Characterisation of a collection of perennial *Panicum* species

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Abstract

A collection of 74 perennial *Panicum* accessions, belonging to 6 different species, maintained at the field genebank of the International Livestock Research Institute, was described using 49 agro-morphological characters in a multivariate analysis. Fifty-four accessions, for which coordinates of the collection site were available, were further characterised using environmental data obtained through use of geographic information systems. Three drought-tolerant species, *P. antidotale, P. turgidum* and *P. phragmitoides,* were very different agro-morphologically from the other species. Of these drought-tolerant species, *P. phragmitoides* appeared to have the best agro-morphological attributes for use as forage in dry areas. *P. maximum*, *P. coloratum* and *P. infestum* appeared more similar, and were not entirely separated using cluster analysis. The accessions of these 3 species could be divided into 5 different clusters with similar characteristics. The majority of the *P. maximum* accessions belonged to 2 clusters, mainly differing in the size and robustness of the plants. A strong correlation was found between characters describing the robustness of the *P. maximum* plant and the annual precipitation at the collection site. Promising *P. maximum* accessions for use in cut-and-carry systems were identified.

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Introduction

Several of the Panic grasses have high forage potential. Guinea grass (*Panicum maximum* Jacq.), blue panic (*Panicum antidotale* Retz.) and coloured Guinea grass (*Panicum coloratum* L.) are some of the better-known and used species. *P. maximum* plays an important role as feed and forage in intensive livestock systems in the tropics and subtropics, especially in Brazil, where it is grown extensively and has received a lot of attention recently (Souza 1999; Carnevalli *et al.* 2006; Andrade *et al.* 2006; Santos *et al.* 2006).

Panicum is a very diverse genus, with its natural range of distribution in the tropics and warmer temperate regions. It is one of the largest genera within the Poaceae, consisting of about 450 annual and perennial species (Aliscioni *et al.* 2003). The diversity in the genus has led to a confusing taxonomy and the delimitation of the genus is not entirely clear. Current names in use to describe *Panicum maximum* are *Urochloa maxima* (Jacq.) R. Webster (ITIS 2006) and *Megathyrsus maximus* (Jacq.) B.K. Simon & S.W.L. Jacobs (Simon and Jacobs 2003). As the confusion surrounding the placement of *P. maximum* in the genus has not yet been settled, this paper uses *Panicum* sensu lato as the definition for the genus, following the definition used in the world grass species database of the Royal Botanical Gardens at Kew (Clayton *et al.* 2006).

The International Livestock Research Institute (ILRI) conserves in its genebank a collection of *Panicum* accessions mainly collected in Africa. Additional cultivars of major importance were acquired from commercial sources and some promising accessions were obtained from a breeding program by the Institut français de recherche scientifique pour le développement en coopération (ORSTOM) in Ivory Coast (Noirot *et al.* 1986). *P. maximum* has the largest number of accessions in the *Panicum* collection held at ILRI.

For a germplasm collection to be useful, it should be properly characterised and described and the information made widely available, so that accessions can be selected for specific uses and environments. With a multi-species collection, it is also important that similar species are compared for their forage potential and agro-morphological characteristics to give a better indication of the agronomic potential of lesser-known species.

In the current study, a wide range of morphological, agronomic and environmental characters were examined for 6 perennial *Panicum* species. The emphasis was on *P. maximum*, which is the most widely used of the Panic grasses. *P. antidotale*, a native grass of India, is the only non-African Panic grass in this study. Some accessions of *P. coloratum* and accessions from some lesser-known forage species, such as *P. turgidum* Forsk., *P. phragmitoides* Stapf and *P. infestum* Anderss ex Peters were also included. Little published information exists on the agronomy and morphological diversity, as well as the forage potential, of these last 3 species.

Materials and methods

The study was carried out at the ILRI Zwai seed multiplication site, in the Rift Valley of Ethiopia (7°54′N, 38°44′E) at an elevation of 1640 m above sea level. The site has an annual average rainfall of 600 mm, of which the majority falls during July–September. The soil at the Zwai site is loamy sand and has been classified as a vitric andosol (King and Birchall 1975). The pH(H_2O) of the soil was 8.1. The plots were fertilised with 200 kg/ha/yr N in the form of 6 split applications of ammonium sulphate. Additionally, 60 kg/ha/yr P in the form of triple superphospate was applied once a year.

Seventy-four accessions were used in the study, 59 being *Panicum maximum* (Table 1). The collection came mostly from Africa, with an emphasis on countries in east Africa (Figure 1). Each accession under study was established by root splits in a 2 × 5 m plot, with a spacing of 50 × 50 cm between individual plants. The plants were irrigated weekly and were cut back to a height of 15 cm at the start of the observation, just before the rainy season.

Forty-nine characters were selected, based on expected variation and possible importance for future uses (Table 2), and were observed on the regrowth, on primary culms with newly fully exserted inflorescences. The inflorescence characters were observed on culms from which 10–30% of the spikelets had shed. All leaf observations were taken on the second leaf below the flag leaf. Wherever possible, observations were made on 10 different plants per accession as suggested by van de Wouw *et al. (*1999b). Spikelet observations were made on 10 randomly sampled spikelets from the harvest of the full plot. To avoid overemphasis on the size of different plant parts, only one measurement each of leaf, spikelet and inflorescence was used as an actual measurement. The other characters were used as ratios to indicate the shape of the observed plant parts. For those accessions, in which clearly 2 different genotypes could be distinguished, with differences beyond those expected for natural variation within a population, observations were carried out separately for each genotype and the letters 'a' and 'b' were added to the accession number.

The correlations between the observed characters were calculated using Pearson's correlation coefficient. Characters that showed a high correlation coefficient (=>0.7) were reviewed, and if the correlation could be explained by an overlap in measurements, one character was excluded to avoid indirect weighting in the cluster analysis. After standardising the variables to a mean of 0 and a variance of 1, principal component analysis was carried out. Hierarchical clusters were formed using the average and complete linkage algorithms of the NTSYS 2.01 program. The first analysis included all accessions, while a second analysis excluded outliers, because outliers tend to distort clustering. The full dataset was explored using a discriminant analysis in SYSTAT 8.0 to find the characters which best described the resulting clusters of accessions.

Geographic Information Systems (GIS) techniques were used to extract data on the collection environment for those accessions with information on the collection site. When coordinates were not known, they were obtained by referring to maps using the collection site description. A set of 19 bioclimatic variables (Table 3) at the collection sites was extracted using climatic surfaces on a 1 km spatial resolution (Hijmans *et al.* 2005). These bioclimatic variables were derived from monthly temperature and rainfall values to generate biologically more meaningful variables. Using the same coverage, the altitude of the
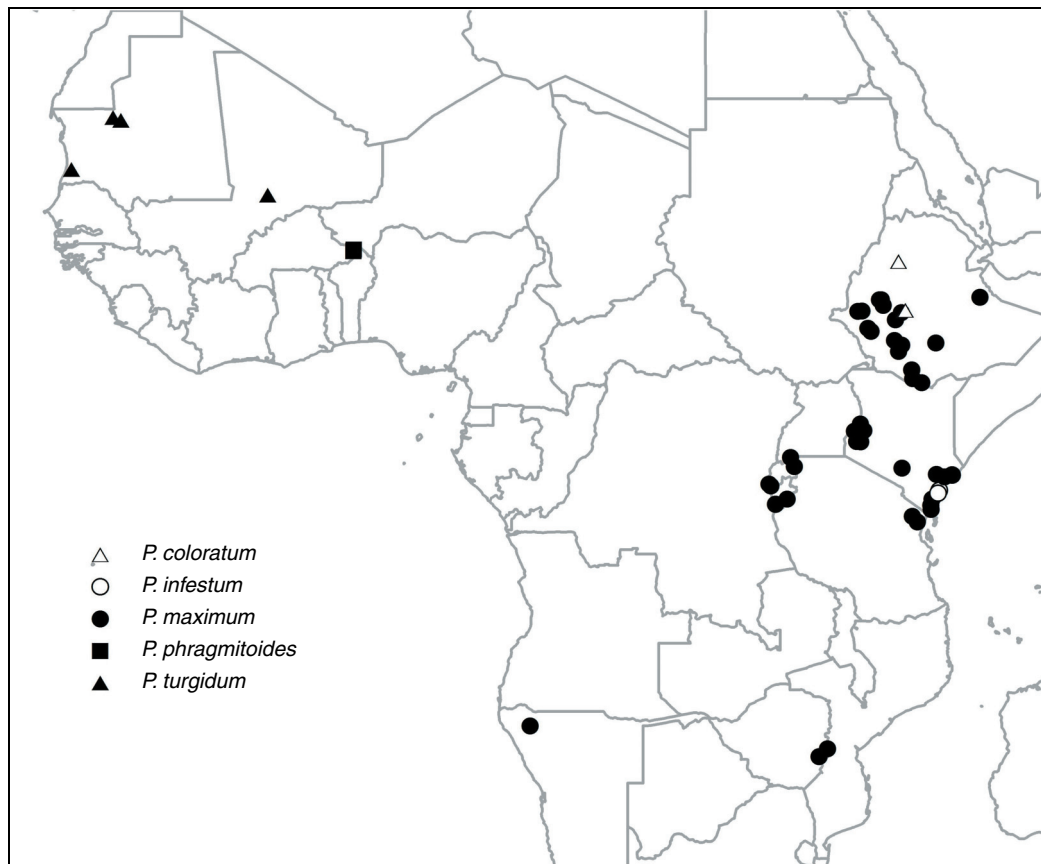
Figure 1. Collection sites of *Panicum* accessions used in the characterisation study.

Table 1. List of accessions and species used in the characterisation study.

ILRI No	Species	Country of collection	Other numbers[2]
6586	*Panicum antidotale*		
6587	*Panicum antidotale*		
7148	*Panicum antidotale*		CPI56977
6584	*Panicum coloratum* var. makarikariense		
9660[1]	*Panicum coloratum*	Ethiopia	CIAT16379
13821[1]	*Panicum coloratum*	Ethiopia	CIAT16378
12797[1]	*Panicum infestum*	Kenya	CIAT16577
12805[1]	*Panicum infestum*	Kenya	CIAT16568
12846[1]	*Panicum infestum*	Kenya	CIAT16569
11[1]	*Panicum maximum* cv. Makueni	Kenya	
12	*Panicum maximum* cv. Riversdale		
13	*Panicum maximum* cv. Colonião		
144	*Panicum maximum* cv. Petrie		
145	*Panicum maximum* cv. Hamil		
978	*Panicum maximum*	Rwanda	
980[1]	*Panicum maximum*	Rwanda	
1009[1]	*Panicum maximum*	Burundi	
1035[1]	*Panicum maximum*	Burundi	
1047[1]	*Panicum maximum*	Burundi	
1048[1]	*Panicum maximum*	Burundi	
2118[1]	*Panicum maximum*	Ethiopia	
2124[1]	*Panicum maximum*	Ethiopia	
2140[1]	*Panicum maximum*	Ethiopia	
2144[1]	*Panicum maximum*	Ethiopia	

ILRI No	Species	Country of collection	Other numbers[2]
6580	*Panicum maximum*		FAO27201
6581	*Panicum maximum*		
6946	*Panicum maximum* cv. Common		
6967	*Panicum maximum* cv. Gatton	Zimbabwe	
7151	*Panicum maximum*		ORSTOM89
9676[1]	*Panicum maximum*	Ethiopia	CIAT16372
10619[1]	*Panicum maximum*	Ethiopia	
10929	*Panicum maximum*		
11084[1]	*Panicum maximum*	Ethiopia	CIAT16374
11085[1]	*Panicum maximum*	Ethiopia	CIAT16375
11549[1]	*Panicum maximum*	Ethiopia	CIAT16373
12784[1]	*Panicum maximum*	Kenya	CIAT16559
12829[1]	*Panicum maximum*	Kenya	CIAT16563
12849[1]	*Panicum maximum*	Kenya	CIAT16561
12851[1]	*Panicum maximum*	Kenya	CIAT16562
12854[1]	*Panicum maximum*	Kenya	CIAT16566
12879[1]	*Panicum maximum*	Kenya	CIAT16564
12911[1]	*Panicum maximum*	Kenya	CIAT16565
13096[1]	*Panicum maximum*	Kenya	CIAT16556
13145[1]	*Panicum maximum*	Kenya	CIAT16557
13152[1]	*Panicum maximum*	Kenya	CIAT16558
13304[1]	*Panicum maximum* cv. Sabi	Zimbabwe	CPI28275
13354[1]	*Panicum maximum*	Ethiopia	CIAT16240
13378[1]	*Panicum maximum*	Ethiopia	CIAT16241
13383[1]	*Panicum maximum*	Ethiopia	CIAT16242
13408[1]	*Panicum maximum*	Ethiopia	CIAT16244
13478[1]	*Panicum maximum*	Ethiopia	CIAT16245
13479[1]	*Panicum maximum*	Ethiopia	CIAT16246
13526[1]	*Panicum maximum*	Ethiopia	CIAT16247
13564[1]	*Panicum maximum*	Ethiopia	CIAT16248
13624[1]	*Panicum maximum*	Ethiopia	CIAT16376
14356[1]	*Panicum maximum* cv. Tobiatã	Tanzania	ORSTOMK187B
14357[1]	*Panicum maximum* cv. Tanzânia-1	Tanzania	ORSTOMT58
14358	*Panicum maximum*		ORSTOM2A5
14359	*Panicum maximum*		ORSTOM2A6
14360	*Panicum maximum*		ORSTOM2A-22
14361	*Panicum maximum*		ORSTOMC1
14362	*Panicum maximum*		ORSTOM2A4
14363	*Panicum maximum*		ORSTOM1A-50
14778[1]	*Panicum maximum*	Burundi	CIAT26264
16007[1]	*Panicum maximum*	Kenya	
16181[1]	*Panicum maximum*	Zimbabwe	CIAT26043
16511[1]	*Panicum maximum*	Kenya	
16671[1]	*Panicum maximum*	Namibia	
13915[1]	*Panicum phragmitoides*	Niger	
13885[1]	*Panicum phragmitoides*	Niger	
15682[1]	*Panicum turgidum*	Mauritania	
15690[1]	*Panicum turgidum*	Mauritania	
15691[1]	*Panicum turgidum*	Mauritania	
15695[1]	*Panicum turgidum*	Mali	

[1] Accessions for which information on latitude and longitude of the collection site could be obtained.
[2] CPI = CSIRO, Australia; CIAT = Centro International de Agricultura Tropical, Colombia; ORSTOM = Institut français de recherche scientifique pour le développement en cooperation.

Table 2. List and definitions of characters observed.

Character	Definition	No of observations	Units
General			
1. Leafiness	Ratio of leaves to stems	Full plot score	
2. First flowering	Number of days after cutting until first inflorescence appears		days
3. 50% flowering[1]	Number of days after cutting until 50% of culms are flowering		days
4. Rhizomes	The average distance of the rhizomes to the stool	Full plot score	cm
5. Leaf canopy height[1]	Average height of leaf canopy	Full plot score	cm
Leaf			
6. Leaf/culm angle	The angle between the culm (above ligule) and the first leaf below the flag leaf	10 Observations	degrees
7. Leaf length	Length from ligule to the tip of leaf	10 Observations	cm

8. Leaf width[1]	Width of leaf at widest point	10 Observations	cm
9. Leaf ratio	Leaf length:leaf width		
10. Leaf hairiness — adaxial[1]	Hairiness of the adaxial face of the leaf; classified as (0) none to (5) dense	Full plot score	
11. Leaf hairiness — abaxial	Hairiness of the abaxial face of the leaf; classified as (0) none to (5) dense	Full plot score	
12. Leaf hairiness — leaf sheath[1]	Hairiness of the leaf sheath; classified as (0) none to (5) dense	Full plot score	
13. Length of hairs — adaxial	Length of the hairs on the adaxial face of the leaf	Full plot score	mm
14. Length of hairs — abaxial	Length of the hairs on the abaxial face of the leaf	Full plot score	mm
15. Length of hairs — sheath	Length of the hairs on the leaf sheath	Full plot score	mm
16. Rigidness of hairs — adaxial[1]	Rigidness of the hairs on the adaxial face of the leaf; classified as (1) very soft to (5) rigid, irritating	Full plot score	
17. Rigidness of hairs — abaxial[1]	Rigidness of the hairs on the abaxial face of the leaf; classified as (1) very soft to (5) rigid, irritating	Full plot score	
18. Rigidness of hairs — leaf sheath[1]	Rigidness of the hairs on the leaf sheath; classified as (1) very soft to (5) rigid, irritating	Full plot score	
19. Leaf margin	The serratedness of the leaf margin at the middle of the leaf blade; classified as (0) smooth to (5) deeply serrated	Full plot score	
20. Leaf midrib[1]	Diameter of the leaf midrib at one-tenth of the leaf length from the ligule	10 Observations	mm
21. Midrib ratio	Leaf width:leaf midrib	Calculated	
22. Glaucousness[1] — leaf	The presence of a waxy bloom; classified as (0) not glaucous to (2) thick coating	Full plot score	
23. Glaucousness[1] — leaf sheath	The presence of a waxy bloom; classified as (0) not glaucous to (2) thick coating	Full plot score	
Culm			
24. Culm length	The length of the culm from first node at plant base up to flag leaf	10 Observations	cm
25. Growth form	Average angle of the lowest 25 cm of the stem to the ground	10 Observations	degrees
26. No of branches	Number of branches per culm	10 Observations	
27. Node number	Number of nodes per culm	10 Observations	
28. Culm thickness	Diameter of the culm at the lowest internode at 1/3 of internode length from base	10 Observations	mm
29. Culm glaucousness	The presence of a waxy bloom; classified as (0) not glaucous to (2) thick coating	Full plot score	
30. Culm hairiness	Hairiness of the third internode from the top; classified as (0) none to (5) dense	10 Observations	
31. Node hairiness	Hairiness of the third node from the top; classified as (0) none to (5) dense	10 Observations	
32. Culm hair length[1]	Length of the hairs on the third internode from the top	10 Observations	mm
33. Node hair length	Length of the hairs on the node	10 Observations	mm
34. Culm hair rigidness[1]	Rigidness of the hairs on the culm; classified as (1) very soft to (5) rigid, irritating	10 Observations	
35. Node hair rigidness	Rigidness of the hairs on the node; classified as (1) very soft to (5) rigid, irritating	10 Observations	
Inflorescence			
36. Inflorescence length	Length of the main rachis from the lowest branch to the top spikelet	10 Observations	cm
373 Glaucousness[1] — rachis	The presence of a waxy bloom; classified as (0) not glaucous to (2) thick coating	Score	
38. Raceme length[1]	Length of the longest primary branch of the inflorescence	10 Observations	cm
39. Raceme ratio	Inflorescence length:raceme length	Calculated	
40. Raceme number	Number of all primary and secondary branches, longer than 6 cm	10 Observations	
41. Branch number — whorl	Number of primary branches in the lowest whorl of the panicle	10 Observations	
42. Grooves of rachis	The depth of grooves in the rachis; classified as (0) no grooves to (5) deep grooves	Score	
43. Spikelet length	Length of spikelet from the node of the glumes to the tip of the spikelet	10 Observations	mm
44. Spikelet width[1]	Width of spikelets at maximum width	10 Observations	mm
45. Spikelet ratio	Spikelet length:spikelet width	Calculated	
46. Spikelet colour ratio	The percentage of the spikelet surface with a reddish colour	Score of 10 spikelets	
47. Spikelet tip	Shape of spikelet tip; classified as (0) obtuse to (5) strongly acuminate	Score of 10 spikelets	
48. Spikelet hair density	Density of hairs on the spikelets; classified as (0) none to (5) dense	Score of 10 spikelets	
49. Length of spikelet hairs[1]	Length of the hairs on the spikelets; classified as (0) none to (5) half of spikelet width	Score of 10 spikelets	

[1] Characters excluded from final analysis.

Table 3. Environmental variables obtained using GIS climatic coverages (Hijmans *et al.* 2005) and used in a discriminant analysis.

	Character	Units
1	Annual mean temperature	°C
2	Mean diurnal temperature range — Mean of monthly (max temp — min temp)	°C
3	Isothermality (Mean diurnal T range/Annual T range) * 100	
4	Temperature seasonality (Standard deviation of monthly temperatures * 100)	
5	Max temp of hottest month	°C
6	Min temp of coldest month	°C
7	Annual temp range (Max temp warmest month – min temp coldest month)	°C
8	Mean temp wettest quarter	°C
9	Mean temp driest quarter	°C
10	Mean temp hottest quarter	°C
11	Mean temp coldest quarter	°C
12	Annual precipitation	mm
13	Precipitation wettest month	mm
14	Precipitation driest month	mm
15	Precipitation seasonality (Coefficient of variation of monthly precipitations)	
16	Precipitation wettest quarter	mm
17	Precipitation driest quarter	mm
18	Precipitation hottest quarter	mm
19	Precipitation coldest quarter	mm
20	Elevation	m
21	Latitude (absolute value of latitude)	Degrees

collection site was also extracted. These variables, together with the absolute value of the latitude of the collection site as an indication of the seasonal day length variation, were used in a discriminant analysis to explore differences between species and clusters obtained in the cluster analysis. Pearson's correlation coefficients between the agro-morphological characters and environmental variables were determined for *P. maximum* only, because of the larger number of accessions available for this species.

Collection data on soil texture, soil pH and drainage were available for a limited number of accessions. These data were explored for differences between clusters or species. The possibility of using soil properties obtained through the digital soil map of the world (FAO 2003) was also explored. Data on soil texture, topography, soil depth and drainage were extracted for each accession with geographic coordinates and used in a discriminant analysis to observe differences between species and clusters.

Results

Agro-morphology

The collection of *Panicum* accessions observed in the current study proved to be extremely variable. The large variation in plant size was obvious.

Culm length varied between 56 and 244 cm, and inflorescence length varied between 8 and 56 cm.

For 3 *P. maximum* accessions (ILRI 2140, 2144, 12784), 2 distinct genotypes could be recognised in the plots, and the observations were performed separately for each genotype. In ILRI 2140, the 2 genotypes recognised differed mainly in culm thickness and leaf hairiness. ILRI 2144 was split into 2 genotypes differing in hairiness of the different plant parts (stems, leaves and spikelets), while the 2 genotypes recognised for ILRI 12784 differed mainly in size and robustness of the plants.

Since a high correlation (>0.8) was found between the glaucousness of the rachis, the main culm and the leaf sheath and the leaves, only the glaucousness of the main culm was used in the multivariate analysis. A high correlation (0.88) was also found between culm length and canopy height, indicating an overlap in measurements, and only culm length was used in the final analysis.

High correlations (0.79–0.96) were found between length of inflorescence, length and number of racemes, width and length of leaf, width of rachis groove and diameter of leaf midrib. All seemed to be indicators of the robustness of the plant. To avoid indirect weighting, ratios were used whenever possible (leaf ratio, midrib ratio and raceme ratio), and the number of variables was reduced accordingly.

The densities of hairs on culm, leaf and leaf sheath were all highly correlated (0.71–0.93) and only density of hairs on the abaxial side of the leaf was used for further analysis. Hairiness of the nodes seemed to be independent of leaf and culm hairiness (correlation coefficient of 0.04–0.13), while spikelet hairiness was also not highly correlated with leaf and culm hairiness (0.24–0.35), so both spikelet hair density and node hair density were retained for further analysis. Spikelet hair length and density were very strongly correlated (0.94), so hair length was omitted in the final analysis. Except for the nodes, in all cases length and rigidity of hairs were strongly correlated (0.76–0.95), and as length is a less subjective measurement, this was retained for the analysis.

Days to first flowering was highly correlated with the number of days to 50% flowering (0.88). As data were more complete for the number of days to first flowering, only this character was kept for further analysis. After excluding characters with high correlations, 32 characters were left for further analysis (Table 2).

The analysis with all species included showed a clear separation in both the principal component analysis and cluster analysis of *P. antidotale*, *P. phragmites* and *P. turgidum* from the other *Panicum* species (Figure 2). The group formed by *P. maximum*, *P. coloratum* and *P. infestum* was extremely variable and these 3 species were not well separated from each other. Discriminant analysis showed that a group of 9 characters contributed most to this division (Table 4). The number of side branches on the main culm and the size of the spikelets were especially important for this division. The characters responsible for the division also included characters of higher agronomic importance, such as leafiness and number of days to first flowering.

In the next step of the analysis, the 3 species that clearly separated from the rest of the accessions (*P. antidotale*, *P. phragmitoides* and *P. turgidum*) were excluded, because outliers tend to distort clustering. Clustering of the *P. maximum* accessions together with *P. infestum* and *P. coloratum* using the complete linkage algorithm revealed 5 groups (Figure 3). Accessions, which are outliers in a group or intermediates between 2 clusters, clustered differently using the UPGMA clustering algorithm. ILRI 9676 of Group V clustered with the accessions of Group IV, ILRI 12829 of Group V clustered with Group I and 2 accessions (ILRI 6581 and ILRI 14778), which are outliers within Group I, clustered together in a separate group. However, in general, the 2 clustering algorithms yielded similar groups.
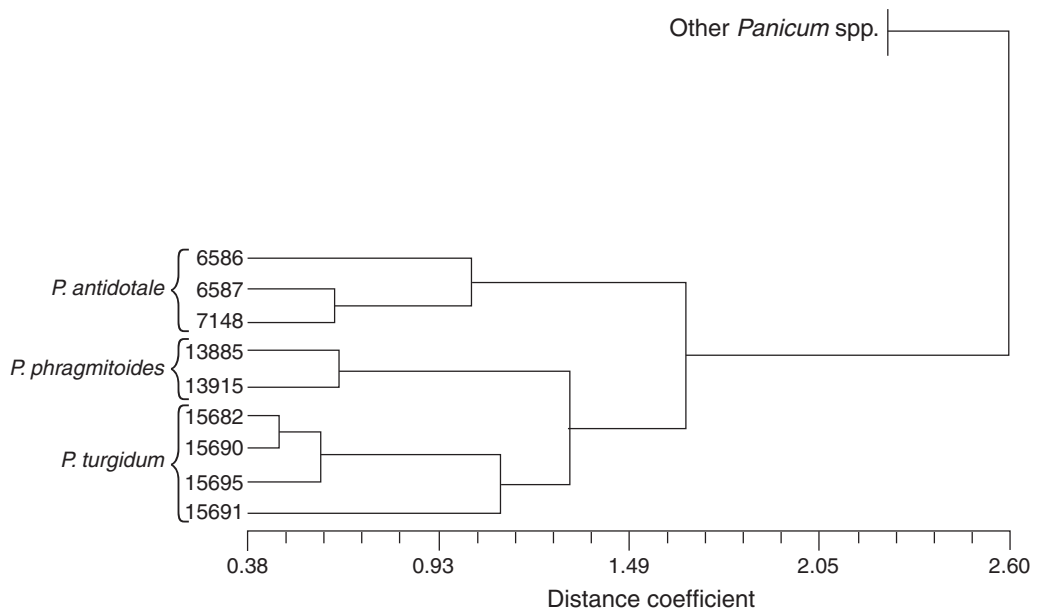
Figure 2. Cluster diagram obtained with the complete linkage algorithm of 74 perennial *Panicum* accessions representing 6 species using 32 characters. Numbers are ILRI accession numbers.

Table 4. Mean and range of characters contributing most to the separation of 3 species from the other *Panicum* species and some additional key characters.

	P. antidotale	P. phragmitoides	P. turgidum	Other Panics
No of accessions	3	2	4	68
First flowering (days)[1,2]	30 (28–32)	53 (49–56)	26 (21–35)	30 (17–63)
Growth form (degrees)[1]	66 (64–70)	69 (64–74)	62 (59–63)	68 (25–83)
Leafiness[1]	1.8 (1.5–2.0)	2.3 (2.0–2.5)	0.9 (0.5–1.0)	3.4 (2.0–5.0)
Leaf length (cm)	25 (24–28)	28 (27–29)	10 (8–14)	48 (15–82)
Leaf width (cm)	1.0	0.8 (0.8–0.9)	0.4	1.7 (0.7–3)
Culm length (cm)	133 (94–155)	93	90 (69–115)	127 (56–244)
Culm thickness (mm)	4.8 (4.3–5.1)	3.2 (3.1–3.4)	3.5 (3.1–4.0)	4.7 (2.3–15.3)
No of branches[1]	10.8 (9.3–12.3)	0	3.3 (1.9–4.0)	1.2 (0–4.9)
Rachis glaucousness[1]	0.4 (0.3–0.5)	0	0.5 (0.3–1)	1 (0–2)
Spikelet length (mm)[1]	2.81 (2.79–2.82)	3.48 (3.32–3.64)	3.56 (3.16–3.86)	3.17 (2.34–3.96)
Spikelet width (mm)[1]	0.98 (0.9–1.1)	1.08 (0.96–1.19)	1.45 (1.39–1.51)	0.94 (0.78–1.29)
Spikelet tip[1]	2.5 (2–3)	4	3.5 (2.7–4)	1.3 (0–5)
Raceme length (cm)[1]	8.4 (8.3–8.6)	13.9 (11.5–16.4)	7.2 (5.9–8.0)	18.6 (9.2–35.3)
Inflorescence length (cm)	19 (17–20)	25 (22–27)	14 (11–15)	32 (8–56)

[1] Characters contributing most to the division in the discriminant analysis.
[2] For definition of characters see Table 2.

Group III included all *P. infestum* accessions, together with 2 *P. coloratum* accessions. These 2 species were also clearly separated within this group. The other *P. coloratum* accession (ILRI 6584) is in Cluster II, together with 2 *P. maximum* cultivars originally collected from Zimbabwe.

The discriminant analysis showed that 4 characters contributed most to the separation of the 5 groups: node hair density, glaucousness of main culm, leaf length and spikelet colour ratio. Besides these 4 characters, other characters also showed variation between the clusters (Table 5), although there was often a large overlap in the range of maximum and minimum values.

Environmental analysis

Information on the site, from which *P. antidotale* accessions were originally collected, was not available, so this species was excluded from the analysis using environmental data. Large differences in the climatic data showed that both *P. turgidum* and *P. phragmitoides* originated from environments very different from those of the other accessions (Table 6). The discriminant analysis showed that seasonality of precipitation was the factor that contributed most to the separation between groups.

Less pronounced differences in the environmental variables were seen between the 5 clusters derived from the second step in the analysis. Discriminant analysis showed that the most important characters, which divided the 5 clusters, were annual precipitation, isothermality and the minimum temperature of the coldest month (Table 7).

For *P. maximum,* low correlations were found between the agro-morphological characters and any of the bioclimatic variables related to temperature. Correlation coefficients above 0.5 were found between annual rainfall and 12 of the agro-morphological characters. The highest significant positive correlation (r = 0.7) was found between leaf width and precipitation (Figure 4). A regression analysis showed that around 49% of the total variation in leaf width of the *P. maximum* accessions could be explained by the variation in the annual precipitation at the collection site. The other characters with a high positive correlation with annual precipitation, were also mainly associated with the robustness of the plant: culm length, number of nodes, culm thickness, rachis groove, inflorescence length, raceme length and number, height, leaf margin, leaf rib diameter and leafiness of the plant. Days to 50% flowering was also positively correlated with the annual rainfall. Positive correlations above 0.5 were also found between the bioclimatic variables (rain in the coldest quarter and rain in the wettest quarter) and some of the agro-morphological characters related to the size of the plant. The absolute value of the latitude was highly negatively correlated (–0.65) with node hairiness, but this appeared mainly due to one accession (ILRI 13304), collected from Zimbabwe, with hairless nodes. No correlation (Pearson correlation coefficient <0.1) was found between time to flowering and latitude.
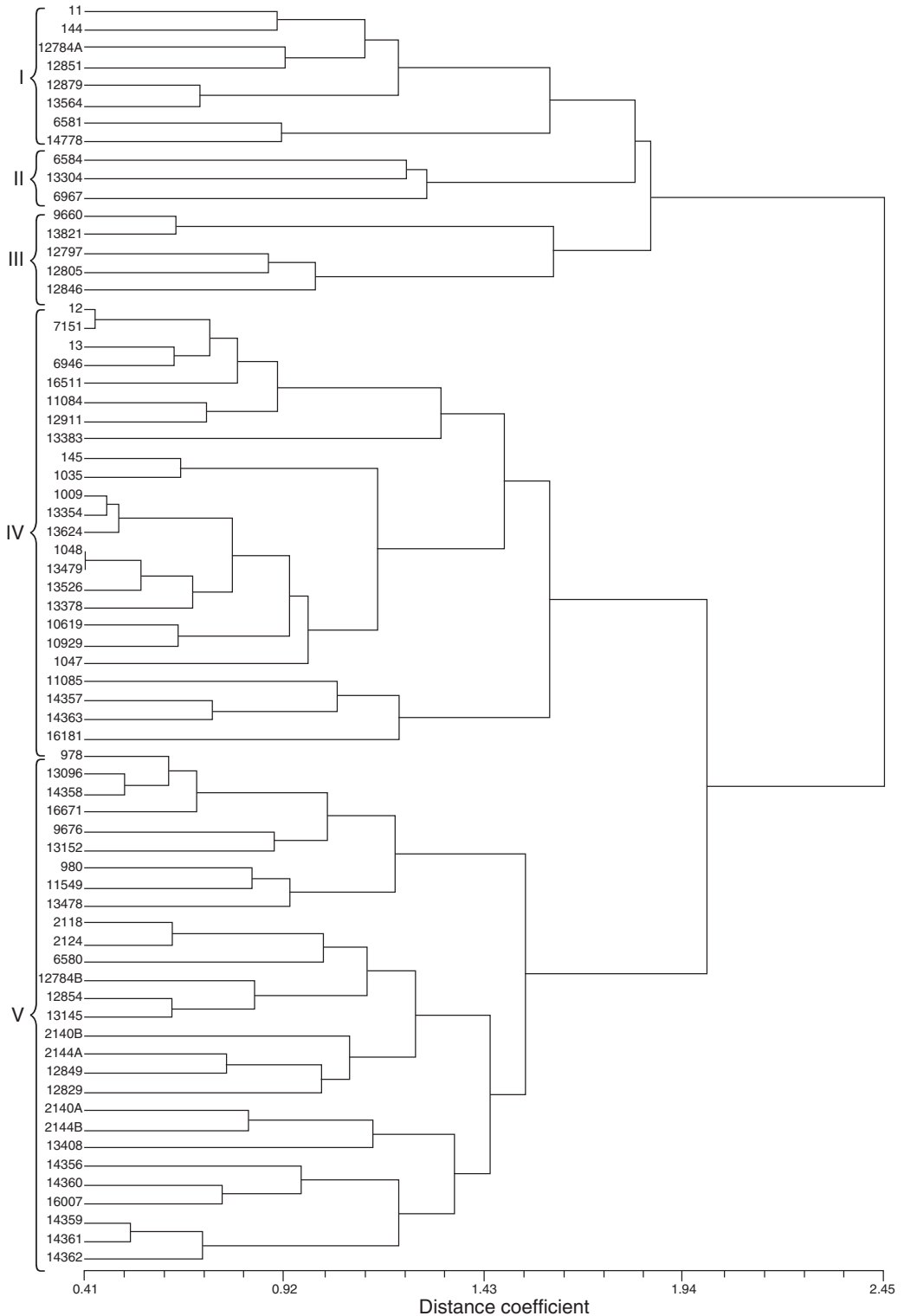
Figure 3. Cluster diagram of 65 *Panicum* accessions representing *P. maximum, P. coloratum* and *P. infestum,* obtained with the complete linkage clustering algorithm by clustering on 32 characters. Numbers are ILRI accession numbers; A or B after the number indicates different genotypes, clusters have been indicated.

Table 5. Mean and range of some key characters showing variation among 5 clusters within the species *P. maximum*, *P. coloratum* and *P. infestum*.

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
No of accessions	8	3	5	24	28
Species	*P. maximum*	*P. maximum* *P. coloratum*	*P. coloratum* *P. infestum*	*P. maximum*	*P. maximum*
First flowering (days)[2]	29 (17–56)	35 (28–42)	22 (18–28)	37 (21–56)	26 (18–63)
Leafiness	2.9 (2.5–4.0)	3.3 (2.0–4.0)	2.2 (2.0–2.5)	4.0 (3.0–5.0)	3.2 (2.5–4.5)
Leaf length (cm)[1]	29 (15–43)	30 (26–40)	26 (20–31)	62 (43–82)	48 (30–70)
Leaf width (cm)	1.4 (1.1–1.9)	1.2 (0.9–1.3)	0.8 (0.7–0.9)	2.4 (1.4–3.0)	1.5 (1.0–2.1)
Culm length (cm)	102 (64–129)	92 (90–96)	72 (56–91)	175 (122–244)	108 (70–150)
Culm thickness (mm)	3.3 (2.3–4.9)	3.8 (2.6–4.5)	2.9 (2.6–3.6)	7.0 (4.9–15.3)	3.7 (2.3–5.6)
No of branches	2.3 (0.8–3.7)	2.9 (1.8–4.9)	1.3 (0–2.1)	0.9 (02–2.0)	0.9 (0.1–2.9)
Node hair density[1]	4.0 (3.2–4.9)	0	1.7 (0.1–2.9)	4.8 (4.4–5)	4.7 (3.1–5.0)
Rachis glaucousness[1]	0.9 (0–2.0)	0.2 (0–0.7)	0	1.8 (0–2.0)	0.7 (0–2.0)
Spikelet colour ratio[1]	71 (48–90)	67 (54–80)	59 (46–80)	49 (24–80)	62 (20–80)
Spikelet length (mm)	2.9 (2.7–3.2)	2.5 (2.3–2.7)	3.0 (2.8–3.2)	3.2 (2.7–4.0)	3.3 (2.8–3.8)
Spikelet width (mm)	1.0 (0.9–1.1)	0.8 (0.8–0.9)	1.0 (0.9–1.1)	0.9 (0.8–1.3)	0.9 (0.8–1.1)
Inflorescence length (cm)	22 (17–28)	21 (17–23)	18 (8–31)	43 (32–56)	29 (21–45)

[1] Characters contributing most to the division in 5 clusters in the discriminant analysis.
[2] For definition of characters see Table 2.

Table 6. Mean and range of some important bioclimatic variables of the collection sites, showing differences between *Panicum* species.

	P. maximum	*P. phragmitoides*	*P. infestum*	*P. turgidum*	*P. coloratum*
No of accessions	59	2	3	4	3
No of accessions with coordinates	43	2	3	4	2
Annual precipitation (mm)	1131 (384–1816)	709 (697–720)	992 (941–1019)	138 (58–302)	1315 (1213–1416)
Seasonality of precipitation (CV)	65 (34–99)	118 (117–119)	81 (71–99)	136 (119–148)	99 (80–117)
Annual mean T (°C)	22.4 (17.5–27.1)	28.5 (28.4–28.5)	26.3 (25.9–26.9)	26.9 (26.3–27.8)	19.4 (19.2–19.5)
Mean T wettest quarter (°C)	22.4 (16.8–27.1)	27.2 (27.1–27.3)	26.3 (25.9–27.1)	31.2 (29.0–33.3)	18.6 (18.4–18.8)

Table 7. Mean and range of some important bioclimatic variables, showing differences between *Panicum* clusters.

	Cluster I	Cluster II	Cluster III	Cluster IV	Cluster V
No of accessions	8	3	5	24	28
No of accessions with coordinates	5	1	5	16	21
Species	*P. maximum*	*P. maximum* *P. coloratum*	*P. coloratum* *P. infestum*	*P. maximum*	*P. maximum*
Annual precipitation (mm)	918(643–1239)	641	1121 (941–1416)	1417 (1167–1714)	987 (384–1816)
Isothermality	71 (65–75)	60	70 (67–77)	74 (58–87)	75 (56–88)
Min T coldest month (°C)	15.4 (11.0–19.5)	9.0	16.2 (9.1–21.4)	14.3 (6.5–19.2)	13.9 (9.0–21.4)
Annual mean T (°C)	23.4 (20.9–26.6)	22.6	23.5 (19.2–26.9)	22.6 (17.5–26.5)	21.9 (17.8–27.1)

The soil properties derived from the FAO soil map showed no clear differences between species or clusters of *Panicum* accessions. For all species and clusters, a wide range of soil characteristics was found, probably due to the large variation of soil characteristics within each grid. Information on soil texture and soil drainage from the passport data was available for 30 accessions, while the soil pH was available for only 20 accessions. *Panicum turgidum* was collected from a sandy soil with a good drainage, while all other accessions were collected from soils ranging from sandy loam to clay, with poorer drainage. The pH of the soil at the collection sites varied from 5 to 8 without any clear trend between species or clusters.
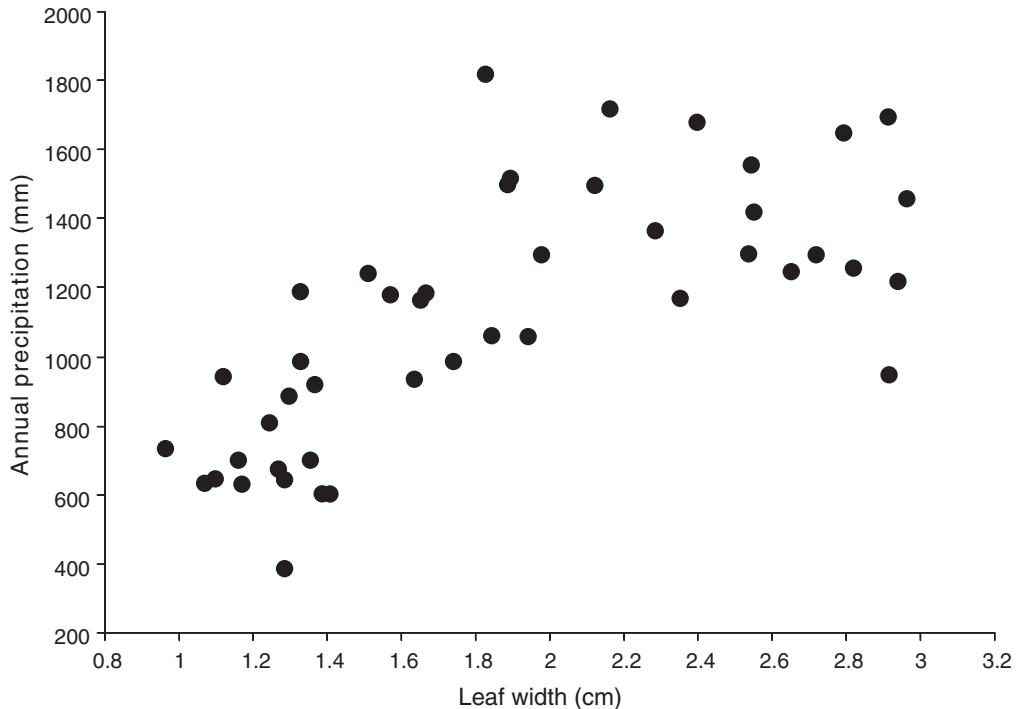
Figure 4. Scatterplot of the relation between annual precipitation at collection site and width of leaf of *Panicum maximum* accessions.

Discussion

Multivariate analysis, like hierarchical cluster analysis and principal component analysis, has proven to be a useful tool in studying diversity in forage germplasm collections (Pengelly *et al.* 1992; Heering *et al.* 1996; van de Wouw *et al.* 1999a). The current *Panicum* collection was successfully clustered into groups with similar characteristics, which will greatly assist future use and evaluation of *Panicum* germplasm.

All 3 species, which separated from the other *Panicum* species after the first clustering, are drought-tolerant. *P. turgidum* and *P. phragmitoides* grow in areas with lower rainfall and a very pronounced dry season. *P. turgidum* grows in areas where the average temperature in the wettest quarter exceeds 31°C. The *P. phragmitoides* accessions in this trial originated from areas with a less extreme climate than *P. turgidum*, with less fluctuation in temperature and precipitation, but from areas with the highest annual mean temperature. Although collection data for the *P. antidotale* accessions were not available, the species is known to be of Indian origin and was introduced

as a drought-resistant fodder grass at a few localities in Kenya and Tanzania (Clayton and Renvoize 1982). Of these 3 drought-tolerant species, *P. phragmitoides* appeared to have the best agro-morphological attributes for use as forage in dry areas. It is of intermediate height, late-flowering and the leafiest among the 3 drought-tolerant species. *P. turgidum* is very stemmy, but has large seeds compared with the other species in this trial, reflecting its use as a human food (Kernick 1992). Only a limited number of accessions for these 3 drought-tolerant species were characterised in the current trial, and more variation in agro-morphological characters probably exists in the wild, offering a wider scope for selection for desirable traits.

Panicum infestum is taxonomically very close to *P. maximum* (Assienan and Noirot 1995), so it was not surprising that it did not separate easily from the *P. maximum* accessions in the agro-morphological clustering. The *P. infestum* and *P. coloratum* accessions were collected from areas with a similar climate to the *P. maximum* accessions. Natural hybrids have been reported between *P. infestum* and *P. maximum* and, although clear

hybrids between the species in the current collection were not observed, it is possible that some hybrids are present within the group of accessions most closely related to the *P. infestum* group. Recently, a spontaneous hybrid between *P. maximum* and *P. infestum,* collected from Tanzania, has been released as a cultivar (Embrapa Gada de Corte 2001). It was found to out-produce cultivar Tanzânia-1, and has an especially high leaf:stem ratio. The group of *P. maximum* accessions most closely related to *P. infestum* in this study had a low score for leafiness.

Panicum coloratum belongs to a different subgenus from *P. maximum* and *P. infestum*. Based on the agro-morphological characterisation in the current study, it appeared similar to *P. infestum* and some of the *P. maximum* accessions. *P. coloratum* var. *makarikariense* was in a cluster with 2 shorter *P. maximum* cultivars, Sabi and Gatton, which were originally collected in Zimbabwe. *P. coloratum* var. *makarikariense* also originated from southern Africa (Skerman and Riveros 1990).

Large *P. maximum* types could be used as an alternative to napier grass (*Pennisetum purpureum*) in the dairy systems of east Africa. Napier grass is currently the main source of feed in these systems and in recent years has been threatened by diseases like head smut and napier grass stunting disease (Orodho 2006). It is important that alternatives are developed to make the system less dependent on a single species. The *P. maximum* accessions belonging to Group IV, which consist of the taller, more robust accessions, could form a promising start for material to be tested for use in cut-and-carry systems. The largest commercial cultivar in this group was cv. Hamil, while the other cultivars in this group were all shorter accessions. Some accessions, which were taller than Hamil, were present in this group and could be promising in cut-and-carry systems. In the drier areas of east Africa, Guinea grass has been found to perform better than napier grass (Boonman 1992). Another advantage of Guinea grass is its tolerance of shading, meaning it would fit well into agroforestry systems, where the combination of leguminous trees and understorey grass increases the total forage output from the system (Seresinhe and Pathirana 2000).

Heritability studies on *P. coloratum* indicated that leaf width was positively correlated with both leaf and culm mass (Young 1994). If the same were true for *P. maximum,* this would be a useful indicator for selection of more productive mate-

rial. *P. maximum* accessions with the widest leaves were found in Group IV, but variation within this group for this character was still considerable. Accessions ILRI 10929, 13479, 1035, 1009 and 13526, belonging to Cluster IV, were all in the top 10 accessions for both culm length and leaf width, while also having a high rating for leafiness. These accessions, originating from Ethiopia and Burundi, are promising material for testing for cut-and-carry systems in subhumid and humid areas.

Robust accessions have been reported to have poor sward stability under grazing and to require a long establishment period (Boonman 1992). Group IV accessions would therefore be less suitable for grazing systems.

In general, the smaller fine-leaved accessions from Cluster V originated from drier areas. ILRI 16671 from Namibia was collected from an area with an annual rainfall of 384 mm and ILRI 2118, 2124, 2140 and 2144 were all collected from areas in Ethiopia with annual rainfall below 700 mm.

Although most accessions from Cluster IV were collected from high rainfall areas, several of these taller accessions were collected from areas with a comparatively low rainfall, with ILRI 13479 from an area with the lowest annual rainfall in this cluster (945 mm), while still having a large culm length of 174 cm and leaf width of 2.9 cm. Although this could be a starting point to find tall accessions with lower rainfall requirements, low annual rainfall does not necessarily reflect lower moisture availability at the specific site where the plants were collected. Plants could be growing in depressions where water accumulates or near small streams.

ILRI 14358, 14359, 14360 and 14362 are hybrids selected from progeny of ILRI 14361 at ORSTOM in the Ivory Coast (Noirot *et al.* 1986). Most of these accessions were very similar to the maternal accession and only ILRI 14358 appeared to be significantly different, although still part of the same cluster of shorter, fine-leaved accessions (Cluster V).

With a few exceptions, there has been very little cross-continent applicability of developed *P. maximum* cultivars. Cultivars developed in Australia have not been taken up to a large extent in South America (Souza 1999), and cultivars from both these continents have found problems in Africa (Boonman 1992). For cultivars to find broader uptake by farmers in Africa, they would need to be developed, with environment and local use in mind. The breeding program of ORSTOM

in west Africa was aimed mainly at finding accessions suitable for grazing, and most of their promising accessions are found in Cluster V, which consisted of the smaller, fine-leaved plants from drier areas.

As no correlation was found between latitude and number of days to flowering, differences in photoperiod in the distribution area of *P. maximum* do not appear large enough to affect the flowering of the accessions. No problems in flowering therefore should be expected, when accessions originating from higher latitudes are grown in equatorial areas.

Seed production in *P. maximum* is problematic due to the extended flowering period, combined with shattering of the seeds. Branching of the main culm is partly responsible for the staggered flowering (Noirot 1991). The current collection showed wide variation in branching, with Group I having a high degree of branching. Accessions in Clusters IV and V did not show clear differences in branching of the main culm, but within the clusters there appeared to be scope for selection of plants with reduced branching, thus improving one of the characters responsible for a more uniform seed production. Very little branching of the main culm was found for accessions ILRI 12829, 16007 and 14359 from Cluster IV and 14363, 13383 and 10619 from Cluster V.

In this research, GIS tools proved useful for data mining of climatic variables when geographical coordinates of the collection site were known. Data on the major soil properties should be recorded at the time of collection of the accession, because soil types change over short distances and often a large range of soil properties can be found within mapping units.

Previous studies on characterisation of *P. maximum* focused on material collected from Kenya and Tanzania (Noirot *et al.* 1986; Jank *et al.* 1989). The current study included material from Ethiopia, Rwanda and Burundi. Germplasm from these countries displays some valuable characteristics, which are beyond the range of variation observed in germplasm collected from Kenya and Tanzania, and will be useful in further selection.

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