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Full Length Research Paper

Dry matter yields and hydrological properties of three perennial grasses of a semi-arid environment in east Africa

Kevin Z. Mganga[1*], Nashon K. R. Musimba[1], Dickson M. Nyariki[1], Moses M. Nyangito[1], Agnes W. Mwang'ombe[2], Wellington N. Ekaya[3], Daniele Clavel[4], Judith Francis[5], Ralph von Kaufmann[6], Jan Verhagen[7] and William M. Muiru[2]

[1]Department of Land Resource Management and Agricultural Technology, University of Nairobi, P. O. Box 29053-00625 Nairobi, Kenya.
[2]Department of Plant Science and Crop Protection, University of Nairobi.
[3]Regional Universities Forum for Capacity Building in Agriculture (RUFORUM), Uganda.
[4]Agricultural Research for Developement CIRAD, France.
[5]Chicago Transit Authority (CTA), The Netherlands.
[6]Forum for Agricultural Research in Africa (FARA).
[7]Wagengen University, The Netherlands.

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***Enteropogon macrostachyus* (Bush rye)*, Cenchrus ciliaris* L. (African foxtail grass) and *Eragrostis superba* Peyr (Maasai love grass) are important perennial rangeland grasses in Kenya. They provide an important source of forage for domestic livestock and wild ungulates. These grasses have been used extensively to rehabilitate denuded patches in semi-arid environment of Kenya. This study investigated the dry matter yields and hydrological properties of the three grasses under simulated rainfall at three phenological stages; early growth, elongation and reproduction. Laboratory seed viability tests were also done. Hydrological properties of the three grasses were estimated using a Kamphorst rainfall simulator. Results showed that there was a significant difference (p > 0.05) in dry matter yields and soil hydrological properties at the different grass phenological stages. Generally, all the three grasses improved the soil hydrological properties with an increase in grass stubble height. *C. ciliaris* gave the best soil hydrological properties followed by *E. macrostachyus* and *E. superba*, respectively. *E. macrostachyus* recorded the highest seed viability percentage. *C. ciliaris* and *E. superba* were ranked second and third, respectively. *C. ciliaris* yielded the highest biomass production at the reproductive stage followed by *E. superba* and *E. macrostachyus*, respectively.**

Key words: *Cenchrus ciliaris*, *Enteropogon macrostachyus*, *Eragrostis superba*, rangeland.

INTRODUCTION

Rangelands in Africa are largely inhabited by the pastoral and agropastoral communities and cover 60% of the continent's land area (Nyangito et al., 2008). Most rangelands of Africa are characterized by high variability in rainfall (Kiringe and Okello, 2005). In these areas, livestock is the main livelihood source, where over 1.9 and 0.6 tropical livestock units (1 TLU is equal to an animal weighing 250 kg) per person per ha are realized in the pastoral and agropastoral areas, respectively (Nyangito et al., 2008).

Kenya's rangelands, which form the vast part of the Arid and Semi-Arid Lands (ASALs) cover over 80% of the total land surface (Herlocker, 1999; GoK/NAP, 2002). The semi-arid lands occupy approximately 30% of the total land area (Biamah, 2005). Rangelands in Kenya are significant as they are inhabited by over 25% of the

***Corresponding author. E-mail: kzowe@yahoo.com, kevinmganga@gmail.com.**

human population. Most of Kenya arid and semi-arid rangelands are however, generally characterized by low human population compared to the high potential areas (Kiringe and

Table 1. Agro-climatic zones of Kenya, excluding areas above 3000 m altitude.

Zone	R/E_o* (%)	Classification	R (mm)	E_o (mm)
I	> 80	Humid	1100-2700	1200-2000
II	65-80	Sub-humid	1000-1600	1300-2100
III	50-65	Semi-humid	800-1400	1450-2200
IV	40-50	S.humid - S.arid	600-1100	1500-2200
V	25-40	Semi-arid	450-900	1650-2300
VI	15-25	Arid	300-560	1900-2400
VII	< 15	Very arid	150-350	2100-2500

Notes: Source Biamah (2005), * R- Average rainfall; E_o- Average annual evaporation.

Okello, 2005). The main livestock types raised are cattle, sheep and goats. The number of animals per household varies a lot, but the overall means are: cattle 5; shoats 8. The main sheep breeds kept are the Red Maasai and Black Persian Head, while goat breeds are small east African and Galla. The main cattle breed is the small east African Zebu which is not native to the region; hence, has low resistance to drought and diseases. The Sahiwal and Boran exotic breeds and their crosses are kept but to a lesser extent (Musimba et al., 2004).

Livestock are important not only as sources of meat, milk and cash but also for manure and draught power. However, livestock production in semi-arid rangelands of Kenya is generally characterized by low productivity. This can be attributed to shortage of water and feed (Musimba et al., 2004) and human-induced rangeland degradation (Nyangito et al., 2008). The sources of degradation include inappropriate cultivation of marginal areas, deforestation and over-grazing. Increasing trends of land degradation in the grazing environment exacerbates low productivity. Productivity maybe in terms of primary production, that is, biomass yield or maybe translated to animal production through reduced and carrying capacity.

Soil erosion is the single most visible and notorious form of environmental degradation in the semi-arid rangelands of Kenya. Accelerated soil erosion occurs when vegetation cover is removed to facilitate soil loss from the forces of water and wind (Rietkerk et al., 2000; Nyangito et al., 2008). Ironically, it is also probably the most reversible, that is, the most responsive to restoration and rehabilitation.

Ecological restoration is the process of assisting recovery of an ecosystem that has been degraded, damaged or destroyed (Visser et al., 2007).

The general aims of restoration are, in most cases to increase vegetation cover, increase biodiversity and to increase production potential for improving grazing capacity (Visser et al., 2007). Previous studies have demonstrated that perennial vegetation can increase infiltration capacity (Broersma et al., 1995; Seobi et al., 2005; Nyangito et al., 2009).

Objectives of this study were: 1) to determine which of the three common perennial grasses in the semi-arid rangelands of Kenya was the most effective in improving soil hydrological responses, thus, reduce runoff and sediment production as a function of soil erosion and 2) to establish the dry matter yields of the same grasses at the three stages of grass growth and development, that is, early growth, elongation and reproduction stages. In this study, the three perennial grass species used were *Enteropogon macrostachyus, Cenchrus ciliaris* and *Eragrostis superba*.

MATERIALS AND METHODS

Study area

The experiment was carried out in the semi-arid district of Kibwezi; Kenya 200 km southeast of the capital city Nairobi, along the Nairobi-Mombasa highway. The Kamba agropastoralists are the main ethnic inhabitants in the study area (Nyangito et al., 2009).

The district lies between the latitudes 2º 6´ S and 3ºS, and longitude 37º36´ E and 38º30´ E, respectively, and has a total area of 3400 km² (CBS, 2000).

The most dominant soils in the Kenyan semi-arid areas are Luvisols, Lixisols, Acrisols, Alisols, Ferralsols, Planosols, Solonchaks, Solonetz, Vertisols and Fluvisols (FAO/UNESCO Classification) (Biamah, 2005). These semi-arid soils are considered problematic, because their physico-chemical properties limit the uses for agricultural purposes (Biamah, 2005). They generally have low organic matter contents and an unstable structure. The main problems associated with these soils are high levels of salinity and sodicity, poor drainage, soil erosion, soil compaction, soil crusting and low soil fertility (Biamah et al., 1994).

Surface crusting properties are enhanced by rainfall of high intensity and short duration that is prevalent in semi-arid Kenya (Biamah, 2005).

The climate is typical semi-arid and the district is representative of many other zones with similar ecological conditions throughout Kenya, characterized by low and unreliable soil moisture for plant growth. Semi-arid lands of Kenya occupy approximately 30% of the total land area and are classified into two agro-climatic zones (ACZ), IV and V, on the basis of the ratio of rainfall to open water evaporation (R/Eo) (Table 1) (Biamah, 2005).

The average annual rainfall, evaporation and temperatures are 600, 2000 mm and 23°C, respectively (Michieka and van der Pouw, 1977; Braunn, 1977). Due to its proximate position along the equator, the area experiences a bimodal pattern of rainfall with long rains from March - May and short rains from November – December. The short rains are more reliable in time than long rains and are therefore more important. According to Braunn (1977), there is a concentration of rainfall at the beginning of the long or short rains. Rainfall intensities are usually very high.

The distribution of the vegetation in the study area is controlled by a number of complex interrelated factors such as climate, geological formation, soil type and the presence or absence of ground water (Musimba et al., 2004). The natural vegetation is woodland and savanna, with several tree species, mainly *Acacia* sp (A) such as *Acacia tortilis* (Forsk) Hayne and *Acacia mellifera* (Vahl) Benth, *Commiphora africana* (A. Rich) Engl, *Adansonia digitata* Linn and *Tamarindus indica* L. Shrubs include *Apis mellifera, Apis senegal* (L) willd and *Grewia* spp. (Nyangito et al., 2009). Perennial grasses such as *C. ciliaris, E. macrostachyus* and *Chloris roxburghiana* can dominate but many succumb to continuous abuse over long periods. *E. superba* is also commonly found in the district (Musimba et al., 2004).

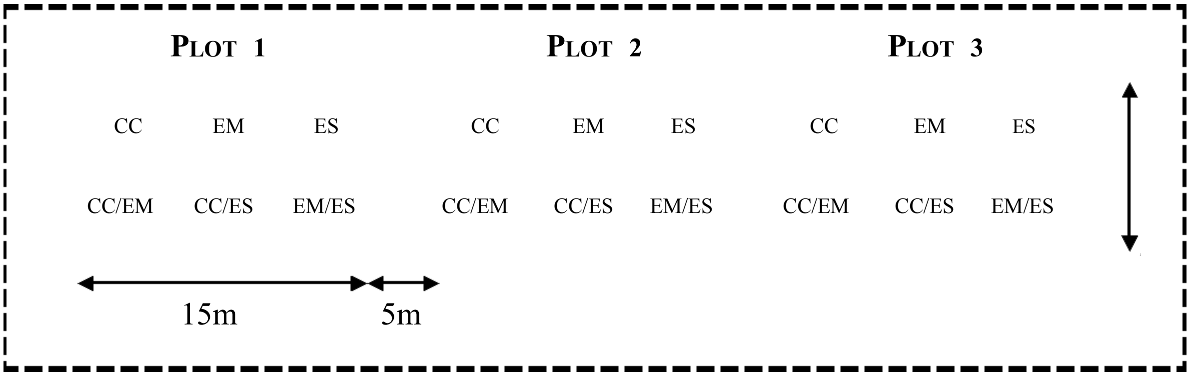

Figure 1. Experimental design of the plots.
CC-*Cenchrus ciliaris*, EM-*Enteropogon macrostachyus*, ES- *Eragrostis superba* and **.........** **-** Fence Line.

Seed viability tests by germination

Germination test as described by Tarawali et al. (1995) was used in the study. Random samples of 100 seeds of the three grass species bought from a farmer who practices grass reseeding in his farm were put on wet Whitman filter paper in a petri dish. The seeds used for the experiment were harvested in 2007. The petri dishes were then placed at room conditions (30°C) in the study area before the field experiment was carried out to establish the viability and germination potential of the seeds to be used. Another random sample of the same seeds was kept in an incubator at 20°C. The grass seeds that germinated everyday were counted and removed from the petri dishes. The seeds were monitored for 14 days. At the end of the 14 days, all germinated seeds were expressed as a per-centage of total number of seeds. Seeds which did not germinate within this period were considered dormant.

Site preparation and experimental design

Site preparation involved seed bed preparation, creation of shallow micro-catchments, approximately 15 cm in depth, setting up the sprinkler irrigation system (simulated rainfall) and fencing the experi-mental plots to prevent destruction from free grazing livestock in the study area. Soil disturbance plays an important role in the success rate of restoration attempts (Curtin, 2002; van den Berg and Kellner, 2005). Ox-driven ploughs were used to disturb the soil and create micro-catchments.

The experimental design was split into three blocks each with an area of 150 m^2 (15 x 10 m). Each block was further divided into six plots of 25 m^2 (5 x 5 m). The three blocks were horizontally separated from each other by a 5 m fire break (Figure 1). The experimental plots were fenced off using locally available *Acacia* branches to keep of free grazing livestock from trampling over the grass seedlings.

The seeds of the grasses were sown (September, 2008) along the created micro-catchments as pure stands; *C. ciliaris, E. macrostachyus* and *E. superba* and as two grass mixture; *C. ciliaris - E. macrostachyus*, *C. ciliaris - E. superba* and *E. macrostachyus - E. superba.*

Soil hydrological responses and sediment production

Simulated rainfall (Young et al., 1972) was used to investigate soil hydrological responses and sediment production of the three grasses at different grass stubble heights. Infiltration capacity ($mlmin^{-1}$) on 0.3 X 0.3 m plots of the perennial grasses at the different stubble heights was measured using a Kamphorst Rainfall Simulator (Kamphorst, 1987). 2.08 cm of water was applied each time (Each simulation consisted of a rain shower of 5 min with an intensity of 375 $mlmin^{-1}$) (Rietkerk et al., 2000). This was again repeated after five minutes to ensure runoff. All simulations were done when the soil was near field capacity.

Runoff was collected from each plot, decanted and weighed. Infiltration capacity was calculated by subtracting runoff from amount of simulated rainfall applied. The sediment produced was washed into storage bottles and dried at 105°C in an oven for 24 h to evaporate all the soil moisture. The dried soil was converted to sediment produced in kg/ha. This index of sheet erosion and calculated as:

Sediment production (kg/ha) = (Sediment collected × Area) / Plot area

Vegetation sampling

Biomass production of the three grasses was estimated using the quadrat method of vegetation sampling. A 0.5 × 0.5 m quadrat was used. Destructive sampling techniques of clipping were used. Clipping was done at a stubble height of 2.5 cm in the quadrat in each plot. Six quadrats were placed at each sub-plot. The har-vested biomass was placed in sealed brown paper bags and oven dried at 80ºC for 96 h to remove the moisture and weighted to estimate dry matter yields (kg/ha). Biomass was collected at grass stubble heights of 15 cm (Early Growth), 30 cm (Elongation) and 60 cm (Reproduction). This was done after two, four and six months, respectively, after sowing (September, 2008).

Statistical analyses

Dry matter yields and soil hydrological responses of the three grasses at the different grass stubble heights were compared using One-Way Analysis of Variance and means separated using Tukey's-b. Mean comparison were performed at $p < 0.05$. The Statistical Package for Social Sciences (SPSS) (Einstein and Abernethy, 2000) computer program was used to analyzed data.

RESULTS AND DISCUSSIONS

The results showed that there was a difference in seed germination between the three grass species tested. Under room ambient temperatures in the study area,

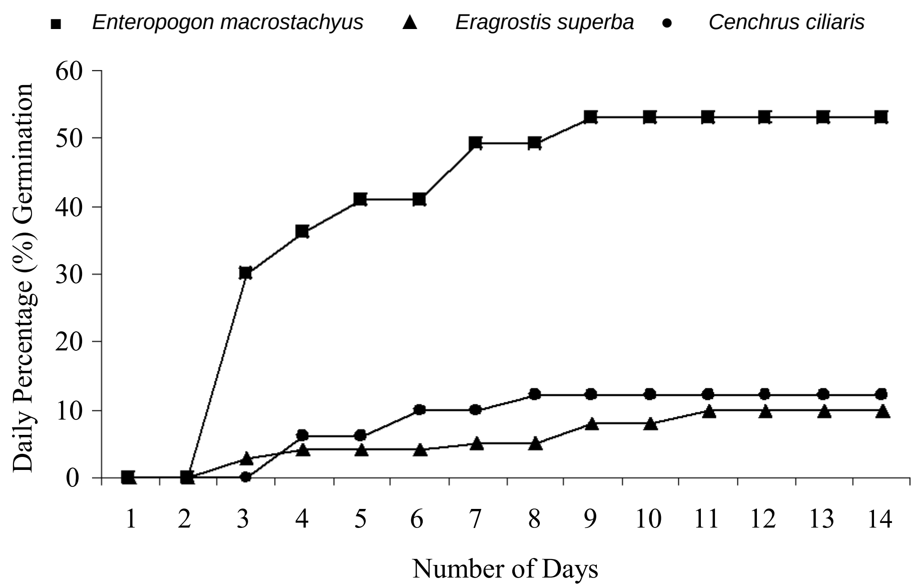

Figure 2. Daily percentage seed germination of *Enteropogon macrostachyus, Eragrostis superba* and *Cenchrus ciliaris* at 30°C in the study area.

where temperatures were at an average of 30ºC, the seeds of *E. macrostachyus* had the highest germination of 53%. The percent seed germination for *C. ciliaris* was 12% while *E. superba* had the lowest percent germination of 10%.

Under controlled laboratory conditions, at 20ºC after 9 months, results also showed differences in seed germination. Seeds of *E. macrostachyus* had the highest germination of 85%. The percent seed germination for *C. ciliaris* was 40%, while *E. superba* had the lowest percent germination of 21%. Results of the daily percentage seed germination of the three grass species under room conditions and under controlled conditions are illustrated in Figures 2 and 3.

The differences observed among the grass species in terms of percent seed germination can be explained by the intrinsic properties of the seeds such as dormancy and integumental hardness, and climatic factors especially ambient temperatures. Poor initial germination percentages may be attributed to the high hygroscopic nature of most seeds of range grasses. Dry seeds, particularly those of rangeland grasses are known to be highly hygroscopic (Ernest and Tolsma, 1988) and exposure of dry seeds to moisture has been reported to worsen the dormancy and often leads to fungal infection (Chin and Hanson, 1999; Tweddle et al., 2003).

Higher percent seed germination of *E. macrostachyus* may be explained by its dormancy mechanism which involves only the integument while the other two species may have both the embryo and/or the integument related dormancy (Bryant, 1985). The hairy bristle coat of the *C. ciliaris* fascicles is likely to have also aided its germination by maintaining a high humidity within the fascicle and thereby help reduce water loss from the caryopsis thus enhancing germination (Cook and Dolby, 1981; Silcock and Smith, 1982; Sharif-Zadeh and Murdoch, 2001) as compared to that of *E. superba.* Faster seed germination is highly desirable under field conditions since it gives the seedlings a head start in the normal plant competition (Kadmon and Schimida, 1990; Keya, 1997). The faster a seed moves from the seed and seedlings stages, the higher the chances for its survival and subsequent establishment if there is no selective predation (Ernest and Tolsma, 1998; Chin and Hanson, 1999).

It is therefore, expected that *E. macrostachyus* to have better seedling survival and establishment compared than *C. ciliaris* or *E. superba.* However, the delay in imbibitions could be advantageous in areas where initial storms are followed by a long dry spells. In such environ-ments, delayed imbibitions could cause fewer seedlings to be affected by the drought. On the other hand, species with delay germination are at a disadvantage since the rains would end while the seedlings are still young. Grasses differed in the infiltration capacity (cm^3), runoff (cm^3) and sediment production (kg/ha) at various grass stubble heights (Tables 2, 3 and 4).

Previous studies have demonstrated that perennial vegetation can increase infiltration capacity (Wood, 1977; Broersma et al., 1995; Seobi et al., 2005). Nyangito et al. (2009) also observed higher infiltration capacity in sites dominated by *E. macrostachyus* than those dominated by *E. superba*, while working with the same grasses in Kibwezi district. Reduced infiltration capacity may lead to low soil water recharge and low soil water availability, precipitating soil water limitations on plant growth and thus, negatively affecting plant ecosystem regulatory

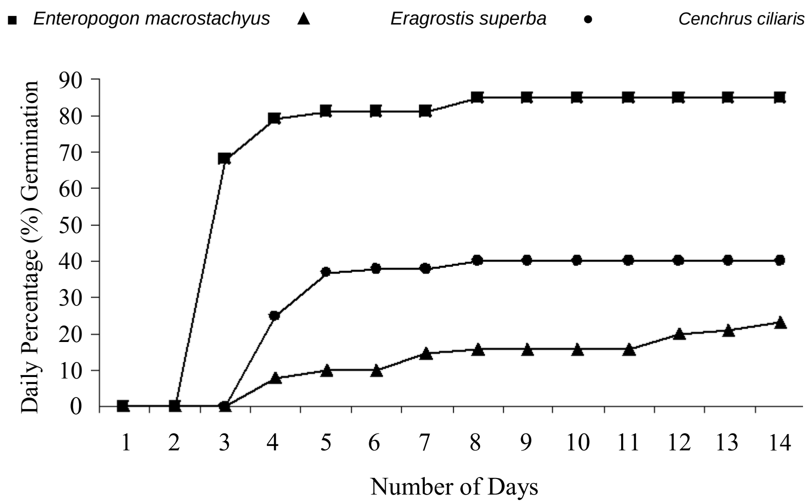

Figure 3: Daily percentage seed germination of *Enteropogon macrostachyus, Eragrostis superba* and *Cenchrus ciliaris* under controlled conditions, 20ºC, throughout the study period.

Table 2. Effect of different grass stubble heights on infiltration capacity (cm^3).

Height (cm)	Infiltration capacity (cm^3)		
	CC	EM	ES
0	1047^{a}	1047^{a}	1047^{a}
20	1530^{b}	1413^{b}	1067^{a}
40	1883^{c}	1760^{c}	1513^{b}

Notes: CC-*Cenchrus ciliaris,* EM-*Enteropogon macrostachyus,* ES-*Eragrostis superba.* Column means with different superscripts are significantly different at $p < 0.05$.

Table 3. Effect of different grass stubble heights on runoff (cm^3).

Height (cm)	Runoff (cm^3)		
	CC	EM	ES
0	953 ^{a}	953 ^{a}	953^{a}
20	470 ^{b}	587^{b}	933^{a}
40	117 ^{c}	240^{c}	487^{b}

Notes: CC- *Cenchrus ciliaris,* EM -*Enteropogon macrostachyus,* ES-*Eragrostis superb*. Column means with different superscripts are significantly different at $p < 0.05$.

Table 4. Effect of different grass stubble heights on sediment production (kg/ha).

Height (cm)	Sediment production (kg/ha)		
	CC	EM	ES
0	4614.27^{a}	4614.27^{a}	4614.27^{a}
20	675.45^{b}	1178.45^{b}	1677.21^{b}
40	41.12^{b}	122.84^{b}	320.85^{c}

Notes: CC-*Cenchrus ciliaris,* EM-*Enteropogon macrostachyus,* ES -*Eragrostis superba*. Column means with different superscripts are significantly different at $p < 0.05$.

services (Yates et al., 2000; Nyangito et al., 2009).

Grasses with higher and lower infiltration capacities gave lower and higher runoffs, respectively. Nyangito et al. (2009) reported similar results under natural pastures. *C. ciliaris* yielded the lowest runoffs followed by *E. macrostachyus* and *E. superba* respectively. This could be attributed to the growth and morphological characteristics of the grasses, given that, the soil type in the site was similar. *C. ciliaris* is densely leafed with branching culms arranged in a funnel shape. The grass is also relatively broad leafed.

These characteristics presents a greater surface area for collecting water and rain drops that is concentrated more into its rhizosphere. *E. macrostachyus*, though narrow leafed, tends to be leafy than steamy especially at its base, therefore, closely compares with *C. ciliaris* in trapping water. In contrast, *E. superba* is stemmier and thus, less effective in concentrating rain water into their rhizosphere.

There was a general decline in sediment production with an increase in grass height. This can be attributed to the reduction of the force of water drops hitting and destabilizing the soil structure. Generally, vegetation cover intercepts rainfall kinetic energy and thereby, decreases the mobilization of soil particles. The taller grasses trap more water drops and funnel it down its crown thus, concentrating more water around the rhizosphere compared to the shorter grasses. The larger leaf blades also reduce

Table 5. Dry matter yields of the three grasses at different stubble heights.

Plot	Dry matter yields, kg/ha (DM)		
	15 cm	**30 cm**	**60 cm**
CC	44.2[a]	104.2 [a]	1026.6[b]
EM	83.9[a]	168.0[a]	744.0[b]
ES	47.0[a]	109.8[a]	896.5[b]
CC/EM	32.0[a]	144.0[a]	780.9[b]
CC/ES	43.4[a]	169.2[a]	808.3[b]
EM/ES	59.0[a]	164.8[a]	709.3[b]

Notes: CC- *Cenchrus ciliaris*, EM- *Enteropogon macrostachyus*, ES- *Eragrostis superba.*

the force of the water drops directly hitting the ground.

This improves infiltration capacity and reduces runoff thus, less sediment production. Row means with different superscripts are significantly different at $p < 0.05$, 15 cm (Early Growth Phase), 30 cm (Elongation Phase), 60 cm (Reproduction Phase). There was a significant difference ($p < 0.05$) in dry matter yields for the 60 cm height compared to the other two stubble heights in all the grasses (Table 5). The difference in biomass yields in plots under pure grass stands across the different grass stubble heights and can be attributed to the growth characteristics and morphological properties of the grasses. Higher biomass yields of *E. macrostachyus* at average heights of 15 cm (Early Growth) and 30 cm (Elongation) can be attributed to its faster seed germination giving its seedlings a head start in the normal plant competition (Kadmon and Schimida, 1990).

E. macrostachyus moves faster through the initial growth stages compared to *E. superba* and *C. ciliaris.*

Higher grass yields of *E. superba* and *C. ciliaris* at an average height of 60 cm (Reproduction) compared to that of *E. macrostachyus* can be attributed to the stemmier nature of both *C. ciliaris* and *E. superba. E. macrostachyus* is less stemmy. *C. ciliaris* had a higher dry matter yields than *E. superba* because it is leafier.

The results showed that above-ground biomass production of the three grass species used were different. This is comparable to the results of Chelishe and Kitalyi (2002) who reported that these grass species have different above-ground biomass yields. These results of dry matter yields were however, much lower compared to the yields of the same grass species under the same land treatment under rainfall as reported by Opiyo (2007) working in neighbouring Kitui district. Biomass yields of 4908.5, 3734 and 2434.5 kg/ha for *E. macrostachyus*, *C. ciliaris* and *E. superba*, respectively, were reported by Opiyo (2007). This confirms what Reichenberger and Pyke (1990) earlier observed that rangeland grasses are known to yield various quantity of fodder depending on the prevailing environmental conditions.

The differences in biomass yields in plots under two grass mixtures can also be attributed to their growth characteristics, morphological and physiological properties and competitive advantage of the individual grass species constituting the mixture.

Conclusions

There was a general improvement in soil hydrological properties with an increase in grass stubble height. That is, there was a general increase in infiltration capacity and reduction in runoff and sediment production with an increase in grass stubble heights in all the three grasses. However, results from this study suggest that *C. ciliaris* is the best in improving soil hydrological properties. *E. macrostachyus* and *E. superba* were ranked second and third, respectively.

Pure stands as opposed to two grass mixtures give better dry matter yields in all the three grass species used. *C. ciliaris* give better dry matter yields compared to *E. superba* and *E. macrostachyus* which were ranked second and third, respectively. Furthermore, results from this study also suggest that *C. ciliaris* is more competitive than *E. superba* and *E. macrostachyus* due to its allelopathic nature.

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