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Improving Hydrological Responses of Degraded Soils in Semi Arid Kenya

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Abstract: A study was conducted to establish the contribution of reseeding using indigenous perennial grasses; *Eragrostis superba* (Maasai love grass), *Enteropogon macrostachyus* (Bush rye) and *Cenchrus ciliaris* (African foxtail grass) in improving soil hydrological properties and thus controlling soil erosion in the degraded areas of Kibwezi district, Kenya. The experiment was carried out using simulated rainfall, Kamphorst simulator, on bare ground and at different grass stubble heights. The experimental plots were set up under sprinkler irrigation controlled conditions to ensure availability of sufficient moisture for seed germination and subsequent establishment. Results showed that sediment production as a function of runoff and infiltration capacity was significantly different ($p<0.05$) at different grass stubble heights. *Cenchrus ciliaris* had the greatest influence on improving soil hydrological properties. *Enteropogon macrostachyus* and *Eragrostis superba* were ranked second and third, respectively. This was attributed to the growth characteristics of the perennial grasses. Generally, an increase in grass height increased infiltration capacity, reduced runoff and sediment production.

Key words: Reseeding, semi-arid, soil hydrological properties, sediment production

INTRODUCTION

The Arid and Semi Arid Lands (ASALs) cover approximately 80% of Kenya's landmass and support over 30% of Kenya's human population, over 50% of cattle, 70% of sheep and goats and nearly 100% of camels and wild ungulates. The ASALs of Kenya have undergone increasingly land use pressure within the last 15 years, largely due to human population increase causing a decline in forage resources and threatened the sustainability of land based production systems (Kitalyi *et al.*, 2002).

Demands placed on land and water resources in these fragile ecosystems by rapidly expanding populations, through agricultural intensification, urbanization and industralisation have combined to intensively exploit the natural resources in these semi-arid environments. This has resulted to land degradation which manifests in forms of impoverishment and depletion of vegetation cover, loss of biophysical and economic productivity, wind and

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water erosion, salinization and deterioration of physical, chemical and biological soil properties. Although, land degradation occurs under a wide variety of conditions and environments, semi-arid to weakly aridic areas of Africa are particularly vulnerable as they have very fragile soils and degradation is evident in a decline in productivity, a loss of biodiversity and an increasing rate of soil erosion (Visser *et al*., 2007).

Soil erosion is the single most visible form of environmental degradation in the semi-arid environment of Southeastern Kenya. Ironically, it is also the most reversible, that is, the most responsive to restoration and rehabilitation. Past experiments in range management and rehabilitation in Kenya suggest that many of the degraded areas, if fenced and protected, are likely to recover rather quickly and dramatically (Musimba *et al*., 2004). However, the ecological stresses in these dryland ecosystems, especially low and unpredictable rainfall amounts are so acute that ecosystem recovery through the process of natural secondary succession is likely to be low, thus would require some external input such as reseeding of native grass species to accelerate the rehabilitation process.

According to Musimba *et al*. (2004), the grasses that have given best results in East Africa are all native grasses. Perennial range grasses have evolved adaptive mechanisms for survival and are thus preferable to all other plants, except in eco-climate zone VI where the rainfall is low to support perennials giving way to annual grasses. Six grass species with high potential for reseeding various ASALs include: *Cynodon dactylon* (Star grass), *Cenchrus ciliaris, Enteropogon macrostachyus, Eragrostis superba, Chloris roxburghiana* (Horsetail grass) and *Chloris gayana* (Rhodes grass).

The primary purpose of range reseeding is to improve existing ground cover and biomass to an extent not possible by grazing management alone (Makokha *et al*., 1999). Range reseeding involves reseeding denuded land by the seeds of superior plants or the establishment of completely new pastures, with or without the aid of irrigation. During the 1950's and 1960's, a number of techniques were developed and introduced for rangeland rehabilitation. Some had the options of pitting and reseeding or over-sowing (Mnene, 2006).

Some techniques were tried in several districts such as Machakos, Taita-Taveta, Baringo and Kitui. Much later, Bekure *et al*. (1991) demonstrated some of the approaches in Kajiado district, but it was observed that unless pastoralists had control over the land, it was only possible to undertake pasture improvement within the confines of reserve grazing areas. Such techniques are used to reduce runoff and sediment production, thus improving soil hydrological processes. This in turn conserves water and improves soil fertility with the addition of organic matter. The aim of this study was to determine the impact of grass reseeding technology in improving soil hydrological properties of a degraded semi-arid environment using *Enteropogon macrostachyus, Cenchrus ciliaris* and *Eragrostis superba*.

MATERIALS AND METHODS

Study Area

The experiment was carried out in Kikumbulyu location, Kibwezi division in the semi-arid district of Kibwezi, Kenya. The division is located about 200 km Southeast of the capital city Nairobi, along the Nairobi-Mombasa highway. The altitude of the area varies from 600 to 1100 m a.s.l. (Musimba *et al*., 2004). This research project was conducted from 2007 to 2009.

The Kamba agropastoralists are the main ethnic inhabitants in the study area (Nyangito *et al*., 2009). The district lies between the latitudes $2^\circ\ 6^1$ S and 3°S and longitude $37^\circ 36^1$ E and $38^\circ 30^1$E, respectively and has a total area of 3400 km^2 (CBS, 2000). The most dominant soils in the semi-arid area 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 their use for agriculture (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 fertility. Surface crusting properties are enhanced by rainfall of high intensity and short duration that is prevalent in semi-arid Kenya (Biamah, 2005).

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* sp. (Nyangito *et al*., 2009). Perennial grasses such as *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Chloris roxburghiana* can dominate but many succumb to continuous abuse over long periods. *Eragrostis superba* is also commonly found in the district (Musimba *et al*., 2004).

The climate is typical semi-arid and the district is representative of many other zones with similar ecological conditions throughout Kenya, characterised by low and unreliable supply of enough moisture for plant growth. The average annual rainfall, evaporation and temperatures are 600, 2000 mm and 23°C, respectively (Michieka and van der Pouw, 1977; Braunn, 1977). Because of its proximate position along the equator, the area experiences a bimodal pattern of rainfall with long rains from March to May, with the peak in April and short rains from November to December, with the peak in November. 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.

Seed Viability Tests by Germination

Germination test as described by Tarawali *et al.* (1995) was used in this study. Random samples of 100 seeds of the three grass species, *Cenchrus ciliaris, Enteropogon macrostachyus* and *Eragrostis superba* were put on wet Whitman filter paper in a petri dish. The petri dishes were then placed at room temperature (30°C) in the study area at the start of the experiment. The same seeds were also tested for germination in an incubator at 20°C after nine months. 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 percentage of total number of seeds. Seeds which did not germinate within this period were dimmed dormant.

Site Preparation and Experimental Design of Reseeded Plots

Site preparation involved the clearing of the bush, creating micro-catchments using a disc ploughing and setting out of the sprinkler irrigation system. Micro-catchments were created by the disc plough to promote better germination of seeds and establishment of seedlings (Visser *et al*., 2007). The experimental design was split into three main plots of 75 cm^2 (15×5 m). The plots were further divided into three sub-plots of 25 cm^2 (5×5 m^2). The three main plots were separated from each other by 5 m spacing. The following treatments were systematically assigned to the three sub-plots within each plot: *Cenchrus ciliaris*, *Enteropogon macrostachyus* and *Eragrostis superba*. The grass seeds were then hand sowed along the created microcatchments to correspond with each treatment. The seeds were covered with a light amount of soil and irrigated to maintain the soil moisture level at near field capacity.

Determining the Application Rate of the Sprinkler Irrigation System

Six cylindrical containers of the same diameter were spaced at an even interval in a line running away from a sprinkler. The last container was placed near the end of the area of coverage. The area was then irrigated for 1 h. The water depths in all the six containers were added and divided by the number of containers (six) to find the number of inches applied per hour. This was the application rate. The duration of application was however adjusted from time to time according to the prevailing environmental conditions and the use of plant indicators to ensure that the soil was maintained at near field capacity and prevent the grass seedlings from wilting. The sprinkler irrigation system application rate was 230 cm^3 h^{-1} (0.638 cm^3 sec^{-1}).

Soil Hydrological Responses and Sediment Production Measurements

The following parameters were recorded in each of the 5×5 m sub-plot: infiltration xxcapacity, runoff and sediment production. The test sub-plots were wetted to near field capacity in the evening using the sprinkler irrigation system to reduce evaporation loss and maintain uniform soil surface water content. Simulated rainfall (Young and Burwell, 1972) was used to study soil hydrological responses and sediment production in all the sub-plots. Infiltration capacity in all the sub-plots at different grass stubble heights was measured using the Kamphorst Rainfall simulator (Kamphorst, 1987). Each simulation consisted of a rain shower of 5 min with an intensity of 375 mL min^{-1} (6 mm min^{-1}) (Rietkerk *et al.*, 2000). The simulations were done in triplicate for each grass species at different stubble heights. From each simulation, runoff was collected and decanted and weighed. The infiltration capacity was calculated by subtracting the runoff from the amount of rainfall applied.

$$\text{Infiltration capacity (cm}^3\text{)} = \text{Simulated rainfall-Total runoff collected}$$

The sediment produced was washed into storage bottles and later filtered off and dried at 105°C for 24 h. The amount produced was converted into sediment yield in kg ha^{-1}. This was used as an index for sheet erosion as given in the equation below (Nyangito *et al.*, 2009).

$$\text{Sediment production (kg ha}^{-1}\text{)} = \frac{\text{(Sediment produced}\times\text{Area)}}{\text{Plot area}}$$

Sediment production and infiltration rates were estimated at different grass stubble heights of 0 cm (bare ground), 20 and 40 cm.

RESULTS

Seed Viability Tests by Germination

The results showed that there was a difference in seed germination between the three grass species tested. Under room conditions (at an average of 30°C) seeds of *Enteropogon macrostachyus* had the highest germination percentage (53%). Percent germination for *Cenchrus ciliaris* and *Eragrostis superba* was 12 and 10%, respectively. A repeat of the

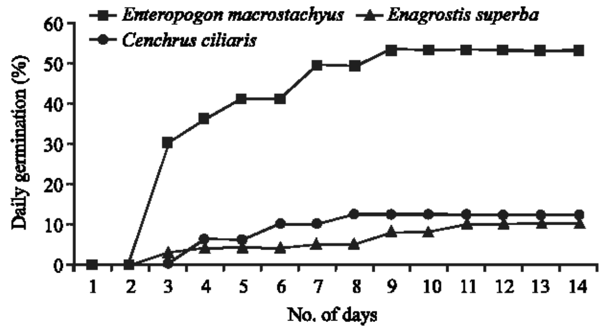

Fig. 1: Daily percentage seed germination of *Enteropogon macrostachyus, Eragrostis superba* and *Cenchrus ciliaris,* under room conditions (30° C) in the study area

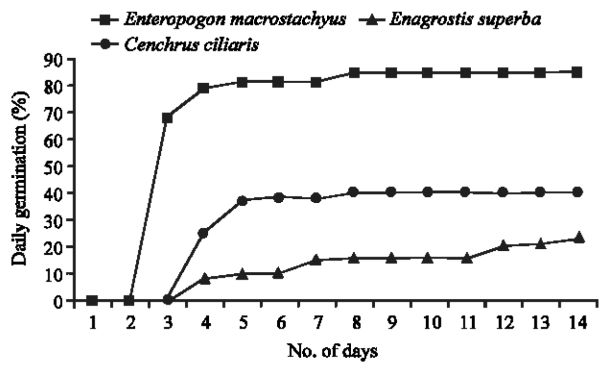

Fig. 2: Daily percentage seed germination of *Enteropogon macrostachyus, Eragrostis superba* and *Cenchrus ciliaris* under controlled conditions (20°C), after 9 months

same experiment under controlled laboratory conditions, at 20°C after 9 months also showed differences in seed germination between the three grass species. Seeds of *Enteropogon macrostachyus* had the highest germination of 85%. Percent seed germination for *Cenchrus ciliaris* and *Eragrostis superba* was 40 and 21%, respectively. Percent germination was an indicator of grass seeds viability and capability of producing normal plants under suitable germination conditions. Results of the daily percentage seed germination of the three grass species under room temperatures in the study area at the start of the experiment and under controlled conditions after 9 months are shown in Fig. 1 and 2.

Soil Hydrological Responses and Sediment Production Measurements

The infiltration capacity (cm^3), runoff (cm^3) and sediment production (kg ha^{-1}) of the three grass species using the Kamphorst rainfall simulator at various grass heights are shown in Table 1-3.

Across stubble heights, *Cenchrus ciliaris* gave the highest infiltration capacity (Table 1). *Enteropogon macrostachyus* and *Eragrostis superba* were ranked second and third, respectively. At 20 and 40 cm stubble heights, *Cenchrus ciliaris* gave a significantly higher infiltration capacity than *Enteropogon macrostachyus* and *Eragrostis superba.* Across stubble heights, *Cenchrus ciliaris* gave the lowest runoff (Table 2). *Enteropogon macrostachyus* and *Eragrostis superba* were ranked second and third, respectively. At

Table 1: Effect of different grass stubble heights on infiltration capacity (cm^3)

	Infiltration capacity (cm^3)		
Height (cm)	CC	EM	ES
0	1047 ± 0^a	1047 ± 0^a	1047 ± 0^a
20	1530 ± 65.57^b	1413 ± 32.15^b	1067 ± 30.55^a
40	1883 ± 25.17^c	1760 ± 55.68^c	1513 ± 70.95^b

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

Table 2: Effect of different grass stubble heights on volume of runoff (cm^3)

	Runoff (cm^3)		
Height (cm)	CC	EM	ES
0	953 ± 0^a	953 ± 0^a	953 ± 0^a
20	470 ± 65.57^b	587 ± 32.15^b	933 ± 30.55^a
40	117 ± 25.17^c	240 ± 55.68^c	487 ± 70.95^b

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 sediment production (kg ha^{-1})

Grass stubble height (cm)	Sediment production (kg ha^{-1})
0	3476 ± 1996^a
20	1178 ± 1010^b
40	652 ± 957

Column means with different superscripts are significantly different at $p<0.05$

20 and 40 cm stubble heights, *Cenchrus ciliaris* gave a significantly lower runoff than *Enteropogon macrostachyus* and *Eragrostis superba*. There a general decline in sediment production with an increase in stubble height (Table 3).

DISCUSSION

Seed Viability Tests by Germination

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). Fungal growth was evident although no data were collected on grass seed infection. However, the individual grass species ability to withstand moisture stress varies between species.

Higher percent seed germination of *Enteropogon 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 *Cenchrus ciliaris* fascicles is likely to have aided its higher germination by maintaining a high humidity within the fascicle and thereby help reduce water loss from the caryopsis (Cook and Dolby, 1981; Silcock and Smith, 1982; Sharif-Zadeh and Murdoch, 2001) compared to that of *Eragrostis superba*.

Differences in germination percentages under controlled and room conditions in similar studies can generally be attributed to various factors including seed preparation and storage, age of the seeds used and environmental conditions especially temperatures.

Fast 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, 1988; Chin and Hanson, 1999). It is therefore expected that *Enteropogon macrostachyus* could have the best seedling survival and establishment compared to *Cenchrus ciliaris* and *Eragrostis superba*. However, the observed delay in imbibition is also advantageous in that in areas where rainfall patterns are such that initial storms are followed by a long dry spell, there could be fewer seedlings affected by the following drought. In contrast, species with delayed germination into the growing season are at a disadvantage since the rains could end while the seedlings are still too young. Grass seeds have the best germination results when planted into a well prepared seed-bed since germination is usually spread over several rainfall events (Andrew and Mott, 1983; Fregeau and Burrow, 1989).

Soil Hydrological Responses and Sediment Production Measurements

From the sprinkler irrigation application rate used (0.638 mL sec^{-1}) minimum runoff was observed. This was attributed to the higher infiltration rates of the soil (3.49 mL sec^{-1}) compared to the application rate of the irrigation system. 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 *Enteropogon macrostachyus* than those dominated by *Eragrostis superba*, while working with the same grasses in Kibwezi district. Nyangito *et al*. (2009) reported much higher infiltration capacities compared to the results in this study. This can be attributed to the higher densities of the already established ungrazed grass swards used in their study. 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 services (Nyangito *et al*., 2009).

Grasses with higher and lower infiltration capacities gave lower and higher runoffs, respectively. Nyangito *et al.* (2009) reported similar results. *Cenchrus ciliaris* yielded the lowest runoffs followed by *Enteropogon macrostachyus* and *Eragrostis 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. *Cenchrus 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 are concentrated more into its rhizosphere. *Enteropogon macrostachyus*, though narrow leafed, tends to be leafy than steamy especially at its base and therefore closely compares with *Cenchrus ciliaris* in trapping water. In contrast, *Eragrostis superba* is stemmier and thus less effective in concentrating rain water into its 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 destablising the soil structure. Generally, vegetation cover intercepts rainfall kinetic energy thereby decreasing the mobilization of soil particles. The taller grasses trap more water drops and funnel them down their crown, thus concentrating more water around the rhizosphere compared to the shorter grasses. The larger leaf blades also reduce the force of the water drops directly hitting the ground. This improves infiltration capacity and reduces runoff, leading to less sediment production.

CONCLUSION

Soil hydrologic condition is the result of an interaction between edaphic and vegetation characteristics. Infiltration capacity and sediment production integrate these factors and are good indicators of soil hydrologic conditions. Infiltration capacity of the three perennial grass swards increased while runoff and sediment production decreased with increasing stubble heights. *Cenchrus ciliaris* and *Enteropogon macrostachyus* were the most suitable perennial grasses with favorable infiltration capacity in the study area. The hydrological responses of the perennial grasses in this study suggest that grazing could negatively affect the soil physical properties leading to increased runoff, sediment loss and decreased infiltration capacity in free grazing environments and subsequently soil erosion. Therefore, range rehabilitation using grass reseeding technology improves the soil hydrological properties of the soil in semi-arid environments particularly by reducing high runoff that is common in bare degrading grazing areas.

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