CHARACTERISATION OF INDIGENOUS SOUTH AFRICAN GRASS AND LEGUME GENETIC RESOURCES FOR IMPROVED FORAGE PRODUCTION UNDER WATER-LIMITED CONDITIONS

Report
to the Water Research Commission

by

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DISCLAIMER

EXECUTIVE SUMMARY

BACKGROUND

The lack of bioclimatically suitable forage species for livestock production in the water-limited agro-ecological areas of South Africa has resulted in significant feed shortages within these areas during periods of drought experienced within the country. This, in turn, has resulted in significant livestock mortalities leading to financial difficulties for the farmers and farming communities within these areas. These cyclic long-term droughts, as well as more common short-term droughts, are expected to increase in frequency, duration and intensity under the predicted future bioclimatic conditions for South Africa. Although there has been significant investment into the development of improved, better-adapted forage crops for these bioclimatically marginal areas, these efforts, to date, have largely been unsuccessful, or the material produced has only had limited success. South Africa, however, houses a large diversity of grass and legume species that naturally occur within water-limited environments, which could be developed into new or alternative forage resources for water-limited areas. If developed properly, these grass and legume species could provide the means to improve the production of water-limited areas and provide a more sustainable means for the farming communities within these areas to make a living. Unfortunately, very little information about the suitability of indigenous grass and legume species as potential alternative forages exists and although prior prioritisation of species has been done, collections of the seeds and their subsequent evaluations are still lacking.

AIMS

This project therefore aimed to prioritise, collect and characterise the drought tolerance abilities of indigenous grass and legume species from South Africa as well as locally adapted ecotypes of commercially available forage species. We aim to use this information to prioritize specific species that can be developed further as forage crops for water-limited areas. To achieve this, the following specific objectives will be pursued:

- Identification and prioritisation of suitable grass and legume genetic resources using a combination of herbaria records and GIS techniques
- Collection of prioritized grass and legume genetic resources
- Characterisation and evaluation of the agronomic performance of the legumes and grasses under water-limited conditions
- Selecting the best adapted legume and grass species for further development as drought resistant forages.

RESULTS AND DISCUSSION

In this project, a total of 342 grass and 89 legume species were prioritised based on their potential to be evaluated as alternative forage crops. This list can be regarded as a guideline for current and future collection initiatives since the collection of all of the species as well as ecotypes from unique populations of these species cannot be done in a short time. However, from this list, it was clear that several grass species prioritised are good candidates for further evaluation since some of the species identified through the selection process already contained several commercially available cultivars. These species include *Anthephora pubescens, Brachiaria nigropedata, Cenchrus ciliaris, Chloris gayana, Cynodon dactylon, Digitaria eriantha, Eragrostis curvula, Panicum coloratum, Panicum maximum*, and *Setaria sphacelata* were locally adapted ecotypes could potentially be used to improve the current genetic resources that are commercially available. In contrast to the grass species, only two of the indigenous legume species that were prioritised have previously been domesticated and commercialised. These species are *Lebeckia ambigua* and *Trifolium africanum*. This highlights the discrepancy in the development of indigenous grass vs. legume species, even though the use of legumes in livestock production systems has become more popular over the years due to the added benefits of biological nitrogen fixation. From the prioritised species, a total of 121 different species with numerous ecotypes within each species were collected in this project and are currently maintained at the National Forage

Genebank. The collection of these prioritised grass and legume genetic resources will be an ongoing initiative, and these plant genetic resources will be used to characterise the forage potential of the indigenous grasses and legumes collected. Apart from the indigenous species collected, 257 cultivars of commercially available forages were also obtained from local seed companies and nurseries. These species will be used to compare the indigenous material with when screening for drought tolerance.

After seeds of the indigenous grass and legume species were collected, it was found that the germination potential of the indigenous plant genetic resources was poor compared to the commercial cultivars of the same species. We tested this by germinating seeds of local ecotypes as well as commercial cultivars of these species to see whether the published methodologies used to germinate and establish these species are suitable for local ecotypes. From these trials, it was found that seed germination and viability of seeds from commercial cultivars were found to be closely related, i.e., the germinated seeds are close to the total viable seeds. This is to be expected as these cultivars have undergone extensive breeding and improvement, which also includes germination stability. The methods published for these species are based on these improved cultivars and therefore, the results obtained for the commercial cultivars were expected. However, when looking at the results for the local ecotypes, it was clear that the published methodologies did not provide the best germination results, as germination and seed viability were not closely related. This may be due to several factors, such as dormancy or factors relating to the local conditions in which the species originated and from where the seeds were collected. One of the key goals for the genebank after observing these trends is therefore to develop improved methods to germinate and establish local ecotypes so that when seeds are distributed to collaborators or crop improvement programmes, the correct methodology to germinate and establish these seeds can be distributed with the seeds.

One of the key species that was prioritised in this work is *Calobota sericea*. *Calobota sericea* is a perennial legume species from the semi-arid rangelands of Namaqualand. Native *C. sericea* populations within the Namaqualand rangelands were found to contribute up to 16 % of livestock diets during the late dry summer months (Samuels et al. 2016). Within these rangelands, *C. sericea* is highly adapted to the low rainfall conditions. The species has undergone previous drought tolerance screening, but information about how climate change may affect its distribution and, thus, its use under future climate change scenarios was lacking. Although the species has a winter rainfall distribution primarily, 2% of its populations occur in areas that receive all year-round rainfall and 2 % of its populations occur in areas that receive summer rainfall. Furthermore, more than 90% of its population lives in areas that receive less than 300 mm of mean annual precipitation. The locations in which these species naturally occur and thrive are regarded as areas with low agricultural productivity. Therefore, this species could potentially significantly improve the agricultural productivity of these locations if it can be developed into a pasture species. One of the major limitations, however, is the current narrow distribution range of the species. This narrow distribution indicates very specific bioclimatic and edaphic requirements, which could mean that under future bioclimatic conditions, the species could face local extinctions and even more reduced distribution ranges. It is for this reason that we modelled the ecological niche of *C. sericea* to determine whether future bioclimatic conditions would lead to possible local extinctions, which will prompt urgent collection initiatives to conserve the plant genetic resources. Results from this study have shown that *C. sericea* has a restricted bioclimatic niche and that under future bioclimatic conditions, its adaptation range will decrease by approximately 2 % of its current distribution range. This range reduction could lead to the loss of approximately 5 % of the current *C. sericea* populations, and possibly more as the different adaptation ranges in this study are modelled to shift. These results compel the collection of *C. sericea* seeds from different populations within the different adaptation ranges to conserve as much genetic variability within the species as possible. These ecotypes, collected from within different adaptation zones within the semi-arid rangelands of South Africa, could, in turn, be used in future breeding initiatives to develop cultivars for specific agro-ecological conditions and to fill agro-ecological niches that may become available due to climate change.

Apart from *C. sericea*, two *Stipagrostis* species were also prioritised for the semi-arid rangelands of Namaqualand. *Stipagrostis ciliata* and *Stipagrostis obtusa* are two perennial grass species native to the semi-arid and arid rangelands in Namaqualand. These species are well adapted to the environmental constraints such as limited soil moisture, high temperatures and nutrient-poor soils, typical of arid rangelands. Their distribution spans from the Nama Karoo to Succulent Karoo biomes and even into the Savanna biome, which spans both winter and summer rainfall areas. Within these rangelands, the two species form important components of the natural veld and contribute significantly to livestock production within these rangelands. The two grasses are naturally grazed by livestock, and their importance is elevated further in the dry seasons, where they are able to maintain above-ground biomass, whereas other, more palatable species do not. Due to these species occurring in both winter and summer rainfall regions, they provide an opportunity to develop improved indigenous forage resources for water-limited areas in both the winter and summer rainfall regions of South Africa. However, no formal comparison between winter and summer rainfall ecotypes in terms of their forage potential has been done. This information would, however, provide important clues as to what the major collection priorities for these species should be for further characterisation and evaluation. Results from this study showed that the two grass species do have the potential to be used as feed for livestock. Their nutritional quality is of such a level that livestock can be maintained by feeding these fodders to the livestock. In general, however, the forages collected from the summer rainfall region were of higher quality compared to the winter rainfall region collections. These differences observed between the winter and summer rainfall collections can be explained by the fact that grasses generally have their active growing period in summer, and therefore, the material collected in the summer rainfall region was generally in their active growing period at the time of collection. A better comparison could be when seeds are collected and grown under the same conditions to do a direct comparison of plant genetic resources from the winter rainfall region to those of the summer rainfall region. Therefore, these results for the two locations cannot be directly compared to each other. Furthermore, the nutritional quality of these species could potentially be improved through improved cultivation practices and improvement of the plant genetic resources through domestication and breeding. Therefore, further research with regard to growing the plants under fertilized conditions and potentially with supplementary irrigation is required to determine the full potential of the two grass species.

From the prioritisation that was done, we made the assumption that populations of species would differ based on the local environments in which they occur. This, in turn, formed the basis of looking at the ecological niche of the species to identify potentially unique populations. This hypothesis was tested by evaluating the morphological characteristics of five indigenous grasses along an aridity gradient. The aim here was to determine whether rainfall could influence species in such a way that it could be used as a tool to select ecotypes of prioritised species. This study demonstrated that rainfall regime strongly influenced the morphological traits of five indigenous grass species in grazed rangelands, confirming rainfall as a major driver of grass growth and adaptation in southern African rangelands. Work presented in this study highlighted the importance of collecting multiple ecotypes across different locations in order to obtain the largest variation in phenological traits within a species. For example, traits such as higher tiller numbers under low rainfall conditions in *T. triandra* and *M. maximus* can be regarded as beneficial traits in lower rainfall areas and could possibly be combined with other beneficial traits from ecotypes collected from higher rainfall locations. This underscores the initiative to collect plant genetic resources from different populations across different ecological niches in order to obtain a wide range of plant genetic traits within each species.

Subsequent to this, a further trial was conducted to compare local ecotypes of commercially available cultivars of the same species as well as indigenous species to commercially available forages. Now that it was clear that the locations from where species are collected could result in differences in morphological features of the plants, it was imperative to determine whether this could possibly be related to drought tolerance. From the work that was subsequently done, it was shown that several of the indigenous species evaluated were able to tolerate drought better or similarly to commercial cultivars of the same species. Under certain conditions, phenotypic plasticity was the main contributor to improved drought tolerance. Phenotypic plasticity in plants gives them the ability to respond quickly to changes in their environments, and is key to the success of plants in natural and agro-ecosystems. In this work, it was shown that plants were able to change the resources allocated to different plant parts, based on the availability of water. It was shown that under water-limited conditions, the majority of the indigenous species evaluated will allocate more resources to root growth, reducing shoot development, which means that they would be able to access deeper water sources as the topsoil dries during periods of water limitation. The importance of root morphology in drought tolerance in plants has resulted in it becoming one of the targeted traits for plant breeders for improving water harvesting from deeper water resources in the soil. Therefore, the improved root traits developed by these species under water limitation may also result in better adaptation of these plants to subsequent water-limited conditions during the growing season.

CONCLUSIONS

The findings from this work provide the baseline for several future projects that could make use of the indigenous grass and legume genetic resources prioritised and collected during this work. The work already done in this project shows that indigenous species can be developed further into forages and that certain of the species may have improved drought tolerance, compared to commercially available cultivars.

RECOMMENDATIONS

The following recommendations are made for future work.

1. Making use of the databases developed to further collection initiatives of prioritised species for inclusion into the genebank.
2. Development of protocols for germination and establishment of the indigenous plant genetic resources and making these available in the form of technical briefs or published methodologies.
3. Additional screening and characterization of plant genetic resources for drought tolerance and determining the mechanisms of drought tolerance of these plant genetic resources.
4. Including the plant genetic resources collected and screened into crop improvement programmes, either to develop new forage resources or improve existing material by using local ecotypes in breeding programs.

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CHAPTER 1: BACKGROUND

1.1 INTRODUCTION

With the rapidly growing human population and the severity of the projected future bioclimatic scenarios, significant trade-offs in the sustainable use of natural resources can be expected to meet the future demands for livestock products. These trade-offs could have significant negative impacts on the health, food security and livelihoods of various vulnerable populations (Luseno *et al.* 2003; McPeak 2006; Morton 2007; Thornton *et al.* 2007; 2009; Herrero *et al.* 2009; 2015; Silvestri *et al.* 2012; Thornton and Herrero 2014). Generally, in South Africa, the projected climate change scenarios indicate a trend of becoming hotter and drier (Mukheibir 2008; Meissner *et al.* 2013a; b), and this, in turn, is expected to result in declines in agricultural production that will affect both food availability and access (IPCC 2007; Rufino *et al.* 2013). In South Africa, approximately 20% of the country is already receiving less than 200 mm of rainfall per annum, and a further 47% receives less than 400 mm of rainfall per annum (DEA 2013). Furthermore, future climate change projections for South Africa generally indicate that the current unpredictability and high variability in the amount and distribution of rainfall will likely increase with climate change, and this, in turn, will be further aggravated with the predicted increases in temperatures under future bioclimatic conditions (DEA 2013).

Current commercial livestock systems are mostly running at full production capacity, and this implies that to meet the future demand for livestock products in South Africa, livestock production will have to increase in areas that are generally not regarded as highly productive. These areas include the more marginal livestock production areas under rangeland conditions, and those livestock production systems that are characterised by water limitation, poor and restrictive edaphic and extreme bioclimatic conditions. Currently, there are few commercial forage options, primarily old man saltbush (*Atriplex numularia* Lindl.) and spineless cactus (*Opuntia ficus-indica* (L.) Mill.), adapted to these marginal areas (Palmer and Ainslie 2006; Dickinson *et al.* 2010; Truter *et al.* 2015). The use of the already limited forage options for these areas is, however, further limited in areas that fall within, or near, protected areas or, areas with high levels of plant endemism, due to their risk of becoming weedy or invasive e.g., cactus pear forages. In addition, these species are non-leguminous, and therefore, farmers do not have the added benefits of the symbiotic nitrogen fixation that legumes offer.

Therefore, there is an urgent need to develop fodder plants that are suitable for use under these marginal conditions and allow for the added benefits such as nitrogen fixation. These new fodder plants, in turn, should allow for improved livestock production in areas that are currently underutilized or unproductive. The use of native species, which are naturally adapted to these marginal areas, would therefore be a more sensible alternative than exotic germplasm and would allow farmers to expand their agricultural systems by diversifying their fodder flow programs within these water-limited areas.

In 2013, 2017 and 2019, Trytsman and Muller produced a list of legume species, and in 2020, Trytsman produced a list of grass species from southern Africa for further characterization and evaluation as potential forage crops (Trytsman 2013, Muller et al. 2017, Trytsman et al. 2019, Trytsman et al. 2020). The selection of these species was based on six factors, which included the distribution, height, and life cycle of the plants, the presence of any anti-nutritional and toxic factors, adaptation to low soil phosphate conditions, and lastly, whether or not the plants were grazed/browsed and/or cultivated (Trytsman 2013). From this, an extensive list of species with varying potential to be evaluated as possible forage crops was produced. Unfortunately, further efforts at evaluating these species have been minimal.

Several reasons exist for the lack of interest in evaluating and developing native grass and legume species for forage production in South Africa itself. The most commonly reported reasons are the easily accessible exotic forage germplasm in South Africa (Palmer and Ainslie 2006; Trytsman 2013), large and well-known South African legume genera that are not generally recognised as livestock feed in South Africa itself due to their perceived toxic qualities, the general lack of knowledge about their agronomic potential (Trytsman 2013), the time required to domesticate new forage species, and the costs associated with producing marketable amounts of seeds (Loi et al. 2008; Nichols et al. 2007; 2010; Muir et al. 2014; Mitchell et al. 2015). This, in turn, resulted in forage breeding programmes in South Africa focusing primarily on producing exotic legume cultivars (e.g., Medicago sativa cv SA Standaard and SA Select) that are adapted to specific conditions (Palmer and Ainslie 2006; Trytsman 2013; Truter et al. 2015). As a result, the National Forage Genebank of South Africa holds less than 5 % of the native South African legume species that could be evaluated as possible forage crops, as opposed to nearly all native grass species (Trytsman 2013, Trytsman et al. 2019, 2020).

The identification of native grass and legume species that are already well adapted to the water-limited and marginal edaphic and bioclimatic conditions would, however, provide a more sustainable means to meet the future demand for livestock products in South Africa. Also, with the general climate change trend in South Africa indicating hotter and drier conditions, new forage species that can withstand these conditions throughout South Africa are needed in order to prepare for future bioclimatic scenarios.

1.2 PROJECT AIMS

The overarching aim of this project is to identify and collect native South African legume and grass genetic resources, especially from water-limited agro-ecological areas. Thereafter, we aim to characterise these plant genetic resources for their agronomic potential under water-limited conditions. To achieve this, the following specific objectives will be pursued:

- Identification and prioritisation of suitable grass and legume genetic resources using a combination of herbaria records and GIS techniques
- Collection of prioritized grass and legume genetic resources
- Characterisation and evaluation of the agronomic performance of the legumes and grasses under water-limited conditions
- Selecting the best adapted legume and grass species for further development as drought-resistant forages.

CHAPTER 2: IDENTIFICATION AND PRIORITISATION OF NATIVE GRASS AND LEGUME GENETIC RESOURCES

2.1 INTRODUCTION

South Africa houses a large diversity of primarily untapped grass and legume genetic resources that are well adapted to water-limited areas in the country (Trytsman et al. 2016, 2019, 2020, Müller et al. 2017). While several South African grass species have been commercialised, only a few indigenous legume species are presently used as pasture crops (Truter et al. 2015, Trytsman et al. 2019, 2020). The breeding and evaluation of South African grass and legume species for pasture production commenced during the early 1900's (Truter et al. 2015). *Eragrostis eriantha, Digitaria eriantha* and *Trifolium* species (*T. africanum, T. burchellianum*) were some of the earlier South African grass and legume species that were included in breeding programs.

Despite the extensive use of indigenous legumes, for example, soil conservation and as green manure for more than 50 years, only a few species are currently used as forages, and are primarily included in conservation agriculture (no or minimum tillage, crop rotation and residue management). These legume species include *Lablab purpureus* (cv. Highworth and Rongai), *Mucuna pruriens* (no cultivar registered) and *Vigna unguiculata* (cv. Encore, and Iron grey), all of which are species found naturally in the Savanna and Grassland biomes of South Africa. Although not a popular pasture species in South Africa, *Listia bainesii* was collected from South Africa and a cultivar, INIA Glencoe was bred in Uruguay in 2005 and is currently popular in Australia. In terms of South African grasses, many popular species are used at present in pasture production. These include *Anthephora pubescens* (cv. Wollie and Ag-Lehani), *Cenchrus ciliaris* (cv. Molopo and Gayndah), *Chloris gayana* (cv. Katambora and Finecut), *Digitaria eriantha* (cv. Irene and Tip Top), *Eragrostis curvula* (cv. Ermelo and Umgeni) and *Panicum maximum* (cv. Gatton and Green panic) (Truter et al. 2015).

More recently, the South African legume genus *Lessertia*, specifically the species *L. capitata*, *L. diffusa, L. excisa, L. herbacea, L. incana* and *L. pauciflora,* have been included in Australian forage evaluation trials and from these trials it was indicated that these species are highly palatable and have shown some degree of grazing tolerance. They were also reported to become prostrate under high grazing pressure in trials done in Australia, which allows them to withstand continuous grazing pressure (Howieson et al. 2008; Gerding et al. 2013a,b). However, the high numbers of resident Rhizobium bacterial strains in the Australian soils that rapidly nodulated these *Lessertia* species but are non-nitrogen fixing led to the discarding of the South African *Lessertia* species as forage legumes in Western Australia (Gerding et al. 2013a,b; Gerding et al. 2014). Another South African legume species, *Lebeckia ambigua*, however, is currently being developed for use as a forage crop in Australia (Edwards et al. 2019). In Australia, it has demonstrated great production potential on the acid infertile sandy soils, and novel strains of symbiotic and non-symbiotic Rhizobium bacteria have been isolated from root nodules collected from these plants (Howieson et al. 2013, De Meyer et al. 2014). Furthermore, *Calobota sericea*, a legume species that is found in the semi-arid rangelands of Namaqualand in the Northern Cape, as well as in the Karoo in the Western Cape, is currently being evaluated for its fodder production capabilities. Current research done on this species by the Agricultural Research Council – Animal Production Institute and National Forage Genebank includes the prioritization of the species for its drought tolerance (Müller et al. 2017), the germination ecology and seedling establishment requirements (Müller et al. 2017, 2019, 2021a), drought tolerance mechanisms (Müller et al. 2021b), and nutritional quality of native stands of *C. sericea* (Müller et al. 2021c, Britz et al. 2022). Additional work on the fertilization requirements of *C. sericea* has indicated that the nutritional quality and yield potential of the species can be significantly increased with small amounts of N-fertilizer applications (Britz et al. 2023).

In recent years, however, the development of forage cultivars from pasture breeding programmes in South Africa has declined and therefore, has been identified as a priority research area needed in South Africa (Truter et al. 2015). The development of local forage varieties that are adapted to local climatic and soil conditions and grazing management practices is of utmost importance to sustain animal production. This was especially evident under the recent extended drought that is being experienced in South Africa, where the lack of adapted commercially available forages for these water-limited conditions resulted in significant feed shortages across the semi-arid and arid agro-ecological areas of South Africa (Truter et al. 2015; Muller et al. 2017; Trytsman et al. 2019, 2020). The drought resulted in significant livestock mortalities and entire farming communities becoming financially insecure and at risk. Due to insufficient forage availability for supplementary feeding during these periods of drought, farmers are forced to put pressure on the already fragile rangeland resources, when the rangelands should rather be rested. This over-dependence on the poor quality and inadequate feed supply from the natural pastures results not only in low livestock productivity within these marginal rangelands (Samuels et al. 2016, Müller et al. 2019), but also further causes rangeland degradation, resulting in further negative impacts on future livestock production, even when the drought is over. The need for developing grass and legumes genetic resources as suitable alternative forages that are adapted to these arid and semi-arid environments is therefore imperative, especially because the predicted climate change scenarios for South Africa are suggesting that the frequency, intensity and duration of these cyclic droughts are expected to increase (DEA 2013).

With many indigenous grass and legume species in South Africa naturally falling within the bioclimatically and edaphically marginal areas, it is proposed that these indigenous species have the potential to be developed into alternative, better-adapted forages for these areas (Müller et al. 2017, 2021; Trytsman et al. 2019, 2020, 2021). Also, naturally occurring ecotypes of already commercially available forages, which fall within these drought-stricken areas, can be used as a means to improve existing commercially available varieties by crossing with ecotypes that naturally occur within these marginal ecological regions. However, even with this large diversity of grass and legume genetic resources, very little information exists regarding the forage potential of these indigenous species, and the potential of their microbial symbionts to improve their production under these marginal bioclimatic and edaphic conditions (Trytsman et al., 2016, 2019, 2021; Muller et al., 2017). This, in turn, has resulted in a decline in recent efforts to domesticate and develop indigenous South African grass and legume species as forages, resulting in the South African National Forage Genebank (SA-NFG) housing less than 5% of indigenous legume and only approximately 24% of indigenous grass germplasm that can be evaluated for their forage potential (Müller et al. 2017, Trytsman et al. 2019, 2020, 2021). The collection of these grass and legume genetic resources, especially those from water-limited regions of South Africa, will allow for the identification of suitable species that can be developed into better-adapted forages for water-limited agro-ecosystems.

The aim of this study was, therefore, to use a combination of herbaria records, published literature and GIS techniques to identify and prioritise suitable grass and legume genetic resources that are potentially suitable for use in water-limited conditions in South Africa.

2.2 MATERIALS AND METHODS

2.2.1 Development of the legume and grass distribution databases

The occurrence records for grasses and legumes indigenous to southern Africa were extracted from the Botanical Database of Southern Africa (BODATSA), maintained by the South African National Biodiversity Institute (SANBI) and stored in the BRAHMS platform and PHYTOBAS, a National Vegetation Data Archive database containing botanical survey records for the period between 2003 and 2009 and maintained by the SA-NFG. The merging of the two datasets resulted in 43890 grass and 31235 legume distribution records. All records were cleaned, i.e., removing all duplicated records, records with missing information and occurrence data occurring outside the boundaries of the country. Published literature was used to identify growth forms, life cycles, plant height, and grazing/browsing potential. The distribution data for legumes and grasses were superimposed on a map indicating mean annual precipitation (MAP) of South Africa (Schulze et al. 2007).

2.2.2 Prioritisation of grass and legume genetic resources

The step-by-step methods for the development of a prioritised legume and grass list are provided in Figures 1 and 2, respectively. Mean annual precipitation was used as the first criterion to prioritise grass and legume species. All species that occurred in areas that received less than 600 mm of rainfall were initially prioritised. Thereafter, all perennial species were selected, and all annual species were discarded. For grasses, all species with high grazing value were selected. For legumes, only species that fell in the high and medium potential classes of Trytsman (2013) were selected. These classes consisted of species that are known to be grazed/browsed and had no known anti-nutritional qualities. After prioritising the species, their total distributions were plotted across South Africa, and species were identified based on province and when the rainfall season starts within each province, which, in turn, would potentially streamline collection activities.

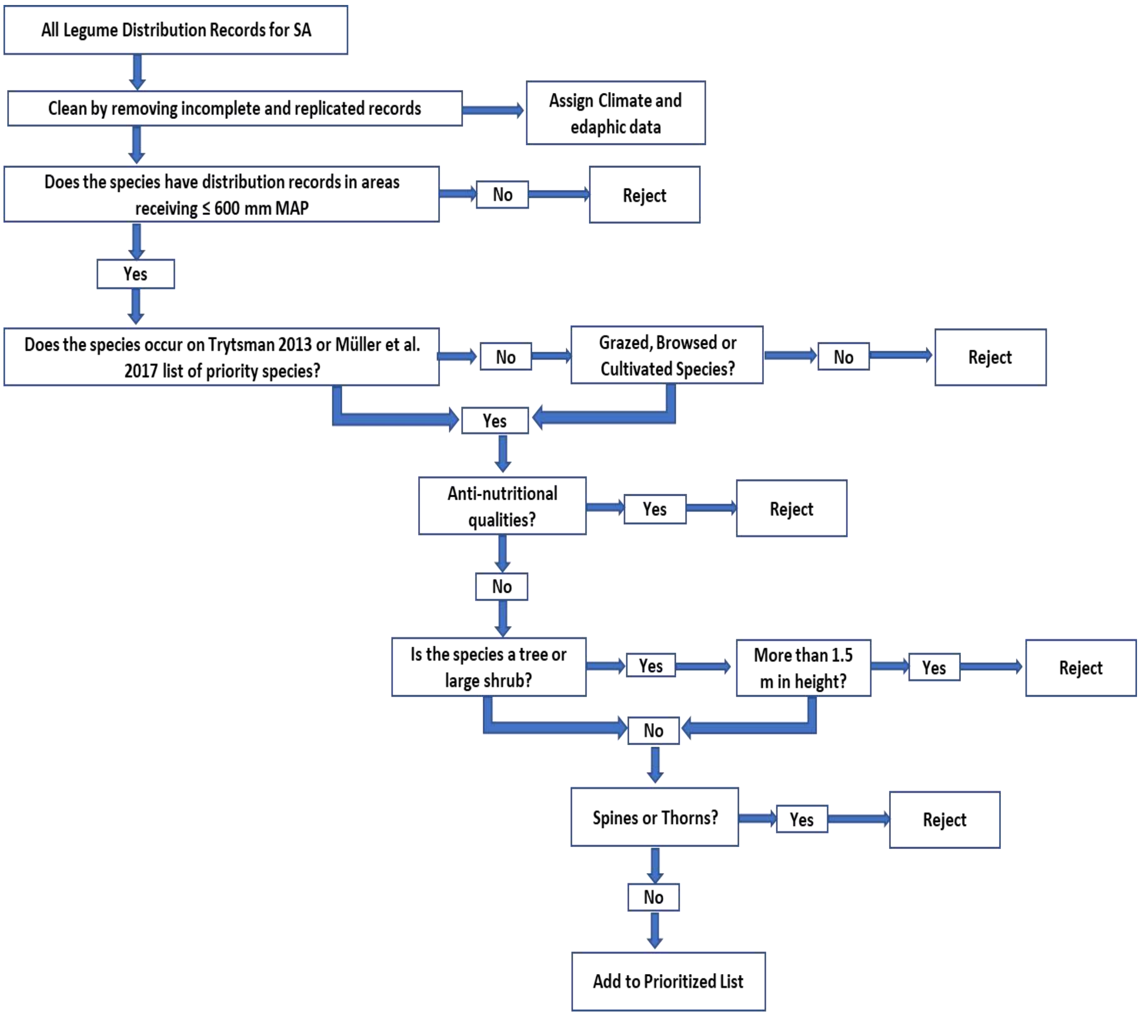


Figure 1: Prioritisation of indigenous legume species for collection.

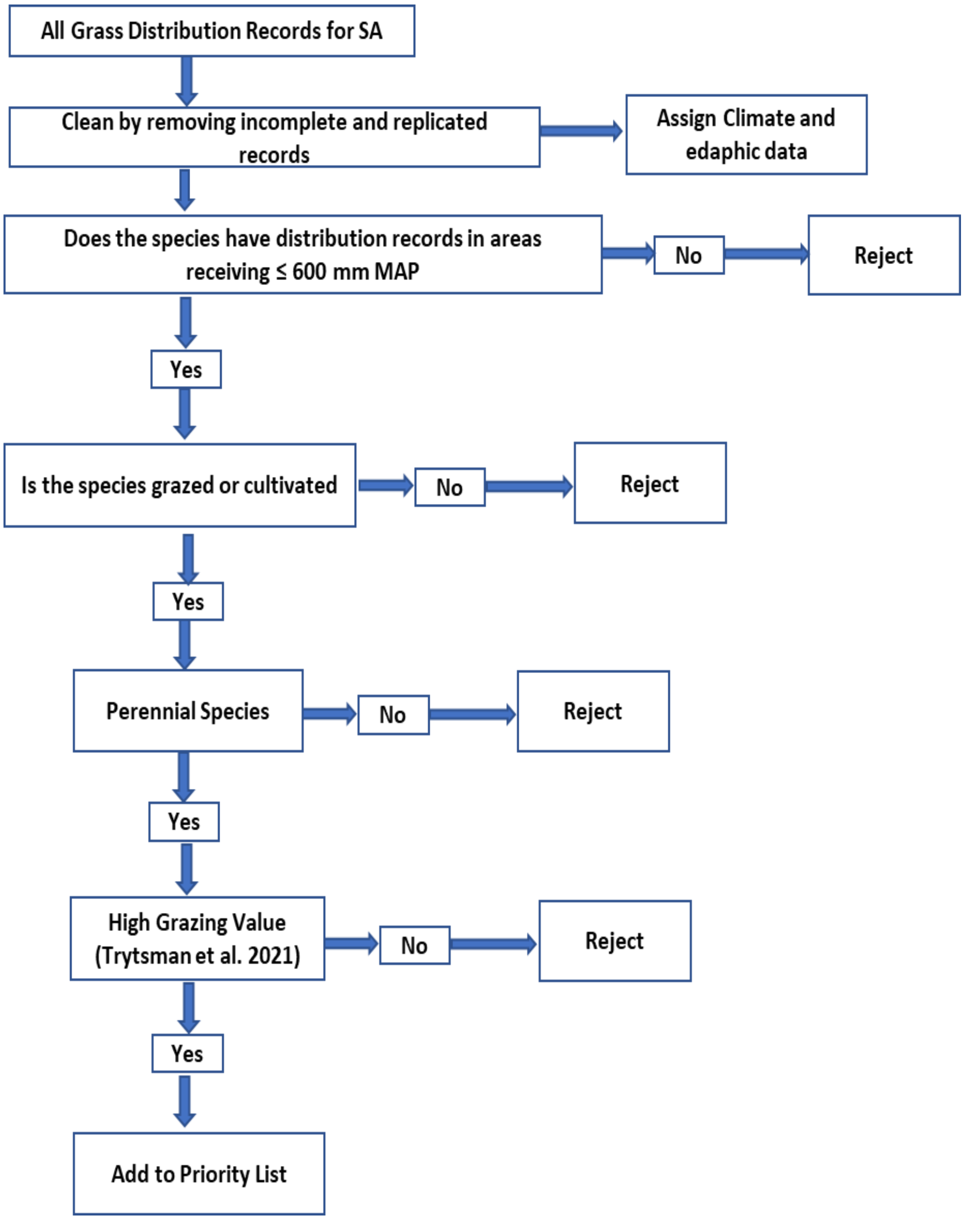


Figure 2: Prioritisation of indigenous grass species for collection.

In order to streamline collection initiatives, the prioritized species were separated into distinct populations based on their climate and edaphic niches. To do this, the distribution records of each prioritised species were plotted across their total distribution ranges. Thereafter rainfall seasonality i.e., when the rainfall season starts (Schulze et al. 2007), mean annual precipitation i.e., the total amount of rainfall that falls within an area in one year, rainfall concentration index (RCI) i.e., the spread of the rainy season (Schulze et al. 2007), coefficient of variation of annual precipitation (CVAP) i.e., the degree of inter-seasonal changes in annual precipitation (Schulze 2007), the mean annual net primary productivity of the area (Schulze et al. 2007), plant available water (PAW) in the soils (Schulze et al. 2007), soil pH, soil salinity and the production potential of the areas where the species occur within South Africa was used to further divide the prioritised PGR into distinct populations from where prioritisation of seed collections will take place.

2.3 RESULTS AND DISCUSSION

2.3.1 Prioritisation of grass and legume genetic resources

Based on the selection criteria above, a total of 89 legume species in 29 genera (Table 1) and 342 grass species in 100 genera (Table 2) were prioritised. For the legume species, more than 10 species in the genera *Indigofera* and *Lessertia* were prioritised, while with the grasses, the family Paniceae contained 22 species that were prioritised. The full list of prioritized species is given in Table 3. From this list, it was clear that several grass species are good candidates for further evaluation since some of the species identified through the selection process already contained several commercially available cultivars. These species include *Anthephora pubescens, Brachiaria nigropedata, Cenchrus ciliaris, Chloris gayana, Cynodon dactylon, Digitaria eriantha, Eragrostis curvula, Panicum coloratum, Panicum maximum,* and *Setaria sphacelata.* In contrast to the grass species, only two of the indigenous species that were prioritised have previously been domesticated and commercialised; these species are *Lebeckia ambigua* and *Trifolium africanum* (Table 3). Several reasons exist for the lack of interest in evaluating and developing indigenous South African legume species for forage production. The most commonly reported reasons are the easily accessible exotic forage germplasm in South Africa which are fairly well adapted to most of the countries bioclimatic and edaphic conditions (Palmer and Ainslie 2006; Trytsman 2013), but also large and well-known South African legume genera that are not generally recognized as livestock feed in South Africa itself due to their perceived toxic qualities and the general lack of knowledge about their agronomic potential (Trytsman 2013). Furthermore, one of the main reasons why new species are not often considered in breeding programs is the time required to domesticate new forage species, and the costs associated with producing marketable amounts of seeds (Loi et al. 2008; Nichols et al. 2007; 2010; Muir et al. 2014; Mitchell et al. 2015).

However, on the list of prioritised species, there are a number of *Lessertia* species (Table 3). Recently, *L. capitata*, *L. diffusa, L. excisa, L. herbacea, L. incana* and *L. pauciflora* have been included in Australian forage evaluation trials, and from these trials it was indicated that these species are highly palatable and have shown some degree of grazing tolerance. They were also reported to become prostrate under high grazing pressure in trials done in Australia, which allows them to withstand continuous grazing pressure (Howieson et al. 2008; Gerding et al. 2013a;b). However, the high numbers of resident Rhizobium bacterial strains in the Australian soils that rapidly nodulated these *Lessertia* species but are non-nitrogen fixing led to the discarding of the South African *Lessertia* species as forage legumes in Western Australia (Gerding et al. 2013a,b; Gerding et al. 2014). This, however, does not mean that these species should not be further evaluated in South Africa and potentially be developed into new forage genetic resources.

Table 1: Summary of legume species prioritised for collection

	Genus	Species	Genus	Species
	Aeschynomene	1	Macrotyloma	2
	Argyrolobium	3	Melolobium	2
	Bauhinia	1	Neonotonia	1
	Calobota	1	Otoptera	1
	Crotalaria	8	Pseudartria	1
	Cullen	1	Psoralea	2
	Dichilus	1	Rhynchosia	10
Legumes	Erythrina	1	Sphenostylis	1
	Indigastrum	1	Stylosanthes	1
	Indigofera	15	Tephrosia	7
	Lebeckia	1	Teramnus	1
	Lessertia	12	Trifolium	3
	Listia	1	Tylosema	1
	Lotononis	1	Vigna	7
			Zornia	1

Table 2: Summary of grass species prioritised for collection

	Genus	Species	Tribe		Genus	Species	Tribe		Genus	Species	Tribe		Genus	Species	Tribe	
	Andropogon	3	Andropogoneae		Chloris	2	Cynodonteae		Acroceras	1	Paniceae		Cladoraphis	2	Eragrostideae	
	Arthraxon	1	Andropogoneae		Coelachyrum	1	Cynodonteae		Alloteropsis	1	Paniceae		Enneapogon	3	Eragrostideae	
	Chrysopogon	1	Andropogoneae		Cynodon	8	Cynodonteae		Anthephora	2	Paniceae		Eragrostis	19	Eragrostideae	
	Cymbopogon	3	Andropogoneae		Dactyloctenium	1	Cynodonteae		Brachiaria	6	Paniceae		Fingerhuthia	5	Eragrostideae	7
	Dichanthium	1	Andropogoneae		Eustachys	2	Cynodonteae		Cenchrus	1	Paniceae		Schmidtia	1	Eragrostideae	
	Elionurus	1	Andropogoneae		Leptochloa	3	Cynodonteae		Digitaria	19	Paniceae		Stiburus	1	Eragrostideae	
	Eulalia	2	Andropogoneae		Lintonia	1	Cynodonteae		Echinochloa	4	Paniceae		Tetrachne	1	Eragrostideae	
	Hemarthria	1	Andropogoneae	14	Lophacme	1	Cynodonteae	14	Entolasia	1	Paniceae		Leersia	1	Oryzeae	
	Hyparrhenia	11	Andropogoneae		Microchloa	1	Cynodonteae		Eriochloa	3	Paniceae		Oryza	1	Oryzeae	3
	Miscanthus	1	Andropogoneae		Mosdenia	1	Cynodonteae		Leucophrys	1	Paniceae		Prosphytochloa	1	Oryzeae	
	Schizachyrium	1	Andropogoneae		Odyssea	1	Cynodonteae		Melinis	2	Paniceae					
	Sehima	1	Andropogoneae		Schoenefeldia	1	Cynodonteae		Oplismenus	1	Paniceae	22				
Grasses	Sorghastrum	1	Andropogoneae		Tragus	1	Cynodonteae		Panicum	14	Paniceae					
	Themeda	1	Andropogoneae		Tripogon	1	Cynodonteae		Paspalidium	1	Paniceae					
	Aristida	10	Aristideae		Capeochloa	3	Danthonieae		Pennisetum	2	Paniceae					
	Sartidia	1	Aristideae	3	Chaetobromus	1	Danthonieae		Sacciolepis	2	Paniceae					
	Stipagrostis	12	Aristideae		Geochloa	1	Danthonieae		Setaria	8	Paniceae					
	Drepanochloa	2	Arundineae	1	Merxmuellera	1	Danthonieae		Stenotaphrum	1	Paniceae					
	Arundinella	1	Arundinelleae	1	Pentameris	55	Danthonieae	10	Stereochlaena	1	Paniceae					
	Oxytenanthera	1	Bambuseae	1	Pentaschistis	2	Danthonieae		Tarigidia	1	Paniceae					
	Brachypodium	2	Brachypodieae	1	Pseudopentameris	3	Danthonieae		Tricholaena	1	Paniceae					
	Bromus	2	Bromeae	1	Schismus	2	Danthonieae		Urochloa	3	Paniceae					
	Centropodia	1	Centropodieae	1	Tenaxia	1	Danthonieae		Melica	1	Meliceae	2				
	Ehrharta	16	Ehrharteae	1	Tribolium	7	Danthonieae		Streblochaete	1	Meliceae					

Table 3: Full list of prioritised legume and grass species for collection

Legumes	Grasses			
Aeschynomene indica	*Acroceras macrum*	*Ehrharta microlaena*	*Panicum arbusculum*	*Schismus scaberrimus*
Argyrolobium collinum	*Agrostis barbuligera*	*Ehrharta ottonis*	*Panicum bechuanense*	*Schizachyrium ursulus*
Argyrolobium tomentosum	*Agrostis eriantha*	*Ehrharta ramosa*	*Panicum coloratum*	*Schmidtia pappophoroides*
Argyrolobium transvaalense	*Agrostis polypogonoides*	*Ehrharta rehmannii*	*Panicum deustum*	*Schoenefeldia transiens*
Bauhinia galpinii	*Alloteropsis papillosa*	*Ehrharta rupestris*	*Panicum dewinteri*	*Secale strictum*
Calobota sericea	*Andropogon appendiculatus*	*Ehrharta setacea*	*Panicum dregeanum*	*Sehima galpinii*
Crotalaria excisa subsp. Namaquensis (ADD: C. excisa subsp. Excisa)	*Andropogon gayanus*	*Ehrharta thunbergii*	*Panicum hygrocharis*	*Setaria appendiculata*
Crotalaria laburnifolia subsp. Australis	*Andropogon lacunosus*	*Ehrharta villosa*	*Panicum infestum*	*Setaria incrassata*
Crotalaria natalitia var. natalitia	*Anthephora argentea*	*Enneapogon pretoriensis*	*Panicum kalaharense*	*Setaria lindenbergiana*
Crotalaria pearsonii	*Anthephora pubescens*	*Enneapogon spathaceus*	*Panicum lanipes*	*Setaria megaphylla*
Crotelaria eremicola subsp. eremicola	*Anthoxanthum dregeanum*	*Enteropogon macrostachyus*	*Panicum maximum*	*Setaria plicatilis*
Crotelaria lotoides	*Anthoxanthum ecklonii*	*Entolasia olivacea*	*Panicum monticola*	*Setaria sphacelata*
Crotelaria monteiroi var. galpinii	*Anthoxanthum tongo*	*Eragrostis acraea*	*Panicum repens*	*Sorghastrum nudipes*
Crotelaria monteiroi var. monteiroi	*Aristida aequiglumis*	*Eragrostis barbinodis*	*Panicum stapfianum*	*Spartina maritima*
Cullen tomentosum	*Aristida dasydesmis*	*Eragrostis bergiana*	*Paspalidium obtusifolium*	*Sporobolus acinifolius*
Dichilus pilosus	*Aristida engleri*	*Eragrostis caesia*	*Paspalum distichum*	*Sporobolus albicans*
Erythrina zeyheri	*Aristida mollissima*	*Eragrostis crassinervis*	*Paspalum vaginatum*	*Sporobolus congoensis*
Indigastrum argyraeum	*Aristida pilgeri*	*Eragrostis curvula*	*Pennisetum glaucocladum*	*Sporobolus conrathii*
Indigofera alternans var. alternans	*Aristida recta*	*Eragrostis elatior*	*Pennisetum unisetum*	*Sporobolus consimilis*
Indigofera arrecta	*Aristida sciurus*	*Eragrostis habrantha*	*Pentameris acinosa*	*Sporobolus fimbriatus*
Indigofera cryptantha var. cryptantha	*Aristida spectabilis*	*Eragrostis hierniana*	*Pentameris ampla*	*Sporobolus fourcadii*
Indigofera dimidiata	*Aristida transvaalensis*	*Eragrostis lappula*	*Pentameris argentea*	*Sporobolus ludwigii*
Indigofera heterotricha	*Aristida vestita*	*Eragrostis micrantha*	*Pentameris aristidoides*	*Sporobolus natalensis*
Indigofera homblei subsp. homblei	*Arthraxon lanceolatus*	*Eragrostis obtusa*	*Pentameris aspera*	*Sporobolus nebulosus*
Indigofera melandadenia	*Arundinella nepalensis*	*Eragrostis planiculmis*	*Pentameris aurea*	*Sporobolus nervosus*
Indigofera meyeriana	*Brachiaria arrecta*	*Eragrostis pseudobtusa*	*Pentameris bachmannii*	*Sporobolus oxyphyllus*
Indigofera nigromontana	*Brachiaria bovonei*	*Eragrostis sabulosa*	*Pentameris barbata*	*Sporobolus pectinatus*
Indigofera pungens	*Brachiaria dictyoneura*	*Eragrostis sarmentosa*	*Pentameris calcicola*	*Sporobolus rangei*

Indigofera rhytidocarpa subsp. rhytidocarpa	*Brachiaria dura*	*Eragrostis sclerantha*	*Pentameris capensis*	*Sporobolus salsus*
Indigofera schimperi var. schimperi	*Brachiaria nigropedata*	*Eragrostis stapfii*	*Pentameris chippindalliae*	*Sporobolus sanguineus*
Indigofera tinctoria var. arcuata	*Brachiaria subulifolia*	*Eragrostis truncata*	*Pentameris cirrhulosa*	*Sporobolus spicatus*
Lebeckia ambigua	*Brachypodium bolusii*	*Eriochloa meyeriana*	*Pentameris clavata*	*Sporobolus subtilis*
Lessertia brachypus	*Brachypodium flexum*	*Eriochloa parvispiculata*	*Pentameris colorata*	*Sporobolus subulatus*
Lessertia depressa	*Bromus firmior*	*Eriochloa stapfiana*	*Pentameris densifolia*	*Sporobolus tenellus*
Lessertia diffusa	*Bromus leptoclados*	*Eriochrysis pallida*	*Pentameris distichophylla*	*Sporobolus virginicus*
Lessertia excisa	*Calamagrostis epigejos*	*Eulalia aurea*	*Pentameris elegans*	*Sporobolus welwitschii*
Lessertia frutescens subsp. frutescens	*Capeochloa arundinacea*	*Eulalia villosa*	*Pentameris ellisii*	*Stenotaphrum secundatum*
Lessertia frutescens subsp. microphylla	*Capeochloa cincta*	*Eustachys paspaloides*	*Pentameris eriostoma*	*Stereochlaena cameronii*
Lessertia incana	*Capeochloa setacea*	*Festuca africana*	*Pentameris galpinii*	*Stiburus conrathii*
Lessertia inflata	*Cenchrus ciliaris*	*Festuca caprina*	*Pentameris glacialis*	*Stipa dregeana*
Lessertia montana	*Centropodia glauca*	*Festuca costata*	*Pentameris glandulosa*	*Stipagrostis amabilis*
Lessertia pauciflora var. pauciflora	*Chaetobromus involucratus*	*Festuca dracomontana*	*Pentameris heptameris*	*Stipagrostis brevifolia*
Listia bainesii	*Chloris gayana*	*Festuca longipes*	*Pentameris hirtiglumis*	*Stipagrostis ciliata*
Lotononis laxa	*Chloris mossambicensis*	*Fingerhuthia sesleriiformis*	*Pentameris holciformis*	*Stipagrostis dregeana*
Macrotyloma axillare var. axillare	*Chrysopogon serrulatus*	*Geochloa decora*	*Pentameris horrida*	*Stipagrostis fastigiata*
Macrotyloma uniflorum var. stenocarpum	*Cladoraphis cyperoides*	*Helictotrichon barbatum*	*Pentameris juncifolia*	*Stipagrostis geminifolia*
Melolobium adenodes	*Cladoraphis spinosa*	*Helictotrichon capense*	*Pentameris lima*	*Stipagrostis hochstetteriana*
Melolobium humile	*Coelachyrum yemenicum*	*Helictotrichon dodii*	*Pentameris longiglumis*	*Stipagrostis lutescens*
Melolobium microphyllum	*Cymbopogon dieterlenii*	*Helictotrichon galpinii*	*Pentameris macrocalycina*	*Stipagrostis obtusa*
Neonotonia wightii	*Cymbopogon marginatus*	*Helictotrichon hirtulum*	*Pentameris malouinensis*	*Stipagrostis proxima*
Otoptera burchellii	*Cymbopogon prolixus*	*Helictotrichon leoninum*	*Pentameris microphylla*	*Stipagrostis schaeferi*
Pseudartria hookeri var. hookeri	*Cynodon bradleyi*	*Helictotrichon longifolium*	*Pentameris montana*	*Stipagrostis zeyheri*
Psoralea arborea	*Cynodon dactylon*	*Helictotrichon longum*	*Pentameris natalensis*	*Streblochaete longiarista*
Rhynchosia emarginata	*Cynodon hirsutus*	*Helictotrichon namaquense*	*Pentameris obtusifolia*	*Tarigidia aequiglumis*
Rhynchosia minima var. minima	*Cynodon incompletus*	*Helictotrichon natalense*	*Pentameris oreodoxa*	*Tenaxia dura*
Rhynchosia schlechteri	*Cynodon polevansii*	*Hemarthria altissima*	*Pentameris oreophila*	*Tetrachne dregei*
Rhynchosia venulosa	*Cynodon transvaalensis*	*Hordeum capense*	*Pentameris pallescens*	*Themeda triandra*
Rhyncosia adenodes	*Dactyloctenium geminatum*	*Hyparrhenia anamesa*	*Pentameris pseudopallescens*	*Tragus koelerioides*
Rhyncosia caribaea	*Danthoniopsis parva*	*Hyparrhenia finitima*	*Pentameris pusilla*	*Tribolium acutiflorum*

Rhyncosia minima var. prostrata	*Danthoniopsis pruinosa*	*Hyparrhenia gazensis*	*Pentameris pyrophila*	*Tribolium brachystachyum*
Rhyncosia sublobata	*Danthoniopsis ramosa*	*Hyparrhenia newtonii*	*Pentameris rigidissima*	*Tribolium curvum*
Rhyncosia totta var. totta	*Dichanthium annulatum*	*Hyparrhenia nyassae*	*Pentameris rupestris*	*Tribolium hispidum*
Rhyncosia confusa	*Digitaria argyrograpta*	*Hyparrhenia poecilotricha*	*Pentameris scabra*	*Tribolium obliterum*
Sphenostylis angustifolia	*Digitaria brazzae*	*Hyparrhenia quarrei*	*Pentameris scandens*	*Tribolium obtusifolium*
Stylosanthes fruticosa	*Digitaria diversinervis*	*Hyparrhenia rudis*	*Pentameris setifolia*	*Tribolium purpureum*
Tephrosia capensis var. capensis	*Digitaria eriantha*	*Hyparrhenia rufa*	*Pentameris swartbergensis*	*Tricholaena capensis*
Tephrosia cordata	*Digitaria eylesii*	*Hyparrhenia schimperi*	*Pentameris thuarii*	*Trichopteryx dregeana*
Tephrosia elongata var. elongata	*Digitaria flaccida*	*Hyparrhenia variabilis*	*Pentameris tomentella*	*Tripogon minimus*
Tephrosia multijuga	*Digitaria maitlandii*	*Leersia denudata*	*Pentameris tortuosa*	*Triraphis ramosissima*
Tephrosia rhodesica var. rhodesica	*Digitaria natalensis*	*Leptochloa chinensis*	*Pentameris trifida*	*Triraphis schinzii*
Tephrosia villosa subsp. ehrenbergiana var. daviesii	*Digitaria polyphylla*	*Leptochloa eleusine*	*Pentameris tysonii*	*Tristachya biseriata*
Tephrosia villosa subsp. ehrenbergiana var. ehrenbergiana	*Digitaria scalarum*	*Leptochloa fusca*	*Pentameris velutina*	*Tristachya rehmannii*
Teramnus labialis subsp. labialis	*Digitaria seriata*	*Leucophrys mesocoma*	*Pentameris veneta*	*Urochloa mosambicensis*
Trifolium africanum var. africanum	*Digitaria setifolia*	*Lintonia nutans*	*Pentameris viscidula*	*Urochloa oligotricha*
Trifolium africanun var. lydenburgense	*Digitaria tricholaenoides*	*Lophacme digitata*	*Pentaschistis aurea*	*Urochloa stolonifera*
Trifolium burchellianum supsp. burchellianum	*Dregeochloa calviniensis*	*Loudetia filifolia*	*Pentaschistis pallescens*	
Tylosema esculentum	*Dregeochloa pumila*	*Loudetia flavida*	*Pentaschistis pallida*	
Vigna luteola var. luteola	*Echinochloa haploclada*	*Loudetia pedicellata*	*Poa binata*	
Vigna oblongifolia var. oblongifolia	*Echinochloa jubata*	*Melica racemosa*	*Poa bulbosa*	
Vigna unguiculata supsp. dekindtiana var. dekindtiana	*Echinochloa pyramidalis*	*Melinis longiseta*	*Prosphytochloa prehensilis*	
Vigna unguiculata supsp. dekindtiana var. huillensis	*Echinochloa stagnina*	*Melinis minutiflora*	*Pseudopentameris brachyphylla*	
Vigna vexillata var. angustifolia	*Ehrharta barbinodis*	*Merxmuellera macowanii*	*Pseudopentameris caespitosa*	
Vigna vexillata var. ovata	*Ehrharta bulbosa*	*Microchloa kunthii*	*Pseudopentameris macrantha*	
Vigna vexillata var. vexillata	*Ehrharta calycina*	*Miscanthus junceus*	*Puccinellia acroxantha*	
Zornia milneana	*Ehrharta capensis*	*Mosdenia leptostachys*	*Puccinellia angusta*	
	Ehrharta dura	*Odyssea paucinervis*	*Sacciolepis chevalieri*	
	Ehrharta eburnea	*Oplismenus undulatifolius*	*Sacciolepis typhura*	
	Ehrharta longigluma	*Oryza longistaminata*	*Sartidia jucunda*	
	Ehrharta melicoides	*Oxytenanthera abyssinica*	*Schismus inermis*	

When plotting the distributions of these prioritised species across their entire distribution ranges in South Africa and subsequently looking at which provinces these species occur in, it was clear that several species have highly ubiquitous ranges. South Africa can be divided into all-year, winter, and summer rainfall zones. The summer rainfall areas can further be divided into early, mid, late, and very late summer rainfall areas (Shulze et al. 2007). The early summer rainfall zones in SA are areas where the rainfall season peaks in December, mid-summer rainfall zones where the rainfall season peaks in January, late summer rainfall zones where the rainfall season peaks in February, and very late summer rainfall zones where the rainfall season peaks in March to May (Figure 3).

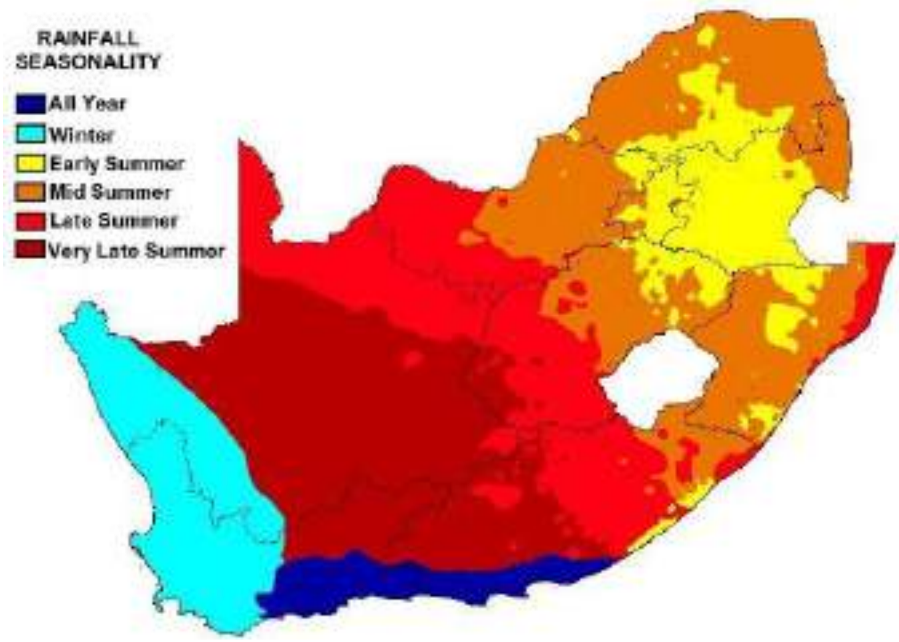


Figure 3: Rainfall seasonality map of South Africa showing six seasonal zones.

A total of 46 legume species were prioritised for collection from the winter and all-year rainfall zones of South Africa (Table 4) and 55 legume species were prioritised for collection from the summer rainfall zones of South Africa (Table 5). A total of 215 grass species were prioritized for collection within the all-year and winter rainfall zones of South Africa (Table 6) and 366 grass species were prioritized for collection within the summer rainfall zones of South Africa (Table 7).

Although only seven prioritised legume species had distributions in all South African provinces (Table 5), a total of 17 grass species had distribution records in all South African provinces (Table 7). Species with wide distribution ranges can be regarded as having various adaptation strategies to the wide range of conditions in which they occur. This, in turn, means that when these species are collected, they could potentially contain unique traits that make them suited for specific growing conditions. This, in turn, means that as much of this population should be collected as this will lead to a larger diversity of genetic resources for these species for inclusion in later breeding and improvement programs.

In contrast, 16 legume species (Table 5) and 89 grass species (Table 7) were found to have limited distribution ranges, occurring in only 1 to 3 provinces. Although these species are important for collection, their agronomic potential may be limited due to their narrow distribution ranges, which could possibly reflect their adaptation ranges. These species should undergo niche modelling in order to determine whether their potential niche can be increased, as this is an important criterion for inclusion in forage breeding and improvement programmes.

Table 4: Legume species prioritised for collection within the winter and all-year rainfall zones of South Africa. WC = Western Cape, EC = Eastern Cape, NC = Northern Cape. X = occurrence within each province

Species	WC	EC	NC	Species	WC	EC	NC
Argyrolobium collinum	x	x		*Lessertia incana*			x
Argyrolobium tomentosum	x	x		*Lessertia pauciflora* var. *pauciflora*	x		x
Calobota sericea	x		x	*Lotononis falcata*	x		x
Crotalaria effusa	x		x	*Lotononis laxa*			x
Crotalaria excisa subsp. *excisa*	x		x	*Lotononis leptoloba*	x		x
Crotalaria laburnifolia subsp. *australis*	x		x	*Melolobium adenodes*	x	x	x
Crotalaria lotoides		x		*Melolobium humile*	x		x
Crotalaria pearsonii			x	*Melolobium microphyllum*			x
Cullen tomentosum	x		x	*Psoralea arborea*	x	x	
Indigastrum argyraeum	x		x	*Rhynchosia adenodes*	x	x	x
Indigastrum argyroides	x		x	*Rhynchosia caribaea*	x	x	
Indigofera alternans var. *alternans*	x		x	*Rhynchosia emarginata*			x
Indigofera meyeriana	x		x	*Rhynchosia minima* var. *minima*	x		
Indigofera nigromontana	x	x	x	*Rhynchosia schlechteri*	x	x	
Indigofera pungens	x		x	*Rhynchosia totta* var. *totta*	x	x	
Indigofera rhytidocarpa subsp. *rhytidocarpa*		x		*Sutherlandia montana*	x		
Lebeckia ambigua	x		x	*Tephrosia capensis* var. *capensis*	x	x	
Lessertia brachypus			x	*Trifolium africanum* var. *africanum*		x	
Lessertia depressa		x		*Trifolium burchellianum* subsp. *burchellianum*	x	x	
Lessertia diffusa	x		x	*Vigna luteola* var. *luteola*		x	
Lessertia excisa	x		x	*Vigna vexillata* var. *vexillata*		x	
Lessertia frutescens subsp. *frutescens*	x	x	x	*Zornia glochidiata*		x	
Lessertia frutescens subsp. *microphylla*	x	x	x	*Zornia milneana*		x	

Table 5: Legume species prioritised for collection within the summer and all-year rainfall zones of South Africa. NC = Northern Cape, LP = Limpopo, KZN = KwaZulu-Natal, NW = North West, GP = Gauteng, MP = Mpumalanga, FS = Free State, WC = Western Cape, EC = Eastern Cape. X = occurrence within each province

	NC	LP	KZN	NW	GP	MP	FS	WC	EC		NC	LP	KZN	NW	GP	MP	FS	WC	EC
Aeschynomene indica		x	x	x		x				*Macrotyloma uniflorum var. stenocarpum*		x				x			
Argyrolobium collinum			x				x	x	x	*Melolobium adenodes*	x							x	x
Argyrolobium tomentosum		x	x			x		x	x	*Melolobium humile*	x							x	x
Argyrolobium transvaalense		x				x				*Melolobium microphyllum*	x		x	x		x	x	x	x
Bauhinia galpinii		x	x	x	x	x		x	x	*Neonotonia wightii*		x	x	x	x	x			
Crotalaria eremicola subsp. Erimicola	x	x		x	x			x		*Otoptera burchellii*	x	x		x	x		x		
Crotalaria laburnifolia	x	x	x	x	x	x				*Pseudarthria hookeri var. hookeri*		x	x			x			x
Crotalaria natalitia var. natalitia		x	x			x				*Psoralea arborea*		x	x			x		x	x
Crotalaria lotoides	x	x		x	x	x	x		x	*Rhynchosia emarginata*	x	x	x	x	x	x	x	x	x
Crotalaria monteiroi var. galpinii		x	x			x				*Rhynchosia minima var. minima*		x	x		x	x	x	x	x
Crotalaria monteiroi var. monteiroi		x	x			x				*Rhynchosia venulosa*	x	x	x	x	x	x	x		x
Cullen tomentosum	x	x	x	x			x	x		*Rhyncosia adenodes*									
Dichilus pilosus	x				x	x				*Rhyncosia caribaea*		x	x	x	x	x	x	x	x
Erythrina zeyheri			x	x	x	x	x			*Rhyncosia minima var. prostrata*	x	x	x	x	x	x	x		x
Indigastrum argyraeum	x		x	x			x	x	x	*Rhyncosia sublobata*		x	x	x		x			
Indigofera alternans var. alternans	x	x		x	x		x	x	x	*Rhyncosia totta var. totta*	x	x	x	x	x	x	x	x	x
Indigofera arrecta		x	x	x	x	x	x			*Rhyncosia confusa*	x	x	x	x	x	x	x		
Indigofera cryptantha var. cryptantha	x	x	x	x	x	x	x	x		*Sphenostylis angustifolia*		x	x	x	x	x			
Indigofera dimidiata		x	x	x	x	x	x		x	*Stylosanthes fruticosa*		x	x	x	x	x			
Indigofera heterotricha	x	x		x	x	x				*Tephrosia capensis var. capensis*	x	x	x	x	x	x	x	x	x
Indigofera hamblei subsp. hamblei	x	x			x	x		x		*Tephrosia cordata*		x			x	x			x
Indigofera melanadenia	x	x	x	x	x	x	x			*Tephrosia elongata var. elongata*		x	x	x	x	x			
Indigofera meyeriana	x							x	x	*Tephrosia multijuga*		x	x	x	x	x	x		x
Indigofera nigromontana	x						x	x	x	*Tephrosia rhodesica var. rhodesica*		x		x	x	x	x		
Indigofera pungens	x							x		*Tephrosia villosa subsp. ehrenbergiana var. daviesii*		x			x	x			
Indigofera rhytidocarpa subsp. rhytidocarpa	x	x		x	x	x	x			*Tephrosia villosa subsp. ehrenbergiana var. ehrenbergiana*		x		x		x			
Indigofera schimperi var. schimperi		x	x			x				*Teramnus labialis subsp. labialis*		x	x	x	x	x			x
Indigofera tinctoria var. arcuata						x				*Trifolium africanum var. africanum*	x	x	x	x	x	x	x	x	x
Lessertia brachypus	x		x					x	x	*Trifolium africanun var. lydenburgense*			x		x	x	x		
Lessertia depressa	x		x			x	x	x	x	*Trifolium burchellianum supsp. burchellianum*	x		x			x	x	x	x
Lessertia frutescens subsp. frutescens	x		x	x	x	x	x	x	x	*Tylosema esculentum*		x		x	x				
Lessertia frutescens subsp. microphylla	x	x	x	x	x	x	x	x	x	*Vigna luteola var. luteola*		x	x		x	x		x	x
Lessertia incana	x									*Vigna oblongifolia var. oblongifolia*			x	x		x	x		
Lessertia inflata	x							x	x	*Vigna unguiculata supsp. dekindtiana var. dekindtiana*		x	x		x	x			
Lessertia pauciflora var. pauciflora	x	x		x			x	x		*Vigna unguiculata supsp. dekindtiana var. huillensis*		x	x	x		x			
Listia bainesii		x		x	x	x				*Vigna unguiculata (L.) Walp. subsp. unguiculata var. unguiculata*	x	x	x	x	x	x	x		x
Lotononis laxa	x	x	x	x	x	x	x	x	x	*Vigna vexillata var. angustifolia*			x		x	x			x
Macrotyloma axillare var. axillare		x	x	x	x	x			x	*Vigna vexillata var. vexillata*		x	x	x	x	x		x	x
										Zornia milneana	x	x	x	x	x	x	x		x

Table 6: Grass species prioritised for collection within the winter and all-year rainfall zones of South Africa. WC = Western Cape, EC = Eastern Cape, NC = Northern Cape. X = occurrence within each province

Species	WC	EC	NC	Species	WC	EC	NC	Species	WC	EC	NC	Species	WC	EC	NC	Species	WC	EC	NC
Acroceras macrum	X	X		Ehrharta ottonis	X	X		Oplismenus undulatifolius		X		Pentameris pusilla	X			Stipagrostis geminifolia			X
Agrostis eriantha	X			Ehrharta ramosa	X	X	X	Panicum aequinerve		X		Pentameris pyrophila	X	X		Stipagrostis hochstetteriana			X
Agrostis polypogonoides	X		X	Ehrharta rehmannii	X	X		Panicum coloratum	X	X		Pentameris reflexa	X			Stipagrostis lutescens			X
Andropogon appendiculatus	X	X	X	Ehrharta rupestris	X		X	Panicum deustum	X	X	X	Pentameris rigidissima	X	X	X	Stipagrostis obtusa	X		X
Anthoxanthum dregeanum	X			Ehrharta setacea	X			Panicum dregeanum		X		Pentameris rosea	X			Stipagrostis schaeferi			X
Anthoxanthum ecklonii	X	X		Ehrharta thunbergii	X	X	X	Panicum lanipes			X	Pentameris rupestris	X	X	X	Stipagrostis zeyheri	X	X	X
Anthoxanthum tongo	X			Ehrharta villosa	X	X	X	Panicum maximum	X	X		Pentameris scabra	X			Tenaxia dura	X	X	X
Aristida dasydesmis	X		X	Eragrostis bergiana	X			Panicum repens	X			Pentameris scandens	X			Themeda triandra	X	X	X
Aristida vogelii			X	Eragrostis caesia	X			Panicum stapfianum	X	X		Pentameris swartbergensis	X			Tragus koelerioides		X	
Aristida vestita	X	X	X	Eragrostis crassinervis	X			Panicum subalbidum	X	X		Pentameris thuarii	X			Tribolium acutiflorum	X		X
Arundinella nepalensis		X		Eragrostis curvula	X	X	X	Paspalum distichum	X	X	X	Pentameris tomentella	X		X	Tribolium brachystachyum	X		
Brachiaria arrecta		X		Eragrostis elatior	X			Paspalum vaginatum	X	X		Pentameris tortuosa	X	X		Tribolium curvum	X	X	
Brachiaria nigropedata	X			Eragrostis obtusa	X	X	X	Pennisetum unisetum	X			Pentameris trifida	X			Tribolium hispidum		X	X
Brachypodium bolusii			X	Eragrostis planiculmis	X	X		Pentameris acinosa	X			Pentameris tysonii		X		Tribolium obliterum	X		
Brachypodium flexum		X		Eragrostis sabulosa	X			Pentameris alticola	X			Pentameris velutina	X			Tribolium obtusifolium	X	X	X
Bromus firmior		X		Eragrostis sarmentosa	X		X	Pentameris ampla	X	X		Pentameris veneta	X		X	Tribolium purpureum	X		X
Capeochloa arundinacea	X	X	X	Eragrostis stapfii			X	Pentameris argentea	X			Pentameris viscidula	X	X		Tricholaena capensis	X		X
Capeochloa cincta	X	X		Eulalia villosa		X		Pentameris aristidoides	X		X	Pentaschistis aurea		X		Triraphis ramosissima			X
Cenchrus ciliaris	X	X	X	Eustachys paspaloides	X	X		Pentameris aspera	X			Pentaschistis pallescens	X	X		Triraphis schinzii	X		
Centropodia glauca			X	Festuca africana	X			Pentameris aurea	X	X		Pentaschistis pallida	X	X	X				
Chaetobromus involucratus	X	X	X	Festuca caprina		X		Pentameris bachmannii	X			Phragmites mauritianus			X				
Chloris gayana	X	X		Festuca costata		X		Pentameris barbata	X			Poa binata		X					
Cladoraphis cyperoides	X		X	Festuca longipes		X		Pentameris calcicola	X			Poa bulbosa	X		X				
Cladoraphis spinosa	X		X	Fingerhuthia sesleriiformis		X		Pentameris capensis	X			Pseudopentameris brachyphylla	X						
Cymbopogon dieterlenii	X		X	Geochloa decora	X	X		Pentameris cirrhulosa	X	X		Pseudopentameris caespitosa	X						
Cymbopogon marginatus	X	X	X	Geochloa lupulina	X			Pentameris clavata	X			Pseudopentameris macrantha	X						
Cymbopogon prolixus	X	X	X	Geochloa rufa	X			Pentameris colorata	X	X		Puccinellia acroxantha			X				
Cynodon dactylon	X	X	X	Helictotrichon barbatum			X	Pentameris densifolia	X			Puccinellia angusta	X	X					
Cynodon incompletus	X	X		Helictotrichon capense	X	X		Pentameris distichophylla	X	X		Schismus inermis	X	X	X				
Cynodon transvaalensis	X			Helictotrichon dodii	X			Pentameris elegans	X			Schismus scaberrimus	X		X				
Digitaria argyrograpta	X	X		Helictotrichon hirtulum	X	X		Pentameris ellisii	X			Secale strictum			X				
Digitaria diversinervis	X			Helictotrichon leoninum	X			Pentameris eriostoma	X	X	X	Setaria lindenbergiana		X					
Digitaria eriantha	X	X		Helictotrichon longifolium	X			Pentameris glacialis	X			Setaria megaphylla	X	X					
Digitaria natalensis	X	X		Helictotrichon longum	X	X	X	Pentameris glandulosa	X	X		Setaria sphacelata	X	X	X				
Digitaria scalarum		X		Helictotrichon namaquense			X	Pentameris heptameris		X		Sorghum bicolor			X				
Digitaria setifolia		X		Hemarthria altissima	X	X	X	Pentameris hirtiglumis	X			Spartina maritima	X	X					
Dregeochloa calviniensis			X	Hordeum capense	X		X	Pentameris holciformis	X			Sporobolus albicans	X						
Dregeochloa pumila			X	Hyparrhenia anamesa	X	X		Pentameris horrida	X		X	Sporobolus fimbriatus	X	X	X				
Echinochloa crus-pavonis	X			Hyparrhenia dregeana		X		Pentameris juncifolia	X			Sporobolus fourcadei	X	X					
Echinochloa jubata		X		Hyparrhenia schimperi	X			Pentameris lima			X	Sporobolus ludwigii	X						
Echinochloa pyramidalis	X	X		Leersia denudata	X			Pentameris longiglumis	X			Sporobolus spicatus			X				
Ehrharta barbinodis	X		X	Leersia hexandra	X	X		Pentameris macrocalycina	X	X	X	Sporobolus subulatus		X					
Ehrharta bulbosa	X			Leptochloa eleusine		X		Pentameris malouinensis	X	X	X	Sporobolus virginicus	X	X	X				
Ehrharta calycina	X	X	X	Leptochloa fusca	X	X	X	Pentameris montana	X			Stenotaphrum secundatum	X	X					
Ehrharta capensis	X		X	Leucophrys mesocoma			X	Pentameris obtusifolia	X			Stipa dregeana	X	X					
Ehrharta dura		X	X	Melica racemosa	X	X	X	Pentameris oreophila	X			Stipagrostis anomala	X		X				
Ehrharta eburnea	X		X	Merxmuellera macowanii		X		Pentameris pallescens	X			Stipagrostis brevifolia	X		X				
Ehrharta longifolia	X		X	Microchloa kunthii		X		Pentameris pseudopallescens	X			Stipagrostis ciliata	X	X	X				
Ehrharta melicoides	X		X	Odyssea paucinervis	X		X	Pentameris pungens	X		X	Stipagrostis dregeana			X				

Table 7: Grass species prioritised for collection within the summer and all-year rainfall zones of South Africa. NC = Northern Cape, LP = Limpopo, KZN = KwaZulu-Natal, NW = North West, GP = Gauteng, MP = Mpumalanga, FS = Free State, WC = Western Cape, EC = Eastern Cape. X = occurrence within each province

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Acroceras macrum		X	X		X	X		X	X
Agrostis barbuligera			X			X	X		X
Agrostis eriantha		X	X		X	X	X	X	X
Agrostis polypogonoides	X							X	
Alloteropsis papillosa			X			X			
Andropogon appendiculatus	X	X	X	X	X	X	X	X	X
Andropogon gayanus		X	X			X			
Anthephora argentea	X		X	X					
Anthephora pubescens	X	X		X	X	X	X		
Anthoxanthum dregeanum								X	
Anthoxanthum ecklonii			X			X	X	X	X
Anthoxanthum tongo								X	
Aristida aequiglumis		X		X	X	X			
Aristida dasydesmis	X				X		X	X	
Aristida engleri	X							X	
Aristida mollissima	X	X		X		X	X		
Aristida pilgeri		X		X	X	X			
Aristida recta		X	X	X	X	X			
Aristida sciurus		X	X		X	X	X		
Aristida spectabilis	X	X		X	X	X			
Aristida transvaalensis		X	X	X	X	X			
Aristida vestita	X	X		X	X		X	X	X
Arthraxon lanceolatus		X			X	X			
Arundinella nepalensis		X	X	X	X	X	X	X	X
Brachiaria arrecta			X			X			X
Brachiaria bovonei		X	X			X			
Brachiaria brizantha	X	X	X	X	X	X			
Brachiaria dictyoneura		X	X			X			
Brachiaria dura	X								
Brachiaria nigropedata	X	X	X	X	X	X	X	X	
Brachiaria subulifolia		X	X		X	X			
Brachypodium bolusii	X		X				X	X	X
Brachypodium flexum		X	X		X	X	X	X	X
Bromus firmior			X			X	X		X
Bromus leptoclados	X		X	X	X	X	X	X	X
Calamagrostis epigejos	X			X	X	X			X
Capeochloa arundinacea	X							X	X
Capeochloa cincta								X	X
Capeochloa setacea								X	
Cenchrus ciliaris	X	X	X	X	X	X	X	X	X
Centropodia glauca	X								
Chaetobromus involucratus	X							X	X
Chloris gayana		X	X	X	X	X	X	X	X
Chloris mossambicensis		X	X			X			
Chrysopogon serrulatus	X	X	X	X	X				
Cladoraphis cyperoides	X	X						X	
Cladoraphis spinosa	X				X			X	
Coelachyrum yemenicum	X	X		X					
Cymbopogon dieterlenii	X		X	X	X	X	X	X	X
Cymbopogon marginatus	X		X		X		X	X	X

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Cymbopogon pospischilii	X	X	X	X	X	X	X	X	X
Cynodon bradleyi	X		X		X		X		
Cynodon dactylon	X	X	X	X	X	X	X	X	X
Cynodon hirsutus	X	X	X	X	X	X	X		X
Cynodon incompletus	X	X	X	X			X	X	X
Cynodon polevansii	X			X			X		
Cynodon transvaalensis	X		X	X	X	X	X	X	X
Dactyloctenium geminatum		X	X			X			
Danthoniopsis parva		X							
Danthoniopsis pruinosa		X				X			
Danthoniopsis ramosa	X								
Dichanthium annulatum	X	X	X	X	X	X	X		
Digitaria argyrograpta	X	X	X	X	X	X	X	X	X
Digitaria brazzae	X	X		X	X	X			
Digitaria diversinervis		X	X		X	X		X	
Digitaria eriantha	X	X	X	X	X	X	X	X	X
Digitaria eylesii		X			X	X			
Digitaria flaccida		X	X			X	X		X
Digitaria maitlandii		X				X			X
Digitaria milanjiana		X				X	X		
Digitaria natalensis		X	X		X	X		X	X
Digitaria polyphylla	X			X					
Digitaria scalarum	X	X	X		X	X	X	X	X
Digitaria seriata	X	X		X	X				
Digitaria setifolia			X			X	X		X
Digitaria tricholaenoides			X	X	X	X	X		X
Dregeochloa calviniensis	X								
Dregeochloa pumila	X								
Echinochloa crus-pavonis			X					X	X
Echinochloa haploclada	X	X	X		X	X	X		
Echinochloa jubata	X	X	X	X	X	X	X		X
Echinochloa pyramidalis		X	X		X	X		X	X
Echinochloa stagnina	X	X	X	X	X	X	X		
Ehrharta barbinodis	X							X	
Ehrharta bulbosa								X	X
Ehrharta calycina	X		X		X		X	X	X
Ehrharta capensis	X							X	X
Ehrharta dura								X	X
Ehrharta eburnea	X							X	
Ehrharta longifolia	X				X			X	X
Ehrharta longigluma			X				X		X
Ehrharta melicoides	X		X						X
Ehrharta ottonis								X	X
Ehrharta ramosa	X							X	X
Ehrharta rehmannii								X	X
Ehrharta rupestris	X							X	X
Ehrharta setacea								X	
Ehrharta thunbergii	X							X	X
Ehrharta villosa	X							X	X
Enneapogon pretoriensis		X		X	X	X			

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Enneapogon scoparius		X							
Enteropogon monostachyus		X	X	X		X			
Entolasia olivacea		X							
Eragrostis acraea		X		X		X			X
Eragrostis barbinodis		X	X	X	X	X	X		
Eragrostis bergiana	X						X	X	X
Eragrostis caesia	X	X	X			X	X	X	X
Eragrostis crassinervis		X						X	
Eragrostis curvula	X	X	X	X	X	X	X	X	X
Eragrostis elatior								X	
Eragrostis habrantha		X				X			
Eragrostis hierniana		X	X	X	X	X			
Eragrostis lappula		X	X	X	X	X	X		
Eragrostis micrantha	X	X		X	X	X	X		X
Eragrostis obtusa	X	X		X	X	X	X	X	X
Eragrostis phyllacantha		X		X					
Eragrostis planiculmis	X	X	X	X	X	X	X	X	X
Eragrostis pseudobtusa	X	X		X	X		X		
Eragrostis remotiflora	X	X	X	X		X	X		X
Eragrostis sabulosa								X	X
Eragrostis sarmentosa	X	X	X			X	X	X	
Eragrostis sclerantha		X	X	X	X	X	X		X
Eragrostis staffii	X	X		X			X		X
Eragrostis tenuifolia		X	X			X			X
Eragrostis truncata	X			X			X	X	X
Eriochloa meyeriana		X	X		X	X			X
Eriochloa parvispiculata			X			X			
Eriochloa stapfiana		X	X		X	X			
Eriochrysis pallida	X	X	X		X	X			X
Eulalia aurea		X							
Eulalia villosa		X	X			X	X	X	X
Eustachys paspaloides	X	X	X	X	X	X	X		X
Festuca africana		X	X			X	X	X	X
Festuca caprina			X	X	X	X	X	X	X
Festuca costata	X	X	X			X	X		X
Festuca dracomontana		X			X				X
Festuca longipes			X			X	X		X
Fingerhuthia sesleriiformis	X	X	X		X		X	X	X
Geochloa decora		X						X	X
Geochloa lupulina								X	
Geochloa rufa								X	
Helictotrichon barbatum	X								
Helictotrichon capense						X		X	X
Helictotrichon dodii							X	X	X
Helictotrichon galpinii			X				X		X
Helictotrichon hirtulum		X	X			X	X	X	X
Helictotrichon leoninum								X	
Helictotrichon longifolium			X			X	X	X	X
Helictotrichon longum	X							X	X
Helictotrichon namaquense	X								

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Helictotrichon natalense			X			X			X
Hemarthria altissima	X	X	X	X	X	X	X	X	X
Hordeum capense	X			X		X	X	X	X
Hyparrhenia anamesa	X	X	X	X	X	X	X	X	X
Hyparrhenia collina		X	X			X			
Hyparrhenia dichroa		X	X			X	X		
Hyparrhenia dregeana		X	X	X	X	X	X	X	X
Hyparrhenia finitima		X				X			
Hyparrhenia gazensis		X	X			X			X
Hyparrhenia newtonii		X				X			
Hyparrhenia nyassae		X				X			
Hyparrhenia poecilotricha		X	X	X	X				X
Hyparrhenia quarrei		X	X	X	X	X	X		X
Hyparrhenia rudis		X	X			X			
Hyparrhenia rufa		X	X			X			
Hyparrhenia schimperi		X	X	X		X		X	X
Hyparrhenia variabilis		X	X			X			
Leersia denudata			X	X				X	
Leersia hexandra	X	X	X	X	X	X	X	X	X
Leptochloa chinensis		X	X			X			
Leptochloa eleusine		X	X	X	X	X	X		X
Leptochloa fusca	X	X	X	X	X	X	X	X	X
Leucophrys mesocoma	X						X		
Lintonia nutans		X	X			X			
Lophacme digitata		X	X		X	X	X		
Loudetia filifolia		X	X			X			
Loudetia flavida		X	X	X	X	X			
Loudetia pedicellata		X		X	X	X			
Melica racemosa	X		X		X	X	X	X	X
Melinis longiseta		X				X			
Melinis minutiflora		X	X			X			
Merxmuellera macowanii			X			X	X		X
Microchloa kunthii	X	X	X	X	X	X	X		X
Miscanthus junceus		X	X	X	X	X	X		X
Mosdenia leptostachys		X		X	X	X			
Odyssea paucinervis	X	X		X			X	X	
Oplismenus undulatifolius		X	X			X	X	X	X
Oryza longistaminata		X							
Oxytenanthera abyssinica		X							
Panicum aequinerve		X	X			X	X		X
Panicum arbusculum	X								
Panicum bechuanense	X								
Panicum coloratum	X	X	X	X	X	X	X	X	X
Panicum deustum	X	X	X	X	X	X	X	X	X
Panicum dewinteri		X							
Panicum dregeanum		X	X		X	X	X		X
Panicum hygrocharis		X		X	X	X			
Panicum infestum		X	X			X			
Panicum kalaharense	X		X	X			X		
Panicum lanipes	X		X						

Table 7: continue

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Panicum maximum	x	x	x	x	x	x	x	x	x
Panicum monticola		x				x			
Panicum repens		x	x	x	x	x		x	x
Panicum stapfianum	x	x		x	x	x	x	x	x
Panicum subalbidum		x	x		x	x	x	x	x
Paspalidium obtusifolium		x	x						
Paspalum distichum	x	x	x	x	x	x	x	x	x
Paspalum vaginatum			x		x		x	x	x
Pennisetum glaucocladum		x	x						x
Pennisetum unisetum		x	x		x	x	x	x	x
Pentameris acinosa								x	
Pentameris alticola								x	
Pentameris ampla			x					x	x
Pentameris argentea								x	x
Pentameris aristidoides	x							x	
Pentameris aspera								x	
Pentameris aurea			x				x	x	x
Pentameris bachmannii								x	
Pentameris barbata					x		x	x	
Pentameris calcicola								x	
Pentameris capensis								x	
Pentameris chippindalliae		x				x			
Pentameris cirrhulosa								x	x
Pentameris clavata								x	
Pentameris colorata								x	x
Pentameris densifolia								x	
Pentameris distichophylla								x	x
Pentameris elegans								x	
Pentameris eriostoma	x		x					x	x
Pentameris galpinii			x				x		x
Pentameris glandulosa	x							x	x
Pentameris heptamera									x
Pentameris hirtiglumis								x	
Pentameris holciformis								x	x
Pentameris horrida	x							x	
Pentameris juncifolia								x	
Pentameris lima	x								
Pentameris longiglumis								x	
Pentameris macrocalycina	x							x	x
Pentameris malouinensis	x		x					x	x
Pentameris microphylla				x				x	x
Pentameris montana								x	
Pentameris natalensis		x	x			x			
Pentameris obtusifolia								x	
Pentameris oreodoxa			x				x		x
Pentameris oreophila								x	
Pentameris pallescens								x	
Pentameris pseudopallescens								x	
Pentameris pungens								x	
Pentameris pusilla								x	

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Pentameris pyrophila								x	x
Pentameris reflexa								x	
Pentameris rigidissima	x							x	x
Pentameris rosea								x	
Pentameris rupestris	x							x	x
Pentameris scabra		x						x	
Pentameris scandens								x	
Pentameris setifolia	x		x				x	x	x
Pentameris swartbergensis								x	
Pentameris thuarii								x	
Pentameris tomentella	x							x	x
Pentameris tortuosa	x							x	x
Pentameris trifida	x							x	
Pentameris tysonii			x					x	x
Pentameris velutina								x	
Pentameris veneta	x							x	
Pentameris viscidula								x	x
Pentaschistis aurea			x						x
Pentaschistis pallescens								x	x
Pentaschistis pallida	x		x					x	x
Phragmites mauritianus	x	x	x	x	x	x			
Poa binata			x			x	x	x	x
Poa bulbosa	x							x	
Prosphytochloa prehensilis		x	x			x			x
Pseudopentameris brachyphylla								x	
Pseudopentameris caespitosa								x	
Pseudopentameris macrantha								x	
Puccinellia acroxantha	x				x		x		
Puccinellia angusta					x		x	x	x
Sacciolepis chevalieri		x	x	x	x	x			
Sacciolepis curvata		x	x			x			
Sacciolepis spiciformis		x	x						
Sacciolepis typhura		x	x		x	x			
Sartidia jucunda		x							
Schismus inermis	x							x	x
Schismus scaberrimus	x							x	x
Schizachyrium ursulus		x	x		x	x			
Schmidtia pappophoroides	x	x	x	x	x	x	x		
Schoenefeldia transiens		x				x			
Secale strictum	x		x		x				x
Sehima galpinii		x	x	x	x	x			
Setaria appendiculata	x	x			x				
Setaria incrassata	x	x	x	x	x	x	x		x
Setaria incrassata	x	x		x	x	x	x		x
Setaria lindenbergiana	x	x	x	x	x	x	x		x
Setaria megaphylla		x	x	x	x	x		x	x
Setaria plicatilis		x	x	x	x	x			x
Setaria sphacelata	x	x	x	x	x	x	x	x	x
Sorghastrum nudipes		x				x			
Sorghum bicolor	x	x	x	x	x	x	x		x

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Spartina maritima								x	x
Sporobolus acinifolius	x	x	x	x			x		
Sporobolus albicans	x	x		x		x	x	x	x
Sporobolus congoensis		x	x	x	x	x	x		x
Sporobolus conrathii		x		x	x	x	x		
Sporobolus consimilis		x			x	x			
Sporobolus discosporus	x	x	x	x	x	x	x		x
Sporobolus fimbriatus	x	x	x	x	x	x	x	x	x
Sporobolus fourcadei	x		x					x	x
Sporobolus ludwigii	x			x			x	x	x
Sporobolus natalensis		x	x	x	x	x		x	x
Sporobolus nebulosus	x								
Sporobolus nervosus	x						x		
Sporobolus oxyphyllus	x			x			x		
Sporobolus pectinatus		x	x	x	x	x			
Sporobolus rangei	x	x		x					
Sporobolus salsus		x							x
Sporobolus sanguineus		x	x	x		x			
Sporobolus spicatus	x	x							
Sporobolus subtilis		x	x		x	x			x
Sporobolus subulatus			x			x	x		x
Sporobolus tenellus	x						x	x	
Sporobolus virginicus	x	x	x					x	x
Sporobolus welwitschii		x							
Stenotaphrum secundatum			x			x		x	x
Stereochlaena cameronii		x							
Stiburus conrathii		x	x		x	x	x		x
Stipa dregeana		x	x	x	x	x	x	x	x
Stipagrostis amabilis	x								
Stipagrostis anomala	x							x	
Stipagrostis brevifolia	x						x	x	
Stipagrostis ciliata	x			x		x	x	x	x
Stipagrostis dregeana	x								
Stipagrostis fastigiata	x								
Stipagrostis geminifolia	x							x	
Stipagrostis hochstetteriana	x		x						
Stipagrostis lutescens	x								
Stipagrostis obtusa	x					x	x	x	x
Stipagrostis proxima							x		
Stipagrostis schaeferi	x								
Stipagrostis zeyheri	x	x	x		x	x	x	x	x
Streblochaete longiarista			x				x		x
Tarigidia aequiglumis				x			x		
Tenaxia dura	x							x	x
Tetrachne dregei	x		x				x	x	x
Tetrapogon tenellus		x				x			
Thamnocalamus tessellatus			x			x	x		x
Themeda triandra	x	x	x	x	x	x	x	x	x
Tragus koelerioides	x	x		x	x		x	x	x
Tribolium acutiflorum	x							x	

	NC	LP	KZN	NW	GP	MP	FS	WC	EC
Tribolium brachystachyum								x	
Tribolium curvum	x		x				x	x	x
Tribolium hispidum	x		x		x			x	x
Tribolium obliterum	x							x	
Tribolium obtusifolium	x							x	x
Tribolium purpureum	x		x				x	x	x
Tricholaena capensis	x					x		x	
Trichopteryx dregeana		x	x		x	x			x
Tripogon minimus		x	x	x	x	x			
Triraphis ramosissima	x								
Triraphis schinzii	x	x	x	x		x		x	
Tristachya biseriata		x		x	x	x	x		
Tristachya rehmannii		x	x	x	x		x		x
Urochloa mosambicensis		x	x	x	x	x	x		
Urochloa oligotricha		x		x	x	x			
Urochloa stolonifera	x	x		x		x			

2.3.2 Elucidating the agro-ecological niche of the prioritised grass and legume species

The prioritised legume species were divided into distinct populations based on their climatic (Table 8) and edaphic (Table 9) niche. Using this information, we created figures indicating where distinct populations occur. Figure 4 shows the example of *Argyrolobium tomentosum* and Figure 5 shows the example of *Trifolium africanum var. africanum*. The species were plotted across their full distribution range. This means that, although species that have distribution records in areas that receive less than 600 mm of rainfall were prioritised, all distributions of these species were now included to account for all variability that may arise within these species. This will also allow for the selection of species that are adapted to very dry areas, as well as those in areas receiving higher rainfall, and may potentially occur in highly saline areas. Furthermore, the timing of the rainfall season has a significant impact on the potential agricultural production of an area as it directly influences the duration of the growing season, and therefore, the species that can be planted. In order to fully exploit the agronomic potential of forage species, it is important to select plant genetic resources (PGR) from a range of bioclimatic conditions, including those that are found in different rainfall distribution zones. The larger the potential distribution of the species, the bigger the agronomic impact it may have. Also, species occurring in different rainfall distribution zones will have different beneficial traits that can be targeted during forage improvement initiatives, and selection of traits for specific agro-ecological conditions and agronomic practices becomes possible. For instance, ecotypes of species that occur in the late and very late summer rainfall zones will have much shorter growth periods than those occurring in early and mid-summer rainfall zones due to the length differences in the wet season.

The next selection criterion was the rainfall concentration index (RCI). The selection of crops as well as the production systems used on a farm depend not only on the annual amounts of rainfall (MAP) or rainfall seasonality for that specific area, but also on the duration of the rainy season, i.e., whether the rainfall season is concentrated over a short period of the year only, or spread over a longer period, expressed by Schulze et al. (2007) as the RCI (%). The inclusion of the RCI allows us to identify species that occur in areas with a short rainfall period, which are often adapted to complete their life cycle faster, and therefore are able to reach maturity earlier than those in areas with a longer rainfall period. In areas where the rainfall/growing season is short, the selection of species that are adapted to short growing periods are important as these will allow for the diversification of production systems and crops and allow for improved production in areas where most agronomic crops are not able to produce appreciable amounts of biomass due to the short growing seasons.

Although MAP, rainfall seasonality and RCI maps are important for selections to be made, they do not show the natural year-to-year variability of rainfall that occurs. For this reason, the CVAP (%) is used (Schulze et al. 2007). The higher the CVAP, the more variable the year-to-year (i.e., inter-annual) rainfall of a locality is. Therefore, the CVAP is an index of climatic risk, indicating a likelihood of rainfall and stored water fluctuations, or crop yield from year to year. Agriculturally, it is perhaps a more crucial statistic to use in marginal areas than in either very dry areas, where farming practices have adapted to variability, or in wet areas, where relatively lower inter-annual variabilities are generally expected. Due to climate change, variability in rainfall distribution and fluctuations in the amount of rainfall across years are expected, which means that species able to cope with fluctuations in rainfall between years will be beneficial for future production practices. This is because these species will be able to better survive years of below average rainfall compared to those adapted to constant high rainfall or low rainfall conditions.

One of the main legume species that stood out in terms of its potential as a fodder resource to use in areas that receive very little rainfall was *Calobota sericea*. From the results below, it was clear that this was primarily a winter rainfall species, with 96% of its distribution records falling within the winter rainfall region of South Africa. However, 2% and another 2% of its population occurred in all year as well as very late summer rainfall regions of South Africa (Table 8). These unique populations could allow for breeding and improvement so that the narrow distribution range of the species can be improved. Furthermore, more than 80% of its distribution occurs in areas that receive less than 200mm of MAP (Table 8) and 45% of its population occurs in areas with less than 20% plant available water in the soil (Table 9). This means that this species is highly adapted to grow and thrive in severely water-limited conditions. Furthermore, nearly 80% of its current population occurs in areas that have a very low agricultural productivity (Table 9). This means that if this species can be developed into a usable fodder resource, the agricultural production potential of these locations could be improved by allowing for increased cultivation of the species and its use for improved livestock production in the area.

Already, the ARC has done substantial work on the agronomic potential of the species. The species has been proposed as a potential alternative forage resource to extensive livestock farmers due to its importance to pastoral livestock within these rangelands and its potential to fill the dry season feed gaps (Samuels et al. 2016; Müller et al. 2017, 2019, 2021). Within the Namaqualand rangelands, Samuels et al. (2016) indicated that wild stands of *C. sericea* contributed up to 16 % of sheep and goat diets during the dry season. Müller et al. (2021), however, indicated that the crude protein content of *C. sericea* forages harvested from wild populations within these rangelands ranged between 6% and 8%, decreasing from the wet to dry season. Although relatively low, these crude protein concentrations of *C. sericea* are significantly higher compared to the 3% (on average) crude protein content of other forages from the natural veld during the dry season (Müller et al. 2019). Britz et al. (2022) further indicated that the nutritional quality of the C. sericea forages harvested from wild populations differed significantly depending on the phenological stage at which the fodders were collected. Results from the Britz et al. (2022) study showed that crude protein, fibre, energy and digestibility of the forage decreased with plant maturity, but not all mineral nutrients showed the same trend. In general, *C. sericea* forage harvested at non-reproductive, early flower bud and full flower stages could provide sufficient energy and protein to maintain livestock condition. At these stages, the neutral detergent fibre and digestibility of the harvested materials are also good, indicating that intake and processing of these forages would not be a problem for the livestock. Britz et al. (2023) took the work on *C. sericea* further and showed that with limited fertilisation, the nutritional quality of planted *C. sericea* pastures can be significantly increased to qualities that would be sufficient to maintain highly productive livestock herds.

Table 8: Characterisation of the agro-climatic niche of the prioritised legume species.

Species	Rainfall Seasonality						MAP (mm)									
	All Year	Early Summer	Mid Summer	Late Summer	Very Late Summer	Winter	<200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000
Argyrolobium collinum	46%	0%	31%	23%	0%	0%	0%	0%	0%	15%	15%	31%	15%	15%	0%	6%
Argyrolobium tomentosum	12%	19%	49%	13%	6%	1%	0%	1%	0%	2%	11%	15%	20%	20%	22%	9%
Calobota sericea	2%	0%	0%	0%	2%	96%	81%	4%	4%	6%	4%	0%	0%	0%	0%	0%
Crotalaria excisa	0%	0%	3%	0%	0%	97%	62%	6%	0%	9%	9%	3%	6%	3%	3%	0%
Crotalaria laburnifolia ssp. australis	0%	28%	70%	0%	0%	2%	2%	0%	7%	7%	26%	31%	6%	6%	11%	4%
Crotalaria pearsonii	0%	11%	0%	0%	22%	67%	89%	0%	0%	0%	0%	0%	0%	0%	11%	0%
Crotalaria lotoides	2%	43%	37%	17%	0%	0%	0%	0%	2%	24%	24%	43%	2%	2%	2%	0%
Cullen tomentosum	3%	1%	13%	39%	34%	10%	23%	15%	17%	23%	15%	1%	3%	1%	1%	0%
Indigastrum argyraeum	2%	0%	10%	38%	48%	2%	26%	7%	17%	27%	7%	10%	7%	2%	0%	0%
Indigofera alternans var. alternans	2%	5%	5%	41%	43%	3%	14%	28%	14%	25%	13%	4%	1%	0%	0%	0%
Indigofera meyeriana	17%	0%	0%	0%	19%	64%	44%	28%	0%	6%	14%	0%	8%	0%	0%	0%
Indigofera nigromontana	21%	0%	24%	24%	0%	30%	24%	6%	0%	12%	18%	21%	18%	0%	0%	0%
Indigofera pungens	11%	0%	0%	0%	44%	44%	89%	0%	0%	0%	11%	0%	0%	0%	0%	0%
Indigofera rhytidocarpa ssp. rhytidocarpa	2%	17%	56%	20%	5%	0%	0%	2%	6%	32%	32%	22%	2%	2%	2%	0%
Lebeckia ambigua	0%	0%	0%	0%	0%	100%	33%	17%	17%	17%	17%	0%	0%	0%	0%	0%
Lessertia brachypus	0%	0%	0%	0%	9%	91%	91%	0%	0%	9%	0%	0%	0%	0%	0%	0%
Lessertia depressa	5%	3%	19%	40%	31%	2%	3%	2%	12%	31%	12%	17%	16%	3%	2%	2%
Lessertia diffusa	0%	0%	0%	3%	0%	97%	79%	18%	3%	0%	0%	0%	0%	0%	0%	0%
Lessertia excisa	0%	0%	0%	0%	0%	100%	35%	13%	13%	17%	0%	4%	4%	4%	9%	0%
Lessertia frutescens ssp. frutescens	13%	2%	8%	14%	21%	42%	20%	22%	6%	16%	12%	3%	13%	3%	2%	1%
Lessertia frutescens ssp. microphylla	7%	13%	23%	14%	18%	24%	14%	7%	10%	17%	17%	17%	12%	2%	1%	2%
Lessertia incana	0%	0%	0%	0%	33%	67%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Lessertia pauciflora var. pauciflora	5%	2%	6%	40%	32%	16%	11%	21%	13%	37%	13%	5%	2%	0%	0%	0%
Lotononis laxa	1%	21%	43%	26%	9%	0%	0%	2%	4%	10%	11%	26%	32%	10%	3%	2%
Melolobium adenodes	12%	0%	0%	0%	19%	69%	58%	15%	0%	15%	8%	0%	4%	0%	0%	0%
Melolobium humile	0%	0%	3%	7%	14%	76%	62%	10%	3%	14%	0%	3%	3%	0%	3%	0%
Melolobium microphyllum	0%	3%	20%	45%	28%	3%	3%	15%	7%	24%	10%	17%	14%	3%	2%	2%
Psoralea arborea	58%	8%	23%	0%	0%	12%	0%	0%	4%	0%	27%	8%	23%	19%	12%	8%
Rhynchosia adenodes	4%	35%	33%	19%	6%	4%	1%	0%	2%	4%	8%	21%	40%	16%	6%	1%
Rhynchosia emarginata	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Rhynchosia minima var. minima	1%	36%	53%	9%	0%	1%	0%	0%	3%	9%	19%	32%	12%	4%	17%	5%
Rhynchosia schlechteri	0%	0%	0%	0%	0%	100%	89%	0%	11%	0%	0%	0%	0%	0%	0%	0%
Rhyncosia totta var. totta	3%	33%	45%	16%	2%	1%	0%	0%	5%	10%	6%	22%	28%	8%	12%	5%
Tephrosia capensis var. capensis	22%	29%	27%	10%	5%	6%	0%	1%	1%	6%	19%	23%	31%	12%	5%	1%
Trifolium africanum var. africanum	1%	38%	43%	11%	8%	1%	0%	2%	2%	4%	9%	20%	38%	12%	6%	5%
Vigna luteola var. luteola	17%	21%	24%	38%	0%	0%	0%	0%	0%	0%	3%	24%	17%	17%	14%	24%
Vigna vexillata var. vexillata	4%	38%	43%	13%	2%	1%	0%	0%	0%	1%	9%	18%	22%	16%	23%	11%
Zornia milneana	1%	49%	30%	19%	0%	0%	0%	0%	3%	13%	17%	29%	12%	12%	10%	5%

Species	Coefficient of variation of annual precipitation (%)						Rainfall Concentration Index (%)							
	> 20	20 - 24	25 - 29	30 - 34	35 - 39	< 40	< 15	15 - 30	30 - 45	45 - 50	50 - 55	55 - 60	60 - 65	> 65
Argyrolobium collinum	0%	15%	38%	38%	8%	0%	31%	23%	8%	8%	23%	8%	0%	0%
Argyrolobium tomentosum	23%	35%	26%	15%	1%	0%	10%	5%	19%	14%	13%	25%	12%	2%
Calobota sericea	0%	0%	0%	9%	70%	21%	2%	4%	9%	6%	13%	49%	17%	0%
Crotalaria excisa	0%	0%	6%	21%	59%	15%	0%	3%	21%	9%	9%	44%	15%	0%
Crotalaria laburnifolia ssp. australis	4%	11%	35%	37%	13%	0%	0%	0%	0%	4%	17%	9%	43%	28%
Crotalaria pearsonii	11%	0%	0%	0%	0%	89%	0%	0%	0%	11%	78%	11%	0%	0%
Crotalaria lotoides	0%	2%	54%	43%	0%	0%	0%	2%	0%	0%	2%	11%	74%	11%
Cullen tomentosum	0%	1%	6%	45%	39%	8%	3%	0%	7%	7%	20%	13%	38%	13%
Indigastrum argyraeum	0%	2%	12%	42%	36%	7%	0%	7%	10%	15%	13%	17%	33%	5%
Indigofera alternans var. alternans	0%	0%	5%	48%	44%	3%	1%	2%	11%	16%	10%	12%	30%	17%
Indigofera meyeriana	0%	3%	0%	33%	61%	3%	11%	17%	33%	3%	8%	19%	8%	0%
Indigofera nigromontana	0%	3%	36%	21%	33%	6%	21%	0%	9%	30%	12%	21%	6%	0%
Indigofera pungens	0%	0%	0%	11%	17%	72%	11%	0%	39%	6%	11%	0%	6%	28%
Indigofera rhytidocarpa ssp. rhytidocarpa	2%	0%	24%	63%	10%	0%	2%	0%	2%	0%	12%	17%	39%	27%
Lebeckia ambigua	0%	0%	0%	17%	67%	17%	0%	0%	0%	0%	33%	33%	33%	0%
Lessertia brachypus	0%	0%	0%	9%	55%	36%	0%	0%	36%	9%	18%	27%	9%	0%
Lessertia depressa	2%	9%	21%	53%	12%	3%	3%	9%	22%	14%	29%	10%	12%	0%
Lessertia diffusa	0%	0%	0%	5%	82%	13%	0%	0%	3%	10%	23%	41%	23%	0%
Lessertia excisa	0%	0%	4%	43%	48%	4%	0%	0%	9%	17%	30%	26%	17%	0%
Lessertia frutescens ssp. frutescens	1%	5%	11%	33%	46%	5%	10%	9%	26%	15%	10%	17%	13%	2%
Lessertia frutescens ssp. microphylla	0%	2%	28%	31%	33%	6%	6%	6%	11%	10%	18%	23%	24%	2%
Lessertia incana	0%	0%	0%	17%	33%	50%	0%	0%	33%	0%	17%	0%	33%	17%
Lessertia pauciflora var. pauciflora	2%	0%	3%	49%	44%	2%	3%	6%	8%	17%	17%	14%	30%	3%
Lotononis laxa	3%	10%	56%	29%	2%	0%	0%	4%	16%	15%	31%	17%	16%	3%
Melolobium adenodes	0%	0%	0%	23%	50%	27%	12%	4%	15%	12%	23%	12%	19%	4%
Melolobium humile	3%	3%	0%	10%	66%	17%	0%	3%	17%	14%	14%	21%	28%	3%
Melolobium microphyllum	1%	2%	30%	42%	21%	3%	0%	3%	22%	29%	20%	13%	9%	3%
Psoralea arborea	12%	31%	35%	23%	0%	0%	54%	4%	12%	4%	0%	15%	12%	0%
Rhynchosia adenodes	1%	18%	63%	15%	3%	0%	1%	9%	16%	14%	16%	33%	8%	1%
Rhynchosia emarginata	0%	0%	0%	0%	10%	90%	0%	0%	70%	10%	10%	0%	10%	0%
Rhynchosia minima var. minima	9%	12%	42%	33%	4%	0%	1%	3%	8%	5%	13%	21%	35%	17%
Rhynchosia schlechteri	0%	0%	0%	0%	44%	56%	0%	0%	44%	11%	0%	44%	0%	0%
Rhyncosia totta var. totta	6%	19%	48%	24%	2%	0%	2%	2%	10%	7%	15%	27%	27%	9%
Tephrosia capensis var. capensis	5%	13%	50%	28%	4%	0%	17%	8%	13%	5%	12%	27%	15%	2%
Trifolium africanum var. africanum	7%	17%	58%	15%	3%	0%	1%	2%	7%	16%	21%	44%	9%	0%
Vigna luteola var. luteola	31%	38%	21%	10%	0%	0%	14%	21%	41%	0%	3%	14%	7%	0%
Vigna vexillata var. vexillata	16%	28%	40%	8%	0%	0%	3%	4%	21%	7%	13%	31%	21%	0%
Zornia milneana	6%	14%	52%	26%	1%	0%	1%	3%	8%	0%	5%	32%	48%	4%

Table 9: Characterisation of the agro-edaphic niche of the prioritised legume species.

Species	PAW (mm)								Soil pH						
	< 20	20 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80-100	> 100	<4.4	>7.5	5.5-6.4	5.5-7.4	6.5-7.4	6.5-8.4	7.5-8.4
Argyrolobium collinum	0%	31%	0%	23%	8%	38%	0%	0%	31%	0%	0%	54%	0%	15%	0%
Argyrolobium tomentosum	0%	15%	10%	10%	22%	16%	9%	18%	66%	0%	0%	22%	2%	10%	0%
Calobota sericea	45%	6%	11%	6%	0%	32%	0%	0%	4%	26%	0%	11%	23%	36%	0%
Crotalaria excisa	38%	3%	6%	18%	0%	35%	0%	0%	16%	26%	0%	15%	21%	21%	0%
Crotalaria laburnifolia ssp. australis	2%	0%	3%	15%	41%	15%	8%	13%	35%	2%	0%	33%	19%	11%	0%
Crotalaria pearsonii	44%	0%	22%	0%	0%	22%	0%	11%	0%	89%	0%	11%	0%	0%	0%
Crotalaria lotoides	0%	4%	11%	9%	24%	24%	26%	2%	37%	4%	0%	43%	4%	11%	0%
Cullen tomentosum	6%	10%	8%	39%	21%	13%	3%	0%	7%	46%	1%	8%	15%	21%	0%
Indigastrum argyraeum	2%	29%	13%	30%	27%	7%	2%	0%	16%	42%	0%	12%	17%	20%	0%
Indigofera alternans var. *alternans*	1%	12%	12%	40%	20%	10%	4%	1%	5%	41%	1%	11%	21%	22%	0%
Indigofera meyeriana	8%	25%	31%	19%	6%	11%	0%	0%	6%	50%	0%	6%	17%	22%	0%
Indigofera nigromontana	18%	15%	9%	0%	27%	30%	0%	0%	30%	6%	0%	12%	27%	24%	0%
Indigofera pungens	44%	0%	50%	0%	0%	6%	0%	0%	6%	89%	0%	6%	0%	0%	0%
Indigofera rhytidocarpa ssp. rhytidocarpa	0%	2%	0%	29%	44%	16%	7%	2%	15%	0%	0%	29%	37%	16%	0%
Lebeckia ambigua	17%	0%	50%	17%	0%	17%	0%	0%	0%	0%	0%	67%	0%	33%	0%
Lessertia brachypus	73%	0%	9%	9%	0%	9%	0%	0%	0%	45%	0%	27%	9%	18%	0%
Lessertia depressa	0%	10%	7%	29%	24%	28%	2%	0%	19%	17%	0%	16%	24%	24%	0%
Lessertia diffusa	49%	0%	26%	8%	0%	18%	0%	0%	0%	23%	0%	10%	23%	44%	0%
Lessertia excisa	9%	4%	39%	17%	0%	30%	0%	0%	26%	9%	0%	26%	13%	26%	0%
Lessertia frutescens ssp. frutescens	7%	22%	22%	22%	13%	14%	1%	0%	18%	33%	0%	16%	14%	19%	0%
Lessertia frutescens ssp. microphylla	4%	13%	14%	11%	18%	28%	10%	2%	22%	18%	0%	31%	16%	16%	0%
Lessertia incana	33%	0%	50%	0%	0%	17%	0%	0%	0%	67%	0%	0%	0%	33%	0%
Lessertia pauciflora var. *pauciflora*	3%	18%	16%	30%	21%	11%	3%	0%	8%	37%	0%	11%	13%	32%	2%
Lotononis laxa	0%	11%	7%	9%	23%	37%	7%	7%	50%	2%	0%	23%	7%	19%	0%
Melolobium adenodes	19%	12%	31%	12%	8%	19%	0%	0%	12%	50%	0%	4%	12%	23%	0%
Melolobium humile	34%	7%	10%	24%	3%	21%	0%	0%	3%	31%	0%	17%	31%	17%	0%
Melolobium microphyllum	0%	19%	6%	26%	26%	24%	1%	2%	26%	22%	0%	13%	19%	21%	0%
Psoralea arborea	0%	19%	50%	0%	8%	4%	0%	19%	73%	0%	0%	23%	4%	0%	0%
Rhynchosia adenodes	1%	10%	7%	9%	23%	34%	11%	6%	53%	1%	0%	28%	8%	10%	0%
Rhynchosia emarginata	100%	0%	0%	0%	0%	0%	0%	0%	0%	90%	0%	10%	0%	0%	0%
Rhynchosia minima var. *minima*	0%	3%	14%	15%	44%	8%	4%	13%	29%	3%	0%	40%	14%	14%	0%
Rhynchosia schlechteri	78%	0%	11%	0%	0%	11%	0%	0%	0%	67%	0%	11%	0%	22%	0%
Rhyncosia totta var. *totta*	0%	7%	8%	12%	27%	26%	12%	8%	55%	2%	0%	25%	10%	8%	0%
Tephrosia capensis var. *capensis*	0%	12%	17%	11%	17%	27%	11%	6%	55%	1%	0%	26%	7%	10%	0%
Trifolium africanum var. *africanum*	0%	5%	2%	6%	30%	36%	15%	7%	60%	2%	0%	23%	10%	5%	0%
Vigna luteola var. *luteola*	0%	3%	3%	7%	59%	17%	3%	7%	59%	0%	0%	31%	10%	0%	0%
Vigna vexillata var. *vexillata*	0%	5%	8%	8%	36%	16%	18%	11%	68%	1%	0%	21%	5%	4%	0%
Zornia milneana	0%	1%	8%	8%	19%	25%	31%	8%	56%	4%	0%	23%	10%	6%	0%

Species	Soil Salinity						Soil Fertility					Production potential (t/ha/season)						
	Alkaline Saline Sodic	Moderately Saline	Non-Alkaline Saline-Sodic	None	Slightly Saline	Sodic	Very Low	Low	Average	High	Very High	> 1	1 - 2	2 - 4	4 - 6.5	6.5 - 9	9 - 11	< 11
Argyrolobium collinum	0%	8%	0%	92%	0%	0%	8%	31%	62%	0%	0%	0%	8%	23%	38%	15%	15%	0%
Argyrolobium tomentosum	1%	1%	0%	98%	2%	0%	10%	63%	24%	2%	1%	0%	1%	3%	21%	30%	38%	7%
Calobota sericea	17%	0%	45%	23%	6%	9%	53%	40%	6%	0%	0%	79%	11%	11%	0%	0%	0%	0%
Crotalaria excisa	9%	0%	44%	38%	3%	6%	53%	32%	15%	0%	0%	68%	6%	21%	6%	0%	0%	0%
Crotalaria laburnifolia ssp. australis	0%	9%	4%	74%	13%	0%	17%	48%	9%	17%	9%	2%	0%	20%	43%	26%	7%	2%
Crotalaria pearsonii	22%	0%	33%	11%	0%	33%	44%	56%	0%	0%	0%	89%	0%	0%	0%	0%	0%	11%
Crotalaria lotoides	0%	0%	2%	91%	7%	0%	2%	41%	17%	24%	15%	0%	0%	15%	54%	28%	2%	0%
Cullen tomentosum	20%	1%	7%	58%	10%	4%	7%	41%	42%	8%	1%	32%	13%	30%	21%	4%	0%	0%
Indigastrum argyraeum	17%	8%	5%	53%	15%	2%	2%	40%	57%	2%	0%	28%	9%	43%	12%	8%	3%	0%
Indigofera alternans var. *alternans*	9%	4%	9%	64%	14%	0%	1%	54%	34%	9%	1%	24%	19%	38%	17%	3%	0%	0%
Indigofera meyeriana	8%	6%	19%	64%	3%	0%	22%	39%	39%	0%	0%	36%	33%	31%	0%	0%	0%	0%
Indigofera nigromontana	0%	0%	24%	64%	12%	0%	33%	27%	33%	6%	0%	27%	12%	9%	27%	21%	3%	0%
Indigofera pungens	6%	0%	22%	33%	0%	39%	44%	44%	11%	0%	0%	89%	0%	11%	0%	0%	0%	0%
Indigofera rhytidocarpa ssp. rhytidocarpa	0%	5%	2%	79%	15%	0%	10%	41%	24%	20%	5%	2%	0%	27%	56%	12%	0%	2%
Lebeckia ambigua	0%	0%	67%	17%	17%	0%	17%	83%	0%	0%	0%	33%	50%	17%	0%	0%	0%	0%
Lessertia brachypus	18%	0%	36%	9%	9%	27%	82%	9%	9%	0%	0%	82%	9%	9%	0%	0%	0%	0%
Lessertia depressa	3%	5%	3%	79%	9%	0%	3%	41%	48%	7%	0%	3%	3%	40%	36%	12%	5%	0%
Lessertia diffusa	15%	3%	46%	18%	15%	3%	51%	44%	5%	0%	0%	82%	10%	8%	0%	0%	0%	0%
Lessertia excisa	4%	0%	35%	39%	22%	0%	26%	61%	13%	0%	0%	26%	22%	48%	4%	0%	0%	0%
Lessertia frutescens ssp. frutescens	12%	4%	13%	63%	7%	2%	18%	40%	42%	1%	0%	22%	24%	36%	7%	8%	2%	0%
Lessertia frutescens ssp. microphylla	4%	2%	11%	75%	8%	0%	6%	53%	30%	10%	1%	19%	12%	25%	23%	17%	4%	0%
Lessertia incana	0%	0%	17%	50%	17%	17%	50%	33%	17%	0%	0%	83%	17%	0%	0%	0%	0%	0%
Lessertia pauciflora var. *pauciflora*	14%	2%	8%	67%	10%	2%	8%	38%	52%	6%	0%	17%	17%	46%	17%	0%	2%	0%
Lotononis laxa	1%	0%	0%	91%	8%	0%	1%	65%	24%	8%	3%	0%	2%	12%	37%	40%	7%	2%
Melolobium adenodes	27%	0%	31%	19%	15%	8%	23%	50%	27%	0%	0%	62%	15%	19%	4%	0%	0%	0%
Melolobium humile	14%	0%	45%	24%	7%	10%	45%	41%	14%	0%	0%	66%	7%	24%	0%	3%	0%	0%
Melolobium microphyllum	6%	1%	3%	79%	10%	0%	1%	50%	42%	5%	2%	6%	15%	30%	27%	16%	6%	0%
Psoralea arborea	0%	0%	19%	73%	8%	0%	15%	50%	35%	0%	0%	0%	0%	31%	19%	35%	15%	0%
Rhynchosia adenodes	0%	1%	3%	89%	7%	0%	2%	56%	26%	10%	6%	0%	2%	7%	30%	45%	17%	0%
Rhynchosia emarginata	0%	0%	30%	0%	0%	70%	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Rhynchosia minima var. *minima*	0%	4%	5%	78%	13%	0%	22%	47%	14%	9%	8%	0%	0%	10%	42%	28%	14%	5%
Rhynchosia schlechteri	11%	0%	22%	22%	0%	44%	78%	22%	0%	0%	0%	89%	11%	0%	0%	0%	0%	0%
Rhyncosia totta var. *totta*	0%	2%	2%	90%	6%	0%	6%	60%	17%	9%	5%	1%	0%	14%	25%	40%	17%	3%
Tephrosia capensis var. *capensis*	0%	1%	10%	79%	9%	0%	11%	54%	21%	10%	4%	1%	1%	20%	27%	36%	13%	3%
Trifolium africanum var. *africanum*	0%	0%	1%	92%	7%	0%	3%	65%	18%	7%	7%	0%	3%	5%	25%	44%	21%	2%
Vigna luteola var. *luteola*	0%	0%	3%	90%	7%	0%	45%	14%	10%	24%	7%	0%	0%	0%	21%	34%	31%	14%
Vigna vexillata var. *vexillata*	0%	1%	1%	96%	3%	0%	14%	54%	16%	9%	6%	0%	0%	1%	19%	45%	30%	6%
Zornia milneana	0%	1%	1%	94%	4%	0%	8%	56%	17%	16%	4%	0%	0%	13%	32%	32%	19%	3%

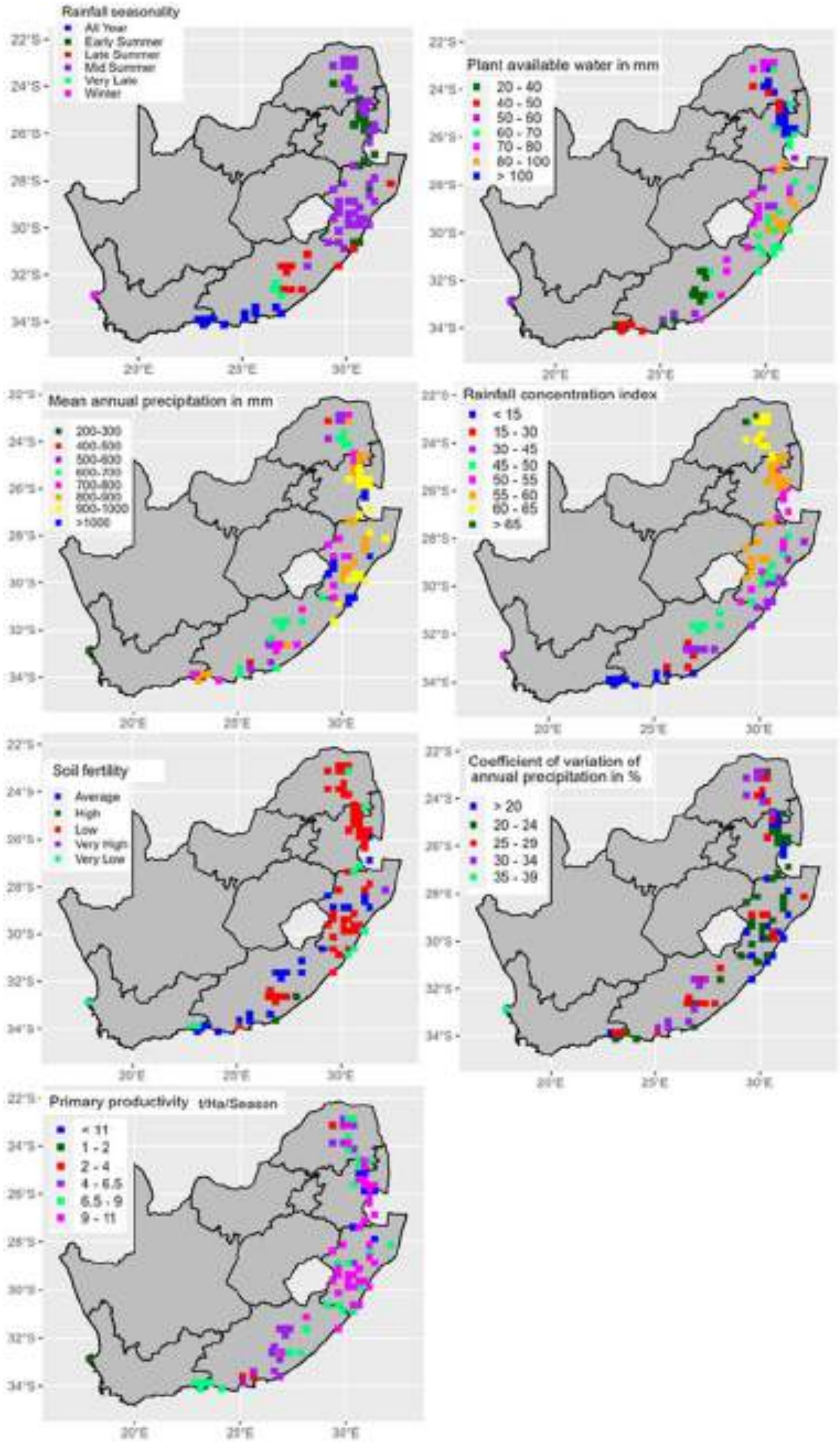


Figure 4: Agro-ecological niche of *Argyrolobium tomentosum* indicating distinct populations for collection prioritisation.

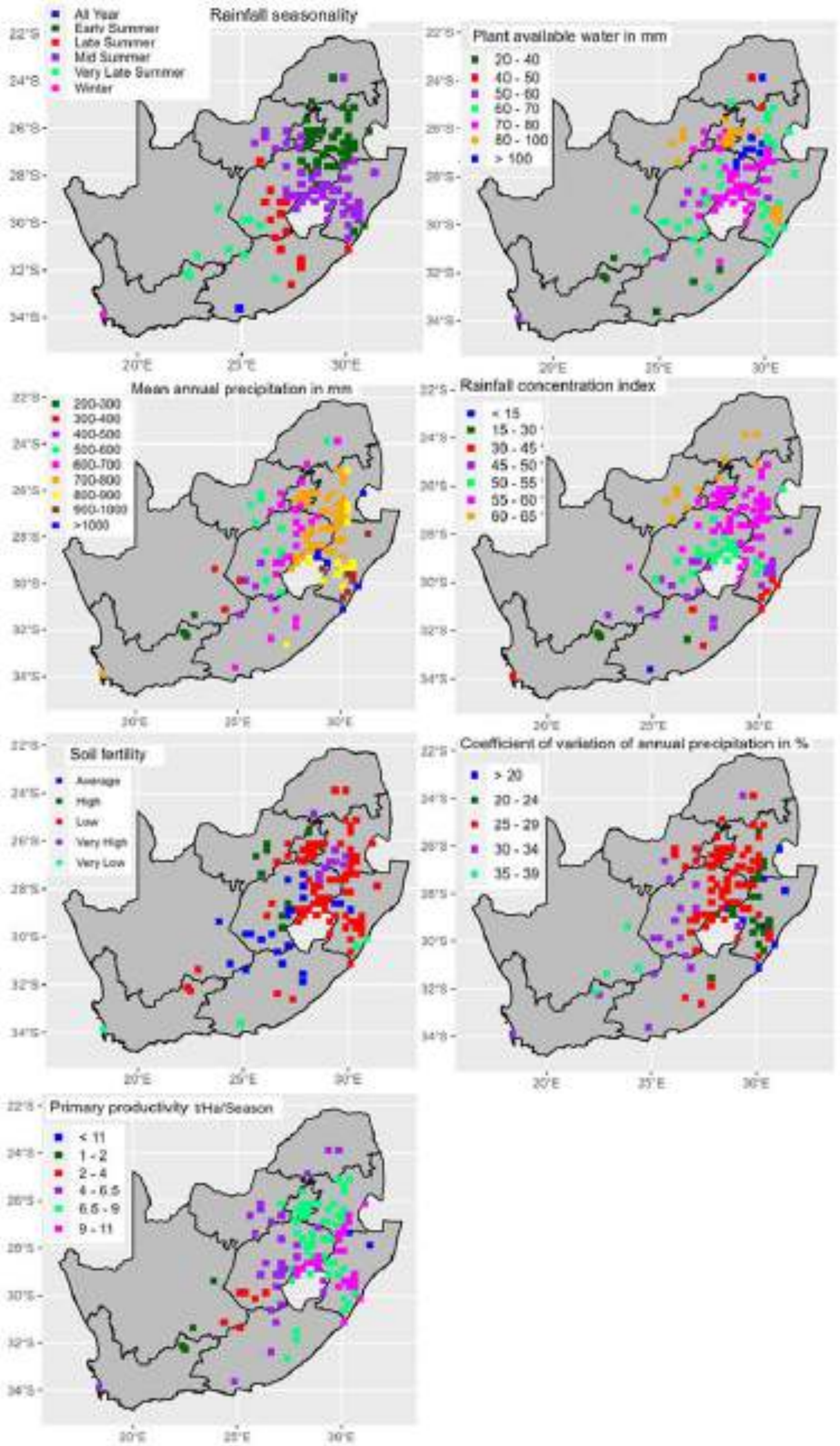


Figure 5: Agro-ecological niche of *Trifolium africanum var. africanum* indicating distinct populations for collection prioritisation.

After the completion of the legumes, the grass prioritisation was done. Like the legumes, the grasses were divided into distinct populations based on their climatic (Table 10) and edaphic (Table 11) niche. Using this information, we created figures indicating where distinct populations occur. Figure 6 shows the example of *Andropogon appendiculatus* and Figure 7 shows the example of *Panicum maximum*. Similar maps were created for all prioritised grass and legume species.

From these tables, two *Stipagrostis* species, i.e., *Stipagrostis ciliata* and *Stipagrostis obtusa,* were found to be interesting species for further characterisation. Both species are primarily summer rainfall species with nearly 70% of S. ciliata and nearly 75% of *S. obtusa* populations falling within the summer rainfall region of South Africa (Table 10). However, both species contained populations that fell within the all-year and winter rainfall regions of South Africa. Like with *C. sericea*, these unique populations could allow for breeding and improvement so that the narrow distribution range of the species can be improved. Furthermore, both species are adapted to areas which receive less than 300mm of MAP, with *S. ciliata* containing nearly 80% of its populations in areas receiving less than 300mm of rainfall ad *S. obtusa* having nearly 75% populations which naturally occur in areas which receive less than 300mm of MAP. Similarly to C. sericea, these species also have most of their populations occurring in areas with low to very low agricultural potential, which means that if these species can be developed into a usable fodder resources, the agricultural production potential of these locations could be improved by allowing for increased cultivation of these species and their use for improved livestock production in the area.

Table 10: Characterisation of the agro-climatic niche of the prioritised grass species.

Species	Rainfall Seasonality						MAP (mm)										Coefficient of variation of annual precipitation (%)						Rainfall Concentration index (%)							
	All Year	Early Summer	Late Summer	Mid Summer	Very Late Summer	Winter	<200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000	> 20	20 - 24	25 - 29	30 - 34	35 - 39	< 40	< 15	15 - 30	30 - 45	45 - 50	50 - 55	55 - 60	60 - 65	> 65
Acroceras macrum	3%	18%	49%	28%	0%	3%	0%	0%	0%	3%	0%	10%	13%	15%	18%	41%	46%	23%	28%	3%	0%	0%	3%	15%	54%	10%	3%	5%	8%	3%
Agrostis eriantha	0%	63%	6%	26%	4%	2%	0%	0%	0%	7%	2%	7%	48%	19%	6%	11%	13%	33%	44%	7%	2%	0%	0%	4%	4%	2%	17%	67%	7%	0%
Agrostis polypogonoides	0%	0%	0%	0%	0%	100%	0%	20%	20%	0%	0%	20%	0%	20%	20%	0%	0%	20%	20%	20%	40%	0%	0%	0%	20%	40%	0%	0%	40%	0%
Andropogon appendiculatus	9%	25%	20%	40%	2%	5%	0%	0%	2%	5%	13%	17%	32%	15%	8%	8%	11%	21%	46%	20%	2%	0%	8%	4%	18%	13%	17%	33%	8%	1%
Anthoxanthum dregeanum	21%	0%	0%	0%	0%	79%	0%	8%	17%	8%	4%	13%	29%	8%	13%	0%	8%	13%	17%	54%	8%	0%	21%	4%	21%	25%	21%	8%	0%	0%
Anthoxanthum ecklonii	8%	6%	20%	62%	2%	2%	0%	2%	0%	2%	0%	12%	34%	22%	10%	18%	14%	34%	34%	16%	2%	0%	8%	4%	10%	16%	30%	32%	0%	0%
Anthoxanthum tongo	8%	0%	0%	0%	0%	92%	4%	8%	8%	16%	0%	16%	40%	4%	4%	0%	8%	8%	24%	48%	12%	0%	8%	4%	32%	20%	20%	12%	4%	0%
Aristida dasydesmis	0%	8%	8%	0%	0%	85%	77%	8%	0%	8%	0%	0%	8%	0%	0%	0%	0%	0%	8%	8%	69%	15%	0%	0%	0%	0%	46%	54%	0%	0%
Aristida engleri	0%	0%	25%	0%	67%	8%	63%	8%	17%	13%	0%	0%	0%	0%	0%	0%	0%	0%	0%	17%	67%	17%	0%	0%	4%	4%	13%	4%	46%	29%
Aristida vestita	8%	5%	38%	2%	33%	14%	8%	20%	24%	32%	5%	6%	4%	0%	1%	1%	0%	1%	11%	48%	38%	2%	7%	4%	12%	8%	13%	25%	31%	1%
Arundinella nepalensis	1%	34%	16%	45%	2%	2%	0%	0%	0%	4%	5%	13%	31%	15%	12%	22%	15%	27%	44%	14%	0%	0%	1%	2%	19%	5%	20%	43%	7%	3%
Brachiaria nigropedata	0%	21%	20%	58%	1%	1%	0%	2%	7%	20%	33%	30%	5%	1%	1%	1%	1%	3%	42%	51%	3%	0%	0%	0%	2%	2%	2%	11%	66%	16%
Brachypodium bolusii	0%	4%	12%	72%	8%	4%	4%	4%	4%	0%	8%	4%	28%	20%	0%	28%	20%	20%	28%	20%	12%	0%	0%	4%	16%	12%	32%	36%	0%	0%
Brachypodium flexum	18%	13%	14%	45%	2%	7%	0%	0%	1%	6%	6%	14%	30%	23%	10%	11%	17%	30%	37%	13%	4%	0%	18%	1%	17%	18%	19%	21%	6%	0%
Bromus firmior	2%	12%	14%	66%	6%	0%	0%	0%	0%	2%	8%	4%	34%	18%	6%	28%	22%	34%	32%	12%	0%	0%	2%	2%	18%	16%	20%	42%	0%	0%
Capeochloa arundinacea	29%	0%	0%	0%	7%	64%	4%	24%	9%	33%	13%	2%	9%	4%	4%	0%	0%	4%	9%	38%	49%	0%	25%	11%	9%	13%	25%	9%	5%	2%
Capeochloa cincta	42%	3%	0%	0%	0%	55%	0%	0%	3%	8%	26%	16%	26%	16%	3%	3%	3%	21%	34%	34%	8%	0%	37%	13%	26%	11%	11%	3%	0%	0%
Cenchrus ciliaris	3%	16%	14%	33%	32%	3%	11%	13%	14%	13%	15%	20%	6%	4%	3%	0%	1%	4%	28%	33%	33%	1%	3%	3%	9%	8%	9%	15%	40%	14%
Centropodia glauca	0%	0%	33%	0%	57%	11%	39%	46%	9%	4%	2%	0%	0%	0%	0%	0%	0%	0%	0%	9%	78%	13%	0%	0%	2%	4%	9%	24%	28%	33%
Chaetobromus involucratus	1%	0%	0%	0%	2%	98%	61%	18%	5%	5%	5%	0%	4%	1%	1%	0%	0%	1%	1%	13%	65%	20%	1%	0%	12%	6%	24%	41%	15%	0%
Chloris gayana	4%	26%	22%	44%	1%	3%	0%	1%	0%	2%	12%	21%	20%	13%	20%	12%	15%	25%	42%	16%	3%	0%	3%	8%	29%	9%	13%	18%	15%	4%
Cladoraphis cyperoides	0%	0%	0%	3%	0%	97%	65%	11%	3%	0%	5%	0%	11%	5%	0%	0%	0%	0%	8%	16%	35%	41%	0%	0%	14%	8%	22%	43%	11%	3%
Cladoraphis spinosa	8%	2%	0%	0%	10%	80%	67%	12%	10%	4%	6%	2%	0%	0%	0%	0%	0%	0%	2%	4%	73%	22%	8%	0%	8%	16%	20%	35%	12%	2%
Cymbopogon dieterlenii	2%	17%	11%	57%	9%	4%	4%	9%	2%	0%	13%	17%	47%	4%	0%	4%	4%	13%	53%	17%	13%	0%	2%	0%	9%	17%	23%	45%	4%	0%
Cymbopogon marginatus	37%	5%	9%	10%	1%	39%	1%	6%	3%	19%	16%	13%	24%	12%	3%	2%	5%	13%	26%	33%	20%	0%	29%	13%	23%	10%	6%	11%	9%	0%
Cymbopogon prolixus	15%	23%	6%	44%	10%	2%	1%	5%	2%	9%	17%	21%	26%	12%	1%	6%	6%	17%	45%	21%	11%	0%	13%	4%	11%	11%	11%	23%	20%	7%
Cynodon dactylon	5%	24%	21%	33%	6%	11%	5%	4%	5%	15%	17%	20%	19%	6%	6%	4%	4%	11%	38%	34%	9%	3%	4%	5%	13%	6%	12%	23%	33%	5%
Cynodon incompletus	8%	2%	40%	9%	39%	3%	1%	11%	14%	39%	20%	7%	6%	2%	1%	0%	0%	4%	8%	65%	23%	0%	7%	7%	20%	22%	15%	14%	16%	0%
Cynodon transvaalensis	3%	26%	26%	37%	3%	6%	0%	0%	0%	14%	29%	14%	31%	6%	6%	0%	9%	3%	46%	40%	3%	0%	3%	0%	14%	9%	20%	43%	11%	0%
Digitaria argyrograpta	6%	19%	20%	39%	14%	1%	1%	11%	5%	10%	19%	24%	14%	9%	5%	1%	3%	5%	41%	33%	19%	0%	5%	5%	22%	3%	16%	23%	27%	0%
Digitaria diversinervis	0%	16%	41%	38%	0%	6%	0%	0%	0%	0%	3%	3%	9%	13%	28%	44%	47%	34%	13%	6%	0%	0%	0%	22%	59%	9%	0%	3%	6%	0%
Digitaria eriantha	5%	17%	23%	39%	13%	2%	1%	4%	10%	19%	20%	21%	13%	6%	4%	3%	3%	7%	35%	42%	12%	0%	4%	3%	14%	10%	12%	17%	31%	9%
Digitaria natalensis	16%	15%	30%	35%	0%	3%	0%	2%	1%	5%	5%	10%	13%	20%	25%	18%	23%	31%	32%	11%	3%	0%	13%	12%	40%	13%	9%	8%	5%	1%
Digitaria scalarum	7%	21%	29%	29%	7%	7%	0%	4%	4%	0%	0%	14%	21%	21%	14%	21%	21%	32%	36%	7%	4%	0%	7%	14%	36%	4%	18%	11%	11%	0%
Digitaria setifolia	10%	28%	21%	41%	0%	0%	0%	0%	0%	0%	5%	10%	26%	26%	10%	23%	21%	44%	23%	13%	0%	0%	5%	5%	26%	5%	21%	38%	0%	0%
Dregeochloa calviniensis	0%	0%	0%	0%	50%	50%	50%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	75%	25%	0%	0%	50%	0%	0%	50%	0%	0%
Dregeochloa pumila	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	75%	25%	0%	0%
Echinochloa jubata	2%	53%	6%	37%	2%	0%	0%	2%	0%	6%	6%	45%	35%	4%	0%	2%	4%	4%	80%	10%	2%	0%	0%	6%	4%	2%	6%	45%	35%	2%
Echinochloa pyramidalis	2%	17%	38%	40%	2%	2%	0%	0%	0%	2%	4%	23%	15%	10%	23%	23%	25%	19%	46%	8%	0%	0%	2%	8%	50%	6%	4%	13%	17%	0%
Ehrharta bulbosa	32%	0%	0%	0%	5%	63%	0%	0%	5%	21%	21%	16%	21%	16%	0%	0%	5%	5%	42%	42%	5%	0%	32%	16%	32%	16%	5%	0%	0%	0%
Ehrharta calycina	20%	2%	10%	3%	9%	55%	24%	16%	7%	13%	12%	6%	9%	4%	4%	6%	5%	8%	9%	27%	44%	7%	17%	12%	27%	10%	13%	15%	6%	1%
Ehrharta capensis	25%	0%	0%	0%	3%	71%	5%	3%	8%	32%	22%	7%	14%	2%	7%	0%	3%	3%	12%	49%	32%	0%	22%	15%	19%	17%	19%	7%	2%	0%
Ehrharta dura	54%	0%	0%	0%	4%	43%	0%	7%	7%	18%	18%	18%	29%	4%	0%	0%	7%	4%	32%	32%	25%	0%	50%	18%	18%	14%	0%	0%	0%	0%
Ehrharta eburnea	0%	0%	0%	0%	0%	100%	43%	43%	0%	14%	0%	0%	0%	0%	0%	0%	0%	0%	0%	29%	71%	0%	0%	14%	57%	14%	0%	14%	0%	0%
Ehrharta longigluma	0%	6%	6%	78%	11%	0%	0%	0%	0%	11%	6%	0%	33%	17%	0%	33%	22%	22%	22%	33%	0%	0%	0%	6%	11%	11%	33%	39%	0%	0%
Ehrharta melicoides	3%	0%	0%	3%	0%	93%	31%	17%	3%	17%	10%	3%	14%	0%	3%	0%	0%	3%	7%	34%	55%	0%	3%	7%	24%	17%	21%	17%	10%	0%
Ehrharta ottonis	31%	0%	0%	0%	3%	66%	0%	0%	6%	9%	28%	16%	31%	9%	0%	0%	6%	3%	31%	50%	9%	0%	22%	22%	38%	19%	0%	0%	0%	0%
Ehrharta ramosa	43%	0%	0%	0%	3%	54%	4%	10%	9%	26%	13%	10%	13%	7%	4%	0%	3%	3%	16%	44%	32%	0%	40%	10%	12%	12%	15%	7%	3%	1%
Ehrharta rehmannii	47%	0%	3%	0%	0%	50%	0%	3%	3%	6%	28%	6%	34%	13%	3%	3%	9%	13%	41%	38%	0%	0%	41%	9%	38%	9%	3%	0%	0%	0%
Ehrharta rupestris	38%	0%	0%	0%	0%	62%	3%	9%	6%	9%	15%	9%	29%	6%	12%	3%	6%	15%	21%	29%	29%	0%	35%	9%	26%	15%	9%	3%	0%	3%

Table 10: Continue

Species	Rainfall Seasonality						MAP (mm)										Coefficient of variation of annual precipitation (%)						Rainfall Concentration index (%)							
	All Year	Early Summer	Late Summer	Mid Summer	Very Late Summer	Winter	<200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000	> 20	20 - 24	25 - 29	30 - 34	35 - 39	< 40	< 15	15 - 30	30 - 45	45 - 50	50 - 55	55 - 60	60 - 65	> 65
Ehrharta setacea	15%	0%	0%	0%	0%	85%	0%	5%	0%	25%	10%	15%	35%	10%	0%	0%	10%	0%	35%	40%	15%	0%	15%	10%	50%	25%	0%	0%	0%	0%
Ehrharta thunbergii	18%	0%	0%	0%	0%	82%	14%	16%	12%	18%	22%	4%	10%	0%	6%	0%	2%	2%	0%	43%	47%	6%	14%	4%	10%	16%	29%	22%	6%	0%
Ehrharta villosa	31%	1%	3%	0%	0%	65%	7%	9%	4%	22%	21%	9%	19%	4%	1%	3%	3%	10%	16%	50%	21%	0%	25%	10%	21%	13%	18%	12%	1%	0%
Eragrostis bergiana	7%	0%	17%	0%	63%	13%	0%	30%	27%	37%	7%	0%	0%	0%	0%	0%	0%	0%	3%	33%	63%	0%	7%	3%	50%	17%	17%	3%	0%	3%
Eragrostis caesia	0%	14%	14%	65%	6%	2%	2%	0%	2%	3%	3%	15%	38%	20%	5%	14%	18%	15%	48%	15%	3%	0%	0%	3%	14%	18%	26%	38%	3%	0%
Eragrostis crassinervis	17%	17%	0%	67%	0%	0%	0%	17%	17%	17%	33%	17%	0%	0%	0%	0%	0%	0%	0%	50%	50%	0%	17%	0%	0%	0%	0%	0%	17%	67%
Eragrostis curvula	7%	18%	22%	31%	15%	7%	2%	6%	8%	15%	15%	18%	18%	9%	6%	4%	5%	13%	36%	32%	14%	0%	6%	4%	16%	14%	15%	22%	21%	1%
Eragrostis elatior	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	40%	0%	40%	20%	0%	0%	0%	0%	40%	40%	20%	0%	0%	40%	40%	20%	0%	0%	0%	0%
Eragrostis obtusa	10%	9%	28%	11%	40%	2%	2%	17%	16%	20%	21%	16%	5%	3%	0%	0%	0%	0%	23%	43%	33%	0%	8%	7%	20%	21%	17%	17%	12%	0%
Eragrostis planiculmis	4%	33%	15%	44%	2%	2%	0%	1%	0%	5%	12%	18%	44%	13%	2%	6%	5%	23%	53%	18%	1%	0%	3%	5%	5%	14%	20%	44%	10%	0%
Eragrostis sabulosa	13%	0%	13%	0%	0%	75%	0%	0%	0%	0%	13%	0%	38%	38%	0%	13%	13%	0%	38%	50%	0%	0%	13%	0%	63%	13%	13%	0%	0%	0%
Eragrostis sarmentosa	17%	7%	4%	4%	4%	63%	15%	4%	9%	13%	11%	9%	17%	9%	9%	4%	4%	15%	20%	30%	22%	9%	15%	4%	26%	20%	13%	13%	4%	4%
Eragrostis stapfii	0%	30%	19%	49%	0%	2%	2%	0%	0%	9%	26%	45%	17%	2%	0%	0%	0%	2%	66%	30%	2%	0%	0%	0%	2%	6%	6%	21%	62%	2%
Eulalia villosa	7%	32%	21%	40%	0%	0%	0%	0%	0%	1%	2%	9%	18%	27%	22%	22%	27%	40%	25%	7%	0%	0%	5%	6%	23%	9%	19%	34%	2%	1%
Eustachys paspaloides	6%	19%	23%	39%	10%	2%	0%	1%	7%	17%	23%	26%	11%	6%	6%	3%	3%	10%	39%	42%	5%	0%	5%	5%	14%	11%	12%	13%	36%	4%
Festuca africana	13%	9%	4%	70%	0%	4%	0%	0%	4%	4%	0%	17%	22%	43%	0%	9%	30%	22%	39%	9%	0%	0%	13%	0%	9%	17%	9%	39%	9%	4%
Festuca caprina	3%	21%	11%	60%	4%	1%	0%	0%	1%	4%	3%	9%	40%	24%	8%	10%	11%	28%	45%	12%	3%	0%	2%	2%	13%	15%	24%	40%	3%	0%
Festuca costata	5%	19%	9%	63%	5%	0%	0%	0%	2%	2%	5%	16%	22%	27%	8%	20%	25%	28%	31%	14%	2%	0%	2%	3%	16%	16%	23%	33%	6%	0%
Festuca longipes	9%	9%	40%	40%	3%	0%	0%	0%	0%	3%	9%	29%	49%	9%	0%	3%	3%	29%	60%	9%	0%	0%	6%	11%	31%	17%	26%	9%	0%	0%
Fingerhuthia sesleriiformis	1%	19%	27%	41%	13%	0%	0%	6%	3%	10%	14%	15%	37%	10%	1%	4%	1%	11%	48%	30%	9%	0%	1%	3%	23%	18%	25%	27%	3%	1%
Geochloa decora	42%	0%	0%	5%	0%	53%	0%	0%	11%	26%	16%	0%	37%	11%	0%	0%	5%	0%	47%	32%	16%	0%	37%	16%	32%	5%	5%	0%	0%	5%
Helictotrichon barbatum	0%	0%	0%	0%	0%	100%	50%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	50%	0%	50%	0%	0%
Helictotrichon capense	18%	6%	18%	0%	12%	47%	0%	0%	0%	12%	18%	6%	41%	24%	0%	0%	18%	0%	35%	41%	6%	0%	12%	24%	41%	18%	0%	6%	0%	0%
Helictotrichon dodii	27%	0%	0%	9%	0%	64%	0%	0%	0%	9%	9%	9%	55%	18%	0%	0%	9%	18%	45%	27%	0%	0%	27%	0%	36%	18%	18%	0%	0%	0%
Helictotrichon hirtulum	24%	7%	29%	20%	7%	13%	0%	2%	0%	11%	18%	24%	20%	13%	7%	7%	11%	18%	27%	40%	4%	0%	18%	16%	33%	18%	4%	9%	2%	0%
Helictotrichon leoninum	0%	0%	0%	0%	0%	100%	0%	13%	0%	13%	0%	25%	38%	13%	0%	0%	0%	0%	50%	38%	13%	0%	0%	0%	38%	50%	13%	0%	0%	0%
Helictotrichon longifolium	0%	6%	34%	55%	2%	2%	0%	0%	0%	11%	11%	15%	30%	17%	4%	13%	15%	17%	40%	26%	2%	0%	0%	2%	21%	28%	28%	21%	0%	0%
Helictotrichon longum	8%	0%	0%	0%	0%	92%	0%	23%	0%	15%	15%	0%	31%	15%	0%	0%	0%	0%	38%	38%	23%	0%	8%	0%	31%	23%	31%	0%	8%	0%
Helictotrichon namaquense	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	50%	50%	0%	0%	0%	50%	0%	0%	50%	0%	0%
Hemarthria altissima	3%	30%	19%	38%	3%	8%	1%	2%	1%	8%	14%	21%	24%	10%	11%	8%	9%	17%	45%	23%	6%	0%	3%	4%	17%	5%	14%	29%	23%	6%
Hordeum capense	7%	1%	21%	21%	19%	31%	6%	15%	4%	18%	18%	12%	25%	1%	1%	0%	0%	7%	28%	38%	26%	0%	4%	6%	35%	29%	18%	6%	1%	0%
Hyparrhenia anamesa	5%	31%	10%	48%	2%	5%	0%	0%	1%	6%	13%	24%	24%	14%	9%	8%	8%	21%	53%	16%	1%	0%	4%	3%	16%	11%	12%	25%	25%	4%
Hyparrhenia schimperi	7%	36%	7%	50%	0%	0%	0%	0%	0%	0%	7%	14%	29%	7%	29%	14%	21%	36%	36%	0%	7%	0%	7%	0%	21%	7%	7%	43%	14%	0%
Leptochloa eleusine	2%	18%	18%	57%	5%	0%	0%	0%	2%	5%	12%	22%	20%	27%	10%	3%	5%	17%	48%	28%	2%	0%	2%	7%	25%	12%	20%	7%	17%	12%
Leptochloa fusca	8%	10%	25%	18%	22%	17%	9%	12%	9%	15%	21%	10%	12%	6%	4%	2%	3%	5%	22%	42%	28%	1%	7%	8%	17%	11%	9%	18%	21%	9%
Leucophrys mesocoma	0%	0%	15%	0%	69%	15%	85%	0%	0%	8%	8%	0%	0%	0%	0%	0%	0%	0%	0%	15%	54%	31%	0%	0%	23%	8%	0%	8%	31%	31%
Melica racemosa	18%	6%	19%	34%	11%	12%	1%	3%	2%	16%	17%	11%	24%	12%	10%	4%	6%	17%	33%	37%	8%	0%	15%	10%	27%	17%	19%	11%	1%	0%
Merxmuellera macowanii	2%	11%	15%	70%	2%	0%	0%	0%	0%	2%	4%	17%	28%	24%	4%	20%	15%	37%	35%	13%	0%	0%	2%	4%	13%	20%	22%	39%	0%	0%
Microchloa kunthii	3%	38%	18%	36%	6%	0%	1%	0%	1%	8%	15%	24%	30%	6%	8%	8%	8%	14%	54%	20%	5%	0%	1%	3%	6%	9%	18%	38%	25%	1%
Odyssea paucinervis	0%	3%	6%	32%	10%	48%	42%	10%	16%	19%	10%	0%	3%	0%	0%	0%	0%	0%	3%	32%	52%	13%	0%	3%	3%	6%	6%	29%	23%	29%
Oplismenus undulatifolius	22%	8%	27%	43%	0%	0%	0%	0%	0%	0%	8%	8%	19%	24%	16%	24%	41%	22%	24%	14%	0%	0%	19%	8%	27%	5%	14%	22%	5%	0%
Panicum coloratum	2%	14%	30%	41%	12%	1%	1%	7%	8%	22%	24%	18%	10%	4%	4%	2%	2%	6%	30%	49%	13%	0%	2%	3%	9%	7%	14%	19%	31%	14%
Panicum deustum	14%	20%	20%	40%	5%	1%	1%	0%	2%	8%	17%	24%	14%	14%	14%	8%	13%	17%	39%	27%	4%	0%	12%	7%	27%	8%	9%	7%	21%	9%
Panicum dregeanum	2%	28%	30%	38%	2%	0%	0%	0%	2%	0%	2%	20%	6%	12%	28%	30%	34%	28%	36%	2%	2%	0%	0%	12%	42%	8%	10%	6%	22%	0%
Panicum laevipes	0%	0%	0%	5%	89%	5%	37%	58%	0%	0%	0%	0%	5%	0%	0%	0%	0%	5%	0%	0%	95%	0%	0%	0%	0%	16%	21%	16%	47%	0%
Panicum maximum	5%	23%	16%	48%	7%	1%	1%	3%	8%	13%	19%	24%	10%	8%	8%	6%	8%	11%	38%	35%	9%	0%	4%	5%	18%	4%	7%	13%	37%	14%
Panicum repens	2%	12%	26%	29%	0%	31%	5%	2%	7%	12%	12%	12%	17%	12%	7%	14%	19%	10%	33%	24%	14%	0%	2%	12%	21%	5%	14%	21%	14%	10%
Panicum stapfianum	6%	9%	39%	11%	25%	8%	2%	2%	9%	34%	30%	15%	9%	0%	0%	0%	0%	0%	25%	66%	9%	0%	4%	9%	9%	18%	20%	17%	21%	1%
Paspalum distichum	3%	26%	24%	33%	8%	7%	2%	1%	1%	7%	16%	22%	21%	12%	9%	7%	7%	11%	47%	29%	4%	1%	3%	6%	19%	15%	16%	23%	18%	1%
Paspalum vaginatum	14%	7%	38%	19%	0%	24%	0%	2%	0%	2%	10%	5%	24%	26%	14%	17%	19%	33%	31%	14%	2%	0%	14%	10%	55%	7%	7%	5%	2%	0%

Table 10: Continue

Species	Rainfall Seasonality						MAP (mm)										Coefficient of variation of annual precipitation (%)						Rainfall Concentration index (%)							
	All Year	Early Summer	Late Summer	Mid Summer	Very Late Summer	Winter	<200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000	> 20	20 - 24	25 - 29	30 - 34	35 - 39	< 40	< 15	15 - 30	30 - 45	45 - 50	50 - 55	55 - 60	60 - 65	> 65
Pennisetum unisetum	0%	15%	12%	65%	0%	8%	0%	0%	0%	4%	0%	8%	27%	19%	31%	12%	15%	31%	46%	8%	0%	0%	0%	0%	35%	15%	19%	23%	8%	0%
Pentameris acinosa	23%	0%	0%	0%	0%	77%	0%	0%	9%	23%	18%	9%	27%	9%	5%	0%	5%	5%	27%	36%	27%	0%	14%	23%	45%	14%	5%	0%	0%	0%
Pentameris ampla	30%	0%	0%	3%	3%	65%	0%	0%	5%	16%	16%	11%	27%	14%	5%	5%	8%	19%	32%	32%	8%	0%	22%	11%	24%	19%	16%	5%	3%	0%
Pentameris argentea	46%	0%	0%	0%	0%	54%	0%	0%	4%	21%	21%	8%	25%	21%	0%	0%	0%	13%	42%	29%	17%	0%	42%	17%	29%	8%	4%	0%	0%	0%
Pentameris aristidoides	11%	0%	0%	0%	0%	89%	9%	6%	11%	20%	20%	9%	20%	6%	0%	0%	6%	6%	20%	43%	26%	0%	6%	11%	29%	17%	20%	9%	9%	0%
Pentameris aspera	0%	0%	0%	0%	0%	100%	0%	0%	0%	14%	14%	0%	43%	29%	0%	0%	0%	0%	57%	43%	0%	0%	0%	0%	71%	0%	14%	14%	0%	0%
Pentameris aurea	19%	0%	4%	37%	4%	37%	0%	0%	4%	4%	4%	19%	26%	15%	7%	22%	15%	22%	41%	19%	4%	0%	19%	7%	15%	15%	22%	22%	0%	0%
Pentameris bachmannii	0%	0%	0%	0%	0%	100%	0%	0%	0%	18%	9%	27%	27%	18%	0%	0%	0%	9%	45%	45%	0%	0%	0%	0%	55%	36%	9%	0%	0%	0%
Pentameris barbata	7%	3%	0%	3%	0%	87%	3%	10%	3%	17%	10%	13%	27%	13%	3%	0%	3%	10%	23%	50%	13%	0%	7%	0%	13%	30%	33%	13%	3%	0%
Pentameris calcicola	42%	0%	0%	0%	0%	58%	0%	0%	0%	42%	50%	0%	8%	0%	0%	0%	0%	0%	17%	75%	8%	0%	25%	50%	25%	0%	0%	0%	0%	0%
Pentameris capensis	8%	0%	0%	0%	0%	92%	0%	0%	8%	8%	0%	17%	58%	0%	8%	0%	17%	0%	42%	42%	0%	0%	8%	0%	50%	17%	17%	8%	0%	0%
Pentameris chippindalliae	0%	75%	0%	25%	0%	0%	0%	0%	0%	13%	13%	0%	63%	13%	0%	0%	13%	13%	50%	25%	0%	0%	0%	0%	0%	0%	0%	63%	25%	13%
Pentameris cirrhulosa	63%	0%	0%	0%	4%	33%	0%	8%	8%	25%	33%	0%	21%	4%	0%	0%	0%	0%	13%	58%	29%	0%	50%	29%	17%	0%	4%	0%	0%	0%
Pentameris clavata	0%	0%	0%	0%	0%	100%	0%	0%	33%	67%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	67%	33%	0%	0%
Pentameris colorata	14%	0%	0%	0%	2%	84%	0%	0%	7%	27%	11%	14%	27%	5%	9%	0%	5%	5%	23%	48%	20%	0%	14%	14%	34%	18%	14%	5%	2%	0%
Pentameris densifolia	7%	0%	0%	0%	0%	93%	0%	11%	11%	25%	0%	14%	21%	4%	14%	0%	4%	11%	18%	50%	18%	0%	7%	7%	21%	29%	25%	7%	4%	0%
Pentameris dolichochaeta	34%	0%	0%	0%	3%	63%	0%	16%	9%	25%	6%	13%	9%	9%	13%	0%	3%	9%	9%	47%	31%	0%	34%	6%	13%	19%	22%	6%	0%	0%
Pentameris elegans	0%	0%	0%	0%	0%	100%	0%	0%	0%	33%	33%	0%	33%	0%	0%	0%	0%	0%	33%	67%	0%	0%	0%	33%	67%	0%	0%	0%	0%	0%
Pentameris elisa	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pentameris eriostoma	33%	0%	1%	2%	1%	63%	4%	11%	11%	27%	22%	3%	14%	2%	3%	2%	3%	5%	5%	47%	38%	1%	26%	18%	18%	8%	15%	12%	2%	0%
Pentameris glacialis	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Pentameris glandulosa	31%	0%	21%	0%	19%	29%	2%	5%	5%	24%	26%	10%	14%	12%	2%	0%	0%	5%	14%	62%	19%	0%	29%	19%	33%	12%	5%	2%	0%	0%
Pentameris heptamera	73%	9%	18%	0%	0%	0%	0%	0%	0%	0%	18%	45%	18%	9%	0%	9%	0%	45%	36%	18%	0%	0%	73%	18%	9%	0%	0%	0%	0%	0%
Pentameris hirtiglumis	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	33%	67%	0%	0%	0%	33%	0%	67%	0%	0%	0%	0%	0%	67%	33%	0%	0%	0%	0%
Pentameris holciformis	17%	0%	0%	0%	0%	83%	0%	0%	0%	0%	17%	0%	83%	0%	0%	0%	17%	17%	33%	33%	0%	0%	17%	17%	67%	0%	0%	0%	0%	0%
Pentameris horrida	36%	0%	0%	0%	0%	64%	9%	18%	27%	9%	9%	0%	18%	9%	0%	0%	0%	0%	0%	55%	45%	0%	36%	0%	27%	0%	27%	9%	0%	0%
Pentameris juncifolia	73%	0%	0%	0%	0%	27%	0%	0%	9%	18%	55%	0%	9%	9%	0%	0%	0%	0%	18%	55%	27%	0%	55%	36%	9%	0%	0%	0%	0%	0%
Pentameris lima	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%
Pentameris longiglumis	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	67%	33%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pentameris macrocalycina	37%	0%	0%	0%	0%	63%	2%	12%	12%	25%	10%	10%	19%	6%	6%	0%	4%	4%	17%	42%	33%	0%	31%	17%	21%	12%	12%	6%	2%	0%
Pentameris malouinensis	40%	0%	0%	2%	0%	58%	2%	10%	10%	22%	10%	10%	24%	8%	4%	0%	4%	10%	22%	34%	30%	0%	38%	10%	22%	14%	6%	8%	2%	0%
Pentameris montana	40%	0%	0%	0%	20%	40%	0%	40%	0%	0%	0%	0%	40%	20%	0%	0%	0%	20%	0%	40%	40%	0%	40%	0%	20%	0%	40%	0%	0%	0%
Pentameris obtusifolia	0%	0%	0%	0%	0%	100%	0%	0%	11%	0%	0%	22%	44%	0%	22%	0%	22%	11%	33%	11%	22%	0%	0%	0%	67%	33%	0%	0%	0%	0%
Pentameris oreophila	0%	0%	0%	0%	0%	100%	0%	0%	0%	20%	0%	30%	30%	0%	20%	0%	20%	20%	10%	40%	10%	0%	0%	0%	30%	30%	30%	10%	0%	0%
Pentameris pallescens	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	57%	29%	0%	14%	0%	14%	14%	29%	43%	0%	0%	0%	0%	29%	57%	14%	0%	0%	0%
Pentameris pseudopallescens	0%	0%	0%	0%	0%	100%	0%	0%	0%	17%	17%	0%	50%	0%	17%	0%	0%	17%	0%	83%	0%	0%	0%	17%	0%	0%	67%	17%	0%	0%
Pentameris pusilla	0%	0%	0%	0%	0%	100%	0%	6%	6%	18%	6%	18%	35%	12%	0%	0%	12%	6%	29%	47%	6%	0%	0%	0%	41%	29%	18%	12%	0%	0%
Pentameris pyrophila	50%	0%	0%	0%	0%	50%	0%	17%	6%	22%	0%	22%	22%	0%	11%	0%	6%	0%	6%	67%	22%	0%	50%	6%	11%	17%	11%	6%	0%	0%
Pentameris rigidissima	27%	0%	0%	0%	0%	73%	4%	12%	15%	15%	0%	15%	23%	4%	12%	0%	8%	8%	12%	54%	19%	0%	27%	4%	23%	19%	15%	8%	4%	0%
Pentameris rupestris	11%	0%	0%	0%	0%	89%	0%	16%	26%	16%	5%	11%	16%	5%	5%	0%	0%	5%	16%	47%	32%	0%	11%	0%	5%	16%	42%	16%	11%	0%
Pentameris scabra	0%	0%	0%	8%	0%	92%	0%	0%	0%	0%	25%	0%	58%	17%	0%	0%	8%	0%	42%	50%	0%	0%	0%	0%	92%	0%	0%	0%	0%	8%
Pentameris scandens	33%	0%	0%	0%	0%	67%	0%	0%	0%	33%	67%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	67%	33%	0%	0%	0%	0%	0%
Pentameris swartbergensis	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%	0%	0%	0%	0%	0%	0%	0%
Pentameris thoarii	42%	0%	0%	0%	0%	58%	0%	0%	4%	42%	13%	13%	21%	4%	4%	0%	8%	4%	33%	29%	25%	0%	38%	17%	8%	25%	13%	0%	0%	0%
Pentameris tomentella	0%	0%	0%	0%	5%	95%	67%	14%	10%	5%	5%	0%	0%	0%	0%	0%	0%	0%	0%	10%	76%	14%	0%	0%	14%	10%	24%	48%	5%	0%
Pentameris tortuosa	30%	0%	0%	0%	0%	70%	0%	0%	4%	15%	4%	15%	44%	15%	0%	4%	7%	15%	37%	33%	7%	0%	26%	11%	26%	22%	15%	0%	0%	0%
Pentameris trifida	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	0%
Pentameris tysonii	8%	0%	28%	52%	8%	4%	0%	0%	0%	4%	12%	12%	28%	12%	4%	28%	20%	24%	44%	12%	0%	0%	4%	16%	20%	12%	16%	32%	0%	0%
Pentameris velutina	0%	0%	0%	0%	0%	100%	0%	9%	27%	36%	0%	0%	18%	9%	0%	0%	0%	9%	9%	55%	27%	0%	0%	0%	18%	27%	27%	9%	18%	0%
Pentameris veneta	0%	0%	0%	0%	0%	100%	0%	11%	11%	11%	0%	11%	33%	0%	22%	0%	11%	22%	11%	44%	11%	0%	0%	0%	11%	22%	44%	11%	11%	0%

Table 10: Continue

Species	Rainfall Seasonality						MAP (mm)										Coefficient of variation of annual precipitation (%)						Rainfall Concentration index (%)							
	All Year	Early Summer	Late Summer	Mid Summer	Very Late Summer	Winter	<200	200-300	300-400	400-500	500-600	600-700	700-800	800-900	900-1000	>1000	> 20	20 - 24	25 - 29	30 - 34	35 - 39	< 40	< 15	15 - 30	30 - 45	45 - 50	50 - 55	55 - 60	60 - 65	> 65
Pentameris viscidula	25%	0%	0%	0%	0%	75%	0%	0%	13%	25%	25%	4%	29%	4%	0%	0%	4%	8%	17%	58%	13%	0%	25%	8%	29%	13%	17%	4%	4%	0%
Pentaschistis aurea	17%	0%	17%	67%	0%	0%	0%	0%	0%	0%	17%	17%	8%	17%	0%	42%	17%	25%	33%	25%	0%	0%	0%	17%	17%	0%	25%	42%	0%	0%
Pentaschistis pallescens	10%	0%	0%	0%	0%	90%	0%	20%	0%	0%	0%	40%	30%	10%	0%	0%	10%	10%	40%	30%	10%	0%	10%	0%	40%	40%	10%	0%	0%	0%
Pentaschistis pallida	32%	0%	4%	3%	2%	58%	2%	11%	4%	16%	22%	6%	20%	11%	4%	3%	5%	10%	16%	45%	24%	0%	27%	14%	22%	13%	15%	6%	2%	0%
Poa binata	6%	14%	15%	59%	5%	1%	0%	0%	0%	5%	7%	5%	38%	25%	8%	13%	11%	38%	34%	19%	0%	0%	5%	8%	19%	18%	26%	25%	0%	0%
Poa bulbosa	0%	0%	0%	0%	3%	97%	33%	37%	13%	0%	3%	0%	7%	0%	7%	0%	0%	3%	0%	23%	73%	0%	0%	3%	37%	13%	17%	13%	17%	0%
Pseudopentameris brachyphylla	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	20%	0%	60%	20%	0%	0%	10%	0%	60%	30%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pseudopentameris caespitosa	0%	0%	0%	0%	0%	100%	0%	8%	0%	0%	17%	8%	50%	17%	0%	0%	0%	0%	50%	50%	0%	0%	0%	0%	67%	33%	0%	0%	0%	0%
Pseudopentameris macrantha	21%	0%	0%	0%	0%	79%	0%	4%	0%	25%	29%	0%	33%	8%	0%	0%	0%	0%	25%	67%	8%	0%	8%	25%	38%	13%	17%	0%	0%	0%
Puccinellia acroxantha	0%	8%	8%	0%	69%	15%	15%	23%	46%	8%	0%	8%	0%	0%	0%	0%	0%	0%	8%	23%	69%	0%	0%	0%	15%	23%	31%	23%	8%	0%
Puccinellia angusta	31%	3%	3%	0%	0%	62%	0%	14%	3%	21%	28%	14%	14%	3%	3%	0%	0%	14%	7%	62%	17%	0%	24%	14%	17%	14%	17%	10%	3%	0%
Schismus inermis	44%	0%	6%	0%	11%	39%	19%	11%	6%	19%	28%	11%	3%	0%	3%	0%	0%	6%	8%	56%	31%	0%	36%	17%	8%	8%	17%	11%	3%	0%
Schismus scaberrimus	4%	0%	7%	0%	4%	85%	44%	41%	0%	4%	7%	4%	0%	0%	0%	0%	0%	4%	0%	15%	78%	4%	4%	7%	41%	7%	15%	19%	7%	0%
Secale strictum	0%	20%	0%	20%	20%	40%	40%	0%	0%	20%	0%	20%	0%	0%	20%	0%	0%	20%	20%	40%	20%	0%	0%	0%	40%	40%	0%	0%	20%	0%
Setaria lindenbergiana	5%	34%	4%	47%	11%	0%	0%	0%	10%	4%	18%	41%	10%	4%	12%	2%	5%	11%	59%	21%	4%	0%	2%	4%	11%	9%	4%	14%	52%	4%
Setaria megaphylla	5%	22%	18%	52%	0%	4%	0%	0%	0%	1%	11%	29%	10%	14%	19%	16%	27%	24%	37%	11%	1%	0%	4%	4%	27%	11%	11%	14%	29%	1%
Setaria sphacelata	7%	28%	20%	40%	4%	2%	0%	0%	0%	8%	20%	22%	23%	11%	9%	7%	8%	17%	49%	25%	2%	0%	5%	7%	17%	8%	12%	23%	24%	3%
Spartina maritima	80%	0%	0%	0%	0%	20%	0%	7%	0%	0%	40%	20%	13%	13%	7%	0%	0%	33%	20%	40%	7%	0%	73%	7%	7%	0%	0%	13%	0%	0%
Sporobolus africanus	0%	19%	37%	11%	30%	4%	0%	7%	19%	37%	15%	11%	11%	0%	0%	0%	0%	0%	19%	52%	30%	0%	0%	0%	0%	19%	22%	41%	15%	4%
Sporobolus fimbriatus	5%	11%	32%	31%	20%	1%	1%	8%	11%	23%	22%	19%	7%	4%	6%	1%	2%	5%	31%	45%	17%	0%	3%	3%	15%	13%	15%	17%	31%	3%
Sporobolus fourcadii	65%	0%	12%	12%	12%	0%	0%	6%	0%	0%	24%	29%	12%	24%	6%	0%	12%	24%	24%	35%	6%	0%	59%	12%	12%	18%	0%	0%	0%	0%
Sporobolus ludwigii	0%	0%	54%	9%	34%	3%	0%	0%	26%	51%	20%	0%	3%	0%	0%	0%	0%	0%	3%	77%	20%	0%	0%	3%	6%	20%	29%	29%	14%	0%
Sporobolus spicatus	0%	0%	0%	75%	0%	25%	25%	0%	75%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	25%	75%
Sporobolus subulatus	3%	14%	43%	40%	0%	0%	0%	0%	0%	0%	3%	3%	14%	14%	31%	34%	29%	29%	37%	6%	0%	0%	3%	9%	57%	6%	6%	20%	0%	0%
Sporobolus virginicus	23%	6%	30%	11%	0%	31%	5%	3%	0%	7%	17%	7%	19%	19%	7%	16%	18%	20%	22%	32%	6%	2%	19%	15%	42%	6%	6%	5%	3%	5%
Stenotaphrum secundatum	18%	11%	34%	18%	0%	19%	0%	0%	0%	3%	11%	3%	23%	16%	16%	26%	27%	37%	21%	15%	0%	0%	15%	19%	53%	8%	2%	3%	0%	0%
Stipa dregeana	32%	8%	15%	28%	10%	7%	0%	3%	5%	12%	19%	15%	18%	19%	4%	6%	10%	22%	25%	36%	8%	0%	27%	13%	25%	8%	10%	8%	5%	2%
Stipagrostis brevifolia	0%	0%	3%	0%	45%	52%	72%	24%	0%	3%	0%	0%	0%	0%	0%	0%	0%	0%	0%	3%	66%	31%	0%	3%	14%	7%	21%	31%	17%	7%
Stipagrostis ciliata	3%	1%	16%	1%	52%	28%	43%	35%	13%	6%	2%	0%	1%	0%	0%	1%	1%	0%	1%	11%	71%	17%	3%	2%	12%	13%	14%	21%	20%	15%
Stipagrostis dregeana	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	25%	75%	0%	0%	0%	0%	50%	50%	0%	0%
Stipagrostis geminifolia	0%	0%	0%	0%	0%	100%	89%	0%	0%	0%	0%	0%	11%	0%	0%	0%	0%	0%	11%	0%	11%	78%	0%	0%	22%	11%	33%	22%	11%	0%
Stipagrostis hochstetteriana	0%	0%	16%	5%	74%	5%	79%	5%	0%	11%	0%	0%	0%	0%	5%	0%	0%	0%	5%	11%	58%	26%	0%	0%	0%	5%	16%	16%	11%	53%
Stipagrostis lutescens	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	33%	67%	0%	0%	0%
Stipagrostis obtusa	2%	0%	18%	0%	56%	23%	39%	35%	18%	7%	0%	0%	1%	0%	0%	0%	0%	0%	0%	15%	69%	16%	2%	2%	16%	14%	18%	16%	21%	13%
Stipagrostis schaeferi	0%	0%	0%	0%	0%	100%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%
Stipagrostis zeyheri	17%	8%	10%	13%	0%	53%	17%	5%	6%	12%	13%	15%	21%	4%	3%	4%	5%	9%	25%	31%	26%	4%	15%	10%	16%	11%	17%	23%	8%	0%
Tenaxia dura	6%	0%	0%	0%	18%	76%	53%	35%	0%	6%	6%	0%	0%	0%	0%	0%	0%	0%	0%	18%	82%	0%	0%	6%	35%	18%	18%	18%	6%	0%
Themeda triandra	7%	21%	21%	37%	8%	6%	1%	3%	4%	14%	18%	19%	20%	9%	7%	6%	6%	16%	39%	32%	8%	0%	6%	4%	15%	12%	15%	23%	23%	3%
Tragus koelerioides	2%	3%	47%	11%	36%	0%	1%	7%	18%	34%	24%	9%	3%	3%	0%	0%	0%	0%	15%	62%	24%	0%	2%	3%	20%	26%	15%	14%	20%	0%
Tribolium acutiflorum	8%	0%	0%	0%	0%	92%	15%	12%	8%	27%	8%	8%	19%	0%	4%	0%	0%	0%	19%	46%	31%	4%	0%	12%	15%	31%	19%	15%	8%	0%
Tribolium brachystachyum	6%	0%	0%	0%	0%	94%	0%	6%	6%	17%	0%	17%	44%	0%	11%	0%	11%	17%	22%	44%	6%	0%	6%	6%	39%	22%	22%	6%	0%	0%
Tribolium curvum	41%	0%	7%	2%	25%	25%	2%	4%	4%	29%	34%	14%	9%	0%	4%	2%	0%	4%	14%	64%	16%	2%	30%	36%	16%	5%	9%	2%	0%	0%
Tribolium hispidum	26%	1%	11%	1%	5%	57%	10%	14%	6%	19%	20%	9%	13%	5%	3%	1%	1%	6%	15%	40%	36%	2%	22%	12%	25%	12%	14%	9%	5%	0%
Tribolium obliterum	32%	0%	0%	0%	2%	66%	0%	10%	2%	17%	37%	5%	20%	5%	5%	0%	5%	2%	15%	49%	29%	0%	24%	20%	27%	15%	15%	0%	0%	0%
Tribolium obtusifolium	31%	0%	0%	0%	3%	66%	3%	6%	3%	29%	29%	9%	14%	9%	0%	0%	0%	3%	20%	54%	23%	0%	23%	20%	37%	6%	11%	3%	0%	0%
Tribolium purpureum	7%	1%	28%	21%	17%	26%	4%	11%	7%	15%	19%	14%	18%	3%	3%	6%	1%	8%	21%	39%	29%	1%	0%	14%	49%	15%	15%	7%	0%	0%
Tricholaena capensis	4%	4%	0%	0%	59%	33%	70%	22%	4%	0%	0%	0%	0%	0%	0%	4%	0%	4%	0%	0%	78%	19%	4%	0%	11%	11%	15%	22%	30%	7%
Triraphis ramosissima	0%	0%	0%	0%	92%	8%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	92%	8%	0%	0%	0%	0%	8%	8%	31%	54%
Triraphis schinzii	3%	19%	58%	19%	0%	0%	0%	0%	14%	14%	22%	14%	14%	17%	0%	8%	8%	11%	39%	42%	0%	0%	3%	6%	31%	0%	0%	3%	47%	11%

Table 11: Characterisation of the agro-edaphic niche of the prioritised grass species.

Species	PAW (mm)								Soil pH								Soil Salinity						Soil Fertility					Production potential (t/ha/season)						
	< 20	20 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 100	> 100	<5.4	>7.5	5.5-6.4	5.5-7.4	6.5-7.4	6.5-8.4	7.5-8.4	>8.4	Alkaline Saline Sodic	Moderately Saline	Non-Alkaline Saline-Sodic	None	Slightly Saline	Sodic	Very Low	Low	Average	High	Very High	> 1	1 - 2	2 - 4	4 - 6.5	6.5 - 9	9 - 11	< 11
Acroceras macrum	0%	5%	0%	8%	69%	5%	10%	3%	56%	0%	0%	36%	5%	3%	0%	0%	0%	3%	5%	90%	3%	0%	44%	31%	10%	5%	10%	0%	0%	3%	8%	28%	38%	23%
Agrostis eriantha	0%	8%	0%	4%	31%	35%	13%	11%	83%	0%	0%	7%	6%	4%	0%	0%	0%	0%	0%	96%	4%	0%	2%	81%	11%	2%	4%	0%	0%	7%	4%	56%	26%	6%
Agrostis polypogonoides	40%	0%	40%	20%	0%	0%	0%	0%	20%	0%	0%	60%	0%	20%	0%	0%	0%	0%	0%	80%	20%	0%	60%	40%	0%	0%	0%	0%	40%	60%	0%	0%	0%	0%
Andropogon appendiculatus	1%	9%	6%	4%	30%	34%	11%	5%	62%	0%	0%	23%	9%	6%	0%	0%	0%	0%	0%	94%	5%	0%	8%	55%	28%	7%	3%	0%	0%	10%	27%	37%	23%	3%
Anthoxanthum dregeanum	17%	42%	13%	13%	4%	13%	0%	0%	42%	13%	0%	38%	8%	0%	0%	0%	0%	0%	13%	83%	4%	0%	50%	33%	17%	0%	0%	0%	8%	83%	4%	4%	0%	0%
Anthoxanthum ecklonii	0%	18%	0%	0%	16%	66%	2%	0%	78%	4%	0%	14%	2%	2%	0%	0%	0%	0%	2%	96%	2%	0%	8%	68%	22%	2%	0%	0%	2%	8%	30%	32%	26%	2%
Anthoxanthum tongo	20%	24%	28%	8%	4%	16%	0%	0%	52%	4%	0%	32%	0%	12%	0%	0%	0%	0%	8%	80%	12%	0%	40%	36%	24%	0%	0%	4%	4%	84%	8%	0%	0%	0%
Aristida [illegible]	46%	15%	23%	8%	0%	0%	8%	0%	8%	23%	0%	0%	23%	46%	0%	0%	8%	15%	31%	31%	15%	0%	46%	54%	0%	0%	0%	85%	0%	0%	8%	8%	0%	0%
Aristida engleri	8%	4%	54%	29%	4%	0%	0%	0%	0%	67%	0%	0%	21%	13%	0%	0%	17%	0%	0%	75%	4%	4%	8%	88%	4%	0%	0%	63%	13%	25%	0%	0%	0%	0%
Aristida [illegible]	4%	28%	12%	19%	26%	9%	1%	1%	6%	27%	0%	11%	28%	26%	5%	0%	0%	5%	6%	71%	14%	2%	11%	45%	41%	2%	1%	11%	20%	52%	14%	2%	1%	0%
Arundinella nepalensis	0%	6%	1%	4%	33%	36%	16%	4%	76%	0%	0%	17%	4%	4%	0%	0%	0%	2%	0%	97%	1%	0%	9%	67%	15%	7%	2%	0%	0%	2%	16%	43%	35%	4%
Brachiaria nigropedata	0%	6%	11%	14%	19%	22%	28%	1%	29%	1%	0%	32%	22%	16%	0%	0%	0%	1%	2%	83%	14%	0%	8%	45%	15%	25%	8%	0%	2%	17%	61%	17%	3%	0%
Brachypodium bolusii	0%	4%	8%	0%	16%	72%	0%	0%	68%	12%	0%	12%	8%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	80%	20%	0%	0%	0%	8%	4%	32%	32%	20%	4%
Brachypodium flexum	1%	12%	12%	6%	19%	38%	4%	8%	83%	1%	0%	11%	0%	4%	1%	0%	0%	0%	2%	88%	10%	0%	11%	60%	26%	4%	0%	0%	0%	14%	15%	32%	33%	5%
Bromus firmior	0%	10%	0%	6%	8%	66%	2%	8%	84%	0%	0%	8%	6%	2%	0%	0%	0%	0%	0%	100%	0%	0%	0%	78%	22%	0%	0%	0%	0%	4%	22%	28%	40%	6%
Capeochloa arundinacea	4%	35%	31%	13%	11%	7%	0%	0%	18%	18%	0%	35%	9%	22%	0%	0%	4%	7%	16%	60%	13%	0%	29%	47%	24%	0%	0%	5%	35%	58%	2%	0%	0%	0%
Capeochloa cincta	8%	24%	29%	21%	0%	18%	0%	0%	50%	0%	0%	26%	18%	5%	0%	0%	0%	3%	18%	63%	16%	0%	24%	24%	45%	8%	0%	0%	5%	50%	34%	11%	0%	0%
Cenchrus ciliaris	1%	11%	15%	21%	33%	8%	9%	2%	17%	24%	0%	23%	18%	18%	1%	0%	4%	5%	7%	68%	15%	1%	13%	50%	20%	12%	5%	12%	14%	24%	32%	14%	3%	0%
Centropodia glauca	0%	11%	28%	48%	7%	7%	0%	0%	0%	67%	0%	4%	9%	13%	7%	0%	17%	2%	9%	81%	11%	0%	0%	85%	15%	0%	0%	54%	30%	15%	0%	0%	0%	0%
Chaetobromus involucratus	22%	9%	20%	18%	5%	27%	0%	0%	8%	33%	0%	13%	12%	34%	1%	0%	23%	0%	40%	29%	7%	0%	37%	54%	10%	0%	0%	61%	26%	12%	1%	0%	0%	0%
Chloris gayana	0%	7%	5%	5%	44%	21%	12%	5%	51%	0%	0%	36%	8%	5%	0%	0%	0%	1%	6%	88%	5%	0%	23%	40%	15%	14%	8%	0%	1%	8%	26%	35%	25%	6%
Cladoraphis cyperoides	19%	0%	0%	32%	3%	46%	0%	0%	16%	41%	0%	5%	14%	24%	0%	0%	22%	0%	49%	19%	5%	5%	46%	54%	0%	0%	0%	65%	14%	19%	3%	0%	0%	0%
Cladoraphis spinosa	16%	27%	22%	10%	6%	16%	2%	0%	2%	47%	0%	14%	12%	22%	2%	2%	25%	2%	35%	33%	4%	0%	22%	49%	27%	2%	0%	68%	24%	6%	0%	2%	0%	0%
Cymbopogon dieterlenii	2%	6%	0%	6%	15%	66%	0%	4%	53%	8%	0%	19%	13%	9%	0%	0%	0%	0%	2%	96%	2%	0%	4%	68%	23%	2%	4%	6%	4%	6%	23%	45%	13%	2%
Cymbopogon marginatus	8%	26%	32%	12%	10%	14%	4%	0%	51%	6%	0%	20%	10%	13%	0%	0%	0%	1%	14%	74%	11%	0%	29%	32%	32%	5%	1%	2%	13%	43%	14%	24%	4%	0%
Cymbopogon prolixus	1%	12%	16%	12%	21%	28%	10%	1%	54%	9%	0%	21%	1%	16%	0%	0%	0%	2%	4%	91%	2%	0%	7%	63%	21%	6%	2%	4%	6%	9%	33%	35%	13%	0%
Cynodon dactylon	2%	11%	13%	13%	21%	22%	14%	3%	38%	8%	0%	26%	15%	13%	1%	0%	2%	2%	7%	77%	11%	1%	13%	48%	20%	12%	7%	5%	5%	20%	31%	26%	10%	2%
Cynodon incompletus	0%	30%	1%	20%	34%	13%	2%	1%	9%	22%	0%	12%	22%	31%	5%	0%	0%	6%	3%	69%	22%	0%	3%	38%	51%	8%	0%	4%	6%	56%	24%	6%	1%	0%
Cynodon transvaalensis	0%	6%	0%	14%	20%	37%	17%	6%	49%	3%	3%	17%	14%	14%	0%	0%	0%	0%	0%	89%	11%	0%	11%	43%	26%	14%	6%	0%	0%	14%	37%	37%	6%	3%
Digitaria argyrograpta	0%	10%	8%	13%	35%	19%	14%	1%	24%	15%	0%	38%	8%	13%	3%	0%	0%	8%	6%	76%	10%	0%	9%	33%	22%	22%	15%	6%	10%	9%	41%	27%	6%	1%
Digitaria diversinervis	0%	0%	0%	6%	75%	0%	16%	3%	63%	0%	0%	28%	9%	0%	0%	0%	0%	0%	3%	94%	3%	0%	59%	19%	6%	6%	9%	0%	0%	3%	6%	19%	44%	28%
Digitaria eriantha	0%	10%	9%	15%	31%	20%	11%	3%	28%	8%	0%	26%	21%	16%	1%	0%	1%	3%	4%	77%	14%	0%	9%	44%	29%	13%	5%	2%	5%	25%	39%	21%	6%	2%
Digitaria natalensis	0%	5%	8%	11%	52%	10%	11%	4%	56%	3%	0%	31%	5%	4%	0%	0%	0%	0%	9%	86%	5%	0%	30%	34%	18%	6%	11%	1%	2%	5%	14%	32%	32%	13%
Digitaria scalarum	0%	0%	7%	7%	50%	14%	18%	4%	57%	0%	0%	29%	4%	11%	0%	0%	0%	0%	11%	89%	0%	0%	43%	28%	14%	11%	4%	0%	4%	11%	11%	21%	36%	18%
Digitaria setifolia	0%	8%	0%	8%	44%	36%	3%	3%	74%	0%	0%	15%	8%	3%	0%	0%	0%	0%	0%	97%	3%	0%	13%	68%	15%	3%	0%	0%	0%	0%	15%	36%	44%	5%
Dregeochloa calviniensis	25%	0%	25%	50%	0%	0%	0%	0%	0%	75%	0%	0%	0%	25%	0%	0%	50%	0%	0%	0%	50%	0%	25%	50%	25%	0%	0%	75%	25%	0%	0%	0%	0%	0%
Dregeochloa pumila	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Echinochloa jubata	0%	0%	10%	6%	24%	35%	20%	8%	55%	2%	2%	33%	4%	4%	0%	0%	0%	0%	2%	96%	2%	0%	6%	63%	10%	10%	12%	0%	2%	2%	25%	67%	0%	4%
Echinochloa pyramidalis	0%	4%	0%	2%	77%	2%	10%	4%	44%	0%	0%	44%	8%	4%	2%	0%	2%	0%	6%	85%	8%	0%	48%	13%	8%	13%	21%	0%	0%	4%	23%	33%	25%	15%
Ehrharta bulbosa	21%	26%	32%	16%	0%	5%	0%	0%	53%	0%	0%	32%	5%	11%	0%	0%	0%	0%	21%	74%	5%	0%	63%	5%	32%	0%	0%	0%	5%	74%	11%	11%	0%	0%
Ehrharta calycina	12%	21%	24%	16%	12%	13%	1%	0%	22%	23%	0%	18%	13%	23%	1%	0%	8%	3%	24%	54%	8%	2%	30%	36%	29%	4%	1%	24%	22%	32%	10%	7%	2%	3%
Ehrharta capensis	12%	24%	42%	7%	3%	12%	0%	0%	29%	7%	0%	39%	14%	12%	0%	0%	2%	0%	29%	58%	12%	0%	34%	29%	37%	0%	0%	2%	20%	71%	7%	0%	0%	0%
Ehrharta [illegible]	18%	50%	25%	0%	0%	7%	0%	0%	32%	4%	0%	43%	4%	18%	0%	0%	4%	0%	21%	68%	7%	0%	61%	18%	21%	0%	0%	0%	11%	68%	18%	4%	0%	0%
Ehrharta eburnea	0%	0%	86%	0%	14%	0%	0%	0%	0%	57%	0%	0%	14%	29%	0%	0%	0%	14%	0%	86%	0%	0%	0%	29%	71%	0%	0%	14%	57%	29%	0%	0%	0%	0%
Ehrharta longiflora	0%	0%	0%	17%	6%	78%	0%	0%	83%	0%	0%	0%	6%	11%	0%	0%	0%	0%	0%	100%	0%	0%	0%	83%	17%	0%	0%	0%	0%	17%	28%	33%	22%	0%
Ehrharta melicoides	17%	18%	55%	7%	3%	7%	0%	0%	10%	28%	0%	38%	7%	17%	0%	0%	0%	0%	21%	62%	17%	0%	24%	31%	45%	0%	0%	17%	34%	41%	3%	3%	0%	0%
Ehrharta ottonis	19%	18%	28%	25%	0%	9%	0%	0%	38%	3%	0%	38%	6%	16%	0%	0%	0%	0%	28%	59%	13%	0%	47%	16%	38%	0%	0%	0%	3%	78%	19%	0%	0%	0%
Ehrharta ramosa	12%	41%	21%	12%	6%	9%	0%	0%	26%	9%	0%	35%	7%	22%	0%	0%	1%	0%	15%	74%	10%	0%	44%	34%	22%	0%	0%	4%	18%	65%	10%	3%	0%	0%
Ehrharta rehmannii	16%	13%	47%	16%	3%	6%	0%	0%	59%	0%	0%	28%	3%	9%	0%	0%	0%	0%	28%	72%	0%	0%	47%	19%	34%	0%	0%	0%	0%	66%	16%	16%	3%	0%
Ehrharta rupestris	21%	32%	29%	9%	0%	9%	0%	0%	35%	12%	0%	35%	9%	9%	0%	0%	0%	0%	26%	68%	8%	0%	56%	15%	29%	0%	0%	3%	12%	65%	10%	8%	0%	0%

Table 11: Continue

Species	FAW (mm)								Soil pH								Soil Salinity						Soil Fertility					Production potential (t/ha/season)						
	< 20	20 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 100	> 100	<6.4	>7.5	5.5-6.4	5.5-7.4	6.5-7.4	6.5-8.4	7.5-8.4	>8.4	Alkaline Saline Sodic	Moderately Saline	Non-Alkaline Saline Sodic	None	Slightly Saline	Sodic	Very Low	Low	Average	High	Very High	>1	1 - 2	2 - 4	4 - 6.5	6.5 - 9	9 - 11	<11
Ehrharta calycina	20%	20%	30%	15%	0%	15%	0%	0%	50%	0%	0%	30%	5%	15%	0%	0%	5%	0%	20%	60%	15%	0%	55%	15%	30%	0%	0%	0%	5%	85%	10%	0%	0%	0%
Ehrharta thunbergii	6%	25%	30%	14%	4%	12%	0%	0%	20%	4%	0%	41%	8%	27%	0%	0%	4%	0%	37%	39%	20%	0%	25%	57%	18%	0%	0%	12%	37%	47%	4%	0%	0%	0%
Ehrharta villosa	7%	24%	35%	15%	4%	15%	0%	0%	40%	4%	0%	25%	12%	18%	0%	0%	3%	0%	32%	44%	21%	0%	28%	46%	19%	7%	0%	6%	13%	57%	18%	4%	1%	0%
Eragrostis bergiana	0%	20%	13%	30%	37%	0%	0%	0%	3%	47%	0%	3%	20%	23%	3%	0%	7%	10%	13%	47%	23%	0%	7%	53%	40%	0%	0%	13%	37%	43%	7%	0%	0%	0%
Eragrostis caesia	0%	8%	5%	5%	23%	53%	0%	8%	71%	2%	0%	20%	2%	6%	0%	0%	0%	2%	0%	95%	3%	0%	0%	80%	18%	0%	2%	2%	0%	3%	26%	44%	21%	5%
Eragrostis crassinervis	0%	17%	17%	17%	50%	0%	0%	0%	17%	33%	0%	0%	50%	0%	0%	0%	0%	33%	0%	50%	17%	0%	17%	33%	0%	50%	0%	0%	17%	50%	33%	0%	0%	0%
Eragrostis curvula	1%	13%	10%	13%	38%	22%	11%	4%	39%	10%	0%	22%	14%	13%	2%	0%	1%	4%	4%	82%	10%	0%	9%	43%	34%	9%	4%	3%	8%	24%	26%	27%	11%	2%
Eragrostis [illegible]	20%	0%	60%	20%	0%	0%	0%	0%	60%	0%	0%	0%	40%	0%	0%	0%	0%	0%	40%	60%	0%	0%	40%	20%	40%	0%	0%	0%	0%	80%	20%	0%	0%	0%
Eragrostis obtusa	1%	21%	5%	18%	34%	13%	5%	1%	9%	24%	0%	19%	22%	22%	5%	0%	3%	7%	5%	68%	17%	0%	4%	39%	43%	10%	4%	6%	18%	36%	29%	11%	1%	0%
Eragrostis planiculmis	0%	3%	4%	9%	24%	42%	13%	6%	54%	1%	0%	24%	14%	7%	0%	0%	1%	0%	2%	91%	6%	1%	0%	59%	25%	9%	8%	0%	0%	7%	24%	48%	19%	1%
Eragrostis sabulosa	13%	0%	13%	63%	13%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	13%	75%	13%	0%	75%	25%	0%	0%	0%	0%	0%	75%	13%	0%	13%	0%
Eragrostis sarmentosa	15%	13%	33%	13%	9%	15%	0%	2%	43%	11%	0%	30%	4%	11%	0%	0%	7%	0%	17%	61%	11%	4%	37%	35%	28%	0%	0%	15%	7%	52%	9%	9%	7%	2%
Eragrostis stapfii	2%	6%	13%	0%	13%	23%	40%	2%	60%	2%	0%	15%	17%	6%	0%	0%	0%	0%	0%	94%	6%	0%	2%	45%	19%	30%	4%	2%	0%	9%	49%	38%	2%	0%
Eulalia villosa	0%	4%	5%	8%	38%	23%	11%	11%	79%	1%	0%	18%	1%	1%	0%	0%	0%	0%	2%	95%	3%	0%	15%	58%	23%	3%	3%	0%	0%	2%	12%	29%	45%	12%
Eustachys paspaloides	0%	10%	10%	11%	38%	15%	16%	2%	30%	4%	0%	30%	18%	17%	1%	0%	0%	2%	5%	81%	13%	0%	10%	38%	29%	18%	6%	0%	2%	25%	40%	24%	7%	2%
Festuca africana	0%	4%	13%	13%	17%	22%	4%	28%	78%	0%	0%	13%	4%	4%	0%	0%	0%	0%	0%	96%	4%	0%	13%	65%	17%	0%	4%	0%	0%	13%	9%	39%	35%	4%
Festuca caprina	0%	3%	1%	9%	24%	49%	6%	7%	77%	0%	0%	16%	3%	4%	0%	0%	0%	0%	0%	99%	1%	0%	3%	72%	21%	2%	2%	0%	0%	4%	21%	44%	28%	4%
Festuca costata	0%	5%	5%	9%	39%	30%	3%	9%	78%	2%	0%	16%	2%	2%	2%	0%	0%	0%	0%	98%	2%	0%	2%	75%	23%	0%	0%	0%	0%	5%	17%	34%	38%	6%
Festuca longipes	0%	26%	0%	6%	17%	51%	0%	0%	49%	0%	0%	31%	14%	6%	0%	0%	0%	3%	0%	91%	6%	0%	0%	49%	37%	14%	0%	0%	0%	3%	29%	54%	14%	0%
Fingerhuthia sesleriiformis	0%	14%	1%	9%	24%	42%	3%	8%	43%	8%	0%	24%	14%	11%	0%	0%	0%	1%	0%	89%	10%	0%	1%	57%	30%	5%	6%	1%	5%	13%	33%	42%	6%	0%
Geochloa decora	11%	37%	37%	16%	0%	0%	0%	0%	53%	0%	0%	26%	11%	11%	0%	0%	0%	0%	21%	74%	5%	0%	63%	21%	16%	0%	0%	0%	5%	68%	16%	11%	0%	0%
Helictotrichon barbatum	50%	0%	50%	0%	0%	0%	0%	0%	0%	50%	0%	0%	0%	50%	0%	0%	0%	0%	0%	100%	0%	0%	50%	0%	50%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Helictotrichon capense	6%	18%	24%	24%	0%	24%	0%	6%	47%	0%	0%	41%	0%	12%	0%	0%	0%	0%	12%	71%	18%	0%	29%	29%	24%	18%	0%	0%	0%	47%	35%	12%	0%	6%
Helictotrichon dodii	9%	18%	27%	27%	0%	18%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	9%	82%	9%	0%	45%	36%	18%	0%	0%	0%	0%	45%	36%	9%	9%	0%
Helictotrichon hirtulum	2%	24%	13%	11%	20%	27%	0%	2%	47%	2%	0%	27%	7%	18%	0%	0%	0%	0%	7%	84%	9%	0%	4%	47%	33%	16%	0%	0%	2%	24%	36%	24%	13%	0%
Helictotrichon leoninum	13%	0%	25%	38%	0%	25%	0%	0%	75%	0%	0%	13%	0%	13%	0%	0%	13%	0%	0%	63%	25%	0%	50%	25%	25%	0%	0%	0%	0%	88%	13%	0%	0%	0%
Helictotrichon longifolium	0%	2%	0%	6%	34%	51%	2%	4%	62%	2%	0%	13%	15%	9%	0%	0%	0%	0%	0%	100%	0%	0%	4%	53%	43%	0%	0%	0%	0%	15%	30%	30%	21%	4%
Helictotrichon longum	8%	8%	15%	62%	0%	8%	0%	0%	54%	0%	0%	15%	8%	23%	0%	0%	0%	0%	31%	38%	31%	0%	69%	23%	8%	0%	0%	0%	23%	62%	15%	0%	0%	0%
Helictotrichon namaquense	50%	0%	50%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	50%	0%	50%	0%	0%	50%	50%	0%	0%	0%	0%	0%
Hemarthria altissima	1%	5%	9%	6%	36%	24%	10%	8%	50%	3%	0%	26%	14%	7%	0%	0%	0%	1%	4%	89%	6%	0%	17%	52%	17%	7%	6%	1%	3%	13%	25%	34%	18%	7%
Hordeum capense	1%	9%	28%	15%	24%	24%	0%	0%	34%	15%	0%	16%	15%	19%	0%	1%	0%	3%	16%	68%	13%	0%	7%	37%	53%	3%	0%	7%	15%	40%	18%	16%	4%	0%
Hyparrhenia anamesa	1%	8%	8%	10%	24%	28%	17%	5%	65%	1%	1%	23%	6%	4%	0%	0%	0%	1%	1%	95%	3%	0%	8%	52%	21%	11%	8%	0%	0%	10%	30%	36%	21%	3%
Hyparrhenia schimperi	0%	0%	14%	14%	43%	7%	14%	7%	71%	0%	0%	29%	0%	0%	0%	0%	0%	0%	7%	93%	0%	0%	7%	57%	21%	7%	7%	0%	0%	7%	7%	29%	50%	7%
Leptochloa eleusine	0%	8%	7%	12%	43%	20%	5%	3%	38%	0%	0%	42%	13%	7%	0%	0%	0%	3%	8%	68%	20%	0%	15%	42%	13%	18%	12%	0%	0%	3%	42%	43%	10%	2%
Leptochloa fusca	8%	14%	9%	28%	25%	14%	6%	1%	17%	19%	0%	23%	22%	19%	1%	0%	5%	6%	12%	64%	13%	0%	16%	36%	30%	10%	5%	15%	9%	32%	28%	14%	3%	2%
Leucophrys mesocoma	15%	0%	62%	0%	15%	8%	0%	0%	0%	85%	0%	0%	15%	0%	0%	0%	31%	0%	0%	54%	0%	15%	15%	69%	15%	0%	0%	85%	0%	0%	15%	0%	0%	0%
Melica racemosa	1%	15%	14%	14%	24%	27%	4%	1%	43%	5%	0%	22%	12%	17%	1%	0%	0%	3%	6%	85%	6%	0%	13%	40%	39%	7%	1%	0%	5%	29%	26%	28%	10%	1%
Merxmuellera macowanii	0%	7%	0%	2%	26%	59%	2%	4%	78%	0%	0%	13%	4%	4%	0%	0%	0%	0%	0%	100%	0%	0%	0%	76%	24%	0%	0%	0%	0%	2%	24%	37%	33%	4%
Microchloa kunthii	0%	6%	9%	5%	26%	31%	13%	10%	56%	4%	0%	24%	10%	6%	0%	0%	1%	0%	0%	95%	4%	0%	4%	61%	19%	13%	4%	1%	0%	6%	29%	41%	18%	4%
Odyssea paucinervis	10%	3%	10%	38%	3%	29%	6%	0%	3%	26%	0%	13%	19%	38%	0%	0%	3%	6%	35%	29%	23%	3%	26%	58%	10%	6%	0%	38%	13%	29%	19%	0%	0%	0%
Oplismenus undulatifolius	0%	16%	8%	3%	32%	14%	8%	19%	81%	0%	0%	16%	0%	3%	0%	0%	0%	0%	0%	92%	8%	0%	16%	62%	16%	3%	3%	0%	0%	5%	16%	32%	35%	11%
Panicum coloratum	0%	8%	2%	20%	37%	16%	12%	3%	19%	12%	0%	22%	27%	18%	1%	0%	1%	2%	5%	76%	16%	0%	12%	37%	27%	18%	7%	5%	4%	28%	42%	15%	4%	2%
Panicum deustum	0%	8%	13%	11%	44%	11%	8%	4%	41%	1%	0%	28%	15%	15%	0%	0%	0%	6%	5%	80%	8%	0%	20%	40%	17%	14%	9%	1%	0%	12%	36%	28%	20%	4%
Panicum dregeanum	0%	0%	12%	2%	58%	0%	22%	6%	64%	2%	0%	32%	2%	0%	0%	0%	0%	0%	6%	94%	0%	0%	30%	52%	6%	4%	8%	0%	0%	2%	8%	36%	38%	16%
Panicum lanipes	0%	11%	32%	37%	21%	0%	0%	0%	5%	89%	0%	0%	0%	5%	0%	0%	16%	0%	5%	58%	21%	0%	0%	84%	16%	0%	0%	42%	53%	0%	0%	5%	0%	0%
Panicum maximum	0%	7%	10%	18%	32%	15%	15%	3%	38%	4%	0%	27%	17%	16%	1%	0%	1%	5%	3%	79%	13%	0%	14%	48%	17%	17%	6%	1%	3%	18%	42%	23%	11%	3%
Panicum repens	0%	5%	19%	17%	40%	12%	5%	2%	48%	2%	0%	33%	2%	14%	0%	0%	2%	2%	7%	76%	12%	0%	31%	48%	7%	7%	7%	5%	5%	21%	17%	26%	17%	10%
Panicum stapfianum	0%	16%	9%	15%	30%	19%	9%	1%	16%	8%	0%	21%	28%	24%	2%	1%	0%	5%	7%	68%	19%	1%	3%	32%	50%	13%	3%	2%	3%	45%	38%	10%	1%	0%
Paspalum distichum	1%	7%	8%	9%	27%	28%	15%	4%	47%	4%	1%	27%	12%	9%	0%	0%	2%	1%	2%	88%	6%	0%	15%	43%	25%	10%	7%	2%	2%	13%	28%	34%	17%	2%
Paspalum vaginatum	5%	5%	17%	10%	45%	14%	5%	0%	60%	0%	0%	29%	10%	2%	0%	0%	0%	0%	19%	79%	2%	0%	52%	12%	17%	10%	10%	0%	2%	19%	12%	26%	26%	14%

Table 11: Continue

Species	PAW (mm)								Soil pH								Soil Salinity						Soil Fertility					Production potential (t/ha/season)						
	< 20	20 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 100	> 100	<5.4	>7.5	5.5-6.4	5.5-7.4	6.5-7.4	6.5-8.4	7.5-8.4	>8.4	Alkaline Saline Sodic	Moderately Saline	Non-Alkaline Saline-Sodic	None	Slightly Saline	Sodic	Very Low	Low	Average	High	Very High	> 1	1 - 2	2 - 4	4 - 6.5	6.5 - 9	9 - 11	< 11
Pennisetum unisetum	4%	0%	0%	19%	38%	19%	12%	8%	73%	0%	0%	23%	0%	4%	0%	0%	0%	0%	4%	96%	0%	0%	19%	42%	23%	4%	12%	0%	0%	4%	12%	42%	42%	0%
Pentaschistis acinosa	27%	27%	27%	9%	0%	9%	0%	0%	32%	0%	0%	41%	18%	9%	0%	0%	0%	0%	23%	73%	5%	0%	50%	14%	36%	0%	0%	0%	18%	77%	5%	0%	0%	0%
Pentaschistis ampla	14%	16%	35%	16%	0%	19%	0%	0%	62%	0%	0%	35%	3%	0%	0%	0%	0%	0%	14%	68%	19%	0%	30%	24%	46%	0%	0%	0%	3%	68%	16%	14%	0%	0%
Pentaschistis argentea	13%	38%	29%	13%	0%	8%	0%	0%	58%	0%	0%	29%	4%	8%	0%	0%	0%	0%	17%	83%	0%	0%	58%	13%	29%	0%	0%	0%	4%	71%	13%	13%	0%	0%
Pentaschistis aristidoides	20%	11%	46%	11%	3%	9%	0%	0%	40%	3%	0%	31%	9%	17%	0%	0%	3%	0%	29%	60%	9%	0%	37%	43%	20%	0%	0%	6%	20%	71%	3%	0%	0%	0%
Pentaschistis aspera	14%	0%	29%	57%	0%	0%	0%	0%	86%	0%	0%	14%	0%	0%	0%	0%	0%	0%	29%	71%	0%	0%	71%	29%	0%	0%	0%	0%	14%	57%	29%	0%	0%	0%
Pentaschistis aurea	19%	15%	7%	7%	7%	44%	0%	0%	63%	4%	0%	30%	0%	4%	0%	0%	0%	0%	4%	93%	4%	0%	33%	33%	33%	0%	0%	0%	0%	52%	15%	19%	15%	0%
Pentaschistis bachmannii	27%	0%	9%	36%	0%	27%	0%	0%	73%	0%	0%	27%	0%	0%	0%	0%	0%	0%	18%	64%	18%	0%	64%	0%	36%	0%	0%	0%	0%	91%	9%	0%	0%	0%
Pentaschistis barbata	13%	10%	23%	37%	0%	13%	3%	0%	57%	3%	0%	27%	3%	10%	0%	0%	10%	0%	20%	50%	20%	0%	50%	30%	17%	3%	0%	3%	13%	67%	3%	13%	0%	0%
Pentaschistis calcicola	0%	0%	100%	0%	0%	0%	0%	0%	25%	8%	0%	17%	25%	25%	0%	0%	0%	0%	92%	8%	0%	0%	8%	67%	25%	0%	0%	0%	0%	92%	8%	0%	0%	0%
Pentaschistis capensis	33%	17%	25%	8%	0%	17%	0%	0%	67%	0%	0%	25%	0%	8%	0%	0%	0%	0%	17%	75%	8%	0%	58%	25%	17%	0%	0%	0%	0%	83%	17%	0%	0%	0%
Pentaschistis chippindalliae	0%	0%	25%	0%	38%	25%	0%	13%	50%	0%	0%	38%	0%	13%	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	13%	75%	0%	13%
Pentaschistis cirrhulosa	4%	42%	50%	4%	0%	0%	0%	0%	17%	13%	0%	38%	8%	25%	0%	0%	0%	4%	54%	42%	0%	0%	42%	21%	38%	0%	0%	4%	8%	83%	4%	0%	0%	0%
Pentaschistis clavata	0%	33%	67%	0%	0%	0%	0%	0%	33%	0%	0%	67%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Pentaschistis colorata	20%	27%	32%	9%	0%	11%	0%	0%	34%	0%	0%	45%	14%	7%	0%	0%	0%	0%	25%	64%	11%	0%	45%	27%	27%	0%	0%	0%	9%	82%	9%	0%	0%	0%
Pentaschistis densifolia	21%	29%	29%	4%	0%	18%	0%	0%	36%	4%	0%	39%	11%	11%	0%	0%	4%	0%	11%	71%	14%	0%	32%	39%	29%	0%	0%	0%	14%	82%	4%	0%	0%	0%
Pentaschistis dactylocarpa	13%	38%	19%	3%	13%	16%	0%	0%	31%	25%	0%	34%	6%	3%	0%	0%	0%	6%	22%	66%	6%	0%	31%	41%	28%	0%	0%	9%	19%	66%	3%	3%	0%	0%
Pentaschistis elegans	0%	0%	100%	0%	0%	0%	0%	0%	33%	0%	0%	33%	33%	0%	0%	0%	0%	0%	100%	0%	0%	0%	33%	0%	67%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Pentaschistis ellisii	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pentaschistis eriostoma	11%	33%	37%	4%	8%	8%	0%	0%	22%	10%	0%	37%	12%	20%	0%	0%	1%	4%	28%	59%	8%	0%	29%	39%	32%	0%	0%	7%	22%	61%	7%	2%	2%	0%
Pentaschistis glacialis	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Pentaschistis glandulosa	0%	24%	29%	21%	14%	12%	0%	0%	33%	5%	0%	21%	19%	21%	0%	0%	0%	2%	17%	74%	7%	0%	17%	17%	62%	5%	0%	2%	0%	64%	24%	10%	0%	0%
Pentaschistis heptamera	0%	45%	0%	0%	9%	45%	0%	0%	36%	0%	0%	18%	9%	36%	0%	0%	0%	0%	0%	45%	55%	0%	0%	55%	0%	45%	0%	0%	0%	0%	91%	9%	0%	0%
Pentaschistis hirtiglumis	67%	0%	0%	0%	0%	33%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	67%	0%	33%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Pentaschistis holciformis	50%	17%	33%	0%	0%	0%	0%	0%	67%	0%	0%	17%	17%	0%	0%	0%	0%	0%	17%	67%	17%	0%	50%	17%	33%	0%	0%	0%	0%	83%	17%	0%	0%	0%
Pentaschistis horrida	0%	73%	18%	0%	9%	0%	0%	0%	18%	27%	0%	36%	9%	9%	0%	0%	0%	0%	0%	100%	0%	0%	36%	45%	18%	0%	0%	0%	36%	55%	9%	0%	0%	0%
Pentaschistis juncifolia	0%	18%	73%	9%	0%	0%	0%	0%	27%	9%	0%	27%	27%	9%	0%	0%	0%	0%	64%	36%	0%	0%	36%	9%	55%	0%	0%	0%	0%	91%	0%	9%	0%	0%
Pentaschistis lima	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	50%	50%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Pentaschistis longiglumis	67%	0%	0%	33%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	0%	67%	33%	0%	0%	0%
Pentaschistis macrocalycina	13%	37%	29%	10%	8%	4%	0%	0%	23%	19%	0%	38%	10%	10%	0%	0%	2%	2%	21%	73%	2%	0%	48%	33%	19%	0%	0%	4%	19%	65%	12%	0%	0%	0%
Pentaschistis malouinensis	16%	38%	26%	6%	0%	14%	0%	0%	40%	8%	0%	30%	6%	16%	0%	0%	2%	0%	18%	70%	10%	0%	56%	14%	30%	0%	0%	4%	10%	70%	10%	6%	0%	0%
Pentaschistis montana	0%	80%	20%	0%	0%	0%	0%	0%	0%	40%	0%	60%	0%	0%	0%	0%	0%	20%	0%	80%	0%	0%	40%	40%	20%	0%	0%	0%	20%	80%	0%	0%	0%	0%
Pentaschistis obtusifolia	78%	11%	11%	0%	0%	0%	0%	0%	44%	0%	0%	44%	11%	0%	0%	0%	0%	0%	0%	89%	11%	0%	78%	22%	0%	0%	0%	0%	22%	67%	11%	0%	0%	0%
Pentaschistis oreophila	40%	30%	0%	0%	10%	20%	0%	0%	40%	0%	0%	40%	20%	0%	0%	0%	0%	0%	10%	80%	10%	0%	40%	40%	20%	0%	0%	0%	10%	90%	0%	0%	0%	0%
Pentaschistis pallescens	43%	0%	0%	14%	0%	43%	0%	0%	57%	0%	0%	43%	0%	0%	0%	0%	0%	0%	14%	57%	29%	0%	57%	0%	43%	0%	0%	0%	0%	86%	14%	0%	0%	0%
Pentaschistis pseudopallescens	0%	67%	17%	0%	0%	17%	0%	0%	50%	0%	0%	50%	0%	0%	0%	0%	0%	0%	17%	83%	0%	0%	0%	67%	33%	0%	0%	0%	17%	83%	0%	0%	0%	0%
Pentaschistis pusilla	35%	18%	18%	18%	0%	12%	0%	0%	65%	0%	0%	24%	6%	6%	0%	0%	6%	0%	0%	82%	12%	0%	53%	35%	12%	0%	0%	0%	12%	82%	6%	0%	0%	0%
Pentaschistis pyrophila	17%	50%	11%	0%	0%	22%	0%	0%	22%	17%	0%	28%	11%	22%	0%	0%	0%	0%	17%	67%	17%	0%	61%	11%	22%	6%	0%	0%	17%	72%	11%	0%	0%	0%
Pentaschistis rigidissima	19%	42%	12%	4%	4%	19%	0%	0%	31%	12%	0%	35%	12%	12%	0%	0%	0%	0%	8%	81%	12%	0%	50%	27%	23%	0%	0%	4%	12%	73%	12%	0%	0%	0%
Pentaschistis rupestris	0%	37%	37%	11%	5%	11%	0%	0%	42%	0%	0%	42%	5%	11%	0%	0%	5%	0%	11%	68%	16%	0%	16%	63%	21%	0%	0%	0%	32%	58%	11%	0%	0%	0%
Pentaschistis scabra	25%	0%	42%	33%	0%	0%	0%	0%	58%	8%	0%	33%	0%	0%	0%	0%	0%	0%	33%	67%	0%	0%	58%	17%	25%	0%	0%	0%	0%	75%	25%	0%	0%	0%
Pentaschistis scandens	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	33%	0%	67%	0%	0%	0%	0%	100%	0%	0%	0%	0%	33%	67%	0%	0%	0%	0%	100%	0%	0%	0%	0%
Pentaschistis swartbergensis	0%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	100%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pentaschistis thunbergii	17%	38%	21%	4%	4%	17%	0%	0%	46%	4%	0%	33%	4%	13%	0%	0%	0%	0%	25%	58%	17%	0%	54%	13%	33%	0%	0%	4%	8%	71%	8%	8%	0%	0%
Pentaschistis tomentella	48%	10%	33%	5%	0%	5%	0%	0%	0%	24%	0%	19%	19%	38%	0%	0%	14%	5%	33%	33%	10%	5%	52%	38%	10%	0%	0%	62%	24%	14%	0%	0%	0%	0%
Pentaschistis tortuosa	19%	22%	33%	15%	0%	11%	0%	0%	56%	0%	0%	41%	0%	4%	0%	0%	0%	0%	11%	70%	19%	0%	52%	22%	26%	0%	0%	0%	0%	74%	19%	7%	0%	0%
Pentaschistis trifida	0%	100%	0%	0%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%
Pentaschistis tysonii	0%	16%	0%	12%	20%	52%	0%	0%	68%	0%	0%	20%	0%	12%	0%	0%	0%	0%	0%	96%	4%	0%	0%	68%	32%	0%	0%	0%	0%	8%	40%	28%	20%	4%
Pentaschistis velutina	0%	18%	45%	27%	0%	9%	0%	0%	45%	9%	0%	45%	0%	0%	0%	0%	0%	9%	0%	82%	9%	0%	27%	55%	18%	0%	0%	0%	27%	64%	9%	0%	0%	0%
Pentaschistis veneta	11%	33%	22%	0%	0%	33%	0%	0%	44%	0%	0%	33%	11%	11%	0%	0%	0%	0%	22%	67%	11%	0%	11%	56%	33%	0%	0%	0%	11%	89%	0%	0%	0%	0%

Table 11: Continue

Species	PAW (mm)								Soil pH								Soil Salinity						Soil Fertility					Production potential (t/ha/season)						
	< 20	20 - 40	40 - 50	50 - 60	60 - 70	70 - 80	80 - 100	> 100	<6.4	>7.5	5.5-6.4	5.5-7.4	6.5-7.4	6.5-8.4	7.5-8.4	>8.4	Alkaline Saline Sodic	Moderately Saline	Non-Alkaline Saline-Sodic	None	Slightly Saline	Sodic	Very Low	Low	Average	High	Very High	> 1	1 - 2	2 - 4	4 - 6.5	6.5 - 9	9 - 11	< 11
Pentameris viscidula	21%	33%	33%	4%	0%	8%	0%	0%	42%	0%	0%	50%	0%	8%	0%	0%	0%	4%	25%	67%	4%	0%	38%	33%	29%	0%	0%	0%	8%	88%	4%	0%	0%	0%
Pentaschistis aurea	0%	0%	0%	17%	25%	58%	0%	0%	67%	0%	0%	17%	17%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	50%	50%	0%	0%	0%	0%	0%	58%	25%	17%	0%
Pentaschistis pallescens	40%	0%	10%	40%	0%	10%	0%	0%	50%	0%	0%	20%	10%	20%	0%	0%	20%	0%	0%	70%	10%	0%	70%	10%	20%	0%	0%	0%	10%	80%	10%	0%	0%	0%
Pentaschistis pallida	10%	23%	45%	10%	2%	9%	0%	0%	43%	6%	0%	29%	10%	11%	0%	0%	1%	5%	27%	56%	10%	0%	29%	34%	35%	1%	0%	3%	14%	58%	15%	8%	2%	0%
Poa binata	0%	8%	1%	11%	25%	49%	5%	1%	73%	0%	0%	18%	2%	7%	0%	0%	0%	1%	0%	94%	5%	0%	7%	60%	27%	5%	1%	0%	0%	7%	20%	44%	27%	2%
Poa bulbosa	7%	20%	63%	0%	3%	7%	0%	0%	3%	40%	0%	20%	10%	27%	0%	0%	7%	7%	13%	70%	3%	0%	7%	37%	57%	0%	0%	20%	60%	20%	0%	0%	0%	0%
Pseudopentameris brachyphylla	30%	0%	40%	30%	0%	0%	0%	0%	80%	0%	0%	20%	0%	0%	0%	0%	0%	0%	30%	70%	0%	0%	70%	10%	20%	0%	0%	0%	0%	80%	20%	0%	0%	0%
Pseudopentameris caespitosa	8%	0%	50%	33%	0%	8%	0%	0%	67%	0%	0%	25%	0%	8%	0%	0%	8%	0%	33%	50%	8%	0%	50%	25%	25%	0%	0%	0%	0%	83%	17%	0%	0%	0%
Pseudopentameris macrantha	8%	0%	67%	25%	0%	0%	0%	0%	46%	0%	0%	25%	13%	17%	0%	0%	4%	0%	58%	25%	13%	0%	38%	38%	25%	0%	0%	0%	0%	92%	8%	0%	0%	0%
Puccinellia acroxantha	0%	8%	8%	8%	69%	0%	8%	0%	8%	46%	0%	0%	0%	31%	15%	0%	8%	0%	15%	31%	46%	0%	0%	62%	31%	8%	0%	8%	38%	46%	0%	8%	0%	0%
Puccinellia angusta	3%	14%	45%	17%	3%	14%	3%	0%	34%	0%	0%	21%	24%	21%	0%	0%	7%	0%	34%	41%	17%	0%	24%	38%	28%	10%	0%	0%	17%	55%	17%	10%	0%	0%
Schismus inermis	14%	14%	36%	14%	3%	19%	0%	0%	6%	17%	0%	17%	25%	36%	0%	0%	6%	3%	33%	42%	17%	0%	17%	31%	36%	17%	0%	22%	8%	50%	19%	0%	0%	0%
Schismus scaberrimus	15%	15%	59%	7%	0%	4%	0%	0%	4%	58%	0%	4%	7%	30%	0%	0%	4%	4%	7%	74%	11%	0%	22%	22%	56%	0%	0%	22%	63%	11%	4%	0%	0%	0%
Secale strictum	0%	0%	40%	20%	0%	0%	40%	0%	20%	0%	0%	20%	0%	60%	0%	0%	0%	0%	0%	80%	20%	0%	0%	20%	60%	20%	0%	0%	20%	40%	0%	20%	20%	0%
Setaria lindenbergiana	0%	4%	12%	4%	29%	12%	35%	5%	50%	2%	0%	28%	6%	13%	1%	0%	0%	2%	0%	88%	10%	0%	3%	50%	12%	28%	8%	0%	1%	10%	40%	39%	9%	2%
Setaria megaphylla	1%	1%	2%	2%	41%	18%	20%	13%	66%	0%	0%	29%	4%	1%	0%	0%	0%	1%	4%	92%	4%	0%	23%	43%	8%	20%	5%	0%	0%	6%	25%	28%	31%	10%
Setaria sphacelata	0%	7%	10%	8%	30%	25%	15%	6%	50%	1%	0%	29%	12%	8%	0%	0%	0%	3%	4%	86%	8%	0%	10%	44%	24%	15%	7%	0%	1%	11%	32%	37%	16%	4%
Spartina maritima	7%	27%	33%	13%	0%	20%	0%	0%	40%	0%	0%	13%	13%	33%	0%	0%	7%	0%	20%	47%	27%	0%	20%	40%	20%	20%	0%	0%	13%	20%	47%	20%	0%	0%
Sporobolus africanus	0%	11%	0%	11%	41%	19%	19%	0%	7%	11%	4%	22%	19%	30%	7%	0%	0%	0%	7%	67%	26%	0%	0%	37%	48%	11%	4%	0%	15%	41%	33%	11%	0%	0%
Sporobolus fimbriatus	1%	15%	5%	16%	33%	17%	12%	2%	20%	12%	0%	22%	25%	18%	2%	0%	0%	3%	5%	76%	16%	0%	7%	38%	34%	15%	6%	2%	6%	31%	38%	15%	6%	1%
Sporobolus fourcadei	0%	35%	29%	18%	6%	6%	6%	0%	53%	6%	0%	24%	6%	12%	0%	0%	0%	0%	6%	88%	6%	0%	18%	24%	53%	6%	0%	0%	6%	24%	24%	35%	12%	0%
Sporobolus ludwigii	0%	11%	0%	26%	46%	17%	0%	0%	0%	23%	0%	9%	23%	40%	6%	0%	3%	3%	6%	69%	20%	0%	0%	31%	57%	11%	0%	0%	6%	66%	26%	3%	0%	0%
Sporobolus spicatus	0%	0%	0%	75%	0%	25%	0%	0%	0%	0%	0%	0%	25%	75%	0%	0%	0%	50%	25%	0%	25%	0%	0%	100%	0%	0%	0%	25%	0%	75%	0%	0%	0%	0%
Sporobolus subulatus	0%	0%	0%	3%	63%	20%	9%	6%	66%	0%	0%	29%	6%	0%	0%	0%	0%	0%	6%	91%	3%	0%	40%	43%	11%	0%	6%	0%	0%	3%	6%	40%	34%	17%
Sporobolus virginicus	1%	7%	25%	11%	35%	18%	2%	0%	47%	2%	0%	26%	13%	13%	0%	0%	2%	1%	27%	60%	9%	0%	39%	30%	16%	13%	3%	5%	5%	27%	18%	16%	20%	9%
Stenotaphrum secundatum	3%	8%	15%	11%	39%	16%	8%	0%	60%	0%	0%	24%	13%	3%	0%	0%	0%	0%	13%	82%	5%	0%	39%	27%	19%	11%	3%	0%	0%	18%	18%	16%	34%	15%
Stipa dregeana	1%	22%	18%	14%	17%	25%	3%	0%	51%	6%	0%	22%	9%	12%	0%	0%	0%	6%	9%	80%	5%	0%	13%	43%	32%	11%	0%	0%	2%	31%	23%	29%	13%	2%
Stipagrostis brevifolia	28%	3%	45%	17%	3%	3%	0%	0%	0%	79%	0%	3%	3%	10%	3%	0%	41%	7%	7%	28%	10%	7%	28%	52%	21%	0%	0%	97%	0%	3%	0%	0%	0%	0%
Stipagrostis ciliata	9%	18%	18%	33%	16%	7%	0%	0%	1%	84%	0%	3%	10%	19%	3%	1%	24%	4%	18%	42%	9%	3%	11%	62%	27%	1%	0%	58%	24%	16%	1%	0%	1%	0%
Stipagrostis dregeana	25%	0%	0%	0%	0%	75%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	75%	0%	25%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Stipagrostis geminifolia	44%	0%	0%	0%	0%	56%	0%	0%	11%	89%	0%	0%	0%	0%	0%	0%	33%	0%	33%	11%	0%	22%	44%	56%	0%	0%	0%	89%	0%	11%	0%	0%	0%	0%
Stipagrostis hochstetteriana	5%	0%	68%	11%	11%	0%	5%	0%	0%	84%	0%	5%	0%	11%	0%	0%	21%	0%	5%	74%	0%	0%	5%	84%	11%	0%	0%	84%	0%	11%	0%	0%	5%	0%
Stipagrostis lutescens	33%	0%	0%	0%	0%	67%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	33%	0%	33%	0%	0%	33%	33%	67%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Stipagrostis obtusa	9%	17%	21%	31%	19%	3%	0%	0%	1%	66%	0%	3%	9%	17%	4%	0%	24%	6%	11%	48%	11%	3%	10%	59%	30%	0%	0%	55%	24%	21%	0%	0%	0%	0%
Stipagrostis schaeferi	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%	100%	0%	0%	0%	100%	0%	0%	0%	0%	0%	0%
Stipagrostis zeyheri	13%	17%	23%	5%	13%	28%	1%	1%	37%	5%	0%	25%	13%	20%	0%	0%	3%	1%	27%	60%	9%	0%	24%	48%	21%	6%	1%	17%	13%	33%	15%	17%	2%	3%
Tenaxia dura	12%	18%	65%	6%	0%	0%	0%	0%	0%	53%	0%	12%	6%	29%	0%	0%	0%	0%	12%	76%	12%	0%	12%	29%	59%	0%	0%	24%	65%	6%	6%	0%	0%	0%
Themeda triandra	1%	11%	10%	8%	30%	23%	13%	5%	44%	7%	0%	25%	14%	10%	1%	0%	0%	1%	5%	83%	11%	0%	11%	44%	29%	11%	5%	1%	4%	21%	31%	27%	13%	3%
Tragus koelerioides	0%	19%	1%	20%	42%	14%	4%	0%	8%	19%	0%	12%	27%	29%	5%	0%	2%	5%	3%	70%	20%	0%	1%	32%	55%	12%	0%	3%	10%	52%	30%	5%	1%	0%
Tribolium acutiflorum	12%	0%	54%	12%	4%	19%	0%	0%	42%	8%	0%	23%	4%	23%	0%	0%	8%	0%	27%	35%	27%	4%	27%	46%	27%	0%	0%	12%	15%	69%	4%	0%	0%	0%
Tribolium brachystachyum	33%	17%	33%	6%	0%	11%	0%	0%	44%	0%	0%	39%	6%	11%	0%	0%	6%	0%	6%	83%	6%	0%	44%	33%	22%	0%	0%	0%	6%	83%	11%	0%	0%	0%
Tribolium curvum	4%	27%	27%	25%	2%	16%	0%	0%	11%	4%	0%	32%	27%	27%	0%	0%	0%	11%	32%	48%	7%	2%	13%	30%	50%	7%	0%	2%	5%	61%	30%	2%	0%	0%
Tribolium hispidum	10%	28%	30%	16%	6%	8%	1%	0%	28%	12%	0%	24%	11%	26%	1%	0%	4%	3%	25%	56%	12%	0%	29%	36%	33%	1%	0%	11%	22%	45%	17%	4%	1%	0%
Tribolium utriculosum	7%	24%	46%	10%	2%	10%	0%	0%	32%	5%	0%	39%	10%	15%	0%	0%	2%	2%	46%	44%	5%	0%	32%	27%	41%	0%	0%	0%	22%	71%	7%	0%	0%	0%
Tribolium obtusifolium	6%	29%	37%	20%	3%	6%	0%	0%	37%	11%	0%	11%	14%	26%	0%	0%	0%	3%	29%	57%	11%	0%	31%	40%	26%	3%	0%	0%	17%	63%	20%	0%	0%	0%
Tribolium purpureum	0%	15%	25%	11%	25%	24%	0%	0%	25%	17%	0%	24%	17%	18%	0%	0%	1%	6%	11%	79%	3%	0%	0%	39%	61%	0%	0%	4%	17%	35%	28%	14%	3%	0%
Tricholaena capensis	15%	19%	44%	11%	4%	7%	0%	0%	4%	70%	0%	0%	11%	11%	4%	0%	30%	4%	15%	41%	4%	7%	22%	70%	7%	0%	0%	78%	19%	0%	0%	0%	4%	0%
Triraphis ramosissima	8%	0%	92%	0%	0%	0%	0%	0%	0%	92%	0%	0%	8%	0%	0%	0%	15%	0%	0%	77%	8%	0%	8%	92%	0%	0%	0%	92%	8%	0%	0%	0%	0%	0%
Triraphis schinzii	0%	6%	14%	17%	44%	14%	6%	0%	19%	0%	0%	61%	19%	0%	0%	0%	0%	0%	19%	78%	3%	0%	31%	44%	6%	6%	14%	0%	0%	22%	33%	14%	19%	11%

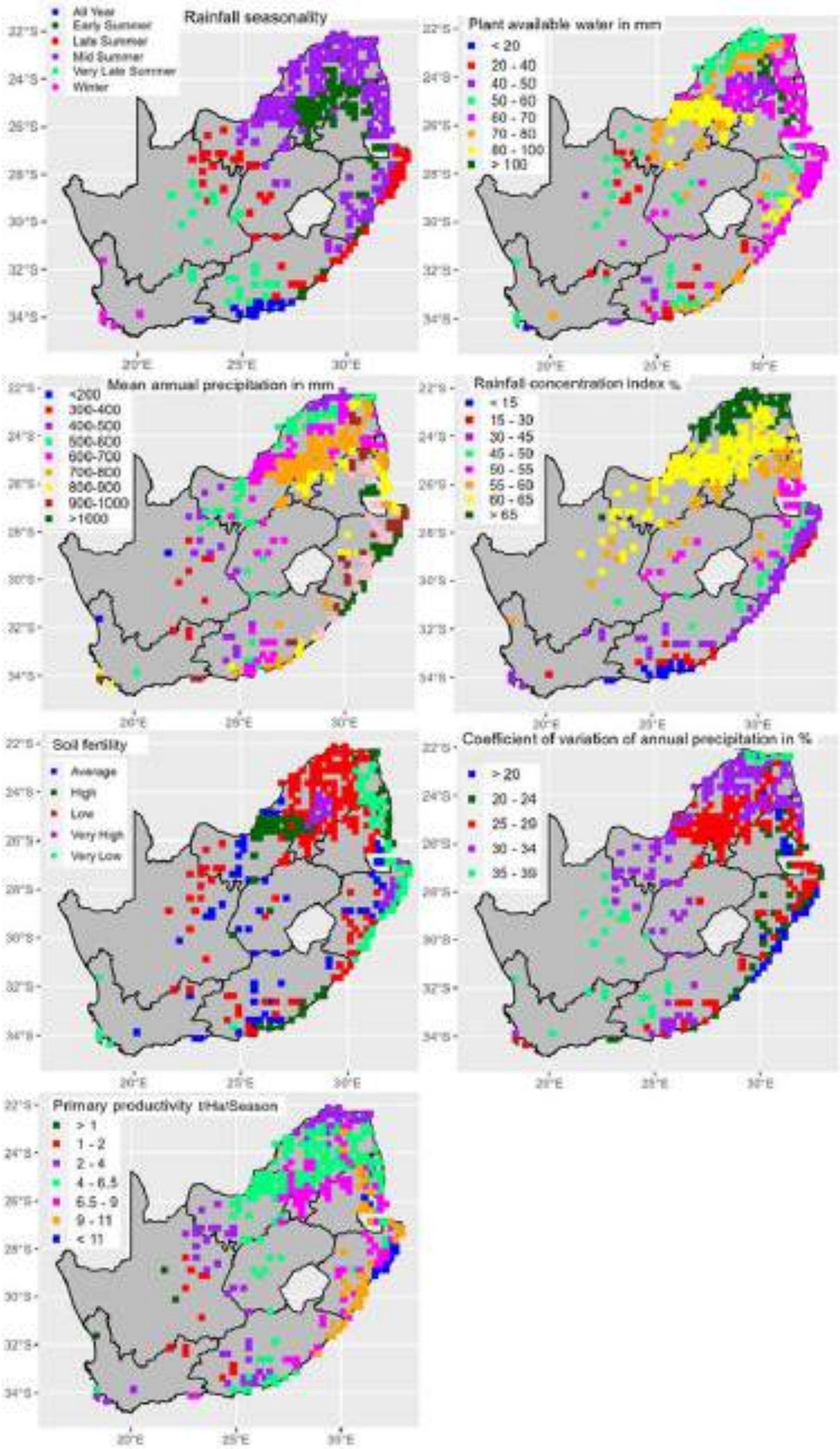


Figure 6: Agro-ecological niche of *Panicum maximum* indicating distinct populations for collection prioritisation.

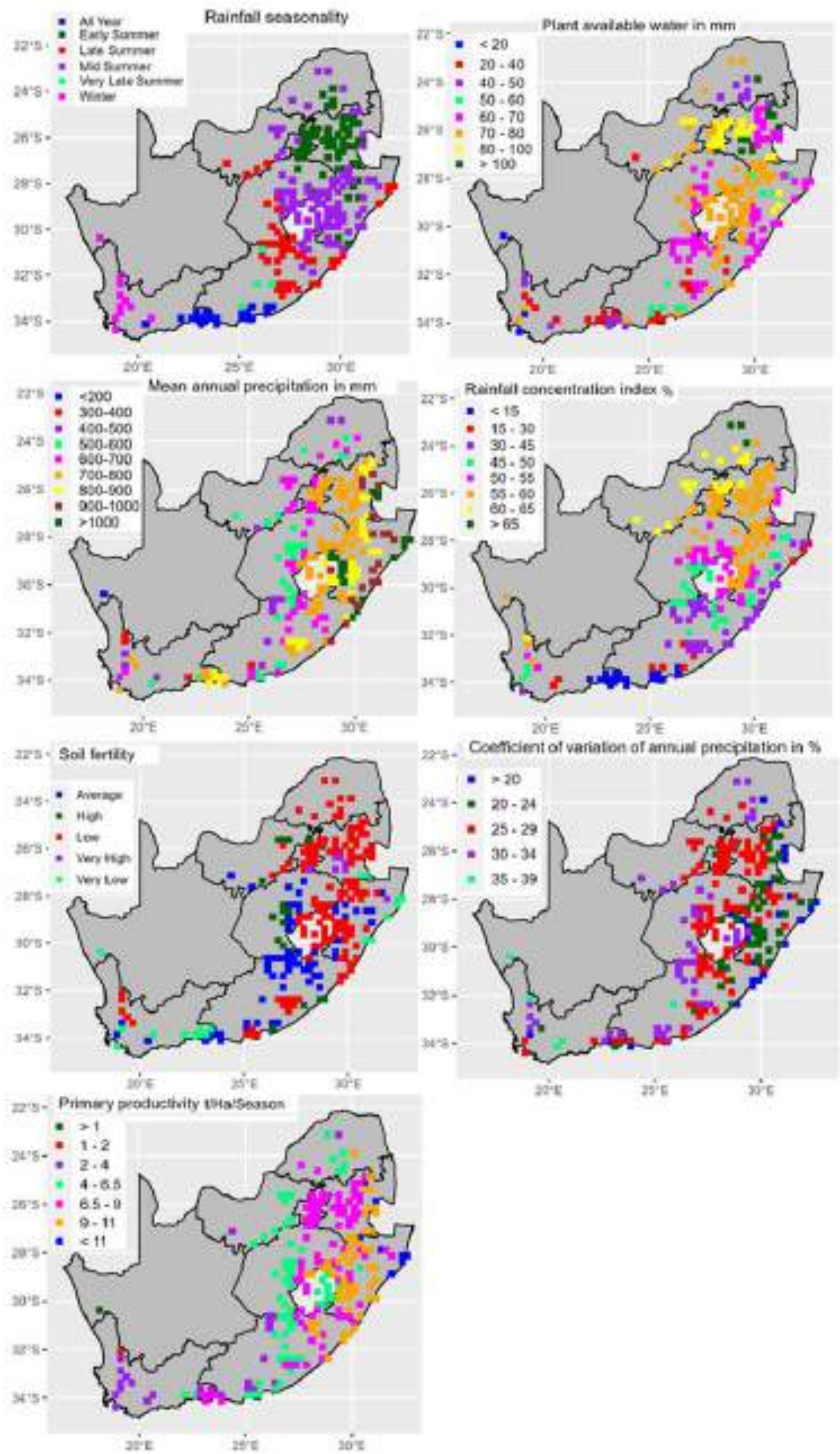


Figure 7: Agro-ecological niche of *Andropogon appendiculatus* indicating distinct populations for collection prioritisation.

2.4 CONCLUSION

The initiative to identify alternative indigenous forage species that can be implemented into fodder flow programs in water-limited areas was motivated by:

1. Knowing that due to rapid population growth and the predicted climate change scenarios for South Africa, vegetable, grain, and fruit production will most likely take priority over forage production systems under irrigated conditions and in suitable bioclimatic areas for rain fed agricultural systems. This, in turn, will most likely mean that livestock and fodder production will have to shift to more marginal areas characterized by water-limitation.
2. The lack of current commercially available forage species suitable for use under dryland or minimum irrigated conditions within these water-limited agro-ecological areas of South Africa.
3. The lack of current forage species that can be used under the predicted hotter and drier South African agro-ecological conditions.
4. The lack of knowledge on the suitability of indigenous grass and legume genetic resources as alternative forage species.

Therefore, this work was done to identify and prioritise indigenous species that could potentially be used to develop forage resources for water-limited environments. In this project, a total of 342 grass and 89 legume species were prioritised based on their potential to be evaluated as alternative forage crops. This list can be regarded as a guideline for current and future collection initiatives since the collection of all of the species, as well as ecotypes from unique populations of these species, cannot be done in a short time. However, from this list, it was clear that several grass species prioritised are good candidates for further evaluation since some of the species identified through the selection process already contained several commercially available cultivars. These species include *Anthephora pubescens, Brachiaria nigropedata, Cenchrus ciliaris, Chloris gayana, Cynodon dactylon, Digitaria eriantha, Eragrostis curvula, Panicum coloratum, Panicum maximum*, and *Setaria sphacelata,* where locally adapted ecotypes could potentially be used to improve the current genetic resources that are commercially available. In contrast to the grass species, only two of the indigenous legume species that were prioritised have previously been domesticated and commercialised. These species are *Lebeckia ambigua* and *Trifolium africanum*. This highlights the discrepancy in the development of indigenous grass vs. legume species, even though the use of legumes in livestock production systems has become more popular over the years due to the added benefits of biological nitrogen fixation. The collection of these prioritised grass and legume genetic resources will be an ongoing initiative, and these plant genetic resources will be used to characterise the forage potential of the indigenous grasses and legumes collected.

CHAPTER 3: THE IMPACT OF CLIMATE CHANGE ON THE DISTRIBUTION AND AGRONOMIC POTENTIAL OF *Calobota Sericea*. IMPLICATIONS FOR COLLECTION PRIORITIES FOR FUTURE FORAGE BREEDING INITIATIVES

3.1 INTRODUCTION

Calobota sericea is a perennial legume species primarily from the semi-arid rangelands in the winter rainfall region of South Africa (Boatwright et al. 2018). The species was prioritized as a potential new fodder crop for the water-limited rangelands of Namaqualand (Müller et al. 2017), where native populations in these rangelands were found to contribute up to 16% of livestock diets during the late dry summer months (Samuels et al. 2016). Within these rangelands, *C. sericea* is highly adapted to the low rainfall conditions of the Namaqualand rangelands, where annual precipitation ranges between 20 mm and 371 mm, with a 36-year (1980 – 2016) mean annual precipitation of 141 mm (Weather SA). Within these rangelands, *C. sericea* has a shrubby growth form, grows up to 1.8 m in height (Schutte 2012, Campbell-Young 2013), and is primarily found on sandy soils with a pH ranging from 6.5 to 8.4, and a total soil phosphate content of 5 to 35 mg/kg (Trytsman et al. 2016, Müller et al. 2017). Furthermore, work done on the nodulation of *C. sericea* indicates that the species is nitrogen fixing and is nodulated by the α-proteobacteria that include *Bradyrhizobium* and *Mesorhizobium* species (Phalane 2008).

It is suggested that the ecological niche of *C. sericea* should be further quantified using existing agronomic, climatic and edaphic information. These will allow for the prioritization of populations for the collection of seeds from ecotypes currently persisting under unique agro-ecological conditions. These ecotypes, in turn, can be used in future breeding initiatives to develop cultivars for specific agro-ecological conditions and to fill agro-ecological niches that may become available due to climate change. Using existing maps created by Schulze et al. (2007) for the South African atlas of climatology and agrohydrology, this study aims to broadly quantify the agro-ecological niche of *C. sericea*. We aimed to identify collection priorities for *C. sericea* for the conservation of genetic variability within the species. This, in turn, is believed to help with future breeding initiatives for *C. sericea*.

3.2 MATERIALS AND METHODS

3.2.1 Species occurrence records

Occurrence data for *C. sericea* was obtained from carefully curated herbarium records cited in the taxonomic revision of *Calobota* by Boatwright et al. (2018), which is based on specimens from various national and international herbaria, with additional distribution data obtained from the Global Biodiversity Information Facility (GBIF.org). The GBIF records were further cleaned by removing all incomplete data points with missing geographical information and replicated data records, resulting in a total of 56 usable data records.

3.2.2 Agro-ecological niche of *Calobota sericea*

To determine whether there were potential differences in the agro-ecological niche between native *C. sericea* populations, the occurrence records for *C. sericea* were plotted in ArcMap and superimposed onto maps indicating rainfall seasonality i.e. when the rainfall season starts, the fertility of the soils where current populations are found, the mean annual net primary productivity of the area (Schulze 2007), mean annual precipitation (MAP) (Schulze et al. 2007), rainfall concentration index (RCI) i.e. the spread of the rainy season (Schulze et al. 2007), coefficient of variation of annual precipitation (CVAP) i.e. the degree of inter-seasonal changes in annual precipitation (Schulze et al. 2007), and plant available water (PAW) in the soils (Schulze et al. 2007) for South Africa. These maps were used to identify populations of *C. sericea* with potentially similar characteristics, which could assist with prioritising the collection of different populations.

3.2.3 Bioclimatic niche of *Calobota sericea*

Ecological niche modelling was performed to determine whether climate change will have an impact on the potential distribution of *C. sericea*, and therefore its agronomic potential. The 19 bioclimatic variables of the WorldClim climate database were downloaded at a resolution of 2.5 arc minutes (Hijmans et al. 2005). This data set includes a summary of averages, extremes, and seasonality patterns of precipitation and temperature. The data were downloaded for the 'current period', defined as 1950 – 2000, as well as for the future scenario (2050), defined as the average of 2041 – 2060. The future climate predictions are the climate projections from global climate models (GCMs) for three representative concentration pathways (RCPs). For the GCM, we utilised the Community Climate System Model 4 (CCSM4), which is considered suitable for the African region. The GCM outputs for this data were downscaled and calibrated (bias corrected) using the WorldClim 1.4 data as a baseline "current" climate. Data for predicting the species distributions under future bioclimatic conditions were downloaded for RCP 2.6, 4.5, and 8.5. These are named after a possible range of radioactive forcing values (difference between sunlight absorbed by the earth and energy radiated back) in the year 2100 relative to pre-industrial values (+2.6, + 4.5, and +8.5 W/m^2, respectively). Although data for different future time periods (such as 2061-2080, 2081-2100) are available, the information generated from only near future (2050) modelling was regarded as sufficient for the purpose of the current study, which was to prioritise *C. sericea* populations that are most at risk of becoming locally extinct in the near future, and to use this information to drive collection initiatives by the South African National Forage Genebank (SA-NFG).

3.2.4 Selection of bioclimatic variables and species distribution modelling

Ecological niche modelling was done using the MaxEnt (version 3.4.1) software. MaxEnt (Phillips et al. 2006) uses presence-only data to predict the distributions of species based on the theory of maximum entropy. The program attempts to estimate a probability distribution of species occurrence that is closest to uniform, while still subject to environmental constraints (Elith et al. 2011). The MaxEnt model used in this study has been shown to perform well with small sample sizes, relative to other modelling methods (Pearson et al. 2007, Elith et al. 2009, Kumar and Stohlgren 2009, Quin et al. 2017). To prioritise bioclimatic variables for use in modelling the bioclimatic niche of *C. sericea*, a first model run, under 'current' bioclimatic conditions, was performed in MaxEnt using all 19 bioclimatic variables. For the initial model, 75% of the data was selected for model training and 25 % for model testing and allowed for a maximum of 5000 iterations to allow for model convergence, and a convergence threshold of 0.0001. This model was replicated 10 times and the average of the 10 replicates was used as the final output for the selection of bioclimatic variables. From the output of the initial model, those bioclimatic variables that did not contribute (had a value of zero) to the permutation importance of the model were removed (Table 12). After removal of these variables, the remaining bioclimatic variables were tested for co-linearity using ArcMap v. 10.2 (Table 13). Once the highly correlated variables (r ≥ 0.9 Pearson's correlation coefficient) were identified, the importance of each variable to model permutation was used to remove the less important variable from each pair of highly correlated variables.

After selection of the bioclimatic variables, all subsequent models were run with only the selected bioclimatic variables using the same other parameters as in the initial model run. A Jackknife test was performed to determine the relative importance of each environmental variable and to determine which variables reduce the model reliability when omitted. MaxEnt measures this by 'gain', which represents how much better the distribution fitted the sample points than the uniform distribution (uniform distribution gain = 0). The Area Under the Curve (AUC) was then used to evaluate the model's performance. The value of AUC ranges from 0 to 1, and the closer the AUC value is to 1, the better the model performs. The final probability map (average of the 10 replicates) was then imported into ArcMap for visualization. Within ArcMap, we used the Jenks natural breaks to cluster the data. Jenks classification is a data clustering method designed to determine the best arrangement of values into different classes and for this study, four classes, i.e., not suitable, adaptive trend, adapted range and highly adapted range, were used. These classes provide probable areas of different degrees of suitability for *C. sericea* populations. The different classes are based on the amount of native *C. sericea* populations occurring within a specific set of bioclimatic conditions. The assumption is that a more suitable bioclimatic niche is found in areas similar to where more *C. sericea* populations are found, and where fewer populations occur are areas with less suitable bioclimatic conditions. These classes therefore contain two important pieces of information, i.e., areas with the most suitable bioclimatic conditions, and potential differences in the adaptive properties of *C. sericea* populations, which are important for the collection of plant genetic resources for future development of improved forage cultivars. This information is also important when considering which populations will be affected more under future bioclimatic conditions. This in turn, will allow for improved prioritisation of collection initiatives to better conserve the vulnerable *C. sericea* populations.

3.3 RESULTS

3.3.1 Agro-ecological niche of *C. sericea*

After plotting the distribution points for *C. sericea,* it was found that all of the distribution records fell within the winter rainfall region of South Africa (Figure 8). However, the different populations within this winter rainfall region were found to occur in areas with different amounts of annual precipitation (Figure 8). Of the total amount of naturally occurring *C. sericea* populations, 85% occurred within locations that received less than 200 mm of annual precipitation, with 9 % of these populations occurring in areas that receive less than 50 mm of annual precipitation and 25% of the populations occurring in areas that receive between 50 and 100 mm of annual precipitation. The occurrence records were also superimposed on a layer indicating the RCI (Figure 8). Approximately 10 % of the *C. sericea* populations occurred in areas that had a relatively short rainy season, i.e., RCI of 60 – 65 %, while more than half (54%) of the populations occurred in areas where the rainfall season is moderately spread i.e., RCI of 50 – 60%. A total of 10% of the population occurred in areas with the longer rainy season spread i.e. RCI of 30 – 45%, but these were also the populations that fell within the locations receiving the lowest MAP. These populations therefore, should be well adapted to low rainfall conditions but also to conditions where rainfall events are spread over longer periods and therefore can possibly withstand droughts better. When considering inter-annual variation in rainfall (Figure 8), it was found that all of the *C. sericea* populations fall within areas with relatively low inter-annual rainfall variability. However, there were differences between different populations, with 5% of the populations occurring in areas with very low inter-annual rainfall variability (below 35%), 69% of the populations in areas with slightly higher inter-annual rainfall variability (below 40%) and 26% of the populations occurring in areas with higher inter-annual rainfall variability (above 40 %). Soil PAW (Figure 8) was also found to differ between the *C. sericea* populations. Although certain populations (30% of C. sericea populations) occurred in areas with relatively high (70 – 80 mm) PAW, approximately 47% of the *C. sericea* populations occurred in areas with PAW of less than 20 mm and 6% of the populations occurred in areas with a soil PAW content of 20 – 40 mm. These populations that occur in locations of lower PAW may have adaptations in their root systems that allow them to access water resources faster or access deeper water sources as the soils dry. Approximately 56% of *C. sericea* populations occurred in locations with an altitude less than 400 m, 38% in locations with an altitude of between 400 m and 800 m, and 6 % that occur in areas with an altitude greater than 800 m (Figure 8). Generally, *C. sericea* populations occurred in locations classified as having either very low or low soil fertility (Figure 8). Approximately 47% of the *C. sericea* populations occurred within areas with very low soil fertility, and 49% in areas with low soil fertility. These areas are also classified as having very low mean annual net primary productivity (Figure 8), with 88% of *C. sericea* populations occurring in areas that have a mean annual net primary productivity of less than 1 ton/Ha/Season, while 8% and 4% of *C. sericea* populations occur in locations that have a mean net primary productivity of 1 – 2 tons/Ha/Season and 2 – 4 tons/Ha/Season, respectively. Areas of low soil fertility that are still used for agricultural production generally require significant financial inputs to become economically viable, especially if soil adjustments are required. These areas, even after adjustments are made, may still not be very productive. Therefore, if *C. sericea* can be developed into an alternative forage for these low fertility areas, farmers can potentially farm these areas without the large financial inputs.

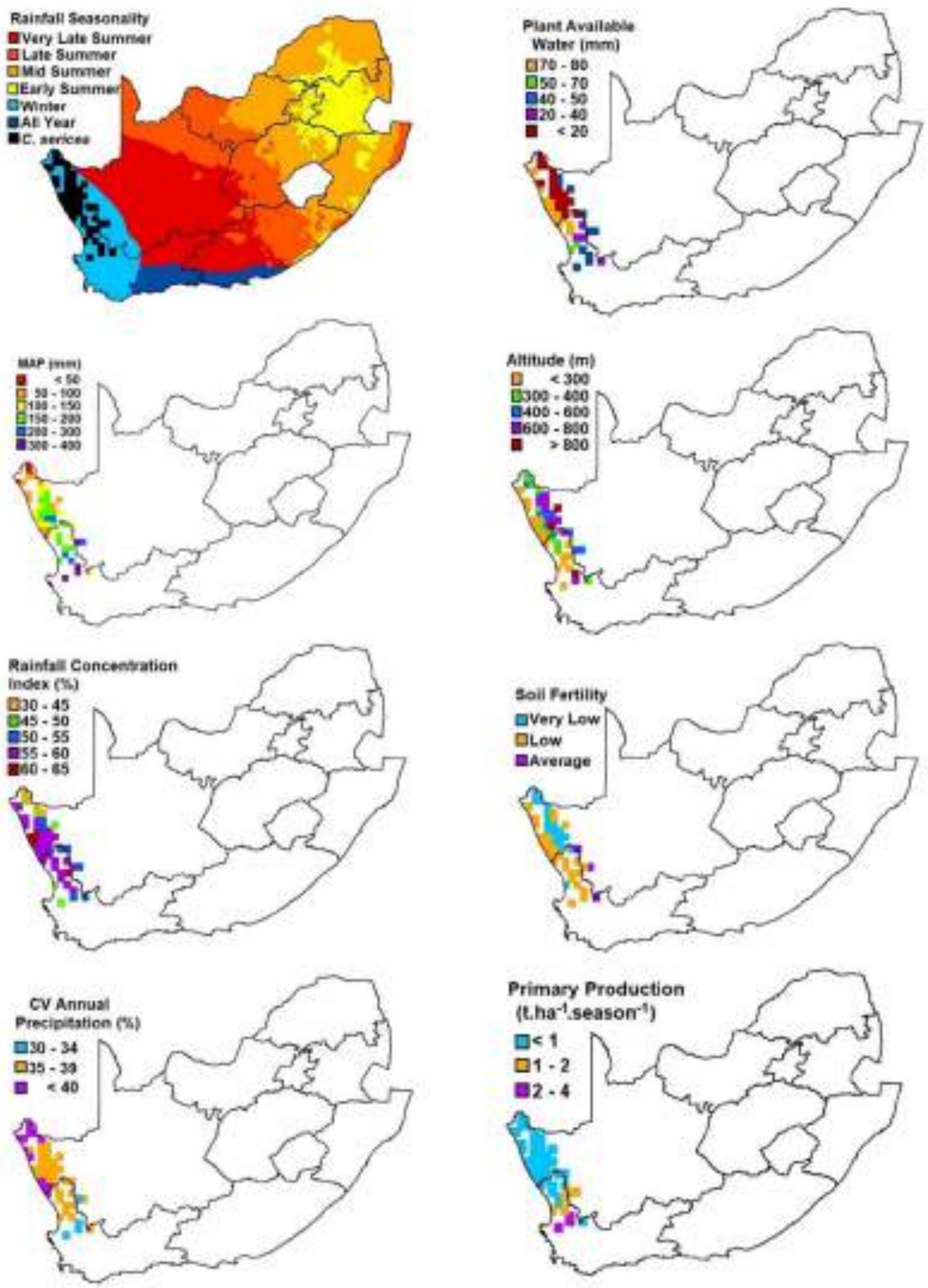


Figure 8: Agro-ecological niche of known *C. sericea* populations.

3.3.2 Bioclimatic niche of *C. sericea*

Out of the 19 bioclimatic variables assessed (Table 12), three variables did not contribute to the permutation of the model and were removed from any further analyses. From the remaining variables, eight pairs of bioclimatic variables were found to be highly correlated (r> 0.9) (Table 13). Using the permutation importance of each pair of highly correlated variables, the least important variable was removed from each pair, resulting in a total of 10 bioclimatic variables (Table 12) used to run the subsequent MaxEnt models under current and future bioclimatic scenarios. The relative contribution (%) of each of the selected bioclimatic variables ranged from 0.3 % (BIO 19) to 67.2 % (BIO 18), with the two dominant bioclimatic variables describing the distributions of *C. sericea* under current bioclimatic conditions being BIO 18 (the amount of precipitation in the warmest quarter) and BIO 9 (mean temperature of the driest quarter), contributing 67.2 % and 10.6 %, respectively to the current bioclimatic niche of the species (Table 12).

Table 12: Relative permutation importance (%) of each bioclimatic variable used to run the initial MaxEnt model. Bold and underlined variables were removed from further analyses either as a result of having a permutation importance of zero or due to being highly correlated with another bioclimatic variable.

Code	Environmental Variables	Permutation importance
BIO 1	Annual Mean Temperature	0.4
BIO 2	**Annual Mean Diurnal Range**	**2.1**
BIO 3	Isothermality	0.6
BIO 4	**Temperature Seasonality**	**0.3**
BIO 5	**Maximum Temperature of the Warmest Month**	**0**
BIO 6	Minimum Temperature of the Coldest Month	0.5
BIO 7	Annual Temperature Range	6.1
BIO 8	Mean Temperature of the Wettest Quarter	2.3
BIO 9	Mean Temperature of the Driest Quarter	10.6
BIO 10	**Mean Temperature of the Warmest Quarter**	**0**
BIO 11	**Mean Temperature of the Coldest Quarter**	**0.2**
BIO 12	**Annual Precipitation**	**1.7**
BIO 13	**Precipitation of the Wettest Month**	**1**
BIO 14	**Precipitation of the Driest Month**	**0.4**
BIO 15	Precipitation Seasonality	0.8
BIO 16	**Precipitation of the Wettest Quarter**	**0**
BIO 17	Precipitation of the Driest Quarter	5.5
BIO 18	Precipitation of the Warmest Quarter	67.2
BIO 19	Precipitation of the Coldest Quarter	0.3

Table 13: Collinearity among the remaining 16 bioclimatic variables of the WorldClim Climate database after the removal of variables that did not contribute to the permutation of the initial model. Bold and underlined correlation coefficients indicate highly correlated bioclimatic variables.

	BIO1	**BIO2**	**BIO3**	**BIO4**	**BIO6**	**BIO7**	**BIO8**	**BIO9**	**BIO11**	**BIO12**	**BIO13**	**BIO14**	**BIO15**	**BIO17**	**BIO18**	**BIO19**
BIO1	-	0.1	0.4	-0.2	0.7	-0.1	0.8	0.6	**0.9**	-0.1	0.0	-0.3	0.5	-0.3	0.1	-0.3
BIO2		-	-0.4	**0.9**	-0.6	**1.0**	0.3	-0.3	-0.3	-0.7	-0.5	-0.7	0.4	-0.7	-0.5	-0.6
BIO3			-	-0.8	0.7	-0.7	0.1	0.6	0.7	0.3	0.4	0.1	0.1	0.2	0.4	0.1
BIO4				-	-0.7	**1.0**	0.2	-0.5	-0.5	-0.6	-0.6	-0.5	0.2	-0.5	-0.6	-0.5
BIO6					-	-0.7	0.3	0.8	**0.9**	0.2	0.3	0.3	0.0	0.3	0.3	0.3
BIO7						-	0.3	-0.4	-0.4	-0.7	-0.6	-0.6	0.3	-0.6	-0.5	-0.6
BIO8							-	0.1	0.6	-0.1	0.1	-0.4	0.6	-0.4	0.2	-0.6
BIO9								-	0.7	-0.1	0.0	0.0	0.0	0.0	-0.1	0.3
BIO11									-	0.1	0.2	0.0	0.3	0.0	0.3	0.0
BIO12										-	**0.9**	0.6	-0.2	0.6	**0.9**	0.4
BIO13											-	0.3	0.1	0.4	**1.0**	0.2
BIO14												-	-0.7	**1.0**	0.3	0.8
BIO15													-	-0.7	0.1	-0.6
BIO17														-	0.3	0.8
BIO18															-	0.1
BIO19																-

Model performance, as indicated by the area under the curve (AUC) value, for the 10 replicated runs, ranged from 0.968 to 0.989, with a mean of 0.977 (± 0.006 SD). This suggests that the environmental variables selected are good descriptors in predicting the bioclimatic niche of *C. sericea* (Figure 9).

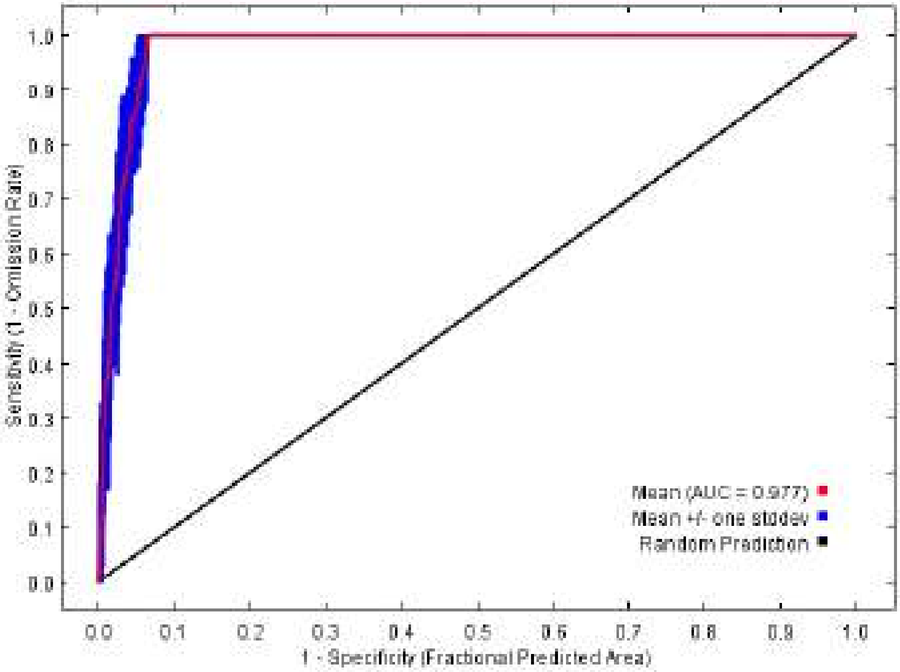


Figure 9. Receiver operating characteristic (ROC) showing the average AUC for 10 replicated runs for *Calobota sericea*.

The Jackknife test for *C. sericea* highlighted that BIO 18 (precipitation in the warmest quarter) is the environmental variable that gives the highest gain when used in isolation. This is followed by BIO 9 (mean temperature in the driest quarter) and BIO 8 (mean temperature in the wettest quarter). BIO 7 (annual temperature range), however, was found to be the environmental variable that decreases the gain the most when omitted and therefore has the most information that isn't present in the other variables (Figure 10).

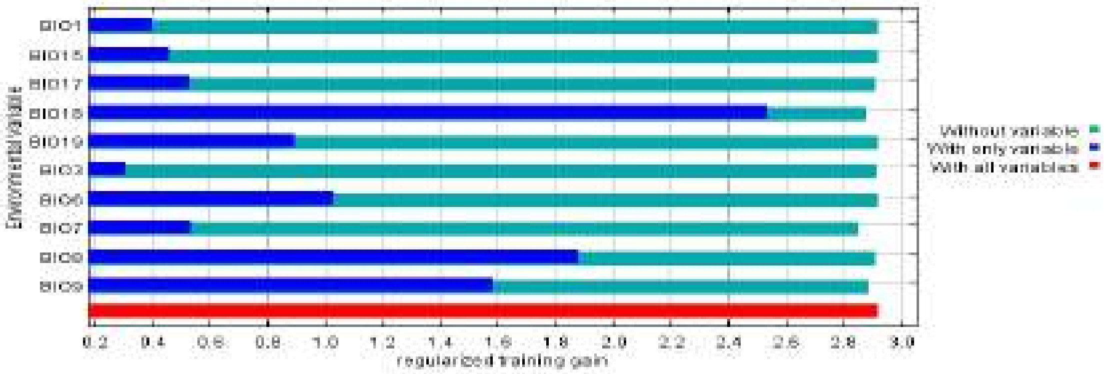


Figure 10. Jackknife test results indicating the bioclimatic variables which results in the highest gain when used in isolation, and the bioclimatic variable which decreases the gain the most when omitted for *Calobota sericea*.

3.3.3 Changes in potential distribution range from current to future bioclimatic conditions

Figure 11 provides the total distribution range (red + grey) under current bioclimatic conditions, and the distributions under future bioclimatic conditions (different shades of grey only) under different RCPs, with distributions lost under each of these climate change scenarios indicated in red. Generally, the predicted total adaptation ranges of *C. sericea* decreased by between 1.6% and 1.8% from current to future bioclimatic conditions, with the largest decrease in the adapted range found under RCP 2.6 conditions (Figure 11).

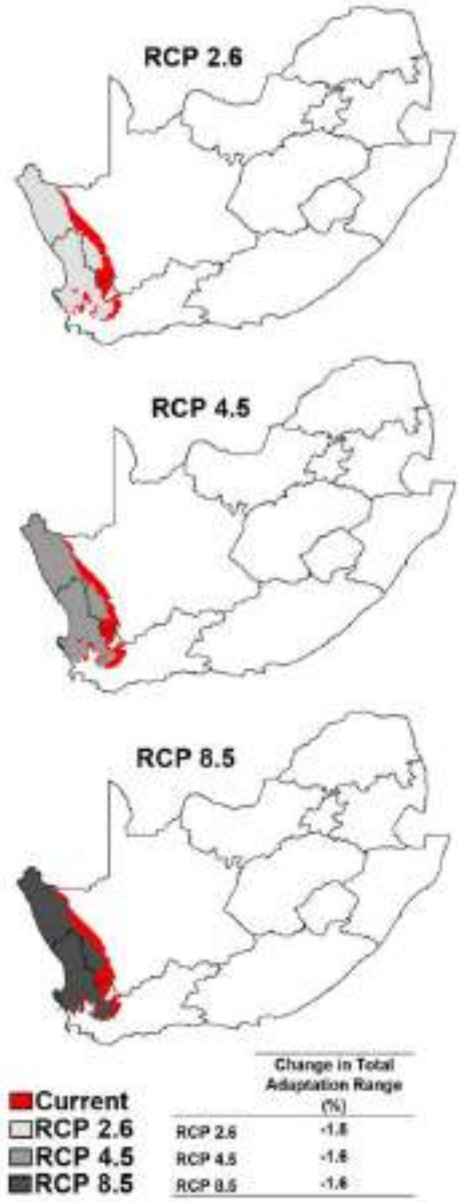
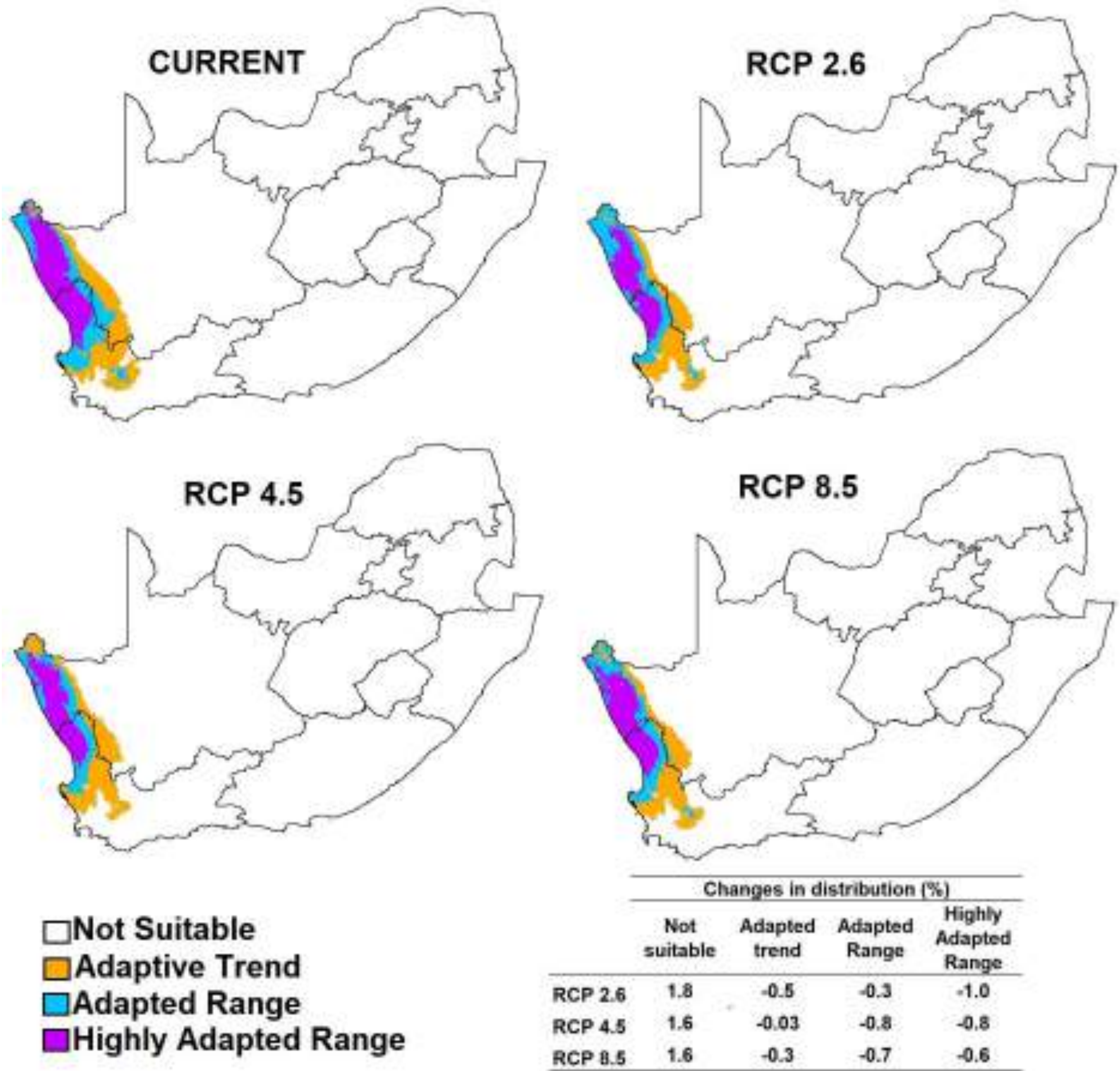


Figure 11. *Calobota sericea* distribution under current and future (RCP 2.6, RCP 4.5 and RCP 8.5) bioclimatic conditions. Areas highlighted in red indicate the portion of the adaptation range lost under future bioclimatic conditions.

The adaptive trend range decreased between 0.03 and 0.5%, the adapted range decreased between 0.3 and 0.8 % and highly adapted range decreased between 0.6 and 1% from current to future bioclimatic conditions (Figure 12). When considering specific adaptation ranges based on the occurrence of the current populations 15 %, 27 % and 58 % of the *C. sericea* populations fell within the adaptive trend, adapted and highly adapted ranges, respectively. From this, it is clear that the adapted and highly adapted ranges in this study are good indications of the potential distribution ranges of *C. sericea*. Under future bioclimatic scenarios, RCP 2.6, RCP 4.5 and RCP 8.5, however, 3%, 5% and 5% of *C. sericea* populations, respectively, will fall in areas that are outside of the adapted range of C. sericea. The portion of *C. sericea* populations in the adaptive trend range increased from 15% under current bioclimatic conditions to 17%, 20% and 22% under the RCP 2.6, RCP 4.5 and RCP 8.5 scenarios, respectively. The *C. sericea* populations in the adapted range increased from 27% under current bioclimatic conditions to 32% in each of the future climate change scenarios. The *C. sericea* populations in the highly adapted range, however, decreased from 58% under current bioclimatic conditions to 48%, 47% and 42% under the RCP 2.6, RCP 4.5 and RCP 8.5 scenarios, respectively.



	Changes in distribution (%)			
	Not suitable	Adapted trend	Adapted Range	Highly Adapted Range
RCP 2.6	1.8	-0.5	-0.3	-1.0
RCP 4.5	1.6	-0.03	-0.8	-0.8
RCP 8.5	1.6	-0.3	-0.7	-0.6

Figure 12. Adaptation ranges of *C. sericea* under current and future bioclimatic conditions, and changes in the potential adaptation ranges from current to future bioclimatic conditions.

3.4 DISCUSSION AND CONCLUSION

In this study, we hypothesised that the adapted range of *C. sericea* would be significantly reduced under future climate change scenarios. We used ecological niche modelling techniques to test this hypothesis. Species distribution models that correlate occurrence records with bioclimatic variables are a trusted method to predict the potential of species to expand their distributions outside of their native ranges or experience a reduction in their distribution ranges under future bioclimatic conditions (Pulliam 2000, Guisan and Thuiller 2005, Hirzel et al. 2006, Barbosa et al. 2012). Climatic niche modelling techniques estimate the climate thresholds within which a species can survive. This allows for the screening of the species' potential adaptation to the predicted future bioclimatic conditions. Identifying potential changes in the species' bioclimatic niche early using these ecological niche models could help with decision-making regarding collection priorities from specific populations in order to effectively conserve a wide range of genetic resources of the species, which, in turn, can help with future breeding initiatives to improve the species' agronomic potential, or reintroductions after local extinctions.

Results from the current study concur with our hypothesis that future bioclimatic conditions will result in the reduction of the adaptation range of *C. sericea*. However, our results indicate that under future bioclimatic conditions, the adaptation range of *C. sericea* is predicted to decrease by less than 2% from its current adaptation range. This modelled reduction in the total adaptation range of *C. sericea* under future bioclimatic conditions, however, predicts that up to 5 % of the mapped populations could be lost. Taking into consideration the narrow-adapted range of *C. sericea*, a reduction of 5 % in its current population numbers could result in a significant loss in genetic variability within the overall *C. sericea* population. The modelled reduction in the total adaptation range of *C. sericea* will primarily be due to a loss in areas that are defined as the adaptive trend zone under current bioclimatic conditions. The adaptive trend zone, within the parameters of this study, is an optimistic representation of the adaptation range of *C. sericea*, with only 15 % of the mapped populations occurring within this distribution zone under current bioclimatic conditions. This optimistic adaptation range, however, is important as it can be regarded as the outermost limit of bioclimatic conditions under which natural populations of the species can survive. These populations, therefore, are perceived to contain morphological, physiological and/or genetic traits not present in other populations. These traits are potentially allowing these populations to currently persist under the outermost limits of the adapted range of *C. sericea*. Collection of seeds from these populations is, therefore, important in order to conserve the genetics of these populations, which, in turn, could help with stabilizing other populations that will also be affected under future bioclimatic conditions.

The models produced in this study also indicate that under future bioclimatic conditions, more of the current *C. Sericea* populations will have to cope with bioclimatic conditions that are less suitable. The models also imply that there will be a shift in the different adaptation ranges, which suggests that populations currently persisting within specific adaptation ranges, i.e. adaptive trend, adapted range and highly adapted range, under the current bioclimatic conditions, would have to adapt to persist in the future, less suitable bioclimatic conditions. For example, under future bioclimatic conditions under RCP 8.5, which represents the scenario that is 'business as usual', with unabated emissions, 12 % of the populations that currently fall within the highly adapted range will under future bioclimatic conditions fall within the adapted range (5 %) and adaptive trend range (7 %). These populations that initially persisted under the modelled most suitable bioclimatic conditions will under future bioclimatic conditions, have to persist under the less desirable conditions, which, in turn, could result in further losses in the current populations. It is therefore suggested that attention should be given to the collection of plant genetic resources within all of the modelled adaptation ranges. The collection of genetic materials from only the best adapted populations within these different adaptation ranges will most likely be the key to develop cultivars from ecotypes adapted to these specific bioclimatic conditions, which, in turn, will be key to the successful exploitation of *C. sericea* as a fodder crop under future bioclimatic conditions. It is therefore suggested that attention should be given to the collection of plant genetic resources within all of the modelled adaptation ranges. The collection of genetic materials from only the best-adapted populations within these different adaptation ranges will most likely be the key to developing cultivars from ecotypes adapted to these specific bioclimatic conditions, which, in turn, will be key to the successful exploitation of *C. sericea* as a fodder crop under future bioclimatic conditions.

In conclusion, this study has shown that *C. sericea* has a restricted bioclimatic niche and that under future bioclimatic conditions, its adaptation range will decrease by less than 2 % of its current distribution range. This range reduction could lead to the loss of approximately 5% of the current *C. sericea* populations, and possibly more as the different adaptation ranges in this study are modelled to shift. These results compel the collection of *C. sericea* seeds from different populations within the different adaptation ranges to conserve as much genetic variability within the species as possible. It is therefore suggested that the ecological niche of *C. sericea* be further quantified using existing agronomic, climatic and edaphic parameters. These, along with the current bioclimatic niche models, will allow for the prioritisation of the collection of seeds from ecotypes currently persisting under unique agro-ecological conditions. These ecotypes, collected from within different adaptation zones within the semi-arid rangelands of South Africa, could, in turn, be used in future breeding initiatives to develop cultivars for specific agro-ecological conditions and to fill agro-ecological niches that may become available due to climate change.

CHAPTER 4: MORPHOLOGICAL TRAITS OF INDIGENOUS GRASSES UNDER DIFFERENT RAINFALL GRADIENTS IN SOUTH AFRICA

4.1 INTRODUCTION

The grass family, i.e. Poaceae (also known as Gramineae), which consists of bamboos and grasses, is considered as one of the most important plant families in the world (Trytsman *et al.*, 2021). Grasses are a valuable group of monocotyledonous plants that dominate most rangelands. Approximately, three-quarters (75%) of the grass species are distributed globally namely Africa, Australia, Eurasia North of the Himalayas, South and Southeast Asia, North America, temperate South America, and tropical America (Gebashe *et al.*, 2019). In South Africa, rangelands (commonly known as veld), cover about of 75% of the country's land surface (Kotze *et al*., 2025). These plant species are crucial as they contribute abundantly to meeting the daily nutritional demands for ruminants (Beyene and Mlambo, 2012), maintaining ecological balance and supporting human livelihoods (Trysman *et al*. 2021), among others. Morphological traits such as leaf characteristics play a vital role in rangeland species resistance and survival by determining the transpiration and photosynthesis rates (Hamdani *et al*., 2019).

Climate change and environmental conditions influence the structural traits such as height, leaf length and width, stem diameter and root length of grasses (Li *et al*., 2013; Magandana *et al*., 2020). Limited water conditions may cause reductions in physiological and morphological grasses functional traits and relative water content and accelerate leaf senescence. In South African rangelands, drought conditions restrict water availability for cell expansion, resulting in suppressed growth, shorter leaves, and thinner stems and reduced root systems. Elevated CO_2 concentrations may partially offset the negative effects of drought by promoting leaf elongation. In contrast, high rainfall supports greater and more consistent soil moisture availability that promotes broader leaves, and increased vegetative growth (Ravhuhali *et al*., 2021). However, the combined effects of climate change, environmental variability, including rising temperature, erratic rainfall patterns, frequent droughts threaten these ecosystems (Rezaei and Gilkes, 2005). In addition to these abiotic factors, several biotic factors such as fire regimes, grazing intensity, interspecific competition among plant species, and bush encroachment (Emery and Gross, 2005; Marion *et al*., 2010; Cingolani *et al*., 2013; Huang *et al*., 2018), may affect the morphology of indigenous grass species. These factors combine with environmental drivers collectively to determine the structure, functionality and forage potential of rangeland ecosystems.

Despite recognition of these challenges, limited research exists on how indigenous grass species differ in their morphological traits across contrasting rainfall regions. This knowledge gap hinders the development of adaptive rangeland management strategies and limits the ability of land users to anticipate shifts in grass species composition under changing climatic and edaphic condition. Therefore, the aim of this study was to explore the impact of rainfall on the morphological characteristics and nutritive value of indigenous grasses across South Africa.

4.2 MATERIALS AND METHODS

4.2.1 Study area

The study was conducted across eight provinces in South Africa, covering diverse ecological regions that differ in rainfall and vegetation structure. Within each province, data was collected from areas representing low, moderate-and high- rainfall regions (Figure 13). This design allowed for the assessment of how rainfall influences morphological traits across different grass species and environmental conditions. Rainfall data for this study was sourced from the South African Weather Services (SAWS) and the Agricultural Research Council Natural Resource and Environment (previously known as Institute for Soil, Climate and Water). The Mean Annual Precipitation (MAP) was used to differentiate between various regions. Areas with low rainfall areas defined as areas that receive rainfall less than or equal to 500 mm per annum in this study were North West, Limpopo, Gauteng and Northern Cape (Department of Water and Sanitation, 2025). High rainfall areas defined as areas that receive rainfall greater than 701 mm per annum in this study were Kwazulu-Natal, Mpumalanga, Eastern Cape and Free State provinces (Department of Water and Sanitation, 2025).

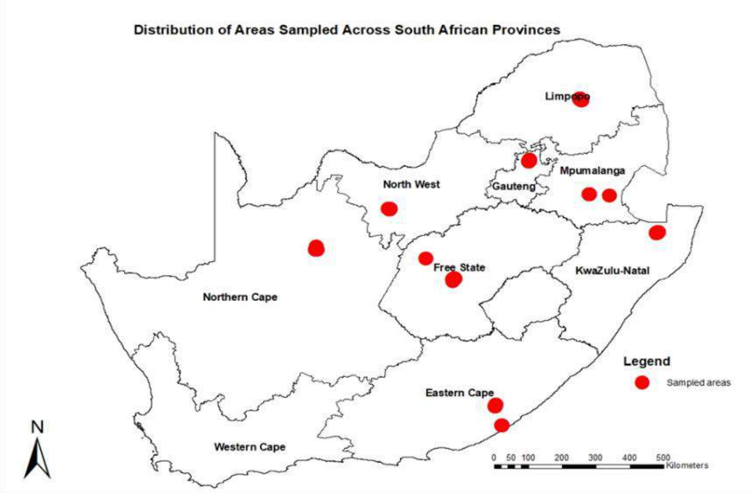


Figure 13: Map indicating the sampled sites (red dots) within each of the provinces in South Africa (represent sites).

4.2.2 Selection of grass species and sampling

The study focused on five indigenous grass species that occur across both low- and high-rainfall gradients. These species were selected based on their ecological status, grazing value, and habitat distribution under varying climatic conditions. The grass species investigated were *Megathyrsus maximus* (Jacq.), *Digitaria eriantha* Steud., *Cenchrus ciliaris* L., *Themeda triandra* Forssk., and *Urochloa trichopus* (Hack.) Dandy.

Sampling was conducted across low and high rainfall gradients during the peak growing season (January to March) in rangelands (natural vegetation) grazed by livestock. Three specimens were collected per area, resulting in twenty-four samples per species per site. Individual grasses were collected using a random sampling approach at each site.

A B C D E

Figure 14. The grass species: (a) *Megathysus maximum* Jacq, (b) *Digitaria eriantha* Steud., (c) *Cenchrus ciliaris* L., (d) *Themeda triandra* Forssk and (e) *Urochloa trichopus* (Hack.) Dandy.

4.2.3 Plant measurements

For each grass species, the following morphological parameters were recorded: plant height, leaf blade length, root depth, and number of tillers. The grass height was measured from the soil surface to the tip of the plant (i.e., the inflorescence) using the measuring tape. The root length was measured using the measuring tape, leaf blade length was measured using a measuring tape and number of tillers were counted.

4.2.4 Statistical Analysis

For each grass species, morphological parameters including plant height, leaf blade length, root depth, and number of tillers were analysed. A two-way analysis of variance (ANOVA) was used to test the effects of rainfall gradient and grass species, as well as their interaction, on each morphological parameter. Prior to analysis, data were tested for normality and homogeneity of variances using the Shapiro–Wilk test and Levene's test, respectively. Where necessary, data were log- or square-root transformed to meet ANOVA assumptions. When significant main effects or interactions were detected ($p \leq 0.05$), mean comparisons were performed using Tukey's honestly significant difference (HSD) post hoc test to separate treatment means.

4.3 RESULTS AND DISCUSSION

Overall, total height significantly differed among grass species ($F_{4.63}=5.885$, $p<.001$), indicating strong differences between species in growth, with species such as *M. maximum* showing greater height and *U. trichopus* remaining shorter. However, area (high and low) had no significant effect of total height ($F_{1,63} = 1.256$, $p = .267$),and species x area interaction were not significant ($F_{4,663} = 0.540$, $p = .707$), indicating that rainfall differences between sites did not substantially affect plant height (Figure 15).

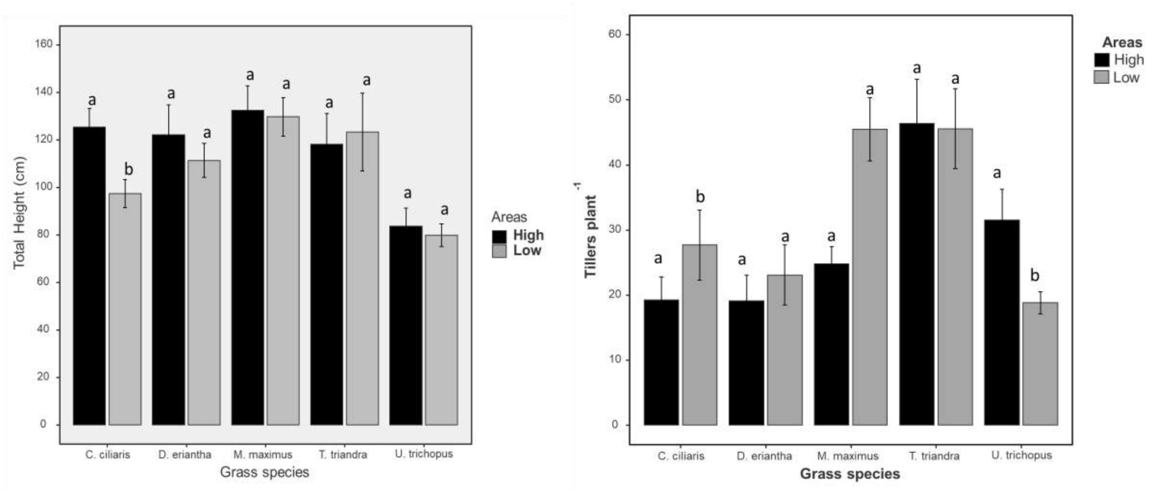


Figure 15. Mean total height and number of tillers of the five grass species between the rainfall areas. High (black bars) and Low (grey bars). The error bars indicate standard error (±). The different letters above bars indicate significant differences at *P<0.05* according to Turkey and Bonferroni post hoc test.

This results aligns with previous studies showing that grass morphology traits like height are often driven more by species-specific functional strategies than moderate variation in rainfall regimes, with rainfall influencing productivity or phenology than height in African rangelands (Sankaran *et al*., 2005; Scott *et al*., 2010; Kirkman *et al*., 2014). For example, Scott et al. (2010) found that grass species height in savanna rangelands were more closely linked to functional group and life history than local rainfall gradients.

The number of tillers per plant differed significantly among grass species ($F_{4,63}$ = 8.99, *p < .001*), reflecting strong species-specific variation in tillering capacity (Figure 15). Although the main effect of area (high vs low) was not significant ($F_{1,63}$ = 1.68, p = .200), the interaction between grass species and area was significant ($F_{4,63}$ = 3.90, *p = .007*), indicating that species responded differently to environmental conditions in each area. *M. maximus* and *T. triandra* maintained similar tiller numbers across both areas, while *C. ciliaris* and *U. trichopus* showed significant differences between High and Low areas, with *C. ciliaris* producing more tillers in the Low area and *U. trichopus* having fewer tillers there. This suggest that factors such as soil moisture or nutrient availability may influence tillering in a species-depended manner. This finding aligns with Volaire (2018) who demonstrated that tillering is a key adaptive strategy enabling grasses to cope with heterogeneous environments and variable rainfall. The significant variation in tiller number among species and its sensitivity to site conditions have important implication for livestock production. Tillering capacity determines a grass species ability to occupy space, compete resources, forage availability and recover from disturbances such as grazing or drought and carrying capacity (du Toit *et al*., 2018). Under climate change scenarios, rangelands are expected to face increased rainfall variability, higher temperatures and more frequent droughts (Letsoalo *et al*., 2023). The findings from this study suggest that tillering capacity of grass species could assist with buffering the negative impacts by allowing grasses to adjust growth strategies in response to changing conditions. Furthermore, species with flexible tillering may sustain forage production despite environmental fluctuations, supporting livestock. However, species less to adjust may decline, altering community and potentially reducing rangeland quality.

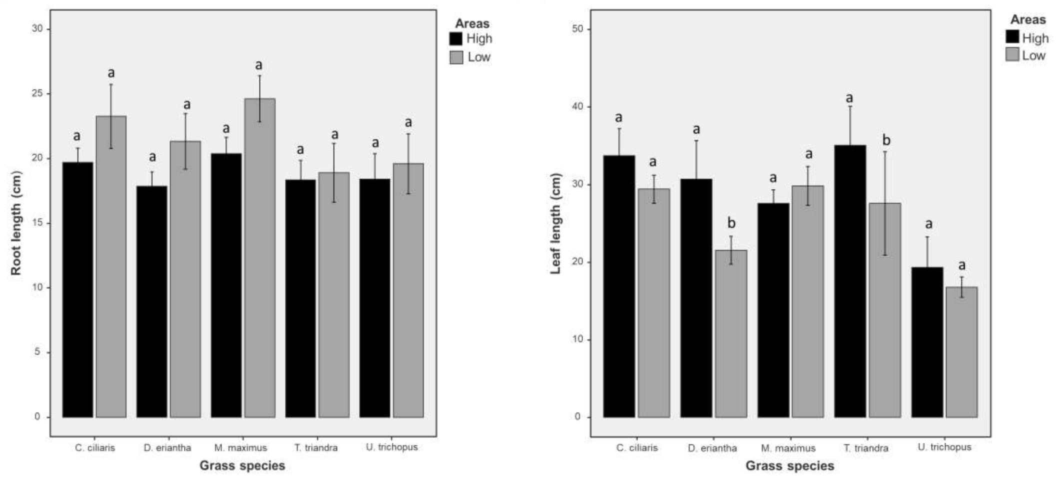


Figure 16 Mean root length and leaf length of the five grass species between the rainfall areas. High (black bars) and Low (grey bars). The error bars indicate standard error (±). The different letters above bars indicate significant differences at *P<0.05* according to Turkey and Bonferroni post hoc test.

Root length differed significantly between areas (High vs Low) ($F_{1,63}$ = 5.007, *p = .029*), with plants in the Low area generally exhibiting longer roots than those in the High area. In contrast, grass species did not differ significantly in root length ($F_{4,63}$ = 1.931*, p = .116*), and the species × area interaction was also non-significant ($F_{4,63}$ = 0.412, *p = .799*), indicating that belowground growth responses were more influenced by site conditions than species identity (Figure 16). The patterns is consistent with previous that show root traits such as length and depth are often strongly shaped by soil moisture availability and nutrient gradients rather than species per season (Comas et al., 2013). Longer roots in drier or resource-limited environment allow grasses to enhance water and nutrient uptake, a critical adaption in a water scarce country like South Africa (Smit and Ruifrok, 2011). The lack of significant species differences suggest belowground strategies among these grasses, which aligns with findings that many savanna grasses share similar root morphologies adapted to fluctuating water availability (Dohn *et al*., 2013). These results are important in environment context in driving root development, with implication for ecosystem resilience and productivity under changing conditions.

Leaf length differed significantly among grass species ($F_{4,63}$ = 4.216, p = .004), indicating notable interspecies variation in leaf morphology (Figure 16). The main effect of area (High vs Low) was not significant ($F_{1,63}$ = 3.256, p = .076), though the near-significant trend suggests that environmental factors such as rainfall or soil moisture may have a limited influence on leaf length. These findings align with research showing that leaf morphological traits in grasses are predominantly species-specific and shaped by evolutionary adaptations, with environmental variation exerting a weaker influence under moderate site differences (Kembel and Cahill, 2011). For example, studies in Southern African grasslands found that leaf size variation correlates more strongly with species functional groups and water-use strategies than with rainfall gradients (Mofutsanyana, 2017). This suggests that while leaf length influences photosynthetic capacity and water balance, it remains a relatively stable trait across different environmental conditions in perennial grasses.

4.4 CONCLUSION

The results show that species traits such as height, tiller number, root length and leaf length primarily influence growth rather moderate environmental differences between sites. This species driven growth stability suggest that grasses possess adaptive traits allowing them to maintain structure and function under variable rainfall conditions common in arid and semi-arid South African rangelands. The study further showed that some grasses might adjust vegetative growth to cope with environmental stress, which is crucial for forage availability. Under climate change, increased rainfall variability and drought frequency may challenge rangelands resilience, but species with flexible traits could sustain rangeland productivity. Effective livestock should therefore prioritize diversity and understanding species-specific traits will be vital to supporting sustainable livestock production in changing climates.

CHAPTER 5: EVALUATING THE POTENTIAL OF TWO STIPAGROSTIS SPECIES FROM THE SEMI-ARID RANGELANDS OF NAMAQUALAND AS FEED FOR LIVESTOCK

5.1 INTRODUCTION

In South Africa, livestock farming is the only option on more than 70 % of the available agricultural land. This is primarily as a result of marginal edaphic and bioclimatic conditions over most part of the country. Emerging farmers in South Africa, especially those who only farm extensively, often experience low livestock productivity due to their over dependence on poor quality and inadequate feed supply from natural pastures. This is especially true during the dry season when reduced rainfall quantities, and reduced availability of mineral nutrients, result in very poor feed sources for the livestock (Müller et al. 2019). One of the ways in which productivity can be increased in these marginal areas is through the use of indigenous forage resources.

South Africa houses a large number of indigenous grasses that are suitable for livestock production. Many of these species occur in areas where agricultural production is severely constrained by marginal bioclimatic and edaphic conditions and therefore, the only agronomic option in these areas are extensive livestock production. However, the use of indigenous grass species that are naturally adapted to water-limited agro-ecological conditions could provide a means to improve the agronomic potential of these marginal areas (Trytsman et al. 2021).

Stipagrostis ciliata and *Stipagrostis obtusa* are two perennial grass species native to the semi-arid and arid rangelands in Namaqualand. These species are well adapted to the environmental constraints such as limited soil moisture, high temperatures and nutrient-poor soils, typical of arid rangelands. Their distribution spans from the nama-karoo to succulent karoo biomes and even into the savanna biome which spans both winter and summer rainfall areas. Within these rangelands, the two species form important components of the natural veld and contribute significantly to livestock production within these rangelands. The two grasses are naturally grazed by livestock, and their importance is elevated further in the dry seasons where they are able to maintain above ground biomass, where other more palatable species do not. Unlike annual grasses, which depend heavily on seasonal rainfall and often disappear during dry periods, these perennial grasses maintain their root systems and can rapidly respond to sporadic rainfall events. This enables them to produce biomass more consistently over time, thereby providing a more reliable forage resource for grazing animals. These grasses therefore play an important role in supporting extensive livestock production systems in dryland environments (Van Oudtshoorn, 2014).

Due to these species occurring in both winter and summer rainfall regions, they provide an opportunity to develop improved indigenous forage resources for water-limited areas in both the winter and summer rainfall regions of South Africa. However, no formal comparison between winter and summer rainfall ecotypes in terms of their forage potential has been done. This information would however provide important clues as to what the major collection priorities for these species should be for further characterisation and evaluation.

The aim of his work was therefore to collect and characterise the nutritional quality of two *Stipagrostis* species (*Stipagrostis ciliata* and *Stipagrostis obtusa*) from the winter and summer rainfall regions of

Namaqualand, prioritised for collection for evaluation as potential alternative forage resources for the semi-arid rangelands in Namaqualand, South Africa.

5.2 MATERIALS AND METHODS

5.2.1 Sample collection and preparation

Ten composite (5–7 plants per sample per species) *Stipagrostis ciliata* and *Stipagrostis obtusa* samples were collected from the winter and summer rainfall areas within the Steinkopf communal rangelands of Namaqualand, in Northern Cape, South Africa. As no domestication and breeding has been done on these species the use of composite samples were done rather than collecting individual plants to minimize the impact of variability between individual plants. After collection, the plant samples were air dried for five days and then oven-dried at 60 °C until a constant mass was achieved. The dried plant materials were milled using a stainless-steel laboratory blender (Waring Products Division, Torrington, USA), after which they were sieved to a size of 0.5 mm to produce a homogenous sample for further processing.

5.2.2 Nitrogen and crude protein determination

To determine the nitrogen (N) content, a 0.2 g sample of the dry milled plant material was digested in 10 ml of a hydrogen peroxide digestion mixture using a Milestone Connect High Performance microwave digestion system (Milestone Inc.). The digestion was carried out at 180–200 °C for 40 minutes according to the manufacturer's instructions. After microwave digestion, the samples were cooled to room temperature and the resulting aqueous solution subsequently filtered and diluted to volume (100 ml) using deionized water (dH_2O). The total N concentration (%) in the digestate was determined by direct titration with 0.01 M HCl after Kjeldahl distillation using a Büchi Nitrogen Distillation unit. The content (%) in the samples obtained was multiplied by a factor of 6.25 to obtain the crude protein (CP) content (%).

5.2.3 Mineral nutrient determination

A 0.5 g sample of the dry, milled grass material was digested in 7 ml concentrated HNO_3 and 3 ml $HClO_4$ at temperatures up to 180 ˚C in a heating block. The digestate was brought to volume (100 ml) using deionized water. After digestion, an aliquot of the digested solution was used for the determination of Ca, Mg, K, and Na, using an ICP–OES (Inductively Coupled Plasma–Optical Emission Spectrometer, Agilent 725 (700 Series), Agilent Technologies, USA). Prior to analyses, the instrument was calibrated against a series of standard solutions, containing all the elements of interest in alignment with the operating procedures of the manufacturer. Fibre content determination and forage quality derived from acid detergent fibre (ADF) were determined using an ANKOM 220 Fibre Analyser using ADF method 5 (Ankom Technology, Fairport, New York, USA). The ADF values obtained were used to calculate the digestible dry matter (DDM), metabolisable energy (ME), total digestible nutrients (TDN), digestible forage energy (DFE), digestible organic matter (DOM), net energy for lactation (NE_L), net energy for maintenance (NE_M) and net energy for gain/ growth (NE_G) using equations 1 to 8:

1. DDM (%) = 88.9 − (ADF × 0.779) (Rasby et al. 2008)
2. ME (Mcal kg−1 DM) = (1.01 × DFE) − 0.45 (Meissner et al. 2000)
3. TDN (%) = 87.84 − (0.7 × ADF) (Schroeder 2009)
4. DFE (Mcal kg^{-1} DM) = 0.04409 × TDN (Meissner et al. 2000)

5. DOM (%) = TDN ÷ 1.05 (Meissner et al. 2000)
6. NE_L (Mcal kg^{-1} DM) = 1.044 − (0.0119 × %ADF) (Rasby et al. 2008)
7. NE_M (Mcal kg^{-1} DM) = [(1.37 × ME) − (0.3042 × ME) + (0.051 × ME)] − 0.508 (Rasby et al. 2008)
8. NE_G (Mcal kg^{-1} DM) = [(1.42 × ME) − (0.3836 × ME) + (0.0593 × ME)] − 0.7484 (Rasby et al. 2008)

5.3 RESULTS AND DISCUSSION

Results from the nutrient determination are shown in Figure 17. Although the concentration of mineral nutrients generally were higher in samples collected from the summer rainfall area, irrespective of species, the quantities obtained is adequate for livestock production (Figure 15).

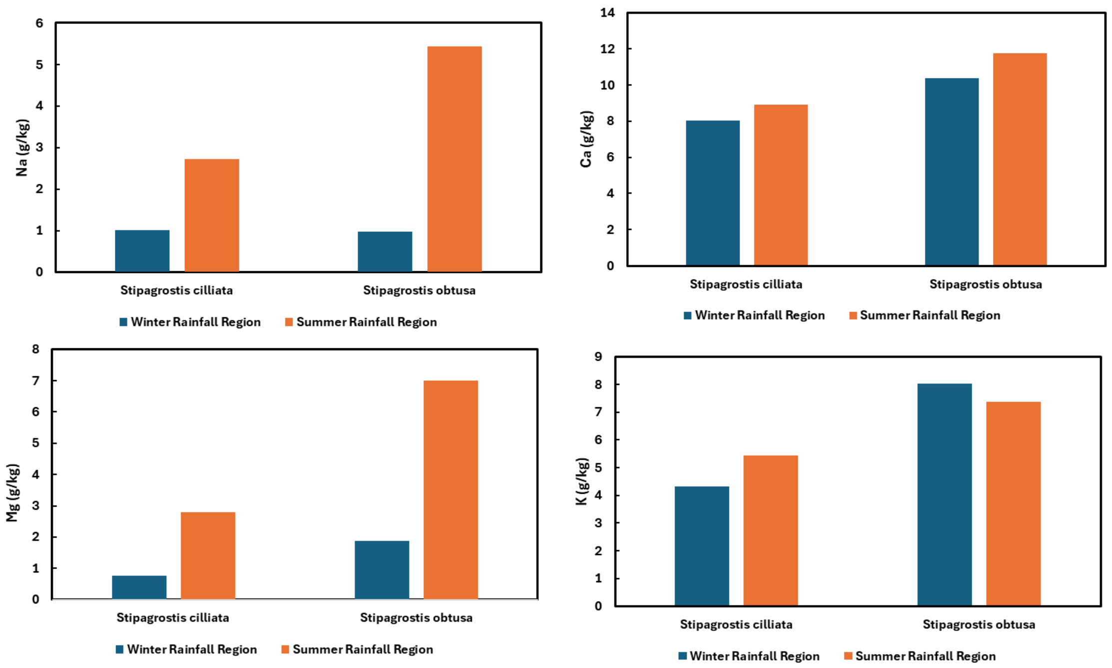


Figure 17: Mineral nutrient content (Na, Ca, Mg and K) of *Stipagrostis ciliata* and *Stipagrostis obtusa* collected from the winter rainfall and summer rainfall regions of Steinkopf in Namaqualand, South Africa.

With regard to the crude protein content (Figure 18) it was also noted that the crude protein content from the grasses collected in the winter rainfall region was less that those collected in the summer rainfall region, irrespective of species. Crude protein content was found to barely meet the minimum requirements of livestock (6 – 7 %) in samples collected from the winter rainfall region, while samples from the summer rainfall region contained crude protein greater than 10%, with S. obtusa from the summer rainfall region containing more than 12% crude protein (Figure 18). Although these amounts are sufficient to maintain livestock condition (Meissner et al. 2000), the concentrations are below the requirements to maintaining highly productive livestock herds which require a crude protein content of 13 – 14 % (Meissner et al. 2000).

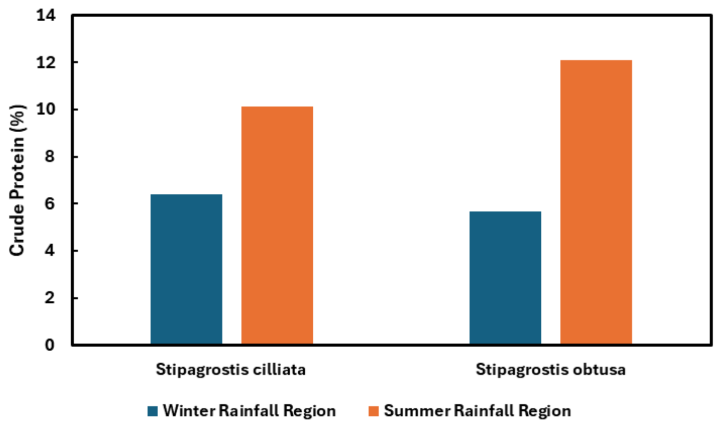


Figure 18: Crude protein content (%) of *Stipagrostis ciliata* and *Stipagrostis obtusa* collected from the winter rainfall and summer rainfall regions of Steinkopf in Namaqualand, South Africa.

Although the crude protein content in the grasses were sufficient to maintain livestock condition, the digestibility of the material collected is relatively low (Figure 17). The ADF (%) content in the grasses ranged from 37% to 56% depending on the location from where the material was collected. Fibre adds bulk to livestock diets and is necessary for proper rumen function (Spencer 2018). The rumen of sheep and goats functions best when the daily diet includes a high concentration of slowly degradable fibres (Spencer 2018). However, high fibre content decreases forage digestibility and intake, which could lead to deficiencies in protein, energy and mineral nutrients (Rinehart 2008; McDonald et al. 2010). The fibre content of S. ciliata collected in the winter rainfall region was 50.6% while in the summer rainfall region, it was 37.7%. For *S. obtusa*, fiber content from material collected in the winter rainfall region was 55.5% and in the summer rainfall region 56.3 % (Figure 19). The high fiber content decreases digestibility and forages with a DDM % of 60 – 69% is regarded as high quality forages from an energy perspective. In tis study, DDM for both species were below 60%, irrespective of the location in which the grasses were collected (Figure 19).

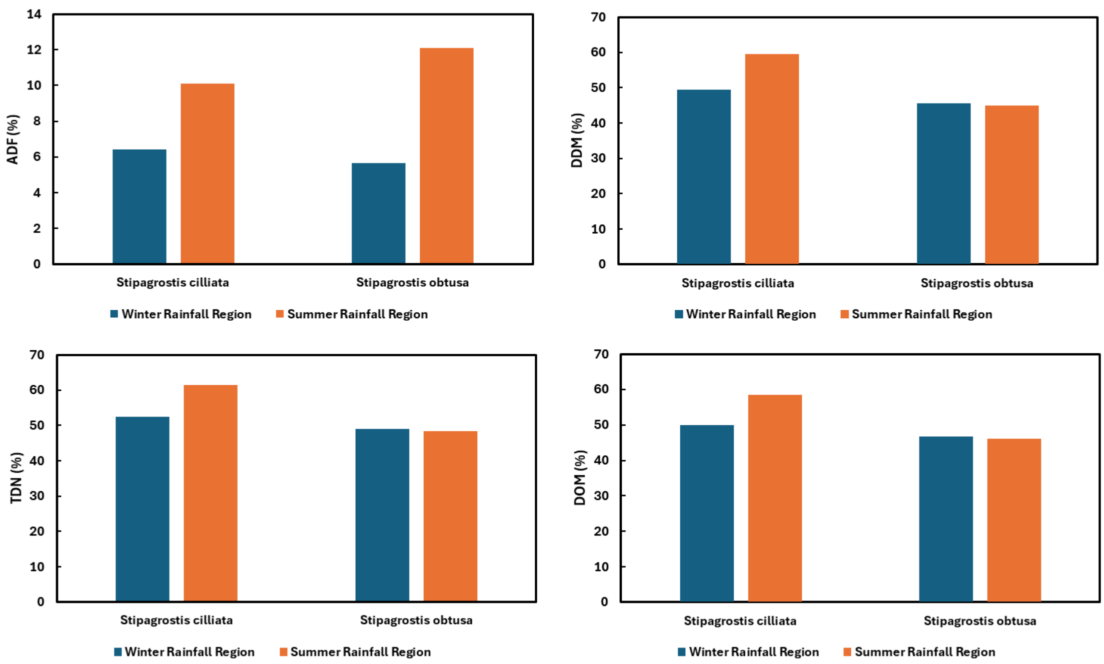


Figure 19: Digestibility of *Stipagrostis ciliata* and *Stipagrostis obtusa* collected from the winter rainfall and summer rainfall regions of Steinkopf in Namaqualand, South Africa.

The energy content of the grasses are shown in Figure 20. Generally, there were larger differences in the energy content of *S. ciliata* between the winter rainfall and summer rainfall collections, compared to that of *S. obtusa*, with summer rainfall specimens containing higher energy content. The ME content of the *S. ciliaris* ranged from 1.66 Mcal kg^{-1} DM to 2.29 Mcal kg^{-1} DM (1 Mcal = 4.184 MJ) while *S. obtusa* contained a ME content of 1.7 Mcal kg^{-1} DM for both winter and summer rainfall collections. Therefore, irrespective of the location from where the grasses were collected, ME content that is sufficient to meet the energy requirements of lambs up to 20 kg (3.9–10.5 MJ kg^{-1} DM). Only S. ciliata contained sufficient ME to maintain dry ewes of 40–60 kg, which has a requirement of 7.6–10.2 MJ kg^{-1} DM) (Meissner et al. 2000). The energy content of both grass species however, irrespective of the location that they were collected from, was found to be insufficient to sustain pregnant (14.5–17.7 MJ kg^{-1} DM) and lactating (15.5–19.4 MJ kg^{-1} DM) ewes (Meissner et al. 2000).

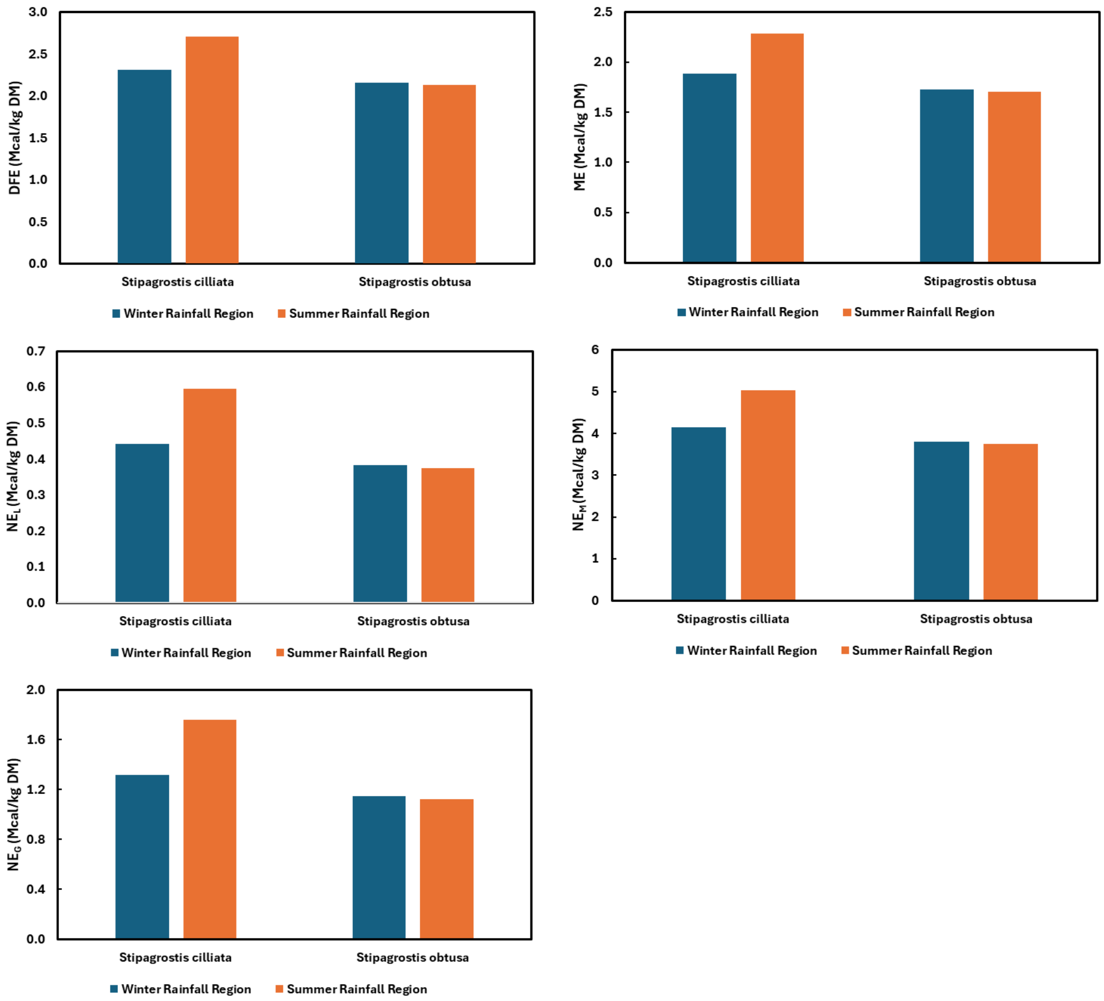


Figure 20: Energy content of *Stipagrostis ciliata* and *Stipagrostis obtusa* collected from the winter rainfall and summer rainfall regions of Steinkopf in Namaqualand, South Africa.

5.4 CONCLUSION

This study aimed to assess the nutritional quality of two grass species, *Stipagrostis ciliata* and *Stipagrostis obtusa*, from the semi-arid rangelands of Namaqualand as potential forage resources for livestock. The grasses were collected in the wet season from the summer rainfall and winter rainfall regions of Namaqualand. The samples were analyzed for their mineral nutrient, crude protein and fiber content after which the digestibility and energy content were calculated. Mineral nutrient content in the grasses was found to generally be adequate to meet the dietary requirements of the livestock in both the winter and summer rainfall areas. However, the samples collected from the summer rainfall areas generally had higher concentrations of certain mineral nutrients. With regard to crude protein content, the grasses collected from the winter rainfall region contained lower crude protein compared to those collected from the summer rainfall region. Furthermore, the material collected from the winter rainfall region barely contained sufficient crude protein content to meet the minimum requirements of 6% for livestock while the samples from the summer rainfall region contained well over the minimum requirement levels, but this was still not sufficient to maintain highly productive livestock herds. Generally, digestibility in the samples from both winter and summer rainfall regions was low due to the high fiber content in both species. The energy content of the two grasses was also generally low and were only sufficient to meet the energy requirements for lambs up to 20 kg and cannot be used as is for highly productive herds or pregnant and lactating ewes.

The differences observed between the winter and summer rainfall collections can be explained by the fact that grasses generally have their active growing period in summer and therefore the material collected in the summer rainfall region was generally in their active growing period at the time of collection. A better comparison could be when seeds are collected and grown under the same conditions to do a direct comparison of plant genetic resources from the winter rainfall region to those of the summer rainfall region. Therefore, these results for the two locations cannot be directly compared to each other.

Furthermore, the results from this work should be considered in the sense that the plant material collected was from indigenous populations and had not undergone any form of domestication. Current commercial forages have undergone years of domestication and breeding to target specific beneficial traits. With these two *Stipagrostis* species, the results presented in this work show that even though these species have not undergone any improvement, they already contain nutritional traits that is beneficial to livestock, traits that could be improved in crop improvement programs or improved cultivation practices. Therefore, in conclusion, results from this study show that the two grass species do have the potential to be used as feed for livestock as is. However, the quality of these species could potentially be improved through improved cultivation practices and improvement of the plant genetic resources through domestication and breeding. Therefore, further research with regard to growing the plants under fertilized conditions and potentially with supplementary irrigation is required to determine the full potential of the two grass species.

CHAPTER 6: COLLECTION, CHARACTERISATION AND EVALUATION OF INDIGENOUS GRASS AND LEGUME GENETIC RESOURCES AND LOCALLY ADAPTED ECOTYPES OF DOMESTICATED FORAGES

6.1 INTRODUCTION

Livestock production in South Africa relies heavily on natural rangelands and planted pastures as the primary source of feed for grazing animals. However, a large proportion of the country occurs within semi-arid and arid climatic zones characterized by low, erratic, and highly variable rainfall patterns. These environmental conditions, combined with increasing climate variability and the growing frequency of drought events, present significant challenges to sustainable livestock production systems (Hoffman and Vogel 2008, Snyman 2010). As a result, there is increasing interest in identifying alternative forage resources that can maintain productivity under water-limited conditions. One potential strategy involves the collection, conservation, and evaluation of indigenous South African grass and legume species as drought-tolerant forage resources adapted to local environmental conditions.

South Africa possesses a rich diversity of indigenous grasses and legumes that have evolved under local climatic and edaphic conditions. Many of these species have developed adaptive traits that enable them to survive in environments characterized by limited rainfall, high temperatures, and nutrient-poor soils (O'Connor and Bredenkamp 1997). Such adaptations often include extensive or deep root systems that allow plants to access water from deeper soil layers, efficient water-use mechanisms, and physiological tolerance to drought stress. These characteristics make indigenous species particularly suitable for use in dryland forage systems and rangeland rehabilitation programs. Furthermore, native species are typically well adapted to local ecological conditions, allowing them to persist under relatively low management inputs compared to introduced forage crops (Tainton 1999).

Despite the ecological and agronomic advantages of indigenous forage species, many remain underutilized in formal pasture production systems. Historically, pasture improvement programs in South Africa have relied heavily on introduced temperate species such as ryegrass and lucerne, which perform well under favourable environmental conditions but often struggle under drought stress or in marginal soils (Tainton 1999). As climate change continues to influence rainfall patterns and increase the frequency of drought events in southern Africa, there is growing recognition that locally adapted species may provide more resilient alternatives for forage production.

The collection and conservation of indigenous forage germplasm therefore represent important steps in identifying and preserving plant genetic resources that may be useful for future pasture development. Germplasm collections allow researchers to maintain genetic diversity and provide plant material for screening and evaluation programs. Through systematic evaluation, promising species or ecotypes can be identified based on desirable traits such as drought tolerance, biomass production, persistence under grazing, seed production, and forage nutritive value.

Therefore, the collection and evaluation of indigenous South African grass and legume species represent a critical strategy for improving the resilience of forage systems in drought-prone environments. Indigenous species possess unique adaptive traits that allow them to survive and remain productive under water-limited conditions, making them valuable candidates for sustainable pasture development. Continued research into the agronomic performance, nutritional value, and ecological functions of these species will be essential for identifying suitable forage resources capable of supporting livestock production in the face of increasing climatic variability.

The aim of this was therefore to collected prioritised grass and legume species for inclusion into the National Forage Genebank and then characterise and evaluate the potential of these species under water-limited growing conditions

6.2 MATERIALS AND METHODS

6.2.1 Seed collection

Using the maps created in chapter 2 as guides for collection of distinct populations, the collection of winter rainfall, all-year rainfall and summer rainfall species were done. A collection sheet (indicated below) developed by the National Forage Genebank was used to capture supporting information for each of the collections. Information collected along with the seeds include the geographic location of the population from which the collections were made, the source of the collection i.e., whether collections were done from wild populations or nurseries, environmental information such as the aspect of the collection site, edaphic conditions and also the number of plants sampled.

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Animal Production: Range and Forage Sciences
South African National Forage Genebank

SA-NFG Plant Genetic Resources – Passport/Voucher information

1. SCIENTIFIC NAME
1.1. Genus
1.2 Species
1.3 Variety (sub-species)
1.4. Sample number

2. COLLECTION DATA
2.1. Collectors name and surname
2.2. Collectors contact details (email)
2.2. Collecting Institute
2.3. Date of Collection (DD/MM/YYYY)
2.4. Country of Collection
2.5. Province
2.6. Location of Collection site
2.7. GPS (Lat/Long)
2.8. Collection source: Wild / Cultivated / Breeders line / Ecotype/cultivar / Unknown

3. COLLECTION ENVIRONMENT
3.1. Altitude of Collection Site (m)
3.2. Rainfall (mm)
3.3. Rainfall Season
3.4. Aspect: Flat / North / East / South / West
3.5. Slope
3.6. Water Relations: Well-drained / Wet / Wetland / Imperfectly
3.7. Grazing Pressure: Nil / Light / Moderate / Heavy
3.8 Botanical details of site (abundance): Rare (1 plant) / Few (1 - 5 plants) / Many (> 5 plants)
3.9. Number of plants sampled
3.10. Size of area sampled (m²)
3.11. Type of sample: Vegetative / Seed
3.12. Rhizobium nodule sample: Collected / Not collected
3.13. Soil Sample collected: Collected / Not collected

4. ADDITIONAL INFORMATION:

Apart from the seeds that were collected, seeds of commercial forage genetic resources were also procured from local seed companies and indigenous nurseries.

6.2.2 Seed characterisation

6.2.2.1. Initial seed germination and viability testing

All seeds collected were tested for their germination potential and viability. The germination trials were conducted according to ISTA accredited rules for species where rules were available while for species where no published methods were available, ISTA methods for similar species were used. Seeds that did not germinate in these trials were then subjected to a tetrazolium chloride test to determine the viability of the remaining seeds. Seeds that germinated and that were viable at the end of the trial were regarded as viable seeds and non-viable seeds were regarded as dead.

6.2.2.2. Germination requirements for commercial vs. indigenous ecotypes

After the initial germination and viability tests were performed, a separate test was done using commercial varieties and local ecotypes of the commercial forage species to determine whether the methodologies used for determining the germination potential of the seeds are working for indigenous ecotypes. To do this three replicates of 100 seeds of commercial cultivars of *Cenchrus ciliaris, Digitaria eriantha, Panicum maximum* and *Panicum coloratum* as well as indigenous ecotypes of these species were germinated in plant growth chambers according to published methodologies. Once the germination period for each of the species were completed, all remaining seeds were tested for their viability using a tetrazolium chloride test. Results were expressed as germinated seeds which was defined as seeds with a radicle of 5mm and viable seeds were expressed as seeds that were viable in the tetrazolium chloride test plus the seeds that germinated.

6.2.2.3. Morphological characterisation of commercial vs local forage ecotypes grown under different temperature and osmotic conditions

An initial trial was conducted where all local ecotypes and commercial cultivars were initially screened for their ability to tolerate water-limitation. From this we selected the best performing local ecotype and commercial cultivar for further evaluation. After the initial screening, 3 species (*E. curvula, C. ciliaris, D. eriantha*) were selected and screened under different temperatures under well-watered and water-limited conditions. The seeds were planted in small pots in a commercial potting soil and allowed to grow for one month after which they were placed in plant growth chambers set to constant temperatures of 20˚C, 25˚C and 30˚C. The pots were watered to capacity every two days using two osmotic treatments, distilled water (non-stressed) and a -0.5 MPa solution which was prepared using PEG6000. The plants were allowed to grow for two weeks in the chambers after which morphological and physiological measurements (shoot height, root length, shoot and root dry mass, and electrolyte leakage from the leaves) were done.

6.2.2.4. Quantifying the germination responses of eight winter rainfall species to temperature and osmotic stress

For this study four replicates of 100 seeds of each temperature and osmotic treatment combination within a species were placed in 9 cm petri-dishes on a layer of filter paper. Germination chambers were calibrated to constant temperatures of 5 ˚C to 30 ˚C at increments of 5 ˚C, under continuous dark conditions. Within each temperature treatment, five osmotic treatments (0 MPa, -0.1 MPa, -0.3 MPa, -0.5 MPa and - 0.7 MPa) were imposed on the seeds. The osmotic treatments were prepared using polyethylene glycol 6000 (PEG6000) in accordance with the methods established by Michael and Kaufmann (1973). The osmotic solutions were stored in the germination chambers at each of the associated temperature treatments. A total of 5 ml of each osmotic solution was added to the petri-dishes and distilled water was used as the 0 MPa or control treatment. After watering, the petri-dishes were sealed using parafilm to prevent excessive water loss. The filter paper and osmotic solutions were replaced every week in order to keep osmotic conditions within the petri-dishes relatively constant.. Seed germination was recorded daily for 15 days, and germinated seeds were removed from the petri-dishes as required.

6.2.2.5. Quantifying seedling establishment, growth, and development of eight winter rainfall species under different levels of drought stress (water-limitation).

A complete randomized block greenhouse trail was conducted in which four replicates of pre-germinated seeds (radicle of ± 0.3 cm) of each species were planted at a depth of 1 cm in pots filled soil. Before planting, the pots were irrigated, and excess water was allowed to drain from the pots for 12 hours to reach pot water capacity. The germinated seeds were planted 1, 2, 3 and 4 days after watering. At each day of planting the corresponding gravitational soil moisture content ($g.g^{-1}$) was determined by removing approximately 15 g of soil (from the first 5 cm soil layer) and weighed to determine wet mass (Mwet). Thereafter, the soil samples were oven dried until a constant mass was achieved and dry mass (Mdry) determined. Gravimetric water content (θg) was determined following equation 1. The gravimetric soil water content was thereafter expressed as a percentage of the pot capacity.

Equation 1: θ_g ($g.g^{-1}$) = ($M_{wet} - M_{dry}$) ÷ M_{dry}

Seedling emergence was counted daily and the maximum seedling emergence per pot was calculated. The corresponding soil water content for each day was determined from unplanted pots in the greenhouse and expressed as a percentage of the pot capacity. At the end of the trial the remaining seedlings were quantified and the percentage mortality calculated from the maximum seedling emergence per pot.

6.2.2.6. Seedling characteristics of eight winter rainfall region species subjected to different durations of drought stress.

We imposed drought on 3 month old seedlings of eight species where we stopped watering for 15 days (final day soil moisture content 35 % of capacity) and 30 days (final day soil moisture content 5 % of capacity) to see how plants will respond to the water-limited conditions. To do this, a complete randomized block greenhouse pot study was conducted at the ARC Roodeplaat farm under greenhouse conditions. The experiment consisted of two treatments, the amount of water (well-watered or water-limited) and the time of harvest (15 or 30 days after water-limitation). Five pre-germinated seeds were transplanted into 17.5 cm wide and 15 cm deep pots filled with a sandy loam soil. After seedling emergence, the pots were thinned to one plant per pot. The pots were watered to capacity (until water started draining from pots) ones a week until 3 months after establishment, after which watering was withheld for water-limited plants. At each harvesting time, the complete seedling was removed from the pot, taking care not to damage the roots. Roots were carefully washed and then blotted dry on paper towel from where shoot and root length measurements were done using a digital calliper. After length measurements, the seedlings were separated into roots and shoots and fresh mass determined. From each pot the gravimetric water content (θ_g) was determined following equation 1, above.

6.3 RESULTS AND DISCUSSION

6.3.1 Seed collection

To date more than 120 species has been collected with several ecotypes within each species. Table 14 lists the species that has been collected. Apart from the collection of indigenous ecotypes, a large number of commercial grass and legume species were also obtained from various seed companies. Table 15 provides a list of species which were obtained from local seed companies. These seeds will be used for comparisons when characterising the indigenous ecotypes of grasses and legumes.

Table 14: Indigenous grass and legume collections to date

1	*Acacia (Vachellia)*	41	*Enneapogon cenchroides*	81	*Panicum natalanse*
2	*Alloteropsis*	42	*Enneapogon scoparius*	82	*Panicum repens*
3	*Anthephora*	43	*Eragrostis capensis*	83	*Paspalum dilatatum*
4	*Aristida bipartita*	44	*Eragrostis cilianensis*	84	*Paspalum notatum*
5	*Aristida canescens*	45	*Eragrostis curvula*	85	*Paspalum urviller*
6	*Aristida congesta*	46	*Eragrostis echinochloidea*	86	*Pentameris colorata*
7	*Aristida congesta.*	47	*Eragrostis gummiflua*	87	*Pogonarthria squarrosa*
8	*Aristida junciformis*	48	*Eragrostis inamoena*	88	*Pseudopentameris macrantha*
9	*Aristida*	49	*Eragrostis nindensis*	89	*Psoralea arborea*
10	*Bauhinia galpinii*	50	*Eragrostis obtusa*	90	*Rendlia altera*
11	*Bothrichloa*	51	*Eragrostis plana*	91	*Schizachyrium sanguineum*
12	*Bracharia brizantha*	52	*Eragrostis racemosa*	92	*Schmidtia kalihariensis*
13	*Brachiaria*	53	*Eragrostis rigidior*	93	*Schmidtia pappophoroides*
14	*Brachiaria serrata*	54	*Eragrostis spp*	94	*Setaria incressata*
15	*Bromus cathaticus*	55	*Eragrostis superba*	95	*Setaria megaphylla*
16	*Calobota sericea*	56	*Eragrostis tef*	96	*Setaria megaphylla (Small form from*
17	*Calobota sericea*	57	*Eragrostis trichophora*	97	*Setaria pumila*
18	*Cenchrus ciliaris*	58	*Eregrotis racemosa*	98	*Setaria sphacelata*
19	*Chaetobromus*	59	*Eustachys paspaloides*	99	*Setaria sphacelata var. sphacelata*
20	*Chamaechrista sp*	60	*Fingerhuthia africana*	100	*Setaria spp*
21	*Chloris gayana*	61	*Harpochloa falx*	101	*Sorghum bicolor*
22	*Chloris virgata*	62	*Heterepogon contortus*	102	*Sporobolus africanus*
23	*Chrysopogon*	63	*Hyparhenia hirta*	103	*Sporobolus consimilis*
24	*Crotalaria natalitia*	64	*Imperata cylindrica*	104	*Sporobolus fimbriatus*
25	*Cymbopogon*	65	*Indigofera tinctoria*	105	*Sporobolus pyramidilis*
26	*Cymbopogon*	66	*Ischaemum fasciculatum*	106	*Stiapagrostis ciliaris*
27	*Cymbopogon*	67	*Lessertia annularis*	107	*Stipagrostis ciliata*
28	*Cymbopogon*	68	*Lessertia diffusa*	108	*Stipagrostis hirtigluma*
29	*Cymbopogon sp.*	69	*Lessertia frutescens subsp. frutescens*	109	*Stipagrostis obtusa*
30	*Cynodon dactylon*	70	*Lessertia frutescens subsp. frutescens*	110	*Tephrosia rhodesica var. rhodesica*
31	*Cynodon*	71	*Loudetia simplex*	111	*Themeda triandra*
32	*Digitaria*	72	*Medicago sativa*	112	*Trachypogon spicatus*
33	*Digitaria eriantha*	73	*Melica decumbens*	113	*Tragus berteronianus*
34	*Digiteria*	74	*Melinis nerviglumis*	114	*Tragus racemosus*
35	*Diheterepogon*	75	*Melinis repens*	115	*Tricholaena monachne*
36	*Diheteropogon*	76	*Miscanthus capensis*	116	*Trichoneura grandiglumis*
37	*Ehrharta calycina*	77	*Osteospermum sinuatum*	117	*Triraphis andropogonoides*
38	*Ehrharta thunbergii*	78	*Panicum coloratum*	118	*Tristachya leucothrix*
39	*Eleusine coracana*	79	*Panicum ecklonii*	119	*Urelytrum agropyroides*
40	*Elionurus muticus*	80	*Panicum maximum*	120	*Urochloa mosambicensis*
				121	*Vigna vexillata var vexillata*

Table 15: Seeds obtained from local seed companies.

	Distributor	Species	Common name	Cultivar
1	Barenbrug	*Lolium perenne*	Perennial Ryegrass	Govenor
2	Barenbrug	*Lolium perenne*	Perennial Ryegrass	Tyson
3	Barenbrug	*Lolium perenne*	Perennial Ryegrass	Viscount
4	Barenbrug	*Festuca arundinaceae*	Soft Leaf Tall Fescue	Paolo
5	Barenbrug	*Festuca arundinaceae*	Soft Leaf Tall Fescue	Baroptima
6	Barenbrug	*Festuca arundinaceae*	Soft Leaf Tall Fescue	Royal Q-100
7	Barenbrug	*Dactylis glomerata*	Cocksfoor Grass	Adremo
8	Barenbrug	*Bromus catharticus*	Prairie Grass	Bareno
9	Barenbrug	*Lolium hybridium*	Diploid Hybrid Ryegrass	Barhill
10	Barenbrug	*Lolium x boucheanum*	Hybrid Ryegrass	Shogun
11	Barenbrug	*Lolium hybridium*	Hybrid Ryegrass	Barsenna
12	Barenbrug	*Lolium multiflorum*	Italian Ryegrass	Tabu +
13	Barenbrug	*Lolium multiflorum*	Italian Ryegrass	Barmultra II
14	Barenbrug	*Lolium multiflorum*	Westerwold ryegrass	Bartimum
15	Barenbrug	*Lolium multiflorum*	Westerwold ryegrass	Ribeye
16	Barenbrug	*Lolium multiflorum*	Westerwold ryegrass	Maximus
17	Barenbrug	*Brachiaria sp.*	Brachiaria Hybrid	Sabia
18	Barenbrug	*Brachiaria sp.*	Brachiaria Hybrid	Cayana
19	Barenbrug	*Brachiaria brizantha*		Marandu

20	Barenbrug	*Panicum maximum*	Buffalo Grass	Mombaca
21	Barenbrug	*megathyrsus maximum*		Agrosavia Sabanera
22	Barenbrug	*Chloris gayana*	Rhodes Grass	Endura
23	Barenbrug	*Chloris gayana*	Rhodes Grass	Tolgar
24	Barenbrug	*Chloris gayana*	Rhodes Grass	Katambora
25	Barenbrug	*Digitaria eriantha*	Smutsfinger Grass	Tiptop
26	Barenbrug	*Digitaria eriantha*	Smutsfinger Grass	Irene
27	Barenbrug	*Cenchrus ciliaris*	Blue Buffalo Grass	Molopo
28	Barenbrug	*Cenchrus ciliaris*	Blue Buffalo Grass	Gayanda
29	Barenbrug	*Antephora pubescens*	Bottle Brush Grass	Wollie
30	Barenbrug	*Eragrostis curvula*	Weeping Lovegrass	Ermelo
31	Barenbrug	*Urochloa mosambicensis*	Sabi Grass	Sabi
32	Barenbrug	*Panicum maximum*	Buffalo Grass	Gatton
33	Barenbrug	*Pennisetum clandestinum*	Kikuyu Grass	Kikuyu
34	Barenbrug	*Cynodon dactylon*	Bermuda Grass	Bermuda
35	Barenbrug	*Panicum coloratum*	Small Buffalo Grass	Klein Verdi
36	Barenbrug	*Paspalum notatum*	Bahia Grass	Bahia
37	Barenbrug	*Sorghum vulgare*	Sweet Sorghum	Barsweet
38	Barenbrug	*Sorghum spp.*	Forage Sorghum	Sweet Choice
39	Barenbrug	*Sorghum spp.*	Forage Sorghum	Bargrazer
40	Barenbrug	*Hybrid Pennisetum*	Hybrid Forage Millet	Nutrifast
41	Barenbrug	*Hybrid Pennisetum*	Hybrid Millet	Pearler
42	Barenbrug	*Pennisetum glaucum*	Pearl Millet	Babala
43	Barenbrug	*Eragrostis Teff*	Teff	Tiffany
44	Barenbrug	*Eragrostis Teff*	Teff	SA Brown
45	Barenbrug	*Medicago spp.*	Medics	Jester
46	Barenbrug	*Medicago spp.*	Medics	Santiago
47	Barenbrug	*Medicago spp.*	Medics	Scimitar
48	Barenbrug	*Medicago spp.*	Medics	Parragio
49	Barenbrug	*Ornithopus sativis*	Pink Serradella	Emena
50	Barenbrug	*Trifolium vesiculsum*	Arrowleaf Clover	Zulu II
51	Barenbrug	*Trifolium michelianum*	Balansa Clover	Paradana
52	Barenbrug	*Trifolium incarnatum*	Crimson Clover	Kardinal
53	Barenbrug	*Trifolium incarnatum*	Crimson Clover	Blaza
54	Barenbrug	*Trifolium resupinatum*	Persian Clover	Lighting
55	Barenbrug	*Trifolium resupinatum*	Persian Clover	Shaftal
56	Barenbrug	*Trifolium subterraneun*	Subterranean Clover	Dalkeith
57	Barenbrug	*Trifolium subterraneun*	Subterranean Clover	Woogenellup
58	Barenbrug	*Trifolium repens*	White Clover	Storm
59	Barenbrug	*Trifolium repens*	White Clover	Haifa
60	Barenbrug	*Trifolium pratense*	Red Clover	Barduro
61	Barenbrug	*Trifolium pratense*	Red Clover	Kenland
62	Barenbrug	*Trifolium fragiferum*	Strawberry Clover	Palestine
63	Barenbrug	*Vicia sativa*	Common Vetch	Morava
64	Barenbrug	*Vicia villosa*	Grazing Vetch	Haymaker
65	Barenbrug	*Vicia americana*	Purple Vetch	Popany
66	Barenbrug	*Medicago sativa*	Lucerne	BarALFA10
67	Barenbrug	*Medicago sativa*	Lucerne	BAR ST
68	Barenbrug	*Medicago sativa*	Lucerne	BAR 7
69	Barenbrug	*Medicago sativa*	Lucerne	SA Standaard
70	Barenbrug	*Sericea lespedeza*	Lespedeza	Au Lotan
71	Barenbrug	*Lupinus angustifolius*	Lupines	Narrow Leaf Lupines
72	Barenbrug	*Vicia faba*	Faba Bean	Stella
73	Barenbrug	*Vigna unguiculata*	Cowpeas	Dr. Saundees
74	Barenbrug	*Vigna unguiculata*	Cowpeas	Bets Wit
75	Barenbrug	*Vigna unguiculata*	Cowpeas	Glends
76	Barenbrug	*Crotalaria juncea L.*	Sunn Hemp	Red
77	Barenbrug	*Crotalaria juncea L.*	Sunn Hemp	Black
78	Barenbrug	*Pisum sativum*	Forage Pea	RIF
79	Barenbrug	*Pisum sativum*	Forage Pea	Arvika
80	Barenbrug	*Pisum sativum*	Grain Peas	Gambit

81	Barenbrug	*Lablab purpureus*	Dolichos	Rongai
82	Barenbrug	*Lablab purpureus*	Dolichos	Highworth
83	Barenbrug	*Macroptilium bracteatum*	Burgundy Bean	B1
84	Barenbrug	*Onobrychis viciifolia Scop*	Sainfoin	Common
85	Barenbrug	*Melilotus alba*	Sweet Clover	Common
86	Barenbrug	*Lotus corniculatis*	Birdsfoot Trefoil	Soa Gabriel
87	Agricol	*Paspalum notatum*	Bahia Grass	Pensacola
88	Agricol	*Antephora pubescens*	Bottle Brush Grass	Common
89	Agricol	*Antephora pubescens*	Bottle Brush Grass	SSW21A
90	Agricol	*Sorghum spp.*	Forage Sorghum	Hunnigreen
91	Agricol	*Sorghum spp.*	Forage Sorghum	Honeymax
92	Agricol	*Sorghum spp.*	Forage Sorghum	Supasweet
93	Agricol	*Sorghum spp.*	Forage Sorghum	AgFlashNIAGARA III
94	Agricol	*Echinochloa esculenta*	Japanese Millet	Normal
95	Agricol	*Pennisetum glaucum*	Babala	Common
96	Agricol	*Pennisetum glaucum*	Babala	Okashana
97	Agricol	*Pennisetum glaucum*	Babala	Agrigreen (hybrid)
98	Agricol	*Sorghum spp.*	Perennial Sorghum	Silk
99	Agricol	*Sorghum spp.*	Perennial Sorghum	Jaffa
100	Agricol	*Chloris gayana*	Rhodesgrass	Katambora
101	Agricol	*Chloris gayana*	Rhodesgrass	Boma
102	Agricol	*Digitaria eriantha*	Smutsfinger	Irene
103	Agricol	*Digitaria eriantha*	Smutsfinger	SSW11D
104	Agricol	*Eragrostis tef*	Teff	SA Brown
105	Agricol	*Eragrostis curvula*	Weeping Lovegrass	Ermelo
106	Agricol	*Eragrostis curvula*	Weeping Lovegrass	Agpal
107	Agricol	*Panicum maximum*	Buffalo Grass	Gatton
108	Agricol	*Panicum maximum*	Buffalo Grass	PUK P8
109	Agricol	*Dactylis glomerata*	Cocksfoot	Aldebaren
110	Agricol	*Dactylis glomerata*	Cocksfoot	Pizza
111	Agricol	*Lolium multiflorum*	Italian Ryegrass	Asset
112	Agricol	*Lolium multiflorum*	Italian Ryegrass	Fox
113	Agricol	*Lolium multiflorum*	Italian Ryegrass	Agriboost
114	Agricol	*Lolium multiflorum*	Italian Ryegrass	Max
115	Agricol	*Lolium multiflorum*	Italian Ryegrass	Firkin
116	Agricol	*Lolium multiflorum*	Italian Ryegrass	Thumpa
117	Agricol	*Avena sativa*	Oats	Pallinup
118	Agricol	*Avena sativa*	Oats	Overberg
119	Agricol	*Avena sativa*	Oats	Magnifico
120	Agricol	*Avena sativa*	Oats	Dunnart
121	Agricol	*Lolium perenne*	Perennial Ryegrass	Prospect
122	Agricol	*Lolium perenne*	Perennial Ryegrass	One50
123	Agricol	*Lolium perenne*	Perennial Ryegrass	Ansa
124	Agricol	*Lolium perenne*	Perennial Ryegrass	Halo
125	Agricol	*Lolium perenne*	Perennial Ryegrass	Mathilde
126	Agricol	*Phalaris acquatica*	Phalaris	Holdfast
127	Agricol	*Bromus wildenowii*	Prairie Grass	Matua
128	Agricol	*Secale Cereale*	Rye	Duiker Max
129	Agricol	*Secale Cereale*	Stooling Rye	MacBlue
130	Agricol	*Secale Cereale*	Stooling Rye	Echo
131	Agricol	*Secale Cereale*	Stooling Rye	Agriblue
132	Agricol	*Secale Cereale*	Stooling Rye	SSR1
133	Agricol	*Festuca arundinacea*	Tall Fescue	jenna
134	Agricol	*Festuca arundinacea*	Tall Fescue	Verdant
135	Agricol	*Festuca arundinacea*	Tall Fescue	Duramax
136	Agricol	*Triticale spp*	Triticale	AG Beacon
137	Agricol	*Triticale spp*	Triticale	CLOC 1
138	Agricol	*Triticale spp*	Triticale	AG Marcell
139	Agricol	*Triticale spp*	Triticale	AG Bently
140	Agricol	*Lolium multiflorum*	Westerwold Ryegrass	Striker
141	Agricol	*Lolium multiflorum*	Westerwold Ryegrass	Energa

142	Agricol	*Lolium multiflorum*	Westerwold Ryegrass	Abundant
143	Agricol	*Lolium multiflorum*	Westerwold Ryegrass	Bruiser
144	Agricol	*Lolium multiflorum*	Westerwold Ryegrass	Grazenova
145	Agricol	*Vigna unguiculata*	Cowpeas	Glenda
146	Agricol	*Vigna unguiculata*	Cowpeas	Agrinawa
147	Agricol	*Vigna unguiculata*	Cowpeas	Mixed
148	Agricol	*Securigera varia*	Crown vetch	Penngift
149	Agricol	*Sericea lespedeza*	Lespedeza	Au Grazer
150	Agricol	*Crotolaria intermedia*	Sunn Hemp	Common
151	Agricol	*Berseem Clover*	Berseem Clover	Elite II
152	Agricol	*Lotus corniculatus*	Birdsfoot Trefoil	San Gabriel
153	Agricol	*Biserrula pelecinus*	Biserrula	Mauro
154	Agricol	*Biserrula pelecinus*	Biserrula	Casbah
155	Agricol	*Lupinus albus*	Bitter Lupins	SSL10
156	Agricol	*Lotus subbiflorus*	Boyds Clover	El Rincon
157	Agricol	*Trifolium incarnatum*	Crimson Clover	Blaza
158	Agricol	*Vicia faba*	Faba Bean	Fanfare
159	Agricol	*Vicia faba*	Faba Bean	Virtigo
160	Agricol	*Vicia faba*	Faba Bean	Fiesta
161	Agricol	*Pisum sativum*	Forage Peas	Slovan
162	Agricol	*Pisum sativum*	Forage Peas	Astronaute
163	Agricol	*Vicia sativa*	Grazing Vetch	Timok
164	Agricol	*Vicia sativa*	Grazing Vetch	Timoi
165	Agricol	*Vicia sativa*	Grazing Vetch	Namoi
166	Agricol	*Medicago sativa*	Lucerne	AGSALFA 9.1
167	Agricol	*Medicago sativa*	Lucerne	ML99
168	Agricol	*Medicago sativa*	Lucerne	Topaz
169	Agricol	*Medicago sativa*	Lucerne	Supernova
170	Agricol	*Medicago sativa*	Lucerne	AG777
171	Agricol	*Medicago spp.*	Medics	Parabinga
172	Agricol	*Medicago spp.*	Medics	Paraggio
173	Agricol	*Medicago spp.*	Medics	Jester
174	Agricol	*Medicago spp.*	Medics	Angel
175	Agricol	*Medicago spp.*	Medics	Santiago
176	Agricol	*Medicago spp.*	Medics	Cavalier
177	Agricol	*Medicago spp.*	Medics	Bindaroo
178	Agricol	*Trifolium resupinatum*	Persian Clover	Maral
179	Agricol	*Trifolium resupinatum*	Persian Clover	Laser
180	Agricol	*Trifolium resupinatum*	Persian Clover	Prolific
181	Agricol	*Trifolium resupinatum*	Persian Clover	Turbo
182	Agricol	*Ornithopus sativus*	Pink Serradella	Emena
183	Agricol	*Ornithopus sativus*	Pink Serradella	Barbara
184	Agricol	*Ornithopus sativus*	Pink Serradella	Cadiz
185	Agricol	*Ornithopus sativus*	Pink Serradella	Margurita
186	Agricol	*Ornithopus sativus*	Pink Serradella	Erica
187	Agricol	*Vicia benghalensis*	Purple Vetch	Popany
188	Agricol	*Vicia benghalensis*	Purple Vetch	Barloo
189	Agricol	*Trifolium pratense*	Red Clover	Redgold
190	Agricol	*Trifolium pratense*	Red Clover	Kenland
191	Agricol	*Trifolium hirtum*	Rose Clover	Sola
192	Agricol	*Trifolium hirtum*	Rose Clover	Hykon
193	Agricol	*Trifolium subterranneum*	Sub-clovers	Campeda
194	Agricol	*Trifolium subterranneum*	Sub-clovers	Losa
195	Agricol	*Trifolium subterranneum*	Sub-clovers	Mintaro
196	Agricol	*Lupinis angustifolius*	Sweet Lupin (broadleaf)	Amira
197	Agricol	*Lupinis luteus*	Yellow Sweet Lupin	Borsaja
198	Agricol	*Lupinus angustifolius*	Narrow Leaf Sweet lupin	Mandellup
199	Agricol	*Lupinus angustifolius*	Narrow Leaf Sweet lupin	Gunyidi
200	Agricol	*Lupinus angustifolius*	Narrow Leaf Sweet lupin	Lila-Baer
201	Agricol	*Hedysarum boreale*	Sweet Vetch	Blanchefleur Lanquedoc
202	Agricol	*Hedysarum boreale*	Sweet Vetch	Rasina

203	Agricol	*Trifolium repens*	White Clover	Agrimatt
204	Agricol	*Trifolium repens*	White Clover	Mainstay
205	Agricol	*Ornithopus compressus*	Yellow Serradella	Charano
206	Agricol	*Ornithopus compressus*	Yellow Serradella	Santorini
207	Agricol	*Ornithopus compressus*	Yellow Serradella	Kin
208	Agricol	*Ornithopus compressus*	Yellow Serradella	Yelbeni
209	Agricol	*Cichorium endivia*	Chicory	Choice
210	Agricol	*Cichorium endivia*	Chicory	Roket Fuel
211	Agricol	*Atriplex nummularia*	Saltbush	Oldman
212	Agricol	*Atriplex nummularia*	Saltbush	Jewish
213	Agricol	*Atriplex nummularia*	Saltbush	Creeping
214	Agricol	*Beta vulgaris subsp. Vulgaris*	Fodder Beet	Poly Ursus
215	Agricol	*Brassica rapa*	Fodder Turnips	Australia Purple-Top
216	Agricol	*Brassica rapa*	Fodder Turnips	Green Globe
217	Agricol	*Brassica Napus*	Forage Rape	Spitfire
218	Agricol	*Raphanus sativus var. Longipinnatus*	Japanese Radish	Nooitgedacht
219	Agricol	*Brassica oleracea sabellica*	Kale	Sovereign
220	Agricol	*Raphanus Sativus*	Tiller radish	Groundhog
221	Agricol	*Plantago major*	Plantain	Tonic
222	Agricol	*Plantago major*	Plantain	AgriTonic
223	Brasuda	*Eragrostis tef*	Teff	
224	Brasuda	*Avena sativa*	Oats	SSH491
225	Brasuda	*Avena sativa*	Oats	Maluti
226	Brasuda	*Lolium spp.*	Ryegrass	Wintergrazer
227	Brasuda	*Lolium spp.*	Ryegrass	Italian
228	Brasuda	*Panicum maximum*	White Buffalo Grass	Aries II
229	Brasuda	*Panicum maximum*	White Buffalo Grass	Tanzania
230	Brasuda	*Panicum maximum*	White Buffalo Grass	Paredao
231	Brasuda	*Brachiaria brizantha*	Bread Grass	MG-4
232	Brasuda	*Brachiaria brizantha*	Bread Grass	MG-5
233	Brasuda	*Brachiaria humidicola*		Humidicola
234	Brasuda	*Brachiaria humidicola*		Llanero
235	Brasuda	*Setaria sphacelata*		Tijuca
236	Brasuda	*Sorghum spp.*	Perennial Sorghum	Super Sorghum SE1
237	Brasuda	*Macrotyloma axillare*		Java
238	Silverhills	*Bauhinia galpinii*		
239	Silverhills	*Setaria sphacelata*		
240	Silverhills	*Pentameris colorata*		
241	Silverhills	*Digitaria eriantha*		
242	Silverhills	*Chloris gayana*		
243	Silverhills	*Panicum maximum*		
244	Silverhills	*Setaria megaphylla*		
245	Silverhills	*Urochloa mosambicensis*		
246	Silverhills	*Pseudopentameris macrantha*		
247	Silverhills	*Vigna vexillata*		
248	Silverhills	*Erharta calycina*		
249	Silverhills	*Eragrostis curvula*		
250	Silverhills	*Erharta thunbergii*		
251	Silverhills	*Lessertia frutescens*		
252	Silverhills	*Setaria megaphylla*		
253	Silverhills	*Cenchrus ciliaris*		
254	Silverhills	*Crotalaria natalitia*		
255	Silverhills	*Psoralea arborea*		
256	Silverhills	*Tephrosia rhodesica var rhodesica*		
257	Silverhills	*Lessertia diffusa*		

6.3.2 Seed characterisation

6.3.2.1. Initial seed germination and viability testing

All species collected were cleaned and the viability tested. Unfortunately, many of the species collected had a viability of below 50 % (Table 16) while the commercial species (those obtained from the seed companies) all had a seed viability above 80 % except for some of the seeds from Silverhills which were below 70 % (Table 17). In order to improve the number of viable seeds per accession, significant seed regeneration and multiplication activities was needed before the accessions of indigenous species can be entered into the genebank and characterisation can start. To enter new accessions into the genebank without seed multiplication and regeneration, a minimum of 70 % viable seeds are required. Therefore, all accessions highlighted in red (including those from silverhills seeds) will be undergoing seed multiplication and regeneration to obtain the optimum seed viability for inclusion into the genebank.

Table 16: Germination potential vs. Viability of grass and legume germplasm collected.

	Plant Name	Germination (%)	Tetrazolium Chloride test (%)	Seed regeneration needed	Is the ISTA rules correct
1	*Stipagrostis hirtigluma*	22	75		
2	*Themeda triandra*	45	70		
3	*Miscanthus capensis*	31	62		
4	*Digitaria eriantha*	55	71		
5	*Setaria sphacelata var. sphacelata*	78	89		
6	*Cymbopogon plurinodis*	21	50		
7	*Panicum coloratum*	33	69		
8	*Eragrostis superba*	22	65		
9	*Eragrostis racemosa*	15	60		
10	*Melinis repens*	16	30		
11	*Elionurus muticus*	8	42		
12	*Melica decumbens*	12	49		
13	*Cymbopogon plurinodis*	16	39		
14	*Tragus berteronianus*	5	32		
15	*Cynodon dactylon*	10	46		
16	*Diheteropogon amplectens*	8	20		
17	*Eragrostis curvula*	65	71		
18	*Harpochloa falx*	8	25		
19	*Trachypogon spicatus*	11	29		
20	*Panicum maximum*	55	69		
21	*Sporobolus africanus*	30	59		
22	*Heteropogon contortus*	25	62		
23	*Eragrostis capensis*	33	66		
24	*Eragrostis superba*	6	35		
25	*Hyparrhenia hirta*	10	46		
26	*Eragrostis plana*	12	48		
27	*Alloteropsis semialata*	5	17		
28	*Imperata cylindrica*	6	21		
29	*Aristida congesta*	33	58		
30	*Eragrostis obtusa*	40	68		
31	*Fingerhuthia africana*	12	33		
32	*Bromus catharticus*	20	45		
33	*Cenchrus ciliaris*	50	71		
34	*Digitaria monodactyla*	15	27		
35	*Schmidtia kalihariensis*	20	33		
36	*Paspalum dilatatum*	18	23		
37	*Panicum maximum*	55	72		
38	*Eragrostis superba*	35	56		
39	*Eragrostis cilianensis*	22	49		
40	*Chloris virgata*	15	41		
41	*Cenchrus ciliaris*	50	68		
42	*Digitaria eriantha*	55	72		

43	*Urochloa mosambensis*	68	79		
44	*Eragrostis rigidor*	9	26		
45	*Themida triandra*	46	71		
46	*Schmidtia pappophoroides*	12	36		
47	*Melinis repens*	15	43		
48	*Eragrostis gummiflua*	8	19		
49	*Medicago sativa*	66	89		
50	*Panicum natalanse*	66	79		
51	*Urelytrum agropyroides*	19	80		
52	*Melinis nerviglumis*	0	40		
53	*Heterepogon contortus*	13	70		
54	*Eragrostis gummiflua*	13	78		
55	*Cynodon dactylon*	40	70		
56	*Cenchrus ciliaris*	40	70		
57	*Themeda triandra*	45	70		
58	*Eragrostis rigidior*	16	65		
59	*Schmidtia pappophoroides*	9	50		
60	*Eragrostis superba*	29	60		
61	*Melinis repens*	31	65		
62	*Panicum natalanse*	33	70		
63	*Eustachys paspaloides*	0	40		
64	*Loudetia simplex*	0	50		
65	*Bothriochloa insculpta*	0	40		
66	*Themeda triandra*	51	80		
67	*Sporobolus africanus*	0	55		
68	*Aristida congesta*	56	77		
69	*Aristida congesta. congesta*	56	80		
70	*Panicum maximum*	76	91		
71	*Digitaria eriantha*	79	90		
72	*Schmidtia pappophoroides*	0	45		
73	*Pogonarthria squarrosa*	0	52		
74	*Fingerhuthia africana*	0	35		
75	*Tragus berteronianus*	0	30		
76	*Cenchrus ciliaris*	77	80		
77	*Urochloa mosambicensis*	71	80		
78	*Chloris virgata*	11	44		
79	*Sorghum bicolor*	41	65		
80	*Sorghum bicolor*	33	70		
81	*Fingerhuthia africana*	0	25		
82	*Themeda triandra*	43	60		
83	*Anthephora pubescens*	56	79		
84	*Diheteropogon amplectens*	15	55		
85	*Panicum maximum*	81	100		
86	*Enneapogon cenchroides*	0	80		
87	*Eragrostis rigidior*	0	37		
88	*Aristida congesta*	11	66		
89	*Cymbopogon caesius*	0	51		
90	*Urochloa mosambicensis*	22	70		
91	*Digitaria eriantha*	82	100		
92	*Setaria sphacelata*	26	56		
93	*Eragrostis superba*	0	33		
94	*Aristida bipartita*	0	30		
95	*Bothriochloa insculpta*	0	40		
96	*Pogonarthria squarrosa*	0	40		
97	*Melinis repens*	0	55		
98	*Trichoneura grandiglumis*	0	55		
99	*Cenchrus ciliaris*	65	92		
100	*Ischaemum fasciculatum*	0	50		
101	*Pogonarthria squarrosa*	0	50		
102	*Digitaria eriantha*	61	88		
103	*Heterepogon contortus*	0	75		

104	*Panicum maximum*	71	80		
105	*Eragrostis rigidior*	0	50		
106	*Eustachys paspaloides*	0	30		
107	*Cenchrus ciliaris*	69	90		
108	*Eragrostis gummiflua*	0	56		
109	*Cymbopogon nardus*	0	35		
110	*Panicum coloratum*	47	88		
111	*Tricholaena monachne*	0	60		
112	*Panicum coloratum*	58	80		
113	*Eragrostis superba*	0	50		
114	*Loudetia simplex*	0	40		
115	*Pogonarthria squarrosa*	0	44		
116	*Aristida meridionalis*	0	35		
117	*Themeda triandra*	61	88		
118	*Eragrostis tef*	69	98		
119	*Fingerhuthia africana*	0	35		
120	*Cymbopogon caesius*	0	40		
121	*Eragrostis gummiflua*	0	40		
122	*Cynodon dactylon*	55	70		
123	*Digitaria eriantha*	59	70		
124	*Tragus racemosus*	0	50		
125	*Melinis repens*	0	35		
126	*Eragrostis racemosa*	0	56		
127	*Heterepogon contortus*	0	75		
128	*Aristida congesta. congesta*	23	75		
129	*Schmidtia pappophoroides*	0	15		
130	*Alloteropsis semialata*	1	35		
131	*Diheteropogon amplectens*	0	35		
132	*Cenchrus ciliaris*	55	70		
133	*Eragrostis echinochloidea*	0	50		
134	*Eragrostis trichophora*	0	56		
135	*Stipagrostis ciliata*	0	60		
136	*Indigofera tinctoria*	0	88		
137	*Brachiaria nigropedata*	56	80		
138	*Enneapogon scoparius*	0	70		
139	*Eustachys paspaloides*	0	30		
140	*Triraphis andropogonoides*	0	35		
141	*Panicum coloratum*	35	65		
142	*Cenchrus ciliaris*	56	90		
143	*Themeda triandra*	61	90		
144	*Urochloa mosambicensis*	59	85		
145	*Sporobolus africanus*	0	65		
146	*Diheteropogon filifolius*	0	35		
147	*Chloris virgata*	0	35		
148	*Heterepogon contortus*	0	30		
149	*Setaria sphacelata*	45	65		
150	*Aristida congesta. congesta*	31	60		
151	*Panicum maximum*	67	78		
152	*Bothriochloa insculpta*	0	30		
153	*Eragrostis superba*	0	45		
154	*Aristida canescens*	0	40		
155	*Digitaria eriantha*	55	75		
156	*Eragrostis inamoena*	0	35		
157	*Cynodon dactylon*	12	50		
158	*Eleusine coracana*	0	40		
159	*Melinis nerviglumis*	0	40		
160	*Eragrostis racemosa*	0	35		
161	*Themeda triandra*	44	68		
162	*Brachiaria serrata*	0	65		
163	*Eragrostis curvula*	63	70		
164	*Eragrostis superba*	12	55		

165	*Imperata cylindrica*	9	60		
166	*Alloteropsis semialata*	0	60		
167	*Heterepogon contortus*	0	50		
168	*Rendlia altera*	0	35		
169	*Tristachya leucothrix*	0	35		
170	*Panicum repens*	0	60		
171	*Chrysopogon serrulatus*	0	35		
172	*Setaria sphacelata*	23	65		
173	*Sporobolus africanus*	0	50		
174	*Eragrostis spp*	12	50		
175	*Setaria spp*	12	50		
176	*Panicum ecklonii*	5	45		
177	*Eragrostis trichophora*	0	30		
178	*Schizachyrium sanguineum*	0	30		
179	*Harpochloa falx*	0	25		
180	*Urochloa mosambicensis*	55	70		
181	*Acacia (Vachellia) karroo*	69	80		
182	*Anthiphora pubescens*	67	88		
183	*Cenchrus ciliaris*	79	90		
184	*Chaetobromus involucratus*	22	65		
185	*Cynodon dactylon*	35	65		
186	*Eragrostis curvula*	78	90		
187	*Eragrostis obtusa*	51	70		
188	*Errharta calycina*	32	66		
189	*Fingerhuthia africa*	12	68		
190	*Lessertia annularis*	9	90		
191	*Osteospermum sinuatum*	0	50		
192	*Sporobolus fimbriatus*	0	60		
193	*Stiapagrostis ciliaris*	25	60		
194	*Stipagrostis obtusa*	19	60		
195	*Themeda triandra*	22	60		
196	*Eragrostis plana*	36	70		
197	*Eustachys paspaloides*	4	50		
198	*Digitaria eriantha*	0	65		
199	*Bromus cathaticus*	60	80		
200	*Paspalum urviller*	4	50		
201	*Bracharia brizantha*	28	78		
202	*Eleusine corecam*	0	50		
203	*Urochloa mosambensis*	0	65		
204	*Sporobolus africanum*	56	80		
205	*Setaria incressata*	0	30		
206	*Chloris gayan*	76	95		
207	*Sporobolus africanum*	0	50		
208	*Sporobolus pyramidilis*	4	45		
209	*Panicum maximum*	0	75		
210	*Digitaria eriantha*	0	75		
211	*Paspalum notatum*	0	80		
212	*Hyparhenia hirta*	24	66		
213	*Diheterepogon amplectens*	4	60		
214	*Cymbopogon prolixus*	0	50		
215	*Tricholaena monachne*	0	50		
216	*Cymbopogon nardus*	0	60		
217	*Paspalun nortatum*	0	60		
218	*Aristida junciformis*	0	30		
219	*Themeda triandra*	4	60		
220	*Eragrostis carvula*	0	35		
221	*Sporobolus africanus*	20	60		
222	*Harpochloa falx*	0	30		
223	*Urochloa masambensis*	0	35		
224	*Eragrostis carvula*	0	55		
225	*Themeda triandra*	4	50		

226	*Eragrostis plana*	0	30		
227	*Eragrostis superba*	0	30		
228	*Trachypogon spicatus*	0	22		
229	*Hyperhenia hirta*	0	50		
230	*Isaac (NB)*	0	40		
231	*Heterepogon contortus*	0	50		
232	*Tristachya leucothrix*	0	25		
233	*Eragrostis nindensis*	0	20		
234	*Paspalum notatum*	0	55		
235	*Panicum coloratum*	0	60		
236	*Alloteropsis semialata*	0	25		
237	*Digiteria sanguinalis*	12	25		
238	*Cynodon nlemfuensis*	0	30		
239	*Eleusine coracana*	0	30		
240	*Setaria pumila*	0	35		
241	*Cynodon dactylon*	0	30		
242	*Chamaechrista sp*	8	25		
243	*Aristida congesta*	0	50		
244	*Cymbopogon*	28	50		

Table 17: Germination potential of seeds obtained from commercial seed companies.

	Distributor	Species	Cultivar	Germination %
1	Barenbrug	*Lolium perenne*	Govenor	88
2	Barenbrug	*Lolium perenne*	Tyson	80
3	Barenbrug	*Lolium perenne*	Viscount	81
4	Barenbrug	*Festuca arundinaceae*	Paolo	85
5	Barenbrug	*Festuca arundinaceae*	Baroptima	88
6	Barenbrug	*Festuca arundinaceae*	Royal Q-100	89
7	Barenbrug	*Dactylis glomerata*	Adremo	90
8	Barenbrug	*Bromus catharticus*	Bareno	80
9	Barenbrug	*Lolium hybridium*	Barhill	88
10	Barenbrug	*Lolium x boucheanum*	Shogun	89
11	Barenbrug	*Lolium hybridium*	Barsenna	88
12	Barenbrug	*Lolium multiflorum*	Tabu +	80
13	Barenbrug	*Lolium multiflorum*	Barmultra II	82
14	Barenbrug	*Lolium multiflorum*	Bartimum	86
15	Barenbrug	*Lolium multiflorum*	Ribeye	88
16	Barenbrug	*Lolium multiflorum*	Maximus	86
17	Barenbrug	*Brachiaria sp.*	Sabia	85
18	Barenbrug	*Brachiaria sp.*	Cayana	85
19	Barenbrug	*Brachiaria brizantha*	Marandu	80
20	Barenbrug	*Panicum maximum*	Mombaca	90
21	Barenbrug	*megathyrsus maximum*	Agrosavia Sabanera	90
22	Barenbrug	*Chloris gayana*	Endura	92
23	Barenbrug	*Chloris gayana*	Tolgar	90
24	Barenbrug	*Chloris gayana*	Katambora	90
25	Barenbrug	*Digitaria eriantha*	Tiptop	80
26	Barenbrug	*Digitaria eriantha*	Irene	100
27	Barenbrug	*Cenchrus ciliaris*	Molopo	95
28	Barenbrug	*Cenchrus ciliaris*	Gayanda	95
29	Barenbrug	*Antephora pubescens*	Wollie	90
30	Barenbrug	*Eragrostis curvula*	Ermelo	85
31	Barenbrug	*Urochloa mosambicensis*	Sabi	80
32	Barenbrug	*Panicum maximum*	Gatton	88
33	Barenbrug	*Pennisetum clandestinum*	Kikuyu	80
34	Barenbrug	*Cynodon dactylon*	Bermuda	80
35	Barenbrug	*Panicum coloratum*	Klein Verdi	87

36	Barenbrug	*Paspalum notatum*	Bahia	88
37	Barenbrug	*Sorghum vulgare*	Barsweet	89
38	Barenbrug	*Sorghum spp.*	Sweet Choice	90
39	Barenbrug	*Sorghum spp.*	Bargrazer	90
40	Barenbrug	*Hybrid Pennisetum*	Nutrifast	90
41	Barenbrug	*Hybrid Pennisetum*	Pearler	90
42	Barenbrug	*Pennisetum glaucum*	Babala	90
43	Barenbrug	*Eragrostis Teff*	Tiffany	95
44	Barenbrug	*Eragrostis Teff*	SA Brown	95
45	Barenbrug	*Medicago spp.*	Jester	95
46	Barenbrug	*Medicago spp.*	Santiago	100
47	Barenbrug	*Medicago spp.*	Scimitar	100
48	Barenbrug	*Medicago spp.*	Parragio	100
49	Barenbrug	*Ornithopus sativis*	Emena	95
50	Barenbrug	*Trifolium vesiculsum*	Zulu II	95
51	Barenbrug	*Trifolium michelianum*	Paradana	90
52	Barenbrug	*Trifolium incarnatum*	Kardinal	95
53	Barenbrug	*Trifolium incarnatum*	Blaza	100
54	Barenbrug	*Trifolium resupinatum*	Lighting	100
55	Barenbrug	*Trifolium resupinatum*	Shaftal	95
56	Barenbrug	*Trifolium subterraneun*	Dalkeith	90
57	Barenbrug	*Trifolium subterraneun*	Woogenellup	80
58	Barenbrug	*Trifolium repens*	Storm	80
59	Barenbrug	*Trifolium repens*	Haifa	85
60	Barenbrug	*Trifolium pratense*	Barduro	82
61	Barenbrug	*Trifolium pratense*	Kenland	80
62	Barenbrug	*Trifolium fragiferum*	Palestine	80
63	Barenbrug	*Vicia sativa*	Morava	83
64	Barenbrug	*Vicia villosa*	Haymaker	89
65	Barenbrug	*Vicia americana*	Popany	97
66	Barenbrug	*Medicago sativa*	BarALFA10	91
67	Barenbrug	*Medicago sativa*	BAR ST	99
68	Barenbrug	*Medicago sativa*	BAR 7	86
69	Barenbrug	*Medicago sativa*	SA Standaard	89
70	Barenbrug	*Sericea lespedeza*	Au Lotan	100
71	Barenbrug	*Lupinus angustifolius*	Narrow Leaf Lupines	82
72	Barenbrug	*Vicia faba*	Stella	84
73	Barenbrug	*Vigna unguiculata*	Dr. Saundees	93
74	Barenbrug	*Vigna unguiculata*	Bets Wit	81
75	Barenbrug	*Vigna unguiculata*	Glends	83
76	Barenbrug	*Crotalaria juncea L.*	Red	97
77	Barenbrug	*Crotalaria juncea L.*	Black	95
78	Barenbrug	*Pisum sativum*	RIF	98
79	Barenbrug	*Pisum sativum*	Arvika	89
80	Barenbrug	*Pisum sativum*	Gambit	84
81	Barenbrug	*Lablab purpureus*	Rongai	83
82	Barenbrug	*Lablab purpureus*	Highworth	85
83	Barenbrug	*Macroptilium bracteatum*	B1	85
84	Barenbrug	*Onobrychis viciifolia Scop*	Common	87
85	Barenbrug	*Melilotus alba*	Common	89
86	Barenbrug	*Lotus corniculatis*	Soa Gabriel	88
87	Agricol	*Paspalum notatum*	Pensacola	95
88	Agricol	*Antephora pubescens*	Common	86
89	Agricol	*Antephora pubescens*	SSW21A	89
90	Agricol	*Sorghum spp.*	Hunnigreen	87
91	Agricol	*Sorghum spp.*	Honeymax	86
92	Agricol	*Sorghum spp.*	Supasweet	89
93	Agricol	*Sorghum spp.*	AgFlashNIAGARA III	99
94	Agricol	*Echinochloa esculenta*	Normal	93
95	Agricol	*Pennisetum glaucum*	Common	80
96	Agricol	*Pennisetum glaucum*	Okashana	88

97	Agricol	*Pennisetum glaucum*	Agrigreen (hybrid)	97
98	Agricol	*Sorghum spp.*	Silk	95
99	Agricol	*Sorghum spp.*	Jaffa	97
100	Agricol	*Chloris gayana*	Katambora	93
101	Agricol	*Chloris gayana*	Boma	80
102	Agricol	*Digitaria eriantha*	Irene	93
103	Agricol	*Digitaria eriantha*	SSW11D	83
104	Agricol	*Eragrostis tef*	SA Brown	80
105	Agricol	*Eragrostis curvula*	Ermelo	89
106	Agricol	*Eragrostis curvula*	Agpal	86
107	Agricol	*Panicum maximum*	Gatton	95
108	Agricol	*Panicum maximum*	PUK P8	82
109	Agricol	*Dactylis glomerata*	Aldebaren	82
110	Agricol	*Dactylis glomerata*	Pizza	81
111	Agricol	*Lolium multiflorum*	Asset	85
112	Agricol	*Lolium multiflorum*	Fox	85
113	Agricol	*Lolium multiflorum*	Agriboost	87
114	Agricol	*Lolium multiflorum*	Max	97
115	Agricol	*Lolium multiflorum*	Firkin	99
116	Agricol	*Lolium multiflorum*	Thumpa	91
117	Agricol	*Avena sativa*	Pallinup	100
118	Agricol	*Avena sativa*	Overberg	86
119	Agricol	*Avena sativa*	Magnifico	89
120	Agricol	*Avena sativa*	Dunnart	84
121	Agricol	*Lolium perenne*	Prospect	95
122	Agricol	*Lolium perenne*	One50	81
123	Agricol	*Lolium perenne*	Ansa	81
124	Agricol	*Lolium perenne*	Halo	87
125	Agricol	*Lolium perenne*	Mathilde	98
126	Agricol	*Phalaris acquatica*	Holdfast	97
127	Agricol	*Bromus wildenowii*	Matua	88
128	Agricol	*Secale Cereale*	Duiker Max	87
129	Agricol	*Secale Cereale*	MacBlue	97
130	Agricol	*Secale Cereale*	Echo	80
131	Agricol	*Secale Cereale*	Agriblue	90
132	Agricol	*Secale Cereale*	SSR1	81
133	Agricol	*Festuca arundinacea*	jenna	98
134	Agricol	*Festuca arundinacea*	Verdant	82
135	Agricol	*Festuca arundinacea*	Duramax	100
136	Agricol	*Triticale spp*	AG Beacon	98
137	Agricol	*Triticale spp*	CLOC 1	93
138	Agricol	*Triticale spp*	AG Marcell	89
139	Agricol	*Triticale spp*	AG Bently	89
140	Agricol	*Lolium multiflorum*	Striker	81
141	Agricol	*Lolium multiflorum*	Energa	90
142	Agricol	*Lolium multiflorum*	Abundant	94
143	Agricol	*Lolium multiflorum*	Bruiser	93
144	Agricol	*Lolium multiflorum*	Grazenova	95
145	Agricol	*Vigna unguiculata*	Glenda	99
146	Agricol	*Vigna unguiculata*	Agrinawa	87
147	Agricol	*Vigna unguiculata*	Mixed	81
148	Agricol	*Securigera varia*	Penngift	93
149	Agricol	*Sericea lespedeza*	Au Grazer	95
150	Agricol	*Crotolaria intermedia*	Common	94
151	Agricol	*Berseem Clover*	Elite II	100
152	Agricol	*Lotus corniculatus*	San Gabriel	87
153	Agricol	*Biserrula pelecinus*	Mauro	98
154	Agricol	*Biserrula pelecinus*	Casbah	97
155	Agricol	*Lupinus albus*	SSL10	89
156	Agricol	*Lotus subbiflorus*	El Rincon	82
157	Agricol	*Trifolium incarnatum*	Blaza	86

158	Agricol	*Vicia faba*	Fanfare	82
159	Agricol	*Vicia faba*	Virtigo	92
160	Agricol	*Vicia faba*	Fiesta	86
161	Agricol	*Pisum sativum*	Slovan	98
162	Agricol	*Pisum sativum*	Astronaute	93
163	Agricol	*Vicia sativa*	Timok	80
164	Agricol	*Vicia sativa*	Timoi	87
165	Agricol	*Vicia sativa*	Namoi	98
166	Agricol	*Medicago sativa*	AGSALFA 9.1	98
167	Agricol	*Medicago sativa*	ML99	95
168	Agricol	*Medicago sativa*	Topaz	80
169	Agricol	*Medicago sativa*	Supernova	99
170	Agricol	*Medicago sativa*	AG777	80
171	Agricol	*Medicago spp.*	Parabinga	90
172	Agricol	*Medicago spp.*	Paraggio	95
173	Agricol	*Medicago spp.*	Jester	92
174	Agricol	*Medicago spp.*	Angel	95
175	Agricol	*Medicago spp.*	Santiago	85
176	Agricol	*Medicago spp.*	Cavalier	93
177	Agricol	*Medicago spp.*	Bindaroo	86
178	Agricol	*Trifolium resupinatum*	Maral	92
179	Agricol	*Trifolium resupinatum*	Laser	88
180	Agricol	*Trifolium resupinatum*	Prolific	80
181	Agricol	*Trifolium resupinatum*	Turbo	95
182	Agricol	*Ornithopus sativus*	Emena	81
183	Agricol	*Ornithopus sativus*	Barbara	91
184	Agricol	*Ornithopus sativus*	Cadiz	93
185	Agricol	*Ornithopus sativus*	Margurita	94
186	Agricol	*Ornithopus sativus*	Erica	89
187	Agricol	*Vicia benghalensis*	Popany	88
188	Agricol	*Vicia benghalensis*	Barloo	97
189	Agricol	*Trifolium pratense*	Redgold	89
190	Agricol	*Trifolium pratense*	Kenland	83
191	Agricol	*Trifolium hirtum*	Sola	96
192	Agricol	*Trifolium hirtum*	Hykon	90
193	Agricol	*Trifolium subterranneum*	Campeda	91
194	Agricol	*Trifolium subterranneum*	Losa	91
195	Agricol	*Trifolium subterranneum*	Mintaro	82
196	Agricol	*Lupinis angustifolius*	Amira	91
197	Agricol	*Lupinis luteus*	Borsaja	81
198	Agricol	*Lupinus angustifolius*	Mandellup	90
199	Agricol	*Lupinus angustifolius*	Gunyidi	96
200	Agricol	*Lupinus angustifolius*	Lila-Baer	86
201	Agricol	*Hedysarum boreale*	Blanchefleur Lanquedoc	90
202	Agricol	*Hedysarum boreale*	Rasina	94
203	Agricol	*Trifolium repens*	Agrimatt	80
204	Agricol	*Trifolium repens*	Mainstay	91
205	Agricol	*Ornithopus compressus*	Charano	95
206	Agricol	*Ornithopus compressus*	Santorini	82
207	Agricol	*Ornithopus compressus*	Kin	88
208	Agricol	*Ornithopus compressus*	Yelbeni	84
209	Agricol	*Cichorium endivia*	Choice	90
210	Agricol	*Cichorium endivia*	Roket Fuel	87
211	Agricol	*Atriplex nummularia*	Oldman	86
212	Agricol	*Atriplex nummularia*	Jewish	100
213	Agricol	*Atriplex nummularia*	Creeping	85
214	Agricol	*Beta vulgaris subsp. Vulgaris*	Poly Ursus	86
215	Agricol	*Brassica rapa*	Australia Purple-Top	99
216	Agricol	*Brassica rapa*	Green Globe	88
217	Agricol	*Brassica Napus*	Spitfire	84
218	Agricol	*Raphanus sativus var. Longipinnatus*	Nooitgedacht	100

219	Agricol	*Brassica oleracea sabellica*	Sovereign	91
220	Agricol	*Raphanus Sativus*	Groundhog	94
221	Agricol	*Plantago major*	Tonic	86
222	Agricol	*Plantago major*	AgriTonic	99
223	Brasuda	*Eragrostis tef*		91
224	Brasuda	*Avena sativa*	SSH491	96
225	Brasuda	*Avena sativa*	Maluti	86
226	Brasuda	*Lolium spp.*	Wintergrazer	86
227	Brasuda	*Lolium spp.*	Italian	80
228	Brasuda	*Panicum maximum*	Aries II	90
229	Brasuda	*Panicum maximum*	Tanzania	86
230	Brasuda	*Panicum maximum*	Paredao	87
231	Brasuda	*Brachiaria brizantha*	MG-4	85
232	Brasuda	*Brachiaria brizantha*	MG-5	98
233	Brasuda	*Brachiaria humidicola*	Humidicola	84
234	Brasuda	*Brachiaria humidicola*	Llanero	83
235	Brasuda	*Setaria sphacelata*	Tijuca	99
236	Brasuda	*Sorghum spp.*	Super Sorghum SE1	91
237	Brasuda	*Macrotyloma axillare*	Java	93
238	Silverhills	*Bauhinia galpinii*		74
239	Silverhills	*Setaria sphacelata*		70
240	Silverhills	*Pentameris colorata*		69
241	Silverhills	*Digitaria eriantha*		80
242	Silverhills	*Chloris gayana*		80
243	Silverhills	*Panicum maximum*		70
244	Silverhills	*Setaria megaphylla*		68
245	Silverhills	*Urochloa mosambicensis*		65
246	Silverhills	*Pseudopentameris macrantha*		52
247	Silverhills	*Vigna vexillata*		63
248	Silverhills	*Erharta calycina*		54
249	Silverhills	*Eragrostis curvula*		75
250	Silverhills	*Erharta thunbergii*		59
251	Silverhills	*Lessertia frutescens*		70
252	Silverhills	*Setaria megaphylla*		66
253	Silverhills	*Cenchrus ciliaris*		72
254	Silverhills	*Crotalaria natalitia*		62
255	Silverhills	*Psoralea arborea*		59
256	Silverhills	*Tephrosia rhodesica var rhodesica*		57
257	Silverhills	*Lessertia diffusa*		72

A more concerning results, however, is the fact that although several of the accessions had viable seeds, we were unable to germinate them. From Table 16 it is clear to see that species that have already undergone breeding and there are proper guidelines to establish the seeds that the germination potential were higher. These include species such as *Panicum maximum, Digitaria eriantha*, *Cenchrus ciliaris, Anthephora pubescens, Themeda triandra* and *Eragrostis tef.* Germination potential of the other indigenous resources were poor. This may be due to several reasons such as seed dormancy or not working at the correct germination temperatures.

For the indigenous species which have not yet undergone breeding, unfortunately the procedures for successfully germinating these species has not been listed in the current published rules. Therefore, her work will significantly contribute to a better understanding of how to germinate and establish our indigenous grass and legume genetic resources, and whether there are differences between accessions that have not undergone any breeding vs their commercial cultivars.

6.3.2.2. Germination requirements for commercial vs. indigenous ecotypes

Results of the seed germination and viability testing of indigenous ecotypes vs. commercial cultivars of *C. ciliaris, D. eriantha, P. maximum* and *P. coloratum* is show in Table 18. Commercial cultivars is highlighted in yellow.

Table 18: Seed germination and viability of commercial cultivars vs. indigenous ecotypes of four grass species.

		Germination (%)	Viability (%)
Gauteng	*Cenchrus ciliaris*	40	70
Gauteng	*Cenchrus ciliaris*	69	90
Western Cape	*Cenchrus ciliaris*	79	90
Limpopo	*Cenchrus ciliaris*	77	80
Limpopo	*Cenchrus ciliaris*	65	92
North West	*Cenchrus ciliaris*	55	70
Mpumalanga	*Cenchrus ciliaris*	56	90
Barenbrug	*Cenchrus ciliaris cv. Molopo*	95	97
Barenbrug	*Cenchrus ciliaris cv. Gayanda*	95	97
Gauteng	*Digitaria eriantha*	61	88
Limpopo	*Digitaria eriantha*	79	90
Limpopo	*Digitaria eriantha*	82	100
North West	*Digitaria eriantha*	59	70
KZN	*Digitaria eriantha*	0	65
KZN	*Digitaria eriantha*	0	75
Barenbrug	*Digitaria eriantha cv. Tiptop*	80	82
Barenbrug	*Digitaria eriantha cv. Irene*	100	100
Gauteng	*Panicum maximum*	71	80
Limpopo	*Panicum maximum*	76	91
Limpopo	*Panicum maximum*	81	100
Mpumalanga	*Panicum maximum*	67	78
Barenbrug	*Panicum maximum cv. Mombaca*	90	95
Barenbrug	*Panicum maximum cv. Gatton*	88	90
Agricol	*Panicum maximum cv. PUK P8*	82	90
Brasuda	*Panicum maximum cv. Aries II*	90	95
Brasuda	*Panicum maximum cv. Tanzania*	96	100
Brasuda	*Panicum maximum cv. Paradao*	87	95
Gauteng	*Panicum coloratum*	47	88
North West	*Panicum coloratum*	58	80
Mpumalanga	*Panicum coloratum*	35	65
Mpumalanga	*Panicum coloratum*	0	60
Barenbrug	*Panicum coloratum cv. Klein Verdi*	87	90

Seed germination and viability of seeds from commercial cultivars were found to be closely related i.e., the germinated seeds is close to the total viable seeds. This is to be expected as these cultivars has undergone extensive breeding and improvement which also includes germination stability. The methods published for these species is based on these improved cultivars and therefore the results obtained for the commercial cultivars was expected. However, when looking at the results for the local ecotypes, it was clear that the published methodologies did not provide the best germination results as germination and seed viability were not closely related. This may be due to several factors such as dormancy or factors relating to the local conditions in which the species originated from and from where the seeds were collected.

Seed germination and seedling establishment are the most critical stages in the life cycle of plants, and therefore, germination timing is crucial for the survival of newly formed seedlings (Bewley and Black 1994, Foley 2001, Gresta et al. 2011, Walck et al. 2011, Baskin and Baskin 2014, Ludewig et al. 2014, Hu et al. 2015). To optimise the time of germination, and therefore, increase the survivorship of seedlings, plants have evolved a range of mechanisms to increase their chance of survival (Foley 2001). One of these mechanisms is seed dormancy (Fenner 2000, Bewley and Black 1994, Foley 2001, Do Canto et al. 2013). Seed dormancy serves at least two ecologically significant roles in the survival of plants. First, it ensures the survival of plants in the absence of seed production through the development of a soil seed bank (Do Canto et al. 2013). Second, it enables seeds to avoid germination during periods where conditions for seedling growth are only viable for short periods of time. Therefore, by having seeds with various degrees of dormancy, plants can distribute their offspring across time, as a mechanism to overcome unpredictable and/or variable environments (Venable 2007, Poisot et al. 2011, Do Canto et al. 2013, Wills et al. 2014). Dormancy, therefore, is under strong environmental control, resulting in a wide range of dormancy types, each suitable for specific bioclimatic, ecological and edaphic conditions in which plants occur (Hilhorst 1995, Vleeshouwers et al. 1995, Bewley 1997, Li and Foley 1997, Baskin and Baskin 2004, Fenner and Thompson 2005, Finch-Savage and Leubner-Metzger 2006, Donohue et al. 2010, Huang et al. 2010, Wills et al. 2014).

Furthermore, the success with which seeds germinate and establish is closely related to the favourability of their surrounding environmental conditions (Bewley and Black 1994). Several bioclimatic and edaphic factors such as water, oxygen, light, temperature, soil pH and seed burial depth, influence both the success and the rate of seed germination (Bewley and Black 1994, Gresta et al. 2011). For germination to commence, after the release of dormancy, seeds have to imbibe water (Bewley and Black 1994; Studdert et al. 1994; Singh et al. 2013). The base water potential that is required for germination has been found to vary greatly among species but is closely related to the environmental conditions in which the species occur (Evans and Etherington 1990; Fenner and Thompson 2005). For instance, seed germination of species adapted to drier environments are usually affected less by water stress than those adapted to wetter environments (Evans and Etherington 1990). In general, however, when the water potential of the germination medium decreases from the optimum, for a specific species, germination may be delayed or inhibited according to the extent of the water potential decline (Hegarty 1978; Singh et al. 2013; Patané et al. 2016). Temperature on the other hand is the major determinant of germination rate, once seed dormancy has been released (Fenner and Thompson 2005; Baskin and Baskin 2014; Hu et al. 2015). Three 'cardinal temperatures' (minimum, optimum and maximum temperatures) generally characterize germination responses to temperature. The minimum or base temperature and maximum or ceiling temperature are those temperatures below and above which germination will not occur, respectively, while the optimum temperature is the one at which germination is most rapid (Bewley and Black 1994; Hu et al. 2015). These 'cardinal temperatures' for germination are generally related to the environmental conditions to which the species are adapted in their native environments. These cardinal temperature ranges generally match the most favourable times for seed germination and subsequent seedling growth and development (Hu et al. 2015). Previous studies have shown large variations in the 'cardinal temperatures' among species as well as within species (Steinmaus et al. 2000; Phartyal et al. 2003; Hardegree 2006). These differences, however, can often be related to ecological or geographical factors (Ascough et al. 2007; Luna et al. 2012; Hu et al. 2015). Therefore, the results obtained in this work, especially for the indigenous ecotypes, could indicate specific requirements of these species based on the environmental conditions were these seeds were collected. This will need to be evaluated further as the lack of knowledge on how to effectively germinate these indigenous ecotypes is a major limiting factor for distribution of the seeds from the genebank.

6.3.2.3. Morphological characterisation of commercial vs local forage ecotypes grown under different temperature and osmotic conditions

The findings from these studies are indicated in tables 19 – 21. Generally, both temperature and osmotic conditions influenced the growth and development of these species. Table 19 shows the growth of *E.*

curvula ecotype and commercial cultivar under different osmotic and temperature conditions. At 20 ˚C and 25 ˚C it was found that shoot and root length was significantly decreased under water-limited conditions for both the local ecotype and the commercial cultivar. However, at 30 ˚C no differences were observed in the shoot and root lengths between well-watered and water-limited conditions for the local ecotype while in the commercial cultivar significant reductions in shoot and root length was observed between well-watered and water-limited conditions. At each of the temperatures significantly more resources were allocated to root development under water-limited conditions as seen by the root:shoot ratios. Furthermore, although *E. curvula* was able to maintain shoot growth at the higher temperatures under water-limited conditions, the seedlings were clearly stressed as shown by the electrolyte leakage from the leaves suggesting that membrane stability was compromised under the stressed conditions (Table 19).

Table 20 shows the growth of *C. ciliaris* ecotype and commercial cultivar under different osmotic and temperature conditions. Generally, at 20 ˚C and 25 ˚C, similar trends were observed with both root and shoot length and mass growth increasing under water-limited conditions, in both the local ecotype and commercial cultivar. However, at 25 ˚C root length growth in the commercial cultivar significantly decreased under water-limited conditions while that in the local ecotype still increased. At 30 ˚C however, shoot length significantly decreased under water-limited conditions in both the local ecotype and commercial cultivar. Root length however in the local ecotype did not differ between water-limited and well-watered conditions at 30 ˚C where the commercial cultivar had significant root length reductions. When considering resource allocation (root:shoot ratio) it was clear that although generally both root and shoot growth increased under water-limited conditions at 20 ˚C and 25 ˚C, the allocation of resources to root growth was greater. Even at 30 ˚C resource allocation was prioritised towards root growth. In both local ecotype and commercial cultivar, irrespective of temperature, water-limitation resulted in increased electrolyte leakage from the leaves which indicates that the seedlings were clearly stressed and that membrane stability was compromised under the stressed conditions (Table 20).

Table 21 shows the growth of *D. eriantha* ecotype and commercial cultivar under different osmotic and temperature conditions. Shoot and root growth significantly decreased under water-limited conditions in both the local ecotype and commercial cultivar, irrespective of temperature. However, at 30 ˚C shoot length in the local ecotype did not differ between well-watered and water-limited conditions. Similarly, at 30 ˚C, root mass in the local ecotype significantly increased under water-limited conditions, while a significant decrease was observed in the commercial cultivar. With regard to resource allocation, it was clear that no resource partitioning was observed between root and shoot growth for the commercial cultivar while for the local ecotype, at each of the temperatures, under water-limited conditions significantly more resources were allocated to root growth, as shown by the increase in root:shoot ratio under water-limited conditions. However, just like with the other two species evaluated, electrolyte leakage from the leaves significantly increased under water-limited conditions in both the local ecotype and the commercial cultivar, irrespective of the temperature.

Table 19: Growth of *E. curvula* ecotypes and commercial cultivar under different osmotic and temperature conditions. Significant differences ($p < 0.05$) between different treatments (non-stressed and stressed) and accessions are indicated by different lower-case letters. Comparisons were made within a temperature.

Temperature (˚C)	Accession	Treatment	Shoot height (mm)	Root length (mm)	Shoot mass (g)	Root mass (g)	Root/Shoot Ratio	Electrolyte leakage (%)
20	Ecotype	Non-stressed	38±0a	32±0.5b	0.8±0.2ab	0.7±0.03a	0.9±0.2a	30.3±2.4b
		Stressed	33±1a	25±1a	0.6±0.1a	0.6±0.19a	1.2±0.6b	37.7±12.7c
	Commercial	Non-stressed	66±0c	35±0.5b	1±0.3b	0.5±0.41a	0.5±0.1a	22.6±9.9a
		Stressed	47±1b	25±3.5a	0.6±0.4a	0.6±0.32a	1.3±0.01b	33±8.3b
25	Ecotype	Non-stressed	66±2.5b	35±1b	1±0.3b	0.5±0.05a	0.5±0.1a	22.6±3a
		Stressed	47±0.5a	25±1.5a	0.6±0.2a	0.6±0.22a	1.3±0.8b	33±19.5b
	Commercial	Non-stressed	65±3.5b	34±0.5b	1.3±0.3c	0.5±0.02a	0.4±0.08a	34.5±3.5b
		Stressed	53±2.5a	24±0.5a	1±0.6b	1.5±0.67b	1.5±0.2b	62±0.7c
30	Ecotype	Non-stressed	75±1.5b	34±1b	1.9±0.02c	1.1±0.04a	0.6±0.03a	37.3±19.3a
		Stressed	74±1b	33±0.5b	1.4±0.1b	2.1±0.11b	1.5±0.04b	65.3±4.1b
	Commercial	Non-stressed	77±1.5b	35±1.5b	1.5±0.04b	0.9±0.25a	0.6±0.2a	41.1±6.9a
		Stressed	40±9.8a	17±2a	1.2±0.1a	2.9±0.32c	2.5±0.5c	67.4±20.6b

Table 20: Growth of *C. cilliaris* ecotypes and commercial cultivar under different osmotic and temperature conditions. Significant differences ($p < 0.05$) between different treatments (non-stressed and stressed) and accessions are indicated by different lower-case letters. Comparisons were made within a temperature.

Temperature (˚C)	Accession	Treatment	Shoot height (mm)	Root length (mm)	Shoot mass (g)	Root mass (g)	Root/Shoot Ratio	Electrolyte leakage (%)
20	**Ecotype**	Non-stressed	57±22a	13±0.5a	2.2±0.1c	0.6±0.1a	0.3±0.06a	35±4a
		Stressed	67±4b	19±7.5b	1.7±0.2b	1.6±0.09b	1±0.17b	45±4b
	Commercial	Non-stressed	55±8a	13±4.5a	2.2±0.01c	0.8±0.03a	0.4±0.03a	43±3b
		Stressed	76±15c	19±3b	1.2±0.2a	1.9±0.15b	1.6±0.04c	68±3c
25	**Ecotype**	Non-stressed	55±1b	13±3a	2.2±0.03b	0.8±0.21a	0.4±0.09a	43±3a
		Stressed	76±9c	19±8b	1.2±0.09a	1.9±0.04c	1.6±0.14c	68±5b
	Commercial	Non-stressed	57±1b	18±3.5b	1.9±0.02b	0.6±0.51a	0.3±0.28a	42±0.2a
		Stressed	23±12a	16±11.5a	1±0.09a	1.2±0.01b	1.1±0.09b	69±4b
30	**Ecotype**	Non-stressed	34±4c	11±1.5a	1.1±0.01b	1.2±0.1a	1.1±0.09a	48±1a
		Stressed	26±0b	10±1.5a	0.8±0.1a	1.7±0.05b	2.1±0.33b	79±0.2c
	Commercial	Non-stressed	25±1b	17±4b	0.8±0.15a	1±0.15a	1.3±0.06a	60±3b
		Stressed	15±0a	11±3a	0.8±0.05a	1.6±0.1b	2.2±0.28b	80±2c

Table 21: Growth of *D. eriantha* ecotypes and commercial cultivar under different osmotic and temperature conditions. Significant differences ($p < 0.05$) between different treatments (non-stressed and stressed) and accessions are indicated by different lower-case letters. Comparisons were made within a temperature.

Temperature (˚C)	Accession	Treatment	Shoot height (mm)	Root length (mm)	Shoot mass (g)	Root mass (g)	Root/Shoot Ratio	Electrolyte leakage (%)
20	**Ecotype**	Non-stressed	67±4d	28±1b	2.6±0b	0.9±0.2a	0.3±0.1a	18±0.01a
		Stressed	60±1c	9±0.5a	1.6±0.2a	1.9±0.9a	1.3±0.7b	37±5.8c
	Commercial	Non-stressed	55±7b	22±1b	2.6±0.1b	0.9±1.2a	0.4±0.4a	29±1.6b
		Stressed	48±11a	9±0.5a	1.8±0.3a	1.1±0.2a	0.6±0.03a	60±1.3d
25	**Ecotype**	Non-stressed	55±3c	22±2c	2.6±0.03b	0.9±0a	0.4±0.003a	29±2.1a
		Stressed	48±2b	9±0.5a	1.8±0.2a	1.1±0.1a	0.6±0.02b	60±1b
	Commercial	Non-stressed	39±2b	18±1.5c	3.3±0.6b	1.1±0.2a	0.3±0.01a	39±6.1a
		Stressed	37±6a	12±0.5b	1.8±0.3a	0.9±0.02a	0.5±0.07ab	67±2.3c
30	**Ecotype**	Non-stressed	54±4b	23±2b	3.3±0.03b	1.2±0.2a	0.4±0.06a	43±1.6a
		Stressed	55±5b	15±0.5a	2.1±0.4a	2.2±1b	1.2±0.7b	68±1.1b
	Commercial	Non-stressed	57±2b	25±0.5b	3.1±1b	2.2±0.04b	0.8±0.2ab	42±1.3a
		Stressed	49±2a	13±0.5a	2.4±0.2a	1.8±0.1b	0.8±0.1ab	75±0.7c

6.3.2.4. Quantifying the germination responses of eight winter rainfall species to temperature and osmotic stress

Figures 21 and 22 provides the seed germination percentage of each of the species at different germination temperatures and osmotic treatments. Figure 21 shows the indigenous legume species, while Figure 22 shows currently commercially available species.

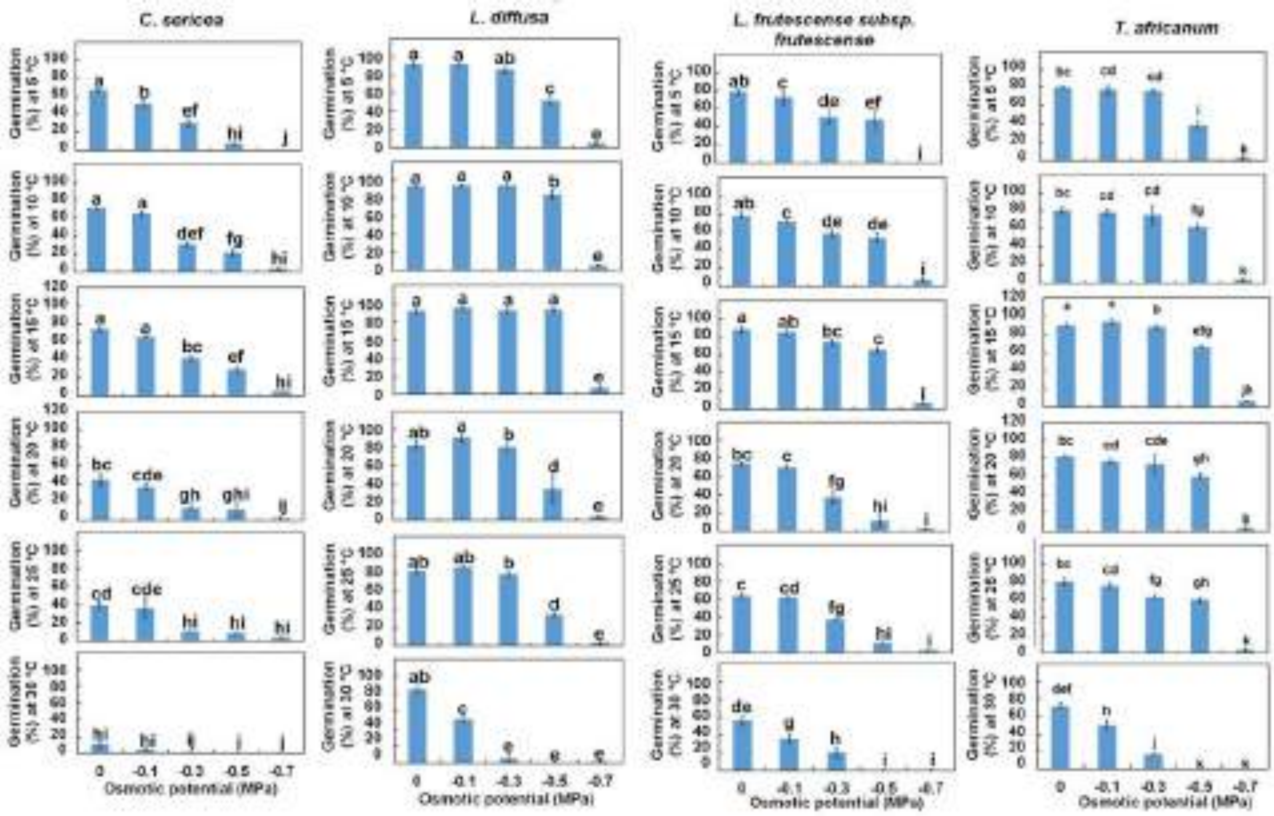

Figure 21: Seed germination (%) in *Calobota sericea, Lessertia diffusa, Lessertia frutescence*, and *Trifolium africanum* at different germination temperatures and osmotic treatments. Different letters indicate significant differences ($p < 0.05$) in seed germination between different osmotic and temperature treatments.

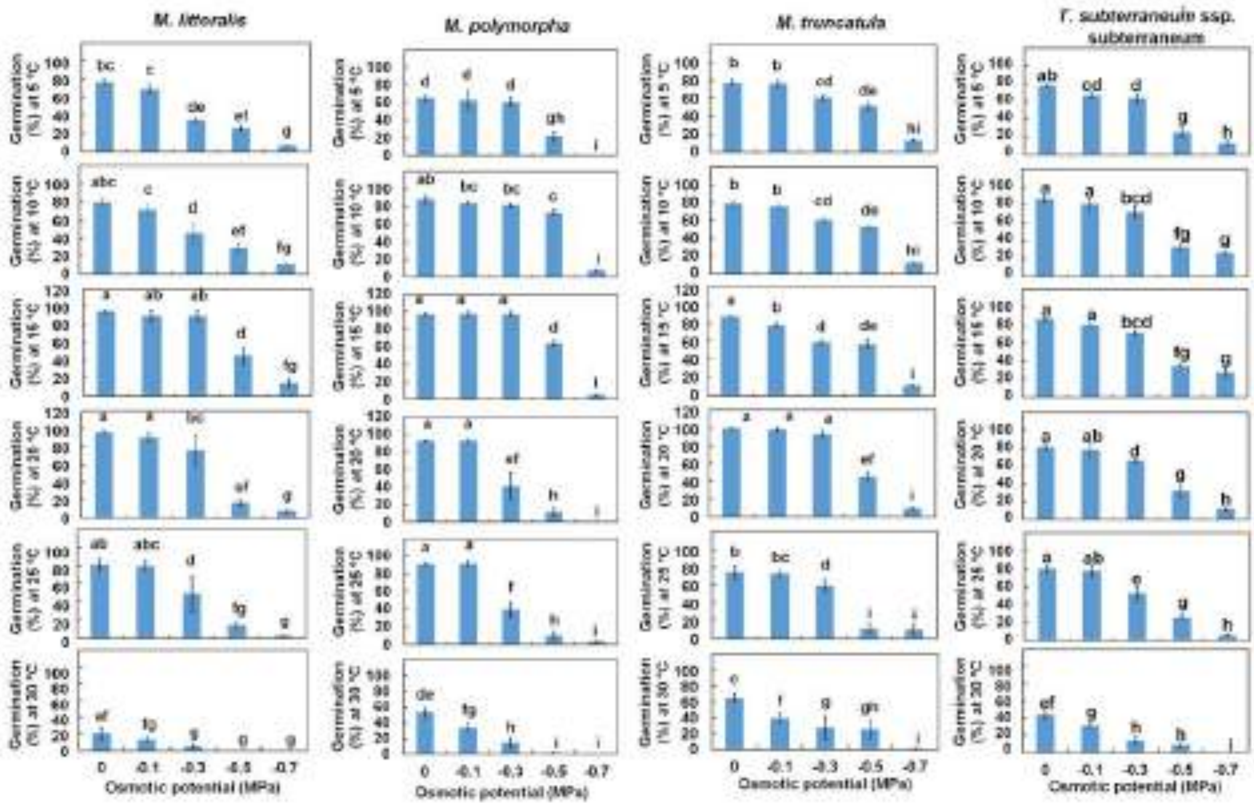

Figure 22: Seed germination (%) in *Medicago littoralis, Medicago polymorpha, Medicago truncatula*, and *Trifolium subterraneum* at different germination temperatures and osmotic treatments. Different letters indicate significant differences ($p < 0.05$) in seed germination between different osmotic and temperature treatments.

Results from the germination trial has shown that the different species differ in their germination responses to temperature and osmotic stress conditions, as well as to combinations of these stresses. Many authors have indicated that the success, and rate, of germination at different germination temperatures and/or osmotic stress levels, can be related to the ecological and geographical conditions from where the seeds were collected (Ascough et al., 2007; Luna et al., 2012; Hu et al., 2015). Thus, because these species are originating from the winter rainfall region, the optimum germination temperatures of 5 ˚C to 15 ˚C under well-watered conditions in this study was expected. However, species such as *L. diffusa* (Figure 21), *T. africanum* (Figure 21), *M. polymorpha* (Figure 22), and *M. littoralis* (Figure 22) were able to germinate optimally (> 70 %) up to 30˚C, 30˚C, 25˚C, and 25˚C respectively, under well-watered or slight drought stressed conditions (- 0.1 MPa). It was therefore clear that certain of the species evaluated are able to cope with increasing germination temperatures as long as water availability is not a limiting factor.

Results also show that occasionally there were species which could germinate optimally (> 70 %) at moderate drought stressed conditions (- 0.3 MPa). Species that could achieve this included M. *polymorpha* (up to temperatures of 15˚C), *T. africanum, M. truncatula*, and *M. littoralis* (up to temperatures of 20 ˚C), and *L. diffusa* (up to temperatures of 25 ˚C). Furthermore, *L. diffusa* was able to achieve a germination percentage of more than 80 %, at temperatures of 10 ˚C and 15 ˚C even at severe water limitation (- 0.5 MPa). For seeds to germinate a low soil moisture conditions, follow up rains would be extremely important to prevent losses due to subsequent desiccation. However, in areas where soil moisture content is low due to regular low rainfall amounts, species such as *M. polymorpha, T. africanum, M. truncatula, M. littoralis* and *L. diffusa* could be considered as pastures due to their ability to germinate well at low soil moisture conditions. These species however should be evaluated first for their ability to establish and grow optimally under these water-limited conditions.

6.3.2.5. Quantifying seedling establishment, growth, and development of eight winter rainfall species under different levels of drought stress (water-limitation).

Even though some of the species mentioned above will be able to germinate and establish at higher temperatures, often these higher temperatures means that soil moisture will decrease rapidly prior to the seedlings having adequate chance to develop deeper root systems, which are able to access water resources from deeper in the soil. This is especially true within semi-arid and arid environments where the water needed for seed germination and subsequent seedling establishment and growth is limited and available only for short periods and follow up rains are spread over longer periods (Hu et al., 2015). In this trial, seedling emergence was counted daily for eight days and the number of emerged seedlings in each pot recorded (Table 22). From this, the maximum percentage of seedlings emerged per pot was calculated (Table 23). The corresponding soil water content for each day was determined from unplanted pots in the greenhouse and expressed as a percentage of the pot capacity. At the end of the trial (day 8) the remaining seedlings were quantified and the percentage mortality calculated from the maximum seedling emergence per pot (Table 25).

Results from this trial indicated that soil moisture content at the time of planting significantly influence seedling establishment and that decreasing soil moisture results in significant seedling mortality (Table 22). We found that seedlings of all species, with the exception of *L. diffusa* and *M. littoralis* would establish at rates greater than 60 %, even when planted at a soil moisture content of 50 % of capacity (Table 23). Seedling establishment for all species were below 25 % when planted at soil moisture content below 50 % of capacity (Table 24). All species that were planted when soil moisture content was high i.e. 100 % were able to obtain a maximum establishment of greater than 75 %. However, when planted at a soil moisture content 70 % of capacity, *T. subterraneum* ssp. subterraneum and *M. littoralis* had significant lower levels of seedling establishment, with only 64 % and 52 % of *T. subterraneum* ssp. subterraneum and *M. littoralis* seedlings establishing, respectively (Table 24). When soil moisture content dropped to 50 % of capacity all species, with the exception of *M. polymorpha* and *M. truncatula* had significantly less seedlings establishing, ranging from 43 % to 74 %, with *M. polymorpha, M. truncatula* and *C. sericea* still having a 90 %, 79 % and 73% successful seedling establishment, respectively (Table 24). At the end of the trial, soil moisture levels reached 6 % of capacity (Table 22). At this stage, significant seedling mortality was observed, with only seedlings that were established at soil moisture contents of 100 %, 70 % and 50 % having seedlings that survived, while 100 % mortality was observed in seedlings established at 40 % of soil moisture capacity (Table 22). In all instances, except when planted at a soil moisture content of less than 50 %, *M. polymorpha, M. truncatula, T. subterraneum* and *C. sericea* had more than 10 % of seedlings surviving to a soil moisture content of only 5 % of capacity (Table 24).

Table 22: Seedling emergence eight winter rainfall species in relation to soil moisture content (% of soil water capacity) at planting. Significant differences ($p < 0.05$) in seedling emergence within a species at each planting time is indicated by different superscript letters. T1, 2, 3 and 4 equates to planting at 100 %, 70 %, 50 % and 40 % of soil water capacity, respectively.

Seedling emergence (%)								**Species**	
0 ± 0^{a}	30 ± 5^{b}	74 ± 4^{c}	92 ± 2^{d}	98 ± 1^{d}	97 ± 2^{d}	80 ± 7^{c}	10 ± 2^{a}	*C. sericea*	
0 ± 0^{a}	39 ± 13^{b}	80 ± 8^{c}	86 ± 8^{c}	95 ± 3^{d}	96 ± 3^{d}	77 ± 7^{c}	9 ± 2^{a}	*L. frutescence subsp. frutescence*	
0 ± 0^{a}	0 ± 0^{a}	50 ± 4^{b}	55 ± 5^{b}	77 ± 2^{c}	77 ± 2^{c}	49 ± 6^{b}	5 ± 3^{a}	*L. diffusa*	
0 ± 0^{a}	3 ± 1^{a}	66 ± 8^{c}	81 ± 5^{d}	95 ± 2^{e}	97 ± 2^{e}	79 ± 6^{d}	11 ± 3^{b}	*T. africanum*	**T1**
0 ± 0^{a}	6 ± 4^{a}	11 ± 4^{a}	60 ± 7^{c}	90 ± 3^{d}	52 ± 2^{c}	32 ± 7^{b}	0 ± 2^{a}	*T. subterraneum spp. Subterraneum*	
0 ± 0^{a}	9 ± 3^{ab}	77 ± 4^{c}	82 ± 4^{d}	93 ± 2^{e}	95 ± 2^{e}	80 ± 8^{c}	11 ± 4^{b}	*M. polymorpha*	
0 ± 0^{a}	11 ± 2^{a}	44 ± 3^{b}	61 ± 4^{c}	74 ± 5^{d}	76 ± 3^{d}	47 ± 8^{b}	12 ± 1^{a}	*M. truncatula*	
0 ± 0^{a}	9 ± 3^{a}	21 ± 11^{b}	47 ± 5^{c}	72 ± 4^{d}	77 ± 4^{d}	61 ± 4^{c}	5 ± 2^{a}	*M. littoralis*	
	0 ± 0^{a}	61 ± 5^{b}	90 ± 2^{c}	93 ± 1^{c}	95 ± 1^{c}	80 ± 3^{b}	2 ± 3^{a}	*C. sericea*	
	0 ± 0^{a}	29 ± 6^{b}	71 ± 7^{c}	97 ± 5^{d}	96 ± 6^{d}	39 ± 7^{b}	2 ± 4^{a}	*L. frutescence subsp. frutescence*	
	0 ± 0^{a}	18 ± 6^{a}	51 ± 7^{b}	64 ± 8^{bc}	76 ± 2^{c}	50 ± 7^{b}	4 ± 2^{a}	*L. diffusa*	
	0 ± 0^{a}	13 ± 3^{b}	70 ± 15^{c}	80 ± 7^{d}	84 ± 8^{d}	61 ± 11^{c}	10 ± 4^{ab}	*T. africanum*	**T2**
	0 ± 0^{a}	9 ± 3^{a}	21 ± 5^{b}	50 ± 6^{c}	64 ± 5^{c}	38 ± 4^{b}	6 ± 3^{a}	*T. subterraneum spp. Subterraneum*	
	0 ± 0^{a}	59 ± 21^{b}	88 ± 3^{c}	91 ± 2^{c}	92 ± 2^{c}	45 ± 2^{b}	15 ± 4^{a}	*M. polymorpha*	
	0 ± 0^{a}	11 ± 4^{a}	40 ± 12^{b}	68 ± 3^{c}	71 ± 2^{c}	56 ± 3^{b}	12 ± 3^{a}	*M. truncatula*	
	0 ± 0^{a}	5 ± 7^{ab}	15 ± 10^{b}	52 ± 2^{c}	47 ± 2^{c}	12 ± 2^{b}	2 ± 1^{a}	*M. littoralis*	
		0 ± 0^{a}	26 ± 7^{b}	66 ± 10^{c}	73 ± 10^{c}	31 ± 3^{b}	10 ± 5^{ab}	*C. sericea*	
		0 ± 0^{a}	50 ± 7^{c}	60 ± 6^{c}	61 ± 5^{c}	30 ± 7^{b}	2 ± 2^{a}	*L. frutescence subsp. frutescence*	
		0 ± 0^{a}	14 ± 3^{a}	52 ± 3^{c}	54 ± 1^{c}	21 ± 2^{b}	2 ± 3^{a}	*L. diffusa*	
		0 ± 0^{a}	24 ± 6^{b}	65 ± 9^{d}	71 ± 6^{d}	42 ± 6^{c}	2 ± 2^{a}	*T. africanum*	**T3**
		0 ± 0^{a}	21 ± 10^{b}	51 ± 2^{c}	60 ± 3^{c}	30 ± 3^{b}	10 ± 1^{a}	*T. subterraneum spp. Subterraneum*	
		0 ± 0^{a}	41 ± 14^{c}	85 ± 3^{d}	90 ± 3^{d}	62 ± 6^{b}	15 ± 3^{a}	*M. polymorpha*	
		0 ± 0^{a}	51 ± 10^{b}	70 ± 10^{c}	79 ± 7^{c}	49 ± 6^{b}	10 ± 1^{a}	*M. truncatula*	
		0 ± 0^{a}	11 ± 4^{b}	28 ± 6^{b}	49 ± 2^{c}	22 ± 7^{b}	0 ± 0^{a}	*M. littoralis*	
			0 ± 0^{a}	14 ± 9^{b}	14 ± 9^{b}	1 ± 1^{a}	0 ± 0^{a}	*C. sericea*	
			0 ± 0^{a}	20 ± 4^{b}	24 ± 3^{b}	0 ± 0^{a}	0 ± 0^{a}	*L. frutescence subsp. frutescence*	
			0 ± 0^{a}	4 ± 3^{a}	7 ± 4^{a}	0 ± 0^{a}	0 ± 0^{a}	*L. diffusa*	
			0 ± 0^{a}	2 ± 1^{a}	6 ± 2^{a}	3 ± 2^{a}	0 ± 0^{a}	*T. africanum*	**T4**
			0 ± 0^{a}	4 ± 3^{a}	6 ± 3^{a}	2 ± 1^{a}	0 ± 0^{a}	*T. subterraneum spp. Subterraneum*	
			0 ± 0^{a}	20 ± 7^{b}	22 ± 7^{b}	14 ± 5^{b}	0 ± 0^{a}	*M. polymorpha*	
			0 ± 0^{a}	5 ± 3^{b}	9 ± 3^{b}	1 ± 1^{a}	0 ± 0^{a}	*M. truncatula*	
			0 ± 0^{a}	5 ± 8^{a}	9 ± 8^{a}	0 ± 0^{a}	0 ± 0^{a}	*M. littoralis*	
100±0^{h}	70±1.4^{g}	50±0.6^{f}	40±1.4^{e}	30±2.1^{d}	15±1.3^{c}	10±1.0^{b}	5±0.5^{a}	**Soil Moisture (% of pot capacity)**	

Table 23: Maximum seedling emergence in eight winter rainfall species planted at 100 %, 70 %, 50 % and 40 % of soil water capacity. Different lower-case letters indicate significant differences ($p < 0.05$) in seedling emergence between species at each soil moisture content and underlined superscript upper-case letters indicate significant differences ($p < 0.05$) within a species between the different soil moisture contents.

	Maximum seedling emergence (%)			
C. sericea	98 ± 1c$^{\underline{C}}$	95 ± 1d$^{\underline{C}}$	73 ± 10cd$^{\underline{B}}$	14 ± 9ab$^{\underline{A}}$
L. frutescence subsp. frutescence	96 ± 3c$^{\underline{C}}$	93 ± 6cd$^{\underline{C}}$	61 ± 5bc$^{\underline{B}}$	24 ± 3b$^{\underline{A}}$
L. diffusa	77 ± 2a$^{\underline{C}}$	76 ± 2b$^{\underline{C}}$	54 ± 1ab$^{\underline{B}}$	7 ± 4a$^{\underline{A}}$
T. africanum	97 ± 2c$^{\underline{C}}$	84 ± 8bc$^{\underline{BC}}$	71 ± 6c$^{\underline{B}}$	6 ± 2a$^{\underline{A}}$
T. subterraneum spp. Subterraneum	90 ± 3b$^{\underline{C}}$	64 ± 5a$^{\underline{B}}$	60 ± 3b$^{\underline{B}}$	6 ± 3a^{A}
M. polymorpha	95 ± 2c$^{\underline{B}}$	92 ± 2cd$^{\underline{B}}$	90 ± 3e$^{\underline{B}}$	22 ± 7b$^{\underline{A}}$
M. truncatula	76 ± 3b$^{\underline{B}}$	71 ± 2b$^{\underline{B}}$	79 ± 7d$^{\underline{B}}$	9 ± 3a$^{\underline{A}}$
M. littoralis	77 ± 4a$^{\underline{D}}$	52 ± 2a$^{\underline{C}}$	49 ± 2a$^{\underline{B}}$	9 ± 8a$^{\underline{A}}$
Soil moisture (% of pot capacity)	100 ± 0	70 ± 1.4	50 ± 0.6	40 ± 1.4

Table 24: Seedling mortality in eight drought stressed winter rainfall species planted at 100 % (T1), 70 % (T2), 50 % (T3) and 40 % (T4) of soil water capacity. Mortality was calculated at the end of the trial when soil water content reached 5 % of capacity.

	Seedling mortality (%)			
	T1	**T2**	**T3**	**T4**
C. sericea	90 ± 2	98 ± 2	90 ± 4	100 ± 0
L. frutescence subsp. frutescence	91 ± 2	98 ± 2	98 ± 2	100 ± 0
L. diffusa	95 ± 0	96 ± 3	98 ± 2	100 ± 0
T. africanum	89 ± 1	90 ± 5	98 ± 2	100 ± 0
T. subterraneum spp. Subterraneum	99 ± 1	94 ± 4	90 ± 3	100 ± 0
M. polymorpha	93 ± 2	85 ± 3	85 ± 5	100 ± 0
M. truncatula	95 ± 2	88 ± 1	90 ± 3	100 ± 0
M. littoralis	95 ± 4	98 ± 4	100 ± 0	100 ± 0

With follow up rains expected to become more variable and the durations between rainfall events expected to become longer under future bioclimatic conditions, it is important to select species that are able to cope longer with decreasing soil moisture content, until follow up rains occur. From these results, *M. polymorpha* and *M. truncatula* seemed to be better suited for establishment and survival under water-limited agro-ecological conditions. Similarly, it is important to realize that *L. frutescense* was able to reach 24 % seedling establishment when planted at a soil moisture content of only 40 %, with *M. polymorpha* having 22 %, and *C. sericea* having 14 % seedling establishment at these water-limited conditions (Table 24). In areas with more variable rainfall early during the wet season, the results obtained from this study show that *M. polymorpha, M. truncatula, T. subterraneum and C. sericea* may be better options for planting as more of their established seedlings may survive water-limited conditions for longer periods until follow up rains occur (Table 25).

6.3.2.6. Seedling characteristics of eight winter rainfall region species subjected to different durations of drought stress.

Due to the fact that all of the species evaluated could germinate and establish at soil moisture contents that are sub-optimal for subsequent growth, it is important to also determine how established plants will respond to the water-limited agro-ecological conditions. The identification of species that are able to grow optimally under water-limited conditions means that under future bioclimatic conditions, pastures could be established under sub-optimum seed germination and seedling establishment conditions without compromising on pasture productivity. This in turn, could result in longer utilization of the pastures as seeds could potentially be sown earlier. However, after successful seed germination and seedling establishment, it is expected that plant growth and development would be impacted more severely later during the wet season, when rainfall is expected to become less and more variable. It was important therefore, to determine how established plants would cope with water-limitation.

Figure 23 shows the morphological characteristics of *C. sericea* under well-watered and water-limited conditions. Results for this species shows that under water-limited conditions, irrespective of the duration of the stress, root length significantly increases while root mass significantly decreases. Shoot length and mass decreases with water-limitation and root:shoot length ratio increases under water-limited conditions.

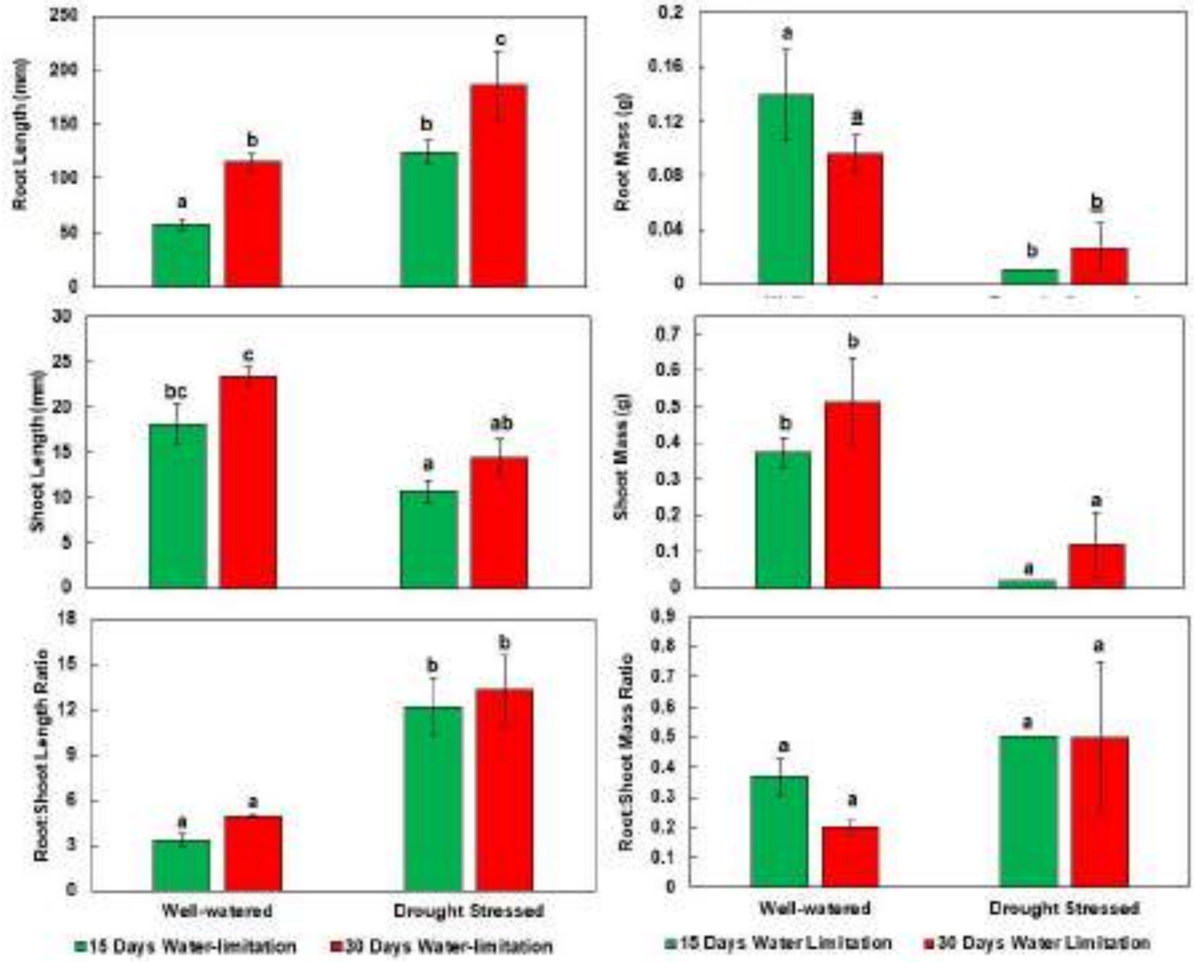

Figure 23: Morphological characteristics of *C. sericea* subjected to 15 and 30 days of water-limitation

Figure 24 shows the morphological characteristics of *L. diffusa* under well-watered and water-limited conditions. Results for this species shows that root length is not influenced by water-limitation, irrespective of the duration of the drought stress. However, root mass under prolonged drought stress results in significantly lighter root systems. With regard to shoot growth, shoot length was found to significantly decrease only under prolonged drought stress conditions while shoot mass decreased significantly under water-limited conditions, irrespective of the duration of the stress. Root:shoot length ratios only increased under extended stressed conditions while mass ratios significantly increased under water-limited conditions, irrespective of the duration of the stress.

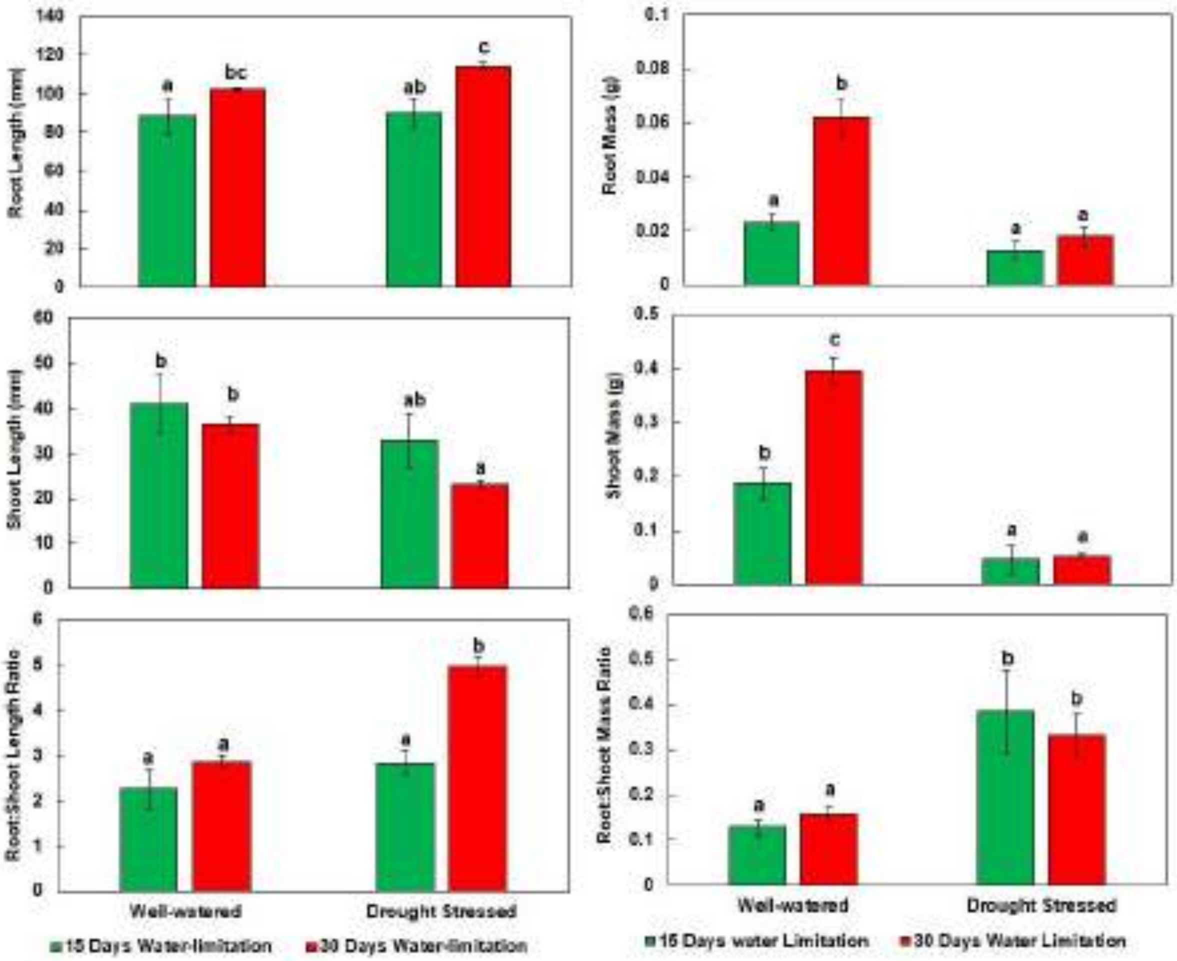

Figure 24: Morphological characteristics of *L. diffusa* subjected to 15 and 30 days of water-limitation

Figure 25 shows the morphological characteristics of *L. frutescense subsp. frutescense* under well-watered and water-limited conditions. Results for this species shows that root length increases under water-limited conditions, irrespective of the duration of the stress. However, root mass significantly decreases with water-limitation, irrespective of the duration of the stress. Shoot length decreased with moisture-limitation but shoot mass only decreased under extended periods of water-limitation. Root:shoot length ratios increased significantly under water-limited conditions while mass ratios did not differ.

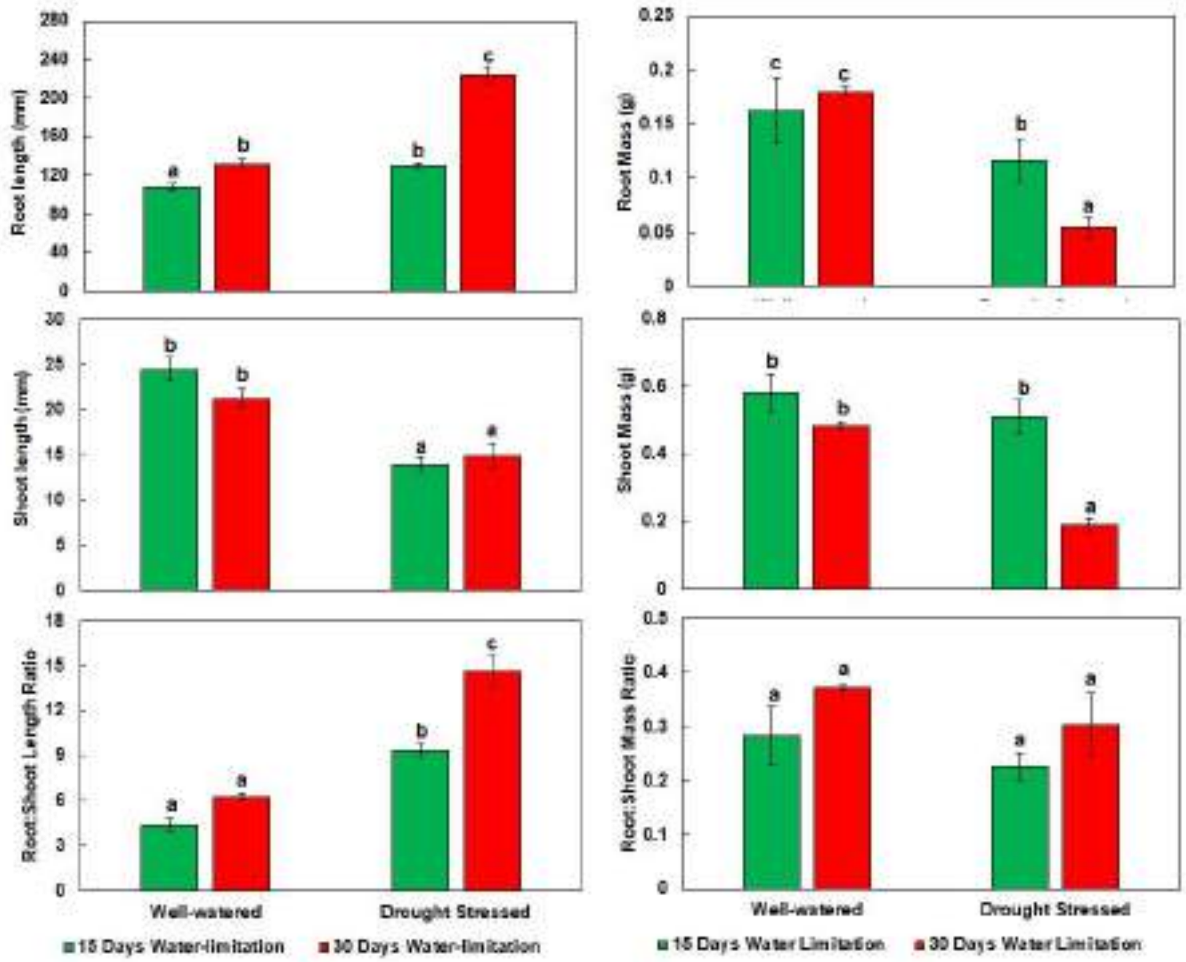

Figure 25: Morphological characteristics of *L. frutescense subsp. frutescense* subjected to 15 and 30 days of water limitation

Figure 26 shows the morphological characteristics of *M. littoralis* under well-watered and water-limited conditions. Results for this species show that root and shoot length decreased under water-limited conditions, but only under extended periods of water limitation. Root and shoot mass, however, decreased significantly under water-limited conditions, irrespective of the period of water limitation. Only root: shoot length ratios and not the mass ratios increased under extended water-limited conditions.

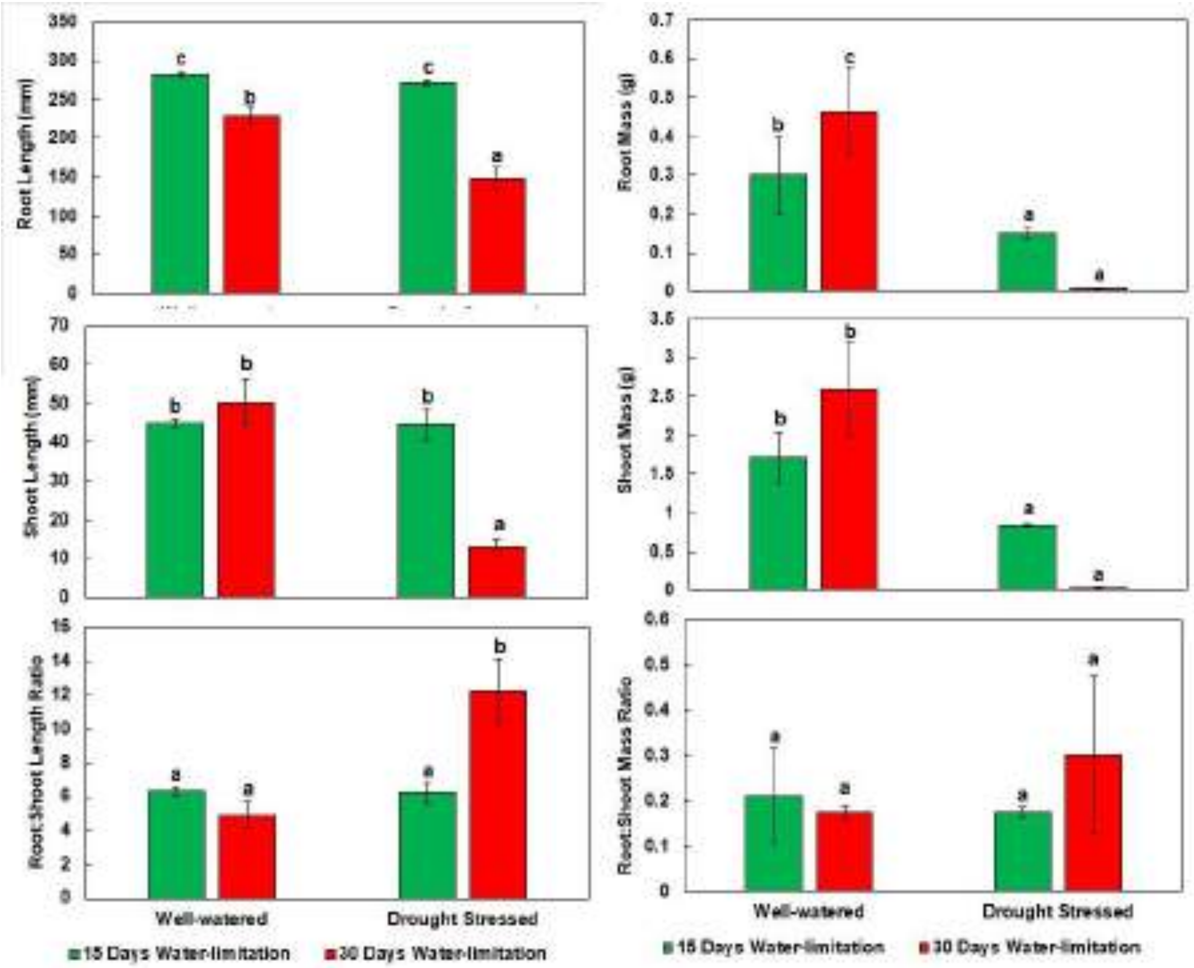

Figure 26: Morphological characteristics of *M. littoralis* subjected to 15 and 30 days of water-limitation

Figure 27 shows the morphological characteristics of *M. polymorpha* under well-watered and water-limited conditions. Results for this species shows that root length increases under water-limited conditions, irrespective of the duration of the stress. However, root mass significantly decreased under water-limited conditions, irrespective of the duration of the stress. Both root: shoot length and mass ratios increased under water-limited conditions under both durations of drought stress.

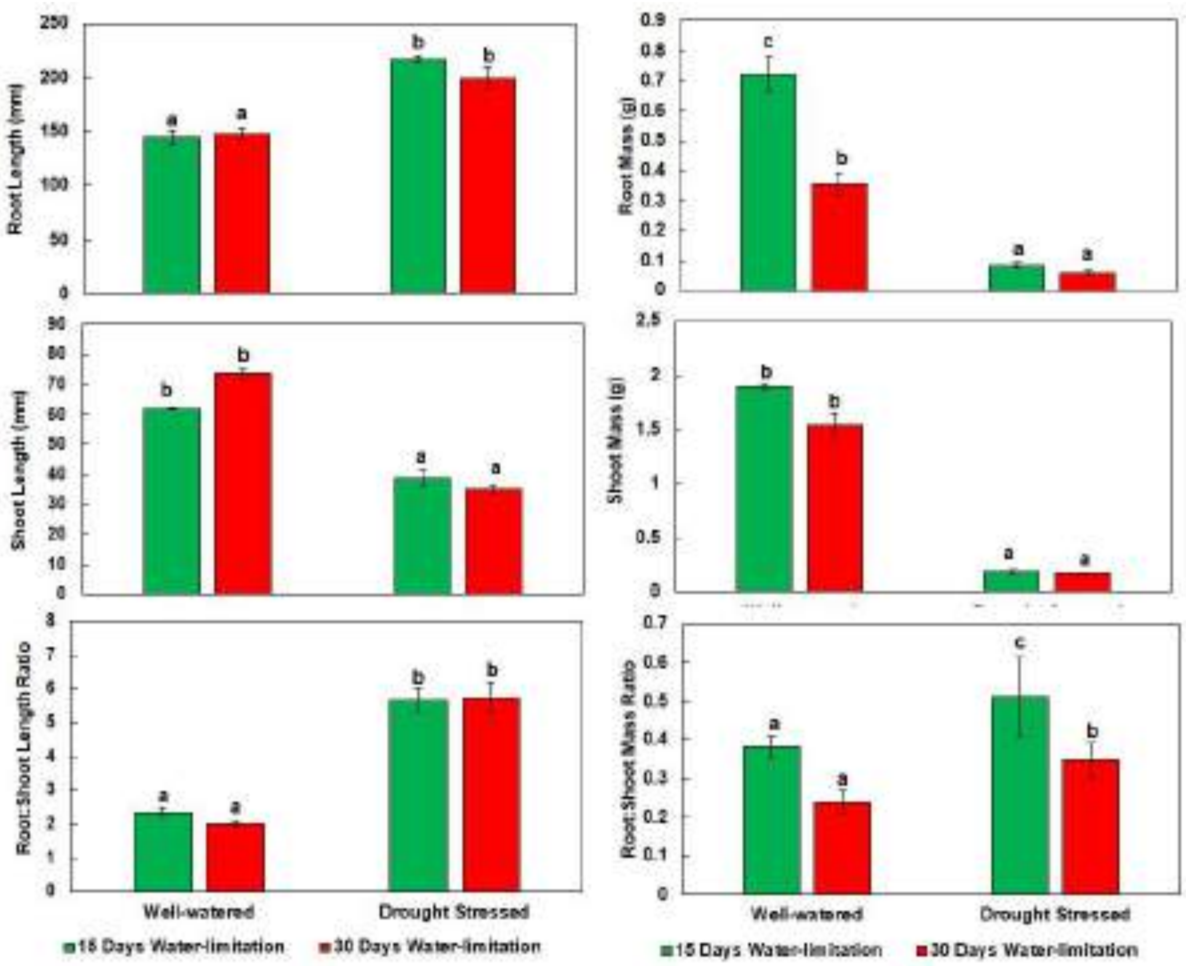

Figure 27: Morphological characteristics of *M. polymorpha* subjected to 15 and 30 days of water-limitation

Figure 28 shows the morphological characteristics of *M. truncatula* under well-watered and water-limited conditions. Results for this species show that root length significantly increases under water-limited conditions, irrespective of the duration of the stress. However, root mass significantly decreases under water-limited conditions. Shoot length only significantly decreased under extended periods of water limitation, while shoot mass decreased under both durations of water limitation. Root: shoot length ratio significantly increased with water limitation, but the mass ratios did not differ between the non-stressed and stressed conditions.

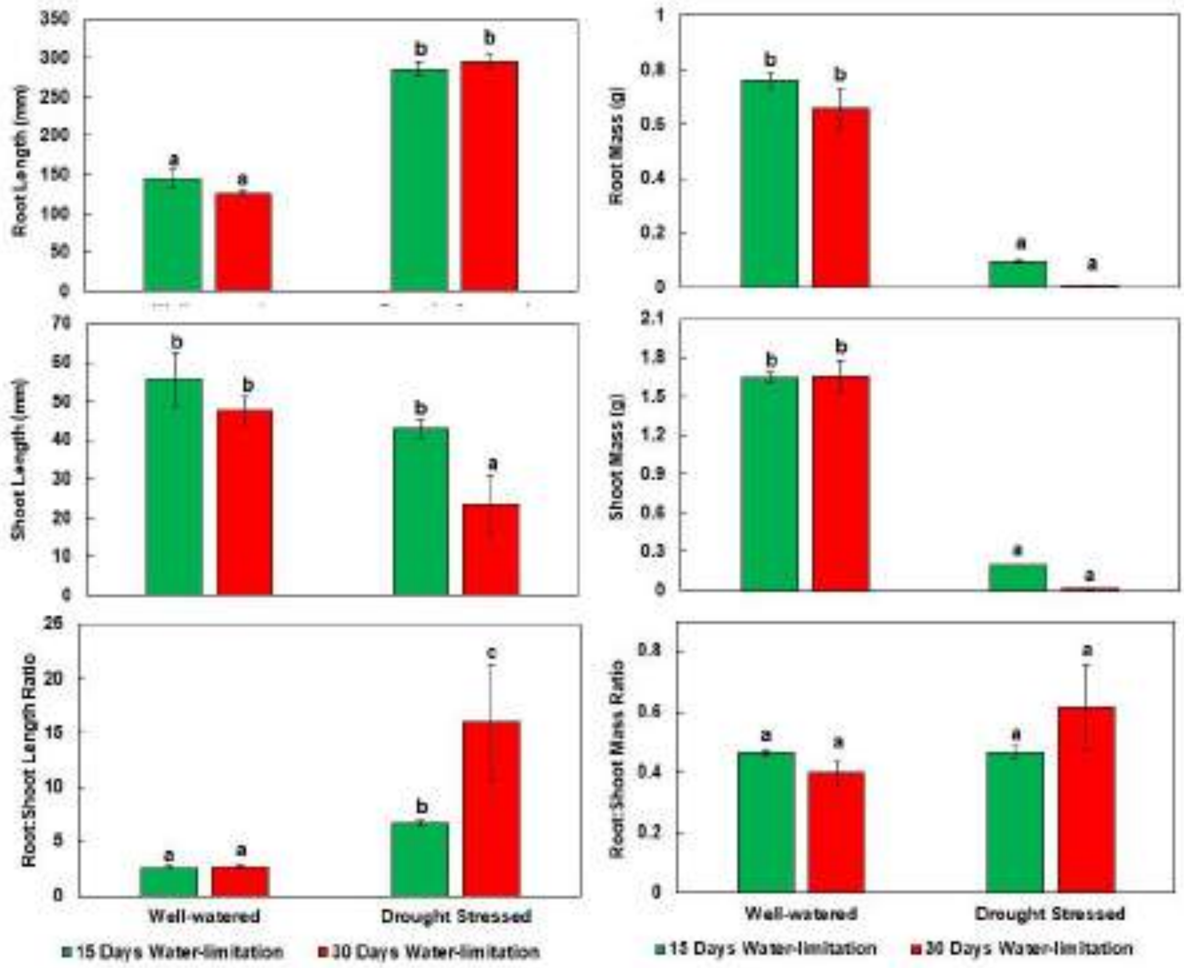

Figure 28: Morphological characteristics of *M. truncatula* subjected to 15 and 30 days of water limitation

Figure 29 shows the morphological characteristics of *T. africanum* under well-watered and water-limited conditions. Results for this species showed increased root growth under water-limited conditions, irrespective of the duration of the water-limited conditions. However, root mass under water-limited conditions did not differ under the shorter duration of the stress, but significantly decreased when the stressed conditions were prolonged. Shoot length and mass decreased only at extended periods of water limitation. Similarly, root: shoot length and mass ratios were only impacted under the extended water-limited conditions, where root: shoot ratios increased under the water-limited conditions.

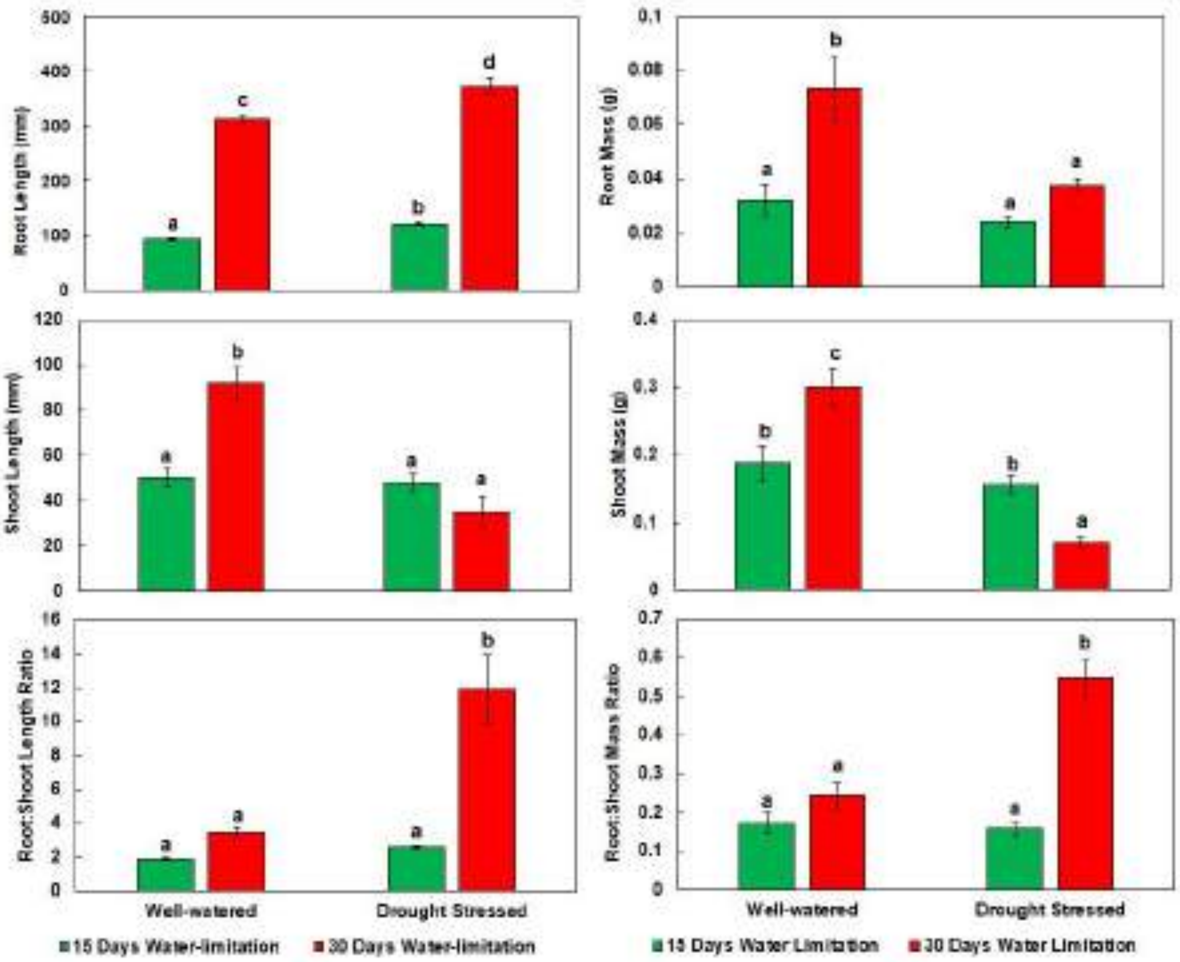

Figure 29: Morphological characteristics of *T. africanum* subjected to 15 and 30 days of water-limitation

Figure 30 shows the morphological characteristics of *T. subterraneum* under well-watered and water-limited conditions. Results for this species show that root length increases under water-limited conditions, irrespective of the duration of the stress period. Root mass, however, significantly decreased under water-limited conditions, but only under extended periods of water limitation. Shoot length significantly decreased under water-limited conditions, while shoot mass also decreased, but only under extended periods of water limitation. Both root: shoot length and mass ratios significantly increased under water-limited conditions, irrespective of the duration of the water limitation.

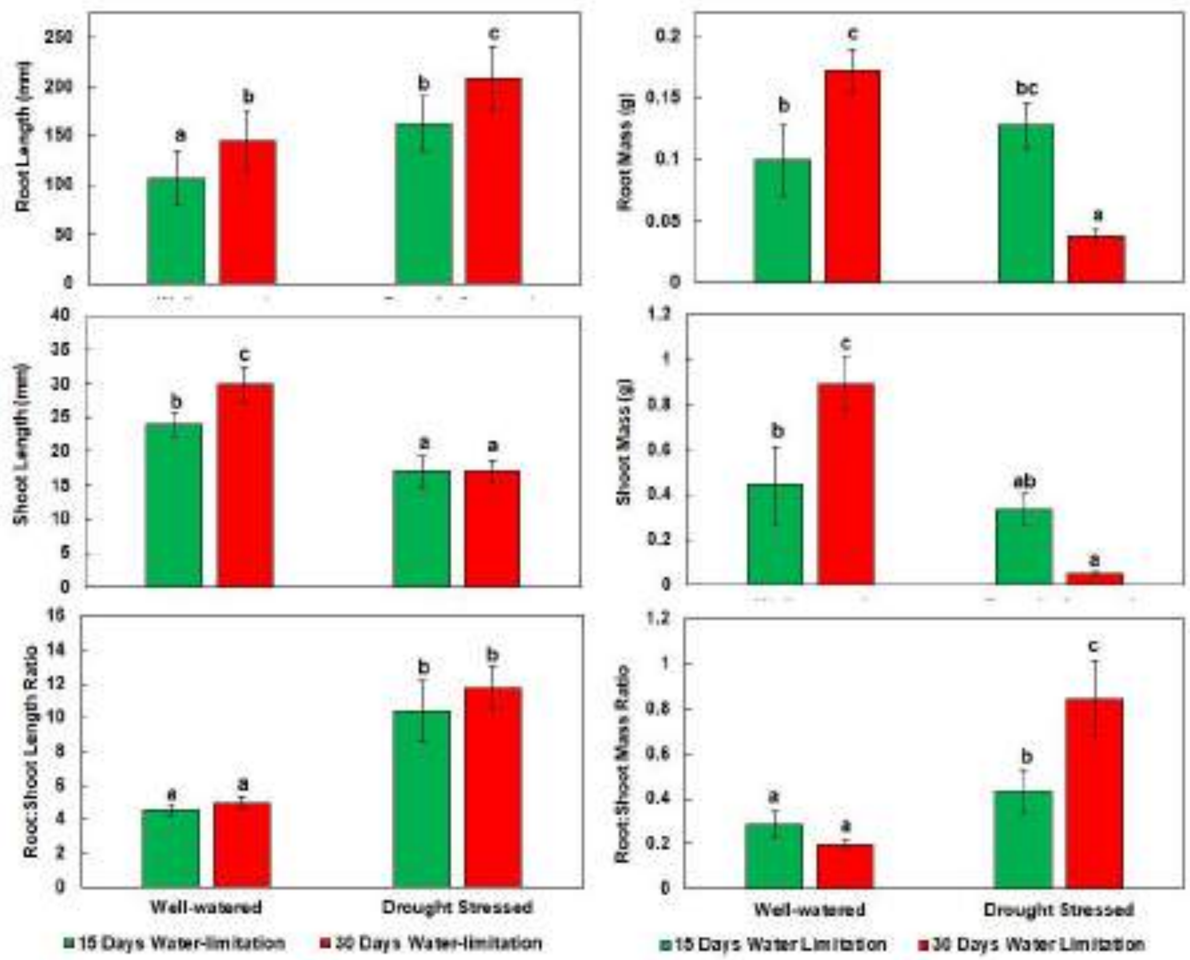

Figure 30: Morphological characteristics of *T. subterraneum subsp. subterraneum* subjected to 15 and 30 days of water limitation

In general, our results indicate that a significant change in above and below ground plant growth under water-limited conditions for all species evaluated. This is accompanied by altered resource partitioning, which generally was in favour of root growth over shoot growth, as shown by the increased root: shoot ratios. This finding corresponds to the optimum partitioning theory (Bloom et al. 1985; Mao et al. 2012; Gargallo-Garriga et al. 2014; Eziz et al. 2017) in that under water-limited conditions, these plants were found to allocate more resources towards the structures that are tasked with capturing the limited resource. The early increased allocation of growth to roots suggests that these species may have access to deeper water resources for longer periods as the drought progresses. The importance of root morphology in drought tolerance in plants has resulted in it becoming one of the targeted traits for plant breeders for improving water harvesting from deeper water resources in the soil (Polle et al. 2019). Therefore, the improved root traits developed by these species under water limitation may also result in better adaptation of these plants to subsequent water-limited conditions during the growing season.

6.4 CONCLUSION

In conclusion, the success with which seeds germinate, and seedlings establish and survive is closely linked to the favourability of their surrounding environmental conditions (Bewley and Black, 1994). Temperature and moisture availability are considered as the most important variables influencing these processes. Results from the current study indicate that the species evaluated respond differently to drought stress. Under agronomic conditions, seeds are sown with their dormancy already broken down, and seeds will imbibe water and germinate even at sub-optimum growing conditions. Thus, there is a need to understand how these species would respond to periods of unfavourable growing conditions. From the results of the current study, specific species have stood out as being able to tolerate incidences of drought at different developmental stages, better than others. Often the best performing species differed when drought was imposed at different development stages. For instance, *M. polymorpha* and *L. diffusa* can germinate well at high temperatures when water is not a limiting factor. These species including *M. truncatula* however, can germinate well at moderate levels (- 0.3 MPa) of water-limitation. Similarly, seedlings of the species mentioned above, with the addition of *T. africanum* are able to establish well under reduced soil moisture conditions, even though only *M. polymorpha* and *M. truncatula* had more than 10 % seedlings that could survive severely low soil moisture conditions. Furthermore, *T. africanum* and *T. subterraneum* ssp. subterraneum were able to maintain their shoot biomass at well-watered levels under moderate drought stress conditions, suggesting that these species have adaptations to cope with short durations of droughts. Other species however, displayed other drought tolerance traits and developed longer roots which allow them to persist under drought conditions. Species such as *T. africanum* and *L. diffusa*, increased root growth was only seen during severe drought conditions while species such as *M. polymorpha, M. truncatula* and *T. subterraneum* ssp. subterraneum increased allocation to root growth occurred early during drought conditions. It is possible that additional physiological and/or biochemical mechanisms of drought tolerance are also employed by these species. These drought tolerance mechanisms could include adaptive responses, which minimize the loss of water e.g. reduced stomatal conductance, transpiration rate or leaf area (Perez-Harguindeguy et al. 2013, Basu et al. 2016). They may also be able to cope with drought through increased production of protective pigments (carotenoid and anthocyanin). One of the ways that plants have evolved to protect themselves against ROS-induced damage under water-limited conditions, is the synthesis of protective pigments such as carotenoids and anthocyanin (Efeoglu et al. 2009; Batra et al. 2014; Basal et al. 2020). These pigments contribute to the avoidance of severe damage to the photosynthetic machinery during the water-limited conditions, and allow for a faster recovery of the photosynthetic activity after re-watering (Hörtensteiner 2009; Frosi et al. 2017).

Therefore, based on the results above, six species namely *M. polymorpha, M. truncatula, T. africanum*, *L. diffusa*, *C. sericea*, and *T. subterraneum* ssp. subterraneum has been provisionally prioritized for further research into variation of drought tolerance between cultivars within these species. Out of these species, all, except *L. diffusa* and *C. sericea* has already been domesticated and commercialised. Over the years, these commercialised species have undergone significant selection for breeding for traits such as deep root systems, extended growing periods, protection from false breaks out of normal growing seasons, more appropriate patterns of hard-seed breakdown, and tolerance to pests and disease (Nichols et al. 2007, 2010). Therefore, a large genetic resource within each of these species exist that could lead to the identification of cultivars within species with beneficial traits for drought tolerance. These traits may not be found in a single existing cultivar but could be bred through crossing different genotypes with beneficial traits into a new cultivar. Therefore, a second phase of this specific project is suggested where all available commercial cultivars as well as South African genebank accessions of these four species are evaluated for differences in their ability to deal with drought tolerance, in each incidence identifying specific traits that are beneficial for drought tolerance, and including these into a new breeding program.

CHAPTER 7: GENERAL CONCLUSIONS & RECOMMENDATIONS

7.1 CONCLUSIONS

Under future bioclimatic conditions, sustainable livestock production systems in semi-arid and arid areas in South Africa are at risk due to a lack of bioclimatically suitable forage crops for these water-limited areas. Furthermore, the predicted future climate change scenarios for South Africa will be coupled with reduced areas suitable for irrigated pastures and fodder production, a rapidly increasing human population, and a subsequent increase in the demand for livestock products. This, in turn, dictates the identification of improved fodder flow programs that can be used in current water-limited areas, and under future bioclimatic conditions. The work done in this project was mainly focused on identifying, prioritising and collecting indigenous forage species as well as locally adapted ecotypes of already domesticated forages for further characterization and evaluation for their forage potential under water-limited conditions. Apart from this, a number of indigenous species e.g. *Stipagrostis ciliata*, *Stipagrostis obtusa*, *Calobota sericea, Trifolium africanum*, *Lessertia diffusa* and *Lessertia frutescence* were further characterised in this study.

The initiative to identify alternative forage genetic resources that can be implemented into fodder flow programs in semi-arid and arid areas of South Africa was motivated by:

1. Knowing that due to rapid population growth and the predicted climate change scenarios for South Africa, vegetable, grain, and fruit production will most likely take priority over forage production systems under irrigated conditions and in suitable bioclimatic areas for rain fed agricultural systems. This, in turn, will most likely mean that livestock and fodder production will have to shift to more marginal areas characterized by water-limitation.
2. The lack of current commercially available forage species suitable for use under dryland or minimum irrigated conditions within water-limited areas of South Africa.
3. The lack of current forage species that can be used under the predicted hotter and drier South African conditions.
4. The recognition that the future demand for livestock products will most likely outweigh their supply if livestock production continues only using current livestock production systems.

It is therefore important to identify alternative forage species, already adapted to the marginal bioclimatic and edaphic conditions as predicted by future climate change scenarios. This in turn, will allow for inclusion of these bioclimatically adapted species into alternative fodder flow programs, and for future breeding focuses to be on improving the growth and nutritional aspects of these prioritised species rather than trying to breed exotic germplasm to become adapted to these water-limited livestock production areas.

The work done in this study provides a database of species that has been prioritised for collection and evaluation for their agronomic potential. Collection initiatives from this study should be an ongoing initiative and the resources collected should become part of a collaborated effort to characterise these plant genetic resources with the end goal of developing improved forage resources for use in water-limited conditions. While the present study provides pieces of information regarding the adaptability of the prioritised species to water-limited conditions, it should still be regarded as a baseline for further work where additional prioritised species should be collected and evaluated further for their agronomic potential, and in comparison, with existing commercially available forages. The work presented in this project highlights the potential of the prioritised species and these species that has been collected and undergone some characterisation provides a baseline for starting with new crop improvement programs which could utilise the plant genetic resources to either improve existing forage genetic resources or develop new forage resources.

7.2 RECOMMENDATIONS

Since the study provided a baseline for species that should be further characterised and evaluated, the following recommendations are given.

1. Making use of the databases developed to further collection initiatives of prioritised species for inclusion into the genebank.
2. Development of protocols for germination and establishment of the indigenous plant genetic resources and making these available in the form of technical briefs or published methodologies.
3. Additional screening and characterisation of plant genetic resources for drought tolerance and determining the mechanisms of drought tolerance of these plant genetic resources.
4. Potentially also screening the collected plant genetic resources for their use under other types of stresses such as salinity or acidity stress.
5. Collection of beneficial rhizobium bacteria from legume species prioritised to develop improved inoculants for improved nitrogen fixation under agronomic conditions.
6. Including the plant genetic resources collected and screened into crop improvement programs either to develop new forage resources or improve existing material by using local ecotypes in breeding programs.
7. Evaluating the impacts of feeding these prioritised species on livestock condition and performance, possible changes in the gut microbiome, especially looking at the impact on greenhouse gas emissions from the livestock.
8. Evaluating the impacts of feeding prioritised species to livestock on meat and milk quality.

These further research focuses will significantly improve our understanding of the suitability of indigenous grass and legume species for improved livestock production under water-limited conditions.

REFERENCES

1. Ascough GD., Erwin JE., Van Staden J. 2007. Temperature-dependent seed germination in *Watsonia* species related to geographic distribution. South African Journal of Botany 73: 650–653.
2. Barbosa F.G., Schneck F., Melo A.S. 2012. Use of ecological niche models to predict the distribution of invasive species: a scientometric analysis. Brazilian Journal of Biology 72: 821–829.
3. Baskin C.C., Baskin J.M. 2004. A classification system for seed dormancy. Seed Science Research 14: 1 – 16.
4. Baskin C.C., Baskin J.M. 2014. Seeds: Ecology, biogeography and evolution of dormancy and germination, 2nd ed. Elsevier/Academic Press, San Diego, California, USA.
5. Bewley J.D. 1997. Seed germination and dormancy. The Plant Cell 9: 1055 – 1066.
6. Bewley J.D., Black M. 1994. Seeds: Physiology of Development and Germination. 2nd ed. Plenum Press. New York.
7. Boatwright J.S., Tilney P.M., van Wyk B.-E. 2018. A taxonomic revision of *Calobota* (Fabaceae, Crotalarieae). Strelitzia 39: 1–94.
8. Britz EA., Cyster LF., Cupido CF., Samuels MI., Masemola EL., Ngcobo N., Müller FL. 2023. Nitrogen fertilization increases the frowth and nutritional quality of the forage legume *Calobota sericea* – A preliminary investigation. Heliyon 9: https://doi.org/10.1016/j.heliyon.2023.e13535
9. Britz EA., Cyster LF., Cupido CF., Samuels MI., Müller FL. 2022. Nutritional quality of *Calobota sericea* fodders harvested at different phenological stages – Opportunities for inclusion in fodder flow programs for extensive livestock farmers. African Journal of Range and Forage Science https://doi.org/10.2989/10220119.2022.2086299
10. Cingolani, A.M., Vaieretti, M.V., Giorgis, M.A., La Torre, N., Whitworth-Hulse, J.I. and Renison, D., 2013. Can livestock and fires convert the sub-tropical mountain rangelands of central Argentina into a rocky desert? The Rangeland Journal, 35(3), pp.285-297.
11. Comas, L.H., Becker, S.R., Cruz, V.M.V., Byrne, P.F. and Dierig, D.A., 2013. Root traits contributing to plant productivity under drought. Frontiers in plant science, 4, p.442.
12. de Meyer S.E., Cnockaert M., Ardley J.K., van Wyk B-E., Vandamme P.A., Howieson J.G. 2014. *Burkholderia dilworthii* sp. nov., isolated from *Lebeckia ambigua* root nodules. International Journal of Systematic and Evolutionary Microbiology 64: 1090 – 1095.
13. DEA (Department of Environmental Affairs) 2013. Long-term adaptation scenarios flagship research program (LTAS) for South Africa. Climate change implications for the agriculture and forestry sectors in South Africa. Pretoria, South Africa.
14. Dickinson E.B., Hyam G.F.S., Breytenbach W.A.S., Metcaf H.D., Williams F.R., Scheepers L.J., Plint A.P., Smith H.R.H., van Vuuren P.J., Viljoen J.H., Archibald K.P., Els J.M. 2010. Pasture Handbook. 2nd Ed. Craft Print International Ltd. Singapore
15. Do Canto J., Reyno R., Real D., Revell C. 2013. Seed softening patterns of forage legumes in a temperate/subtropical environment in Uruguay. Chilean Journal of Agricultural Research 73: 41 – 47.
16. Dohn, J., Dembélé, F., Karembé, M., Moustakas, A., Amévor, K.A. and Hanan, N.P., 2013. Tree effects on grass growth in savannas: competition, facilitation and the stress-gradient hypothesis. Journal of Ecology, 101(1), pp.202-209.
17. Donohue K., Rubio de Casas R., Burghardt L., Kovach K., Willis C.G. 2010. Germination, post-germination adaptation, and species ecological ranges. Annual Review of Ecology, Evolution and Systematics 41: 293–319.
18. du Toit, J.C., Ramaswiela, T., Pauw, M.J. and O'Connor, T.G., 2018. Interactions of grazing and rainfall on vegetation at Grootfontein in the eastern Karoo. African Journal of Range & Forage Science, 35(3-4), pp.267-276.

19. Edwards T., Howieson H., Nutt B., O'Hara G., van Wyk B-E. 2019. A ley-farming system for marginal lands based upon a self-regenerating perennial pasture legume. Agronomy for Sustainable Development 39: https://doi.org/10.1007/s13593-019-0558-2
20. Elith J., Leathwick J. 2009. Species distribution models: ecological explanation and prediction across space and time. Annual Review of Ecology, Evolution, and Systematics 40: 677–697.
21. Elith J., Phillips S.J., Hastie T., Dudík M., Chee Y.E., Yates C.J. 2011. A statistical explanation of maxent for ecologists. Diversity and Distributions 17: 43–57.
22. Emery, S.M. and Gross, K.L., 2005. Effects of timing of prescribed fire on the demography of an invasive plant, spotted knapweed Centaurea maculosa. Journal of Applied Ecology, 42(1), pp.60-69.
23. Evans C.E., Etherington J.R. 1990. The effects of soil water potential on seed germination of some British plants. New Phytologist 115: 539 – 548.
24. Fenner M. 2000. Seeds: The ecology of regeneration in plant communities, 2nd ed. CABI Publishing, Wallingford, UK.
25. Fenner M., Thompson K. 2005. The ecology of seeds. Cambridge University Press, Cambridge, UK
26. Finch-Savage W.E., Leubner-Metzger G. 2006. Seed dormancy and the control of germination. New Phytologist 171: 501–523.
27. Foley M.E. 2001. Seed dormancy: An update on terminology, physiological genetics, and quantitative trait loci regulating germinability. Weed Science 49: 305–317
28. Gebashe, F., Aremu, A. O., Finnie, J. F., & Van Staden, J. 2019. Grasses in South African traditional medicine: A review of their biological activities and phytochemical content. South African Journal of Botany 122, 301–329 https://doi.org/10.1016/j.sajb.2018.10.012.
29. Gerding M., Howieson J.G., O'Hara G.W., Real D., Bräu L. 2013a. Establishment and survival of the South African legume *Lessertia* spp. and rhizobia in Western Australian agricultural systems. Plant and Soil. DOI 10.1007/s11104-013-1632-1.
30. Gerding M., O'Hara G.E., Bräu L., Nandasena K., & Howieson J.G. 2013b. Diverse *Mesorhizobium* spp. with unique nodA nodulating the South African legume species of the genus *Lessertia*. Plant and Soil 358: 385 – 401.
31. Gerding M., O'Hara G.E., Howieson J.G., Bräu L. 2014. Overcoming non-selective nodulation of *Lessertia* by soil-borne rhizobium in the presence of inoculant Mesorhizobium. Plant and Soil 380: 117 – 132.
32. Gresta F., Avola G., Onofri A., Anastasi U., Cristaudo A. 2011. When Does Hard Coat Impose Dormancy in Legume Seeds? Lotus and Scorpiurus Case Study. Crop Science 51:1739–1747.
33. Guisan A., Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. Ecological Letters 8: 993 – 1009.
34. Hamdani, M., Krichen, K. and Chaieb, M., 2019. Predicting leaf trait variability as a functional descriptor of the effect of climate change in three perennial grasses. Diversity, 11(12), p.233.
35. Hardegree S.P. 2006. Predicting germination response to temperature. I. Cardinal temperature models and subpopulation-specific regression. Annals of Botany 97: 1115 – 1125.
36. Hegarty T.W. 1978. The physiology of seed hydration and dehydration, and the relation between water stress and the control of germination: a review. Plant Cell and Environment 1:101–119.
37. Hilhorst H.W.M. 1995. A critical update on seed dormancy. I. Primary dormancy. Seed Science Research 5: 61–73.
38. Hirzel A.H., Lay G.L., Helfer V., Randin C., Guisan A. 2006. Evaluating the ability of habitat suitability models to predict species presences. Ecological Modelling 199: 142–152

39. Hoffman, M.T. & Vogel, C., 2008. Climate change impacts on African rangelands. *Rangelands*, 30(3), pp.12–17.
40. Howieson J.G., De Meyer S.E., Vivas-Marfisi A., Ratnayake S., Ardley J.K., Yates R.J. 2013. Novel Burkholderia bacteria isolated from *Lebeckia ambigua* – a perennial suffrutescent legume of the fynbos. Soil Biology and Biochemistry 60: 55 – 64.
41. Howieson J.G., Yates R.J., Foster K.J., Real D., Besier R.B. 2008. Prospects for the future use of legumes. In: Dilworth M.J, James E.K., Sprent J.I., Newton W.E. (eds) Nitrogen-fixing Leguminous Symbioses. Springer, Dordrecht, pp 363–393.
42. Hu X.W., Fan Y., Baskin C.C., Baskin J.M., Wang Y.R. 2015. Comparison of the effects of temperature and water potential on seed germination of Fabaceae species from desert and subalpine grassland. American Journal of Botany 102: 649 – 660.
43. Huang X., Schmitt J., Dorn L., Griffith C., Effgen S., Takao S., Koornneef, M., Donohue K. 2010. The earliest stages of adaptation in an experimental plant population: strong selection on QTLS for seed dormancy. Molecular Ecology 19: 1335–1351.
44. Huang, Y., Wang, K., Deng, B., Sun, X. and Zeng, D.H., 2018. Effects of fire and grazing on above-ground biomass and species diversity in recovering grasslands in northeast China. Journal of Vegetation Science, 29(4), pp.629-639.
45. IPCC (Intergovernmental Panel on Climate Change), 2007. Climate Change 2007: Impacts, Adaptation and Vulnerability. Summary for Policy Makers. http://www.ipcc.cg/SPM13apr07.pdf
46. Kembel, S.W. and Cahill Jr, J.F., 2011. Independent evolution of leaf and root traits within and among temperate grassland plant communities. PloS one, 6(6), p.e19992.
47. Kirkman, K.P., Collins, S.L., Smith, M.D., Knapp, A.K., Burkepile, D.E., Burns, C.E., Fynn, R.W., Hagenah, N., Koerner, S.E., Matchett, K.J. and Thompson, D.I., 2014. Responses to fire differ between South African and North American grassland communities. Journal of Vegetation Science, 25(3), pp.793-804.
48. Kotzé, E., Paulse-Ross, J., Malan, P.J. and Franke, A.C., 2025. Grazing management and edapho-climatic factors: drivers of soil carbon and vegetation dynamics in South African rangelands. Plant and Soil, pp.1-23.
49. Kumar S., Stohlgren T.J. 2009. Maxent modelling for predicting suitable habitat for threatened and endangered tree *Canacomyrica monticola* in New Caledonia. Journal of Ecology and The Natural Environment 1: 94 – 98
50. Letsoalo, N., Samuels, I., Cupido, C., Ntombela, K., Finca, A., Foster, J., Tjelele, J. and Knight, R., 2023. Coping and adapting to drought in semi-arid Karoo rangelands: Key lessons from livestock farmers. Journal of Arid Environments, 219, p.105070.
51. Li B., Foley M.E. 1997. Genetic and molecular control of seed dormancy. Trends in Plant Science 2: 384–389.
52. Li, X.L., Gao, J., Brierley, G., Qiao, Y.M., Zhang, J. and Yang, Y.W., 2013. Rangeland degradation on the Qinghai-Tibet plateau: Implications for rehabilitation. Land degradation & development, 24(1), pp.72-80.
53. Loi A., Nutt B.J., Revel C.K. 2008. Domestication of new annual pasture legumes for resilient Mediterranean farming systems. Options Méditerranéennes 79: 363 – 371.
54. Ludewig K., Zelle B., Eckstein R.L., Mosner E., Otte A., Donath T.W. 2014. Differential effects of reduced water potential on the germination of flood plain grassland species indicative of wet and dry habitats. Seed Science Research 24: 49 – 61.
55. Luna B., Perez B., Torres I., Moreno JM. 2012. Effects of incubation temperature on seed germination of Mediterranean plants with different geographical distribution ranges. Folia Geobotanica 47: 17–27
56. Luseno W.K., Mcpeak J.G., Barrett C.B., Little D., Gebru G. 2003. Assessing the value of climate forecast information for pastoralists: evidence from Southern Ethiopia and Northern Kenya. World Development 31:1477–1494.

57. M. Trytsman, F.L. Müller., C.D. Morris, A.E. van Wyk. 2021. Biogeographical patterns of grasses (Poaceae) indigenous to South Africa, Lesotho and Eswatini. African Journal of Range and Forage Science https://doi.org/10.2989/10220119.2021.1918247
58. Magandana, T.P., Hassen, A. and Tesfamariam, E.H., 2020. Seasonal herbaceous structure and biomass production response to rainfall reduction and resting period in the semi-arid grassland area of South Africa. Agronomy, 10(11), p.1807.
59. Marion, B., Bonis, A. and Bouzillé, J.B., 2010. How much does grazing-induced heterogeneity impact plant diversity in wet grasslands? Ecoscience, 17(3), pp.229-239.
60. McDonald P, Edwards RA, Greenhalgh JFD, Morgan CA, Sinclair LA, Wilkinson RG. 2010. Animal nutrition. 7th Edn. New York: Longman.
61. McPeak J. 2006. Confronting the risk of asset loss: what role do livestock transfers in northern Kenya play? The Journal of Development Studies 81: 415 – 437.
62. Meissner H.H., Scholtz M.M., Engelbrecht F.A. 2013a. Sustainability of the South African livestock sector towards 2050. Part 2: Challenges, changes and required implementations. South African Journal of Animal Science 43: http://dx.doi.org/10.4314/sajas.v43i3.6
63. Meissner H.H., Scholtz M.M., Engelbrecht F.A. 2013b. Sustainability of the South African Livestock Sector towards 2050. Part 2: Challenges, changes and required implementations. South African Journal of Animal Science 43: 298 – 319.
64. Meissner HH. 2000. Nutrient supplementation of the grazing animal. In: Tainton NM (ed.), Pasture management in South Africa. Pietermaritzburg: University of Natal Press. pp 96–115.
65. Mitchell M.L., Norman H.C., Whalley D.B. 2015. Use of functional traits to identify Australian forage grasses, legumes and shrubs for domestication and use in pastoral areas under a changing climate. Crop and Pasture Science 66: 71 – 89.
66. Mofutsanyana, S.S., 2017. Relationship among functional traits of wetland plants and climatic variables along an aridity gradient across the Highveld, South Africa.
67. Morton J.F. 2007. The impact of climate change on smallholder and subsistence agriculture. Proceedings of the National Academy of Sciences 104: 19680–19685.
68. Muir J.P., Dubeux J.C.B., Dos Santos M.V.F., Maposse I.C., Pitman W.D., Butler T.J. 2014. Challenges to domesticating native forage legumes. Tropical Grasslands 2: 94 – 96.
69. Mukheibir P. 2008. Water resources management strategies for adaptation to climate-induced impacts in South Africa. Water Resources Management 22: 1259-1276.
70. Müller F.L., Raitt L.M., Chimphango S.B.M., Samuels M.I., Cupido C.F., Boatwright J.S., Knight R., Trytsman M. 2017. Prioritisation of native legume species for further evaluation as potential forage crops in water-limited agricultural systems in South Africa. Environmental Monitoring and Assessment 189:512. DOI 10.1007/s10661-017-6230-x
71. Müller F.L., Samuels M.I., Cupido C.F., Swarts M.B.V., Amary N.M., Hattas D., Morris C., Cyster L.F., Boatwright J.S. 2019. The impacts of season and livestock management strategy on the quality of diets selected by goats and sheep in the semi-arid rangelands of Namaqualand. South Africa. African Journal of Range and Forage Science 36: 105-114.
72. Müller FL., Cupido CF., Samuels MI. 2021. Nutritional quality of *Calobota sericea* fodders. A preliminary assessment. African Journal of Range and Forage Sciences https://doi.org/10.2989/10220119.2021.1989722
73. Müller FL., Masemola EL., Modiba S., Ngcobo N. 2022. Seedling establishment and early growth in *Calobota sericea* subjected to drought stress. African Journal of Range and Forage Science https://doi.org/10.2989/10220119.2022.2119277
74. Müller FL., Raitt LM., Cyster LF., Chimphango SBM., Cupido CF., Samuels MI., Boatwright JS. 2021. Morphological and physiological responses of *Calobota sericea* plants subjected to water limitation and subsequent re-watering. African Journal of Range and Forage Science https://doi.org/10.2989/10220119.2021.1954089
75. Müller FL., Trytsman M., Masemola EL., Kgonothi MI., Mkhize NR., Tjelele TJ. 2021. Collection priorities of pasture genetic resources in the Paniceae from South Africa.

Proceedings of the Joint International Rangelands and International Grassland Congress. https://uknowledge.uky.edu/cgi/viewcontent.cgi?article=4701&context=igc

76. Nichols P.G.H., Loi A., Nutt B.J., Evans P.M., Craig A.D., Pengelly B.C., Dear B.S., Lloyd D.L., Revell C.K., Nair R.M., Ewing M.A., Howieson J.G., Auricht G.A., Howie J.H., Sandral G.A., Carr S.J., de Koning C.T., Hackney B.F., Crocker G.J., Snowball R., Hughes S.J., Hall E.J., Foster K.J., Skinner, P.W., Barbetti M.J., You M.P. 2007. New annual and short-lived perennial pasture legumes for Australian agriculture – 15 years of revolution. Field Crop Research 104: 10 – 23.
77. Nichols P.G.H., Loi A., Nutt B.J., Snowball R., Revell C.K. 2010. Domestication of new Mediterranean annual pasture legumes. In: Huyghe, C. (ed.), Sustainable Use of Genetic Diversity in Forage and Turf Breeding. Springer Science + Business Media B.V. pp 137 – 141.
78. O'Connor, T.G. & Bredenkamp, G.J., 1997. Grassland. In: R.M. Cowling, D.M. Richardson & S.M. Pierce (eds.). Vegetation of Southern Africa. Cambridge: Cambridge University Press, pp.215–257.
79. Palmer A., Ainslie A. 2006. Country Pasture/Forage Resource Profiles: South Africa. FAO.
80. Patané C., Saita A., Tubeileh A., Cosentino SL., Cavallaro V. 2016. Modelling seed germination of unprimed and primed seeds of sweet sorghum under PEG-induced water stress through the hydrotime analysis. Acta Physiologiae Plantarum 38:115. DOI 10.1007/s11738-016-2135-5
81. Pearson R.G., Raxworthy C.J., Nakamura M., Peterson A. 2007. Predicting species distributions from small numbers of occurrence records: a test case using cryptic geckos in Madagascar. Journal of Biogeography 34: 102–117.
82. Phalane F.L. 2008. The diversity of root nodule bacteria associated with Lebeckia species in South Africa. University of Pretoria. Masters Thesis
83. Phartyal S.S., Thapliyal R.C., Nayal J.S., Rawat M.M.S., Joshi G. 2003. The influences of temperatures on seed germination rate in Himalayan elm (*Ulmus wallichiana*). Seed Science and Technology 31: 83 – 93
84. Phillips S.J., Anderson R.P., Schapire R.E. 2006. Maximum entropy modeling of species geographic distributions. Ecological Modelling 190: 231–259.
85. Poisot T., Bever J.D., Nemri A., Thrall P.H., Hochberg M.E. 2011. A conceptual framework for the evolution of ecological specialisation. Ecology Letters 14: 841–851.
86. Pulliam H.R. 2000. On the relationship between niche and distribution. Ecological Letters 3: 349–361.
87. Quin A., Liu B., Guo Q., Bussmann R.W., Ma F., Jian Z., Xu G., Pei S. 2017. Maxent modelling for predicting impacts of climate change on the potential distribution of *Thuja sutchuenensis* Franch., an extremely endangered conifer from southwestern China. Global Ecology and Conservation 10: 139 – 146.
88. Rasby RJ., Kononoff PJ., Anderson BE. 2008. Understanding and using a feed analysis report. University of Nebraska – Lincoln Extension, Institute of Agriculture and Natural Resources. Report G1892. https://extensionpublications.unl.edu/assets/pdf/g1892.pdf [Accessed 21 August 2021].
89. Ravhuhali, K.E., Mlambo, V., Beyene, T.S. and Palamuleni, L.G., 2021. Effect of soil type on spatial distribution and nutritive value of grass species growing in selected rangelands of South Africa. South African Journal of Plant and Soil, 38(5), pp.361-371.
90. Rezaei, S.A. and Gilkes, R.J., 2005. The effects of landscape attributes and plant community on soil chemical properties in rangelands. Geoderma, 125(1-2), pp.167-176.
91. Rinehart L. 2008. Ruminant nutrition for graziers. ATTRA – National Sustainable Agriculture Information Service. https://extension.usu.edu/rangelands/ou-files/Ruminant_nutrition_grazing.pdf [Accessed 21 August 2021].

92. Rufino M.C., Thornton P.K., Ng'ang'a S.K., Mutie I., Jones P.G., van Wijka M.T., Herrero M. 2013. Transitions in agro-pastoralist systems of East Africa: Impacts on food security and poverty. Agriculture, Ecosystems and Environment 179: 215 – 230.
93. Samuels I., Cupido C., Swarts M.B., Palmer A.R., Paulse J.W. 2016. Feeding ecology of four livestock species under different management in a semi-arid pastoral system in South Africa. African Journal of Range and Forage Science 33: 1 – 9.
94. Sankaran, M., 2005. Fire, grazing and the dynamics of tall-grass savannas in the Kalakad-Mundanthurai Tiger Reserve, South India. Conservation and Society, 3(1), pp.4-25.
95. Schroeder JW. 2009. Forage nutrition for ruminants. NDSU Extension Publication AS-1250. Fargo: North Dakota State University Extension Service. https://www.ag.ndsu.edu/publications/livestock/quality-forage-series-forage-nutrition-forruminants [Accessed 21 August 2021].
96. Schulze R.E., Maharaj M., Warburton M.L., Gers C.J., Horan M.J.C., Kunz R.P., Clark D.J. 2007. South African atlas of climatology and agrohydrology. Water Research Commission, Pretoria, RSA, WRC Report, 1489(1), p.06.
97. Scott, R.L., Hamerlynck, E.P., Jenerette, G.D., Moran, M.S. and Barron-Gafford, G.A., 2010. Carbon dioxide exchange in a semidesert grassland through drought-induced vegetation change. Journal of Geophysical Research: Biogeosciences, 115(G3).
98. Singh P., Ibrahim H.M., Flury M., Schillinger W.F., Knappenberger T. 2013. Critical water potentials for germination of wheat cultivars in the dryland Northwest USA. Seed Science Research 23: 189–198.
99. Smit, C. and Ruifrok, J.L., 2011. From protégé to nurse plant: establishment of thorny shrubs in grazed temperate woodlands. Journal of Vegetation Science, 22(3), pp.377-386.
100. Snyman, H.A., 2010. Influence of rainfall on rangeland productivity in arid and semi-arid South Africa. African Journal of Range & Forage Science, 27(1), pp.1–10.
101. Spencer R. 2018. Nutrient Requirements of Sheep and Goats, ANR-0812. Alabama Cooperative Extension System. https://www.aces.edu/blog/topics/livestock/nutrient-requirementsof-sheep-and-goats/?cn-reloaded=1 [Accessed 21 August 2021].
102. Steinmaus S.J., Prather T.S., Holt J.S. 2000. Estimation of base temperatures for nine weeds species. Journal of Experimental Botany 51: 275 – 286.
103. Studdert G.A., Wilhelm W.W., Power J.F. 1994. Imbibition response of winter wheat to water-filled pore space. Agronomy Journal 86: 995–1000.
104. Tainton, N.M., 1999. Veld Management in South Africa. Pietermaritzburg: University of Natal Press.
105. Thornton P.K., Herrero M. 2014. Climate change adaptation in mixed crop-livestock systems in developing countries. Global Food Security 3:99–107.
106. Thornton P.K., Herrero M., Freeman H.A., Mwai A.O., Rege E., Jones P.G., McDermott J. 2007. Vulnerability, climate change and livestock- opportunities and challenges for the poor. Journal of Semi-Arid Tropics Agricultural Research 4: 1 – 23.
107. Thornton P.K., van de Steeg J., Notenbaert A., Herrero M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. Agricultural Systems 101: 113–127.
108. Truter W.F., Botha P.R., Dannhauser C.S., Maasdorp B.V., Miles N., Smith A., Snyman H.A., Tainton N.M. 2015. South African pasture and forage science entering the 21st century: past to present. South African Journal of Range and Forage Science 32: 73 – 89.
109. Trytsman M. 2013. Diversity and pasture potential of legumes indigenous to southern Africa. PhD Thesis, University of Pretoria, South Africa.
110. Trytsman M., Masemola E.L., Müller F.L., Calitz F.J., van Wyk A.E. 2019. Assessing legumes indigenous to South Africa, Lesotho and Swaziland for their pasture potential. African Journal of Range & Forage Science. 36: 27 – 40.

111. Trytsman M., Müller F.L., van Wyk A.E. 2020. Diversity of grasses (Poaceae) in southern Africa, with emphasis on the conservation of pasture genetic resources. Genetic Resources and Crop Evolution 67: 875 – 894.
112. Trytsman M., Westfall R.H., Brytenbach P.J.J., Calitz F.J., van Wyk, A.E. 2016. Diversity and biogeography pattern of legumes (Leguminosae) indigenous to southern Africa. PhytoKeys 70: 53 – 96.
113. Van Oudtshoorn, F., 2014. *Guide to Grasses of Southern Africa* (3rd ed.). Pretoria: Briza Publications.
114. Venable D.L. 2007. Bet hedging in a guild of desert annuals. Ecology 88: 1086-1090.
115. Vleeshouwers L.M., Bouwmeester H.J., Karssen C.M. 1995. Redefining seed dormancy: An attempt to integrate physiology and ecology. Journal of Ecology 83: 1031–1037.
116. Volaire, F., 2018. A unified framework of plant adaptive strategies to drought: crossing scales and disciplines. Global change biology, 24(7), pp.2929-2938.
117. Walck J.L., Hidayati S.N., Dixon K.W., Thompson K., Poschlod P. 2011. Climate change and plant regeneration from seed. Global Change Biology 17: 2145 – 2161.
118. Wills C.G., Baskin C.C., Baskin J.M., Auld J.R., Venable D.L., Cavender-Bares J., Donohue K., Rubio de Casas R., NESCent Germination Working Group. 2014. The evolution of seed dormancy: environmental cues, evolutionary hubs, and diversification of the seed plants. New Phytologist 203: 300-309.

APPENDIX A: POSTER 1: D MALEPE, TJ TJELELE, NL LETSOALO AND FL MULLER. 2025. DISTRIBUTION, MORPHOLOGICAL TRAITS, AND NUTRITIONAL QUALITY OF INDIGENOUS GRASSES IN LOW AND HIGH RAINFALL AREAS OF SOUTH AFRICA. 60TH ANNUAL CONGRESS OF THE GRASSLAND SOCIETY OF SOUTHERN AFRICA.

Poster 1: D Malepe, TJ Tjelele, NL Letsoalo and FL Muller. 2025. Distribution, morphological traits, and nutritional quality of indigenous grasses in low and high rainfall areas of South Africa. 60th Annual Congress of the Grassland Society of Southern Africa.

RESEARCH PROPOSAL POSTER: DISTRIBUTION, MORPHOLOGICAL TRAITS AND NUTRITIONAL QUALITY OF INDIGENOUS GRASSES IN LOW AND HIGH RAINFALL AREAS OF SOUTH AFRICA

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South Africa's diverse rangelands support a wide variety of indigenous grass species that play a critical role in sustaining both natural ecosystems and agricultural productivity. The productivity of these different indigenous grass species could be distinctly different based on the agro-ecological zone, environmental factors like temperature, light intensity, total rainfall, soil type, fertilization level, and by stage of maturity. Therefore, this study aims to investigate the distribution, morphological characteristics, and chemical composition of indigenous grasses across low and high rainfall regions of South Africa. The study will focus on five indigenous grass species: "*Megathyrsus maximus* (Jacq.) B.K.Simon & S.W.L.Jacobs,, *Themeda triandra Forssk, Urochloa trichopus (Hochst) Stapf, Cenchrus ciliaris L.*, and *Digitaria eriantha Steud.*," which are found throughout the different rangelands in the country. These species are known for their resilience and adaptability in arid and semi-arid environments, and their contribution to both livestock productivity and ecological stability. Data will be collected in high rainfall areas (>500 mm/year) and areas with low rainfall (<500 mm/year) across the country. The selected grass species will be sampled simultaneously during the peak growing season to ensure the assessment of their optimal morphological and nutritional characteristics. Three composite specimens will be collected per area, resulting in twenty-four samples per species. In addition to grass species, soil samples will be collected at each site where the grass is collected to evaluate soil properties that may influence species occurrence and traits. Data collection will include recording the GPS location of each sampled plant to document its geographical distribution. Morphological traits such as the number of tillers, plant height, vegetative height, leaf blade length and width, and inflorescence length will be measured. For nutritional analysis, crude protein, fibre fractions, digestibility, and mineral content will be evaluated. We hypothesize that grass species in high rainfall regions will exhibit greater biomass production and higher nutritional content, whereas in low rainfall areas drought-adapted species will display distinct morphological adaptations such as reduced leaf area and deeper root systems to cope with water scarcity. Understanding these adaptations is critical for assessing rangelands resilience under future climate scenarios, particularly given projections of reduced precipitation and increase in temperatures in many parts of the country. By integrating distribution data with morphological and nutritional profiles, this study will assist identifying which species are most suitable for sustainable forage production under changing climatic conditions. Furthermore, the findings will contribute to improved rangeland management strategies, including the selection of appropriate grass species for reseeding degraded areas. This research aligns with national priorities for climate-smart agriculture and ecosystem-based adaptation and aims to inform both policy and practice.

Distribution, morphological traits and nutritional quality of indigenous grasses in low- and high-rainfall areas of South Africa

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BACKGROUND

- South Africa's diverse rangelands support a wide variety of indigenous grass species that play a critical role in sustaining natural ecosystems and agricultural productivity.
- The productivity of these different indigenous grass species could be distinctly different and influenced by abiotic and biotic factors.
- Currently, little is known about morphological characteristics and relative nutritional value of native grass species in South African rangelands.

THE AIM OF THE STUDY :

- To investigate the distribution, morphological characteristics, and nutritional quality of indigenous grasses across low- and high-rainfall regions of South Africa.
- Specifically, the following objectives will be explored:
- To evaluate the impact of high- and low-rainfall on the distribution, morphological characteristics, and nutritive value of indigenous grasses.
- To evaluate the effect of physical and chemical soil properties on the morphological characteristics and nutritional value of indigenous grasses in low- and high-rainfall areas in South Africa.

METHODOLOGY

- The research will focus on five indigenous grass species:

Themeda triandra

Digitaria eriantha

Cenchrus ciliaris

Megathyrsus maximus

Urochloa mosambicensis

- The selected grass species will be sampled during the peak growing season: morphological and nutritional characteristics.
- Three specimens will be collected per area, resulting in twenty-four samples per species.
- Soil samples will be collected at each site.

METHODOLOGY

Morphological measurements on each plant:
Number of tillers, plant height, vegetative height, leaf blade size (length and width) and inflorescences size (length).
Nutritional content:
Crude protein, fibre, digestibility, and mineral content.
Soil samples:
Soil organic carbon (SOC), Total Nitrogen (TN), Phosphorus (P), Potassium (K), Sodium (Na), Calcium (Ca), Magnesium (Mg) and pH.

Data will be collected in:

High rainfall areas: FS, MP, KZN and EC (>500 mm/year) (represented in yellow).
Low rainfall areas: LP, GP, NC and NW (<500 mm/year) (represented in green). (Figure 1).

Figure 1: Showing provinces where data will be collected.

CONTRIBUTIONS OF THE STUDY

- This study will assist identifying which species are most suitable for sustainable forage production in a changing climatic conditions.
- Findings will contribute to improved rangeland management strategies, including the selection of appropriate grasses for restoration of degraded areas.

APPENDIX B: POSTER 2: SELAELO KOBE, FRANCUOIS MULLER, JULIUS TJELELE. 2025. EVALUATION OF INDIGENOUS GRASS SPECIES FOR FORAGE POTENTIAL USE UNDER WATER LIMITED CONDITIONS IN SOUTH AFRICA – A PROPOSAL. 60TH ANNUAL CONGRESS OF THE GRASSLAND SOCIETY OF SOUTHERN AFRICA 21 - 25 JUL, 2025

60th Annual Congress of the Grassland Society of Southern Africa

RESEARCH PROPOSAL POSTER: EVALUATION OF INDIGENOUS GRASS SPECIES FOR FORAGE POTENTIAL USE UNDER WATER LIMITED CONDITIONS IN SOUTH AFRICA – A PROPOSAL

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There are several tropical and subtropical grasses that are in areas that receive less than 600mm of rainfall per annum. These could be developed to improve pasture species or local ecotypes could be used to improve existing commercial genetic resources. With climate change predictions indicating that scenarios of increased temperatures, droughts, and erratic rainfall will increase in the future, it is essential to plan for the development of improved pasture genetic resources for use under these marginal conditions. This study aims to evaluate drought tolerance in commercial and indigenous ecotypes of three grass species namely *Panicum maximum*, *Digitaria eriantha* and *Cenchrus ciliaris*. To achieve this, three objectives will be investigated:

1. Evaluating germination and seedling establishment of selected grasses under increasing temperature and osmotic stress. Seeds will be sown in petri dishes and placed in germination chambers calibrated to four different temperatures temperature (15°C to 30°C) with applications of three osmotic treatments (0MPa, - 0.1 MPa, -0.3MPa). Germination will be recorded daily for 20 days.
2. Determining the impact of moisture stress and seed burial depth on seedling emergence and early seedling growth. 15 seeds of each genotype will be planted in pots watered to 100% and 50% capacity. In each water treatment seeds will be planted at 1, 2, 3, 4 and 5 cm depths. Seedling emergence will be counted daily, and seedling morphology will be monitored for 30 days.
3. Evaluating the effects of dryland, irrigation and 30% rainfall exclusion on the growth, development (morphological and physiological), agronomic potential and nutritional quality of the grasses. A field plot trial will be stablished where the different grass genotypes will be planted in three treatment blocks in 10m² plots. After establishment the plants will be characterized based on their growth performance (shoot height, tiller numbers), biomass yields and nutritional quality over a two year growing period.

Evaluation of indigenous grass species for forage potential use under water limited conditions in South Africa

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INTRODUCTION

- There are several tropical and subtropical grasses that are in areas that receive less than 600mm of rainfall per annum. These could be developed to improved pasture species or local ecotypes could be used to improve existing commercial genetic resources.
- With climate change predictions indicating that scenarios of increased temperatures, droughts, and erratic rainfall will increase in the future, it is essential to plan for the development of improved pasture genetic resources for use under these marginal conditions.

OBJECTIVES

1. Evaluating germination and seedling establishment of selected grasses under increasing temperature and osmotic stress.
2. Determining the impact of moisture stress and seed burial depth on seedling emergence and early seedling growth.
3. Evaluating the effects of dryland, irrigation and 30% rainfall exclusion on the growth, development (morphological and physiological), agronomic potential and nutritional quality of the grasses.

METHODOLOGY

SEED GERMINATION

- Four grass species namely, *Digitaria eriantha*, *Panicum maximum*, *Cenchrus ciliaris* and *Eragrostis curvula* will be evaluated.
- Four replicates of 100 seeds will be sown in petri dishes and placed in germination chambers.
- Germination chambers will be calibrated to four different temperatures (15˚C, 20˚C, 25˚C and 30˚C).
- Within each temperature treatment, three water treatments will be applied i.e., 0MPa, - 0.1MPa, - 0.3MPa prepared using distilled water and PEG6000.
- Seeds with 5mm radicle will be considered germinated
- Germination recorded daily for 20 days.

SEEDLING ESTABLISHMENT

- 17cm pots will be filled with a commercial grade potting soil (Hygromix). Thereafter 15 seeds of each genetic resource will be planted at 1, 2, 3, 4 and 5 cm depths, replicated four times.
- The pots will be watered to 50% and 100% of pot capacity using distilled water.
- Seedling emergence will be recorded daily for 30 days.
- Seedling morphology (root and shoot height, weight, resource allocation) will be measured at the end of the 30 day period.

AGRONOMIC CHARACTERISATION

- A nursery trial will thereafter be established to measure (morphological and physiological), agronomic potential and nutritional quality of the grasses.
- Three replicates of 15 established seedlings will be transplanted into 10m^2 nursery plots under each of three growing conditions i.e., dryland, irrigation and 30% rainfall exclusion.
- Plants will be allowed to grow for two growing seasons during which time growth performance characterization i.e., time to flowering, shoot height, tiller numbers, branching intensity, biomass yields at flowering, time to regrowth, nutritional quality of each harvest, as well as total annual yield.

EXPECTED OUTCOMES

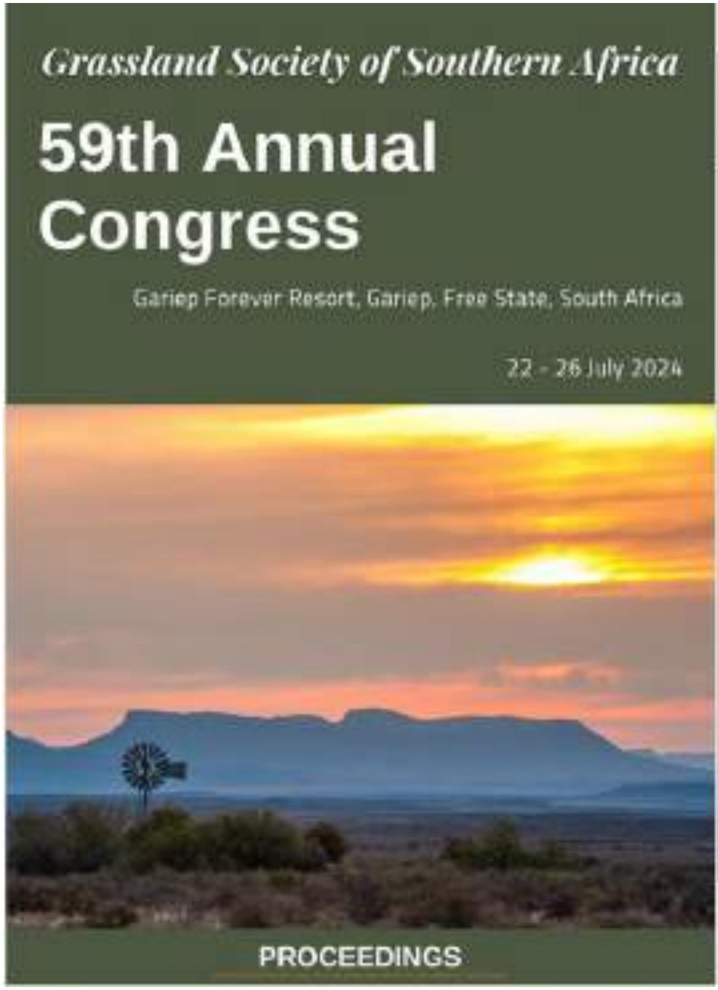
- Identification of grass genotypes that are better suited to germinate, establish and grow under drought stress conditions.
- Identification of plant genetic resources that should be included into pasture improvement programs.

ACKNOWLEDGEMENTS

agriculture

WATER RESEARCH COMMISSION

APPENDIX C: PRESENTATION 1: N. NGCOBO., F. MULLER. 2024. DETERMINING THE IMPACT OF INCREASED TEMPERATURES AND REDUCED WATER-AVAILABILITY ON THE AGRONOMIC PERFORMANCE AND NUTRITIVE VALUE OF DIFFERENT INDIGENOUS FORAGE GRASS ECOTYPES. 59TH ANNUAL CONGRESS OF THE GRASSLAND SOCIETY OF SOUTHERN AFRICA 22 – 26 JUL 2024



STANDARD POSTER PRESENTATION: DETERMINING THE IMPACTS OF INCREASED TEMPERATURES AND REDUCED WATER-AVAILABILITY ON THE AGRONOMIC PERFORMANCE AND NUTRITIVE VALUE OF DIFFERENT INDIGENOUS FORAGE GRASS ECOTYPES

Nothando Ngcobo, Francuois Muller*

Water limitation and adverse temperatures are abiotic factors that negatively influence plant production by negatively impacting root and shoot growth, nutrient and water uptake, as well as plant physiological processes such as photosynthesis, transpiration and respiration. In forage crops specifically, limited water availability and high temperatures can cause a decrease of forage yield by 30%, resulting in significant feed shortages. Indigenous South African grasses has contributed significantly to global pasture production. However, there is a large diversity of unexploited grass and legumes genetics that are well adapted to water-limited conditions. Species such as *Digitaria eriantha, Eragrostis curvula, Panicum maximum, Cenchrus ciliaris, Chloris gayana* have already made significant impacts on global livestock production systems. Studies which focused exclusively on forages in Southern Africa, revealed that in order to maintain a successful pasture economy in South Africa, it is necessary to identify and breed grass species that can adapt to challenging climates. The proposed study aims to evaluate agronomic performance and nutritional quality of various commercial forage grasses in comparison to indigenous ecotypes of these grasses grown under water-limited conditions. This study will be carried out at the Agricultural Research Council's Roodeplaat Experimental Farm in Gauteng. This research farm holds the National Forage Genebank, from which seeds will be gathered for research. Four replicates of 50 seeds of each species *P. maximum* and *D. eriantha*, from both commercial varieties and collections made from indigenous populations, breaking seed dormancy and germination will be done according to International Rules for Seed Testing in seed germination chambers. Germination will be recorded daily for 7 days. Thereafter 4 replicates of 20 germinated seedlings will be planted in 10 x 15 cm pots watered to 70, 50 and 40% of soil moisture holding capacity. A further 4 replicates will be planted under 100% soil moisture holding capacity. All pots will be placed in the plant growth chambers calibrated to constant temperatures of 20, 25 and 30 °C and a 10h/14h day/night circle for 30 - 45 days. Seedling emergence and survival will be recorded daily, after 30 and 45 days morphological characteristics plant height, leaf width, date to first, 50 % and full flowering duration, leafiness and branching intensity will be recorded. At 30 days half of the surviving plants will be harvested, the shoots will be clipped at 10 cm above the soil level and divided into root and shoots and the remaining will be harvested after 45 days. Nutritional quality such as mineral nutrients, crude protein, NDF, ADF, energy and digestibility will be determined from oven dried biomass samples. The evaluation of different grass species for their ability to overcome drought stress is crucial since the results of these experiments will inform future breeding initiatives aimed at improving drought tolerance in these forage grass species.

Determining the impact of increased temperatures and reduced water-availability on the agronomic performance and nutritive value of different indigenous forage grass ecotypes

Nothando Ngcobo and Francuois Müller

Agricultural Research Council – Animal Production: Rangeland and Forage Sciences

Introduction:

- Plant production is negatively influenced by water limitation and adverse temperatures causing a decrease of forage yield by 30%, resulting in significant feed shortages.
- Indigenous South African grasses has contributed significantly to global pasture production.
- However, there is a large diversity of unexploited grass and legume genetic resources that are well adapted to drought conditions.

Aim

The study aims to assess the agronomic performance and nutritional quality of commercial forage grasses compared to their indigenous ecotypes grown under water-limited conditions.

agriculture, land reform & rural development
Department: Agriculture, Land Reform and Rural Development
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APPENDIX D: PRESENTATION 2: F. MULLER., LETSOALO L., TRYTSMAN M., TJELELE J., MANGANYI-VALOYI F., NGCOBO N., MASEMOLA L., KGONOTHI I., RAKAU P. 2024. INDIGENOUS GRASS AND LEGUME SPECIES FROM THE GAUTENG PROVINCE THAT COULD BE DEVELOPED INTO FORAGE SPECIES FOR USE UNDER FUTURE BIOCLIMATIC CONDITIONS. 16TH ANNUAL AGRICULTURAL RESEARCH SYMPOSIUM AND INNOVATION EXPO OF THE GAUTENG DEPARTMENT OF AGRICULTURE, LAND REFORM AND RURAL DEVELOPMENT