Production and water-use efficiency of semi-arid grasslands of South Africa as affected by veld condition and rainfall

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Abstract

Water is one of the most important determinants of plant production, especially under semi-arid conditions. In the past, pasture science researchers in South Africa paid very little attention to water-balance studies under semi-arid conditions, thus identifying the need for this study.

Plant production, runoff and water-use efficiency (i.e. above-ground phytomass production per unit of evapotranspiration) were determined on runoff plots on veld (rangeland) in 3 different conditions, over a period of 12 years. Evapotranspiration was calculated using the soil water-balance equation.

Runoff, water-use efficiency and plant production differed significantly ($P < 0,01$) among the veld conditions. High runoff and low water-use efficiency of veld in a poor condition resulted in apparent droughts, even during periods of average rainfall. Veld condition, rather than rainfall, appeared to be the more important factor controlling runoff and water-use efficiency.

Introduction

Of the total area of the Republic of South Africa (RSA), 85% consists of natural veld (rangeland). The extensive grazing areas of the RSA, with an average annual rainfall of 500 mm and less, comprise 65% of this veld (Snyman, 1985).

The production capacity of veld, per unit of water, in association with the stocking rate, was largely ignored in the past. The attention was focused more on the end products, rather than the determinants of the veld ecosystem. Of all the determinants of veld production, water is the most limiting in the arid and semi-arid regions (Snyman et al., 1987). 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 water-balance model, is therefore necessary.

Relatively little work in the RSA has been done with regard to water relations in the veld. Most of the research that has been undertaken in this field has mainly dealt with surface runoff. The early work on the interrelationship between vegetation condition, soil loss and runoff by Bennett (1945) and Scott (1951) has been added to quite appreciably in recent years in work on the effects of veld management practices on soil loss and runoff (Sherry, 1959; Haylett, 1960; Du Plessis and Mostert, 1965; Opperman, 1975; Snyman, 1985; Venter, 1988). Significant correlations between total rainfall and total annual runoff have also been recorded from undisturbed veld, moderately grazed veld and heavily grazed veld both in the RSA and Zimbabwe by Scott (1953), Hudson (1957), Haylett (1960), Du Plessis and Mostert (1965), Barnes and Franklin (1970) and Snyman and Van Rensburg (1986b).

In the RSA the first intensive water-balance studies on veld were done by Opperman and Roberts (1975); Opperman et al. (1977) and Snyman et al. (1980) in the central grassveld. The water-balance in 3 plant communities of a savanne ecosystem was determined by Moore et al. (1982; 1988). The aim of this study was to investigate the production potential and water-balance of veld under different conditions.

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Procedure

Experimental site

The research was conducted at Sydenham, the experimental farm of the University of the Orange Free State, 5 km west of Bloemfontein (29° 06'S, 26° 75'E; altitude 1 350 m) which is situated in the semi-arid, summer rainfall region (annual average 560 mm, of which 55% falls during the period January to April) of the RSA. In January the average maximum daily temperature ranges from 30°C to 33°C and in July it is approximately 17°C, but extremes of 41°C in January and 28°C in July have been recorded. On average, frost occurs on 119 d each year.

Grassveld typical of the dry *Themeda - Cymbopogon* veld (Acocks, 1988) was used for this study. The soil was that of the Shorrock Series (Hutton Form) (Macvicar et al., 1977). The three distinct horizons (A: 0 to 200 mm, B_2: 200 to 600 mm and IIB_2: 600 to 800 mm) contained respectively 10,6%; 19,0%; and 38,8% clay, and the respective bulk densities were: 1 484, 1 563 and 1 758 kg/m^3. The soil was representative of the sandy loams of the central Orange Free State on which most veld is situated.

Data collection

Three different veld conditions termed good, moderate and poor were studied. The data were collected over a period of 12 years (1977 to 1989).

The study involved 9 runoff plots, each measuring 2 x 15 m, with an average slope of 4,13%. Plot edging was done by overlapped short lengths of iron sheeting placed into the soil to a depth of 200 mm. The water was collected by a gutter fixed at the downslope end of each plot. An outlet from the centre of the gutter led to 1 200 ℓ water tanks (placed into the soil) in which sampling took place. The construction and use of runoff plots was described by Snyman and Opperman (1984) and Snyman (1985). The experiment was randomly designed with 3 replications for each of the 3 treatments.

The basal cover and botanical composition were determined with a bridge point apparatus (3 m long), with 20 points spaced 150 mm apart (Walker, 1970). At the end of every second season 500 points (strikes and nearest plant) were recorded per plot. The

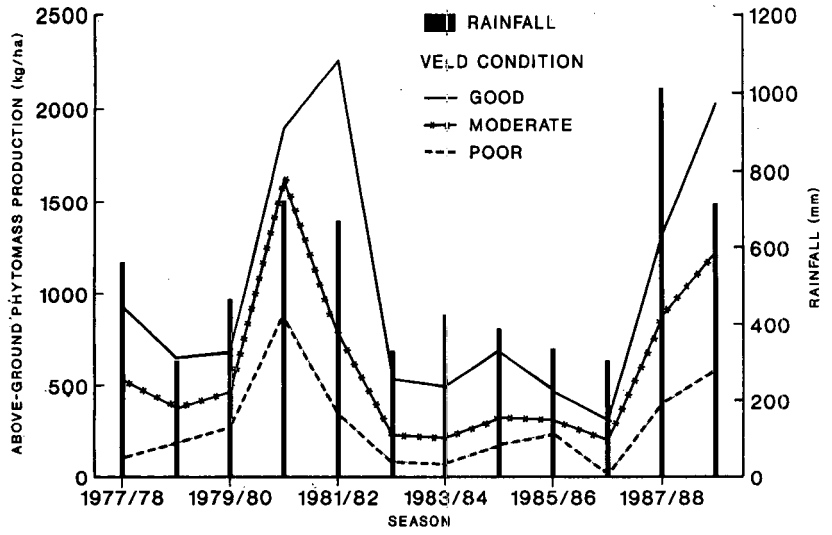

Figure 1
Seasonal above-ground phytomass production (kg/ha) for different veld conditions, and seasonal rainfall (mm) for the 1977/78 to 1988/89 seasons

botanical composition and basal cover of the 3 veld conditions in terms of classical Clementsian plant succession, were typical of those in the central grassveld area described by Snyman (1988) as being in a good, moderate and poor condition.

Range condition was determined according to Fourie and Du Toit (1983). When classifying the species, desirability in terms of grazing value (dry-matter production, palatability, nutritive value, whether it is a perennial or annual and grazing resistance) as well as ecological status (decreasers and increasers), as defined by Foran et al. (1978), were taken into consideration. The classification of Central Grassveld species into different ecological groups as described by Fourie and Visagie (1985), was used.

At the end of each growing season (July), all plants in every runoff plot were clipped to a height of 30 mm, to determine the water-use efficiency (WUE) for each veld condition. WUE is defined as that quantity of above-ground phytomass produced per unit volume of water evapotranspired. Evapotranspiration (Et) was determined by quantifying the soil water-balance equation (Hillel, 1971). Rainfall was measured daily with rain gauges. Deep percolation or drainage out of the root zone was measured using hydraulic non-floating lysimeters (0,8 m deep), as well as from soil water content measurements. These lysimeter studies of Opperman and Roberts (1975) and Snyman (1988; 1989) were conducted simultaneously, on the same soil type and under the same veld conditions as those of the present study. The soil water content was monitored with the aid of a neutron hydroprobe (model CPN 503). Two neutron probe access tubes were placed in the middle of each plot, to a depth of 1 m. The soil water content was monitored at 200 mm depth intervals. The neutron hydroprobe was calibrated for each horizon (Snyman et al., 1987).

Results and discussion

Botanical composition and basal cover

The average veld condition scores over the twelve-year period were, respectively 96,67%; 69,00% and 31,28% for veld in a good, moderate and poor condition. The corresponding average basal cover scores were 8,47%; 6,56%; and 2,86%, respectively. Decreaser species dominated the veld when conditions were good, comprising 68% of the total composition, of which *Themeda triandra* constituted 45%. Increaser II(a) species were dominant in veld in a moderate condition, comprising 70% of the total composition with *Eragrostis lehmanniana* comprising 38%. When in a poor condition, the botanical composition of the veld consisted of 65% Increaser II(c) species with *Tragus koelerioides* as the dominant species (48%).

Above-ground phytomass production

The seasonal above-ground phytomass production and total rainfall of each season (July to June) are shown in Fig. 1.

The average seasonal (July to June) rainfall over the study period was 521 mm compared to 560 mm for the long-term average seasonal rainfall in this area. The seasonal rainfall was above and below the long-term average, for 5 and 7 years, respectively. Two years with above-average rainfall were within 9 mm of the long-term average. During the 1978/79 and the 1986/87 seasons, rainfall figures as low as 306 mm were recorded. In contrast during the 1987/88 season the extremely high rainfall of 1 011 mm was recorded.

The average seasonal above-ground phytomass productions for veld in good, moderate and poor conditions were 1 022, 598 and 281 kg/ha, respectively. The phytomass production of the 3 veld conditions differed significantly ($P < 0,01$) each season. It is noteworthy that the lowest seasonal production measured on veld in a good condition (313,4 kg/ha) was even slightly higher than the average over the 12 seasons, of the veld in a poor condition (281 kg/ha). This suggests that veld condition and not only rainfall, is also an important determinant of production.

The highest production for veld in a good condition, recorded during the 1981/82 season (669,7 mm rainfall) was 2 255,6 kg/ha. The lowest recorded (15 kg/ha) was produced by veld in a poor condition during the 1986/87 season (306 mm rainfall).

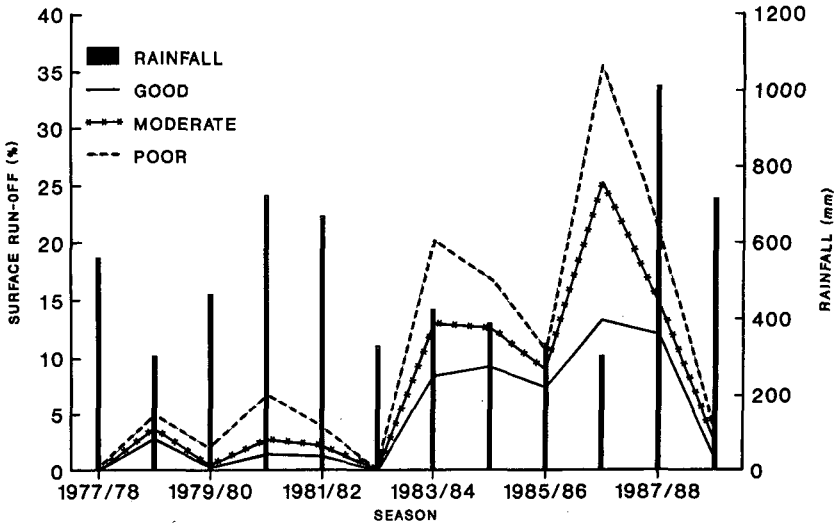

Figure 2
Seasonal surface runoff (expressed as a percentage of seasonal rainfall) for different veld conditions and the seasonal rainfall (mm) for the 1977/78 to 1988/89 seasons

Water balance

Surface runoff

The total seasonal surface runoff of each veld condition, expressed as a percentage of the total seasonal rainfall is presented in Fig. 2.

Over the 12 years 4,75%; 6,81%; and 10,21% of the average seasonal rainfall (520,4 mm) ran off good, moderate and poor veld, respectively. The runoff between conditions differed significantly ($P < 0,01$) each season. Surface run-off was highest during the 1987/88 season when 12,05%; 14,66%; and 21, 34% of the 1 011 mm rain was lost from veld in a good, moderate and poor condition, respectively. There were no runoff losses from veld in each condition during two seasons (1977/78 and 1982/83).

The annual average surface runoff on bare (unploughed) soil in the RSA can, according to Haylett (1960), Du Plessis and Mostert (1965) and Barnes and Franklin (1970), vary between 30 and 49% of the total annual rainfall. According to these respective authors and Opperman (1975) between 1,5 and 6,8% of the annual rainfall can be lost over a period of 10 to 27 years, from ungrazed veld in a good condition, with a red, sandy loam soil (3,5 to 5% slope). On heavily grazed veld, an average loss of 5,8% of the annual rainfall was recorded over a period of 18 years (Du Plessis and Mostert, 1965). Generally all the surface runoff results for the RSA are in agreement with the trend observed in this study, i.e. that it is lowest on densely covered veld. Snyman and Van Rensburg (1986a) found that the lower the basal cover, the smaller the effect of slope on runoff and concluded that the effect of slope on runoff is secondary to that of basal cover.

The heaviest and lightest falls producing runoff in this study measured 191 and 20 mm, respectively. The low and unreliable rainfall which is characteristic of the semi-arid areas, prevented any significant relationship between rainfall and runoff for any of the veld conditions. Surface runoff in the arid and semi-arid areas is greatly affected by factors such as the soil water content, before the rain and the intensity of the rain. Research over 7 years on the same runoff plots showed a significant relationship between surface runoff and the number of rainfalls with an intensity higher than 25 mm/h (Snyman and Van Rensburg, 1986b). Significant correlations between the total annual rainfall and total annual surface runoff on undisturbed veld and moderately and heavily grazed veld in South Africa and Zimbabwe have also been established by Scott (1953), Hudson (1957), Haylett (1960) and Barnes and Franklin (1970).

Deep percolation (drainage)

Throughout the study period, deep percolation beyond the root zone, i.e. deeper than 0,8 m, occurred only once in all the veld conditions during the 1987/88 season. The abnormally high rainfall of 475,5 mm in February 1988, which was 472% higher than the long-term average for that month, provided percolation water of 261, 210 and 142 mm for veld in a good, moderate and poor condition, respectively. According to Opperman et al. (1977) and Snyman (1988; 1989) deep percolation on veld in the arid and semi-arid areas only occurs under extremely high rainfall conditions.

Water-use efficiency (WUE)

The average WUE for each veld condition in every season is shown in Fig. 3.

During the study period the average WUE on veld in a good, moderate and poor condition was respectively 2,0; 1,2 and 0,6 kg/ha·mm. The WUE differed significantly ($P < 0,01$) between conditions within each season. The highest WUE, 3, 4 kg/ha·mm, was recorded for veld in a good condition during the 1981/82 season, which coincided with the highest production.

Over a four-year period, the average seasonal WUE of veld in a good, moderate and poor condition in the Central Grassveld was, according to Snyman (1988), 2,68; 1,58; and 0,93 kg/ha·mm, respectively. Under optimum soil water conditions, the respective WUE were 9,15; 7,55; and 5,65 kg/ha·mm (Snyman et al., 1980).

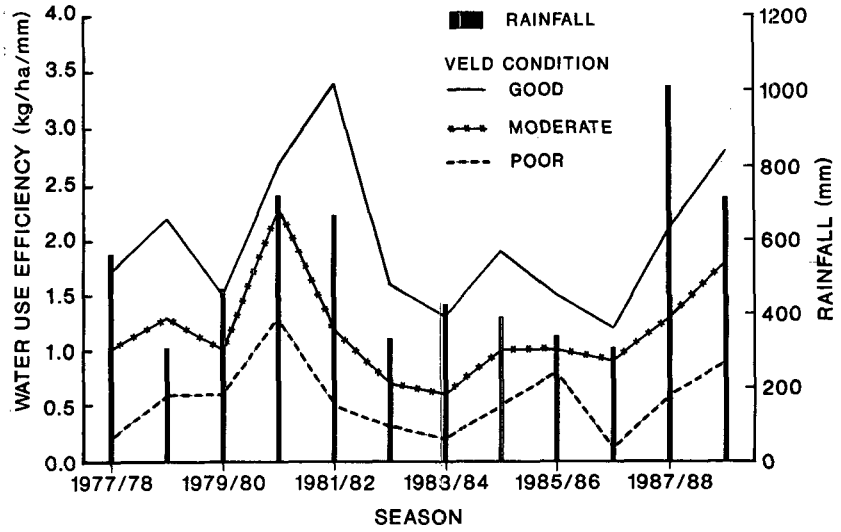

Figure 3
Seasonal water-use efficiency (kg/ha·mm) for different veld conditions, and the seasonal rainfall (mm) for the 1977/78 to 1988/89 seasons

The WUE results of the present study were lower than those reported for various veld conditions by Snyman et al. (1980), Snyman (1989) and Snyman and Van Rensburg (1990), which had been measured over a shorter period. The values obtained in this study can be regarded as long-term values for the various veld conditions. Secondly, the WUE data of this study also included the evapotranspiration which occurred during winter, which had not been taken into account by the previous authors. The present WUE results therefore apply to the soil water supply for the whole year and not only that during the active growing period.

Also significant in this study was the observation that the lowest WUE for veld in a good condition, the highest WUE for veld in a poor condition and the average WUE for veld in a moderate condition were all the same. It may therefore be concluded that irrespective of the quantity of rain, veld in a poor condition will be unable to convert rain into dry matter efficiently. This again emphasises the importance of veld condition supplementing rainfall in the actual production of veld per unit of water. The higher WUE observed with an increase in basal cover is in agreement with the conclusion of Snyman (1989), that the effect of plant cover on the WUE is just as important as the species itself.

According to Snyman (1989) climax species are better adapted in terms of water consumption for plant production, whereas pioneer species are adapted for survival and therefore use water less efficiently. Snyman et al. (1980) and Snyman (1988; 1989) found that veld in good, moderate and poor conditions utilises water more efficiently during early summer than during late summer.

Relationship between rainfall and WUE

The linear relationships between the seasonal WUE for each veld condition and the total seasonal rainfall (Fig. 4) were all highly significant ($P < 0,01$).

Figure 4 clearly shows that the WUE of veld in a good condition increases markedly with an increase in rainfall. Although the efficiency with which a climax grass consumes water is significantly affected by soil water content (Snyman 1988; 1989), Fig. 4 clearly illustrates that veld in a poor condition uses water inefficiently, irrespective of rainfall.

Conclusions

The results of this study demonstrate the importance of plant cover and veld condition. These appear to be the two most important factors controlling runoff and water-use efficiency and, in the arid and semi-arid areas at least, they also influence production. Since both are under the influence of management, whereas other controlling factors such as rainfall are not, they play a central role in conservation management. Veld condition of both the semi-arid Grassveld (Snyman, 1988) and False Thornveld of the Eastern Cape (Danckwerts, 1982) was reported as having seemingly the greatest effect on production and grazing capacity.

The high runoff and low production of veld in a poor condition result in a very poor utilisation of rainfall. This in turn leads to apparent droughts, during periods of even reasonable rainfall. Replacing undesirable with desirable species is definitely beneficial to improving the water-use efficiency of veld. Apart from natural droughts, injudicious grazing management practices contribute to an increased frequency and intensity of droughts, which were termed man-made or apparent droughts by Fouché et al. (1985). According to these authors, droughts will, theoretically, not occur at a stocking rate of 6,2 ha/LSU in the Central Grassveld of the RSA, whereas the probability of their occurence at a stocking rate of 3 ha/LSU is 72%.

The ecosystems of the arid and semi-arid areas of Southern Africa are subject to an erratic moisture supply, which results in substantial and unpredictable fluctuations in plant production and changes in the basal cover and botanical composition, especially in the herbaceous layer. With rapidly increasing demands to use land more economically and efficiently, procedures resulting in maximum production over the years, yet still minimising the stress on livestock and vegetation, especially during droughts, are urgently required. However, this is limited by inadequate knowledge and a comprehensive study of the effects of rainfall fluctuations on plant and livestock production, botanical composition and soil cover is long overdue. The low and unreliable rainfall in the arid and semi-arid areas must influence the validity of all experimental work done on a seasonal basis. The results of the present study, spanning a period of 12 years, number amongst the few, if not the only,

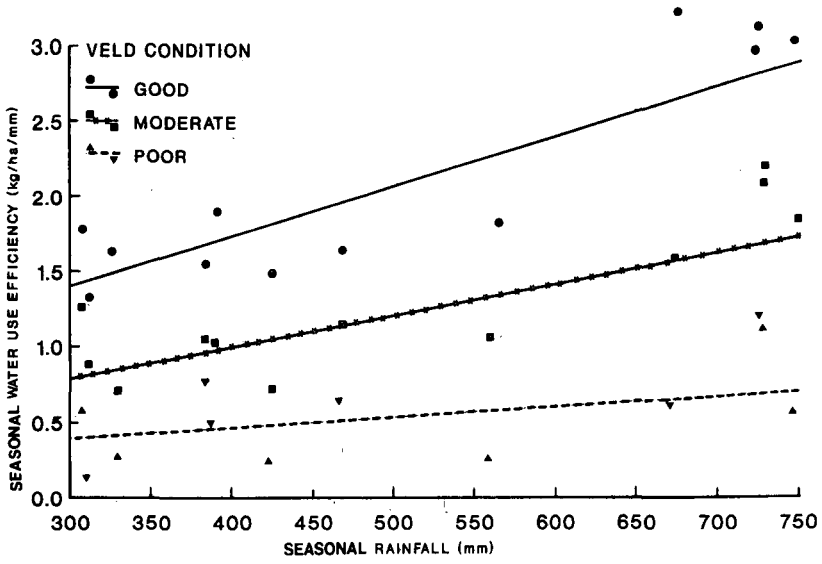

Figure 4
Relationships between seasonal water use efficiency (kg/ha·mm) and seasonal rainfall (mm), for veld in good, moderate and poor conditions (n=12). Equations:

- *Good condition*
  $y = 0{,}4281 + 0{,}0033\,x,\ r = 0{,}76^{**}$
- *Moderate condition*
  $y = 0{,}1436 + 0{,}0021\,x,\ r = 0{,}72^{*}$
- *Poor condition*
  $y = -0{,}0167 + 0{,}0012\,x,\ r = 0{,}55$

known in the RSA to include different veld conditions. Data concerning the effects of defoliation frequency and intensity on the water-use efficiency of veld in various conditions are urgently needed, since the results of Snyman and Opperman (1983) and Snyman (1985) were only of a preliminary nature.

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