THE INFLUENCE OF RANGE CONDITION ON THE HYDROLOGICAL CHARACTERISTICS IN A SEMI-ARID RANGELAND

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ABSTRACT

Herbage production, water-use efficiency (i.e. above-ground phytomass production per unit of evapotranspiration), surface runoff, deep percolation, soil loss and soil organic matter content were determined on rangeland in three different ecological conditions, viz. poor, moderate and good, for 20 years. Hydraulic non-floating lysimeters were used to determine evapotranspiration (Et), soil evaporation (E) and deep percolation. Runoff and soil loss were recorded on runoff plots. Above-ground phytomass production, water-use efficiency, deep percolation and soil organic matter content decreased ($P \leq 0.01$) when plant cover was reduced or range and soil condition declined. The dense plant cover of veld in good condition provides a situation in which surface runoff and soil loss rates are lower ($P \leq 0.01$) than that from veld in poor condition.

KEYWORDS

Evapotranspiration, organic matter, percolation, production, range condition, surface runoff, water balance, water-use efficiency

INTRODUCTION

In the extensive grazing areas of the Republic of South Africa, with a mean annual rainfall of 500 mm or less (about 65% of the rangeland in the country), water availability is the environmental factor most limiting to herbage production (Snyman, 1993). One of the important principles in sustainable rangeland production in semi-arid regions is efficient soil-water management (Snyman, 1994). In such areas with a water deficit during the year, its use must be carefully planned. An assessment of the extent and reliability of the water resources, using a soil-water balance model, is therefore necessary. Given the important role of available water on the productivity of the rangeland ecosystem, it is necessary to know how water-use efficiency is affected by different soil and range conditions. Thus, the aim with this investigation was to quantify the different factors affecting sustainable production in a semi-arid rangeland ecosystem.

MATERIAL AND METHODS

The research was conducted 5 km west of Bloemfontein (29°06'S; 26°57'E, altitude 1 350 m) which is situated in the semi-arid, summer rainfall (annual average 560 mm) region of the Republic of South Africa. The data were collected from a typical dry *Themeda - Cymbopogon* grassveld (Acocks, 1988). The fine sandy loam soil is that of the Bloemdal Form (Roodeplaat family - 3 200) (Soil Classification Working Group, 1991).

Veld in three different condition classes (good, moderate and poor) and undisturbed bare ground were studied with three replications for each treatment over a period of 20 years (1977/78 to 1995/96 seasons). The botanical composition and basal cover of the veld in each of the three veld condition classes were typical of those in the study area as being under practical farming situations in good, moderate and poor condition. The veld has been artificially kept for 20 years in the above-mentioned condition classes. After determining the basal cover, botanical composition and range condition as described by Snyman & Fouché (1993), all undesirable or invader species (with respect to each specific veld condition class) were removed with a minimum of disturbance.

Hydraulic non-floating lysimeters (0.80 m deep, diameter 0.60 m) (Snyman, 1994) were used to determine Et, E and deep percolation. Runoff and soil loss were recorded on runoff plots, measuring 2 m x 15 m with an average slope of 4.1%. At the end of each growing season (July), all plants in the different veld condition plots were clipped to a height of 30 mm. Water-use efficiency is defined as that quantity of above-ground phytomass produced per unit volume of water evapotranspired.

Composite soil samples were collected to depth of 300 mm at 50 mm depth intervals and analysed to investigate the organic (C) (Mebuis procedure) and total nitrogen (N) content (Kjeldahl method), as measures of organic matter content. Soil temperature was recorded once a week at ± 14:00 at 50, 100 and 150 mm depths in plots with veld in poor and good conditions using glass thermometers.

RESULTS AND DISCUSSION

The average veld condition score (expressed as a percentage of that in a benchmark site) over the experimental period ranged from 88.9% to 28.8%, and the basal cover from 8.3% to 2.9% (Table 1). Basal cover decreased linearly with deterioration in veld condition. The dense plant cover of veld in good condition, not only provides a situation in which runoff and soil loss rates are lower ($P \leq 0.01$) than from veld in poor condition ($P \leq 0.01$), but it also leads to efficient water use ($P \leq 0.01$), high production ($P \leq 0.01$) and relative sustainable soil organic matter (Table 1). It appears that in the arid and semi-arid areas, deep percolation only occurs under extremely high rainfall conditions (Table 1). The results of this study, spanning a period as long as 20 years, constitute the only long-term data set which included different veld conditions in the semi-arid rangelands of southern Africa.

It is cause for concern, that only 2 years after an induced change in the condition of the veld from good to poor, the organic carbon and total nitrogen content within the upper 50 mm layer declined by 4.3% and 9.3% respectively. The change in veld condition from good to moderate and poor induced a loss of 21% and 33% in organic carbon content respectively, with associated declined in total nitrogen content of 14% and 23%, in the upper 50 mm, within 15 years. Soil temperature increase as cover declines. Soil temperatures as high as 52°C at a depth of 50 mm have been measured on soil of veld in poor condition, compared with temperatures of only 44°C where the veld is in good condition. The temperature of the topsoil of veld in poor condition has been measured as high as 70°C. Such high soil temperatures can severely restrict the recovery of areas with a poor plant cover.

The veld in different conditions reacts differently to different amounts of rainfall. In terms of herbage production, veld in poor condition resulted in unefficient use of available water, leading to apparent droughts (man-made) (Snyman & Fouché, 1993) even during periods of reasonable rainfall. Herbage production was relatively low, even in years of high rainfall, when the veld is in poor condition. It increase as veld condition improved, even in dry years, but particularly in years which experience a good rainfall. These results confirm observations made by Le Houérou (1984) and Snyman (1994) that rain-use efficiency depends markedly on soil and range condition, which can range between 2 and 6 kg ha^{-1} mm^{-1} for well managed arid and semi-arid grazing lands.

Seasonal rainfall and veld condition score were regressed on seasonal above-ground phytomass production. This interaction is described by the highly significant ($r = 0.88$; $n = 57$; $P \leq 0.01$) equation:

$$y = -1195.13 - 9.49 X_1 + 4.91 X_2 + 0.064 X_1^2 - 0.004 X2^2 + 0.027 X_1 X_2$$

where y = seasonal above-ground phytomass production (kg ha^{-1})
X_1 = seasonal rainfall (mm) and
X_2 = veld condition score.

Evapotranspiration is a major component of the soil-water balance for arid and semi-arid rangelands (Table 1). Wight & Hanson (1990) in the USA and Snyman & Van Rensburg (1986) in southern Africa also estimated that as much as 93% to 96% of the incoming precipitation from rangelands in good condition was returned directly to the atmosphere as Et. The contribution of E to Et increased with veld degradation (Table 1). Soil evaporation is only 24%, 20% and 16% less, respectively for veld in good, moderate and poor condition, than the seasonal Et. The seasonal Et for the different veld conditions did not differ significantly (P>0.05) (Table 1). The relationships between the seasonal Et and the seasonal herbage production for each veld condition (Figure 1), were all highly significant ($P \leq 0.01$). Figure 1 clearly shows that the production of veld in a good condition increases markedly with an increase in Et.

Losses of soil organic matter can be attributed to reduced phytomass production, increased soil erosion and change in soil climate. The loss of soil organic matter from degraded veld may therefore inhibit veld recovery. This investigation illustrates the importance of good veld condition in order to prevent soil degradation, especially in the semi-arid regions. Veld condition and plant cover appear to be the two most important factors controlling runoff and soil loss, and in the semi-arid areas at least, they also have an important bearing on sustainable production and water-use efficiency. Since both are under the influence of management, whereas other controlling factors such as rainfall are not, they assure a central role in conservation management.

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Table 1

Production, hydrological characteristics and soil loss for different veld conditions, over the 1977/78 to 1995/96 seasons (Average annual rainfall: 530 mm)

	Veld condition		
	Good	Moderate	Poor
Basal cover (%)	8.3	6.4	2.9
Veld condition score (%)	88.9	63.5	28.8
Above-ground production (kg ha-1yr-1):			
Mean	1238**	768**	368**
Range	(313-2678)	(200-1633)	(15-889)
Evapotranspiration (Et)(mm yr-1)	496 NS	486 NS	472 NS
Average (et) (mm day-1)	1.73*	1.67*	1.55*
Highest (Et) (mm day-1)	7.42*	7.00*	5.95*
Et/soil evaporation (E)	1.32	1.25	1.19
Water-use efficiency (kg ha-1mm-1)	2.50**	1.58**	0.78**
Deep percolation (>0.8 m)			
(% of total seasonal rainfall)	0.5*	0.2*	0.1*
Surface runoff			
(% of total seasonal rainfall)	3.50**	5.55**	8.71**
Soil loss (ton ha-1 yr-1)	0.41**	1.20**	3.55**
Relative loss of organic C (kg ha-1)			
(degraded over 15 years)(upper 300 mm soil)	0	2659	5225
Relative loss of total N (kg ha-1)			
(degraded over 15 years) (upper 300 mm soil)	0	180	331

NS : non significant (P>0.05)
* : significant ($P \leq 0.05$)
** : significant ($P \leq 0.01$)

Figure 1
Relationships between seasonal above-ground phytomass production and seasonal evapotranspiration for rangeland in different conditions (n = 19). Equations:

Good condition: $y = e^{5.0562+0.0035x}$; r = 0.94; $P \leq 0.01$
Moderate condition: $y = e^{4.4384 + 0.0037x}$; r = 0.93, $P \leq 0.01$
Poor condition: $y = e^{3.0935 + 0.0047x}$; r = 0.76, $P \leq 0.01$.