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Research Paper

Effect of water harvesting and re-seeding on forage biomass production from rangelands in Sheikan Locality, North Kordofan State, Sudan

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Abstract. This study was conducted at Sheikan Locality, North Kordofan State, Sudan. The area has a unimodal annual rainfall of 300 to 400 mm occurring during July to October. The main economic activities are crop and livestock production. Livestock are raised either under sedentary or migratory systems where natural grazing is practiced. The dominant livestock species are sheep, cattle, goats and camels. This study aims to investigate effect of three water harvesting techniques namely contour ridges, runoff strips and flat (control); and two planting methods specifically reseeding and natural regeneration (un-reseeded) on forage biomass production, plant density and vegetation cover. Forage biomass production in the reseeded site was 3.65, 2.25 and 0.65 t/ha for the three treatments respectively. In the un-reseeded site the values were 2.85, 1.75 and 0.55 t/ha respectively ($P < 0.001$). A similar trend was found for plant density and plant cover. It was concluded that water harvesting and reseeding resulted in increased forage biomass production and plant cover from rangelands. The results were discussed in relation to effect of increasing soil moisture content on improving livelihoods and mitigating environmental degradation.

Keywords: Semi-arid, soil physical characteristics, range rehabilitation, gravimetric moisture, rangeland condition.

INTRODUCTION

The study was conducted in two growing seasons over two years (2009/10 to 2010/11) to assess the effect of water harvesting and re-seeding on forage biomass production and other parameters of rangelands condition in a semi-arid environment of North Kordofan State, Sudan. The objective of the experiment was to capture water run-off from sandy clay loam soils locally known as “gardud” for range improvement and to rehabilitate degraded environment in an area with an average annual rainfall of only 300 to 400 mm. These soils are characterized by hard compacted surface with high run-off potential resulting in inadequate water percolation that leads to poor establishment of natural vegetation and low forage biomass production.

Livestock production in pastoral areas is affected by numerous problems of which environment degradation is prominent. Environmental degradation is a world wide scenario for which pastoralists are often held responsible. A main determinant of livestock production is low forage production resulting from low soil moisture due to low total precipitation and also to poor water infiltration rate associated with the prevalent type of sandy clay soils locally known as “gardud”. These soils are widespread and are prone to excessive runoff. Water harvesting is thought to increase soil moisture content and hence pasture productivity.

Sheikan Locality is characterized by a short rainy season. It provides grazing area with limited grazing potential for nomadic or Baggara cattle owning tribes. The area is affected by vegetation misuse; over-grazing and excessive tree cutting. Frequent cyclic droughts are yet another hazard. The locality has a large area of sandy clay/loam soil locally known as “gardud” soils that are characterized by hard compacted soil surface with high runoff potential. It has a good water harvesting potential compared to sandy soil once treated. The runoff results in inadequate water percolation leading to poor establishment of natural range plants. This severely affected the rangelands vegetation, species composition and the vegetation biomass production. It is postulated that the introduction of water management techniques will accelerate the recovery of the range and may even reverse the present downward trend.

The situation is further aggravated by the high grazing pressure exerted by both sedentary and transhumant livestock during the growing season which adversely affected next year’s plant growth. The degradation of the rangeland vegetation in the study area has led to increase of short–lived un-preferred annual plant species rather than the palatable perennial species. The application of reseeding is seen as a suitable management practice that may increase the production of vegetation from rangeland thus leading to increased animal performance and productivity.

MATERIALS AND METHODS

Three treatments involving three methods of water harvesting were applied. These included runoff strips (ROS), contour ridges or bunds (CR) and flat as a control (C). Moreover the effect of re-seeding was compared with natural regeneration (un-reseeded range). A split plot design was thus adopted with water harvesting practices as main factor and reseeding as sub-plots with three replications. Plot size was 10 × 18.70 m, the area of each replication was10 × 56.1 m and the total experimental area was 0.42 ha. Contour ridges were established on 6 plots at mid-June just before the onset of rains (Bancy *et al.*, 2006); while ROS were established after receiving a few showers of rainfall after the soil became friable and suitable for reseeding (Hatibu and Mahoo, 1999). In June 2010 and July 2011and after the establishment of CR and ROS, seeds of rangeland species *Dactyloctenium aegyptium*, *Blepharis linarifolia*, *Crotalaria* spp*.* and *Aristida mutabilis* were broadcasted on 9 plots while the other 9 plots were left to regenerate naturally (un-reseeded). Forage biomass production (t/ha), plant density (plant/m^2) and vegetation cover (%) were then measured at the reseeded and un-reseeded sites to determine the effect of treatments on the various vegetation attributes.

At each of the 3 treatments in the water harvesting experiment 6 plots were located making 18 plots in all. Three quadrates of 1 × 3 m area were taken from each of the 6 plots making 18 quadrates/ treatment. Herbaceous vegetation within the quadrates was cut at 3 cm above ground level. Samples were dried at 105°C to constant weight. Plant density (plant/m^2) was measured in 18 quadrates from each treatment (Holecheck *et al.*, 2004). Plant cover was estimated by 3 observers in each quadrate covered by vegetation. Total vegetation cover within each of the 54 quadrates from all treatments was recorded over two seasons. Soil moisture samples were taken from each experimental unit (18 plots) at different depths (0 to 15, 15 to 30 and 30 to 45 cm) by an auger, at wet condition (2 days after rain) and after a long dry spell (15 days after rain). Samples were covered and taken to laboratory for gravimetric moisture analysis (Michael, 1978). Gravimetric moisture contents were calculated by expressing the percentage moisture on dry mass basis.

$$\text{Soil moisture content \%} = \frac{(a) - (b)}{(b)} \times 100$$

Where: (a) = Mass of moisture sample and (b) = Mass of oven-dry sample.

An analysis of variance was conducted as a mixed model with water harvesting as main treatments and planting methods as sub-treatments in a split plot deign with Duncan’s multiple range test for variable of SAS 1988.

Over the two seasons in the water harvesting experiment 18 quadrats per treatment were used to measure plant density by counting the number of plant/m^2 (Holecheck *et al.*, 2004).

$$\text{Plants density} = \frac{\text{Number of species A counted in all quadrats}}{\text{Total number of quadrats}}$$

RESULTS AND DISCUSSION

Rainfall pattern

Total annual rainfall was 304.5 and 297.8 mm in 2010 and 2011, respectively. Rainfall distribution was more even in 2010 (18 rainy days in 5 months) compared with 2011 (16 rainy days in 3 months). In 2010 rainfall was 18.0 mm in June, 121.1 mm in July, 108.6 mm in August, 28.0 mm in September, and 28.8 mm in October. In 2011 there were 58.9 mm in July, 160.0 mm in August and 78.9 mm in September.

Vegetation cover % at different water harvesting techniques

Table 1 illustrates vegetation cover at CR, ROS and flat at the two sites for two seasons. Differences between treatments in cover were highly significant ($P < 0.001$),

Table 1. Vegetation cover (%) under contour ridges, runoff strips and flat.

Treatments	Management system	1st season	2nd season	Mean for two seasons	Probability
CR	Reseeded site	88.3	83.5	85.9[a]	P < 0.001
	Un-reseeded site	83.3	76.7	80.0[a]	
ROS	Reseeded site	88.3	85.6	86.9[a]	P < 0.001
	Un-reseeded site	80.0	73.3	76.7[a]	
Flat	Reseeded site	46.7	31.1	38.9[b]	P < 0.001
	Un-reseeded site	33.3	18.9	26.1[b]	

flat being significantly lower than CR and ROS at both sites. At reseeded site mean cover for CR and ROS was 85.9% and 86.9% respectively; for flat it was 38.9%. At un-reseeded site CR and ROS also produced higher cover than flat. It is suggested that water harvesting enhanced vegetation cover by capturing and conserving more soil water compared with flat.

Plant density (plant/m²)

At reseeded range site plant densities were 262, 292 and 162 plant/m² for CR, ROS and flat respectively. At the un-reseeded site densities were 223, 236 and 124 plant/m² respectively (Table 2). In both range sites CR and ROS resulted in higher plant density compared with flat. Water harvesting treatments might have led to capture and conservation of more water than in the flat leading to good seed germination and seedling establishment thus the higher density. These results may be due to soil surface disturbance by chiseling at runoff strips and contour ridges, which led to capture and conservation of more water than in the flat. Various species were observed to grow in the chiselled plots indicating an increase in the biodiversity of species. In the contour ridges, disappearance of *Blepharis linarifolia* after the first month of germination may be due to water logging and the species is adapted to dry regions, but *Crotalaria* spp. and *Dactyloctenium aegyptium* are of normal growth. The result in the table also indicates that some plant species are responding better to water harvesting techniques than others. *Echinocloa colonum* for example had shown the highest plant density in most water harvesting techniques. Generally, when comparing the total plant densities on the reseeded and un-seeded plots under the different water harvesting techniques, there were no significant differences. It is clear that the determinant factor to range grass establishment and growth is the water conservation rather than the seeding or not seeding. It is probably that the seed bank contains enough seeds to establish good plant cover provided that water is available, which in this case secured by the water harvesting intervention.

Forage biomass production (t/ha) at contour ridges, runoff strips and flat

Forage biomass production is given in Table 3. Highly significant differences were observed between treatments; CR resulting in highest yields followed by ROS. Flat gave lowest yields. The results suggest that water harvesting allowed capture and conservation of water to support plant requirements for growth while at flat water could not be captured adequately. A similar result was obtained by Elsadig *et al.* (2008) who reported that, water harvesting gives a positive indicator to improve the rangeland characteristics in terms of quantity and quality. Hani *et al.* (2011) reported significantly higher forage biomass production within contour furrows than within crescent and V- shape water harvesting techniques. (Figure 1)

Soil moisture content (%) two days after rainfall

The results of soil moisture content two days after rainfall at different depths is shown in Figure 2. During the 2010 season, soil moisture content in CR, ROS and Flat was 15 to 25%, 10 to 21% and 2 to 5%, respectively. Differences between treatments in soil moisture content were highly significant (P < 0.001) suggesting that more water was retained by the terracing structures. This agrees with Elwaleed (2005) and Ahmed (2008) who reported significant differences in soil moisture content between water harvesting and control treatment.

At CR, soil moisture content was higher at depths of 0 to 15 and 15 to 30 cm than at a depth of 30 to 45 cm probably due to the concentration of water at the upper layers of soil. Runoff strips showed higher soil moisture content at 15 to 30 and 30 to 45 cm depths than at 0 to 15 cm depth. This may be because chiselling that used in runoff strips improved the physical characteristics of “gardud” soil such as soil porosity thus permitted more water to infiltrate into the soil. Similar results were reported by Ahmed (2008) who found an increase in soil moisture content under the chisel and ridge systems presumably due to surface modifying effect of these

Table 2. Plant densities (plant/m²) under different water harvesting techniques.

Scientific name	Type of plant	Reseeded range			Un-reseeded range		
		CR	ROS	F	CR	ROS	F
Ipomoea blepharosepala	Forb	12	16	8	19	13	7
Sesbania sesban	Forb	16	10	3	27	6	4
Echinocloa colonum	Grass	83	74	29	61	46	19
Crotalaria spp.	Forb	4	4	2	0	0	0
Indigofera spp.	Forb	4	3	2	4	4	2
Acanthus spp.	Forb	36	78	9	43	93	19
Ipomoea sp.	Forb	10	6	4	6	5	4
Tephrosia spp.	Forb	2	3	6	1	2	4
Dactyloctenium aegyptium	Grass	6	8	5	0	0	0
Commelinia subulata	Forb	0	1	2	2	1	0
Blepharis linarifolia	Forb	3	3	2	0	0	0
Schoenefoldia gracils	Grass	8	2	4	6	7	4
Corchorus olitorius	Forb	1	1	1	1	1	1
Cyprus spp.	Grass	6	0	0	5	0	0
Acanthospermum hespidum	Forb	7	5	2	6	8	2
Ipomea concinperma	Forb	1	1	0	0	1	0
Acacia nubica	Shrub	1	1	2	2	1	1
Indigofera aspera	Forb	1	0	1	1	1	0
Aristida mutablis	Grass	38	52	51	21	23	34
Cassia tora	Forb	0	1	0	1	1	0
Achryanthes aspera	Forb	1	2	0	1	0	0
Tribulus terrestris	Forb	0	1	8	1	0	5
Requienia obcordata	Forb	14	0	0	0	0	0
Eragrostis tremula	Grass	0	3	10	12	11	24
Pennisetum typhoidum	Grass	0	2	0	0	2	0
Cenchrus biflorus	Grass	0	3	0	0	1	1
Pennisetum pedicellatum	Grass	1	4	0	0	3	0
Farsetia longisclizua	Forb	1	2	1	0	1	1
Justicia kotschyi	Forb	1	1	0	0	2	0
Dicoma tomentosa	Forb	2	0	0	0	1	1
Polygala eriotera	Forb	1	1	2	1	1	1
Abutilon glaucm	Forb	1	0	0	1	0	0
Zornia glochidiata	Forb	1	3	8	1	1	8
Total		262	291	162	223	236	124

Table 3. Forage biomass production (t/ha) at CR, ROS and flat at reseeded and un-reseeded sites.

Treatments	Management system	1st season	2nd season	Mean	Probability
CR	Reseeded	4.1	3.2	3.65[a]	P < 0.001
	Un-reseeded	3.5	2.2	2.85[a]	
ROS	Reseeded	2.6	1.9	2.25[b]	P < 0.001
	Un-reseeded	1.9	1.6	1.75[b]	
Flat	Reseeded	0.7	0.6	0.65[c]	P < 0.001
	Un-reseeded	0.6	0.5	0.55[c]	

Table 3. Soil moisture content after two days of rainfall (12.6 mm).

Plot no.	Depth (cm)	Moisture %	Plot no.	Depth (cm)	Moisture %	Plot no.	Depth (cm)	Moisture %
	0 – 15	22.54		0 – 15	5.06		0 – 15	15.11
CR. 1	15 – 30	22.51	F. 1	15 – 30	3.28	RS. 1	15 – 30	21.41
	30 – 45	20.05		30 – 45	4.86		30 – 45	17.09
	0 – 15	23.87		0 – 15	5.22		0 – 15	10.79
CR. 2	15 – 30	22.59	F. 2	15 – 30	2.92	RS. 2	15 – 30	13.95
	30 – 45	17.31		30 – 45	3.65		30 – 45	11.59
	0 – 15	22.85		0 – 15	6.43		0 – 15	13.32
CR. 3	15 – 30	22.54	F. 3	15 – 30	2.85	RS. 3	15 – 30	17.68
	30 – 45	19.96		30 – 45	3.6		30 – 45	15.18
	0 – 15	25.36		0 – 15	5.83		0 – 15	10.71
CR. 4	15 – 30	24.89	F. 4	15 – 30	3.25	RS. 4	15 – 30	15.56
	30 – 45	17.55		30 – 45	4.53		30 – 45	14.64
	0 – 15	22.07		0 – 15	5.55		0 – 15	14.57
CR. 5	15 – 30	20.01	F. 5	15 – 30	3.85	RS. 5	15 – 30	17.74
	30 – 45	17.04		30 – 45	4.83		30 – 45	16.98
	0 – 15	17.40		0 – 15	4.34		0 – 15	14.48
CR. 6	15 – 30	17.07	F. 6	15 – 30	2.97	RS. 6	15 – 30	17.84
	30 – 45	15.85		30 – 45	3.01		30 – 45	16.89

*CR = Contour Ridges, RS = Runoff strips and F= Flat. *F value = 232.17. ***$P < 0.0001$.

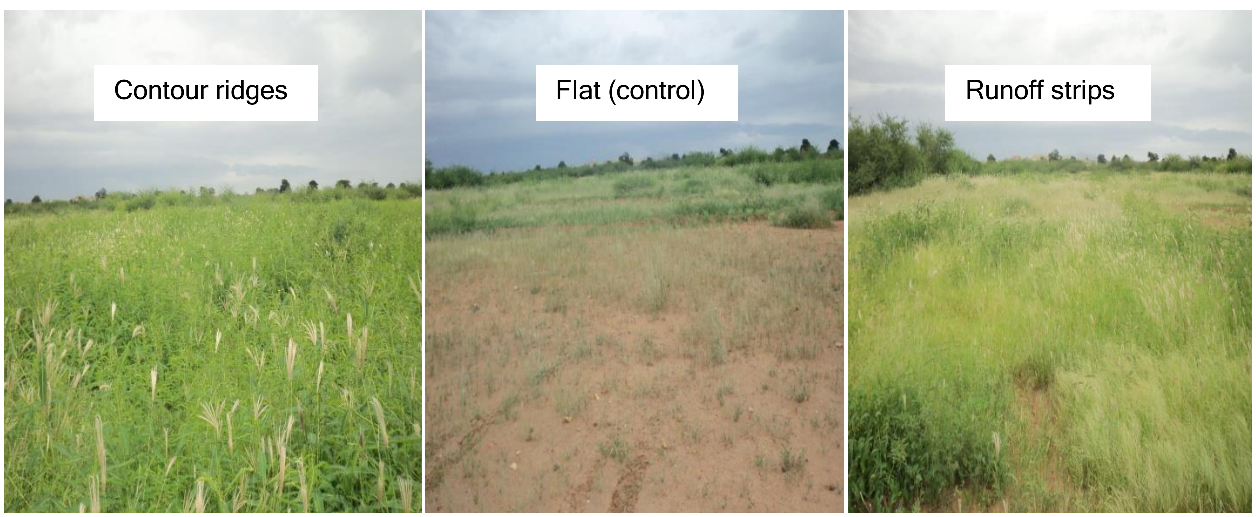

Figure 1. Vegetation cover on CR, flat and ROS.

tillage practices, which had improved the bulk density and increased soil porosity.

There were highly significant differences ($P < 0.001$) between treatments fifteen days after rainfall, CR showed the highest soil moisture % which ranged between 9 and 13% compared with ROS and flat which ranged between 3 to 5% and 2 to 3% respectively (Figure 3). At CR the upper layer 0 to 15 cm had higher soil moisture % than the 15 to 30 cm and 30 to 45 cm layers probably due to the concentration of water at upper layer of "gardud" soil. The second stratum of soil (15 to 30 cm) at ROS had higher soil moisture than the layers 0 to 15 cm and 30 to 45 cm probably because of infiltration of water into the soil due to chiselling practice. Soil moisture content was

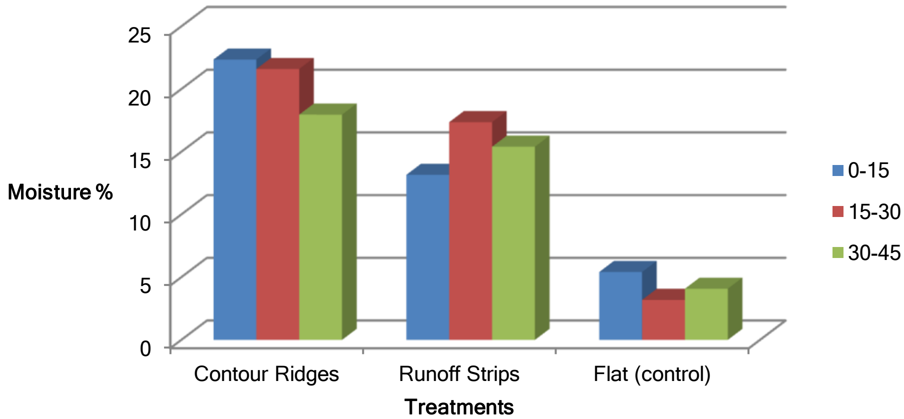

Figure 2. Soil moisture content two days after rainfall (12.6 mm) under three depths (cm).

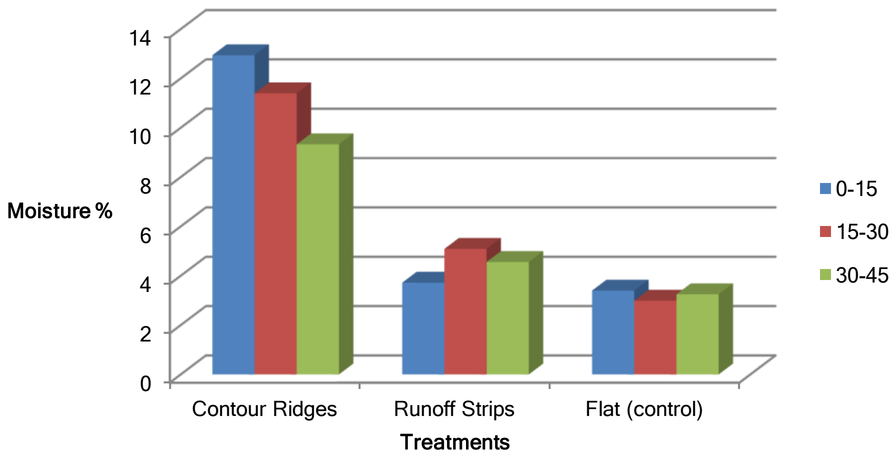

Figure 3. Soil moisture content at dry spell after 15 days of rainfall under three depths (cm).

Table 4. Soil moisture content at dry spell after 15 days of rainfall.

Plot no.	Depth (cm)	Moisture %	Plot no.	Depth (cm)	Moisture %	Plot no.	Depth (cm)	Moisture %
	0 – 15	14.65		0 – 15	4.42		0 – 15	4.14
CR. 1	15 – 30	14.21	F. 1	15 – 30	3.93	RS. 1	15 – 30	5.35
	30 – 45	13.31		30 – 45	4.36		30 – 45	4.82
	0 – 15	13.60		0 – 15	2.47		0 – 15	4.02
CR. 2	15 – 30	11.09	F. 2	15 – 30	2.31	RS. 2	15 – 30	4.41
	30 – 45	9.87		30 – 45	2.39		30 – 45	4.35
	0 – 15	15.22		0 – 15	2.79		0 – 15	3.81
CR. 3	15 – 30	12.98	F. 3	15 – 30	2.32	RS. 3	15 – 30	5.26
	30 – 45	10.35		30 – 45	2.70		30 – 45	5.00
	0 – 15	8.43		0 – 15	3.42		0 – 15	3.85
CR. 4	15 – 30	7.88	F. 4	15 – 30	3.11	RS. 4	15 – 30	5.43
	30 – 45	5.66		30 – 45	3.19		30 – 45	4.20

Table 4. Contd.

	0 – 15	12.96		0 – 15	3.68		0 – 15	3.14
CR. 5	15 – 30	10.71	F. 5	15 – 30	3.43	RS. 5	15 – 30	4.69
	30 – 45	8.22		30 – 45	3.63		30 – 45	4.26
	0 – 15	12.80		0 – 15	3.61		0 – 15	3.35
CR. 6	15 – 30	11.53	F. 6	15 – 30	2.81	RS. 6	15 – 30	5.43
	30 – 45	8.59		30 – 45	3.20		30 – 45	4.72

lowest at flat (control).

CONCLUSION

Application of water-harvesting techniques (CR and ROS) in soils with low water infiltration properties has improved soil physical characteristics, led to increased soil moisture content and enhanced forage biomass production. Water harvesting and reseeding also resulted in improved vegetation cover, plant density, relative density and frequency which suggest that these may be effective tools to increase forage biomass production from soils with low infiltration rate and high runoff potential, thus increasing livestock productivity and improving livelihoods in semi-arid environments.

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