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Hydrologic properties of grazed perennial swards in semiarid southeastern Kenya

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Identification of plant resources that persist under grazing pressure, support desirable levels of production and at the same time protect the grazing environment is central to sustainable livestock production. This study assessed the infiltration capacity and soil loss associated with perennial swards subjected to different levels of utilization using simulated rainfall. The hypothesis was tested that grazed perennial swards have similar hydrologic properties and threshold removal levels below which runoff increases markedly. Infiltration capacity for the perennial swards increased with increasing stubble height before leveling off towards the highest stubble height. A 50% removal of current growth was the upper limit above which runoffs from the swards increased rapidly. Aggregate stability, organic carbon and percent ground plant cover were the most significant attributes that influenced infiltration capacity. *Panicum maximum* and *Enteropogon macrostachyus* were the most suitable perennial swards with favourable soil physical properties and infiltration capacities in the study area. The results support the existence of a threshold level of sward stubble height for minimizing runoff.

Key words: Perennial swards, water infiltration capacity, runoff thresholds.

INTRODUCTION

The trade-offs between resource extraction regimes to realize secure livelihoods, while maintaining environmenttal integrity continues to dominate the sustainable development agenda. Yet, research connecting the use of resources to resource conservation is of low priority, particularly in areas characterized by low returns to investments. Rangelands have received lowest scientific attention (Stafford Smith, 1998). Rangelands in Africa cover about 60% of the land area and are subjected to human-induced degradation, with 31% of the area estimated to suffer severe loss of productivity (de Leeuw and Reid, 1995). The sources of degradation include inappropriate cultivation of marginal areas, deforestation and grazing. Grazing contributes about 34.5% of the total soil degradation (Greijn, 1994).

Increasing land degradation in the grazing environment is exacerbated by mismanagement of livestock grazing pressure, which reduces regrowth capacity of defoliated plants (Belsky, 1986) and depletes the soil protective cover (Taddese et al., 2002). Grazing changes the vegetation structure which in turn, alters surface hydrological characteristics. Reductions in the amount of vegetation may increase raindrop impact, decrease soil organic matter and aggregate stability, increase surface soil crusting, and decrease infiltration rates (Blackburn, 1975; Wood and Blackburn, 1981; Graetz and Tongway, 1986; Eldridge and Koen, 1993; Yates et al., 2000).

Accelerated soil erosion occurs when vegetation cover is removed to facilitate soil loss from the forces of water and wind (Thurow et al., 1986; Weltz et al., 1998; Rietkerk et al., 2000). Accelerated erosion is the most severe consequence of overgrazing because replenishment of lost soil is a slow process. Therefore, losses of soil result in nearly permanent reductions in grazing capacity. In Kenya, high rates of soil loss of up to 50 tonnes per hectare per year from degraded grazing land in semiarid areas are common (Nyaoro, 1996). In the study area, increasing human population density and associated increasing animal density, expanding cropping patterns into grazing land, and bush encroachment have exacerbated the deterioration of the limited grazing land. In the area, 50% of the natural pastures are degraded (Mnene, 2004).

The best protection against erosion lies in establishing

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and maintaining good vegetation cover. Perennial vegetation cover is central to protecting landscapes against runoff and erosion. The litter layer that accumulates beneath perennial vegetation prevents soil crusting (Belnap, 2001), increase soil organic matter (Hibbard et al., 2001) and promote infiltration and moisture retention (Dunkerely, 2002a; 2002b). Perennial grass tufts improve water infiltration much more effectively than annual grasses by channeling rainwater via the root base into their own rhizospheres (Kelly and Walker, 1976; Rietkerk et al., 2000), stimulating biological activity and decreasing bulk density, thereby increasing retention and availability of soil water. Bulk density beneath perennial grass is also lower than on bare ground (Rietkerk et al., 2000). Heng et al. (2001) established that perennial grass pastures extract more soil water than annual grass pastures. Also, perennial pastures have less surface runoff, subsurface flow and deep drainage. Thus, perennial grass pasture can play a critical role in enhancing rainwater use efficiency. However, the infiltration enhancing processes of perennial vegetation become less efficient when disturbed (Fierer and Gabet, 2002), especially by the hoof action that removes biotic crusts (Belnap, 1995) and compacts the soil (Taddese et al., 2002). Also, not all vegetation types have threshold vegetation cover below which runoff increases sharply (Eldrige and Rothon, 1992).

This study aimed to determine the threshold use of four key perennial swards to protect the grazing areas of semiarid southeastern Kenya. The effects of different levels of utilization of the perennial swards on water infiltration capacity and soil loss were determined. Further, the analysis tested the hypothesis that grazed swards of the four perennial grasses have similar hydrologic properties and threshold removal levels below which runoff increases markedly.

MATERIALS AND METHODS

Study area

The study was conducted in Kibwezi Division of Makueni District in southeastern Kenya during 2003/2004 period. The district covers about 7,263 sq. km (RoK, 1994), and lies between 1.5°-3°S and 37°-38.5°E. It is bordered by Kitui District to the east, Taita District to the south, Kajiado District to the west and Machakos District to the north. The district receives an average annual rainfall of 500 mm in the lowlands in the south and 1200 mm in the highlands in the north. The rainfall is characterized by small total amounts, strong seasonal and bimodal distribution, with high temporal and spatial variability between seasons and years. Annual mean temperatures experienced in the District range between 19 to 26°C (Jaetzold and Schmidt, 1983).

The district is classified into six agro-climatic zones (ACZs) (Sombroek and Braun, 1980). The dominant ones are IV and V where risks of crop failure are high. Based on ACZ, the district has three main soil types: AEZ UM2/LM2 is dominated by red clay onhills and sand soils and black cotton soils on lowlands; AEZ LM4/LM5, has red clay and black cotton soils; and AEZ UM3/LM3 has mostly black cotton soil (Jaetzold and Schmidt, 1983). 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. The main perennial grasses include *Cenchrus ciliaris* L, *Chloris roxburghiana* Schultz, *Panicum maximum* Jacq, *Eragrostis superba* Peyrs, *Digitaria milanjiana* (Rendle) Stapf and *Enteropogon macrostachyus* Benth.

Kibwezi Division covers 47% of Makueni District and has a total area of 3,400 km^2 with a human population density of 92 persons per km^2 (Rok, 2002). It lies in ACZ IV and V of the district described as low potential maize zone, and high potential livestock and millet zone; and very low potential maize zone and medium potential livestock and millet zone, respectively (Jaetzold and Schmidt, 1983; Rok, 1989). The area was not settled by people until the 1930s due to its low agricultural potential and heavy infestation by tsetse flies. Thereafter, high population pressure in the high potential areas forced populations to expand into the region.

The Kamba agropastoralists are the main ethnic inhabitants in the study area. Their mainstream economic activity is raising livestock and cultivating cereals and pulses (Tiffen et al., 1994). Farm sizes in the study area ranges from 2 to 14 acres with over 50% of the inhabitants holding less than 10 acres. Land tenure is mainly freehold. Livestock kept consists of local breeds mainly Small East African Shorthorn Zebu cattle, Red Maasai sheep and East African goats. The animals are kept under free range/herding in defined household grazing areas. However, sometimes in the dry season livestock are temporarily moved into cultivated fields to utilize crop residues. The crops grown include different drought tolerant varieties of maize, sorghum, millet, pigeon peas and beans. Small-scale irrigation of horticultural crops is carried out in some parts of the division, especially along Athi River and its tributaries. In the study area, about 80% of the farmers practice mixed farming (crop/livestock production), with half of the land holding used for grazing. The production system is largely geared to subsistence production. Drought and famine occur every 7 to 10 years with high crop failures nearly every 2 to 4 years (Musimba et al., 2004). The study sites were in ecological zone V, where the landscape is gently undulating and largely of mixed sandy-clay soils.

Data collection

Simulated rainfall (Young et al., 1972) was used to study soil hydrologic responses and sediment production of grazed and ungrazed sites dominated by four perennial swards. Infiltration capacity (mlmin^{-1}) on 0.3 x 0.3 m plots of the perennial grasses at five stubble heights representing different levels of utilization (100, 75, 50, 25 and 0%) was measured using The Kamphorst Rainfall Simulator. The plots were taken in a completely randomized design. Each simulation consisted of a rain shower of 5 min. with an intensity of 375 mlmin^{-1} (6 mmmin^{-1}) (Rietkerk et al., 2000). This was repeated for another five minutes to ensure runoff. The simulations were run in duplicate in the grazed area and grazing exclosure. All simulations were done when soil was near field capacity. That is, the test plots were wetted to near field capacity, covered with polythene papers for 24 h to reduce evaporation loss and maintain uniform soil surface water content. From each plot, runoff was collected, 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 later filtered off and dried at 105°C for 24 h. The dried solids were converted to sediment yield in kg/ha. This was used as an index of sheet erosion as given below.

$$\text{Sediment production (kg/ha)} = \frac{\text{Sediment produced} \times \text{area}}{\text{Plot area}}$$

Table 1. Infiltration capacity (cm^3) of grazed and ungrazed sites dominated by four perennial swards at various stubble heights.

Sward type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	1595.0[af]	3357.5[af]	3427.5[af]	3595.0[ag]	3715.0[ag]
Chloris roxyburghiana (UG)	1890.0[g]	3390.0[g]	3515.0[g]	3610.0[g]	3720.0[g]
Ent. Macrostachyus (G)	2415.0[bf]	3335.0[af]	3480.0[bf]	3645.0[bg]	3690.0[ag]
Ent. macrostachyus (UG)	2350.0[g]	3425.0[g]	3590.0[g]	3655.0[g]	3700.0[g]
Eragrostis superba (G)	2100.0[cf]	3065.0[bf]	3220.0[cf]	3450.0[bf]	3632.5[bf]
Eragrostis superba (UG)	2175.0[g]	3130.0[g]	3375.0[g]	3595.0[g]	3605.0[g]
Panicum maximum (G)	2190.0[df]	3415.0[cf]	3595.0[df]	3700.0[cg]	3700.0[ag]
Panicum maximum (UG)	1925.0[g]	3455.0[g]	3640.0[g]	3707.5[g]	3710.0[g]

Column means with different superscript are significantly different at $p<0.05$
The superscripts [f] and [g] are for comparisons within a plant species.
G – grazed site, UG - ungrazed site
Ent - *Enteropogo*

Table 2. Stubble height-species interaction on infiltration capacity (cm^3) of grazed sites dominated by four perennial swards.

Grass type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	1595.0[a]	3357.5[a]	3427.5[a]	3595.0[a]	3715.0[ab]
Ent. macrostachyus (G)	2415.0[b]	3335.0[a]	3480.0[a]	3645.0[a]	3690.0[a]
Eragrostis superba (G)	2100.0[c]	3065.0[b]	3220.0[b]	3450.0[b]	3632.5[ac]
Panicum maximum (G)	2190.0[d]	3415.0[c]	3595.0[c]	3700.0[c]	3700.0[ab]

Column means with different superscript are significantly different at $p<0.05$
G – grazed site
Ent - *Enteropogon*

Two disturbed soil samples per plot taken to depths of 0 to 20 cm and bulked across the grass species per site were used to determine soil moisture, soil texture, soil organic matter, and soil aggregate stability. Soil moisture content was determined by the gravimetric method (Rowell, 1994). Soil texture was determined following the hydrometer method as described by Gee and Baunder (1988). The fine fraction of soil passing through a 2 mm sieve was taken for texture analysis using Bouyoucos hydrometer. The textural class was determined using the standard USDA triangle (USDA, 1975). The soil organic matter content (soil carbon) was determined using the wet oxidation method as described by Nelson and Sommers (1982). Soil aggregate stability was determined by the wet sieve procedures (Hillel, 1980). Disturbed soil samples passing through a 4 and 2 mm sieve were used for the analysis.

Soil core samples taken to depths of 0 to 5 cm in duplicate per plot per grass species were used to determine soil bulk density and soil porosity. Bulk density was determined by the core method (Blake and Hartge, 1986). Soil porosity was derived from values of bulk density as outlined by Landon (1991). Percent foliar cover of the grasses was determined by ocular estimates on each plot from griddled quadrants.

Data analysis

A logistic multiple linear regression analysis was used to determine the most important factors influencing infiltration capacity and sediment production. Skewness and Kurtosis tests were analyzed for frequency distribution for each variable to determine the normality of data (Snedecor and Cochran, 1971). A two-way analysis of variance without blocks was then conducted to determine the effects of grass species and stubble height (0, 12.5, 25, 37.5 and 50 cm or 100, 75, 50, 25 and 0 % utilization, respectively) on infiltration capacity and sediment production. The least square difference (L.S.D) procedure was used to determine significant differences at the 0.05 level of probability (Steel and Torrie 1980).

RESULTS

Infiltration capacity of sites dominated by perennial swards

The infiltration capacity (cm^3) of sites dominated by four perennial swards at various stubble heights in the grazed area is shown in Table 1. Infiltration capacity of grazed sites dominated by the perennial swards increased with increasing stubble height before stabilizing off towards the highest stubble height. *P. maxmum* site maintained a significantly ($p<0.05$) higher infiltration capacity between 12.5 to 37.5 cm stubble height, followed by *E. macrostachyus, C. roxyburghiana* and lastly *E. superba* sites.

On comparing grazed and ungrazed sites with perennial swards at similar stubble heights, the ungrazed sites re-

Table 3. Soil physical characteristics under various perennial swards in grazed and ungrazed sites

Sward type	Soil characteristic				
	BD	PO	AGS	C	SMC
Chloris roxyburghiana (G)	1.557[a]	41.10[a]	42.8[a]	2.416[a]	20.20[a]
Chloris roxyburghiana (UG)	1.549[a]	41.40[a]	48.2[b]	3.217[b]	21.35[a]
Ent. macrostachyus (G)	1.505[a]	43.30[a]	25.1[a]	2.631[a]	16.29[a]
Ent. macrostachyus (UG)	1.343[a]	49.20[a]	37.5[b]	3.369[b]	17.01[a]
Eragrostis superba (G)	1.519[a]	42.60[a]	31.8[a]	2.195[a]	16.68[a]
Eragrostis superba (UG)	1.499[a]	43.40[a]	36.4[b]	3.041[b]	18.51[a]
Panicum maximum (G)	1.445[a]	45.50[a]	38.6[a]	2.078[a]	18.24[a]
Panicum maximum (UG)	1.339[a]	49.30[a]	46.2[b]	3.608[b]	19.15[a]

Column means within plant species with different superscript are significantly different at $p<0.05$
G- grazed site, UG - ungrazed site
BD - Bulk density (gm^{-3}), PO - Porosity (%), AGS - Aggregate stability (%),
C - Organic carbon (%), SMC - Soil moisture content (%).

Table 4. Multiple linear regression analysis and factors influencing infiltration capacity.

Variable	Regression coefficient	P<0.05	VIF*
Intercept	-	0.061	-
Bulk density	0.113	0.398	1.758
Aggregate stability	0.294	0.033	1.579
Organic carbon	0.273	0.049	1.644
Cover	0.515	0.043	5.500
Standing crop	0.203	0.369	4.975
Soil moisture	-0.027	0.820	1.472

*A factor with a Variance Inflation Factor (VIF) value of less than 10 is acceptable to be included in the regression analysis. Above 10, problems of multicollinearity arise (Gujarati 1995).

corded higher infiltration capacities. The grazed swards showed significant interactions between stubble height and grass species on infiltration capacity (Table 2). *P. maximum* site recorded the highest significant interaction between 12.5 to 37.5cm stubble heights, followed by *E. macrostachyus. E. superba* gave the lowest significant interaction.

The soil physical characteristics under the various swards in the grazed and ungrazed sites are presented in Table 3. Swards in the ungrazed sites had higher porosity, aggregate stability and organic carbon and lower bulk density compared to those in the grazed sites. Aggregate stability (AGS) and percent organic carbon (C), and percent cover (CR) were the most significant ($p<0.05$) soil and plant attributes that influenced infiltration capacity, respectively (Table 4). The predictive equation for infiltration capacity based on Ordinary Least Squares (OLS) for the study area is given by the following equation:

$$10(\text{Infiltration capacity}) = 2.94AGS + 2.73C + 5.15CR, \quad R^2=0.83$$

Runoff of sites dominated by perennial swards

The runoffs (cm^3m^{-2}) of grazed sites with the perennial swards at various stubble heights are shown in Table 5. Swards with higher and lower infiltration capacities gave lower and higher runoffs, respectively. *P. maxmum* yielded significantly ($p<0.05$) lower runoff between 12.5 to 37.5cm stubble height, followed by *E. macrostachyus, C. roxyburghiana* and *E. superba.* Similarly, the swards in the grazed sites gave higher runoff than in the ungrazed sites. For all the perennial swards, runoff increased rapidly below 25 cm stubble height, pointing to existence of a threshold level at 50% stubble height removal. The grazed swards recorded significant ($p<0.05$) interactions between stubble height and grass species on runoff (Table 6). *P. maximum* site gave the lowest significant runoff interaction between 12.5 to 37.5 cm stubble heights, followed by *E. macrostachyus. E. superba* gave the lowest significant interaction.

Sediment production of sites dominated by perennial swards

The sediment loss (gm^{-2}) from the perennial swards at various stubble heights in the grazing sites is given in Table 7. *P. maximum* gave significantly ($p<0.05$) lower sediment loss across stubble heights. Sediment loss from the swards followed the trends in runoff. Higher runoffs

Table 5. Runoff (cm^{3}m^{-2}) from grazed and ungrazed sites dominated by perennial swards at various stubble heights

Sward type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	2155.0^{af}	392.5^{af}	322.5^{af}	155.0^{ag}	35.0^{ag}
Chloris roxyburghiana (UG)	1860.0^{g}	360.0^{g}	235.0^{g}	140.0^{g}	30.0^{g}
Ent. macrostachyus (G)	1335.0^{bf}	415.0^{af}	270.0^{bf}	105.0^{bg}	60.0^{ag}
Ent. macrostachyus (UG)	1400.0^{g}	325.0^{g}	160.0^{g}	95.0^{g}	50.0^{g}
Eragrostis superba (G)	1650.0^{cf}	685.0^{bf}	530.0^{cf}	300.0^{cf}	117.5^{bg}
Eragrostis superba (UG)	1575.0g	620.0g	375.0^{g}	155.0^{g}	95.0^{g}
Panicum maximum (G)	1560.0df	335.0cf	155.0^{df}	50.0^{dg}	50.0^{ag}
Panicum maximum (UG)	1825.0g	295.0g	110.0^{g}	42.5^{g}	40.0^{g}

Column means with different superscript are significantly different at $p<0.05$
The superscripts ^{f} and ^{g} are for comparisons within a plant species.
G – grazed site, UG - ungrazed site.

Table 6. Stubble height-species interaction on runoff (cm^{3}m^{-2}) of grazed sites dominated by four perennial swards.

Grass type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	2155.0^{a}	392.5^{ac}	322.5^{a}	155.0^{a}	35.0^{a}
Ent. macrostachyus (G)	1335.0^{b}	415.0^{a}	270.0^{a}	105.0^{ac}	60.0^{ab}
Eragrostis superba (G)	1650.0^{c}	685.0^{b}	530.0^{b}	300.0^{b}	117.5^{b}
Panicum maximum (G)	1560.0^{d}	335.0^{c}	155.0^{c}	50.0^{c}	50.0^{a}

Column means with different superscript are significantly different at $p<0.05$
G – grazed site
Ent - *Enteropogon.*

Table 7. Sediment loss (gm^{-2}) from grazed and ungrazed sites dominated by perennial swards at various stubble heights.

Sward type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	248.5^{bf}	81.0^{af}	71.5^{bf}	46.0^{bf}	32.5^{bf}
Chloris roxyburghiana (UG)	167.5^{g}	70.5^{g}	38.5^{g}	28.5^{g}	16.0^{g}
Ent. macrostachyus (G)	208.0^{bf}	88.0^{bf}	55.0^{bf}	44.5^{ag}	35.0^{bf}
Ent. macrostachyus (UG)	169.0^{g}	54.0^{g}	33.0^{g}	26.5^{g}	15.5^{g}
Eragrostis superba (G)	218.5^{bf}	118.0^{bf}	96.5^{bf}	52.0^{bf}	41.5^{bf}
Eragrostis superba (UG)	183.0^{g}	80.0^{g}	53.0^{g}	35.5^{g}	20.5^{g}
Panicum maximum (G)	206.0^{bf}	67.5^{bf}	43.5^{bf}	31.0^{af}	28.5^{bf}
Panicum maximum (UG)	133.5^{g}	37.5^{g}	26.0^{g}	21.5^{g}	15.0^{g}

Column means with different superscript are significantly different at $p<0.05$
The superscripts ^{f} and ^{g} are for comparisons within a plant species.
G – grazed site, UG - ungrazed site

that occurred at lower stubble heights yielded more sediment loss across the swards. Swards in the grazed sites also gave significantly ($p<0.05$) higher sediment loss than swards in the ungrazed sites. Furthermore, the grazed swards showed significant interactions between stubble height and grass species on sediment loss (Table 8). *P. maximum* gave the lowest significant interaction on sediment loss compared to the other grass between 12.5 to 37.5 cm stubble heights.

DISCUSSION

Differences in infiltration capacity of the swards could be attributed to the growth characteristics of the grasses given that the soil type in the study area was largely similar. *P. maximum* is leafy, less stemmy and broad-leafed. Therefore, this grass presents a greater surface area for collecting rainwater that is concentrated more into its rhizosphere. In contrast, *C. roxyburghiana and E.*

Table 8. Stubble height-species interaction on sediment loss (gm^{-2}) of grazed sites dominated by four perennial swards.

Grass type	Stubble height (cm)				
	0	12.5	25.0	37.5	50.0
Chloris roxyburghiana (G)	248.5^{a}	81.0^{a}	71.5^{a}	46.0^{a}	32.5^{a}
Ent. macrostachyus (G)	208.0^{b}	88.0^{a}	55.0^{ab}	44.5^{a}	35.0^{a}
Eragrostis superba (G)	218.5^{b}	118.0^{b}	96.5^{c}	52.0^{ab}	41.5^{a}
Panicum maximum (G)	206.0^{b}	67.5^{a}	43.5^{b}	31.0^{ac}	28.5^{a}

Column means with different superscript are significantly different at p<0.05
G – grazed site
Ent - *Enteropogon*

superba are stemmier and thus less effective in concentrating rainwater into their rhizosphere. *E. macrostchyus,* though narrow leafed, tends to be more leafy than stemmy and closely compares with *P. maximum* in trapping rainwater.

The ungrazed sites recorded higher infiltration capacities than the grazed sites. The ungrazed sites were in an exclosure of over ten years within the study area and may have recovered from influences of past grazing. This suggests that the effects of grazing might have degraded soil physical properties resulting in low infiltration capacities. 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 affects plant ecosystem regulatory services (Yates et al., 2000). The grass stands protected from grazing recorded favourable soil physical properties for enhanced infiltration capacity. Chaichi et al. (2003) reported similar results. *P. maximum* and *E. macrostachyus* were the most suitable perennial swards, with favourable soil physical properties and infiltration capacity. These grasses also gave lower runoff and sediment loss. However, reducing the stubble height beyond the 50% (25 cm) threshold level undermines the protective function of the grasses to the environment. That is, appropriate sward height can partly compensate for the deleterious effects of grazing on the environment. Also, this confirms the existence of plant cover-environment protecttion thresholds (Chartier and Rostagno, 2006), particularly in plant-animal interfaces.

Higher sediment loss from the grazed swards could be attributed to the deleterious effects of grazing (Van de koppel et al., 1997). Grazing reduces the soil surface protective cover (Weltz et al., 1998; Rietkerk et al., 2000), and the hoof action tends to compact and loosen soil particles (Belnap, 1995; Taddese et al., 2002), which allows raindrops to directly pound the soil surface and easily wash off soil particles. This leads to increased sediment and nutrient loss that can reduce primary productivity and grazing capacity.

The hydrological responses results of the perennial swards attest to the fact that grazing can negatively affect soil physical properties, leading to increased runoff and sediment loss, and decreased infiltration capacity in the grazed environment. In the study area, up to 70% of the grazing areas were observed to have grass stubble heights of less than 25 cm by the end of the dry season. This situation increases the risk of runoff effects and sediment loss with the onset of rains that usually come in heavy storms in such semiarid environments, and partly accounts for the observed widespread degradation in the grazing environment in the area (Mnene, 2004). Therefore, the management challenge in the study area is to regulate grazing to maintain a productive environment.

To enhance favourable water balance in the grazed environment, surface cover, organic carbon and aggregate stability were the most critical factors. Surface cover and organic carbon are amenable to management. Organic carbon can be enhanced through the application of mulch and manure, while appropriate percent cover can be achieved by observing correct levels of utilization. As concluded by Liniger and Thomas (1998), surface cover is important in determining the movement of water in a system. Lack of it precipitates high runoffs and sediment loss from grazing land (Thomas et al., 1981), which leads to rapid degradation of these lands.

Appropriate cover can partly be achieved by propagateing plant resources that can enhance favourable soil hydrologic responses, persist grazing pressure, and support desirable levels of livestock production. From the results of this study, *P. maximum* and *E. macrostachyus* were the most suitable showing positive hydrologic responses in the grazing environment. Therefore, these native grasses should be given priority in range rehabilitation strategies targeting reseeding in the area. Suitability of native species that are usually persistence under grazing is enhanced by existence of a 50% stubble height removal threshold that coincides with a significant and positive stubble height-species interaction. This threshold should be maintained as guide to productive use of such native rangelands.

Conclusions

Infiltration capacity for the perennial swards increased with increasing stubble height before stabilizing off towards the highest stubble height. *P. maximum* and *E. macrostachyus* were the most suitable perennial grasses with favourable soil physical properties and infiltration capacity in the study area. Aggregate stability, organic carbon and percent plant cover are the most important and significant attributes influencing infiltration capacity. Variability of these attributes makes the various perennial swards have different hydrologic responses. A 50% threshold level of removal of current growth is the upper limit above which runoffs and sediment loss from the swards increase rapidly. Thus, perennial swards have similar hydrologic thresholds below which resource degradation trends sets in. In the study area, grazing management strategies that maintain grazing thresholds and minimize grazing damage to the environment could be central to sustainable livestock production. This could partly include applying appropriate stocking rates to match available forage over time.

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