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APPENDIX 1

SOIL PROPERTIES

INTRODUCTION

In this appendix the soils are described. The soils are important because soil type is a primary determinant of savanna structure and functioning (Frost *et al*. 1986), and the soils have therefore been described to allow comparison with other studies.

METHODS

The physico-chemical properties of the soils of each site were described from 24 surface samples (0-15 cm), and five samples each from 30-40 cm and *ca*. 60 cm depth. The depth of the A-horison and the profile depth were measured for each sample (n=8 for profile depth at Utha). The samples were air-dried, sieved through a 2 mm sieve, and individually analysed for pH (KCl and H_2O) and conductivity, the concentrations of phosphorus, calcium, magnesium, sodium, potassium and zinc (Anon 1982), organic carbon (Nelson & Sommers 1975), and the percentage clay, derived from a regression (r^2=84%) between % clay and soil bulk density:

$\%clay=e^{7.87-3.84sd}$

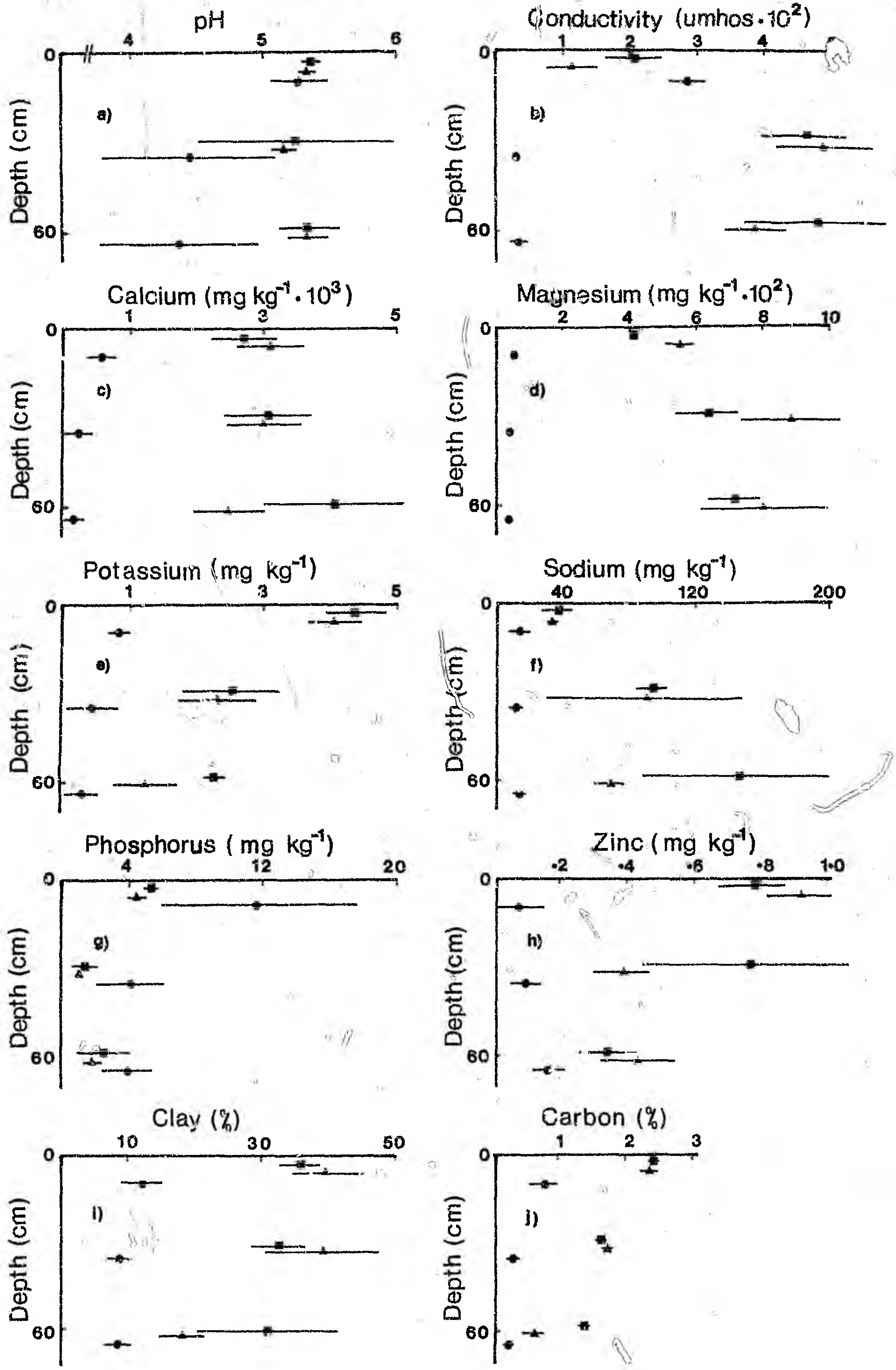
where sd=0.2(sample bulk density) (SASOL fertiliser laboratory). The proportion of gravel and grit (>2mm fraction) was determined by air-dried weight.

RESULTS AND DISCUSSION

The soils of the gabbro sites were both heavy textured clays (Figure A1.1), and were classified as Glendale series of the Shortlands form (an alfisol in USDA terminology) (MacVicar *et al.* 1977). The soils of the sandveld site were mainly Clovelly form, but there was variation down the slope. The soils of the two clay soil sites, and of the A horison of the sandveld site, were weakly acidic to neutral, but the deeper levels of the sandveld site were more strongly acidic (Figure A1.1). The physico-chemical environment of the two sites on gabbro was very similar (Figure A1.1), except at the 60 cm depth. This difference is attributable to differences in profile depth. The Thlavekisa profile was 55±2.6 cm (± 1 S.E., n=24) compared to the 85±2.7 cm (n=8) profile depth at Utha. The values of soil variables for Thlavekisa at 60 cm depth were therefore influenced by partly decomposed bedrock material. The 20±1.1 cm deep A-horison at Utha was a well-defined and darkened layer (Munsell dry: 10YR2/1 or 5YR2/2 most commonly). There was no readily evident A-horison at the Thlavekisa site, and the surface soil was reddish (Munsell dry: 5YR3/2). The deeper soil of both clay sites was similar in colour (Munsell dry: 2.5YR3/2 most common).

The pH, conductivity, percentage of clay and of carbon, and the concentration of calcium, potassium, magnesium and sodium, were considerably lower on the sandveld than on the two clay soils, but the

Figure A1.1. The soil physico-chemical characteristics at three depths of the Sandveld (circle), Utha (square) and Thlavekisa (triangle) sites: a) pH, b) conductivity, the concentrations of c) calcium, d) magnesium, e) potassium, f) sodium, g) phosphorus, h) zinc, and the percent of i) clay and j) carbon. Horizontal bars denote ± 1 S.E..

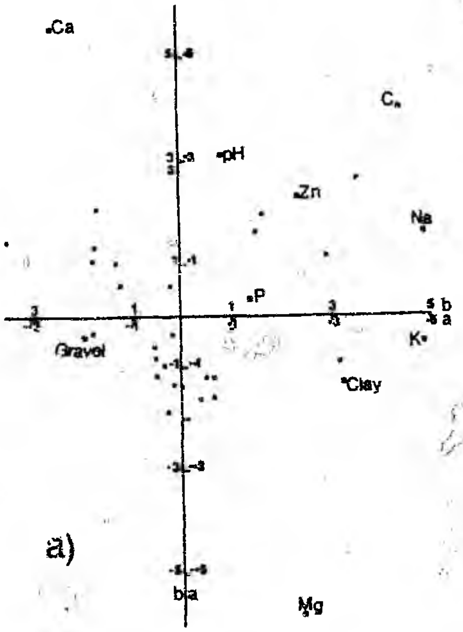

pH
4
5
6
0
60
Depth (cm)
a)
Conductivity (umhos·10²)
1
2
3
4
b)
Calcium (mg kg⁻¹·10³)
1
3
5
c)
Magnesium (mg kg⁻¹·10²)
2
4
6
8
10
d)
Potassium (mg kg⁻¹)
1
3
5
e)
Sodium (mg kg⁻¹)
40
120
200
f)
Phosphorus (mg kg⁻¹)
4
12
20
g)
Zinc (mg kg⁻¹)
·2
·4
·6
·8
1·0
h)
Clay (%)
10
30
50
i)
Carbon (%)
1
2
3
j)

concentration of phosphorus was substantially higher on the sandveld site. The pattern of change with depth of the soil variables is strikingly different between the sandveld and clay soil sites. All variables measured, except sodium and zinc, show a marked decrease in amount or concentration with depth on the sandveld site. On the clay soil sites, the concentration of magnesium and sodium, and to a slight degree calcium (but not potassium) show an increase with depth, which explains the similar pattern for conductivity.

An R-type principal components analysis of the 24 surface cores of each site (using 10 soil variables) was used to describe the spatial variation in the soils of the sites . The variation accounted for respectively by the first and second axes was 26% and 18% for Thlavekisa, 25% and 22% for Utha, and 41% and 19% (with one outlier deleted) for the sandveld site. The outlier deleted from the sandveld site was collected from an anomalous depression which held water following rain.

The first axis for the Thlavekisa ordination described a gradient from a few samples with high concentrations of potassium and sodium (quite closely correlated), associated with high levels of clay and organic carbon, through to the majority of samples with lower concentrations of these cations but greater amounts of calcium and of gravel (Figure A1.2a). The second axis separated out samples with high concentrations of calcium and a high pH from those with high concentrations of magnesium. The third axis (16% of the variance) was principally determined by phosphorus (loading=0.56), zinc (loading=0.54) and gravel (loading=0.47).

Figure A1.2. An ordination of the first two axes of a principal components analysis of ten soil variables for a) Thlavekisa, b) Utha and c) Sandveld sites. The a scale is for variables, the b scale for samples.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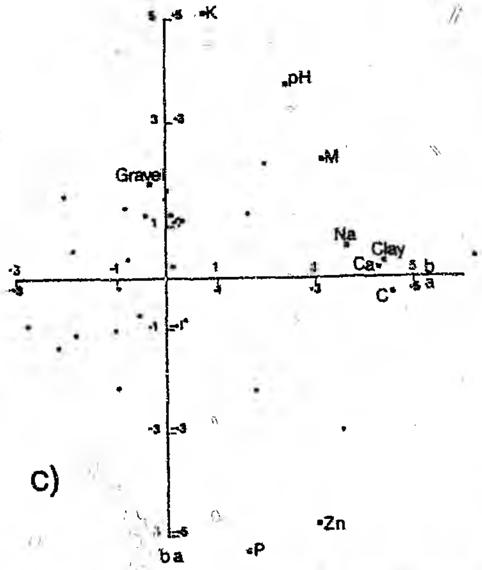
K
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-3
-5
b
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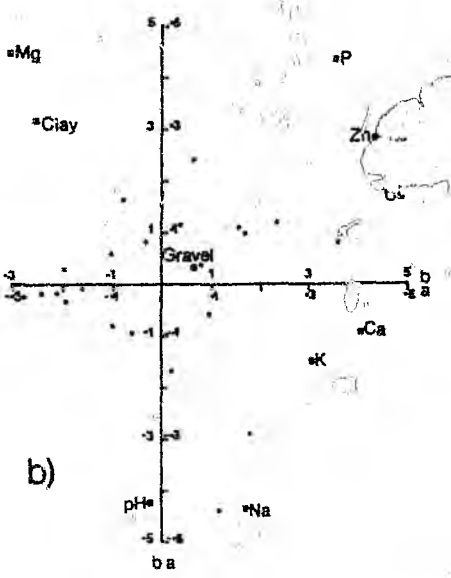
c)


Mg
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-3
-5
b
a
b)

The range in sample scores on the first axis from -3.5 to 3.53 indicated fairly substantial spatial variation in the soil. Part of this variation was associated with the influence of tree canopies (five cores), and was associated with higher levels of organic carbon, clay, potassium and sodium. Twelve cores from the open formed a distinguishable clump (Figure A1.2a). The remaining cores which formed a loose clump were all to be found in relatively close proximity to one another in the one corner of the plot.

Although the Utha soil was similar in characteristics, the relationship between the variables was very different. The first axis of the Utha ordination described a gradient from samples with a high concentration of potassium, calcium, phosphorus and high levels of carbon, through to samples with a high concentration of magnesium and high amounts of clay (Figure A1.2b). The second axis identified a few samples with high pH and associated high concentrations of sodium, through to an effect of higher concentrations of magnesium associated with higher amounts of clay, or higher amounts of phosphorus. There were strong correlations between the concentration of magnesium and the amount of clay, the pH and the concentration of sodium, and the concentrations of calcium and potassium. The third axis (15% of the variance) was principally determined by pH (loading=0.51), percent clay (loading=0.49), potassium (loading=0.45) and calcium (loading=0.42). The Utha site displayed a similar degree of spatial variation in soil conditions, with first axis scores of the principal components analysis ranging from -2.72 to 3.55, but this variation could not be related to tree canopy cover or to location within the site.

The relationship between variables on the sandveld site was dissimilar to both of the above. The first axis identified a gradient from samples with higher concentrations of calcium and sodium and with high amounts of carbon and clay (all four variables strongly correlated), through to samples with the converse (Figure A1.2c). The marked variability between samples is shown by the range in first axis scores from -2.75 to 6.28. The highest scores on the first axis were associated with the influence of tree canopies. The second axis separated samples with high potassium concentrations, and usually a high pH, from those with high phosphorus and zinc concentrations. The third axis (14% of the variance) was principally determined by gravel (loading=0.73) and pH (loading=-0.43).

APPENDIX 2

THE WOODY VEGETATION OF THE TWO CLAY SOIL SITES

INTRODUCTION

In this appendix the woody vegetation of hte two clay soil sites is described. The woody component can influence herbaceous composition (Bosch & van Wyk 1970; Kennard & Walker 1973; Griffioen & O'Connor 1990). Further, heavy grazing can promote an increase in the woody component of savannas (Walker *et al.* 1981; Skarpe 1990), which could therefore lead to compositional change in the herbaceous stratum. The composition of the woody component and the size structure of the main species are described for reference purposes. The population structure and identity of the main species provide a first indication of possible woody vegetation dynamics, but it was beyond the scope of this study to study the dynamics of the woody vegetation in any detail.

METHODS

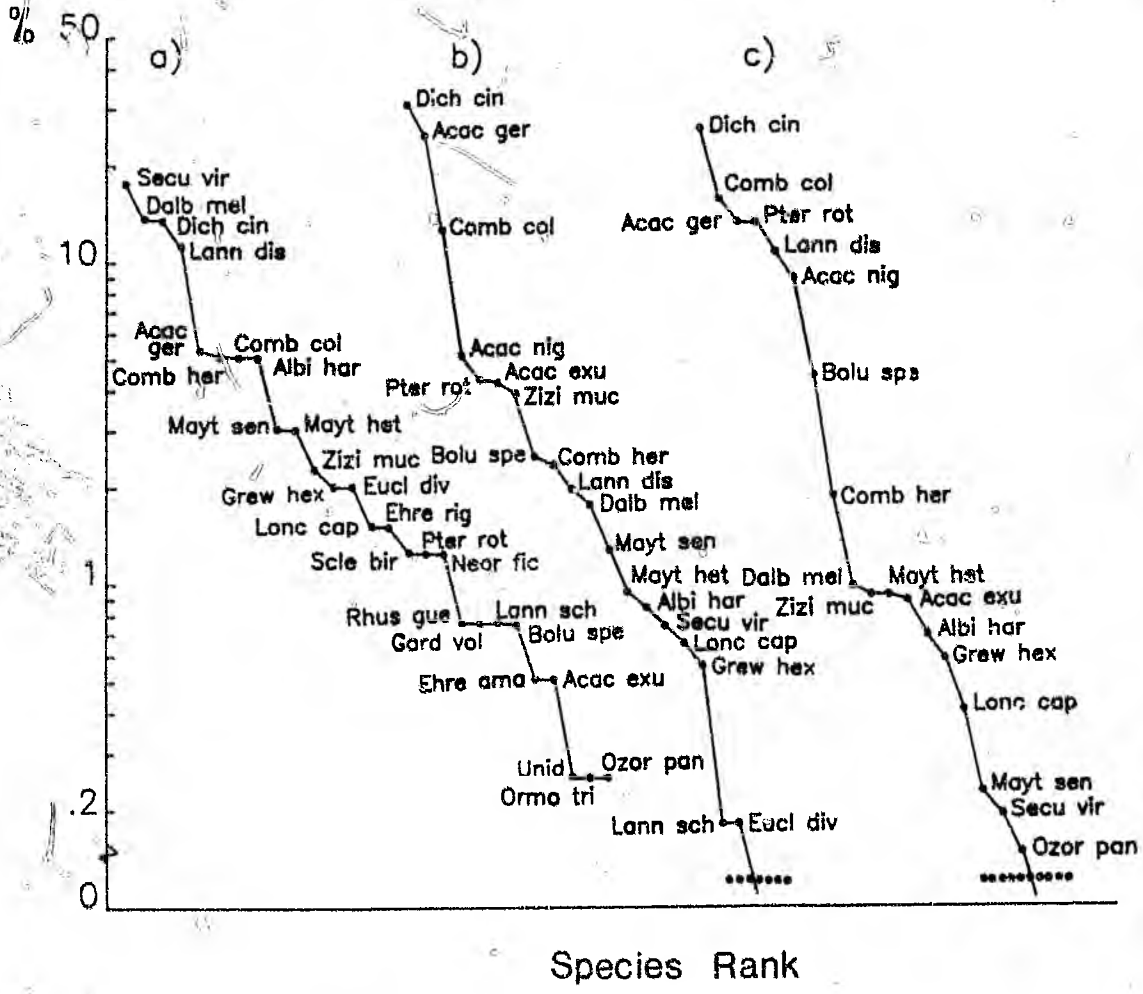
The data for the Thlavekisa site was collected as part of an undergraduate project by Marneweck (1989). The site was divided into contiguous 5 m square blocks, and the height and basal circumference of all individuals >0.5 m in height was measured. At Utha, the height and basal circumference of all individuals >2 m in height was measured, while only the height of individuals 0.5-2 m high (termed shrubs) was measured.

The population structure of the predominant species was described in terms of central tendencies and patterns of dispersion, including the skewness coefficient (g_1) (SAS 1985). The size inequality of individuals within the predominant species populations was described with the coefficient of variation (CV - SAS 1985), which is sensitive to changes in location (i.e. mean), and the skewness coefficient, which is invariant to changes in both location and scale - it is primarily a shape statistic (Bendal *et al.* 1989).

RESULTS AND DISCUSSION

Altogether 18 species (of 28) comprised 99% of the number of individuals >2 m in height (594 ha^{-1}), with *Dichrostachys cinerea* (31%), *Acacia gerrardii* (25%) and *Combretum collinum* (12%) the most abundant species (Figure A2.1c). In contrast, 14 species contributed 99% of the stem basal area of the site (3.958 m^2 ha^{-1}), with the four most prominent species again *Dichrostachys cinerea* (26%), *Combretum collinum* (16%), *Acacia gerrardii* (13%) and *Pterocarpus rotundifolia* (13%) (Figure A2.1b). The shrub stratum had a more equitable representation of species (Figure A2.1a), 23 species (of 27) contributed 99% of the number of individuals (n=399). *Securinega virosa* (17%), *Dalbergia melanoxylon* and *Dichrostachys cinerea* (each 14%), and *Lannea discolor* (11%) were the four most prolific shrub species.

Figure A2.1. The percentage contribution by each species to a) shrub density (individuals 0.5-2 m in height), b) basal area (individuals >= 2 m in height) and c) number of individuals >= 2 m in height, of the woody component at the Utha site. Key to species: Acac exu - *Acacia exuvialis*, Acac ger - *Acacia gerrardii*, Acac nig - *Acacia nigrescens*, Albi har - *Albizia harveyii*, Bolu spe - *Bolusanthus speciosus*, Comb col - *Combretum collinum*, Comb her - *Combretum hereroense*, Comb imb - *Combretum imberbe*, Dalb mel - *Dalbergia melanoxylon*, Dich cin - *Dichrostachys cinerea*, Dios mes - *Diospyros mespiliformis*, Ehre amo - *Ehretia amoena*, Ehre rig - *Ehretia rigida*, Eucl div - *Euclea divinorum*, Gard vol - *Gardenia volkensii*, Grew hex - *Grewia hexamita*, Lann dis - *Lannea discolor*, Lonc cap - *Lonchocarpus capassa*, Mayt het - *Maytenus heterophylla*, Mayt sen - *Maytenus senegalensis*, Neor fic - *Neorautanenia ficifolius*, Ormo tri - *Ormocarpum trichocarpum*, Ozor pan - *Ozoroa paniculosa*, Pter rot - *Pterocarpus rotundifolius*, Rhus gue - *Rhus guenzii*, Scle bir - *Sclerocarya birrea*, Secu vir - *Securinega virosa*, Unid - unidentified, Xime caf - *Ximenia caffra*, Zizi muc - *Ziziphus mucronata*.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Species Rank

There were 27 species recorded at Thlavekisa. Only four species, namely *Albizia harveyii* (32%), *Dichrostachys cinerea* (20%), *Ormocarpum trichocarpum* (18%) and *Maytenus senegalensis* (12%), accounted for 82% of the individuals (2055 ha^{-1}), with a further five species each contributing 1-10%, and seven species each contributing <1% (Figure A2.2b). Similarly, the contribution to basal area was concentrated in a few species; *Combretum collinum* (32%), *Dichrostachys cinerea* (16%), *Diospyros mespiliformis* (15%), *Albizia harveyii* (11%) and *Lannea schweinfurthii* (8%) comprised 82% of the tree basal area of 4.713 m^2 ha^{-1} (Figure A2.2a). Eight individual trees accounted for 30% of tree basal area, *viz Combretum collinum* (4), *C. imberbe* (1), *Diospyros mespiliformis* (2) and *Lannea scweinfurthii* (1).

At Thlavekisa, *Combretum collinum* was the tallest, *Dichrostachys cinerea* was relatively tall, *Ormocarpum trichocarpum* was the shortest, *Maytenus senegalensis* was relatively short, while *Acacia gerrardii*, *Albizia harveyii*, *Lonchocarpus capassa* and *Maytenus heterophylla* were of a similar height (Table A2.1). The height inequality within populations (CV) differed markedly between species at Thlavekisa (Table A2.1). *Dichrostachys cinerea*, *Albizia harveyii*, *Maytenus senegalensis* and *Ormocarpum trichocarpum* were least variable, *Lannea schweinfurthii*, *Lonchocarpus capassa*, *Sclerocarya birrea* and *Combretum hereroense* were most variable. The height distributions of *Lonchocarpus capassa* and *Lannea schweinfurthii* were strongly right skewed, those of *Acacia gerrardii*, *Combretum collinum*, *C. hereroense*, *Maytenus heterophylla*, *Ormocarpum trichocarpum* and *Sclerocarya birrea* were moderately skewed, *Albizia harveyii* and *Maytenus senegalensis* were weakly skewed, while *Dichrostachys cinerea* showed no skewness (Table A2.1). The height distribution of all individuals combined was strongly right skewed. There were correlations ($p<0.01$) between height and basal area for all species. Patterns for basal area were similar but more pronounced (Table A2.1).

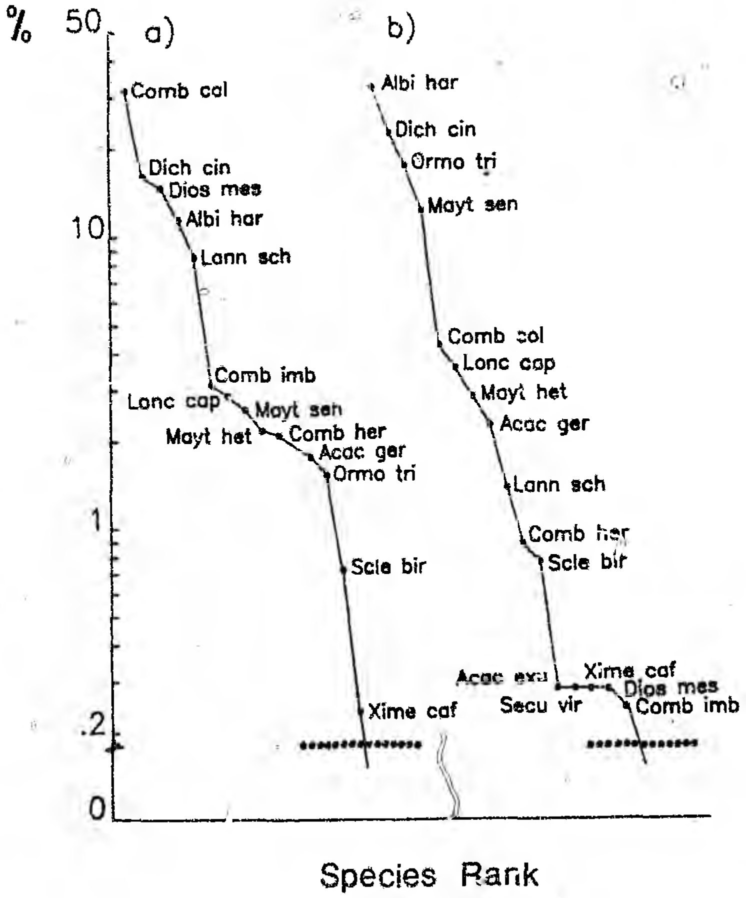

Figure A2.2. The percentage contribution by each species to a) basal area and b) number of individuals of the woody component (>= 0.5 m in height) at the Thlavekisa site. Key to species: Acac exu - *Acacia exuvialis*, Acac ger - *Acacia gerrardii*, Albi har - *Albizia harveyii*, Comb col - *Combretum collinum*, Comb her - *Combretum hereroense*, Comb imb - *Combretum imberbe*, Dich cin - *Dichrostachys cinerea*, Dios mes - *Diospyros mespiliformis*, Lann sch - *Lannea schweinfurthii*, Lonc cap - *Lonchocarpus capassa*, Mayt het - *Maytenus heterophylla*, Mayt sen - *Maytenus senegalensis*, Ormo tri - *Ormocarpum trichocarpum*, Scle bir - *Sclerocarya birrea*, Secu vir - *Securinega virosa*, Xime caf - *Ximenia caffra*.

At Utha, the mean height of shrubs 0.5-2 m high was 1.1 m, although this was highly variable (CV = 52%) and positively skewed (g_1=0.752). The most strongly positively skewed species were *Albizia harveyii*, *Combretum hereroense*, *Dalbergia melanoxylon* and *Securinega virosa*. *Maytenus senegalensis* was one of the few species with a strong negative skew. The dominant canopy individuals at Utha were *Lannea discolor*, *Combretum collinum* and *Pterocarpus rotundifolius*, with some *Acacia nigrescens* and *Bolusanthus speciosus*, while *Dichrostachys cinerea*, *Acacia gerrardii*, *Combretum hereroense* and *C. collinum* dominated the mid-stratum. *Acacia nigrescens* showed the greatest height inequality, as it included some of the tallest canopy individuals and also shrub individuals. All species except *Lannea discolor* were right skewed, *Bolusanthus speciosus*, *Acacia nigrescens*, *A. gerrardii* and *Combretum collinum* quite markedly so. *Dichrostachys cinerea* had noticeably little variation. There were correlations (p<0.01) between height and basal area for all species. Basal area therefore reflected the same patterns as height, although variability was more marked.

At Thlavekisa, *Albizia harveyii*, *Maytenus senegalensis*, *Dichrostachys cinerea*, *Lonchocarpus capassa*, *Lannea scweinfurthii* and *Ormocarpum trichocarpum* were highly significantly clumped, whereas *Combretum collinum* was randomly dispersed (Marneweck 1989). There was a significant association between three species pairs, namely *Albizia harveyii* with *Lonchocarpus capassa*, and *Ormocarpum trichocarpum* with *Lonchocarpus capassa* and *Maytenus senegalensis* (Marneweck 1989).

The size structure of a population tells little about the past, but allows some inference on possible future states. The composition and size structure of the woody component of both clay soil sites indicate a potential for bush encroachment. At Thlavekisa there is a high density of relatively small individuals of the microphyllous species *Dichrostachys cinerea* and *Albizia harveyii*, while at Utha there is a reasonable number of small individuals of *D. cinerea*, *Combretum collinum*, *Acacia nigrescens* and *A. gerrardii*. These populations were all quite strongly right skewed, and there was therefore the possibility that many individuals could still increase in size. *Dichrostachys cinerea* and *Acacia* species are conventionally considered to be encroachment species. It is therefore concluded that the physiognomy of these two sites could change in the medium term (5-10 yr) depending on utilisation regime. At Thlavekisa, the canopy elements have been reduced to supply building materials, but smaller individuals were not affected.

Table A2.1. The population structure of the predominant woody species at Utha and Thlavekisa.

Site, species		Height (m)					Basal Area (cm²)				
	n	$\overline{x}$	S.E.	med	g_1	CV	$\overline{x}$	S.E.	med	g_1	CV
Thlavekisa											
Acacia gerrardii	56	1.2	0.12	0.9	2.85	80	18	7.6	3.9	6.47	311
Albizia harveyii	796	1.3	0.02	1.2	0.77	48	8	0.5	2.9	6.08	166
Combretum collinum	104	2.6	0.20	1.8	1.41	78	172	34.4	27.3	3.50	203
C. hereroense	22	1.7	0.33	1.3	2.65	89	54	32.4	8.8	3.28	280
Dichrostachys cinerea	504	1.9	0.04	2.0	-.05	46	18	1.0	11.5	2.40	120
Lonchocarpus capassa	87	1.2	0.12	1.0	5.39	96	19	8.0	2.9	7.27	400
Lannea schweinfurthii	34	1.7	0.37	1.0	3.05	130	141	98.1	2.9	5.20	405
Maytenus heterophylla	70	1.2	0.09	1.0	1.64	65	18	5.2	3.9	3.99	247
M. senegalensis	302	1.0	0.03	0.9	1.04	48	5	0.5	2.9	5.72	176
Ormocarpum trichocarpum	439	0.7	0.02	0.5	2.34	54	2	0.2	1.3	5.89	136
Sclerocarya birrea	19	1.4	0.28	0.6	1.83	91	22	10.7	3.9	3.44	214
All individuals	2482	1.4	0.02	1.1	3.07	75	23	3.1	2.8	21.05	693
Utha											
Acacia exuvialis	45	2.9	0.09	2.8	0.70	20	14	1.1	11	2.53	51
A. gerrardii	264	3.1	0.05	2.8	1.61	28	35	2.2	23	2.56	100
A. nigrescens	55	3.6	0.36	2.8	2.79	73	114	39.4	23	3.66	256
Bolusanthus speciocus	26	3.3	0.22	3.0	3.39	34	122	27.6	67	2.46	115
Combretum collinum	133	3.2	0.10	2.9	1.72	36	84	8.8	52	3.49	120
C. hereroense	25	3.0	0.15	2.9	0.46	25	53	10.4	35	1.67	98
Dichrostachys cinerea	328	3.2	0.03	3.1	0.15	17	56	2.3	50	1.48	73
Lannea discolor	21	5.9	0.52	7.0	-.78	40	363	63.5	390	0.67	80
Pterocarpus rotundifolia	46	4.5	0.23	4.3	0.54	35	202	30.8	151	2.[illegible]	104
Ziziphus mucronata	42	2.8	0.07	2.8	0.54	17	16	1.5	13	[illegible]5[illegible]	62
All individuals	1070	3.2	0.04	2.9	3.35	37	67	3.6	33	6.05	178

25x

25×1

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Name of thesis: The Influence Of Rainfall And Grazing On The Population And Compositional Response Of Some Savanna Grasslands.

PUBLISHER:
University of the Witwatersrand, Johannesburg