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Morphological and agronomic characterisation of a collection of napier grass (*Pennisetum purpureum*) and *P. purpureum* × *P. glaucum*

MARK VAN DE WOUW, JEAN HANSON AND SAMUEL LUETHI
International Livestock Research Institute, Addis Ababa, Ethiopia

Abstract

A collection of 53 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum* maintained in the field genebank of the International Livestock Research Institute was described using 8 agronomic characters and 20 morphological characters. The collection proved to be very variable both in agronomic and morphological attributes, although several accessions were found to be so similar that they could not be distinguished and possibly are duplicates. The accessions formed 6 groups based on morphological characters and 5 groups using the agronomic characters. This result will assist in future evaluation and use of the collection. Three dwarf accessions formed a distinct group. The morphological and agronomic classifications are unable to separate the hybrid accessions (*Pennisetum purpureum* × *P. glaucum*) from *P. purpureum.*

Introduction

One of the major forages used in zero-grazing systems is napier or elephant grass (*Pennisetum purpureum*) and its hybrids with *Pennisetum glaucum*. It is a tall, perennial grass that is indigenous to tropical Africa, and performs well from sea level up to an altitude of 2000 m. It can withstand repeated cutting and regrows rapidly, producing a high biomass that is very palatable in the leafy stage. It can be made into silage for feeding during the dry season (Woodard *et al.* 1991). Pests and disease problems are rare (Skerman and Riveros 1990). When grown in conjunction with leguminous trees or climbing legumes like *Clitoria ternatea,* total yield and nutritive value are increased (Mureithi *et al.* 1995). Besides its use as fodder, napier grass can also be used for soil regeneration and mulching and the dry stems can be used as fencing material or for house walls. In some countries, it is used for the manufacture of paper pulp (Boonman 1993).

The International Livestock Research Institute (ILRI) maintains a collection of *Pennisetum purpureum* and its hybrids with *Pennisetum glaucum* in its field genebank in Ethiopia. This collection has been assembled from several African countries and the USA and shows considerable morphological variation. A large number of accessions were donated by the ICRISAT program in Bulawayo (Zimbabwe). In this study, the morphological and agronomic characters of 53 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum* were described and characters identified which could be used to distinguish between or group similar accessions.

Materials and methods

The trial was carried out in the Ethiopian highlands at the ILRI Debre Zeit Research Station on a vertisol of pH 7 at an altitude of 1850 m above sea level. The area has an average annual rainfall of around 850 mm, of which 80% falls between June and September. Fifty-three accessions of napier grass and its hybrids with *Pennisetum glaucum* (Table 1) were planted from stem cuttings in 3 randomised blocks in 1.5 × 2.7 m plots, using 22 cuttings per plot with a spacing of 50 cm within rows and 60 cm between rows. The plants were irrigated and allowed to grow undisturbed for one year. One hundred kg/ha N (as urea) was applied in a single application during the establishment period. Plant height of each

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Correspondence: M. van de Wouw, c/o GRU, ICARDA, PO Box 5466, Aleppo, Syria. e-mail: MILVUS@worldonline.nl

accession was recorded and all plots were cut back to 20 cm at the start of the rains. Twenty-eight characters (Table 2) were observed on the regrowth in each plot 10–15 weeks after cutting. Wherever possible, characters were observed on 10 plants per plot as suggested by van de Wouw *et al.* (1999). The last harvest was made at the end of the rainy season, 15 weeks after the initial cutting.

Table 1. List of accessions used in the trial.

ILRI no.	Species	Origin	Other numbers[1]
14355	*Pennisetum purpureum*	Ethiopia	
14389	*Pennisetum purpureum*	Nigeria	
14982	*P. purpureum* × *P. glaucum*		N1423174
14983	*Pennisetum purpureum*		N12
14984	*Pennisetum purpureum*		N24-5
15743	*Pennisetum purpureum* cv. Mott		N75, PI517947
16621	*Pennisetum purpureum*	Namibia	
16782	*Pennisetum purpureum*	Tanzania	AMF531, SDPP1
16783	*Pennisetum purpureum*	Tanzania	AMF533, SDPP2
16784	*Pennisetum purpureum*	Tanzania	AMF425, SDPP3
16785	*Pennisetum purpureum*	Tanzania	AMF017, SDPP4
16786	*Pennisetum purpureum*	Swaziland	SDPP5
16787	*Pennisetum purpureum*	Swaziland	SEL49, SDPP6
16788	*Pennisetum purpureum*	Swaziland	SDPP7
16789	*Pennisetum purpureum*	Swaziland	SDPP8
16790	*Pennisetum purpureum*	Swaziland	SDPP9
16791	*Pennisetum purpureum*	Swaziland	SDPP10
16792	*Pennisetum purpureum*	Mozambique	IPA1, SDPP11
16793	*Pennisetum purpureum*	Cuba	IPA2, SDPP12
16794	*Pennisetum purpureum*	Mozambique	IPA3, SDPP13
16795	*Pennisetum purpureum*	Zimbabwe	SDPP14
16796	*Pennisetum purpureum*	Zimbabwe	SDPP15
16797	*Pennisetum purpureum*	Zimbabwe	SDPP16
16798	*Pennisetum purpureum*	Zimbabwe	SDPP17
16799	*Pennisetum purpureum*	Zimbabwe	SDPP18
16800	*Pennisetum purpureum*	Zimbabwe	SDPP19
16801	*Pennisetum purpureum*	Zimbabwe	SDPP22
16802	*Pennisetum purpureum*	Zimbabwe	SDPP23
16803	*Pennisetum purpureum*	Zimbabwe	SDPP24
16804	*Pennisetum purpureum*	USA	N7, SDPP25
16805	*Pennisetum purpureum*	USA	N9, SDPP26
16806	*Pennisetum purpureum*	USA	N13, SDPP28
16807	*Pennisetum purpureum*	USA	N14, SDPP29
16808	*Pennisetum purpureum*	USA	N16, SDPP30
16809	*Pennisetum purpureum*	USA	N20, SDPP31
16810	*Pennisetum purpureum*	USA	N23, SDPP32
16811	*Pennisetum purpureum*	USA	N34-1, SDPP33
16812	*Pennisetum purpureum*	USA	N39-2, SDPP34
16813	*Pennisetum purpureum*	USA	N67, SDPP35
16814	*Pennisetum purpureum*	USA	N74, SDPP35
16815	*Pennisetum purpureum*	USA	N114, SDPP37
16817	*Pennisetum purpureum*	USA	N126, SDPP40
16818	*Pennisetum purpureum*	USA	N127, SDPP41
16819	*Pennisetum purpureum*	USA	N132, SDPP42
16821	*Pennisetum purpureum*	Zimbabwe	SDPP50
16822	*Pennisetum purpureum*	Malawi	SDPP51
16834	*P. purpureum* × *P. glaucum*		SDPN2
16835	*P. purpureum* × *P. glaucum*		SDPN3
16836	*Pennisetum purpureum*		SDPP21
16837	*P. purpureum* × *P. glaucum*		SDPN29
16838	*P. purpureum* × *P. glaucum*		SDPN38
16839	*Pennisetum purpureum*		SDPP48
16902	*P. purpureum* × *P. glaucum*		SDPN20

[1] N = Tifton, Georgia, USA; PI = Plant Introduction No. USA; SDPP, SDPN = SADC/ICRISAT Bulawayo; IPA, SEL, AMF = Local numbers.

Variation between accessions was assessed using univariate analysis of variance. Correlation between the observed characteristics was determined by calculation of the Pearson's correlation coefficient. Where pairs of variables had a coefficient greater than 0.8, one variable was omitted to avoid indirect weighting in the cluster analysis. The remaining variables were standardised to a mean of 0 and a variance of 1 and used in a principal component analysis using the PRINCOM procedure of the SAS program (SAS 1987). Hierarchical clusters were formed using the average linkage and complete linkage algorithms of the SAS program (SAS 1987). Clustering was done separately for the morphological characters, which are less site-specific, and the agronomic characters, which are influenced by environment, and for the two sets of data combined.

Results

All characters observed showed significant variation (at 95% confidence level) within the group of accessions used. The height of the accessions at the end of the establishment year varied from 1.4 m to 4.2 m. Accessions attained a height of 1.2–3.4 m and the length of the internodes varied from 2.1 cm to more than 21 cm at 10 weeks after cutting. The indumentum of the plants also varied, some accessions being practically glabrous while others had very dense hairs on the observed plant parts. The hairiness of the leaves varied not only between accessions, but also within accessions. For 26 accessions, the estimate of the average hairiness of at least one observed plant part varied considerably between plots. The density of the hairs on the nodes was particularly variable and large variation in hairiness was observed on leaf, leaf sheath and leaf sheath edge. Some accessions flowered 2 months after cutting back, but 38 accessions did not flower at all during the experiment. Several accessions were very similar with no significant differences in any of the characters observed. Accessions 16796 and 16797, both from Zimbabwe, did not differ significantly. Other groupings of similar accessions were: 16802, 16808, 16809 and 16822; 16803, 16806 and 16836; and 16800, 16789, 16792, 16795 and 16798.

Table 2. List of characters observed.

Character	Definition	No. of plants observed
Agronomic		
1. Yield — 10 weeks[1]	Dry matter yield 10 weeks after cutting (kg/m^2)	
2. Yield — 15 weeks[1]	Dry matter yield 15 weeks after cutting (kg/m^2)	
3. Leaf percentage — 10 weeks	Percentage of the leaf blade and leaf sheath 10 weeks after cutting	
4. Leaf percentage — 15 weeks[1]	Percentage of the leaf blade and leaf sheath 15 weeks after cutting	
5. Plant height — 10 months	Average height of the plants 10 months after establishment (m)	Full plot
6. Plant height — 10 weeks[1]	Average height of the plants 10 weeks after cutting (m)	Full plot
7. Stool diameter[1]	Average diameter of the stool 12 months after establishment (cm)	4 plants
8. Weeks to first flowering	Number of weeks until the first flower appears; until 16 weeks after cutting	Full plot
Growth habit		
9. Growth form[1]	Average angle of stem to the ground from 0° to 90°	Full plot
10. Rhizome number	Average number of tillers with a length of more than 10 cm from the stool	4 plants
11. Rhizome length[1]	Average length of rhizomes from the stool (cm)	4 plants
Leaf characteristics		
All observations were done on the third leaf below the first completely unrolled leaf at the top of the plants.		
12. Leaf length[1]	Length from ligule to tip of leaf (cm)	10 plants
13. Leaf width[1]	Width of leaf at widest point (cm)	10 plants
14. Ligule length[1]	Length of ligule at longest point (mm)	10 plants
15. Leaf serrateness[1]	An estimate of the average number of teeth on 1 cm of leaf edge at middle of the leaf; (1) < 15, (2) 15–20, (3) > 20	10 plants
16. Leaf hairiness — adaxial[1]	An estimate of the average hairiness of the adaxial face of the leaf at the middle of the leaf; (0) none, (3) sparse, (6) dense	10 plants
17. Leaf hairiness — abaxial	An estimate of the average hairiness of the abaxial face of the leaf at the middle of the leaf; (0) none, (3) sparse, (6) dense	10 plants
18. Length of hairs — adaxial	An estimate of the average length of hairs on the adaxial face of the leaf at the middle of the leaf; (1) < 1.0 mm, (2) 1.0 –1.5 mm, (3) 1.5–2.0 mm, (4) > 2.0 mm	10 plants
19. Length of hairs — abaxial	An estimate of the average length of hairs on the abaxial face of the leaf at the middle of the leaf; (1) < 1.0 mm, (2) 1.0–1.5 mm, (3) 1.5–2.0 mm, (4) > 2.0 mm	10 plants
20. Leaf roughness — adaxial	An estimate with the tip of the finger of the average roughness of the adaxial face of the leaf; (1) smooth, (5) very rough	10 plants
21. Leaf roughness — abaxial[1]	An estimate with the tip of the finger of the average roughness of the abaxial face of the leaf; (1) smooth, (5) very rough	10 plants
22. Leaf sheath hairiness[1]	An estimate of the average hairiness of the leaf sheath (excluding the edge of the leaf sheath); (0) none, (3) sparse, (6) dense	10 plants
23. Length of the sheath hairs[1]	An estimate of the average length of the hairs on the leaf sheath (excluding the edge of the leaf sheath); (1) < 2 mm, (2) 2–3 mm, (3) 3–4 mm, (4) > 4 mm	10 plants
24. Leaf sheath edge hairiness[1]	An estimate of the average hairiness of the edge of the leaf sheath; (0) none, (3) sparse, (6) dense	10 plants
Stem characteristics		
25. Stem thickness[1]	Diameter of the stem above the lowest node (cm)	10 plants
26. Internode length[1]	Length of the fifth internode from the lowest internode (cm)	10 plants
27. Node hairiness[1]	An estimate of the hairiness of the lowest node; (0) none, (3) sparse, (6) dense	10 plants
28. Length of the node hairs	An estimate of the length of the hairs on the lowest node; (0) < 0.5 mm, (1) 0.5–1 mm, (2) 1–2 mm, (3) 2–3mm, (4) 3–4 mm, (5) >4 mm	10 plants

[1] Characters used for final analysis.

Except for the hairs on the leaf sheath, a high correlation was found between the density and length of the hairs (Pearson correlation coefficients between 0.87 and 0.92). The hairiness of the abaxial and adaxial sides of leaves were highly correlated (Pearson = 0.81) and the roughness of the adaxial side of the leaf was highly correlated with the hairiness (Pearson = –0.88). Further, a high correlation (Pearson = 0.95) was found between the number and length of rhizomes. A high correlation was also found between height at 10 months after planting and height at 10 weeks after cutting (Pearson = 0.81) and between leaf percentage at 10 weeks and the leaf percentage at 15 weeks (Pearson = 0.90). Since the use of highly correlated characters is an implicit weighting of these characters (Aldenderfer and Blashfield 1984), the total number of variables was reduced to 19 for the final analysis.

Morphological characters

The plot diagram of the first 2 principal components obtained with the first run of the principal component analysis shows that ILRI accession 16621, collected in Namibia, was very different from the other accessions, mainly because of its very strong rhizomatous habit and very short leaves. It formed an average of 11.7 rhizomes per plant extending to 130 cm from the stool and its leaves were only 52 cm long. Since clustering methods can be very sensitive to outliers, this accession was excluded from the analysis of the morphological characters.

The first 2 components of the principal component analysis on the morphological characters explain 51% of the total variation. Almost all characters contribute more or less equally to the first 2 principal components. No clear separation in groups is visible when the accessions are plotted against the first 2 components (Figure 1). Clustering using average and complete linkage methods highlighted 6 main groups. (Figure 2).

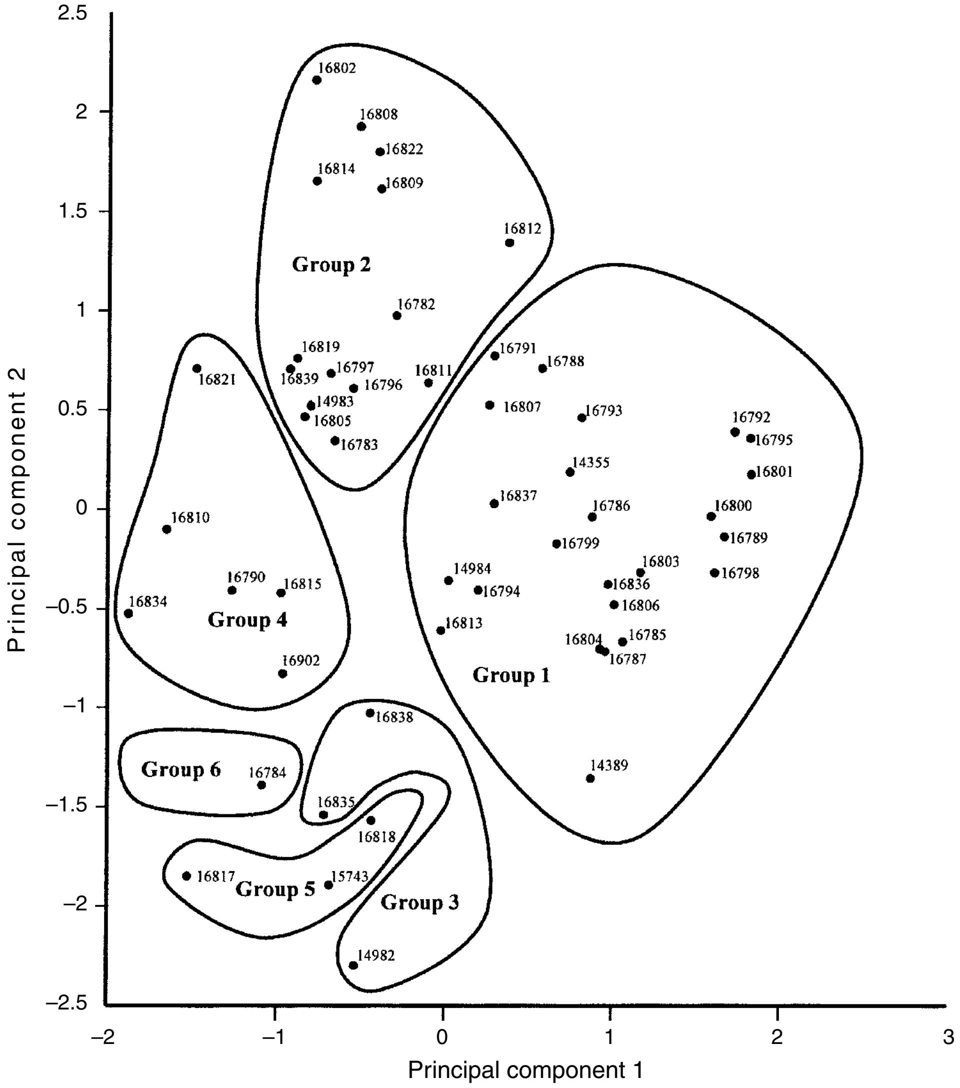

Figure 1. Scatter diagram of 52 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum* plotted against the first 2 principal components of the covariance matrix (explaining 51% of the variance) of the morphological characters. Groupings of accessions as obtained with the average linkage cluster analysis are indicated.

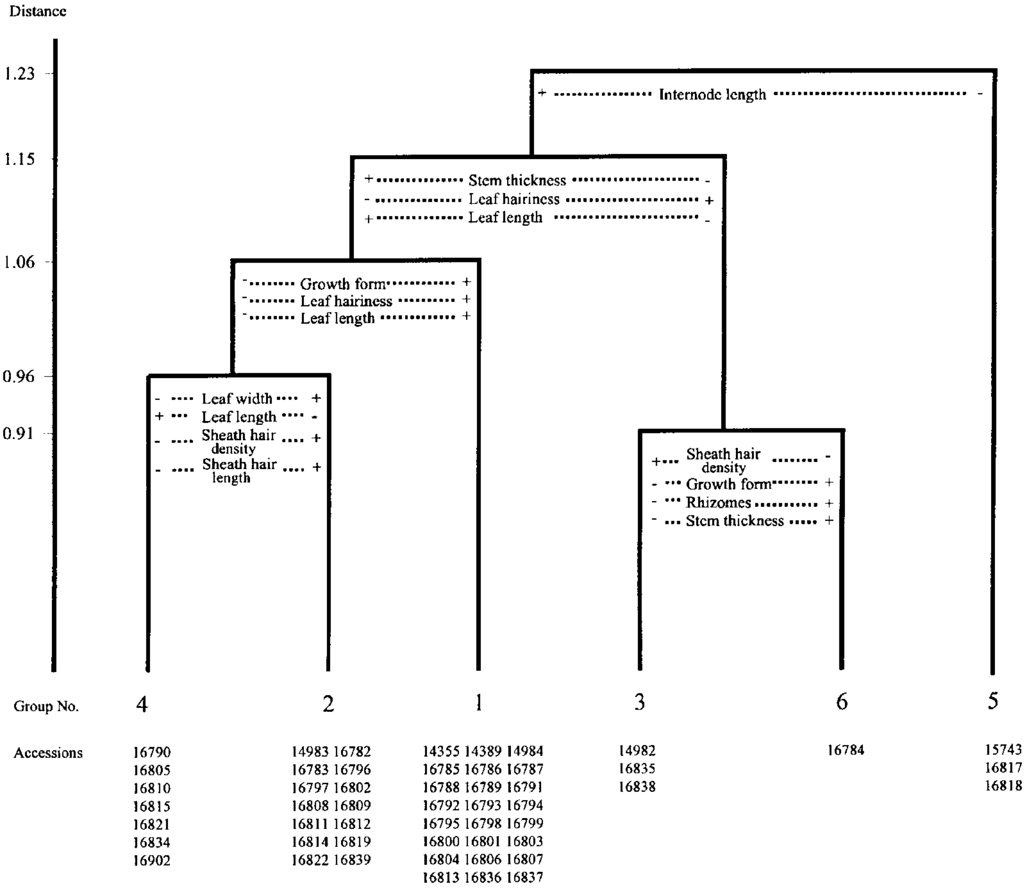

Figure 2. Dendrogram of the morphological classification by average linkage cluster analysis of 52 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum*.

The first level of separation is mainly due to the length of the internodes. Cultivar Mott and 2 other accessions developed at Tifton, USA (Group 5) produce very little stem and are separated from the other accessions. The next dichotomy occurs on leaf length and stem thickness. Three of the accessions registered as hybrids with *Pennisetum glaucum* belong to the group with smaller leaves, while the remaining 3 hybrids fall in the main cluster with the more robust plants. The division within this main group is due to a combination of several variables; for example, accessions belonging to Group 1 have generally longer leaves with more hairs on the leaves and are more erect. Accessions belonging to Group 2 differ from those in Group 4 in leaf size and the hairiness of the leaf sheaths. Group 1 consists mainly of accessions originating from Swaziland, Zimbabwe and Mozambique and some accessions from the USA. Group 2 consists of most of the Tanzanian accessions and some accessions from Zimbabwe and USA plus the accession from Malawi.

Agronomic characters

In contrast to the examination of the morphological characters, all accessions were used in the multivariate analysis of the agronomic traits. The first 2 principal components are plotted in Figure 3 and describe 73% of the variation. The plot diagram shows several accessions that are quite different from the main group. Further clustering using the average linkage logarithm shows 5 clusters (Figure 4). The majority of the accessions (35) fall in one group of tall, late flowering and high yielding accessions (Table 3). Group 2, which comprises 11 accessions, differs from this large group mainly because of its early flowering. Four of the hybrid accessions fall in this group. Agronomic Cluster 3, which includes cultivar Mott, is the accessions that produce very little stem. The fourth group contains one hybrid accession and the accession from Namibia that was excluded from the morphological analysis. The last group (Group 5) contains 2 tall, high yielding, but very stemmy accessions.

The main group (agronomic Group 1) includes most accessions from the morphological Groups 1, 6 and 2. Agronomic Cluster 2 contains all

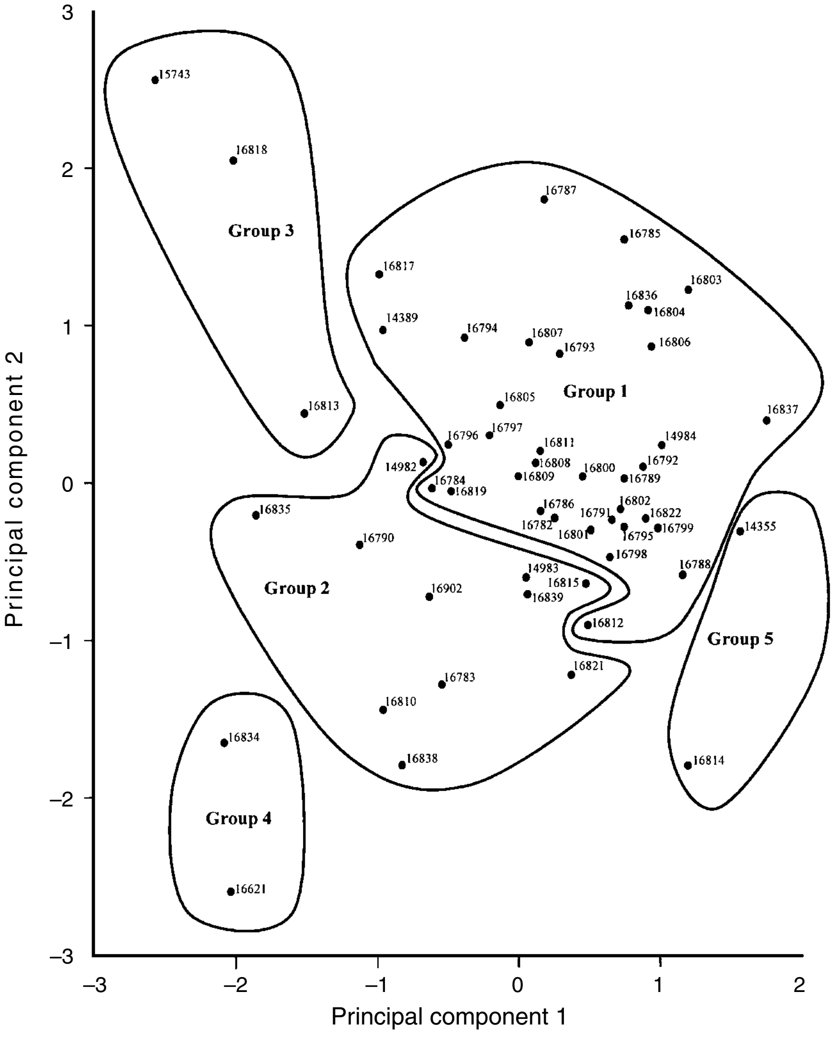

Figure 3. Scatter diagram of 53 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum* plotted against the first 2 principal components of the covariance matrix (explaining 73% of the variance) of the agronomic characters. Groupings of accessions as obtained with the average linkage cluster analysis are indicated.

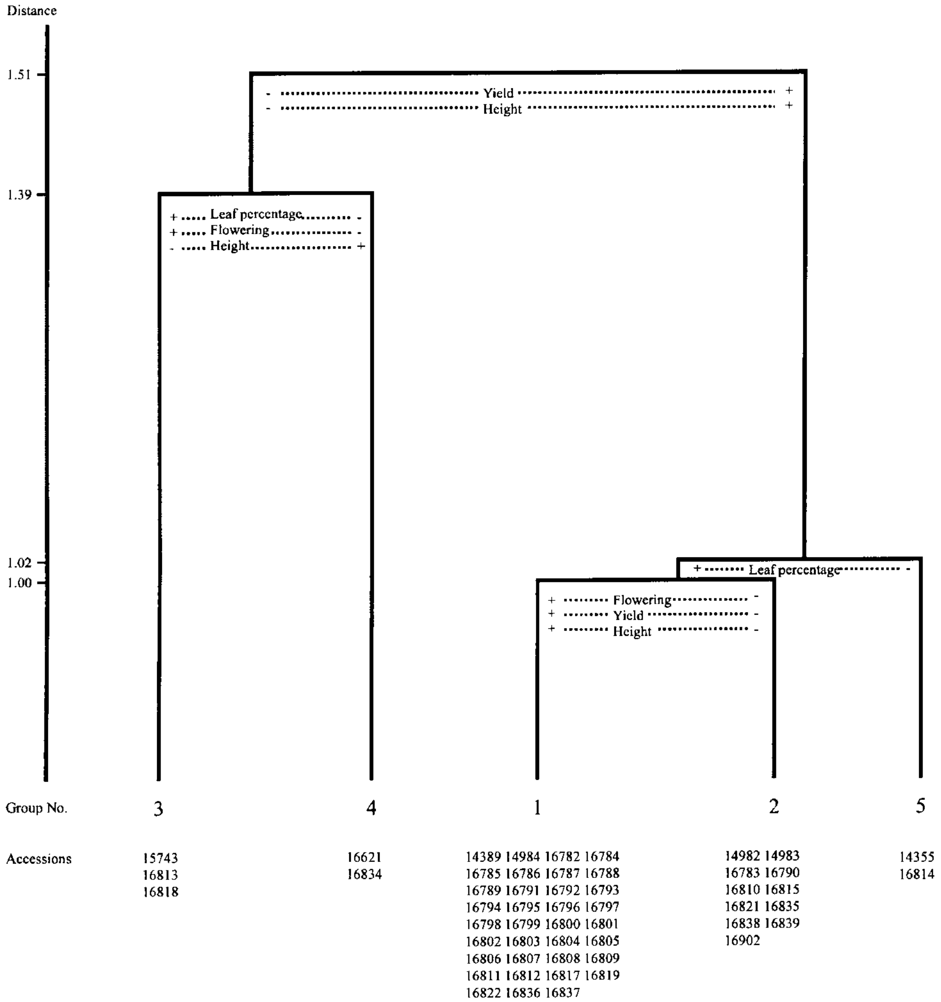

Figure 4. Dendrogram of the agronomic classification by average linkage cluster analysis of 53 accessions of *Pennisetum purpureum* and *P. purpureum* × *P. glaucum*.

accessions of morphological Group 3, the majority of morphological Group 4 and some accessions of morphological Group 2.

Table 3. Means (± SD) of some of the agronomic characters for the clusters obtained with the average linkage algorithm.

Cluster no.	No. of accessions	Yield at 15 weeks (kg/m^2)	Height at 10 weeks (m)	Leaf % at 15 weeks	Flowering
1	35	3.4 ±0.8	2.6 ±0.3	49 ±7	late
2	11	2.5 ±1.1	2.2 ±0.3	47 ±6	early
3	3	1.3 ±0.6	1.5 ±0.2	76 ±14	late
4	2	1.0 ±0.0	2.0 ±0.0	51 ±11	early
5	2	4.4 ±1.2	3.3 ±0.2	35 ±1	mixed

Combined morphological and agronomic characters

The results of the clustering with the average linkage and complete linkage methods with the combined data set were very similar to those obtained with the morphological characters only. The groups are joined together on different levels and accession 14984 switches groups. This indicates the dominance of the morphological characters in the clustering.

Discussion

Hierarchical cluster analysis has proven to be a useful tool in studying diversity in germplasm collections (Peeters and Martinelli 1989) and allowed the collection to be clustered successfully in groups with similar characteristics which will assist in future evaluation and use of the collection.

The large variation within accessions in leaf and stem pubescence found in this trial was also observed by other researchers (Tcacenco and Lance 1992). Since the accessions are clones (except for ILRI 16621), this can not be due to genetic differences. It seems the environment or perhaps, in the case of node hairiness, the age of the plant organ has a large effect on the observed pubescence. Although this makes hairiness a less reliable character, it still is an important character for distinguishing between accessions which are practically glabrous and accessions with dense hairs on the stem or the leaf, provided sufficient plants are observed. Accessions belonging to morphological Group 4 have leaves which are practically glabrous, a low number of teeth at the leaf margins and few hairs on the leaf sheaths while still maintaining a good yield.

Cultivar Mott falls in the agronomic group with the low yielding accessions. The low yields of the dwarf napier grass accessions compared with the other accessions have been reported by several researchers. Sollenberger *et al.* (1988) found Mott to have one-third of the yield of the taller accessions, while in a trial carried out by Brandelard (1994), Mott yielded half that of the taller accessions. Williams and Hanna (1995), who tested several dwarf and semi-dwarf accessions (including ILRI 16815, 16818 and cv. Mott), found that dry matter yield of these accessions was similar to that of Mott, and only half of that of the tall accession. Better quality of the dwarf napier grass accessions partly compensates for the low yield and the dwarf accessions are therefore better suited for grazing systems.

The collection of napier grass which was studied in this trial, although very variable, might still not reflect the variation found in this species. The accession which was collected from Namibia is very distinct and suggests the availability of more variation. The present collection originates mainly from Zimbabwe, Tanzania and Swaziland and few accessions were collected from natural stands of *P. purpureum*. Germplasm from other regions of Africa could be a useful addition to this collection.

The morphological groups found in this study generally agree with those found in a study using random amplified polymorphic DNA (RAPDs) markers (Lowe *et al.* in press). The RAPD analysis was able to separate hybrid accessions (*P. purpureum* × *P. glaucum*) from pure *P. purpureum* individuals. The morphological and agronomic classifications were unable to separate all hybrid accessions from non-hybrid accessions. The RAPD study was, however, unable to separate the dwarf accessions, which have been developed from selfed progeny of a tall cultivar (Williams and Hanna 1995), from some of the tall accessions. This confirms the value of morphological classification together with a more genetic approach. Genetically closely related accessions can have a very different morphology and therefore a very different prospective use and agronomic value.

Several accessions were found to be very similar with no significant differences in any of the characters observed. In the molecular analysis (Lowe *et al.* in press), these accessions also proved to be genetically closely related, and some accessions could not be distinguished. Since napier grass is propagated mainly by vegetative cuttings, there is a strong possibility that some of the similar accessions may be duplicates. Further study will be required to determine true duplicates. The size of the collection could be reduced if duplicates within the collection exist, allowing more efficient management of the field genebank collection.

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