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Root studies on grass species in a semi-arid South Africa along a degradation gradient

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ABSTRACT

Understanding changes in hydrological characteristics of rangeland ecosystems with degradation is essential when making rangeland management decisions in arid and semi-arid areas to ensure sustainable animal production. The impact of rangeland degradation on root production, root/shoot ratio and water-use efficiency was therefore determined for a semi-arid rangeland, over a 7-year period (1999/00 to 2005/06 growing seasons).

Water-use efficiency (WUE) is defined as the quantity of above- and/or belowground phytomass produced over a certain period of time per unit of water evapotranspired. Sampling was from rangeland artificially maintained in three different rangeland conditions, viz. good, moderate and poor.

As much as 86, 89 and 94% of the roots for rangelands in good, moderate and poor conditions, respectively, occurred at a depth of less than 300 mm. Root mass was strongly seasonal with the most active growth taking place during March and April. Root mass appears to be greater than aboveground phytomass for this semi-arid area, with an increase in roots in relation to aboveground phytomass production with rangeland degradation. The mean monthly root/shoot ratios for rangelands in good, moderate and poor conditions were 1.16, 1.11 and 1.37, respectively. Rangeland degradation significantly lowered above- and belowground phytomass production as well as the water-use efficiency. The mean WUE (root production included) were 4.79, 3.54 and 2.47 kg ha^{-1} mm^{-1} for rangelands in good, moderate and poor conditions, respectively. These water-use efficiency observations are among the few also including root production in its calculation. As a proportion of annual phytomass, litter fall of 7.17, 4.64 and 3.41% was obtained for rangelands in good, moderate and poor conditions, respectively. Increasing rangeland degradation increased the replacement of total root system by about 10 months and decomposition time of litter by 6 months.

The importance of a well-established root system for sustainable production in the semi-arid rangelands cannot be overemphasized.

1. Introduction

Actual water use depends on the balance of above- and belowground plant dimensions (Schenk and Jackson, 2002; Flemmer et al., 2003). Aboveground observations of plants are often used to make inferences about mechanisms that influence interactions among plants within a community and between seasons (Forteyn and Mahall, 1981; Knapp and Smith, 2001; Knapp et al., 2006). However, ecological interactions in arid ecosystems, such as competition and other factors that control plant distributions, primarily occur belowground (Brisson and Reynolds, 1997; Ghebrehiwot et al., 2006; Hartle et al., 2006; Palacio and Montserrat-Marti, 2007; Rodriguez et al., 2007a). Thus, extrapolating from aboveground observations to belowground functions can be misleading (Hartle et al., 2006). Little is known about seasonal patterns of root growth and their reaction to water stress (O'Connor and Bredenkamp, 1997; Snyman et al., 1997; Venter et al., 1997; Ekaya et al., 2001; Busso and Bolletta, 2007). In the past, plant ecological studies have largely concentrated on aboveground parts of the rangeland ecosystem (Snyman, 1998, 2005a; Holm et al., 2003; Fernández, 2007; Swemmer et al., 2007). However, belowground information is essential for predicting rangeland responses to seasonal patterns of rainfall, (Oesterheld et al., 2001; Snyder and Tartowski, 2006; Busso and Bolletta, 2007) especially on those with rangeland degradation (Flemmer et al., 2002a,b; Snyman, 2000, 2004a; Wiegand et al., 2004).

Ecologically sensitive arid and semi-arid areas are increasingly subjected to severe grazing pressure (Snyman and Fouché, 1991;

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O'Connor, 1994; Holm et al., 2003; Rodriguez et al., 2007b), causing their rapid degradation (Snyman and Fouché, 1993; O'Connor and Roux, 1995; Flemmer et al., 2003; Wilcox and Thurow, 2006). Degradation of semi-arid grasslands mostly follows a general pattern where grazing alters the species composition from long-lived perennials to annuals or short-lived perennials (O'Connor et al., 2001). Changes in species composition are also correlated with a decline in basal cover (Snyman, 1998, 1999a). Because of lower cover, greater runoff and soil and nutrient loss, overall productivity declines with increasing degradation, a pattern that is widely found in grasslands (Snyman and Fouché, 1991, 1993; Du Preez and Snyman, 1993, 2003; Milchunas and Lauenroth, 1993; O'Connor and Roux, 1995; O'Connor and Bredenkamp, 1997; Snyman, 1998; McNaughton et al., 1998; O'Connor et al., 2001) and other semi-arid vegetation types (Danckwerts and Nel, 1989; O'Connor, 1994; Hoffman and Ashwell, 2001). It is therefore essential to develop a better understanding of seasonal patterns of root growth, their production and how roots relate to the driving influences of water (Loik et al., 2004; Fernández, 2007). This information can serve as guidelines for sustainable utilization of the rangeland ecosystem in arid and semi-arid areas (Busso et al., 2003; Snyman, 2005a). Under rain-fed conditions, the available water should be used by the most appropriate plants in the most efficient way (Snyman, 1998). For example, in South Africa rangelands used for animal production and forestry utilize approximately 62% of the total annual rainfall (Snyman, 1999a).

The following hypotheses were tested: (1) aboveground plant production, (2) water-use efficiency, (3) root development and distribution in terms of depth and seasonality and (4) root and litter turnover vary depending on the degree of rangeland degradation. This research was conducted using three different plant communities in a semi-arid rangeland representing different histories of grazing intensity. Each plant community was further associated with a particular diversity and abundance of species.

2. Material and methods

2.1. Site description

The research was conducted in Bloemfontein (28°50′S; 26°15′E, altitude 1350 m a.s.l.), situated in the semi-arid region of South Africa. Rain falls almost exclusively during summer (October–April), with a summer mean of 560 mm, and a mean of 78 rainy days per year. Mean monthly maximum temperatures range from 17 °C in July to 33 °C in January, with a mean of 119 frost-days annually (Schulze, 1979). Precipitation events are usually intense, with the potential for substantial soil loss by runoff depending on plant cover (Snyman, 1999a).

The study area is situated in the Dry Sandy Highveld Grassland vegetation type described by Bredenkamp and Van Rooyen (1996). The botanical composition of the study site was determined from the 1995/96 to the 1998/99 seasons by Snyman (1999b) and Snyman (2000). Soils in the study area are mostly of the Bloemdal Form (Roodepoort family – 3200) (Soil Classification Working Group, 1991). Clay content increases with soil depth from 10% in the A-horizon (0–300 mm), to 24% in the B_1-horizon (300–600 mm) and 42% in the B_2-horizon (600–1200 mm). Bulk densities are 1484 kg m^{-3} for the A horizon, 1563 kg m^{-3} for horizon B_1 and 1758 kg m^{-3} for horizon B_2, and the upper limits for soil-water holding capacity are 69, 73 and 164 mm per horizon, respectively (Snyman, 2000).

2.2. Treatments

Rangeland in three condition classes (good, moderate and poor) was studied from 1999 to 2006. The three species composition states chosen closely reflect distinct species composition and basal cover arising from different grazing histories in this rangeland type (Potts, 1923; Mostert, 1958; Van den Berg et al., 1975; Snyman, 1988, 1997). Grazing is selective in this rangeland and this has lead to as a result of grazing mismanagement. This led to fundamental changes in community composition. A distinct species composition and basal cover therefore characterized each treatment. The good condition rangeland is dominated by the perennial bunchgrass *Themeda triandra*, the moderate condition rangeland is dominated by perennial bunchgrasses from the genus *Eragrostis*, and the poor condition rangeland is dominated by the stoloniferous perennial *Tragus koelerioides* and the short-lived perennial bunchgrass *Aristida congesta*. Good condition rangeland does not persist either in the absence of fire or moderate grazing intensity, and is transformed to moderate and then to poor condition rangeland through sustained, severe grazing (Mostert, 1958).

The experiment was established on an area that was initially in good condition and was not grazed during the experiment. From 1995 onwards, the rangeland was artificially maintained in three conditions described. The good condition treatment remained intact whereas the moderate and poor condition treatments were created and maintained by selectively pulling out individual tufts of species that were not characteristic of that condition, keeping soil disturbance to a minimum. Few plants had to be removed after the first 3 years and thereafter each rangeland condition was stable. Plant basal cover was not taken into account when establishing the three rangeland conditions to work on.

There were three randomly assigned replicates per compositional state (synonymous with treatment). Each experimental unit was 2 m × 15 m (laid out parallel to each other on their longest side), with a mean slope of 3.5%. A very detailed soil survey was done before assignment of the treatments to ensure that there was no spatial variation in soil (Table 1). Information on soil measurements and analysis done is described in detail by Snyman (2003).

Plot edging was achieved by overlapping short lengths of iron sheets, placed into the soil to a depth of 200 mm. Runoff water in each plot was collected with a gutter fixed at the bottom end of each plot, and sampled in 1000 L water tanks (placed into the soil). Botanical composition was determined by recording the plant nearest to 500 points in each unit during the growing season using a bridge-point apparatus (Walker, 1970; Snyman and Fouché, 1991). Basal cover, which is an index of lateral resistance of vegetation to runoff, was determined as the percentage strikes of these points.

Botanical composition was summarized as the percentage contribution of each species quantitative variable. Rangeland condition was determined according to the method of Fourie and Du Toit (1983) and Van der Westhuizen et al. (1999). When the species were classified, their desirability to animals in terms of grazing value (dry-matter production, palatability, nutritive value,

Table 1

Mean organic C total N, pH and nutrient content for the 0–50 mm soil layer before assignment of the treatments. Means ($n = 3$) within a soil property with identical letters are not significantly different at $P < 0.01$ based on Tukey test.

Soil property	Rangeland condition		
	Good	Moderate	Poor
Organic C (%)	1.024[a]	1.086[a]	1.055[a]
Total N (%)	1.002[a]	1.026[a]	1.022[a]
pH	5.86[a]	5.81[a]	5.80[a]
Ca (mg kg^{-1})	862[a]	851[a]	842[a]
Mg (mg kg^{-1})	164[a]	185[b]	159[a]
K (mg kg^{-1})	200[a]	211[a]	198[a]
Na (mg kg^{-1})	28[a]	28[a]	27[a]
P (mg kg^{-1})	2.33[a]	2.41[a]	2.01[b]