Livestock grazing impact on vegetation, soil and hydrology in a tropical highland watershed

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Abstract

The aim of this research was to establish vegetation, soil and hydrologic responses to grazing pressure; and determine thresholds for optimum herbage utilisation of pastures and grazing land resources conservation. The treatments were no grazing (NOG, control), where animal grazing was excluded using 10 m by 10 m fenced enclosure, moderate grazing (MDG) and heavy grazing (HVG). During free grazing period (January–May) stocking rate on medium and heavily grazed plots depends much on the preference of grazing animals, and in some cases the stocking rate in controlled or medium grazing pressure exceeds that of the heavily grazed plots. The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha. Grazing pressure increased the percentage cover of annual plant species and composition as compared with no grazing pressure. Particularly, in medium-grazing pressure annual plant species coverage has improved significantly. The soil loss at 4–8% slope was high in heavily grazed plots. Besides, the soil loss in grazed plots was below the soil tolerance limit for natural pasture. The infiltration rate was lower in heavily grazed plots.

Introduction

In livestock production systems at smallholder levels, the overriding considerations are to increase the efficiency of using local natural resources that are not directly beneficial to human unless converted to useful products (Daniel 1988). A successful livestock development strategy, therefore, needs to fit into the overall resource management plans and complement the wider economic, ecological and sociological objectives. The combination of moderate temperature, adequate rainfall and freedom from many tropical diseases has encouraged the growth of large human populations and diverse farming systems (Jahnke and Assamenew 1983). Grazing of pasture and rangelands is an integral component of livestock production systems in many countries (Johanston et al. 1996). Livestock grazing stimulates nutrient mobilisation and uptake through consumption of vegetation, in that mobilisation of nutrients to the growing points per root biomass is enhanced by frequent defoliation (Mohamed Saleem 1998). It is clear that the degradation of the highlands relates to the combination of human exploitation exceeding the natural carrying capacity of the land resources systems, and inherent ecological fragility of the systems (Mohamed Saleem and Abyie 1998). Investigations into how grazing can induce different bio-physical process including vegetation and hydrological changes that are related to bio-diversity, nutrient uptake and cycling in the grassland ecosystems are required for developing models to predict levels of primary productivity to meet grazing requirements of livestock and also predict vegetative cover required to protect soil from degradation. The general objectives of this research are, therefore, to establish vegetation, soil, and hydrologic responses to grazing pressure; and determine thresholds for optimum herbage utilisation of pastures and grazing land resources conservation.

Materials and methods

Study description

The study was conducted for four years starting from 1996 at Tero Jemjem watershed in Ginchi, 80 km west of Addis Ababa, Ethiopia (38°13′9″E and 9°1′5″N) in Yubdo Legebatu Peasant Association where farmers graze their livestock within and around Tero Jemjem watershed. The annual rainfall is 1150 mm and the rainy season starts in June, peaks in August and tails off in September (Figure 1). The mean annual temperature is about 17°C with insignificant seasonal variation; however, the period from October to March is slightly warmer and June to September is cooler. The elevation of the Tero Jemjem watershed ranges from 2190 to 2770 metres above sea level (masl), and the study area is approximately 350 ha.

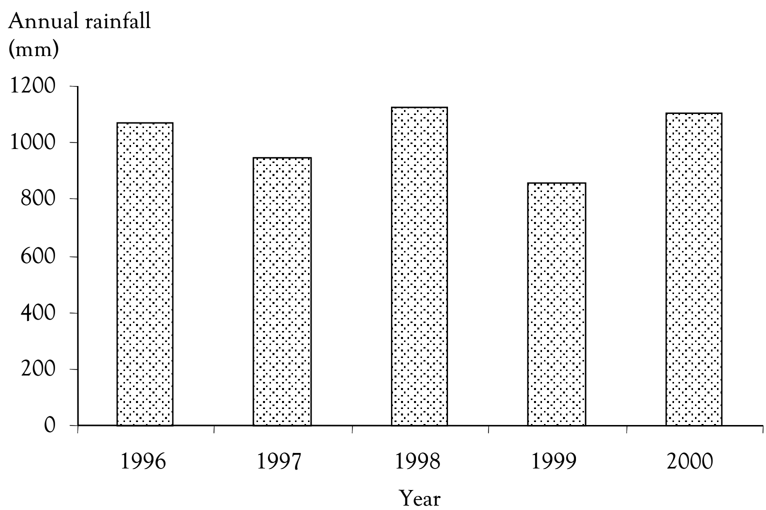

Figure 1. *Mean annual rainfall of the study area.*

The area has clay soils of the Vertic Cambisol Association (55–78%) on <10% slopes (Kamara and Haque 1988). Due to high smecite clay content, these soils have marked swelling and shrinking properties. Clay soils of the Chromic Cambisols Association (55–72% clay) occur on the upper slopes (>10% slope).

The vegetation was largely dominated by *Andropogon abyssinicus*, *Bothrichloa inscuplta*, *Eleusine floccifolia*, and *Eragrostis tenuifolia* grass species and by *Acacia abyssinica*. The balance of the vegetation is composed of a very diverse assemblage of grass and forbs species most of which are readily accepted by grazing livestock.

The treatments were no grazing (NOG, control), where animal grazing was excluded using a 10 × 10 m fenced enclosure, moderate grazing (MDG) and heavy grazing (HVG). The grazing pressure at MDG was regulated by opening flexible fencing around the plots for three days a week to allow free access for farmers' animals. There was no fencing around plots subjected to HVG. The NOG plots were fenced and kept closed to livestock grazing throughout the experiment. The number and type of animals and duration of grazing in the MDG and HVG treatments were recorded daily to determine the stocking rate and grazing intensity. Similar cultural practices as used by surrounding farmers were imposed; manure was collected from grazed plots by the herders and used as source of fuel.

Stocking density was expressed as animal units per hectare (AU/ha) and calculated as proposed by Scarnecchia (1985). An animal unit (AU) is defined as a 450 kg steer at 30 months of age (Edwards 1981; Le Hou'erou 1989). Animals kept were local zebu cattle, donkeys and horses, sheep and goats that belonged to the farmers in the watershed.

Vegetation assessment

Metal quadrants (0.5 × 0.5 m) were used for vegetation sampling. Two samples were taken on monthly basis by clipping the herbage in the quadrants to the ground level from each plot within and outside of the movable cages to measure regrowth, residual and biomass consumed by the animals. After clipping the herbage the cages were moved at random each month to a new spot along transect, but outside a 3 × 6 m area demarcated to study the soil erosion (Figure 2). The clipped samples were oven-dried at 70°C for 24 hours, weighed and biomass was converted to t/ha. Within each plot every year in September, October and December a total of 100 points (10 × 10 m), using a 1 m long metal frame species richness and botanical composition were determined. Every year botanical composition and species richness were measured in August, October and December.

Hydrological studies

In mid-October the effect of livestock trampling on water infiltration was measured in three replicates on each plot using a double-ring infiltrometer (Bower 1986).

Surface runoff measurement

To measure runoff and soil loss, each plot had an installation consisting of a metal gutter at the lower end of the plot, a sedimentation box, and a drum connected to a collection drum.

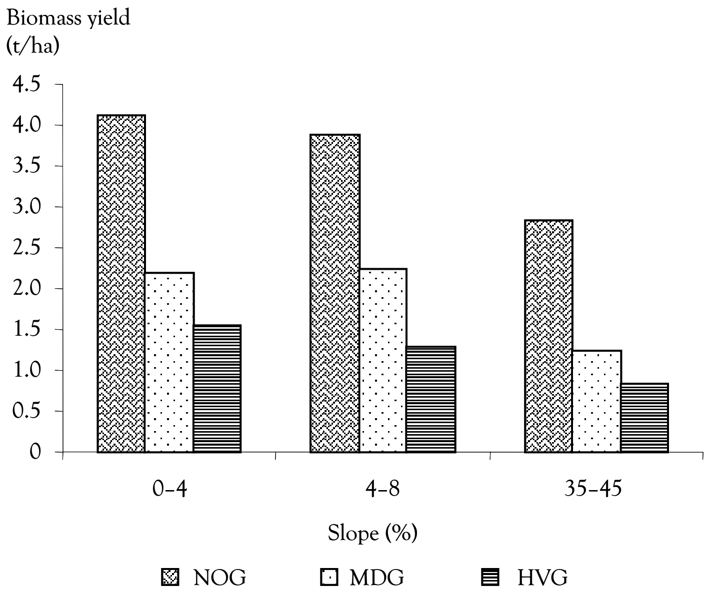

Figure 2. *Effect of grazing on mean biomass yield (t/ha) at different slopes (1996–2000).*

The metal gutters intercepted runoff and directed it to the collection tank. The sedimentation box also acted as a multi-pipe divisor with seven pipes. Only the middle pipe was connected to the runoff-collecting tank through a 12.5-mm diameter plastic hose, thus allowing only (in theory) 1/7 of the runoff to be collected during each rainfall event. The actual amount going into the drum was determined using a calibration curve. The box and tank were shielded from direct rainfall and animal trampling by an iron sheet cover. Each plot was also provided with up-slope runoff by run-on barrier and an interceptor drain at the upper end on the plot.

Sediment and water samples were collected after each rainfall event that produced runoff in the treatment. Samples were collected from the sedimentation box and the overflow drum after stirring the mixture vigorously. Concentration of suspended material was determined using the fixed-volume method (Barnett and Holladay 1965). Runoff was measured in the field as soon as possible after each rainfall event that produced runoff. The total amount of runoff consisted of the amount collected in the sedimentation box, the amount collected in the drum and the amount drained through the six pipes. In theory, the total volume overflowing from the sedimentation box (*OVcal*) is equal to seven times the amount collected in the drum. The actual total amount overflowing from the sedimentation box (*OVactual*) was determined using the calibration curve shown in equation (1).

$$OVactual = OVcal \times F \quad (1)$$

where, *OVactual* is the actual volume of runoff overflowing from the sedimentation box; *OVcal* is 7 times the amount collected in the drum and *F* is the multiplication factor, which varied from plot to plot.

Soil loss measurement

The total weight of a fixed volume of soil and water is equal to the weight of water with soil plus the weight of soil, minus the weight of water dispersed by the soil:

$$W_{s+w} = W_w + W_s - W_s/S_g \qquad (2)$$

where W_{s+w} is the total weight of water and soils; W_w is the weight of water in fixed volume without soil; W_s is weight of soil; and S_g is specific gravity of soil assumed to be 2.65. After making an allowance for the water displaced by soil, the weight of the soil in the sample was calculated. Then the weight of the soil was converted to sediment yield in tonnes per hectare (Heron 1990; Hudson 1993).

Data analyses

General Linear Model/multivariate and simple linear correlations were used for data analysis (SPSS 1999).

Results and discussion

Grazing pressure

Grazing pressure on natural pasture in the Ethiopian highlands follows four distinct patterns (Table 1). During free grazing period (January–May) stocking rate on medium and heavily grazed plots depends much on the preference of grazing animals, and in some cases the stocking rate in controlled or medium grazing pressure exceeds that of the heavily grazed plots. As a result, the stocking rate in medium grazing pressure was higher even than the heavily grazed plots. Except draft animals, most of the livestock species are moved from bottomland of the communal grazing lands to upper slopes (Jahnke and Assamenew 1983; Daniel 1988). October to December is the period when sown crops get maturity and gradual cessation of natural pasture begins, and the stocking rate on the natural pasture rises again. After crop harvest predominantly free grazing on agricultural field is resumed, and burden on natural pasture is reduced. During this time cattle are needed for threshing the harvested crops, and donkeys are needed for transporting harvested crops from agricultural field to nearby settlement areas, and the available crop stalks can be kept for winter as supplementary feed (Mwendera et al. 1997; Mohamed Saleem 1998; Mohamed Saleem and Abyie 1998).

Influence of grazing pressure on biomass production

As grazing pressure increases biomass production decreases. The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha

(Figure 2). Biomass yield decreased as the slope increases. Biomass production over time varies and therefore causes seasonal variation in forage availability (Holechek et al. 1998). Likewise, grazing pressure varies across time because of differences in forage production among spatially separated plant communities (Zerihun 1986). Under heavy grazing pressure, plants may not compensate sufficiently for the biomass removed by grazing animals (Wood and Blackburn 1984; Zerihun 1986). Hence, net primary production (NPP), which is the difference between non-grazed and grazed biomass production, is a useful tool to establish the defoliation level of plant vegetation (Dawson 1974; Mills and Lee 1990).

Table 1. *Grazing pressure as expressed per animal unit (AU/t).*

	0–4% slope		4–8% slope	
Year	MDG	HVG	MDG	HVG
1996	20.69	41.28	118.01	336.73
1997	22.99	60.38	124.08	351.8
1998	60.75	160.31	108.66	455.6
1999	88.29	161.83	97.82	389.95
2000	95.1	170.31	115.75	367.5

Plant species and species richness

Botanical composition of plant species and productivity of the pasture are highly influenced by animal species, intensity of grazing and edaphic factors. Under very high stocking rate plant species such as *Pennisetum sphacelantum-Commelina africana* type may develop to *Andropogon abyssinicus-Hyparrhenia arrhenobasis* type when grazing is relaxed (Zerihun 1986). Grazing pressure increased the percentage cover of annual plant species and composition as compared with no grazing pressure (Table 2). Particularly, in medium-grazing pressure annual plant species coverage over the grazed area has improved significantly. At 4–8% slope, the vegetative cover of annual species in no grazing plots was almost nil. Predominantly perennial plant species were observed in no grazing treatment at both slopes compared with the grazed plots. Grazing has demonstrated positive effect on species composition and diversity (Janzen 1982a, b). The species richness was high in medium grazed plots compared with the rest of the treatments (Figure 3). The species richness in the lightly to moderately grazed plots remained relatively high as this was encouraged by selective grazing in the growth of the vegetation species.

Runoff, soil loss, bare-ground and infiltration rate

The overall mean annual soil loss in non-grazed and heavily grazed plots varied from 0.65–1.1 t/ha per year, and from 3.1–5.52 t/ha per year, respectively. The soil loss at 4–8% slope was high in heavily grazed plots (Figure 4). Besides, the soil loss in grazed plots was below the soil tolerance limit for natural pasture (Belay 1992; Mwendera et al. 1997). This was due to low formation of bare-ground patches. Moreover, no bare-ground patches were observed on non-grazed plots (Figure 5). The infiltration rate was lower in heavily grazed plots (Figure 6). The type and amount of vegetative cover alter surface runoff and water intake rate (Figure 7). Livestock grazing effects on infiltration, runoff, erosion, on-site water use, and consequent downstream impact are of great concern particularly in highland agriculture (Mwendera and Mohamed Saleem 1996). When vegetation cover declines, soil bulk density increases, rate of water infiltration decreases and sediment production increases.

Table 2. Effect of grazing pressure on dominant plant species cover* (%) at different slopes (1997–2000).

Area	Life form of dominant species	0–4% slope				4–8% slope			
		1997	1998	1999	2000	1997	1998	1999	2000
NOG	Annual	0	5	8	11	0	0	10	14
	Perennial	70	82	71	80	45	31	73	81
MDG	Annual	45	33	10	11	32	22	14	20
	Perennial	23	27	70	75	31	35	61	69
HVG	Annual	18	2	10	12	18	8	15	17
	Perennial	27	18	65	70	27	25	64	67

* Plant species with 5% cover are included in the data.

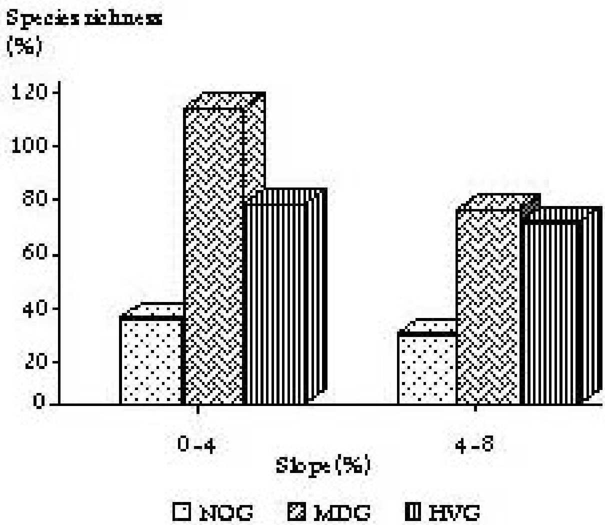

Figure 3. Effect of grazing pressure on mean species richness (%) at different slopes (1996–2000).

The nutrient balance

The nutrient balance under natural pasture in the absence of fertiliser or manure was negative for each nutrient. As the soil nutrient pool has to offset the negative balance, it implies that the grazing system is mining soil nutrients and not sustainable (Girma et al. 2001). The farmers removed the cow dung for fuel. This had negative impact on nutrient recycling and biomass improvement (Table 3).

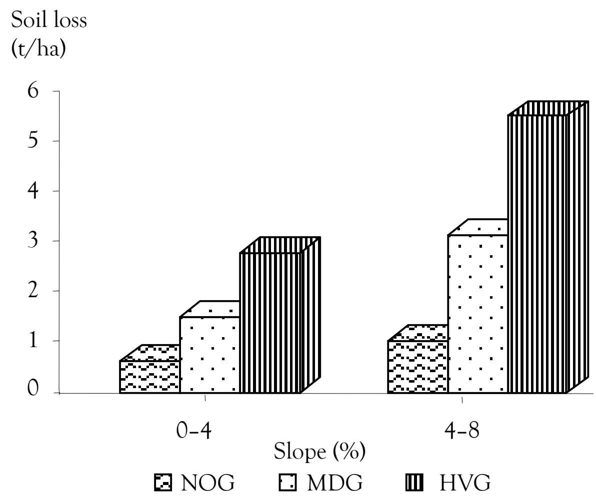

Figure 4. *Effect of grazing pressure on mean soil loss (t/ha) at different slopes (1996–2000).*

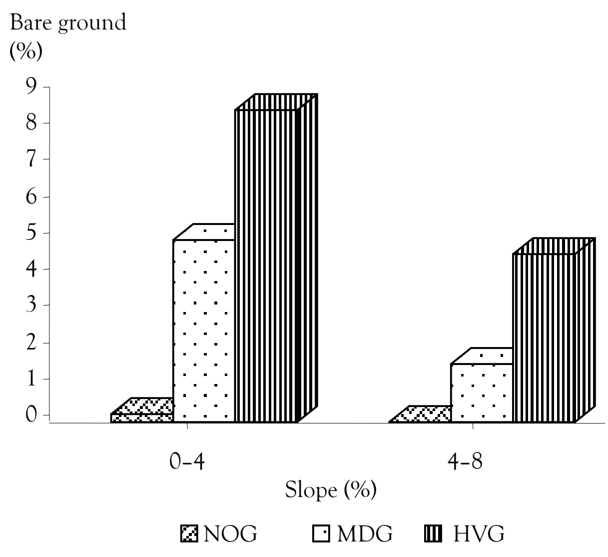

Figure 5. *Effect of grazing pressure on bare ground formation (%) at different slopes (1996–2000).*

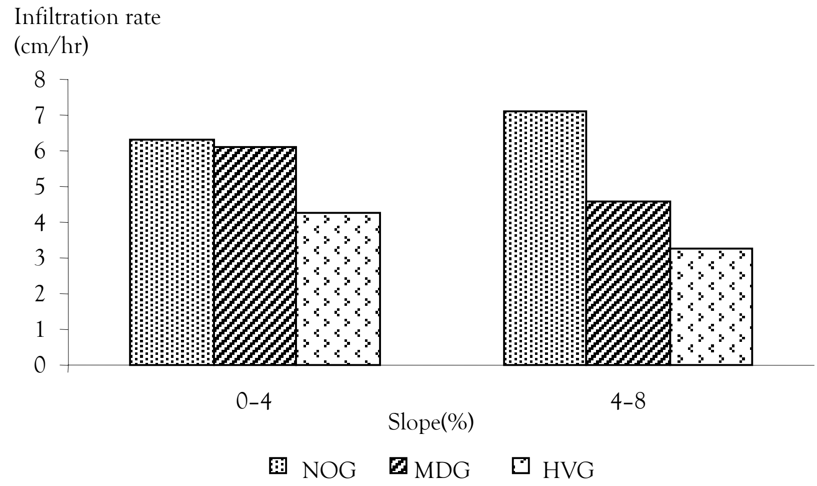

Figure 6. *Effect of grazing pressure on mean inflitration rate (1998–2000).*

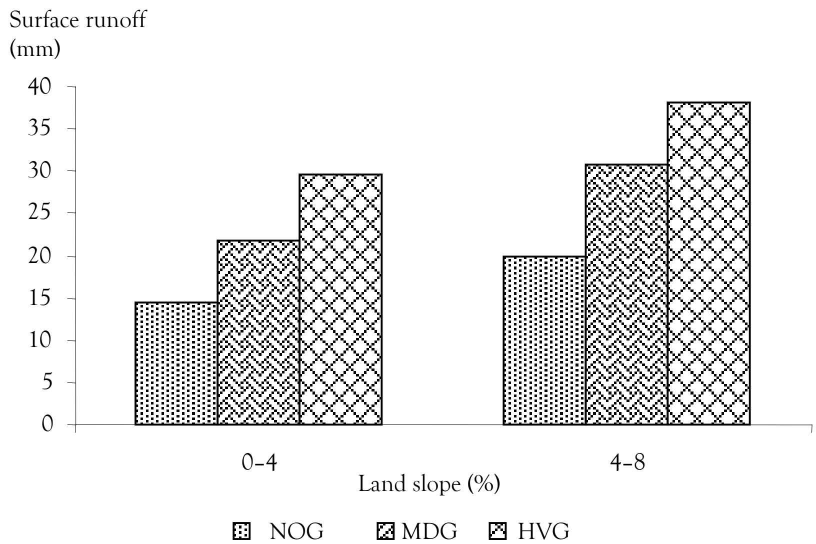

Figure 7. *Effect of grazing pressure on runfall (300 mm rainfall) at different land slopes.*

Table 3. Mean nutrient balance of the natural grazed pasture at smallholder farmer's level (kg/ha per year), 1996–99.

	0–4% slope			4–8% slope		
	In–Out			In–Out		
Treatment	N	P	K	N	P	K
NOG	52.2	8.7	62.66	–104.06	–13.69	–93.71
MDG	–361.07	–43.37	–234.52	–804.57	–116.26	–514.43
HVG	–587.87	–82.01	–383.73	–1043.36	–115.92	–671.71

Source: Adapted from Girma et al. (2001).

Conclusions

The biomass yield on non-grazed plots varied from 2.84–4.13 t/ha, and on grazed plots from 0.84–2.25 t/ha. Particularly, in medium-grazing pressure annual plant species coverage has improved significantly. The soil loss at 4–8% slope was high in heavily grazed plots. The infiltration rate was lower in heavily grazed plots.

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