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Annual Net Primary Productivity of Different Functional Groups as Affected by Different Intensities of Rainfall Reduction in the Semiarid Grasslands of the Gauteng Province in South Africa

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Abstract: Rainfall variability is expected to change the soil water regime thereby impacting negatively on rangeland species composition, productivity and ecosystem services. The aim of this study was to assess the impact of different intensities of rainfall reduction (RR) on vegetation annual net primary productivity (ANPP). Twenty 7 × 7 m experimental plots with different intensities of RR structures consisting of transparent acrylic bands were built on a natural grassland. The interspaces between acrylic bands varied in size to intercept different intensities of ambient rainfall (0, 15, 30 and 60%) as RR treatments, with each RR treatment replicated five times in a complete randomised block design. A fixed 1 m^2 quadrat was marked at the centre of each plot and the ANPP within the quadrats was determined by harvesting the quadrant at the end of the growing season. Generally, as compared to the control (ambient rainfall intensity) the overall grass ANPP ($P > 0.05$) showed resilience to lower and moderate intensities of (15 and 30%) RR, but at a severe intensity of RR (60%) the ANPP was significantly reduced. Compared to the control the percentage contribution of grasses towards the overall ANPP increased at a lower intensity of RR (15%). In contrast, the percentage contribution of forbs towards the overall ANPP significantly reduced at lower intensity of RR. Within the grass species, however, those grasses that decrease when the veld is undergrazed or overgrazed (decreaser grass species) showed resilience at lower intensity (15 and 30%) of RR, while at a severe intensity of RR the ANPP of decreaser grasses were significantly reduced (1841 vs. 220 kg DM/ha). Those grasses that increase with undergrazing or overgrazing (increaser I or increaser II grass species) recorded a higher ANPP at moderate intensity of RR (30% RR) than at a higher intensity of RR, while the difference between 60% RR and 0% RR in terms of increaser grasses ANPP were not significant ($P > 0.05$) (650 kg DM/ha). Up to 88% reduction in ANPP were recorded for decreaser grass species at severe intensity of RR as compared to the control the corresponding reduction in ANPP noted for increaser grasses were relatively less (up to 56% reduction in ANPP at 60% RR vs. 0% RR). Generally, the overall ANPP yield of the semiarid grassland in Gauteng province showed resilience to a low intensity of RR (15% RR) and moderate intensity of RR (30% RR) partly due to a shift in the species composition of grasses from decreasers to increasers ecological groups, as well as due to a decrease and an increased contribution of forb functional groups at a lower and moderate intensity of RR, respectively.

Keywords: ANPP; decreasers; ecological status; forbs; grass

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1. Background

The global climate models forecast an increase in frequency and climate extremes [1]. Those extremes include drought. Drought can be defined as a natural hazard which is complex in nature and characterised by below-average rainfall beyond a given threshold over a period of time, impacting society and ecosystems in different ways [2,3]. Drought is classified into four types, namely: hydrological, socioeconomic, meteorological and agricultural. The focus of our study is on the meteorological drought, which occurs as a result of rainfall reduction (RR) for a prolonged period of time [4]. There is evidence that change in precipitation alters natural resources such as trees and grass productivity [5,6]. Water availability also affects terrestrial species composition as some of these species have now shifted their geographic occurrence and abundance as a result of changes in species interactions associated with the climate change [5]. The forecasted global increase in land surface temperatures is expected to be between 1.1 and 6.4 °C by the end of the century [7]. This increase in temperatures is expected to affect rainfall amount and/or patterns, which in turn will lead to more rainfall variability and the occurrence of extreme precipitation events [8]. Rainfall variability will have a significant impact on soil moisture availability, which in turn influences annual net primary productivity ANPP and ecosystem productivity [6,9]. Rainfall variability includes rainfall intensity (ratio of the total amount of rain falling during a given period to the duration of the period), duration (period of time during which continuous rainfall is observed) and frequency (number of times that rain occurs during a specified period of years). In this study, we focused on the impact of rainfall intensity.

Climate change in the form of floods, storms and droughts have adverse socioeconomic impacts on human and animal welfare mainly through its effect on primary productivity and animal production and services from the grassland ecosystem [8]. Developing countries such as South Africa with scarce resources for adaption and mitigation strategies are most likely to be affected by these threats [10]. Extreme rainfall variability and events such as droughts are already evident from the reports of recorded shifts in intra-annual rainfall patterns [6]. The major factor that controls the grassland ecosystem and structure globally is the climate [9], and of which rainfall plays a major role in the semiarid and arid environments. Rainfall variability and/or events affect soil water content, which in turn alters the primary productivity of grassland ecosystem in semiarid and arid environments. Grasslands are likely to respond rapidly and strongly to variability and extreme precipitations, as this determines soil water content [11].

The sustainability and productivity of natural grasslands mainly depend on rainfall and temperature, and these will be affected by forecasted warmer temperatures and forecasted reduction in precipitation [12,13]. When severe reduction in precipitation is accompanied by higher temperatures it is likely to lead to more frequent and intense droughts [14], which in turn will lead to plant deterioration that will lead to grassland degradation [15]. Perennial forage species are the ones that are often expected to grow under reduced precipitation [13]; however, only plants with drought survival strategies will adapt best under increasing RR conditions [16]. It is argued that different grass species and genotypes use different strategies to tolerate and avoid drought stress as a result plant responses to drought are poorly understood and described [17]. Some ecological groups of grasses decrease with undergrazing or overgrazing (referred as decreasers) while others grass species increase with undergrazing or overgrazing (referred to as increasers). The intensity of aboveground biomass harvested by animals affects the root size. Because decreasers are frequently consumed, they may have less vigor and less root biomass, which makes them disadvantaged to extract soil water as compared to increaser grasses that are less grazed and thus may have well-developed root systems. It is reported that rainfall reduction also reduce decreasers and increase increasers [18]. Increasers use rainfall more efficiently than decreasers due to well-established leaf areas as a result of lower defoliation frequency and intensity associated to their lower palatability, while decreaser species, often highly palatable, are expected to have less leaf area due to more frequent and intensive defoliations of the leaves. Hence, increasers are considered more tolerant to grazing than decreasers. Drought may lead to physiological and morphological plant modifications [19]. However, most genotypes that survive in most arid regions are the ones that become dormant in winter [20,21]. Under limited resources, growth of individual plants is also affected by the neighbouring plants [22]. Thus, resource availability will regulate the plant community and this is the main contributing factor to the abundance of forbs during or after a drought [22].

Climate change has triggered many studies around the world, which include studies that determine the impact of reduced rainfall on rangeland productivity. Rainfall in South Africa will decline by about 15% by the end of the 21st century [23]. There are few studies conducted in Africa in general and South Africa in particular that show the impact of such amount of RR on species composition, primary productivity and overall productivity of the grassland ecosystem. The increasing RR in South Africa remains poorly described, although there is some evidence that the vegetation is changing due to climate change [3,18]. In particular, it is important to evaluate the long-term effect of intensity of RR on semiarid grasslands as there is less information on this topic at regional scale in South Africa. This study complements the previous study reported by [18] for the same grassland that evaluate the impact of intensity of RR and resting period on rangeland productivity over the different seasons. Unlike the previous one [18], this study investigates how intensity of RR will affect the overall annual net primary productivity and the ANPP of different ecological and functional groups in the grassland. It generates some evidence on how the forecasted reduction in rainfall will affect the South African grassland productivity, species composition in terms of ecological grouping and functional groups, and how the farmers should manage their grasslands in the future under different intensities of rainfall reduction scenarios.

2. Materials and Methods

2.1. Site Description

The study was conducted in a semiarid natural grassland at the University of Pretoria, Hatfield Experimental Farm (Figure 1). The farm is situated at an altitude of 1372 m above sea level. The coordinates of the study sites are 25°45′ S and 28°16′ E. The farm is situated in a summer rainfall area with a long-term annual precipitation of 674 mm. The soil at the farm is categorized as being sandy loam with 20–35% clay [24] and a pH of 5.1. The soil is noncalcareous with a homogenous red colour, weak structure and is of Hutton form [25]. The study site has not been grazed for more than 65 years.

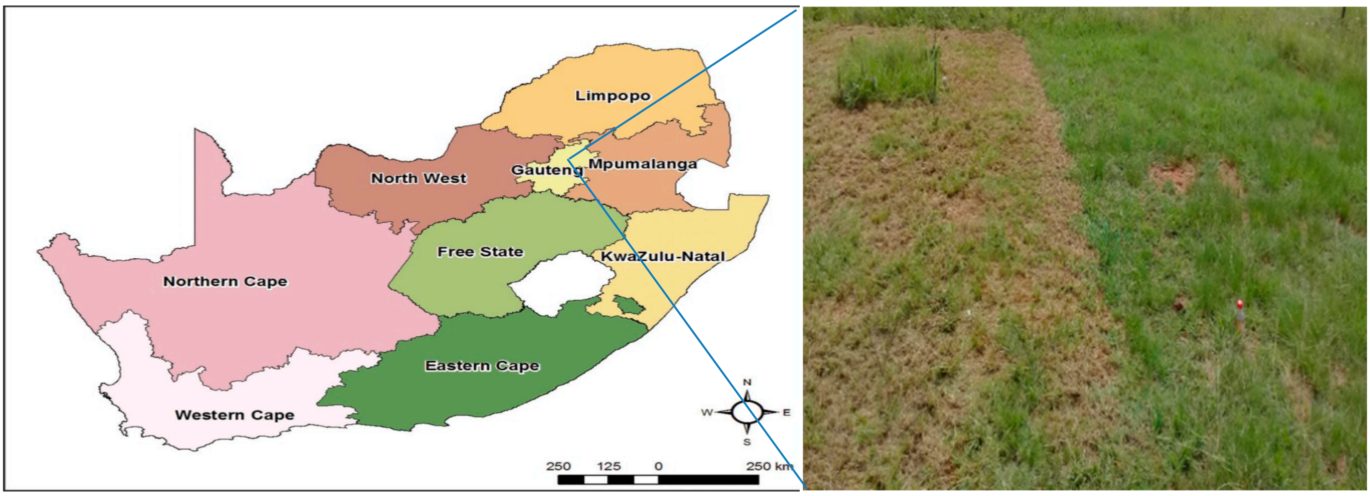

Figure 1. South Africa map showing study site (https://geology.com/, accessed on 11 February 2021).

2.2. Experimental Design and Data Collection

The long-term experimental rainout shelters have been in existence since 2013 (Figure 2). Twenty 7 × 7 m experimental structures (plots) consisting of transparent acrylic bands were built on a natural grassland (Appendix A). Rainfall reduction was conducted at four different intensities namely (0, 15, 30 and 60%) using the rainout shelters for each treatment that were replicated five times in a complete random block design (Figure 2). Different intensity of rainfall reduction was achieved by intercepting the ambient rainfall using a different number of acrylic bands fixed per rainout structure. A fixed 1 m^2 quadrat (Figure 2a) was marked at the centre of each plot and the ANPP within the quadrats was harvested once at the end of the growing season every year (year 1 and year 2). The bands were constructed with a longitudinal plate of 120° angle at the top and a mean height of 1 m at the lowest sides of the shelter. A 25 cm ditch was excavated along the structures to avoid water runoff into the plots. Water was collected from the acrylic material and channeled through the gutters away from the neighbouring plots. The vegetation was cleared at the height of 5 cm above the ground at the beginning of the experiment for all the plots during November 2016. This was done to ensure that the experiment was started at the same growth height. The ANPP samples harvested to determine annual net primary productivity (ANPP) were taken in November 2017 and 2018. A 1 × 1 m quadrat of ANPP was harvested from each plot. The harvested ANPP samples were oven-dried to a constant weight at 60 °C for 72 h [24]. Plants were grouped into functional groups (grasses and forbs). Grasses were further grouped into ecological statuses: (1) decreasers- those grasses abundant in a veld that is in good condition but decrease when the veld is undergrazed or overgrazed; and (2) increasers- those grasses that increase due to undergrazing (termed as increaser I) or overgrazed (termed as increaser II). The former include mostly pioneer and subclimax species, and they are also common in lower rainfall areas [26]. This was done because different grass ecological groups respond in different ways to different levels of grazing [26] and rainfall (Table 1). Rainfall was recorded after every rainfall event using a rain gauge (Figure 3).

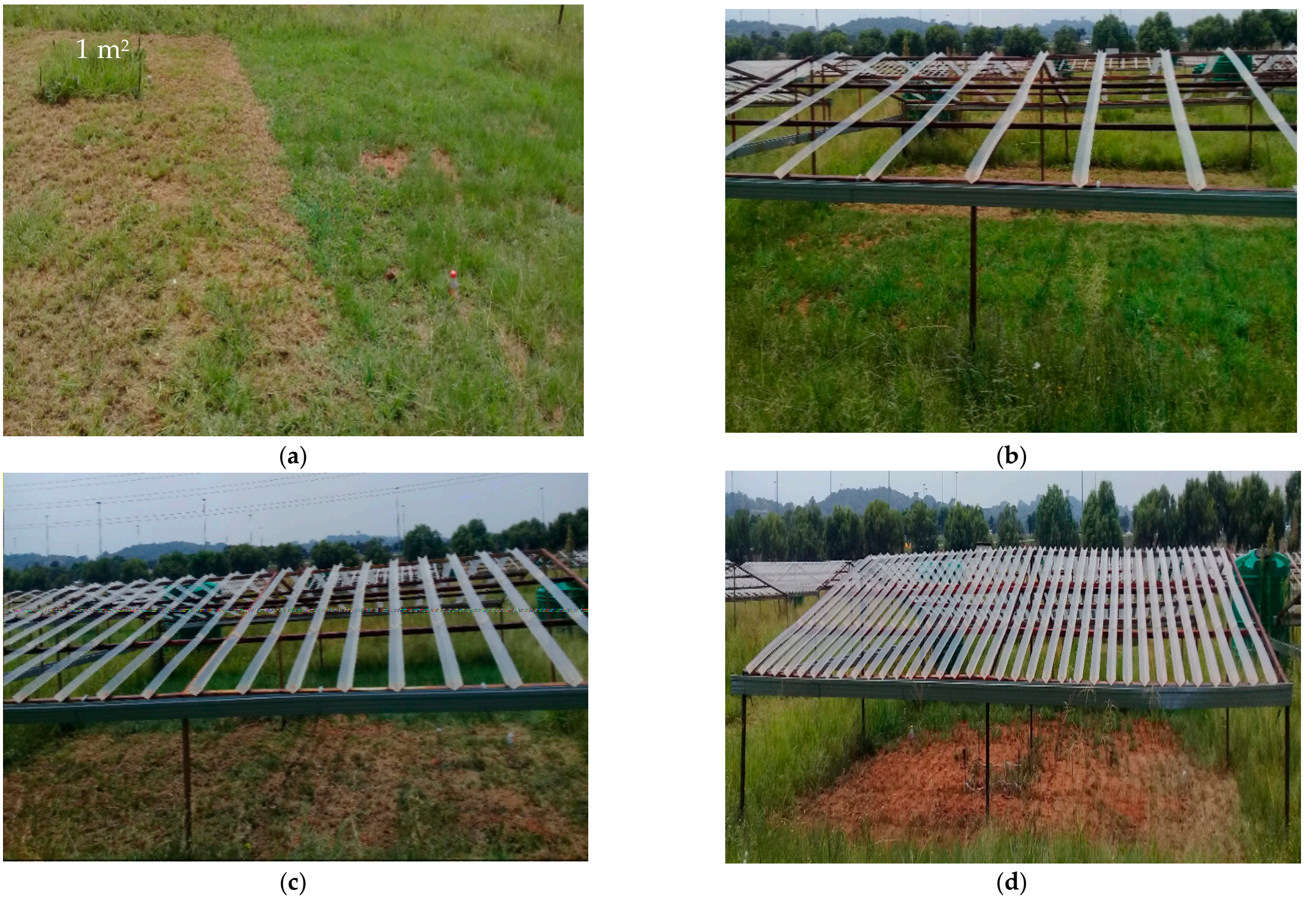

Figure 2. Experimental design: (**a**) 0% rainfall reduction, (**b**) 15% rainfall reduction, (**c**) 30% rainfall reduction and (**d**) 60% rainfall reduction.

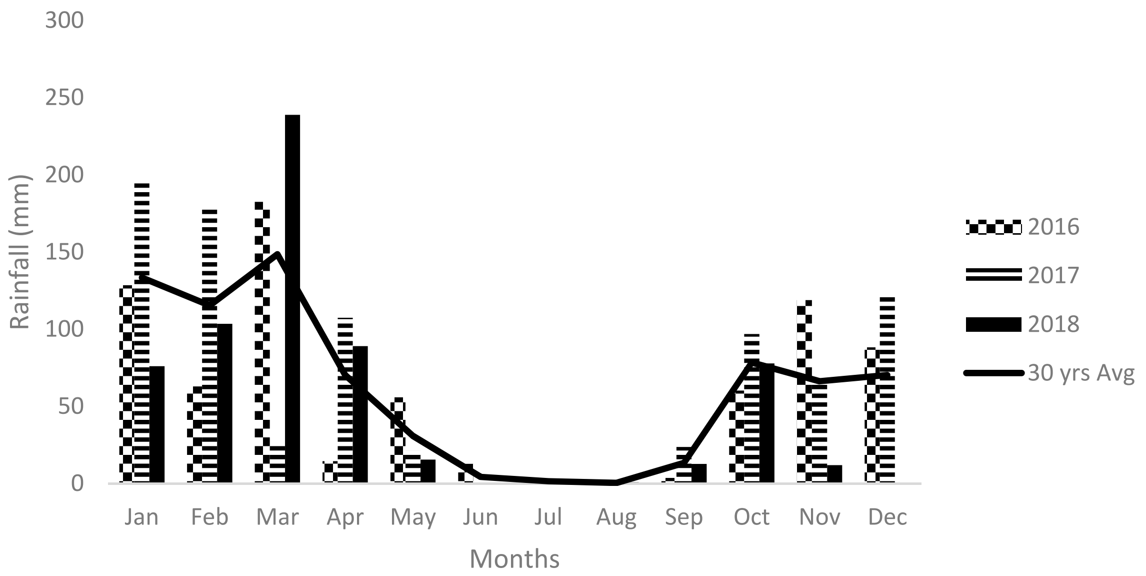

Figure 3. Rainfall distribution across different months and years.

3. Statistical Analysis

The data on the ANPP were subjected to the general linear model (PROC GLM) procedure of [27] to determine the main effects of the RR intensities on overall, species functional (grasses and forbs) and ecological (decreasers and increasers) groups' ANPP. The blocks were added as a random factor in the model; however, they are not reported on the results section because there were no significant interactions between rainfall reductions and blocks. Data were tested for normality and homoscedasticity using the Shapiro–Wilk test. Where the factors showed a significant effect on the ANPP, Tukey's test was used for mean separation at a significance level of 5%. The results were reported as a mean ± standard error. Principal component analysis (PCA) was used to conduct ordination between treatments and grass species. Species that were identified in different treatments were used for PCA. Only grasses that were common in all of the treatments were included in the PCA, while forbs were not included because they were not identified at species level. All the RR intensities were included in the analysis. The ordination analysis was executed using Past3 software.

4. Results

Increaser grasses such as *Eragrostis curvula*, *Cynodon dactylon* and *Heteropogon contortus* occurred more at 30 and 60% RR (Table 1). On the other hand, decreaser grass species such as *Digitaria eriantha*, *Setaria sphacelata*, *Setaria nigrirostris* and *Themeda triandra* occurred more at 0, 15 and/or 30% rainfall reduction. Moreover, forbs such as *Nidorella resedifolia* and *Ipomoea crassipes* occurred mostly at 30 and 60% RR, while a shrub, which is *Elephantorrhiza elephantina,* was more common at 30% rainfall reduction.

In both years, control plots (Y1RR0 and Y2RR0) were on the forth quadrat of the principal component analysis (PCA) in terms of densities per square metre (Figure 4). This means that the control plots responded the same in both years. Meanwhile, the 15% RR plots (Y1RR15 and Y2RR15) were on the first quadrat in both years. This means that there were no differences in these plots in both years. However, 30% RR plots (Y1RR30 and Y2RR30) are on different quadrats. This means that there were differences in way these plots were affected between 2017 and 2018. Moreover, 60% RR plots (Y1RR60 and Y2RR60) were on different quadrats. The 60% RR did not respond the same way in 2017 and 2018. T15 favoured *E. curvula*, *D. eriantha* and *H. contortus*. In 2017, both Y1RR30 and Y1RR60 favoured *I. crassipes*, *E. elephantina*, *N. resedifolia*, *B. pilosa* and total forbs densities, while 60% RR favoured *C. dactylon* in 2018. The 0% RR favoured decreaser grass species and the total densities.

Table 1. Ecological status, presence or absence and level of occurrence of grass/forb species in the various plots subjected to different intensities of rainfall reduction at the University of Pretoria experimental farm.

Scientific Names	Functional Group	Life Form	Growth Form	Ecological Status	Grazing Value	Intensity of Rainfall Reduction (%)			
						0	15	30	60
Aristida congesta	Grass	WP	Tufted	Increaser II	Low			+	++
Brachiaria serrata	Grass	P	Tufted	Decreaser	Ave			+	
Melinis repens	Grass	P	Tufted	Increaser II	Low		+	+	
Cynodon dactylon	Grass	P	Creeping	Increaser II	High		+	++++	+++++
Digitaria eriantha	Grass	P	Tufted	Decreaser	High	+++++	+++++	++++	+++
Elephantorrhiza elephantina	Forb	P	-	Shrub	Low		+	++++	
Rhynchosia monophylla	Forb	P	-	Increaser II	Low	+			
Eragrostis curvula	Grass	P	Tufted	Increaser II	Eve	+++	++++	+++++	+++++
Heteropogon contortus	Grass	P	Tufted	Increaser II	Ave	+++	+	+++	+++++
Hyparrhenia hirta	Grass	P	Tufted	Increaser I	Low			+	
Hypoxis hemorocallida	Forb	A	-	Invader	Low	+			+
Ipomoea crassipes	Forb	A	-	Invader	Low	++	+	++++	+++++
Nidorella resedifolia	Forb	A	-	Invader	Low	++	++	++++	++++
Setaria nigrirostris	Grass	P	Tufted	Increaser II	Low	++++	++	+++++	
Setaria sphacelata	Grass	P	Tufted	Decreaser	High	+++++	+++++	+++++	++
Themeda triandra	Grass	P	Tufted	Decreaser	High	++++	+	++++	
Verbena officinalis	Forb	A	-	Invader	Low				++

WP = weak perennial, P = perennial, Ave = average, + = appearing in one of the five replicates, ++ = appearing in two of the five replicates, +++ = appearing in three of the five replicates, ++++ = appearing in four of the five replicates, +++++ = appearing in all five of the five replicates.

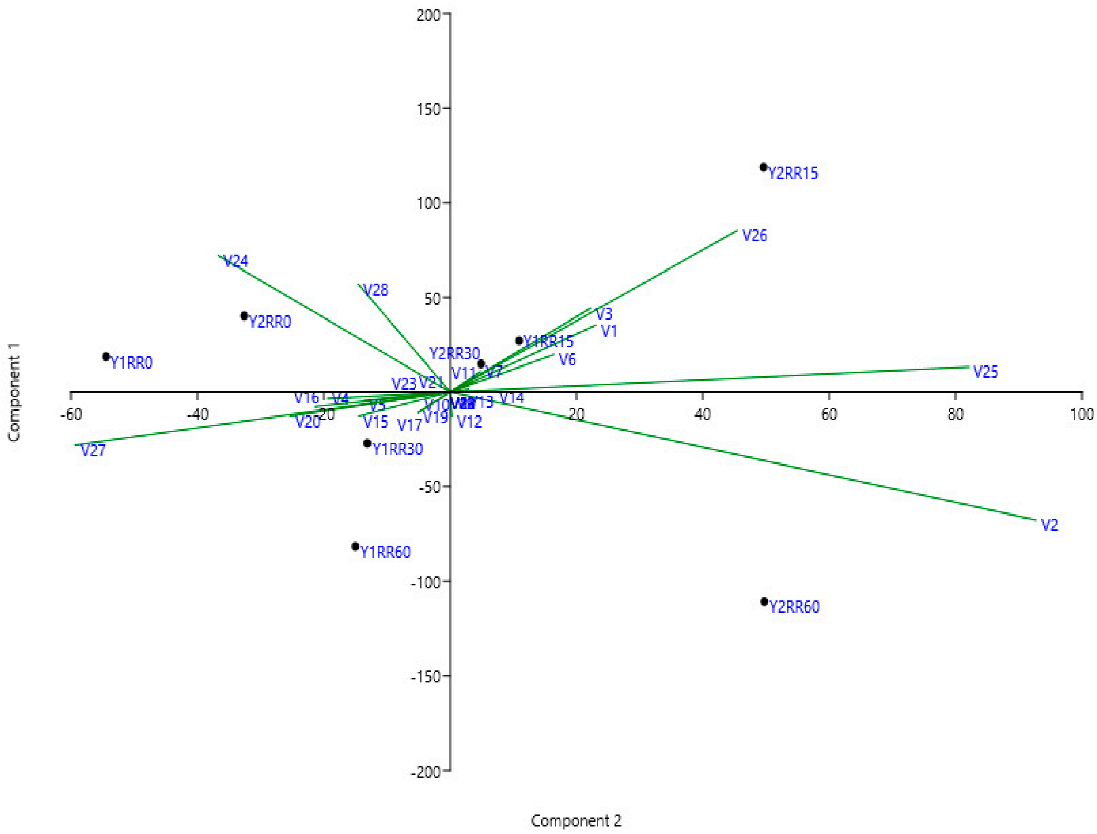

Figure 4. Grass and forb species densities per square meter over a period of two years (2017 and 2018): V1 = *Eragrostis curvula*, V2 = *Cynodon dactylon*, V3 = *Digitaria eriantha*, V4 = *Setaria nigrirostris*, V5 = Themeda triandra, V6 = *Heteropogon contortus*, V7 = *Setaria sphacelata*, V8 = *Eragrostis barbinodis*, V9 = *Melinis repens*, V10 = *Brachiaria serrata*, V11 = *Aristida congesta*, V12 = *Ipomoea crassipes*, V13 = *Elephantorrhiza elephantina*, V14 = *Rhynchosia monophylla*, V15 = *Bryophyllum delagoense*, V16 = *Hypoxis hemorocallida*, V17 = *Nidorella resedifolia*, V18 = Conyza *fleabane*, V19 = *Verbena officinalis*, V20 = *Bidens pilosa*, V21 = *Cyperus* species, V22 = *Urochloa mosambicensis*,V23 = *Solanum* species, V24 = decreasers, V25 = increasers, V26 = forbs, V27 = total density, Y1RR0 and Y2RR0 = 0% RR in 2017 and 2018, respectively, Y1RR15 and Y2RR15 = 15% RR in 2017 and 2018, respectively, Y1RR30 and Y2RR30 = 30% RR in 2017 and 2018, respectively, Y1RR60 and Y2RR60 = 60% RR in 2017 and 2018, respectively.

Both 15% RR treatments were close together in terms of annual net primary productivity (ANPP) (Figure 5). Both 30% RR treatments were close to each other. Meanwhile, 60% RR were in the same place. This means that the treatments behaved the same way in both years. *D. eriantha* and total decreasers were closely correlated to 15% rainfall reduction. On the other hand, *C. dactylon* was closely correlated with 60% rainfall reduction. Forbs and total increaser ANPP were closely correlated with 30% rainfall reduction.

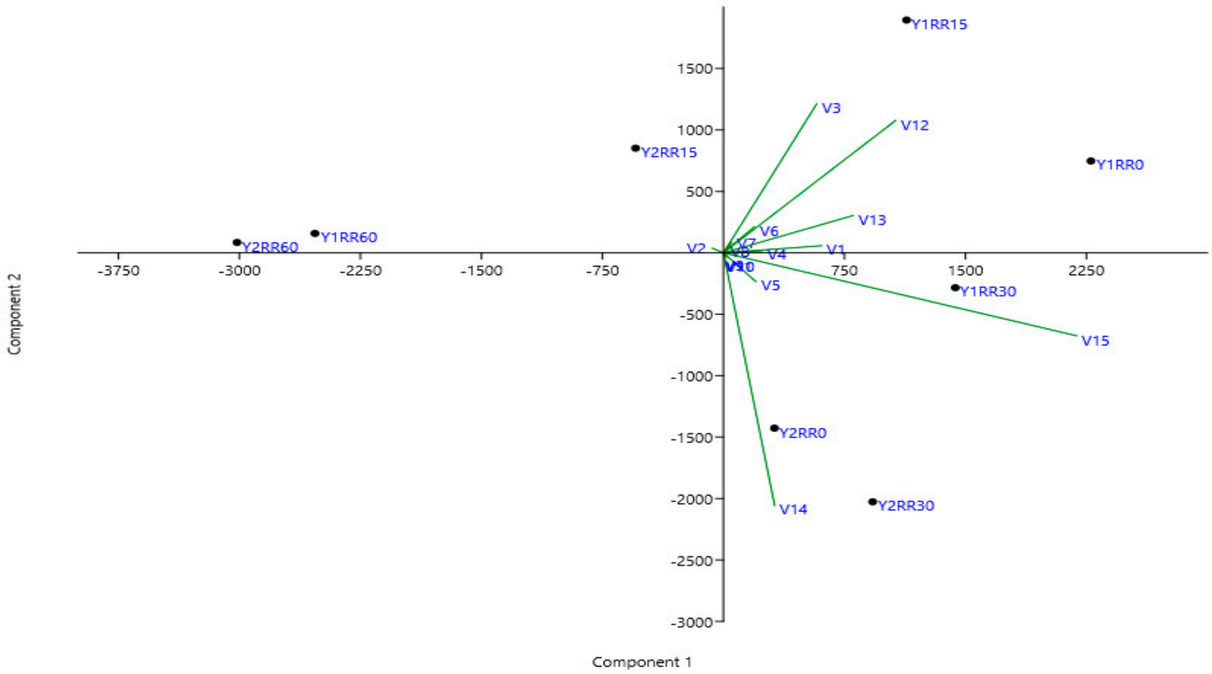

Figure 5. Principal component analysis (PCA) of ANPP of various species and functional groups in 2017 and 2018: V1 = *Eragrostis curvula,* V2 = *Cynodon dactylon*, V3 = *Digitaria eriantha*, V4 = *Setaria nigrirostis*, V5 = *Themeda triandra,* V6 = *Heteropogon contortus,* V7 = *Setaria sphacelata*, V8 = *Eragrostis barbinodis*, V9 = *Melinis repens,* V10 = *Brachiaria serrata,* V11 = *Aritida congesta,* V12 = decreaser, V13 = increaser, V14 = forbs, V15 = total ANPP, Y1RR0 and Y2RR0 = 0% RR in 2017 and 2018, respectively, Y1RR15 and Y2RR15 = 15% RR in 2017 and 2018, respectively, Y1RR30 and Y2RR30 = 30% RR in 2017 and 2018, respectively, Y1RR60 and Y2RR60 = 60% RR in 2017 and 2018, respectively.

The 30% RR was grouped together and correlated with forbs in terms of occurrences (Figure 6). *Eragrostis curvula, C. dactylon*, and total increasers were closely correlated with 60% rainfall reduction. *Setaria sphacelate*, *D. eriantha* and total decreasers were closely correlated with 15% rainfall reduction. The 0% RR favoured *Setaria nigrirostris*, *Heteropogon contortus* and *Melinis repens.*

Year and RR interaction had no significant effect on overall, forbs, decreaser, and overall grass ANPP after data were log transformed (Table 2). Years had no significant effects amongst the same treatments. However, RR had a significant effect on overall, forbs, decreaser, and overall grass ANPP. Moreover, year had a significant effect on forbs, increaser and overall grass ANPP, while it had no significant effect on overall and decreaser ANPP. The 60% RR resulted in significantly low overall ANPP, decreaser, increaser and overall grass ANPP. Overall ANPP, decreaser and overall grass ANPP were resilient up to 30% RR after which they declined at 60% RR. Meanwhile, unlike grasses, forbs were significantly lower at 15% RR, while there was no significant difference between 0, 30 and 60% RR. Although there was no significant difference between 0, 15 and 60% on increaser grass ANPP, 60% RR had a significantly low ANPP compared to 30% RR. Forbs ANPP was significantly higher in 2018 than 2017. On the other hand, unlike forbs, increaser grass and overall grass ANPP was significantly higher in 2017 than 2018.

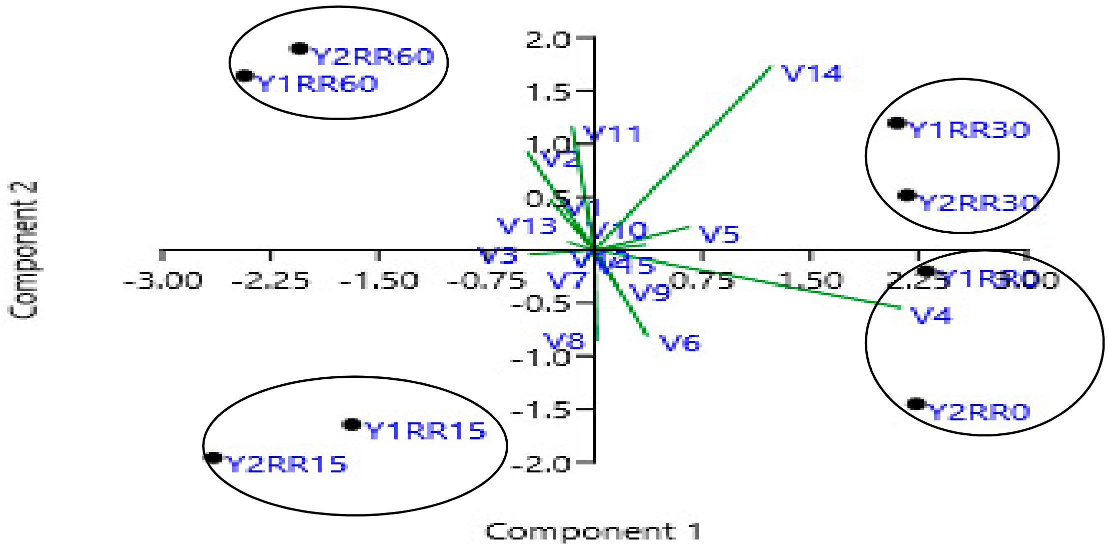

Figure 6. PCA analysis of occurrence of species and functional groups in various plots subjected to different intensity of RR: V1 =*Eragrostis curvula,* V2 = *Cynodon dactylon,* V3 = *Digitaria eriantha*, V4 = *Setaria nigrirostis*, V5 = *Themeda triandra*, V6 = *Heteropogon contortus*, V7 = *Setaria sphacelata*, V8 = *Eragrostis barbinodis*, V9 = *Melinis repens*, V10 = *Brachiaria serrata*, V11 = *Aritida congesta,* V12 = decreaser; V13 = increaser; V14 = forbs. Y1RR0 and Y2RR0 = 0% RR in 2017 and 2018, respectively, Y1RR15 and Y2RR15 = 15% RR in 2017 and 2018, respectively, Y1RR30 and Y2RR30 = 30% RR in 2017 and 2018, respectively, Y1RR60 and Y2RR60 = 60% RR in 2017 and 2018, respectively.

Table 2. Annual net primary productivity (ANPP) of different functional groups as affected by different intensity of rainfall reduction (RR) in Pretoria.

Intensity of Rain Reduction	Annual Net Primary Productivity (kg DM/ha)				
			Grass ANPP		
	Overall ANPP	Forbs ANPP	Decreaser Grass ANPP	Increaser Grass ANPP	Overall Grass ANPP
0%	4979 ^{a}	1666 ^{a}	1841 ^{a}	1472 ^{ab}	3312 ^{a}
15%	3761 ^{a}	316 ^{b}	2029 ^{a}	1416 ^{ab}	3445 ^{a}
30%	5029 ^{a}	2066 ^{a}	1147 ^{a}	1816 ^{a}	2963 ^{a}
60%	1716 ^{b}	846 ^{a}	220 ^{b}	650 ^{b}	869 ^{b}
S.E	658.8	312.75	500.06	327.05	562.38
P-value	0.0068	<0.0001	0.0553	0.0598	0.0020
Year					
2017	4184	760 ^{b}	1673	1752 ^{a}	3424 ^{a}
2018	3558	1688 ^{a}	946	925 ^{b}	1870 ^{b}
S.E	465.9	221.1	353.6	231.3	397.7
P-value	0.3488	0.0462	0.4608	0.0226	0.0188

Different small letter superscripts along the same column were significantly different. S.E = Standard error.

Year and RR had no significant interaction effect on forbs, decreasers, increasers and overall grass percentage contribution on ANPP (Table 3). However, year and RR had a significant effect on forbs and overall grass percentage contribution on ANPP. Forbs were significantly lower at 15% RR than 0, 30 and 60% RR. Year 2018 resulted in significantly high forbs proportion than 2017. On the other hand, unlike forbs overall, grass percentage contribution was significantly higher at 15% than 0, 30 and 60% RR, while year 2017 had a significantly high overall grass percentage than 2018. Meanwhile, year and RR had no significant effect on ecological status of the grass (decreasers and increasers).

Table 3. Percentage (%) contribution of different functional groups in terms of annual primary productivity (ANPP) as affected by intensity of rainfall reduction (RR) in Pretoria.

Rainfall Reduction	% Contribution in Terms of ANPP			
		Grass ANPP		
	Forbs	Decreaser	Increaser	Overall Grass
0%	36 [a]	33	31	64 [b]
15%	6 [b]	44	50	94 [a]
30%	42 [a]	22	36	58 [b]
60%	48 [a]	17	35	52 [b]
S.E	7.4	8.3	8.8	7.0
P-value	<0.0001	0.2540	0.5341	0.0010
Year				
2017	23 [b]	32	45	77 [a]
2018	43 [a]	26	31	57 [b]
S.E	5.2	5.8	6.2	5.1
P-value	0.0222	0.7639	0.0877	0.0042

Different small letter superscripts along the same column were significantly different. S.E = Standard error.

Year and RR interaction had no significant effect on rain use efficiency (RUE) (Figure 7). However, RR had a significant effect on RUE. Meanwhile, year had no significant effect on RUE. The 30% RR resulted in a significantly high RUE than 15 and 60% RR, while there was no significant difference between 0 and 30% RR.

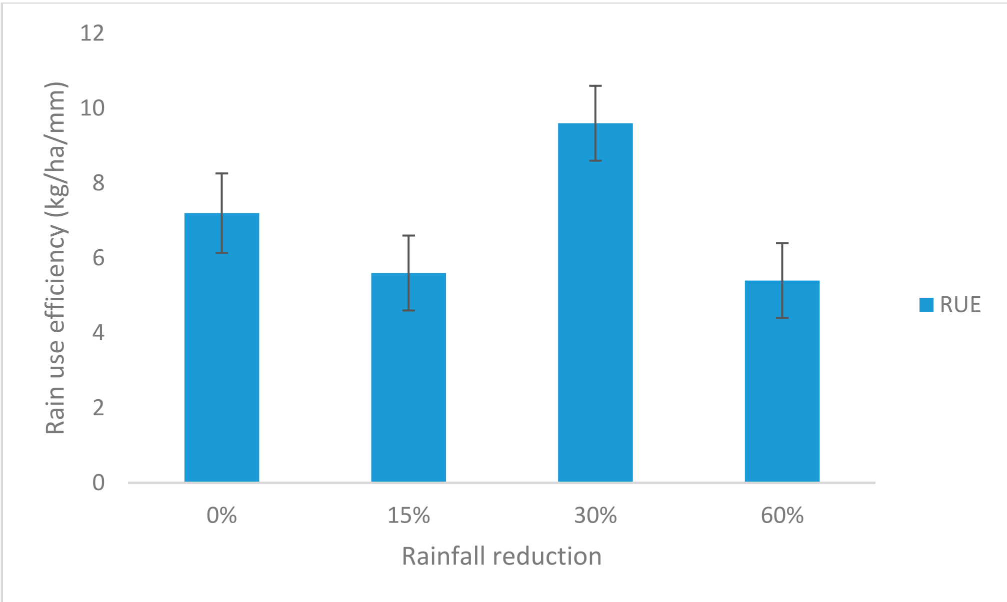

Figure 7. Rain use efficiency (RUE) of the semiarid grassland as affected by different intensity of rainfall reduction (RR) in Pretoria.

Rainfall reduction and year had no significant interaction effect on all grass species ANPP (Table 4). Year had no significant effect on all grass species ANPP. However, RR had a significant effect on *C. dactylon* and *S. nigrirostris*, while it had no significant effect on other grass species. *Cynodon dactylon* was significantly higher at 60% RR compared to other treatments. The 15% RR resulted in a significantly low *S. nigrirostris* compared to 0% RR, while there was no significant difference between 30 and 15% RR.

Table 4. Percentage species contribution on grass ANPP of the semiarid grassland as affected by different intensity of rainfall reduction (RR) in Pretoria.

	Grass Species (%)						
Intensity of Rainfall Reduction (%)	***Eragrostis curvula* Log**	***Cynodon dactylon* Sqrt**	***Heteropogon contortus***	***Digitaria eriantha* Log**	***Setaria nigrirostris* Log**	***Themeda triandra***	***Setaria spacelata***
0	37.9	0.2 [b]	7.7	23.0	12.3 [a]	0.2	0.9
15	37.2	1.2 [b]	9.7	40.6	4.5 [bc]	0.1	1.7
30	54.5	0.9 [b]	5.5	16.0	5.1 [ab]	0.2	0.8
60	40.8	18.7 [a]	1.5	30.3	0c	0	3.4
S.E	11.64	4.3	3.18	8.92	3.47	0.06	1.41
P-value	0.2206	0.0253	0.3880	0.4242	0.0036	0.1248	0.5684
Year							
2017	48.6	5.5	5.5	28.4	4.6	0.1	1.2
2018	36.6	5.0	6.8	26.6	6.3	0.1	2.1
S.E	8.23	3.04	2.25	6.31	2.45	0.04	1.03
P-value	0.5852	0.9586	0.8621	0.5919	0.9152	0.9335	0.5269

Different small letter superscripts along the same column were significantly different. S.E = Standard error.

5. Discussion

A semiarid grassland ecosystem was exposed to reduced rainfall for a period of two years in this study. Our objectives were to determine the effects of different intensity of RR on ANPP, plant density and RUE. Rainfall reduction and year interaction had no significant effect on all the parameters. Rainfall reduction effects dominated parameter responses with 2017 having higher ANPP than 2018. This response was as a result of reduced rainfall which resulted in reduced ANPP. The results concur with those reported by [28] who reported that imposed drought reduced ANPP below the fifth percentile of the historical contribution of ANPP values for a particular site. Previous study on the ecosystem by [29] showed that forbs mainly rely on deep soil moisture in order to avoid water stress during dry periods; on the other hand, grasses rely mainly on shallow soil moisture to tolerate dry periods.

Rainfall reduction owing to climate change has a potential to affect species representation of the semiarid grassland (Table 1). The results of this study show that reduced rainfall benefited increaser grass species and invaders. These results concur with those reported by [30] who reported that change in rainfall patterns as a result of climate change affects population dynamics of invasive species. In this study, we show how effects of climate change in the form of reduced rainfall will affect the structure of the semiarid grassland. We can say that rainfall is the major driver of the vegetation change, especially when other species are reduced.

Plant densities were higher at 0 and 15% compared to 30 and 60% RR (Figure 4). Plant densities were reduced with the increase in rainfall reduction. This means that more soil will be exposed to water and wind erosion with less soil cover. This is as a result of reduced densities of the decreaser grass species through reduced rainfall, which is supported by [31] who reported that the major factor contributing to decline in the abundance of highly desirable grass species is drought. Reduced rainfall paves a way for invaders and some undesirable plants to dominate over highly desirable grass species.

The PCA also showed a certain trend that certain grasses and forbs behaved in a certain way (Figure 5). *Digitaria eriantha* and all the decreasers that are highly desirable grass species correlated with 15% RR, while *C. dactylon* correlated with 60% RR. The forbs and total ANPP correlated with 30% RR. The *D. eriantha* is less resistant to water stress; hence, it only performed well at 15% RR and began to decline beyond this treatment. We can say that other grasses and forbs were suppressed by these decreaser grasses at 15% RR, while they gained advantage at 30% RR after decreaser declined as a result of rainfall reduction. Forbs gained advantage because of the deeper root system that allows them to access water from the deeper layers of the soil compared to some of the tropical grasses that are able to close stomata to reduce water loss through transpiration.

In this study, semiarid grassland ecosystem was exposed to four different intensities of RR to simulate different levels of available moisture to the soil from rainfall. The RR effect on ANPP was extreme under 60% RR. The results show that reduced rainfall has a significant effect on the overall ANPP production only when it is severe (Table 2). Rainfall reduction had no significant effect on overall ANPP at moderate drought simulations (15 and 30% RR) in both years. Overall ANPP includes all the grasses and forbs that were harvested at the plots. In 2017, there was more rainfall and higher ANPP than in 2018. These results concur with those reported by [32–35] who reported that RR reduces biomass yield.

The fact that differences between the overall ANPP for 0, 15 and 30% RR were not significantly different, it means that the overall ANPP was resilient up to 30% RR, after which it declined. The 0% RR had the highest overall ANPP, while 60% RR had the lowest overall ANPP. The overall ANPP decreased by 74% at 60% RR compared to 0% RR ANPP. These results were a result of reduced rainfall due to increased intensity of rainfall reduction. Although there was no significant difference between 0, 15 and 30% RR, overall ANPP decreased with increase in RR. Therefore, we can say that increased precipitation leads to increased ANPP production as it was the case with our results. We can also say that most ANPP accumulated in summer (December, January and February) when the rainfall was higher than the other seasons (Figure 2).

Grass ANPP was significantly lower under 60% rainfall reduction. Although there was no significant difference between 0, 15 and 30% RR, grass ANPP decreased linearly with the increase in rainfall reduction. The grass ANPP decreased by 74% at 60% RR (Table 2). These results concur with those reported by [34], who suggested that ANPP is significantly affected by precipitation scenarios. Previous studies have established a close relationship between plant growth and rainfall amount [36–38], while [39] found no significant effect of drought simulation on ANPP productivity. The reason for the decrease in grass ANPP productivity is because the grasses prefer to extract soil moisture from top layers of soils because of their shallow root system [29]. The shallow root system of the grasses limits the uptake of resources such as water, nitrogen and phosphorus [40], which are necessary for plant growth that leads to reduced grass ANPP.

Unlike grasses, forbs increased with the decrease in rainfall as they had higher ANPP in 2018 than 2017 (Table 2). These results concur with those that were reported by [41,42] who reported that forbs productivity does not correlate with the precipitation amount within years. In our study, forbs responded contrary to grasses. The ANPP for the forbs was also increased because there is less competition with the grasses as there are fewer grasses with less rainfall; this was the case with previous studies [41,42]. We can argue that the contradictory response of forbs and grasses to reduced rainfall is because of contrasting root systems and competitive interactions [43]. The deeper root system allows forbs to access water and soil nutrients that are in the deeper layers of the soil, while shallow root system of the grasses only allows grasses to access water available in the top layer of the soil [44–46]. Therefore, the response of the two plant types (grasses and forbs) to resource availability determines distribution [44]. Grasses eventually die in the absence of water and nutrients, giving space to more forbs to grow. A large volume of soil water that percolates from the topsoil layer is exploited by the deep root system of the forbs, while the grasses exploited the smaller volume of soil water accessible in the topsoil layers [43]. This explains how forbs are likely to be less affected by higher intensity of reduced soil moisture as opposed to grasses. The ANPP of the forbs is enhanced by the increased pools of resources that percolate deep into deeper layers of the soil, which are not available to shallow roots of grasses [47]. The ANPP of the forbs under 60% RR decreased by 49% compared to 0% RR, while that of grasses decreased by 74% at 60% RR compared to 0% RR.

Our results showed that RR has a negative impact on the ANPP of common grass species in both years. All the grasses at the site were perennial C_4 pathway species, while the forbs were C_3 pathway species. The *S. nigrirostris* ANPP percentage contribution was highest at 0% RR, *D. eriantha* at 15% RR, *E. curvula* at 30%, while that of *C. dactylon* was highest at 60% RR (Table 4). Both *D. eriantha* and *S. nigrirostris* grass species are highly palatable decreaser grass species and they decreased with the increase in RR, with 60% RR having the lowest ANPP. The *D. eriantha* is a nondrought tolerant grass species that is also adapted to a wide range of soil types [48]. The increase in RR led to decreased soil moisture, which eventually led to decreased percentage contribution of most palatable grass species.

Moreover, *E. curvula* is tolerant to drought and is also tolerant of soil acidity [49]. For this reason, the University of Pretoria experimental farm uses *E. curvula* because of its adaptability to the area and superior palatability to animals. These grass species contributed most ANPP in the overall and grass ANPP. Grass leaf and stem size are affected by moisture availability and when moisture is limited morphological development of organs gets affected negatively [50]. According to the tradeoff hypothesis, species with a wide range of morphological characteristics differ largely in drought tolerance, with fast-growing species being very susceptible to low moisture content [51]. According to [52], variability in rainfall overrides grazing in grass species change in semiarid regions. Change in rainfall has a reflective effect on changes in grass ANPP. Other common grass species that contributed into grass ANPP were *Heteropogon contortus, Setaria sphacelata, Melinis repens, Brachiaria serrata* and *Aristida congesta.* However, these species did not constitute much of the ANPP.

Decreaser grass species contributed higher ANPP in 0 and 15% RR as compared to increaser, while increasers had higher ANPP under 30% RR than decreaser grass species. Decreaser grass species (*D. eriantha, T. triandra, B. serrata, S. nigrirostris* and *S. sphacelata*) were fewer than increaser grass species (*A. congesta*, *C. dactylon*, *E. barbinodis*, *E. curvula*, *H. contortus* and *M. repens*); however, decreasers contributed more ANPP than increasers under higher soil moisture. Increaser grass species use water more efficiently than decreaser species [53], thereby leading to more ANPP under less soil moisture. It can be argued that decreaser grass species require more water to survive than increaser grass species. *Cynodon dactylon* is a rhizomatous grass species with more roots and shoots coming from the nodes of the rhizomes compared to other perennial tufted grasses [48], which increase the surface area to absorb more soil water and nutrients.

A total of 840 mm of rainfall was received in the 2017 growing period, while 749 mm was received in 2018. This makes an 11% reduction in rainfall and therefore agrees with the previous studies that there is likelihood of future reduction in rainfall in years to come. The forecasted reduced rainfall will not only reduce grass production in grasslands but also affects livestock and wildlife production as these animals rely on these natural resources to survive. Reduction in rainfall will lead to change in species composition and deterioration in grassland productivity that will ultimately lead to a reduction in wildlife and livestock production. Reduced grass cover could lead to more soil erosion, which could lead to land degradation and less vegetation for grazing animals. Less soil cover can also lead to poor water retention as less grass cover leads to more bare patches and more water runoff.

6. Conclusions

Overall, reduced rainfall had a significant negative impact on ANPP at 60% RR. Reduced rainfall significantly affected grass ANPP more than forbs ANPP. While grass ANPP decreased with the decrease in rainfall from 2017 to 2018, that of forbs increased. Forbs have a deep root system that allows them to access water and nutrients from the deeper layers of the soil, which gives them a competitive advantage over grasses with shallow root system. Different grass species respondedt in different ways to the reduced water supply as those tropical grass species equipped with better ability to fix CO_2 while closing their stomata are likely to be affected less by the reduction in rainfall than temperate and other tropical grass species adopted to water logged areas. From this study, we can say that *E. curvula* requires less water to produce dry matter as opposed to *D. eriantha.* Livestock farmers who rely on natural grazing land should promote growth of grasses such as *E. curvula* in order to produce enough grass during period of low to moderate intensity rainfall reduction; as such grass species are more favourable for those conditions and able to produce more biomass per unit of rainfall. This can be done by reseeding grasslands using *E. curvula* seeds. However, it is also important to avoid overgrazing as this will modify competition between grasses and forbs to the advantage of the later functional groups, which may lead to less feed for animals. Increaser species are more adapted to low soil moisture than decreaser species. Increaser grass and forbs species are more drought tolerant than decreaser grass species. Therefore, increaser grass species will be most tolerant to predicted future rainfall reduction scenarios than decreaser grass species. However, adoption of management practice that enhances soil moisture availability will likely benefit to increase the proportion of the decreaser species with in the grassland.

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Appendix A

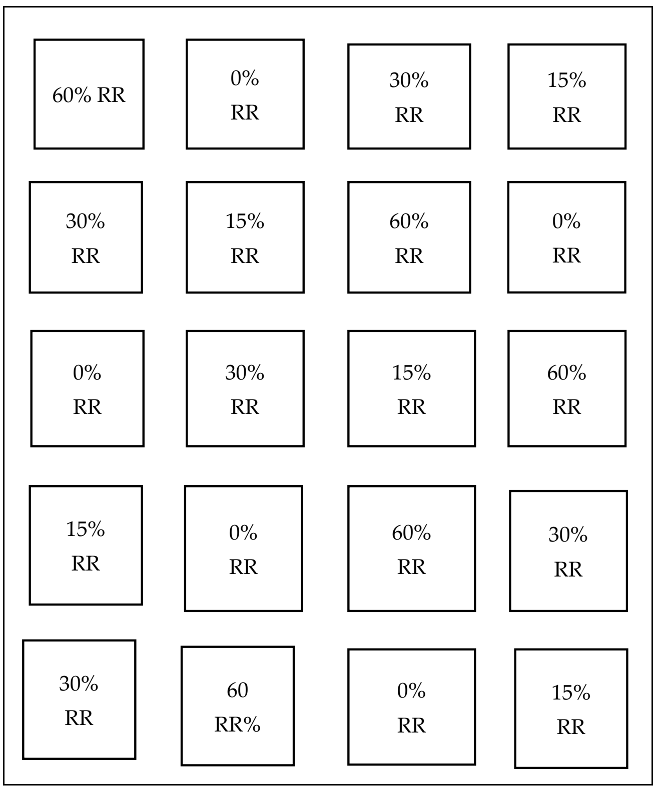

Figure A1. Sketch of the experimental layout at the university of pretoria experimental farm.

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