Water-Use Efficiency and Infiltration under Different Rangeland Conditions and Cultivation in a Semi-Arid Climate of South Africa

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WATER-USE EFFICIENCY AND INFILTRATION UNDER DIFFERENT RANGELAND CONDITIONS AND CULTIVATION IN A SEMI-ARID CLIMATE OF SOUTH AFRICA

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Abstract

The objective of this study was to determine the impact of rangeland in different botanical composition classes (good, moderate and poor), on water-use efficiency (WUE: crude protein produced per unit of evapotranspiration) and soil-water content. The same measurements were also made on an undisturbed bare soil surface and soil cultivated twice per annum. Evapotranspiration was determined by quantifying the soil-water balance equation with the aid of runoff plots and soil-water content measurements done by a neutron hydroprobe. Water-use efficiency declined significantly ($P \leq 0.01$) with rangeland degradation. Rangeland in good condition averaged a WUE of 0.28 kg crude protein ha^{-1} mm^{-1}. Higher surface runoff occurring in rangeland in poor condition due to less vegetation cover, caused soil-water content to be much lower than that of grassland in good condition. Soil-water storage increased by 31% due to cultivation. The study shows it is important to keep rangeland in optimal condition to utilise limited soil water for sustainable plant and therefore animal production.

Keywords: soil-water content, water-use efficiency, runoff, evapotranspiration,

Rangeland condition, degradation

Introduction

The cyclic nature of the annual precipitation and the unreliable distribution of the seasonal rainfall of southern Africa, result in long extensive droughts and shorter seasonal droughts (Snyman, 1999). Accurate balancing of the stored soil water with the expected water deficit for rangelands in different condition is a means of lowering risk in fodder flow planning (Snyman, 1998). This requires a sound knowledge of the soil-water balance and the quantification of each component thereof. Although the farmer cannot control the rainfall on his farm, he can directly and/or indirectly influence its effectiveness, since rangeland condition is influenced by management practices. In calculating water-use efficiency, most researchers (Le Houérou, 1984; Snyman, 1998; Snyman, 1999) only express it in terms of the quantity of dry matter produced per unit water consumed, while its calculation in terms of crude protein produced per unit of water consumed, receives little attention at present. The latter calculation can make a large contribution to the estimation of short-term nutritive value of rangeland in a specific condition, given the quantity of rainfall received or water consumed. The aim with this study was to investigate the ability of rangeland to efficiently utilise limited soil water in a semi-arid climate and to identify the influence of rangeland degradation on water-use efficiency.

Material and Methods

The study was conducted in Bloemfontein (28^{o}50'S; 26^{o}15'E, altitude 1350 m), which is situated in the semi-arid summer rainfall (annual average 560 mm) region of South Africa. The data were collected from a typical Dry Sandy Highveld

Rangeland. The experimental layout was a fully randomised design consisting of five treatments with three replications. Rangeland in three different compositional classes (good, moderate and poor), undisturbed bare soil surface and a soil cultivated twice per annum were studies from 1995/96 to 1998/99 seasons. Rangeland condition was determined according to the method of Foran *et al*. (1978). Water-use efficiency (WUE) is defined as the quality (crude protein content) of dry matter produced per unit of water evapotranspired. Monthly herbage production that was determined for each rangeland condition class, by clipping 10 m^2 of plants in each treatment at the end of each month, was used to determine N-content following Kjeldahl digestion of the plant material in concentrated sulphuric acid. Crude protein content calculated from N-content of the whole aboveground organs (leaves, stems and seed), was determined in the middle and end of each month. Evapotranspiration was determined by quantifying the soil-water balance equation. The study involved 15 runoff plots, each measuring 2 m x 15 m, with an average slope of 3.5%. The soil water content was monitored with the aid of a neutron hydroprobe, at 200 mm depth intervals every fourth day.

Results and Discussion

The average rangeland condition score (expressed as a percentage of that in a benchmark site) ranged from 92.21% to 32.01% and the basal cover from 9.00% to 3.40% (Table 1). With rangeland degradation, Et decreased significantly ($P \leq 0.01$) (Table 1). Rangeland in good condition evapotranspired on average 22% more water than rangeland in poor condition. The bare uncultivated area had a 35% lower evaporation obtained from rangeland in good condition. The dense plant cover of rangeland in good condition proves a situation in which surface runoff and soil loss were lower ($P \leq 0.01$) than that from rangeland in poor condition (Table 1). After only three years of cultivation the A; B1 and first half of B2 horizon were filled to full storing capacity, while the rest of B2 horizon were only filled up to 60% storing capacity. Therefor the upper limit (drained upper limit) soil-water holding capacity of the layers 0 to 300 mm; 300 to 600 mm and 600 to 900 mm for this soil form are 68 mm; 73 mm and 80 mm. In all compositional classes, the soil-water content deeper than 900 mm, was only slightly supplemented over the growing seasons. These results confirm observations made by Fischer and Turner (1978) that deep percolation in semi-arid areas, only occurs under extremely high rainfall condition. The lower limit plant available water for the different layers 0 to 300 mm; 300 to 600 mm; 600 to 900 mm and 900 to 1200 mm for this rangeland ecotope are 15 mm; 25 mm; 28 mm and 22 mm.

The lower ($P \leq 0.01$) crude protein content found in plant material as rangeland condition improves, is possibly caused by the soil reserves of water being used for high dry matter production per unit area delivered by rangeland in good condition (Table 1). Though rangeland in poor condition had for most of the years a significantly ($P \leq 0.01$) higher seasonal percentage of crude protein, expressed in kg ha^{-1} was very low due to lower ($P \leq 0.01$) above-ground dry matter production accompanying rangeland degradation (Table 1). A general conclusion is that in semi-arid rangeland, annual primary production depends mainly on the interaction between rainfall and composition/basal cover (Snyman, 1999).

The monthly and annual WUE differed significantly ($P \leq 0.01$) between the different compositional stages for all growing seasons (Fig. 1 and Table 1). The highest seasonal WUE occurred during the 1996/97 seasons, during which rangeland in good, moderate and poor condition produced 0.34; 0.25 and 0.14 kg crude protein $ha^{-1}mm^{-1}$ respectively.

It is clear that rangeland degradation caused an enormous decrease in plant available water in the soil profile, specifically from the high runoff and high evaporation loss. This limited available water contributes to increase drought risks. Fodder flow planning and risk management are therefore much more complicated due to lower production and of rangeland in poor condition. The efficiency and risk with which rainfall is converted into plant production by fodder plants and eventually grass farming income, without deterioration of natural resources, forms the basis of sustainability of the rangeland ecosystem.

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Table 1 - Average hydrological characteristics for three rangeland conditions during the 1995/96 to 1998/99 seasons (** = significant at P≤0.01)

	Rangeland condition		
	Good	Moderate	Poor
Basal cover (%)	9.0	6.1	3.4
Rangeland condition score as (%) of benchmark	92	63	32
Evapotranspiration (mm yr^{-1})	530**	472**	436**
Surface runoff (% of total seasonal rainfall)	2.26**	10.77*	16.50**
Soil loss (t $ha^{-1}yr^{-1}$)	0.15**	0.49**	0.91**
Above-ground phytomass production (kg $ha^{-1}yr^{-1}$)	2 145**	1 317**	551**
Water-use efficiency (kg CP ha^{-1} mm^{-1})	0.28**	0.22**	0.11**

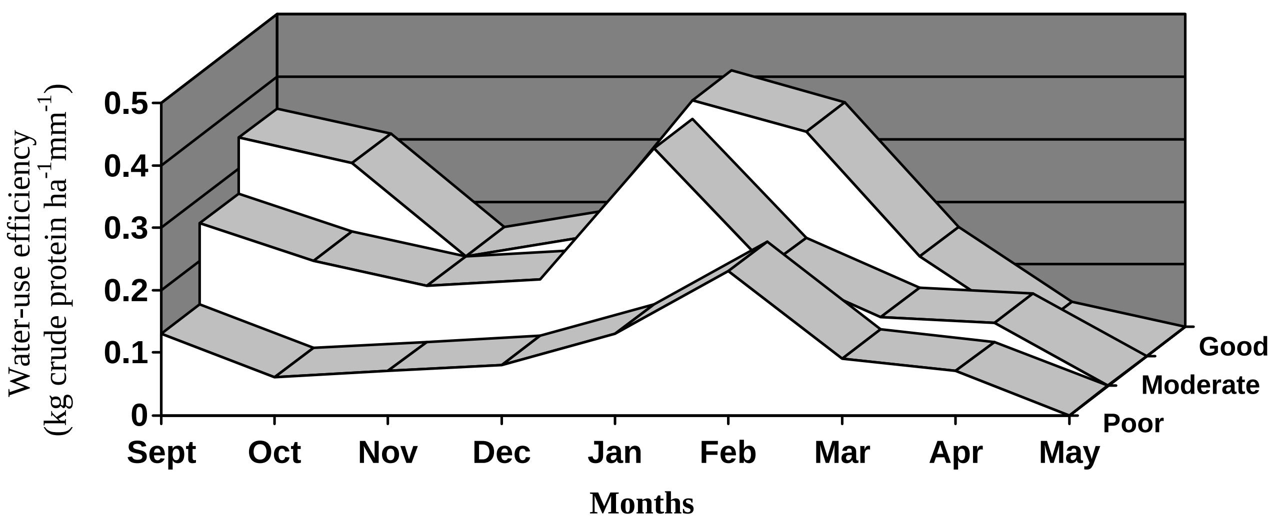

Figure 1 - Monthly average water-use efficiency (kg crude protein ha^{-1} mm^{-1}) for different rangeland conditions during the 1995/96 to 1998/99 seasons.