African Journal of Plant Science Vol. 5(8), pp. 460-468, August 2011
Available online at http://www.academicjournals.org/ajps
ISSN 1996-0824 ©2011 Academic Journals

*Full Length Research Paper*

# Seedbed preparation influence on morphometric characteristics of perennial grasses of a semi-arid rangeland in Kenya

**F. E. O. Opiyo[1,4], W. N. Ekaya[2,4] D. M. Nyariki[3,4] and S. M. Mureithi[4]***

[1]Welthungerhilfe e.V German Agro Action P. O. Box 38829-00623, Nairobi, Kenya.
[2]Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), Plot 151 Garden Hill, Makerere University Main Campus. P. O. Box 7062, Kampala, Uganda.
[3]Department of Range and Wildlife Sciences, South Eastern University College (SEUCO), Kitui Campus. P. O. Box 170-90200, Kitui, Kenya.
[4]Department of Land Resource Management and Agricultural Technology, University of Nairobi P. O. Box 29053- 00625, Nairobi, Kenya.

Accepted 15 June, 2011

**Semi-arid rangelands in Kenya are an important source of forage for both domestic and wild animals. However, indigenous perennial grasses notably *Cenchrus ciliaris* (African foxtail grass), *Eragrostis superba* (Maasai love grass) and *Enteropogon macrostachyus* (Bush rye grass) are disappearing at an alarming rate. Efforts to re-introduce them through restoration programs have often yielded little success. This can partly be attributed to failure of topsoil to capture and store scarce water to meet germination and plant growth requirements. A study was undertaken in the semi-arid environment of eastern Kenya to determine the effects of land treatment on morphometric characteristics of *E. superba*, *C. ciliaris* and *E. macrostachyus*. Seed viability of the grasses was estimated by germination tests. Land treatments involved soil ripping using a tractor and hand-clearing. Thirty-five plants were randomly selected per sub-plot and tagged for sampling. Morphometric characteristics of the grass species were measured weekly. Aboveground biomass was estimated by harvesting standing biomass three months after establishment. Seed viability tests showed significant differences ($p<0.05$) among the three grass species. This was attributed to intrinsic properties of the grass seeds such as dormancy and tegumental hardness. Seedling survival, foliage cover, plant height, leaf and tiller numbers, and aboveground biomass were significantly higher in ripped plots than hand-cleared plots. It was concluded that soil disturbance influences plant morphometric characteristics and plays an important role in the success rate of restoration attempts in semi-arid rangelands.**

**Key words:** Perennial grasses, morphometric characteristics, hand-clearing, reseeding, ripping, semi-arid rangelands.

## INTRODUCTION

In Kenya, arid and semi-arid lands (ASALs) cover 80% of the country's landmass, support 30% of the human population (Mganga et al., 2010a), 60% of the livestock population and the largest proportion of wildlife (Ngugi and Nyariki, 2003). These areas have undergone increasing land use pressure within the last 15 years, largely due to a number of factors that threatened the sustainability of land-based production systems (Kitalyi et al., 2002). These include climatic factors notably recurrent droughts and low amounts of rainfall, increase in livestock and human population, migration of populations from the high rainfall areas to marginalized areas and changes in land use.

*Corresponding author. E-mail: stemureithi@uonbi.ac.ke. Tel/Fax: +254-20-3592736-9 Ext 27021.

In the past, livestock production in Kenya's ASALs was sustainable due to low livestock and human populations, and was based on various forms of pastoralism as the main source of livelihood (Mbogoh and Shaabani, 1999). However, over the years, land use systems have changed resulting in increased sedentarization and land subdivision, thereby impinging on pasture lands (Ego and Kibet, 2003). For example, most of the former ranches in the southern semi-arid areas of Kenya have been sub-divided e.g. Malili Ranch (Makueni County), while others, for example, Konza Ranch (Makueni-Machakos County) are in the verge of being sub-divided. This encroachment into the grazing areas by cultivation and settlement has led to shrinking of pastoral production resource base, as pastoralists are increasingly confined to less productive ASALs (Alemu et al., 2000). Similarly, effects of drought, termites, inappropriate cultivation and overgrazing in some areas for example Kitui, have resulted in diminished or total loss of some important forage species, especially grasses. Examples include, *Chloris roxburghiana, Eragrostis superba*, *Cenchrus ciliaris* and *Enteropogon macrostachyus* (Mnene et al., 2005).

In Kenya, options for improving pasture cover and quantity where graminoid and non-graminoid plant species have disappeared have been limited to destocking, bush management, and intermittent grazing (Mnene et al., 2000). However, Jordan (1957) and Bogdan and Pratt (1967) made some of the early re-seeding attempts as a means of rehabilitating degraded natural pasture with some encouraging success. The International Crops Research Institute for the Semi-arid Tropics (ICRISAT) has carried out reseeding trials in semi-arid Makueni and Kajiado Counties (Ego and Kibet, 2003). Indigenous perennial grasses notably *E. superba* (Maasai Love Grass), *E. macrostachyus* (Bush Rye) and *C. ciliaris* (African Foxtail Grass) have been used extensively in rehabilitation programs in the ASALs in Kenya. These grasses have the potential to rehabilitate degraded grazing lands in Kenya (Verdoodt et al., 2010). Moreover, these grasses have also been observed to be highly palatable to livestock (Mnene et al., 2000). A review of numerous ecological studies undertaken in Kenya's ASALs in the last decade by Ekaya et al. (2001), Kitalyi et al. (2002), Musimba et al. (2004), Mnene (2005) and Mganga et al. (2010b) on the performance of indigenous African rangeland grasses shows that a considerable amount of work has been done. However, little progress has been made on how to improve the establishment success of grasses in ASALs (Chelishe and Kitalyi, 2002; Mganga et al., 2010a).

One possible reason for low establishment is failure of soil to capture scarce rain water to meet germination, emergence and growth requirements of grasses. Soil disturbance plays an important role in the success rate of restoration attempts (van den Berg and Kellner, 2005; Kinyua et al., 2009). This intervention has a number of ultimate effects: it promotes better root growth; enhance germination of seeds and establishment of seedlings; increase the soils water retaining capacity (Visser et al., 2007). Soil disturbance ensures that the grass seeds trap enough water for a prolonged period of time thus improving the chances of the grass seeds to germinate and establish. Factors affecting germination and early seedling growth are often the primary determinants of the distribution of adult plants (Snyman, 2004). Of the environmental factors, soil-water is the key limiting factor to seedling establishment in the semi-arid rangelands. Such information is essential in devising successful rangeland rehabilitation techniques for possible up-scaling and adoption by communities.

The objective of this study was to determine the effects of two seed bed preparation methods; ripping and hand-clearing, on morphometric characters of three important perennial grasses; *E. superba* Peyr, *C. ciliaris* L. and *E. macrostachyus* (Hochst ex A Rich) Monro ex Benth.

## MATERIALS AND METHODS

### Study area

This study was conducted on the Endau hill escarpment of Kitui county, eastern Kenya (Figure 1) over a period of six months between June and December, 2003. The study area lies between latitudes 0° 3.7′ and 3° 0′ S and longitudes 37° 45′ and 39° 0′ E. The agro-pastoral Kamba community is the predominant ethnic group in the Kitui. Their main source of livelihood is raising local livestock breeds and growing different drought tolerant crops. The climate is typical semi-arid characterised by high temperature throughout the year, with the minimum and maximum temperatures ranging from 15 to 18℃ and 25 to 28℃, respectively (Opiyo, 2007). The rainfall pattern is bimodal with long rains between March and May and short rains from October to December. The rain is low, erratic and unpredictable in nature, varying between 250 and 900 mm annually. Figure 2 represents eleven years mean monthly rainfall and coefficient of variations between 1990 and 2001.

The dominant soils are generally of sandy-clay medium texture, shallow to moderate in depth, and greyish-brown in colour (Thomas et al., 1981). The natural vegetation is highly heterogeneous due to variation in both soil type and history of land use (Jaetzold and Schmidt 1983) and rainfall. The predominant woody species in the area include C*ommiphora africana, Commiphora riparia, Acacia tortilis, Acacia mellifera, Acacia senegal, Acacia nilotica, Cordia ovalis, Combretum* spp*, Balanites aegyptiaca* and *Terminalia orbicularis*. The baobab trees, *Adansonia digitata* are also common. Grasses such as *Premna resinosa*, *Dobera glabra*, *Sporobolus pellucidus*, *C. ciliaris, E. superba, Enteropogon* spp. and *Pennisetum* species dominate. However, within the last decade, annual grasses and shrubs like *Brachiaria leersioides, Justicia exigua, Eragrostis cilianensis, Tetrapogon tenellus* and *Aristida adscensionis* have continued to dominate the non-cultivated areas, a phenomenon closely associated with overgrazing and land degradation (Belkhodja et al., 2003).

### Experimental plots

The experimental design was a Randomized Block Design (RBD)

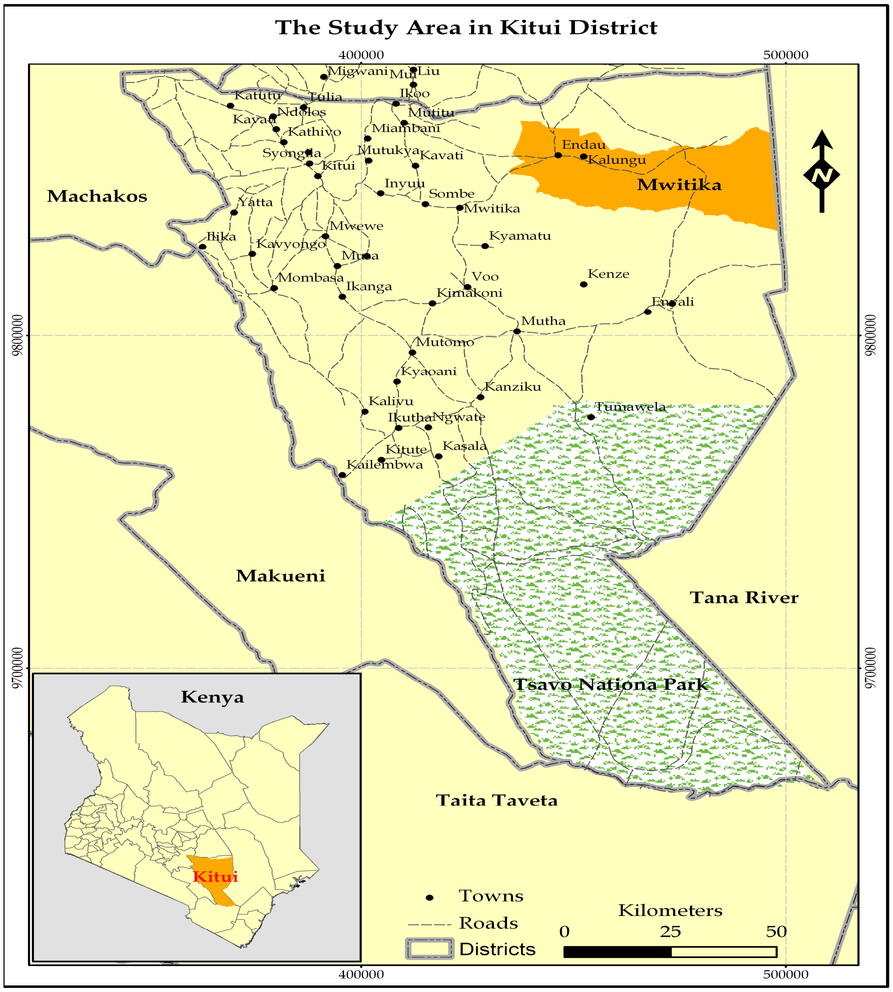


**Figure 1**. Map of Kenya (inset) location of study area and site.

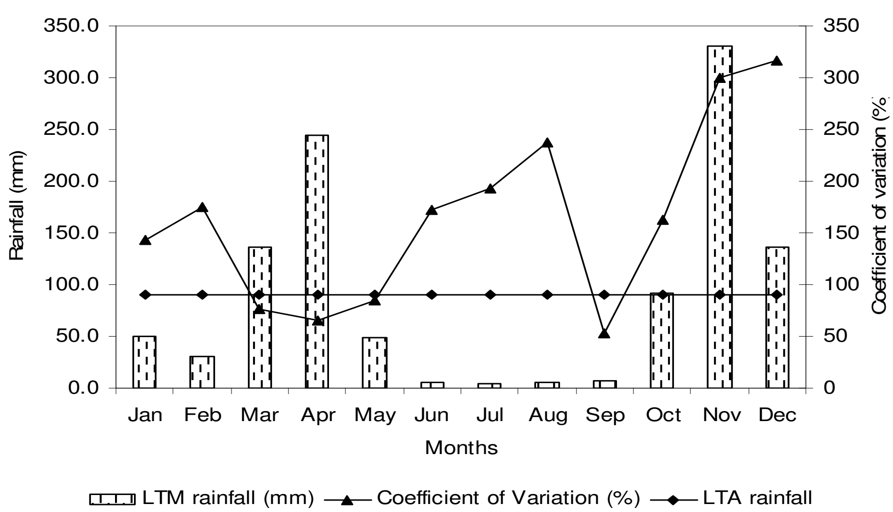


**Figure 2.** Mean monthly (LTM) rainfall and mean annual (LTA) rainfall and coefficient of variation at Endau (1990-2001).

with seedbed preparation methods and grass species considered as the main factors. Within each homogenous block, the treatment where assigned at random to each unit. Six sub plots measuring 6 × 6 m were laid out in each treatment where the grass species were sowed randomly.

The two seed bed preparation methods were: (i) Ripping – this treatment involved a minimum tillage of one run-over by 65-capacity tractor; and (ii) hand-clearing treatment involved hand slashing the experimental plots using a machete without scratching the surface soil. The plots were prepared during the dry season just before the onset of long- rains (March-May, 2003). The seeds of *E. superba*, *C. ciliaris* and *E. macrostachyus* were randomly broadcasted at the beginning of March as pure stands. The experimental plots were fenced with live thorns prior to seed sowing to deter wild and domestic animal interference.

### Sampling procedures

#### *Seed viability tests*

The percent germination of the grass seeds as a measure of seed quality was examined under laboratory conditions. Germination test as described by Tarawali et al. (1995) was used. Random samples of 100 seeds obtained from bags of seeds collected were put on wet Whitman filter paper in a petri dish. Ten replicates were used for each grass species. The petri dishes were then placed in an incubator under room temperature (25℃) and moistened everyday with 5 mm of water for 17 days. The grass seeds that germinated every day were counted and removed from the incubator. Germination was considered to have occurred when a clearly identifiable radicle emerged from the seed in the petri dish (Koning, 1994). At the end of the 17 days, all germinated seeds were expressed as a percentage of total seeds incubated.

Percent germination was calculated using the following formula:

$$\%\ \text{Seed Germination} = \frac{\text{No. of seeds germinated}}{\text{Seeds per petri dish} \times \text{replicates}} \times 100$$

#### *Morphometric characteristics*

Thirty-five plants were randomly selected per sub-plot and tagged for sampling. The following parameters were monitored on a weekly between June and December, 2003:

a) Plant height (cm) was measured on the primary shoot from the soil surface to the base of the top-most leaf weekly
b) The leaves on each primary plant shoot were counted weekly.
c) The live tillers visible on each plant were counted weekly.
d) The plants that withered or died were identified and recorded weekly.
e) Plant foliage cover was estimated using a 1 $m^2$ quadrat in each treatment sub-plot in June.

#### *Aboveground biomass production*

After three months of grass establishment, aboveground biomass production was estimated by harvesting all the plant material in each sub-plot, leaving a stubble height of 2.5 cm. The harvested material was separated by species and the sub-samples of the harvested materials of each species were packed in paper bags, sun dried for five days, and weighed using a half-kilogram spring balance to derive the average dry matter biomass production.

### Data analysis

Statistical analyses were conducted using Statistical Package for Social Sciences (SPSS 17.0) for Windows. The effects of seed bed preparation on seedling mortality, foliage cover, plant height, tillers and leaves and aboveground were tested using an analysis of variance (ANOVA) model for a RBD. For each species, the effects on morphological characteristics were tested differently for each site preparation method. Mean separation tests were performed using least significant difference (LSD) at 5% level.

## RESULTS

### Seed viability tests

The percent seed germination for the grass species for a period of 17 days is shown in Figure 3. Seed germination among the three grass species showed significant difference ($p<0.05$). Among the three species, seeds of *C. ciliaris* had the highest percent germination of 28.4%. *E. macrostachyus* (20.1%) and *E. superba* (8.6%) were ranked second and third respectively. Percent seed germination of *C. ciliaris* and *E. macrostachyus* increased up to the $14^{th}$ day, unlike *E. superba* which increased up to the $13^{th}$ day. The plateaus observed on the germination curves were the period during which no further germination was observed.

There was significant difference in mean daily germination rate among the species. Seeds of *C. ciliaris* had the highest mean daily germination rate of 2.9%, followed by *E. macrostachyus* (2.3%) and *E. superba* (0.7%) respectively. Although the seed germination of *C. ciliaris* started a day after that of *E. macrostachyus,* it attained the highest germination rate on the fifth day. *E. superba* started on the 6th day and took seven days to attain maximum mean daily germination rate.

### Morphometric characters

#### *Seedling mortality and plant foliage cover*

The percent seedling mortality and foliage cover of three grasses in the two seed bed preparations after 12 weeks are presented in Table 1. Seedling mortality varied considerably between the seed bed preparations. The seedling mortality was significantly higher ($p<0.05$) in hand-cleared than ripped seed beds. In both seed bed preparations, seedling mortality was highest in *E. superba,* indicating its poorest adaptation to the two land treatment plots. *C. ciliaris* had the lowest seedling

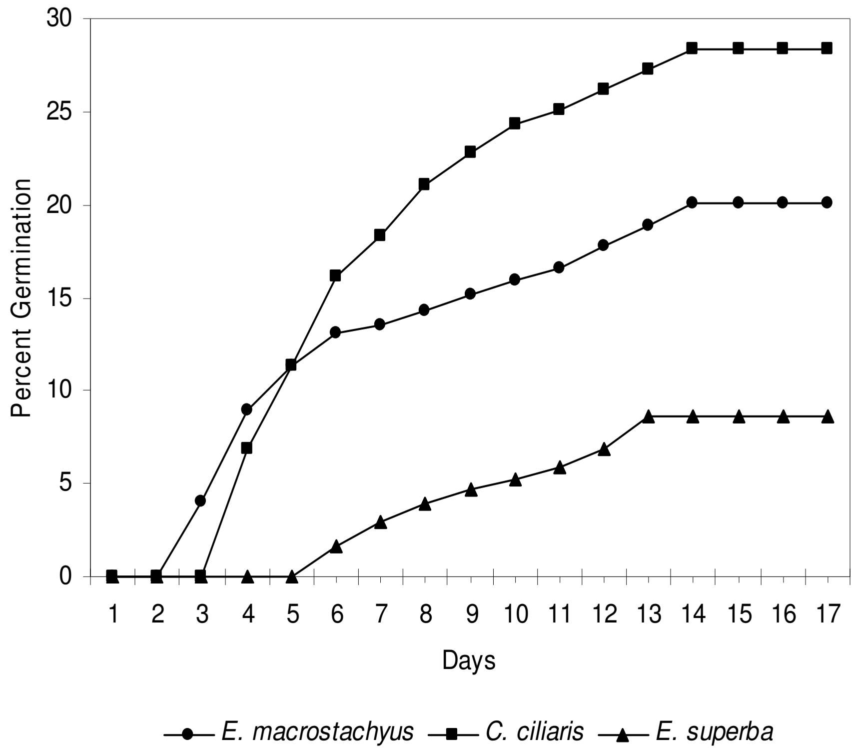


**Figure 3.** Percent seed germination of *E. macrostachyus*, *C. ciliaris* and *E. superba* under laboratory (25°C) conditions.

**Table 1.** Percent seedling mortality and foliage cover of three grass species in two land treatments within a period of twelve weeks.

| Species | (%) Seedling mortality | | (%) Foliage cover | |
|---|---|---|---|---|
| | Ripped | Hand-cleared | Ripped | Hand-cleared |
| *E. macrostachyus* | 15.4[a] | 20.5[b] | 46.2[a] | 20.1[b] |
| *C. ciliaris* | 10.5[a] | 18.2[b] | 65.8[b] | 31.4[c] |
| *E. superba* | 24.8[b] | 32.4[c] | 20.8[c] | 8.4[d] |

Means followed by different letter superscripts in the same column, and those with different letter superscripts in the same row are significantly different at $p<0.05$ as determined by LSD test.

mortality though not significantly lower ($p>0.05$) than that of *E. macrostachyus.* The results further revealed that percent seedling mortality of *E. macrostachyus* and *C. ciliaris* within the same seed bed preparation were not significantly different ($p<0.05$).

The seedling survival of all the three grass species were significantly higher ($p<0.05$) on ripped than on hand cleared seed bed plots. Similarly, mean percent foliage cover was significantly higher ($p<0.05$) in the ripped than in the hand-cleared plots. *C. ciliaris* had the highest percent foliage cover. *E. macrostachyus* and *E. superba* which had the lowest cover in both treatment plots were ranked second and third respectively.

***Plant height***

The weekly inventory showed that both land preparation methods influenced plant height. However, the mean grass height was significantly higher ($p<0.05$) in ripped plots than in the hand-cleared seed bed plot. At the end of 12 weeks of the experiment, *E. macrostachyus* had the tallest plants, followed by *C. ciliaris*, while *E. superba* was the shortest in the ripped treatment plots (Figure 4). In the ripped plots *C. ciliaris* (32.3 cm); *E. macrostachyus* (44.7 cm) and *E. superba* (18.5 cm) showed significant difference between their mean heights. Significant difference was similarly observed between *C. ciliaris* and

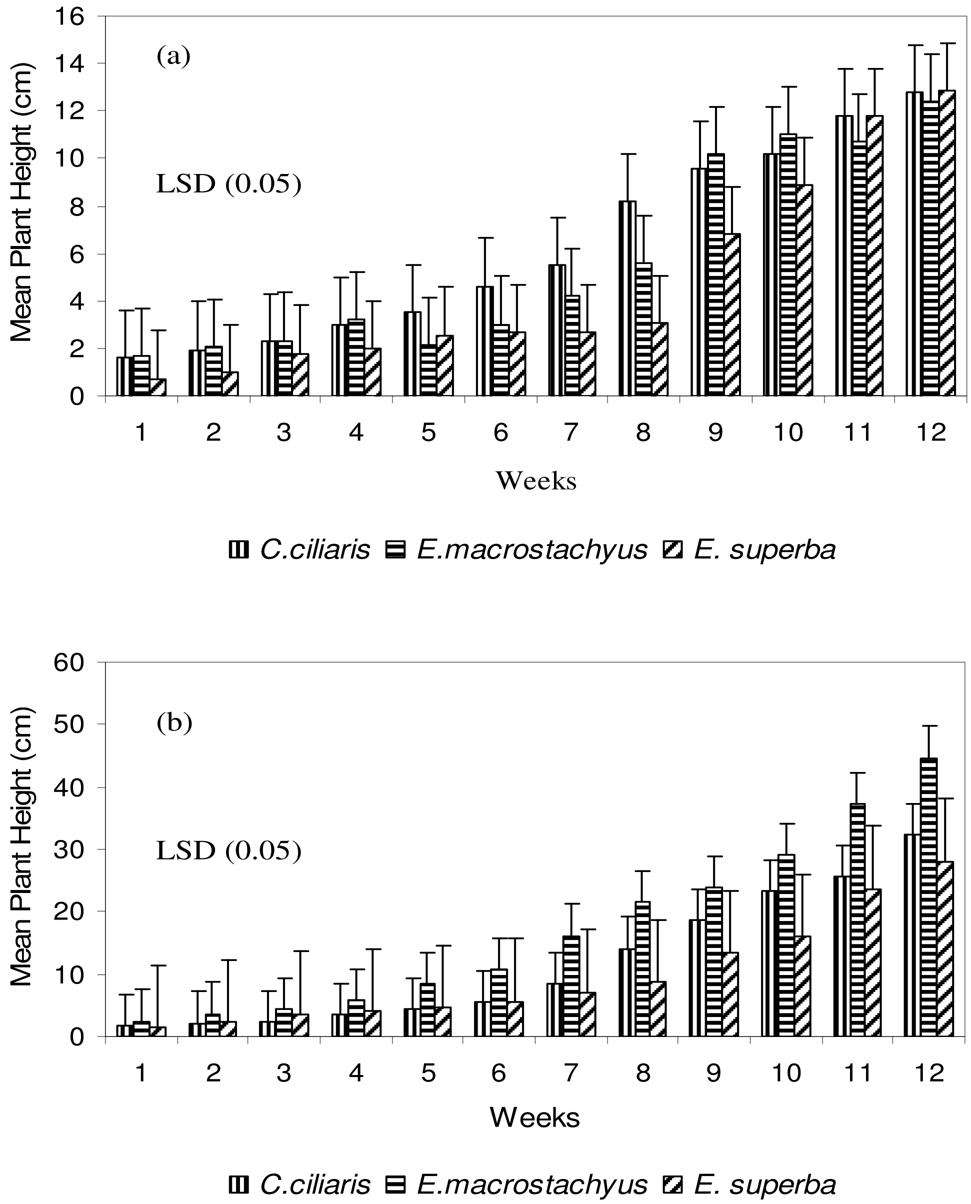


**Figure 4.** Mean plant height for three grass species in *(a)* hand-cleared and *(b)* ripped seed bed preparations.

*E. superba; E. macrostachyus* and *E. superba* in the hand-cleared plots.

### *Tillers*

There was a general increase in the number of tillers under the two seed bed preparations with time. The mean number of tillers was significantly ($p<0.05$) affected by the seed bed preparation (Table 2). The mean number of tillers was significantly higher ($p<0.05$) in ripped than in hand-cleared plots. Results also showed that ripped plots had the highest number of tillers, right from the first week up to the 12$^{th}$ week. However, in both treatment plots, *C. ciliaris* (7.2) had the highest mean number of tillers (7 tillers). *E. macrostachyus* (5.0) and *E. superba* (4.7) were ranked second and third respectively.

### *Leaves*

The effects of seed bed preparations on the mean

**Table 2.** Mean number of tillers per shoot, Mean number of leaves per shoot and aboveground biomass production (Kg DM ha$^{-1}$) of three grass species in ripped and hand-cleared plots.

| Species | Mean No. of tillers per shoot | | Mean No. of leaves per shoot | | Kg DM ha$^{-1}$ | |
|---|---|---|---|---|---|---|
| | Ripped | Hand-cleared | Ripped | Hand-cleared | Ripped | Hand-cleared |
| *E. macrostachyus* | 3.3(2.0)$^{a}$ | 2.3 (0.6)$^{b}$ | 4.6 (1.3)$^{a}$ | 4.1 (1.2)$^{b}$ | 4,908.5$^{a}$ | 3,682.5$^{b}$ |
| *C. ciliaris* | 4.6(1.1)$^{b}$ | 3.7 (1.0)$^{c}$ | 5.0 (1.2)$^{b}$ | 4.8 (1.1)$^{bc}$ | 3,734.0$^{b}$ | 2,213.0$^{c}$ |
| *E. superba* | 2.2(0.8)$^{c}$ | 1.5 (0.7)$^{d}$ | 3.4 (1.2)$^{c}$ | 2.8 (1.2)$^{d}$ | 2,434.5$^{c}$ | 1,899.5$^{d}$ |

Figures followed by different letter superscripts in the same row, and those with different letter superscript in the same column are significantly different at p<0.05 as determined by LSD test.

number of leaves are summarized in Table 2. Grasses in the ripped plots had significantly higher ($p<0.05$) number of leaves than those in the hand-cleared plots. However, the mean number of leaves were significantly different ($p<0.05$) among the three grass species. In both seed bed preparations, *C. ciliaris* (3.8) had the highest mean number of leaves, followed by *E. macrostachyus* (3.5) and *E. superba* (2.0) had the lowest. Total leaf counts for *C. ciliaris* and *E. macrostachyus* exhibited a general increase with time. This was not the case with *E. superba* which was leafy for the first four weeks, but became stemmy at the end of the 12$^{th}$ week of the study.

### *Aboveground biomass production*

Table 2 present's aboveground biomass production of *C. ciliaris, E. macrostachyus* and *E. superba* harvested from the two seed bed preparations. Ripped plots had significantly higher ($p<0.05$) aboveground biomass yield than hand-cleared plots. Although the tiller and leaf numbers of *C. ciliaris* were much higher than those of *E. macrostachyus* and *E. superba,* its aboveground biomass was significantly lower ($p<0.05$) than that of *E. macrostachyus*. In both treatment plots, *E. macrostachyus* had the highest mean biomass yield (3,682.5 to 4,908.5 Kg DM ha$^{-1}$), followed by *C. ciliaris* (2,213.0 to 3,734.0 Kg DM ha$^{-1}$), while *E. superba* had the lowest (1,899.5 to 2,434.5 Kg DM ha$^{-1}$) respectively in the hand-cleared and ripped plots.

## DISCUSSION

The differences observed among the grass species in terms of percent seed germination may be explained by the intrinsic properties of the grass seeds such as dormancy and tegumental hardness. Seed morphology, for example, the hairy bristle coat of the *C. ciliaris* fascicles is likely to have aided germination by maintaining a high humidity within the fascicle, thereby helping to reduce water loss from the caryopsis thus enhancing germination (Sharif-Zadeh and Murdoch, 2001). These fascicles are known to contain more than one caryopsis as shown in studies by Daehler and Georgen (2005). *C. ciliaris* seed dormancy mechanism may involve only the integument which allows water and gaseous exchange between the embryo and the micro-environment with subsequent embryo growth, while *E. macrostachyus* and *E. superba* may have embryo or both the embryo and integument related dormancy (Keya, 1997).

Poor and variable establishment of the grasses sown in hand-cleared seed beds compared to their establishment in ripped, reaffirms the problems of establishing perennial pastures species. Seedling mortality varied significantly between seed beds and species. Poor seedling survival in the hand-cleared plots was attributed to the failure of hand-cleared seed bed to harvest sufficient rain water. Seedling mortality of *C. ciliaris, E. macrostachyus* and *E. superba* were significantly higher in the hand cleared compared to the ripped seed beds. Results from this study closely compares with those reported by Njenga (1992), Adams and Danckwerts (1993), Oliver and Barapour (1996) under similar ecological conditions. Similar observations have also been made by Humphreys (1959), Hacker (1989), Neuteboom and Lantinga (1989), Skerman and Riveros (1990), Too (1995), and James et al. (2002) in different sites. In addition, studies by Synman (2003) and Kinyua et al. (2009) showed that ripping hard surface soil allows roots to penetrate deeply and extensively, placing roots in greater contact with scarce water held by soil particles. In this study, the relatively higher foliage cover, mean height, tiller and leaf numbers and biomass yield for the grass species in the ripped over in the hand-cleared plots is also attributable to the capture of the scarce water by the ripped seed bed.

Other than the effect of seed bed preparation on morphometric characteristics observed, results can also be attributed to the adaptation characteristics of the species as dictated by their genetic constitution. *E.*

*macrostachyus* produced taller plants, with more tillers, higher number of leaves and high percent seedling survival than *C. ciliaris* and *E. superba* in both the seed bed preparation methods. This may have been a survival strategy and a fitness-enhancing mechanism of the species in the ASALs. *E. macrostachyus* showed better performance in terms of pasture production among the three grasses used in this study. However, *C. ciliaris* produced more aboveground biomass than *E. superba*. Research studies (Mnene, 2005) show that *E. macrostachyus* exhibits drought resistance characteristics which might have favoured its survival. However, it was argued that high shoot/root ratio of *E. superba* (Taerum, 1977) which is a disadvantage to this grass might have caused high seedling mortality during this study.

Grass species with numerous tillers have a higher chance of contributing its genes to the next generation (Sarukhan et al., 1994). Results from this study suggest that *E. macrostachyus* would be at an advantage than *C. ciliaris* and *E. superba*. Others studies by Hacker (1989), Skerman and Riveros (1990) and Laidlaw (2005) showed that tillers are known to increases plant's chances of survival and amount of foliage cover. This concurs with the findings of this study, that grass species with highest number of tillers had also the highest percent foliage cover and low seedling mortality. In contrast, *E. superba* had the highest seedling mortality, lowest percent foliage and the least number of tillers. However, *E. macrostachyus* and *C. ciliaris* had relatively low percent seedling mortality and higher number of tillers. In addition, the high leaf numbers is known to be an important criterion for agronomists since it can indicate high growth rate. Plants with high leaf numbers and more pigmentation are likely to achieve a greater photosynthetic capacity resulting in fast growth of plants (Mnene, 2005). The leafy structure of plants, though suited for photosynthesis, is also conducive for a high water loss via transpiration. The experiment suggests that breaking the surface crust of semi-arid soils should be encouraged when reintroducing grass species in degraded sites by direct reseeding.

## Conclusion

Seed bed preparation affect morphometric characteristics of perennial grasses in semi-arid rangelands in Kenya. Ripping is a good seed bed preparation method compared to hand clearing as it enhances seedling survival, foliage cover, plants height, tiller and leaf number and aboveground biomass, thereby reducing the risk of rehabilitation failure. Results from this study are a good indicator of the expected performance and establishment of perennial grasses in semi-arid rangelands under different seed bed preparation methods. However, due to the short duration of this study, we recommend long-term monitoring, covering more than two seasons and using different perennial grasses to draw comprehensive conclusions and recommendations.

## ACKNOWLEDGEMENTS

This research was part of the first author's M.Sc. research at the University of Nairobi, Department of Land Resource Management and Agricultural Technology (LARMAT). The funds for the study were provided by the Integrated Natural Resource Management in Ukambani (INRMU) project, under the coordination of Jan Vaan De Abeele of the Belgian Technical Cooperation (BTC). The authors are also grateful for the valuable contribution on the manuscript by Mganga Zowe.

**Abbreviations: ASALs,** Semi-arid lands; **ICRISAT,** International Crops Research Institute for the Semi-arid Tropics; **RBD,** Randomized Block Design; **ANOVA,** analysis of variance; **LSD,** least significant difference.

### REFERENCES

Adams K, Danckwerts JE (1993). Regeneration of *Themeda triandra* in humid South African rangelands. Proceedings of the XVII International Grassland Congress.

Alemu DT, Nyariki DM, Farah O (2000). Changing land use systems and socio-economic roles of vegetation in semi-arid Africa: The case of the Afar and Tigrai of Ethiopia. J. Soc. Sci., 4: 199-206.

Belkhodja K, Manegene S, Njoroge SN, Nyariki DM, Oosteron AP (2003). Where pastures meet; a natural resource management study of the former Kitui Eastern Stateland, Kenya. Part 11: Draft Management Plan. Prepared for Integrated Natural Resource Management Project in Ukambani, Belgian Technical Co-operation (BTC), Kingdom of Belgium.

Bogdan AV, Pratt DJ (1967). Reseeding denuded pastoral land in Kenya. Republic of Kenya, Ministry of Agriculture and Animal Husbandry, Government Printers, Nairobi, pp. 1-46.

Chelishe EC, Kitalyi A (2002). Management of rangelands. Use of natural grazing resources in southern province, Zambia. Regional Land Management Unit-RELMA, Technical Handbook No. 28, Nairobi.

Daehler C, Georgen EM (2005). Experimental restoration of an indigenous Hawaiian grassland after invasion by buffel grass (*Cenchrus ciliaris*). Restor. Ecol., 13: 380-389.

Ego W, Kibet PFK (2003). Evaluation of the potential productivity of *Cenchrus ciliaris* in the semi-arid rangelands of Kenya. Proceedings of VII$^{th}$ International Rangelands Congress, 26th July - 1 August 2003. Durban, South Africa.

Ekaya WN, Kinyamario JI, Karue CN (2001). Abiotic and herbaceous vegetational characteristics of an arid rangeland in Kenya. Afr. J. Range For. Sci., 18: 117-124.

Hacker JB (1989). The potential for buffel grass renewal from seed in 16 years-old buffel grass-siratro pastures in south-east Queensland. J. Appl. Ecol., 26: 213-222.

Humphreys LR (1959). Studies on the germination, early growth, drought survival and field establishment of buffel grass (*Cenchrus ciliaris*) and of birdwood grass (*C. setigerus* Vahl) with particular reference to the Yalleroi district. J. Austral. Inst. Agric. Sci., 25: 321.

Jaetzold R, Schmidt H (1983). Farm management handbook of Kenya. Ministry of Agriculture, Kenya.

James TK, Rahman A, Webster T, Waller J (2002). Emergence of weeds as affected by vertical seed distribution in arable soils. NZ Plant Prot., 55: 213-217.

Jordan SM (1957). Reclamation and pasture management in the semi-arid areas of Kitui district, Kenya. East Afr. Agric. Forest. J., 25: 18-22.

Keya GA (1997). Effects of herbivory on the production ecology of perennial grass *Leptothrium senegalense* (Kunth.) in the arid lands of northern Kenya. Agric. Ecosys. Environ., 66: 101-111.

Kinyua D, McGeoch LE, Georgiadis N Young TP (2009). Short-Term and Long-Term Effects of Soil Ripping, Seeding, and Fertilization on the Restoration of a Tropical Rangeland. Restor. Ecol., 18(s1): 226–233.

Kitalyi A, Musili A, Suazo J, Ogutu F (2002). Enclosures to protect and conserve. For better livelihood of the West Pokot community. Technical Pamphlet No. 2. RELMA.

Koning RE (1994). Seeds and seed germination. Plant physiology information website http://koning.ecsu.ctstateu.edu/plants_human/seedgerm.html.

Laidlaw AS (2005). The relationship between tiller appearance in spring and contribution to dry-matter yield in perennial ryegrass (*Lolium perenne* L.) cultivars differing in heading date. Grass For. Sci., 60: 200-209.

Mbogoh SG, Shaabani SB (1999). Socio-economic study on characterization of recommendation domains for pasture improvement in pastoral and agro-pastoral production systems in Kenya. Part II Consultancy Report. KERI/EU ARSP II. KARI, Nairobi, Kenya.

Mganga KZ, Musimba NKR, Nyangito MM, Nyariki DM, Mwang'ombe AW (2010a). Improving hydrological properties of degraded soils in semi-arid Kenya. J. Environ. Sci. Technol., 4(3): 217-225.

Mganga KZ, Musimba NKR, Nyariki DM, Nyangito MM, Mwang'ombe AW, Ekaya WN, Clavel D, Francis J, Kaufmann R, Verhagen J, Muiru WM (2010b). Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in East Africa. Afr. J. Plant Sci., 4(5): 138-144.

Mnene WN, Hanson J, Ekaya WN, Kinyamarioa JI, Mweki P, Lall G, Stuth JW, Jamnadass RH (2005). Genetic variation between ecotypic populations of *Chloris roxburghiana* grass detected through RAPD analysis. Afr. J. Range Sci., 22: 107-115.

Mnene WN, Wandera FP, Lebbie SH (2000). Arresting environmental degradation through accelerated on site soil sedimentation and revegatation using micro-catchment and reseeding. Proceedings of the 3rd All Africa Conference on Animal Agriculture, Alexandria, Egypt.

Musimba NKR, Nyariki DM, Ikutwa CN, Teka T (2004). Dryland Husbandry for sustainable development in the southern rangelands of Kenya. OSSREA, Addis Ababa.

Neuteboom JH, Lantinga EA (1989). Tillering potential and relationship between leaf and tiller production in perennial ryegrass. Ann. Bot., 63: 265-270.

Ngugi RK, Nyariki DM (2003). Rural livelihoods in the arid and semi-arid environment of Kenya: Sustainable alternatives and challenges. Agric. Hum. Values, 22(1): 65-71.

Njenga FM (1992). The effect of land treatment and seeding methods on establishment of three range grasses in the semi-arid rangelands of Makueni District, Kenya. MSc Thesis, University of Nairobi, Kenya.

Oliver LR, Barapour MT (1996). Effect of tillage on *Senna obtusifolia* and *Xanthium strumarium* population, interference and seed bank. Proceedings 21st Annual Southern Conservation Tillage Conference for Sustainable Agriculture.

Reis RE, Svejcar TJ (1991). The grass seedling: When is it established? J. Range Man, 44: 574-576.

Sarukhan J, Martinez-Ramos M, Pinero D (1984). The analysis of demographic variability at the individual level and its population consequences. In: Sarukhan J and Dirzo R (eds) Perspectives on population ecology. Sinauer Associates Inc., Sunderland, Massachusetts, USA, pp. 141-165.

Sharif-Zadeh F, Murdoch AJ (2001). The effects of temperature and moisture on after-ripening *Cenchrus ciliaris* seeds. J. Arid Environ., 49: 823-831.

Skerman PJ, Riveros F (1990). Tropical grasses. Food and Agriculture Organization of the United Nations, Rome.

Snyman HA (2004). Soil seed bank evaluation and seedling establishment along a degradation gradient in a semi-arid rangeland. Afr. J. Range For. Sci., 21(2): 37-47.

Synman HA (2003). Revegetation of bare patches in a semi-arid rangeland of South Africa: An evaluation of various techniques. J. Arid Environ., 55: 417-432.

Taerum R (1977). A study on the growth and development of grasses with emphasis on their root system. PhD Thesis, University of Nairobi, Kenya.

Tarawali SA, Tarawali G, Larbi A, Hanson J (1995). Methods for evaluation of forage legumes, grasses and fodder trees for use as livestock feed. International Livestock Research Institute- ILRI.

Thomas DB, Barber RG, Moore TR (1981). Terracing of cropland in low rainfall areas of Machakos District, Kenya. J. Agric. Eng. Res., 25: 57-63.

Too DK (1995). Increasing primary production of Kenya Rangelands through bush control and grass seeding. PhD Dissertation. Colorado State University. Fort Collins, USA.

Van den Berg L, Kellner K (2005). Restoring degraded patches in a semi-arid rangeland of South Africa. J. Arid Environ., 61: 497-511.

Verdoodt A, Mureithi SM, Van Ranst E (2010). Impacts of management and enclosure age on recovery of the herbaceous rangeland vegetation in semi-arid Kenya. J. Arid Environ., 74: 1066-1073.

Visser N, Morris C, Hardy MB, Botha JC (2007). Restoring bare patches in the Nama-Karoo of South Africa. Afr. J. Range For. Sci., 24(2): 87-96.