003). Invaded grasslands are transformed into shrubland. The trees also re-sprout easily after cutting (Weber, 2003). Finding a way to take advantage of these properties would be very paramount. There is therefore a felt need by the communities in *Prosopis* infested areas to disregard its negative impacts and capitalize on its benefits. Efforts have been made in different parts of the world to eradicate the species by mechanical, chemical, and biological (seed feeding beetles) methods, but these methods have been found expensive and ineffective (McConnachie *et al*., 2012; Sato, 2013). Therefore, utilization enterprises are advocated to be the best options to control the species from invasion as they provide employment to low-income groups of people in developing countries (Borokini and Babalola, 2012; Wakie *et al*., 2016).

It is estimated that one *Prosopis* tree can produce up to 80 kg of pods in one season. In Kenya, where *Prosopis* is estimated to cover 2% of the land mass, pod yields could reach 200,000 tonnes per year (Mwangi and Swallow, 2005). The high number of viable seeds that germinate and grow very fast when in contact with moisture contributes to its adaptability to arid areas and the high densities of invasions that out-compete and suppress other plant species with relative ease (Fagg and Stewart 1994; Pasiecznik *et al*., 2001). Despite its invasiveness, *Prosopis juliflora* is known for its good qualities when used as animal feed and may provide an opportunity for increasing income generation among pastoralists through pod sales to animal feed processors.

Previous research has shown that the nutrient content of *Prosopis* pods' is similar to that of brans and could therefore serve as an alternative supplement to the 400000 tonnes of maize and wheat bran used in the animal feed rations in

Kenya (Wahome *et al.,* 2008). Laboratory analysis has shown that its nutritive content includes 87% dry matter, 10% energy in mj/kg, 12% crude protein, 11% crude fiber, 30% Nitrogen free extract and 45% dry matter digestibility (Primo *et al.,* 1986; Mathur and Bohra, 1993; Pasiecznik *et al.,* 2001; Wahome *et al.,* 2008). Given the increasing cost of animal feeds in Kenya, its utilization may provide cheap livestock feeds (Githinji *et al.,* 2009), and help in controlling its spread. However, despite the documented properties of *Prosopis* pods as animal feed ingredients, there is little uptake by the pastoral communities and the animal feed manufactures in Kenya.

Inconsistencies in information on the productivity of the *Prosopis* and the lack of reliable supply of the *Prosopis* pod flour to the feeds factories is attributed to the low the uptake. Production of *Prosopis* pods has not been well documented therefore feed manufacturers and consumers lack reliable information (Pasiecznik *et al.,* 2001; Choge and Pasiecznik, 2006; Wahome *et al.,* 2008). The demand for animal feeds produced in Kenya is highest during droughts when individuals, Non-Governmental Organizations (NGOs) and the government look for it as part of drought intervention strategies to minimize livestock loss (GoK-PDNA, 2012; Nanyingi *et al.,* 2012). *Prosopis* based animal feed is a suitable alternative because it exists in (17 out of 22) counties in the drylands of Kenya, where the livestock sector is frequently threatened by scarcity of forage due to recurrent droughts.

P. juliflora can be the raw materials in a pod-flour enterprise to control its invasion through removal of the mesquite's seeds after being crushed to the flour together with dried-pods. This could be a good investment in Kenya where the species is spreading absurdly. Local residents can benefit from this opportunity as they can leave behind the old practice of free range grazing to feed their livestock. To make the pod-flour enterprise remunerative, the animal feed needs to be supplemented with antiemetic medicines and its marketing needs to be done as an animal feed that controls worms and increases livestock productivity (Syomiti et al., 2015). The specific objectives of this study were therefore to estimate the variation in seasonal pod production in the managed and unmanaged *Prosopis* natural stands and also to compare the variation in yields in different landscapes in the drylands of Magadi region of Kajiado County in Kenya. This information is expected to provide ecological and socio-economic empirical data required to inform exploitation opportunities presented by the spread of *Prosopis juliflora* in the drylands.

Materials and methods

Description of the experimental sites

The study was conducted in Magadi division of Kajiado County. The area is located in the south rift of Kenya, bordering Tanzania to the south and Narok County to the west, 1°40'S to 2°S, and longitude from 36°E, to 36°15'E in Magadi, Kajiado County (Fig. 1). The mean altitude for the area is 600 m above the sea level (masl) with the Nguruman escarpment rising approximately to 2000m compared to the 600m in the Olkiramatian floodplains.

The area has a bimodal rainfall pattern with an annual total of approximately 460 mm and mean temperatures of 32°C. The Olkiramatian floodplain receive 400 mm of rainfall annually and is characterized with an average temperature of 350C. Vegetation in the floodplain is mainly dominated by Prosopis shrubs and bare land. The Nguruman escarpment receives 600 mm of rainfall annually with mean temperatures of 280C. It is characterized by dense Acacia woodland (mostly Acacia tortilis) and Prosopis bushland with patches of irrigation fields. The soils are saline and therefore classified as Solonchaks (Agriculture, 2014). The clay mineralogy is variable ranging from montmorillonitic, kaolinitic and interstratified clay (Kenya soil survey, 1997). Nguruman area is mainly under Ecological Zone IV while Olkiramatian floodplain is in Zone V according to the ecological zone classification system of Pratt and Gwynne (1977). It is sparsely populated except for the agricultural zones of Nguruman escarpment.

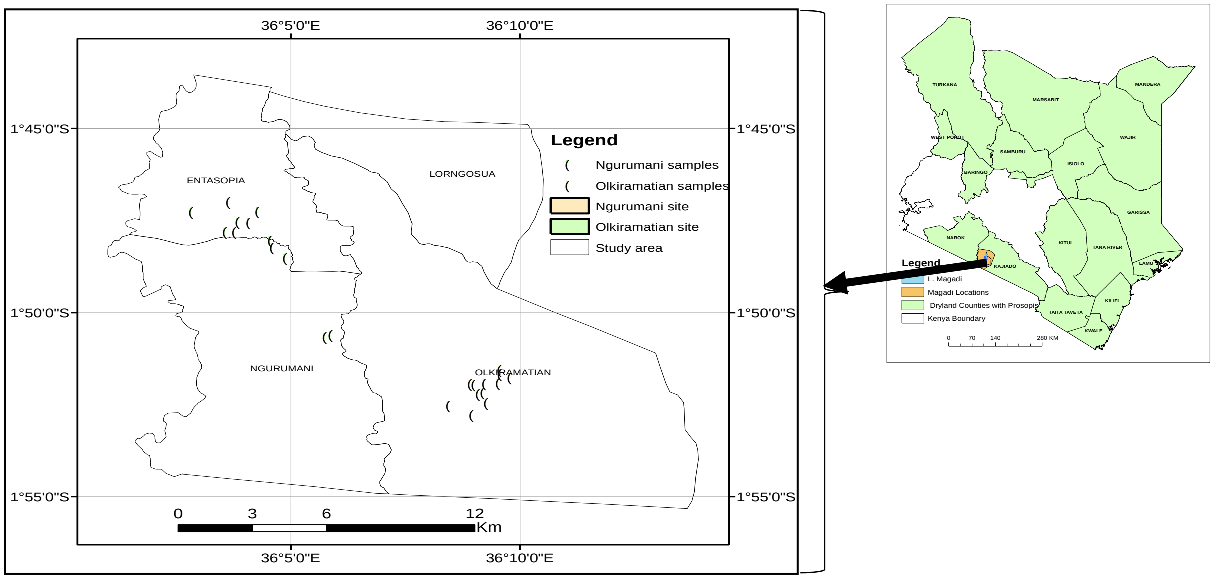

Figure 1: ***Study area in Magadi region in Kajiado County, Kenya***

The study area is inhabited mainly by the Maasai community, who are predominantly pastoralists although a few have adopted to crop farming. The climate is hot and arid and the vegetation cover consists of Acacia, Ficus, and *Cordia sinensis* trees among other native species. The understorey consists of shrubs such as *Grewia spp*., Boscia and *Trichilia roka*, and grass species that include *Echinochloa haploclada* (Agnew et al., 2000).

Prosopis juliflora is mainly found in Olkiramatian, Nkurumani, OlchorroOlepo and Entasopia sub-locations of Okiramatian location. These are the sites where *Prosopis* was originally introduced in Magadi Sub-county. The species is also found in other areas in Magadi, such as Musenge, Lorngosua sub-locations of Okiramatian location; Kamukuru and Kora sub-locations of Oldonyo-Nyoike location and Lenkobei sub-location of Shompole location, although the plant cover is lower. The study was conducted in Olkiramatian, Nguruman, Olchorro Olepo and Entasopia sub-locations of Olkiramatian location where there were well established *Prosopis* stands (Fig. 1) both within the escarpment and the floodplains.

Delineation of the landscapes and Prosopis density clusters

Local key informants including socially respected people in the community and who are very knowledgeable about *Prosopis* and its history in the cool hillslopes and the dry-hot floodplain were sought. Young Maasai youth served as field assistants and informants on perceptions of the local people about *Prosopis.* Participatory mapping of *Prosopis* clusters was done with help of local key informants who composed of three elderly men, one woman and one young man. The local community informants helped to map *Prosopis* invaded landscapes into the water endowed and cooler "escarpment" and the drier and hotter "floodplains." Three sites representing three density classes of *Prosopis* stands namely, sparse (less than 30%), moderate (50 to 70%) and dense (greater than 70%) were identified and delineated using participatory mapping techniques in the two purposefully selected landscapes. Four (4) plots of 30m x 30m were randomly selected in the demarcated sites. In the dense *Prosopis* sites, four (4) more plots were selected randomly, where management practices were applied and were labelled "managed plots." That brings a total of 16 plots in each landscape.

The community was involved in sketching the areas invaded by *Prosopis* on a printed 1:50000 topomap to allow mapping and demarcation of the study sites. The identified *Prosopis* sites were then digitized using GIS software (ArcGIS) to create a GIS shapefile. The *Prosopis* density shapefiles were then partitioned using square grids and each grid assigned a unique number. Four random numbers were then generated from the unique numbers in each of the three *Prosopis* density sites using MS Excel and used as the identifiers of the random sampling sites in which 30 x 30-meter sampling plot was demarcated and fenced off. In the dense *Prosopis* site, two (2) 30 x 30-meter plots were demarcated side by side, one on which management practices involving pruning of two (2) to three (3) stems per plant and thinning to space them at five (5) meters apart was applied. Control plots were left unmanaged. Any vegetation undergrowth and re-growth was regularly removed in the managed plots. In the unmanaged plots observations were taken on the naturally occurring trees with no management practices applied.

A total of 32 sampling plots were selected from the two landscapes, identified on the ground and referenced using GPS for this study. The total number of plots in the whole study area of both landscapes can be computed as (2*(4+4+4+4)) = 32. The *Prosopis* plants (3 meters and above in height and producing pods were identified and counted in each sampling plot. Ten (10) *Prosopis* plants in each plot were randomly selected and pods measurements (weights in kg) taken in the sampled trees once every week for ten (10) months in the sparse, moderate, managed dense and unmanaged dense plots.

Data collection methods

Ground GPS data was collected and used to calibrate and validate the presence of *Prosopis juliflora* in the different levels of *Prosopis* invasions of the two landscapes of Olkiramatian plains and Nguruman escarpment. The two landscapes of the study area were identified purposively with the help of the knowledgeable local informants using participatory mapping and topomaps. GPS points were taken in each site with the help of research assistants and used for spatial data overlay analysis, ground truthing and verification using GIS tools. *Prosopis* pods were collected every week by hand from the 32 sampling plots for 10 months covering one wet and two dry seasons for the determination of seasonal pods yield production. The pods collected from each plot were weighed (in kilograms) using hand held weighing machines.

Data analysis

Descriptive statistics (means and standard deviations) were determined for *Prosopis* pod production using MS Excel software. Estimation of the quantities of *Prosopis* pods in the dense managed, dense unmanaged, moderate and sparse densities of the Nguruman escarpment and Olkiramatian floodplains landscapes were determined and comparisons of pod production in the different densities undertaken. The least significant difference (LSD) was used to separate the means of pod production in the different density classifications. Analysis of Variance (ANOVA) was used to test for differences between the density categories.

Results

Prosopis pod yield in the dense managed, dense unmanaged, moderate and sparse density plots in Nguruman escarpment and Olkiramatian floodplains landscapes are presented in Table 1. The results show that the mean pod production was highest in the dense managed plots followed by dense unmanaged plots in Nguruman escarpment landscape. On the other hand, mean pod production in the Olkiramatian floodplain was highest in the dense unmanaged plots. The dense managed plots in the Nguruman escarpment registered the highest total pod production of (44.3 tha^{-1}) compared to the unmanaged dense plots (24.5 tha^{-1}), the moderate (15.4 tha^{-1}) and sparse plots (1.3 tha^{-1}) respectively. This further suggested that management improves pod production (Table 2)

Table 1: *Prosopis Pod production in Nguruman and Olkiramatian landscapes*

	Prosopis production t/ha			
	Nguruman escarpment		*Olkiramatian floodplains*	
Density class	**Mean**	**Std Dev**	**Mean**	**Std Dev**
Dense unmanaged	2.04	1.4	1.47	2.32
Dense managed	3.69	2.21	0.78	1.21
Moderate	1.28	0.84	0.12	0.27
Sparse	0.11	0.12	0.01	0.04

Table 2: *Estimates of total Prosopis pod production across the densities and landscapes*

	Total Pods (Average t/ha)	
Density class	*Nguruman landscape*	*Olkiramatian landscape*
Dense unmanaged	20.39[a]	14.68[a]
Dense managed	36.88[b]	7.77[b]
Moderately dense	12.82[c]	1.21[c]
Sparse	1.06[d]	0.13[d]

Means with different letter superscripts down each column are significantly different (*P<0.05). The superscripts a, b, c and d are indicative of significant differences among the treatments.

However, it was found that in the floodplains landscape, which experiences higher temperatures and lower rainfall, the managed dense plots had lower pod production compared to the unmanaged dense plots (Table 2). The pod production pattern was contrary to the production in the Nguruman escarpment, where there was higher pod production in the managed dense plots compared to the unmanaged dense, moderate and the sparse density plots respectively.

Seasonal variation of pod yields

The pod yield trendlines for dense (managed and unmanaged), moderate and sparse densities were fitted with error bars (Fig. 2) for pod production in all the *Prosopis* density classes. In Nguruman escarpment, pod production reached its peak at dense managed (6.0 tha^{-1}), dense unmanaged (5.5 tha^{-1}) moderate (2.7 tha^{-1}) and sparse (0.4 tha^{-1}) during the long rains (May, 2014), and was lowest in the dry months of February and August 2014. The dense and managed plots recorded the highest pod production quantities throughout the study period (Fig. 3).

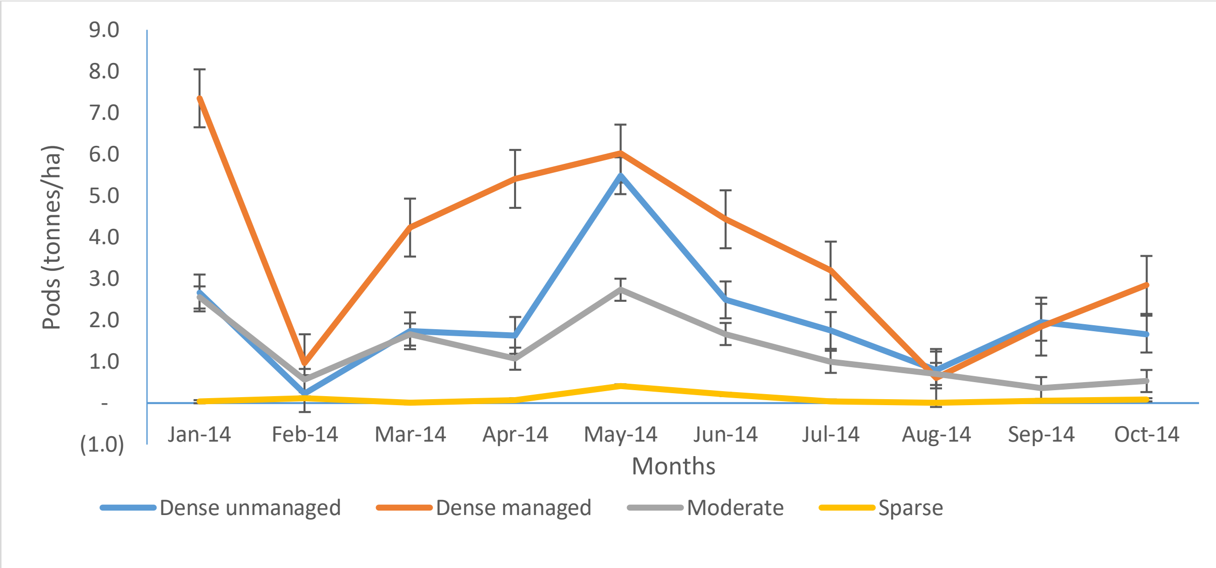

Figure 2: *Prosopis pod production trends in Nguruman region*

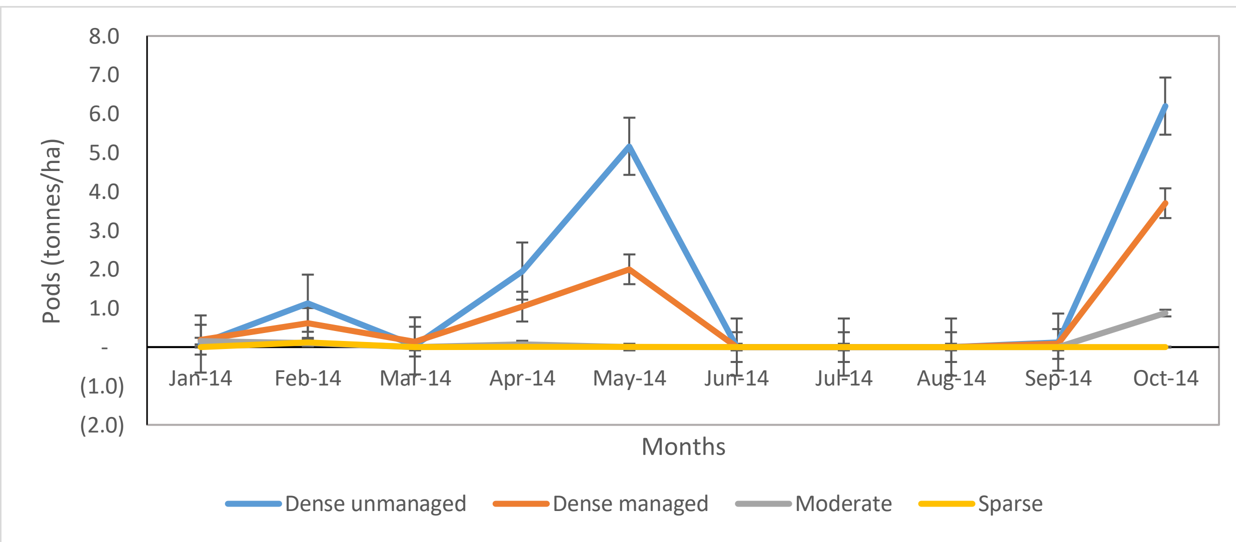

Figure 3. *Prosopis pod production trends in Olkiramatian region*

Similar trends in pod production were observed in the Olkiramatian floodplain where production reached a lower peak in dense managed (2.0 tha-1) and dense unmanaged (5.2 tha^{-1}) during the long rains (May) as provided in Fig. 1. The lowest pod production levels were recorded in the dry seasons (January to March) and (June to September). The patterns were the same in the moderate and sparse densities. The effect of management on pod production in the dense and managed plots was, however, not evident as the pod quantities in the managed plots was lower than in the unmanaged plots. The observed differences in the pod production in Nguruman escarpment and Olkiramatian floodplains can be attributed to the lower temperatures, higher rainfall and water availability in the escarpment than in the floodplains.

Discussion

In Nguruman escarpment, the higher pod production in dense managed plots compared to dense unmanaged plots, the moderate and sparse plots could be due to management through pruning and spacing which can reduce competition for tree growth resources including Photosynthetically Active Radiation (PAR), water and nutrients. This is in agreement with the findings obtained in the study by Kumar and Bhimani (2011) who established that spacing and pruning of *Prosopis* enhances pod production in India. Spacing has been known to allow plants to develop to their full potential and also prevent the spread of pests and diseases from one plant to the other. This could also explain higher pod productivity in the managed plots. Pruning, which involves removing of dead and dying branches could have allowed room for new growth, promoted the natural shape and healthy growth of the plant. Previous studies show that pod yields were affected by pruning, spacing, other vegetation trends, livestock population dynamics, terrain and landscape (Geesing *et al.*, 2004).

Management of *Prosopis* was found useful only in the Nguruman landscape where fast growth of *Prosopis* was possible because of higher total rainfall and more humid conditions. Management (pruning and spacing) also increased pod production in the well-watered escarpment landscape, an important point to note for when commercialization is realized. This suggested that the management of the *Prosopis* trees increased pod production in the escarpment but not in the floodplains. Reduction in competition for water and light in the dense and managed plots in the water endowed and lower temperature zone of the Nguruman escarpment is a possible reason for this observation (Agnew *et al.*, 2000).

The other possible explanation for the low pod production in both landscapes was the dry months of January to March and from June to September which could have resulted to low moisture content due to prolonged dry spells and high temperatures. This is in line with the finding of (Mwangi and Swallow, 2005), who observed depressed pod production in all the density classes during the dry seasons. In the dry season, the crops could have tended to utilize stored energy resources and even lose some water to the soil under severe conditions. Lack of moisture in the soil meant that the *Prosopis* roots were not absorbing dissolved nutrients which could explain low pod productivity during the dry season. The linkage between pod production and climate is evidenced by differences in pod production across the year of this research. Total rainfall seems to play a major role in determining pod production which probably could have resulted to more pod production when the total precipitation was high.

The results also showed that the managed dense plots in low landscapes had lower pod yields compared to the dense and unmanaged plots. The possible reason for this could be that the unmanaged dense plots increased light interception resulting in more pod yields. This is further supported by the findings in (Kinama et al., 2011) which showed increased light interception to increased pod formation. It is also possible that the dense unmanaged plots could have reduced evaporation from the soil and enhanced tree growth resulting in high pod production. Other previous studies have shown that cropping density has a significant role in increasing the pod production. Liphadzi *et al.*, (2003) have reported that higher plant density can increase the phyto-extraction ability of crops, relative to lower plant density. Plant density is affected by many factors, including both external and internal, which directly or indirectly affect the seedling emergence and growth (Grundy *et al.*, 2003; Zhou *et al.*, 2005). The other explanation for increased pod production in dense unmanaged plots could be the variation in seed emergence, relative to sparse plots. There is a substantial influence of seed density on the emergence and growth of seedlings of many crops and weed species (Grundy *et al.*, 2003; Maddonni and Otegui, 2004; Chauvel *et al.*, 2005).

Finally, all aspects leading to the management of *Prosopis* trees increased pod production in the escarpment when compared to the floodplains. *Prosopis* pods utilization options include manufacture of livestock and poultry feeds and also human food (Cruz, 1986; Choge and Pasiecznik, 2006). In order to realize this potential, it is imperative that pod production dynamics are explored and the necessary information is availed to the animal feeds and human food manufacturers and the pastoralists in equal measure. The three challenges of the 21st

century namely climate change, shortage of animal feeds and impoverishment caused by lost livelihoods will be addressed, with the ultimate goal of improving livestock productivity and household incomes for enhanced pastoral resilience against climate variability (Resilience Alliance, 2010). Other challenges presented by the envisaged commercialization of *Prosopis* pods include inadequate infrastructure, the long distance to the animal feed factories and socio-cultural aspects (Choge and Pasiecznik, 2006; Wahome *et al.,* 2008); the labour needs, bulkiness and processing requirements.

Speculatively, different spatial locations could have resulted to development of soils with different characteristics. This phenomenon follows the Dokuchaev's hypothesis which states that soil properties will be the same where all the five factors of soil genesis are the same (Hudson 1992). This hypothesis was echoed by Hartemink (2015) and Mwendwa *et al*., (2020) and could explain the differences in pod yield between the hillslope and the floodplain as crop growth is hugely influenced by the soil characteristics including soil nutrients and water holding capacities.

Prosopis utilization may provide cheap livestock feeds (Githinji *et al.,* 2009) as well help control its spread or invasion of critical resource patches. Commercial livestock feeds venture however requires further exploration. Therefore, a study for the economics of a viable *Prosopis* pods-based animal feeds ingredient, especially during the drought periods when feed ingredients are scarce would be a major advance. However, studies have shown that if properly managed and utilized, *Prosopis* may be the panacea in providing alternative livestock feed during drought and, therefore, secure dryland livelihoods (Pasiecznik *et al.,* 2004; Wahome *et al.,* 2008).

Conclusion and recommendations

The findings of this study suggested that management increased pod production in the hill slopes, which had better moisture regime than the floodplains. The results also showed that *Prosopis* pod production was highest during the wet season which can be attributed to early flowering during the dry season. Pod production was evident throughout the year with low quantities during the dry seasons. There were indications of viable pods quantities in the managed *Prosopis* stands of the escarpment landscape which could sustain animal feeds production for drought mitigation initiatives (a cow requires an equivalence of a 25kg hay bale per week for maintenance during the dry period (Nanyingi *et al.,* 2012). Commercial livestock feeds venture is however a possibility that requires further exploration. Therefore a study for the economics of a viable *Prosopis* pods based animal feeds ingredients, especially during the drought periods when feed ingredients are scarce and needs to be undertaken. Future studies may include *prosopis* pod production for Carbon stocks.

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