Assessing legumes indigenous to South Africa, Lesotho and Swaziland for their pasture potential

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Abstract
In contrast to the exploration and use of southern African grass plant genetic resources over the past century, only a few indigenous legume species are currently used as forages, notwithstanding the vast untapped legume diversity available in southern Africa. The aim of this study was to assess legumes, indigenous to South Africa, Lesotho and Swaziland and propose a list of species with pasture potential for further evaluation. Towards this end, legume species documented as being cultivated, grazed or browsed as well as plant collection data from the National Herbarium, South Africa, were used. The majority of cultivated, grazed or browsed species were recorded in the Central Bushveld, Lowveld and Mopane Bioregions, the Drakensberg Foothill and Coastal Region, Savanna Group and Northern Mistbelt leguminochoria and is largely enclosed by the Wolkberg Centre of Plant Endemism. The Phaseoleae tribe was found to contain the highest percentage of cultivated legume species. Legume species adapted to low soil phosphorus levels were identified, with 22 of these species previously noted for their pasture potential. It is suggested that the results of this study be used in the continued search for alternative indigenous legumes species for eventual integration into local and international pasture systems.

Keywords: Fabaceae, fodder crops, Leguminosae, phosphorus, plant genetic resources

Introduction

The protection of African plant diversity is important since the continent is noted to be vulnerable to climate change (McClean et al. 2005; Davis-Reddy and Vincent 2017), whereas southern Africa has been identified as being highly vulnerable (Gonzalez et al. 2010). It is predicted that the geographical ranges of African plant species will decrease in size and/or shift to locations at higher altitude, such as the Drakensberg, with concomitant large geographical changes in species composition (McClean et al. 2005). The impacts of climate change on the potential production of forage crops in southern Africa is therefore particularly important when selecting new forage species for screening and breeding programmes.

Even though many southern African grass species have been evaluated, improved and made commercially available, only a few indigenous legume species are presently used as pasture crops (Strickland et al.1999; Whitbread and Pengelly 2004; Makoi 2009; Whitbread et. al. 2011; Howieson 2014; Smýkal et al 2015; Bell et al. 2016). The need for developing legumes adapted to arid and semi-arid environments are imperative (Graham and Vance 2003; Sprent and Gehlot 2011; Sennhenn et al. 2017), especially if the predictions of climate change in southern Africa are taken into consideration (Davis 2011; Davis-Reddy and Vincent 2017). Hitherto only a few southern African legumes species have gone through a forage selection and/or evaluation process. These include: *Alysicarpus rugosus*, *Lablab purpureus*, *Listia bainesii*, *Macrotyloma axillare*, *Mucuna pruriens*, *Neonotonia wightii*, *Rhynchosia minima*, *Stylosanthes fruticosa*, *Vigna unguiculata* and *Vigna vexillata* (Smith 1977; Kategile 1985; Clatworthy and Madakadze 1988; Lusembo et al. 1995; Nyoka et al. 2004; Rootman et al. 2004; Real and Altier 2005; Mapiye et al. 2006; Morris 2008; Maass et al. 2010). More recently, interest in southern African legumes focused on *Cullen tomentosum*, *Lebeckia ambigua* and *Lessertia* spp. (Gerding et al. 2013; Howieson et al. 2013; Kaholongo 2016).

Global initiatives to collect, evaluate and develop pasture cultivars have largely been abandoned or significantly reduced due to a lack of funding. In a recent study that analysed the access to plant genetic resources (PGR) in Africa, it was concluded that the limitation in documentation of indigenous knowledge and the lack of complete inventories of PGR are constraints that limit the access and benefit-sharing of PGR (Elliott 2008). Even though South Africa was not included in this study, actions are also needed to develop and implement access to PGR and benefit-sharing in South Africa. These include programmes that maintain *in situ* conservation and *ex situ* facilities. There is, however, a general lack of interest in evaluating and developing indigenous southern African legume species, in Africa itself. This can be attributed, among others, to the fact that large numbers of species in prominent genera are not commonly recognised as livestock feed. These are, for example, *Aspalathus* (±335 spp.), *Crotalaria* (±55 spp.), *Indigofera* (±196 spp.) and *Tephrosia* (±62 spp.) (Trytsman 2013), bearing in mind that this estimate was based on the South African National Biodiversity Institute's (http://posa.sanbi.org) data of 2008 and that species numbers fluctuate over time. Most legume species are also most likely to have a low preference by grazing animals and/or production and could contain secondary plant metabolites, generally known to be anti-nutritional factors. Known anti-nutritional factors within southern African legume species include cyanogenic glucosides, alkaloids and saponins (Van Wyk 1989; Wink 2013). Even though anti-nutritional compounds are found in many legume species, these substances do not necessarily exclude them from being valuable fodder species. This is evident from well-known and valuable fodder species, such as *Lablab purpureus* and *Mucuna pruriens* with the former containing trypsin inhibitors, tannins and phytic acid (Kumar et al. 2016) and the latter containing phenolics, tannins and L-DOPA (Pugalenthi et al. 2005).

One of the major reasons leading to the indifference to explore local genetic resources in South Africa is the easily available improved pasture legumes from especially Australia and southern America. Alien legume germplasm were brought into South Africa since the late 1970s, with the first pasture legume-breeding programme (temperate species) in South Africa commencing in 1976 at Cedara near Pietermaritzburg, KwaZulu-Natal. Later, Kruger (1999) discussed in depth the acquisition of primarily alien tropical and subtropical legume genetic resources with the aim of alleviating problems associated with agricultural land-use practices in South Africa. This programme focused on screening, characterisation, description, evaluation, selection and breeding of potential and/or promising introduced pasture legumes, such as *Desmanthus virgatus*, *Leucaena leucocephala* and *Stylosanthes guianensis*.

Given that many legumes acquire nitrogen through symbiotic nitrogen fixation, phosphorus (P) is the most limiting element for growth in nitrogen-fixing legume plants (Vance 2001; Divito and Sadras 2014; Sulieman and Tran 2015). The use of phosphate fertiliser in legume pastures is thus relatively high to maintain productivity (Miles and Manson 2000), especially where legumes are cut for hay and silage, and therefore species adapted to low soil P are economically invaluable. Soil in tropical and subtropical regions is especially P-deficient (e.g. the savanna regions), and the use of legume cover crops to reclaim acid soils low in P and nitrogen is recommended by many researchers (Oberson et al. 2006; Sheoran et al. 2010; de la Peña and Pueyo 2012). Some studies on southern African pasture legume species have been conducted to test their phosphate use efficiency. For example, *Listia bainesii* was shown to produce more biomass under low P levels than lucerne in a glasshouse experiment (Pang et al. 2010) and with *Vigna unguiculata*, planted at high plant densities and intercropped with sorghum, the acid and alkaline phosphatase activities in the soil were significantly increased, especially with the farmer-selected cultivar 'Sanzie' (Makoi et al. 2010). Other indigenous legumes with pasture value could thus also show promising results under low soil P levels.

Earlier, Trytsman et al. (2016) confirmed that indigenous legumes can successfully be integrated in pasture systems and that the available legume genetic resources should be further exploited. Therefore, the principal aim of the present study was to use available descriptive data to assess legumes indigenous to South Africa, Lesotho and Swaziland and propose a list of species for further evaluation in terms of their pasture potential. For convenience, the intraspecific taxa (23% of the total number of species) are counted and referred to as 'species' in this contribution.

Materials and methods

Legume species recorded by Glen (2002) as being cultivated (have not necessarily been through a breeding and selection process) and grazed/browsed (Trytsman 2013) were used as the data set for the present study. Distribution records provided in 2008 by the South African National Herbarium (PRE) Computerised Information System (PRECIS 2008) were used to generate a map for the number of cultivated and grazed/browsed legume species contained in each quarter-degree grid cells (QDGCs) within the borders of South Africa, Lesotho and Swaziland. According to Victor et al. (2016), new accessions recorded since 2008 have been minimal compared with prior to this date and therefore it is assumed that more recent collections will not significantly change the findings of this study. The bioregions map of Rutherford et al. (2006) and ArcView GIS 3.2 (ESRI Inc., Redlands, CA, USA, 2002) were used to create the layers for the maps that are presented.

The distribution of cultivated and grazed/browsed legume species within their latitudinal and longitudinal lines was analysed by Table Curve 2D 5.01 (Systat Software, Inc., San Jose, CA, USA) to fit the most appropriate function. All curves were polynomials that fitted a wide range of curvatures and used when the functional relationship was complicated but repeatable and is described as:

$$y = a + bx^{0.5} + cx + dx^{1.5} + ex^2 + fx^{2.5} + gx^3$$

Legume species present near the maximum turning point for both the latitudinal and longitudinal lines were included in further evaluations and scored for their potential pasture value. To score species present in the selected latitudes and longitude lines and divide them into a lower, medium or higher potential pasture value, known attributes were selected from data available in the publications that follow. Germishuizen and Meyer (2003) was used to describe each species in terms of its life cycle (annual or perennial) and height. Steyn (1934), Watt and Breyer-Brandwijk (1962), Shearing and Van Heerden (1997) and Kellerman et al. (2005) were mainly consulted to establish if a legume species contains anti-quality and/or poisonous substances. A summary of indigenous legume species' distribution pattern, growth form, life cycle, height and anti-quality attributes is available in Trytsman (2013).

The attributes and scores used to assess species for their potential pasture value were assigned according

Table 1: Attributes assigned to legumes indigenous to South Africa, Lesotho and Swaziland in order to score each legume species for its potential pasture value. Bioregions are defined by Rutherford et al. (2006)

Attributes	Scores
Anti-quality	1 = Contains anti-qualities or poisonous substances (e.g. cyanogenic glycosides)
	2 = Contains minor anti-qualities (e.g. condensed tannins, alkaloids)
	3 = Contains no known anti-qualities or is present in the root system
Cultivated, grazed/browsed	1 = Not recorded as being cultivated, grazed/browsed
	2 = Recorded as cultivated, grazed/browsed
Distribution	1 = Narrow distribution, i.e. present in one bioregion
	2 = Intermediate distribution, i.e. present in two or three bioregions
	3 = Wide distribution, i.e. present in more than three bioregions
Duration	1 = Annual
	2 = Short-lived perennial, occasional perennial or perennial
Plant height	1 = Mean height > 2 m and any shrub or tree described as climbers
	2 = Mean height ± 1.5 m
	3 = Mean height 0.5–1.5 m or herbs taller than 1m
	4 = Mean height < 0.5 m including creepers and climbers
Soil phosphorus	1 = Adapted to soil phosphorus > 10 mg kg^{-1}
	2 = Adapted to soil phosphorus ≤ 10 mg kg^{-1}
Total score	Minimum = 6; Maximum = 16

to criteria defined in Table 1. In terms of potential pasture production, the rationale for including species distribution was to give a higher value to species with a wider distribution (and presumed adaptability) above those with a limited distribution range. Given that annual pasture species have to be established yearly and perennial pasture species are more productive than annuals due to a higher regrowth potential, perennials were assigned higher scores. Legume species containing no known anti-qualities with a plant height of <0.5 m (to include bulk grazers) were also assigned higher scores. The minimum score a given species could obtain was six and the maximum 16. Agglomerative hierarchical clustering using PC-ORD 5.31 (MjM Software, Gleneden Beach, OR, USA) was applied to the data (583 species and total scores) to determine clusters of low, medium and high pasture values.

To identify legume species adapted to low soil P levels (≤10 mg kg^{-1}), a map supplied by the Agricultural Research Council–Soil, Climate and Water (ARC-SCW 2009) was used. Furthermore, the 69 legume species recorded in QDGCs with soil P ≤ 10 mg kg^{-1} (covering 49% of the total number of QDGCs) were selected and used in a discriminant analysis (DA) to investigate which predictor (driver) contributed most to separate groups. Jombart et al. (2010) stated that DA maximises the separation between groups and minimises the variation within groups. The distribution records (4 898 PRECIS records) and range of tolerance to rainfall, mean annual minimum and maximum temperature, and soil pH were extracted from Trytsman (2013). The discriminant analysis program of XLSTAT 2012.4.03 (Addinsoft, New York, USA) was used.

The following shortcomings of the data used and/or lack thereof were identified and are worth mentioning because they could affect the order of species proposed for future evaluation:

- distribution patterns are based on plant collection (herbaria) databases that have geographical bias (e.g. along main roads or in a nature reserve), taxonomic bias (species that are easy to collect or more conspicuous) and temporal bias (collected in one season) (Robertson and Barker 2006);
- incorrect geo-referencing (Soberón and Peterson 2004);
- incorrect identification of specimens;
- outdated taxonomy;
- insufficient data on plant height (creeping or climbing herbs are often described as longer than 5 m);
- unknown production data for most legume species;
- unknown anti-quality/poisonous traits of many species;
- availability of physical traits data (e.g. hairiness and thorns).

Results and discussion

Occurrence of cultivated legume species

The numbers of cultivated legume species recorded in each QDGCs were divided into three classes as shown in Figure 1. The classes were divided as follow: ≤20 species per QDGC (low); 21–40 species per QDGC (medium) and 41–66 species per QDGC (high). Interesting to note is when Figure 1 is compared with a collection intensity map published by Trytsman et al. (2011) it is clear that, although similar patterns of low to high species numbers are observed, there are QDGCs with low collection intensities but with high number of cultivated species. This, for example, is true for the Mopane and Lowveld Bioregions. There are also QDGCs with high legume collection intensities but with low numbers of cultivated species, for example in the Fynbos Biome. This suggests that the intensity of collection data (PRECIS 2008) does not fully reflect the patterns of occurrence of cultivated legume species.

The medium to high number of cultivated species per QDGCs occurs mainly in the Central Bushveld, Lowveld and Mopane Bioregions (inclusive to the Savanna Biome) as well as the Mesic Highveld Grassland Bioregion (part of the Grassland Biome). In terms of leguminochoria (Table 2; data from Trytsman et al. 2016), cultivated species occurs mainly in the Drakensberg Foothill and Coastal Region,

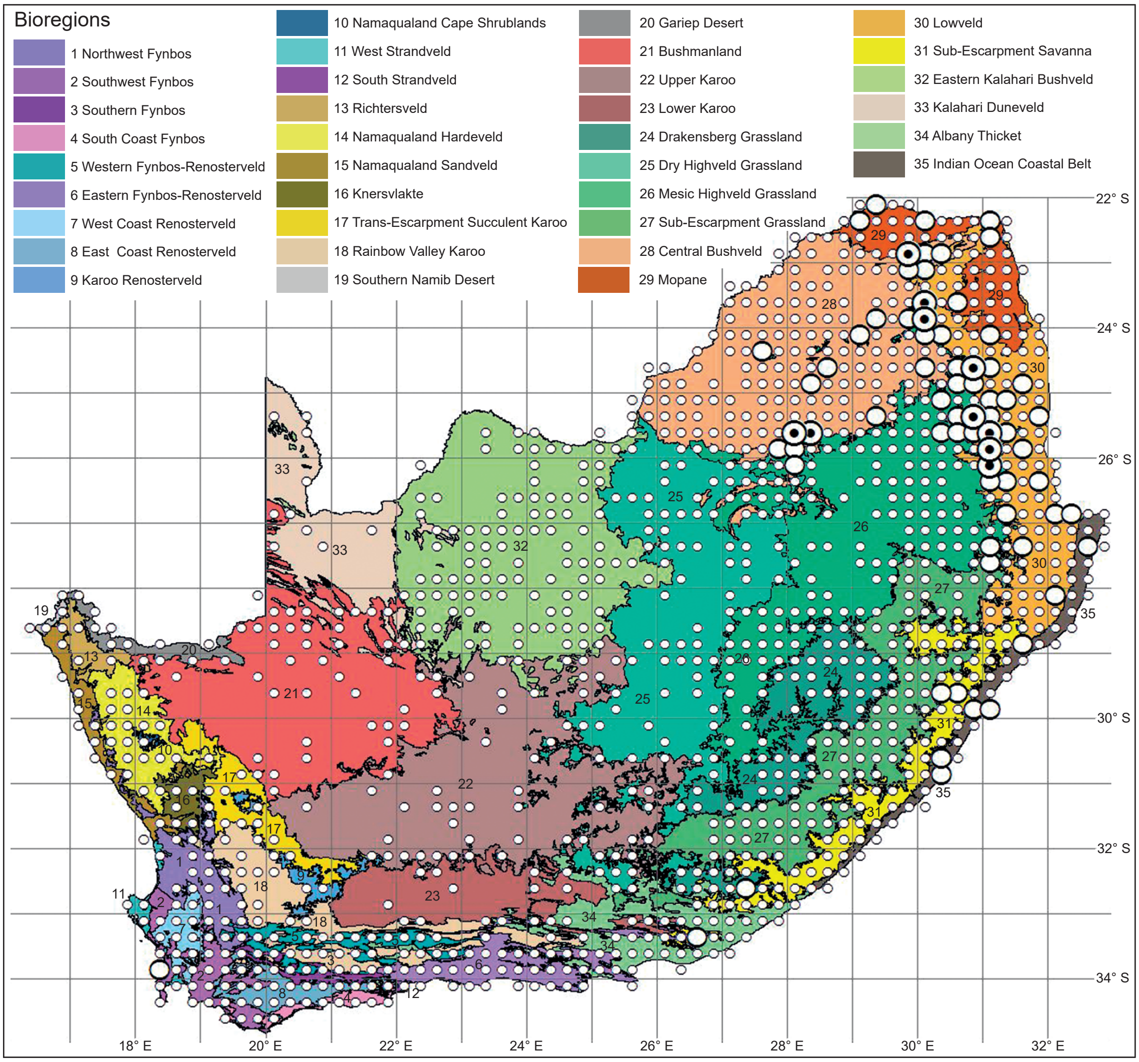

Figure 1: Number of indigenous legume species recorded as cultivated species mapped on the bioregions map of South Africa, Lesotho and Swaziland (Rutherford et al. 2006). Small white dots: ≤20 species; larger white dots: 21–40 species; white-black dots: 41–66 species

the Savanna Group (Central Bushveld and Subtropical Lowveld and Mopane Regions) and the Northern Mistbelt. The predominant climate and soil properties as well as agrohydrology (Schulze 2007) of each leguminochorion is discussed in Trytsman et al. (2016).

To select QDGCs in which high numbers of cultivated species occur, species numbers in both latitudes and longitudes were plotted separately where the polynomial curves are respectively shown in Figure 2 and Figure 3. The latitudes and longitudes enclosed by the ellipsoids were used to generate a list of legume species present as recorded by PRECIS. Thus, all the legume species present in the latitudinal lines that lie between 23.875° S and 26.125° S (Figure 2) and the longitudinal lines between 30.125° E and 31.375° E (Figure 3) were selected for further evaluation. It is worth noting that the model explains more of the variability of the response data around its mean for the longitudinal than for the latitudinal lines (r^2 = 0.83 vs r^2 = 59). This is probably due to a larger data set included for the longitudinal than for the latitudinal analysis.

Occurrence of grazed/browsed legume species

The results for the grazed/browsed legume species recorded in QDGCs are shown in Figure 4. The three classes of low, medium and high number of species per QDGCs are ≤10 species (low), 11–20 species (medium) and 21–27 species (high). Similarly to cultivated legume species, there are QDGCs with low collection intensities (Trytsman et al. 2011) but with high numbers of browsed species, e.g. the Mopane and Lowveld Bioregions (Figure 4). The highest number of grazed/browsed species has a distribution pattern similar to that of cultivated species in that they also occur mainly in the Central Bushveld and Lowveld Bioregions. In terms of leguminochoria (Table 2), grazed/browsed species occur mainly in the Savanna Group.

The number of grazed/browsed species in both latitudes and longitudes were plotted and the polynomial curves presented in Figure 5 and Figure 6, respectively. Figure 5 shows that the latitudinal lines between 24.625° S and 25.875° S and also 28.625° S and 28.875° S contain a high number of grazed/browsed species. Figure 6 shows

Table 2: Summary of the classification of leguminochoria of southern Africa (from Trytsman et al. 2016, which should be consulted for detailed descriptions and maps depicting the location of these floristic areas). Key bioregions from Rutherford et al. (2006) with additional descriptions accessed from published literature

Cluster	Leguminochorion	Key bioregions[1]	Additional description[2]
A	**Sourveld and Mixed Veld Group (medium- to high-rainfall areas)**		
A1	Southern Afromontane	MHG, SEG, SES	Forest biome (Lo); Moist subtropical (Kr)
A2	Albany Centre	AT, DG, SEG	Albany Centre (Va); Forest biome (Lo); Dry subtropical (Kr)
A3	Northern Highveld Region	CBV, DHG, MHG	Rocky Highveld Grassland (Lo); Moist subtropical (Kr); Bankenveld and North-eastern Sandy Highveld (Ac)
A4	Drakensberg Alpine Centre	DG, MHG, SEG	Drakensberg Alpine Centre (Va); Forest biome (Lo); Alpine (Kr); *Themeda–Festuca* Alpine Veld (Ac)
A5	Drakensberg Foothill and Coastal Region	IOCB, LV, SES	Maputaland-Pondoland Region (Va); Coastal Bushveld-Grassland (Lo); Moist and humid subtropical (Kr)
B	**Seasonal Rainfall Group (all-year, winter and summer rainfall)**		
B1	Arid Western Region	NHV, BML	Gariep Centre (Va); Warm desert (Kr); Namaqualand Broken Veld, Succulent Karoo and Strandveld (Ac)
B2	Lower-rainfall Cape Floristic Region	AT, EFR	Maritime (Kr); Coastal Fynbos and Coastal Renosterveld (Ac); Karoo Mountain, Langebaan, Agulhas Plain and Southeastern Centres (Go)
B3	Central Arid Region	EKB, NK	Nama-Karoo and Western Savanna biomes (Ru); Cold and warm desert, Dry subtropical (Kr)
B4	Generalist Group	All regions except Fynbos, Northern Mistbelt Afromontane, IOCB	Non-specific, Non-Cape group
B5	Summer Rainfall Region	MHG, CBV	
B6	Northern and Northeastern Savanna Region	CBV, LV	Mopane Bushveld, Mixed Lowveld Bushveld, Mixed Bushveld (Lo)
B7	Kalahari Bushveld Region	EKB	Griqualand West Centre (Va); Kimberley Thorn Bushveld and Kalahari Plateau Bushveld (Lo); Kalahari Thornveld (Ac)
C	**Higher-rainfall Cape Floristic Region**	EFR, SWF	Mediterranean (Kr); False Sclerophyllous Bush types and Coastal Renosterveld (Ac); mainly Southwestern and Northwestern Centres (Go)
D	**Savanna Group**		
D1	Central Bushveld Region	CBV	Moist subtropical (Kr); Springbok Flats Turf Thornveld and Sour Bushveld (Ac)
D2	Subtropical Lowveld and Mopane Region	LV, M	Mopane Bushveld and Mixed Lowveld Bushveld (Lo); Dry and moist tropical (Kr)
E	**Northern Mistbelt**	Transitional MHG, LV, CBV	Afromontane Forest (Lo); Inland Moist tropical and moist subtropical (Kr); Tropical Forest Type (Ac)

[1] AT: Albany Thicket; BML: Bushmanland; CBV: Central Bushveld; DG: Drakensberg Grassland; DHG: Dry Highveld Grassland; EFR: Eastern Fynbos-Renosterveld; EKB: Eastern Kalahari Bushveld; IOCB: Indian Ocean Coastal Belt: LV: Lowveld; M: Mopane; MHG: Mesic Highveld Grassland; NHV: Namaqualand Hardeveld; NK: Nama-Karoo; SEG: Sub-Escarpment Grassland; SES: Sub-Escarpment Savanna; SWF: Southwest Fynbos

[2] Ac: Acocks (1988); Lo: Low and Rebelo (1996); Kr: Kruger (1999), Va: Van Wyk and Smith (2001); Go: Goldblatt and Manning (2002); Ru: Rutherford et al. (2006)

the longitudinal lines between 27.875° E and 31.875° E to be included in the selection of grazed/browsed species. When comparing the r^2 coefficients for the longitudinal and latitudinal lines, the former shows less variability of the response data around its mean ($r^2 = 81$ compared with $r^2 = 71$), similar to cultivated species and probably for the same reason mentioned.

Proposed list of legume species with potential pasture value

The highest number of legume species known to be either cultivated, grazed or browsed occurred in the one degree grid square between the 25° S and 26° S latitudinal lines (Figures 2 and 5) totalling ±100 to 420 species. In terms of longitudes (Figures 3 and 6), higher numbers of cultivated, grazed or browsed species occur in the 30° E and 31° E longitudinal lines, i.e. ±100 to 560 species. In terms of bioregions, the 2530 grid falls largely within the Mesic Highveld Grassland Bioregion of Rutherford et al. (2006). This area also forms part of the Wolkberg Centre of Plant Endemism (Van Wyk and Smith 2001) and is associated with high elevations and high rainfall of the Great Escarpment. Commercial afforestation has already destroyed much of the high-rainfall grasslands in this particular part of the Wolkberg Centre (Van Wyk and Smith 2001).

The 583 legume species recorded in the selected QDGCs of cultivated and grazed/browsed species were scored for their pasture potential value according to the criteria outlined in Table 1. The percentage species scoring between nine and 16 are shown in Figure 7. Based on the AHC results, three distinct groups formed and are labelled as species with lower, medium and higher pasture value. The 112 species that scored 9–11 (19%) are labelled as species with lower pasture value, the 405 species that scored 12–14

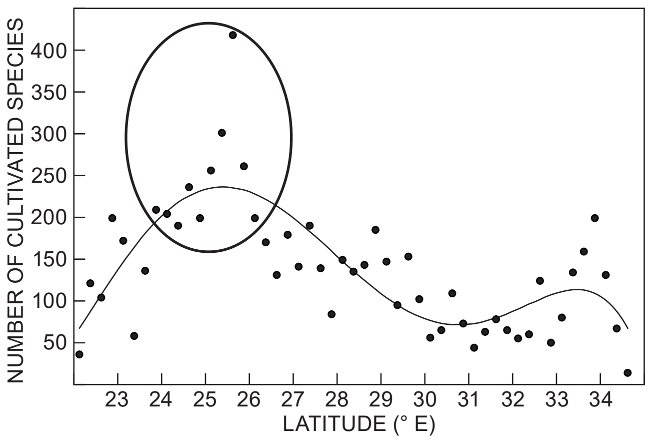

Figure 2: Number of cultivated legume species recorded in the latitudinal lines of southern Africa and fitted with a polynomial curve ($y = -0.0035x^6 + 0.5584x^5 - 37.215x^4 + 1\,317.4x^3 - 26\,167x^2 + 276\,961x - 1E{+}06$; $r^2 = 0.59$). The ellipsoid encloses the legume species selected for further evaluation within the given latitudinal lines

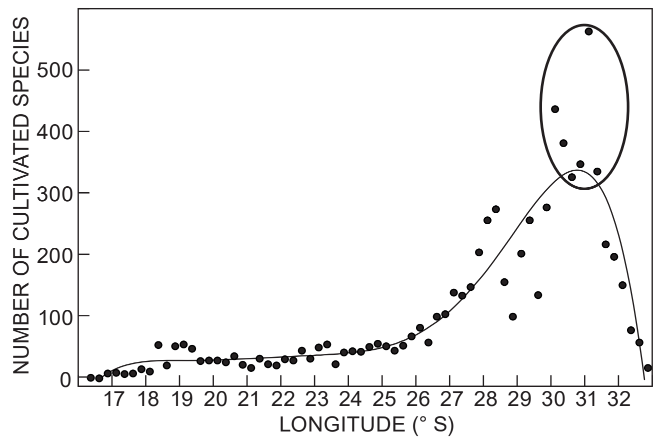

Figure 3: Number of cultivated legume species recorded in the longitudinal lines of southern Africa and fitted with a polynomial curve ($y = -0.002x^6 + 0.2756x^5 - 15.736x^4 + 475.49x^3 - 8\,026.2x^2 + 71\,790x - 265\,893$; $r^2 = 0.83$). The ellipsoid encloses the legume species selected for further evaluation within the given longitudinal lines

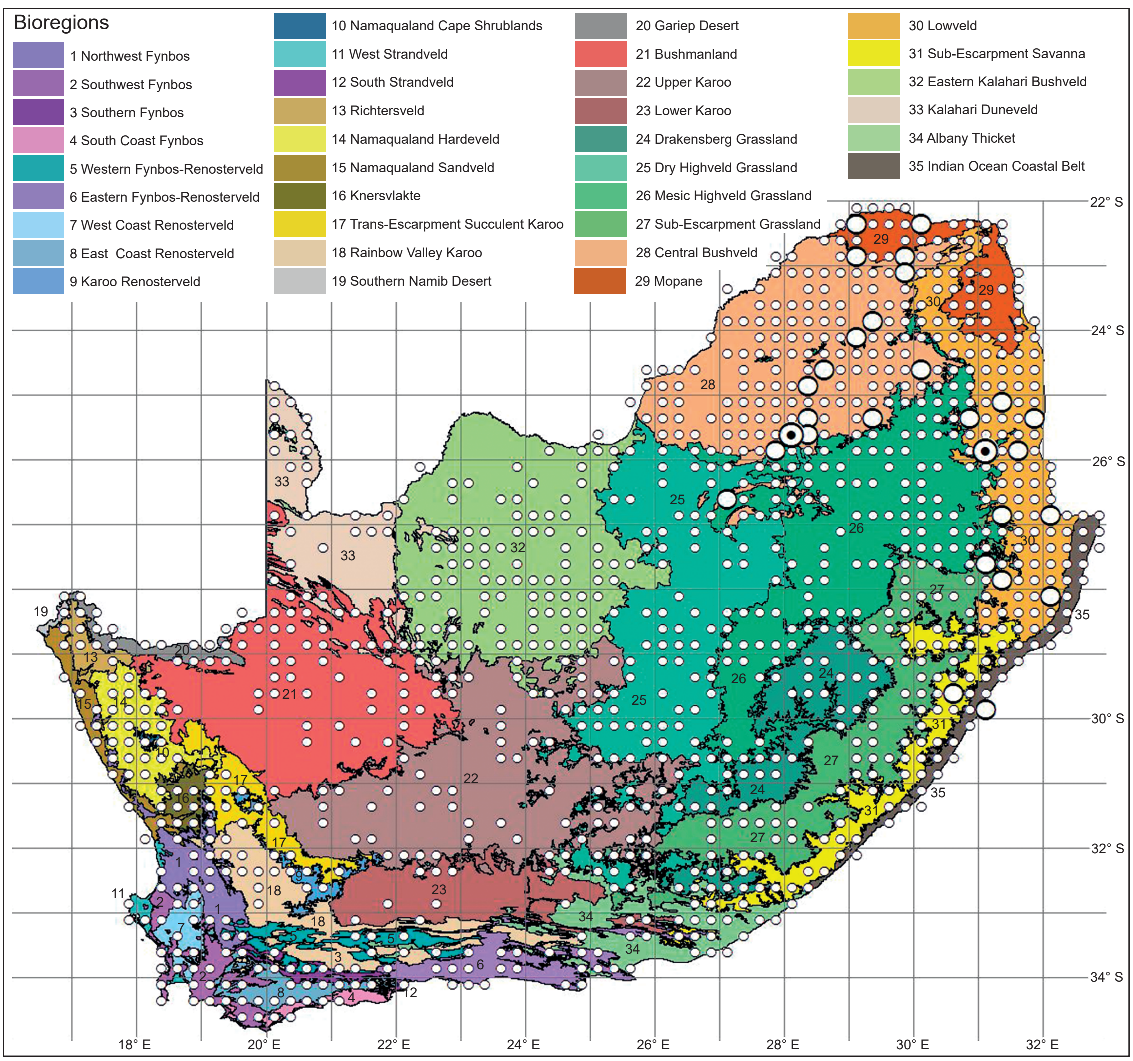

Figure 4: Number of indigenous legume species recorded as grazed/browsed species mapped on the bioregions map of South Africa, Lesotho and Swaziland (Rutherford et al. 2006). Small white dots: ≤10 species; large white dots: 11–20 species; white-black dots: 21–27 species

(70%) as having medium pasture value and the 66 species that scored 15 and 16 (11%) as having higher pasture value.

A summary of the 583 cultivated and grazed/browsed legume species within the Leguminosae tribes is presented in Table 3. The tribe Phaseoleae contains the highest percentage of cultivated legume species (20.4%) and almost twice the number compared with the next highest tribes, Millettieae (11.1%) and Indigofereae (10.4%). Grazed and/or browsed species are mostly contained in the tribe Acacieae (20.8%), followed by the Crotalarieae (15.6%) and Indigofereae (12.5%). Given that the Phaseoleae contains the third largest number of legume species indigenous to South Africa, Lesotho and Swaziland (10.8% of the total number of indigenous legume species) (Trytsman et al. 2011; Trytsman 2013), species within this tribe could hold potentially valuable pasture species. Within the tribe Phaseoleae, genera of interest are *Canavalia* (5 spp.), *Dolichos* (12 spp.), *Eriosema* (46 spp.), *Erythrina* (10 spp.), *Lablab* (1 sp.), *Macrotyloma* (5 spp.), *Mucuna* (4 spp.), *Neonotonia* (1 sp.), *Neorautanenia* (3 spp.), *Rhynchosia* (59 spp.), *Sphenostylis* (2 spp.), *Teramnus* (1 sp.) and *Vigna* (20 spp.).

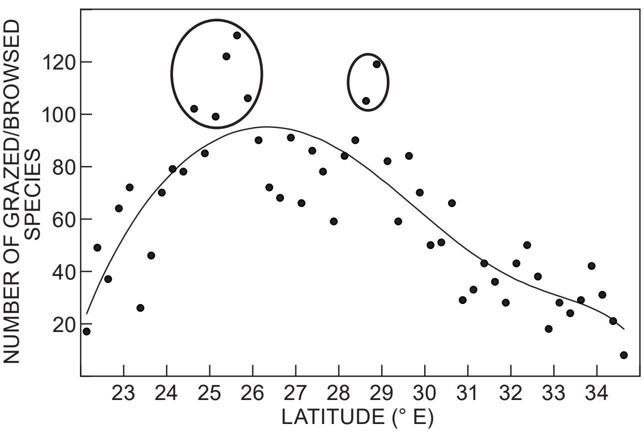

Figure 5: Number of grazed/browsed legume species recorded in the latitudinal lines of southern Africa and fitted with a polynomial curve ($y = -0.0007x^6 + 0.108x^5 - 7.4388x^4 + 272.08x^3 - 5\,582.7x^2 + 61\,034x - 278\,243$; $r^2 = 0.71$). The ellipsoid encloses the legume species selected for further evaluation within the given latitudinal lines

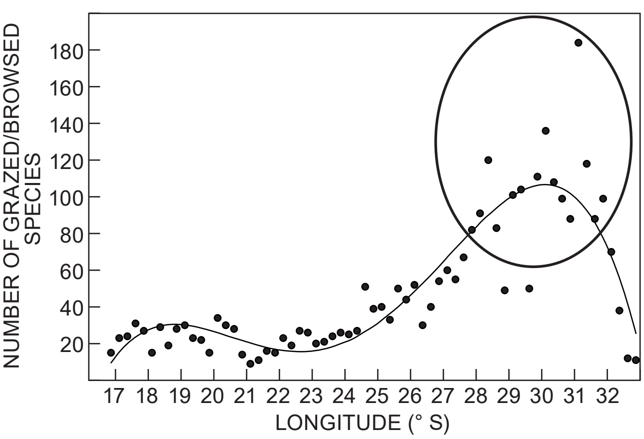

Figure 6: Number of grazed/browsed legume species recorded in the longitudinal lines of southern Africa and fitted with a polynomial curve ($y = -0.0431x^4 + 4.107x^3 - 144.08x^2 + 2\,207x - 12\,450$; $r^2 = 0.81$). The ellipsoid encloses the legume species selected for further evaluation within the given longitudinal lines

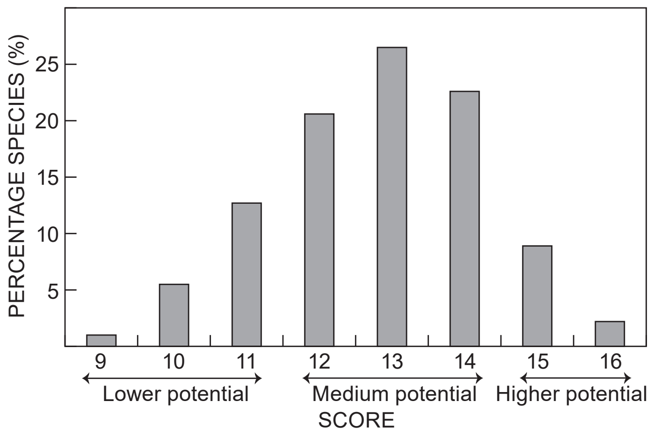

Figure 7: Lower, medium and higher potential pasture value scores (%) of legumes indigenous to South Africa, Lesotho and Swaziland based on selected criteria that include anti-qualities, distribution, adaptation to low soil phosphorus, plant height and duration, cultivated and/or grazed/browsed (Trytsman 2013)

Table 3: Cultivated and grazed/browsed species shown as a percentage present in the three subfamilies and 24 tribes of Leguminosae indigenous to South Africa, Lesotho and Swaziland. The percentage of the total number of indigenous legume species within each tribe is also shown

Tribe	Cultivated species (%)	Grazed/browsed species (%)	Legume species (%)
Caesalpinioideae			
Cercideae	4.7	1.0	0.8
Detarieae	4.7	2.1	0.6
Cassieae	1.7	0.0	0.7
Caesalpinieae	2.3	0.0	1.0
Mimosoideae			
Mimoseae	0.0	5.2	1.1
Acacieae	5.2	20.8	3.0
Ingeae	1.2	4.2	0.8
Faboideae			
Swartzieae	0.6	0.0	0.1
Sophoreae	1.7	1.0	0.3
Podalyrieae	5.2	3.1	8.4
Crotalarieae	8.7	15.6	38.0
Genisteae	4.1	3.1	4.6
Dalbergieae	4.1	4.2	1.7
Hypocalypteae	0.0	0.0	0.2
Indigofereae	10.4	12.5	12.7
Millettieae	11.1	2.1	4.6
Abreae	0.0	0.0	0.1
Phaseoleae	20.4	11.5	10.8
Desmodieae	3.5	3.1	0.9
Psoraleeae	3.5	1.0	5.2
Sesbanieae	2.9	1.0	0.6
Loteae	0.0	0.0	0.1
Galegeae	2.9	6.4	3.4
Trifolieae	1.1	2.1	0.3
Total	100.0	100.0	100.0

Legume species categorised as having high potential pasture value (scores of 15 to 16 in Figure 7) are listed in Table 4. At least 19 of the 66 listed species are known to have been through a screening, selection and/or evaluation process as cited by the various authors listed in Table 4. The acquisition of viable and genetically sound seed of the species listed, especially the 10 *Indigofera* spp., eight *Rhynchosia* and *Tephrosia* spp. and seven *Vigna* spp., is proposed as a collection target for the National Forage Genebank project of the Agricultural Research Council. The list of legume species categorised with lower and medium pasture value (517 species) is available in Trytsman (2013).

All species listed in Table 4 have nodulating abilities (rhizobial association) except for *Bauhinia galpinii*,

Table 4: Selected properties of legumes indigenous to South Africa, Lesotho and Swaziland categorised as having high pasture potential values based on selected criteria. Taxa, which have already been through a screening, selection and/or evaluation process, are followed by one or more references to the relevant literature. [I] Improved species; [N] non-nodulating; [P] tribe Phaseoleae; [S] plants spiny and may reduce pasture potential; [U] unknown nodulation

No known anti-qualities

Wide distribution, adapted to low soil P, plant height <0.5 m or climber/creeper, perennial, is grazed or cultivated

Argyrolobium collinum
Crotalaria eremicola subsp. *eremicola*[S]
Eriosema parviflorum subsp. *parviflorum*[P]
Indigastrum argyraeum
Indigofera rhytidocarpa subsp. *rhytidocarpa*
Lessertia depressa (Müller et al. 2017)
Lotononis tenella
Otoptera burchellii[P] (Kaholongo 2016)
Rhynchosia confusa[P]
Rhynchosia minima var. *minima*[P] (Maposse et al. 2003; Njarui et al. 2004a)
Rhynchosia totta var. *totta*[P] (Maposse et al. 2003; Njarui et al. 2004a)
Rhynchosia venulosa[P]
Vigna vexillata var. *vexillata*[IP] (Damayanti et al. 2010; Dakora 2013)
Zornia milneana (Hakiza et al. 1988; Muir and Maposse 2002; Njarui et al. 2004a)

Wide distribution, adapted to low soil P, plant height <0.5 m or climber/creeper, perennial, no record of being grazed or cultivated

Argyrolobium humile
Chamaecrista biensis (Clatworthy 1975)
Eriosema squarrosum[P]
Indigofera angustifolia var. *tenuifolia*
Indigofera ionii[U]
Indigofera torulosa var. *torulosa*
Leobordea divaricata
Lessertia affinis
Lotononis macrosepala
Melolobium calycinum[S]
Melolobium obcordatum
Neptunia oleracea
Pomaria sandersonii[U]
Rhynchosia cooperi[P]
Tephrosia burchellii
Tephrosia capensis var. *acutifolia*
Tephrosia capensis var. *hirsuta*
Tephrosia linearis
Tephrosia marginella[U]
Tephrosia natalensis subsp. *natalensis*[U]
Tephrosia pietersii[U]

Wide distribution, adapted to low soil P, plant height 0.5–1.5 m, perennial, is grazed or cultivated

Indigofera alternans var. *alternans* (Tjelele 2006; Müller et al. 2017)
Indigofera cryptantha var. *cryptantha* (Hassen 2006)
Lessertia pauciflora var. *pauciflora* (Gerding et al. 2013; Müller et al. 2017)
Listia heterophylla (Smith 1974; Clatworthy 1980)
Sutherlandia microphylla (= *Lessertia frutescens* subsp. *microphylla*) (Venter 2006; Tucker 2012)
Tephrosia multijuga (Grobler 1966; Clatworthy 1975)

No known anti-qualities

Wide distribution, not adapted to very low soil P, plant height <0.5 m or climber/creeper, perennial, is grazed or cultivated

Bauhinia galpinii[N]
Erythrina zeyheri[PS]
Indigofera dimidiata
Indigofera hedyantha
Indigofera longibarbata
Listia bainesii[I] (Smith 1974; Clatworthy 1980; Van Wyk 1989; Real and Altier 2005; and one of the 13 most researched legume pastures, Truter et al. 2015)
Lotononis laxa
Macrotyloma axillare var. *axillare*[IP] (Smith 1977; Blumenthal et al. 1989; Morris 2008; de Andrade Gimenes et al. 2017)
Neonotonia wightii[PI] (Clatworthy and Madakadze 1988; Le Roux et al. 1988; Mapiye et al. 2006; de Andrade Gimenes et al. 2017; and one of the 13 most researched legume pastures, Truter et al. 2015)
Rhynchosia adenodes[P]
Rhynchosia caribaea[P]
Rhynchosia minima var. *prostrata*[P] (Maposse et al. 2003; Njarui et al. 2004a)
Senegalia schweinfurthii[N] (= *Acacia schweinfurthii* var. *schweinfurthii*)
Sphenostylis angustifolia[P]
Stylosanthes fruticosa[I] (Clatworthy 1980, 1985; Njarui et al. 2004a, 2004b)
Trifolium africanum var. *africanum*[I] (Jones et al. 1974)
Trifolium burchellianum subsp. *burchellianum*[I] (Jones et al. 1974; Rumball and Lambert 1980; Kahurananga 1988)
Vigna oblongifolia var. *oblongifolia*[P] (Mokoboki et al. 2002; Nyoka et al. 2004)
Vigna unguiculata subsp. *dekindtiana* var. *huillensis*[IP] (Nyoka et al. 2004; Odhiambo 2004; Rootman et al. 2004; Dakora and Chimphango 2006; Chiulele 2010)
Vigna unguiculata subsp. *dekindtiana* var. *dekindtiana*[IP] (Nyoka et al. 2004; Odhiambo 2004; Rootman et al. 2004; Dakora and Chimphango 2006; Chiulele 2010)
Vigna unguiculata subsp. *stenophylla*[IP] (Nyoka et al. 2004; Odhiambo 2004; Rootman et al. 2004; Dakora and Chimphango 2006; Chiulele 2010)
Vigna vexillata var. *angustifolia*[IP] (Damayanti et al. 2010; Dakora (2013)
Vigna vexillata var. *davyi*[IP] (Damayanti et al. 2010; Dakora 2013)

Intermediate distribution, adapted to low soil P, plant height <0.5 m or climber/creeper, perennial, is grazed or cultivated

Tylosema esculentum[IN] (Müseler 2005; Chimwamurombe 2010; Damayanti et al. 2010; Dakora 2013)

Some known anti-qualities

Wide distribution, adapted to low soil P, plant height <0.5 m or climber/creeper, perennial, is grazed or cultivated

Indigofera vicioides var. *vicioides* (Hassen 2006; Tjelele 2006)

Senegalia schweinfurthii var. *schweinfurthii* and *Tylosema esculentum*, which are non-nodulating, and *Pomaria sandersonii*, *Tephrosia marginella*, *Tephrosia natalensis* subsp. *natalensis* and *Tephrosia pietersii*, which are unknown in their ability to form nodules (Grobbelaar et al. 1967; Harrier et al. 1997; Dakora et al. 1999). In a recent study with *Burkholderia*, a rhizobial isolation was made from *Indigofera ionii*, previously of unknown nodulating ability (Lemaire et al. 2016).

Legume species adapted to low soil phosphorus content

Legume species adapted to low soil P levels (<10 mg kg^{-1}) are listed in Table 5. Descriptions in terms of the key bioregions (Rutherford et al. 2006), key leguminochoria (Trytsman 2013), growth form (Germishuizen and Meyer 2003) and potential pasture value (Trytsman 2013) are also noted for the 69 species. *Senegalia* and *Vachellia* (= *Acacia s.l.*) (15) as well as *Indigofera* spp. (13) represent the largest genera. The majority of these species are found in the Central Bushveld followed by the Eastern Kalahari Bushveld Bioregion, whereas the Subtropical Lowveld and Mopane Region leguminochorion contains the majority of species followed by the Central Arid Region. Of the few species that are also adapted to relatively low rainfall, *Indigofera alternans* var. *alternans* is the only herb recorded, occurring mainly in the Central Arid Region Group.

Of great interest is the 22 legume species noted for their potentially high pasture value and low soil P adaptation (Table 5). *Indigofera* represents the largest genus and included *I. alternans* var. *alternans*, *I. cryptantha* var. *cryptantha*, *I. rhytidocarpa* subsp. *rhytidocarpa*, *I. torulosa* var. *torulosa* and *I. vicioides* var. *vicioides*. The *Rhynchosia* genus followed with members that included *R. confusa*, *R. minima* var. *minima*, *R. totta* var. *totta* and *R. venulosa*. Even though *I. cryptantha* var. *cryptantha* and *I. vicioides*

Table 5: Legume species indigenous to South Africa, Lesotho and Swaziland adapted to relatively low soil phosphorus levels (<10 mg kg^{-1}), listed according to key bioregions (Rutherford et al. 2006), key leguminochoria (Trytsman 2013), growth form (Germishuizen and Meyer, 2003) and pasture value (Trytsman 2013). [I] Improved species; [N] non-nodulating; [P] tribe Phaseoleae; [S] plants spiny and may reduce pasture potential; [U] unknown nodulation; NE = not evaluated

Scientific name	Key bioregion	Key leguminochorion	Growth form	Pasture value
Albizia anthelmintica	Central Bushveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Medium
Bauhinia petersiana subsp. *macrantha*[N]	Central Bushveld	Generalist Group	Shrub, tree, climber	Medium
Bauhinia tomentosa[N]	Indian Ocean Coastal Belt	Drakensberg Foothill and Coastal Region	Shrub, tree	Medium
Bolusanthus speciosus	Lowveld	Subtropical Lowveld and Mopane Region	Tree	Medium
Chamaecrista biensis	Eastern Kalahari Bushveld	Central Bushveld Region	Herb	High
Chamaecrista mimosoides	Central Bushveld	Drakensberg Foothill and Coastal Region	Herb	Medium
Crotalaria distans subsp. *distans*	Central Bushveld	Generalist Group	Herb	Medium
Crotalaria griquensis[U]	Eastern Kalahari Bushveld	Kalahari Bushveld Region	Herb	NE
Crotalaria lotoides	Central Bushveld	Central Bushveld Region	Herb	Medium
Crotalaria monteiroi var. *monteiroi*[U]	Lowveld	Subtropical Lowveld and Mopane Region	Dwarf shrub, shrub	Medium
Crotalaria sphaerocarpa subsp. *sphaerocarpa*	Central Bushveld	Generalist Group	Herb	Low
Crotalaria virgultalis	Eastern Kalahari Bushveld	Central Arid Region; Generalist Group	Shrub	NE
Cullen tomentosum	Eastern Kalahari Bushveld	Central Arid Region	Herb	Medium
Dichrostachys cinerea subsp. *africana* var. *africana*[S]	Central Bushveld	Northern and Northeastern Savanna Region	Shrub, tree	Medium
Elephantorrhiza elephantina	Central Bushveld	Northern Highveld Region; Generalist Group	Dwarf shrub, shrub	Medium
Indigastrum argyraeum	Eastern Kalahari Bushveld	Central Arid Region	Herb	High
Indigofera alternans var. *alternans*	Eastern Kalahari Bushveld	Central Arid Region	Herb	High
Indigofera charlieriana var. *charlieriana*	Eastern Kalahari Bushveld	Generalist Group; Subtropical Lowveld and Mopane Region	Herb	Medium
Indigofera cryptantha var. *cryptantha*	Central Bushveld; Eastern Kalahari Bushveld	Kalahari Bushveld Region; Central Bushveld Region	Dwarf shrub, shrub	High
Indigofera daleoides var. *daleoides*	Eastern Kalahari Bushveld	Kalahari Bushveld Region	Herb	Medium
Indigofera filipes	Central Bushveld	Central Bushveld Region	Dwarf shrub, shrub, herb	Medium
Indigofera heterotricha	Central Bushveld	Central Bushveld Region	Dwarf shrub, herb	Medium
Indigofera holubii	Central Bushveld	Subtropical Lowveld and Mopane Region	Herb	Medium
Indigofera rhytidocarpa subsp. *rhytidocarpa*	Central Bushveld	Subtropical Lowveld and Mopane Region	Herb	High
Indigofera schimperi var. *schimperi*	Lowveld	Subtropical Lowveld and Mopane Region	Shrub	Medium
Indigofera sessilifolia	Eastern Kalahari Bushveld	Central Arid Region	Dwarf shrub, herb	Medium
Indigofera torulosa var. *torulosa*	Central Bushveld	Subtropical Lowveld and Mopane Region	Herb	High
Indigofera vicioides var. *vicioides*	Central Bushveld	Subtropical Lowveld and Mopane Region	Herb	High
Indigofera zeyheri	Indian Ocean Coastal Belt; Mesic Highveld Grassland	Albany Centre; Summer Rainfall region	Dwarf shrub, herb	Medium
Leobordea divaricata	Mesic Highveld Grassland	Northern Highveld Region	Herb	High
Leobordea platycarpa	Bushmanland	Central Arid Region	Herb	Medium
Lessertia depressa	Dry Highveld Grassland	Generalist Group	Dwarf shrub	High
Lessertia pauciflora var. *pauciflora*	Eastern Kalahari Bushveld	Central Arid Region	Herb	High
Listia heterophylla	Central Bushveld	Central Bushveld Region	Herb	High
Melolobium calycinum[S]	Dry Highveld Grassland	Generalist Group	Dwarf shrub	High

Scientific name	Key bioregion	Key leguminochorion	Growth form	Pasture value
Melolobium candicans[S]	Eastern Kalahari Bushveld	Central Arid Region	Dwarf shrub, shrub, herb	NE
Melolobium microphyllum[S]	Dry Highveld Grassland	Generalist Group	Dwarf shrub, shrub, herb	Medium
Mundulea sericea subsp. *sericea*	Central Bushveld	Summer Rainfall Region	Shrub, tree	Medium
Neorautanenia mitis[P]	Central Bushveld	Subtropical Lowveld and Mopane Region	Dwarf shrub, herb, succulent	Medium
Otoptera burchellii[P]	Central Bushveld	Northern and Northeastern Savanna Region	Shrub, herb, climber	High
Peltophorum africanum[NP]	Central Bushveld	Northern and Northeastern Savanna Region	Tree	Medium
Rhynchosia confusa[P]	Eastern Kalahari Bushveld	Kalahari Bushveld Region	Herb, climber	High
Rhynchosia minima var. *minima*[P]	Lowveld	Subtropical Lowveld and Mopane Region	Herb, climber	High
Rhynchosia totta var. *totta*[P]	Central Bushveld	Summer Rainfall Region	Herb, climber	High
Rhynchosia venulosa[P]	Central Bushveld	Central Bushveld Region	Herb, climber	High
Schotia brachypetala[N]	Lowveld	Subtropical Lowveld and Mopane Region	Tree	Medium
Senna italica subsp. *arachoides*[N]	Eastern Kalahari Bushveld	Central Arid Region	Herb	Medium
Senegalia ataxacantha[NS] (= *Acacia ataxacantha*)	Central Bushveld	Northern Mistbelt Forest	Shrub, tree, climber	Medium
Senegalia caffra[S] (= *Acacia caffra*)	Central Bushveld	Northern Mistbelt Forest	Shrub, tree	Low
Senegalia galpinii[NS] (= *Acacia galpinii*)	Central Bushveld	Northern and Northeastern Savanna Region; Central Bushveld Region	Tree	Medium
Senegalia mellifera[S] (= *Acacia mellifera* subsp. *detinens*)	Central Bushveld	Central Arid Region; Generalist Group	Shrub, tree	Medium
Senegalia senegal[S] (= *Acacia senegal* var. *leiorhachis*)	Central Bushveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Medium
Sutherlandia frutescens (= *Lessertia frutescens* subsp. *frutescens*)	Eastern Kalahari Bushveld	Central Arid Region	Dwarf shrub, shrub	Medium
Sutherlandia microphylla (= *Lessertia frutescens* subsp. *microphylla*)	Dry Highveld Grassland	Central Arid Region	Shrub	High
Tephrosia burchellii	Eastern Kalahari Bushveld	Kalahari Bushveld Region	Herb	High
Tephrosia multijuga	Central Bushveld	Northern Highveld Region; Central Bushveld Region; Northern Mistbelt Forest	Dwarf shrub, shrub, herb	High
Tephrosia purpurea subsp. *leptostachya* var. *pubescens*	Central Bushveld	Central Bushveld Region	Herb	Medium
Vachellia erioloba[S] (= *Acacia erioloba*)	Eastern Kalahari Bushveld	Central Arid Region	Shrub, tree	Low
Vachellia exuvialis[S] (= *Acacia exuvialis*)	Lowveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Low
Vachellia grandicornuta[S] (= *Acacia grandicornuta*)	Lowveld	Subtropical Lowveld and Mopane Region	Tree	Medium
Vachellia hebeclada[S] (= *Acacia hebeclada* subsp. *hebeclada*)	Eastern Kalahari Bushveld	Kalahari Bushveld Region	Shrub, tree	Low
Vachellia karroo[S] (= *Acacia karroo*)	Central Bushveld	Generalist Group	Shrub, tree	Medium
Vachellia luederitzii[SU] (= *Acacia luederitzii* var. *retinens*)	Central Bushveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Medium
Vachellia nilotica[S] (= *Acacia nilotica* subsp. *kraussiana*)	Central Bushveld	Subtropical Lowveld and Mopane Region	Tree	Medium
Vachellia robusta[S] (= *Acacia robusta* subsp. *clavigera*)	Lowveld	Subtropical Lowveld and Mopane Region	Tree	Low
Vachellia swazica[S] (= *Acacia swazica*)	Lowveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Low
Vachellia tortilis[S] (= *Acacia tortilis* subsp. *heteracantha*)	Central Bushveld	Subtropical Lowveld and Mopane Region	Shrub, tree	Low
Vigna vexillata var. *vexillata*[IP]	Central Bushveld; Mesic Highveld Grassland	Drakensberg Foothill and Coastal Region	Herb, climber	High
Zornia milneana	Central Bushveld	Central Bushveld Region	Herb	High

var. *vicioides* contain indospicine, a free amino acid that causes hepatotoxicity when grazed by cattle, they are still valued pasture plants (Hassen et al. 2008). *Indigofera alternans* var. *alternans* and *R. totta* var. *totta* have the widest distribution patterns of the aforementioned taxa (Trytsman 2013). *Lessertia depressa*, *Lessertia pauciflora* var. *pauciflora* and *Sutherlandia microphylla* (= *Lessertia frutescens* subsp. *microphylla*) have all been noted for being highly palatable (Le Roux et al. 1994).

All species listed in Table 5 have nodulating abilities except for *Bauhinia petersiana* subsp. *macrantha*, *Bauhinia tomentosa*, *Peltophorum africanum*, *Schotia brachypetala*, *Senegalia ataxacantha, Senegalia galpinii* and *Senna italica* subsp. *arachoides*, which are non-nodulating. *Crotalaria griquensis*, *Crotalaria monteiroi* var. *monteiroi* and *Vachellia luederitzii* var. *retinens* are unknown in their ability to form nodules (Grobbelaar et al. 1967; Grobbelaar and Clarke 1975; Palo et al. 1993).

The results of the discriminant analysis of legumes species adapted to low soil P is shown in Figure 8, where the Pearson's correlation matrix indicated that for F1, mean annual rainfall and mean annual maximum temperature

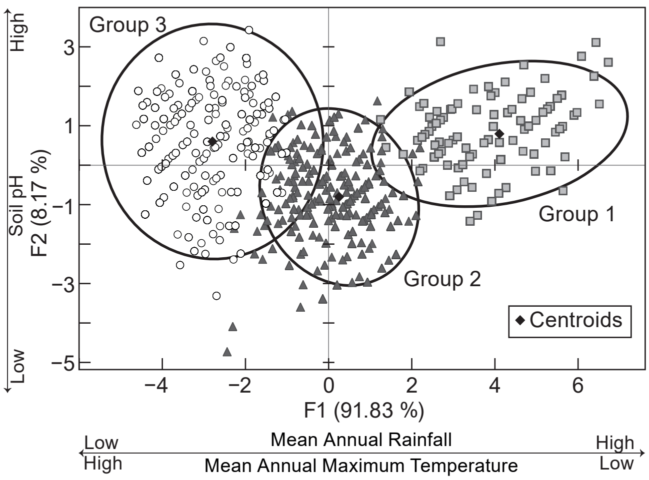

Figure 8: Discriminant analysis for legume species indigenous to South Africa, Lesotho and Swaziland adapted to low soil phosphorus levels (<10 mg kg^{-1}). Symbols represent legume species present in quarter-degree grid cells (4 898 records) and confidence ellipses around centroids represent groups. MAR = Mean annual rainfall, MAMT = mean annual maximum temperature

(negative) are the main drivers for distinguishing among legume species, whereas for F2, soil pH level is the main driver. The F1 function accounted for 91.83% of the independent variables and the F2 function accounted for 8.17% of the independent variables.

All legume species, except for 11 species, were present in Groups 1, 2 and 3. Group 1 represents relatively higher annual rainfall, lower annual maximum temperatures and higher soil pH, Group 2 relatively intermediate annual rainfall and maximum temperatures and lower soil pH, and Group 3 relatively lower annual rainfall, higher annual maximum temperatures and higher soil pH. The majority of legumes recorded in soils low in P are thus tolerant to a wide range of rainfall, maximum temperature and soil pH ranges. *Sutherlandia frutescens* (= *Lessertia frutescens* subsp. *frutescens*) was predominantly recorded as an outlier in Groups 2 and 3, thus present in regions with very low mean annual rainfall, high mean annual maximum temperature and low soil pH.

The 11 species not tolerant to the rainfall, maximum temperature and soil pH ranges were present in groups as follows:

- *Bolusanthus speciosus*, *Senegalia ataxacantha*, *Senegalia galpinii*, *Vachellia exuvialis* and *Vachellia swazica* present in Groups 1 and 2 (higher rainfall and lower maximum temperatures)
- *Bauhinia petersiana* subsp. *macrantha*, *Crotalaria virgultalis*, *Otoptera burchellii*, *Rhynchosia confusa* and *Vachellia erioloba* present in Groups 2 and 3 (lower rainfall and higher maximum temperatures)
- *Crotalaria griquensis* present in Groups 1 and 3 (extreme rainfall and maximum temperatures ranges).

In terms of leguminochoria, Group 1 represents the Southern Afromontane, Drakensberg Foothill and Coastal Region and Northern Mistbelt Forest, Group 2 the Albany Centre, Northern Highveld Region, Cape Floristic Group and Central Bushveld Region, and Group 3 the Arid Western Region, Central Arid Region and Kalahari Bushveld Region.

Conclusion

The highest occurrence of indigenous legume species known to be cultivated are recorded in the Central Bushveld, Lowveld, Mopane and Mesic Highveld Grassland Bioregions. Legume species known to be grazed and browsed occurred primarily in the Central Bushveld and Lowveld Bioregions. The collection and conservation of viable seed from the highly threatened Wolkberg Centre are a matter of some urgency. The importance of the tribe Phaseoleae is evident from the high numbers of species cultivated, grazed and browsed compared with other tribes and could be a starting point in a screening and evaluation process. Even though this study selected against known anti-quality traits it could be of minor importance in animal health and published data should be consulted for a complete species list. However, it is proposed that species with unknown anti-quality traits, highlighted in this study, be screened for anti-nutritional compounds. A critical step in the development of indigenous pasture legumes species will be the acquisition of genetic representative legume germplasm with reliable passport data before it disappears, either by natural processes or by human interference. Given that legumes are known for their lack of persistence, it will be an important breeding goal besides improved yield, nutritive value and tolerance to extreme biotic and abiotic stresses.

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