The classification of a *Sesbania sesban* (ssp. *sesban)* collection. II. Agronomic attributes and their relation to biomass estimation

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Abstract

A collection of *Sesbania sesban* accessions was grown out in the field and classified using real and standardised values of 10 agronomic attributes. Clustering the accessions using the observed values of the attributes produced several groups which were mainly based on the dry matter yields after the first and second harvests. The cluster analysis on the standardised values of the descriptors provided 10 similarity groups. These groups were identified and compared with an earlier morphological classification.

Some of the observed characters were used to establish their relationship with biomass yield of the trees. The data were therefore subjected to linear regression analysis. Predictive equations were obtained for the logarithmical transformed biomass yield using stem diameter at 30 cm from ground level plus the plant height with r^2 values between 84 and 89%.

Introduction

The objectives of a classification study are *inter alia* to facilitate an inventory of what is available in a collection and therefore to help determine which accessions are of value and should be grown for seed increase. This enables an efficient management and maintenance of the collection. It can further help a breeder in the selection of material for inclusion in a breeding program.

The numerical classification using morphological attributes of a collection of *Sesbania sesban* ssp. *sesban* was successful in identifying groups within the species (Heering *et al.* 1996). However, a morphological characterisation does not always provide guidelines to the agronomic potential of the groups of accessions that are formed. Agronomic information should also be collected in order to get an understanding of the full range of variation available in the accessions as a guide to the existing desirable combinations of characters. Therefore, an attempt was made to establish a classification based on features of agronomic potential, using the same *Sesbania sesban* collection.

The study further tried to verify whether productive equations for the dry matter biomass yield as established for many forest species (Pardé 1980) could also be constructed for this multi-purpose tree species. This would allow a quick and non-destructive estimation of the biomass production which could be used in future evaluation and on-farm experiments. An earlier study on *Sesbania sesban* (Otieno *et al.* 1991) showed that significant correlations exist between biomass yield and stem diameters measured at knee and breast height. Predictive equations for biomass yields with r^2 value between 64 and 71% could be made using these measurements. This study tried to refine the biomass estimates by using diameter at 30 cm from ground level plus plant height in the equation for regression analyses. The results of both studies are reported in this paper.

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Materials and methods

The details regarding the location of the site and its soil characteristics are described elsewhere (Heering *et al*. 1996).

Classification

Two 5m-long rows containing 10 plants were planted for each accession. One row was used for observations regarding flowering and seed production, whereas the other was used for the characters related to biomass production. The diameter and height measurements were carried out according to the procedure described by

MacDicken *et al.* (1991). At 6 months after planting, one row was cut back to 75cm height and the harvested material was weighed fresh in the field. A representative sub-sample was taken from each row and sorted into leaf (leaves plus fine stem to 5mm in diameter) and wood (stems > 5mm in diameter). Each sorted sample was weighed and oven-dried at 70°C for 48 hours to determine the dry matter yields. The complete list of the attributes used in the analysis is given in Table 1.

The procedures of the Statistical Analysis System (SAS 1987) were followed in the data analyses. The correlation between the observed characteristics was determined and principal component and cluster analyses were carried out on both the observed and standardised values of the descriptors. In the latter case, the data were first standardised to a mean of 0 and a standard deviation of 1, using PROC STANDARD. The hierarchical cluster procedure according to the average linkage method as executed by PROC CLUSTER option AVERAGE was used. This agglomerative method begins with the calculation of a matrix of euclidean distances among group means and produces a dendrogram showing successive fusions of individuals which ends at the stage where all individuals belong to the same cluster.

Biomass estimation

For biomass estimation, linear regression was carried out with the SAS procedure, using the following equations:

$$\log y = a + b \log d^2h \quad (1)$$

and

$$\log y = a + b \log d + c \log h \quad (2)$$

in which y = biomass yield; d = diameter of the stem in mm at 30 cm above ground level; h = height of the tree in cm; and a,b and c = regression constants.

Results

Classification

One accession (ILCA 9256) was taken out of the analysis since all plants died after the first cut. The significant correlation coefficients of the agronomic characters are given in Table 2. Principal component analysis (PCA) was carried out with all the observed characters. The first component in the principal component analysis,

Table 1. Agronomic characters observed on the *Sesbania sesban* collection.

1	Height at 6 months (HGT6)	Total stem length, measured in cm, 6 months after planting from the ground to the highest (apical) growing point (average of 5 trees).
2	Diameter at 6 months (DIAM)	Measured in mm at 30 cm height above ground level (average of 5 trees).
3	Plant yield 1 (PYLD1)	Average dry matter yield per plant in g when cut back to 75 cm above ground level after 6-months growth.
4	Leaf percentage (LFPC)	The amount of leaves as percentage of the total yield at the first cut.
5	Regrowth height (HGTR)	Height of the trees in cm, measured 6 months after the first cut (average of 5 trees).
6	Plant yield 2 (PYLD2)	Average dry matter yield per plant in g when cut back 6 months after the first cut.
7	Days to flowering (FLOW)	Number of days from planting until 50% of the plants reached flowering.
8	Days to seeding (SEED)	Number of days from planting until 50% of the plants produced ripe pods.
9	Seed set (SSET)	Rated as (1) very poor; (2) poor; (3) fair; (4) good; (5) very good.
10	Thousand-seed weight (TSWG)	Weight in g; measured for 6 samples with 100 dried seeds each.

Table 2. The significant correlation coefficients between descriptor pairs for the observed agronomic attributes in the *S. sesban* collection.

		1	2	3	4	5	6	7	8	9
1	HGT6									
2	DIAM	0.78								
3	PYLD1	0.77	0.81							
4	LFPC	–0.54	–0.54	–0.46						
5	HGTR	0.54	0.44	0.46	–0.43					
6	PYLD2	0.32	0.44	0.38	–0.27	0.73				
7	FLOW		–0.23*[1]	–0.23*	0.30	–0.22*				
8	SEED				0.27	–0.25	–0.24*	0.79		
9	SSET				–0.27					
10	TSWG				–0.30			–0.20*		0.21*

[1]Significant at 5% level; all others significant at 1% level.

which was mainly related to the yield after the first harvest, explained 88% of the total variance. The second component referred to the yield of the regrowth harvest and accounted for another 9% of the total variance (Table 3). When the accessions were plotted against the first 2 components, 2 outliers, accessions with very high plant yield at the first harvest (ILCA 15024 and 15368), were noted. When these 2 accessions were left out of the PCA, a better separation of the remaining ones occurred in which some groups could be visualised (Figure 1). Cluster analysis identified these groups as 8 clusters, which were formed mainly on the basis of their dry matter yields (Table 4).

Table 3. Eigenvectors of the first 4 principal components.

Variable	PRIN1	PRIN2	PRIN3	PRIN4
HGT6	0.141	−0.043	0.848	0.317
DIAM	0.002	0.0	0.003	0.001
PYLD1	0.971	−0.176	−0.154	−0.027
LFPC	−0.010	−0.003	−0.057	0.023
HGTR	0.052	0.183	0.262	0.023
PYLD2	0.175	0.963	−0.038	0.051
FLOW	−0.020	−0.028	−0.150	0.723
SEED	−0.013	−0.051	−0.208	0.596
SSET	0.0	0.0	0.006	−0.003
TSWG	0.001	−0.002	−0.003	−0.009
% Variation explained	88.4	8.5	1.4	1.1

Table 4. Means and standard deviations of the agronomic characters — total dry matter plant yield after the first (PYLD1) and second (PYLD2) cuts for the observed clusters using real values.

Cluster no.	No. of accessions	PYLD1 (g)	PYLD2 (g)
1	1	1690.1	336.6
2	15	1292.1 ± 101.7	202.0 ± 101.9
3	4	1103.9 ± 102.1	715.0 ± 104.3
4	9	984.3 ± 58.7	220.0 ± 90.6
5	1	448.8	636.3
6	28	124.0 ± 53.3	83.6 ± 55.4
7	2	275.2 ± 35.6	377.8 ± 73.6
8	45	498.4 ± 163.7	166.1 ± 82.0

Standardisation reduced the influence of plant yield in the covariant matrix. The dendrogram formed after the hierarchical clustering of the standardised values of the original descriptors is presented in Figure 2. The cluster analysis on the standardised values of all the observed characters, including the morphological ones, emphasised the varietal differences found within the *S. sesban* collection. A list with the details on origin and group allocation of the individual accessions can be found in Appendix 1.

Biomass estimation

The linear regression analysis for the models which included both height and diameter as

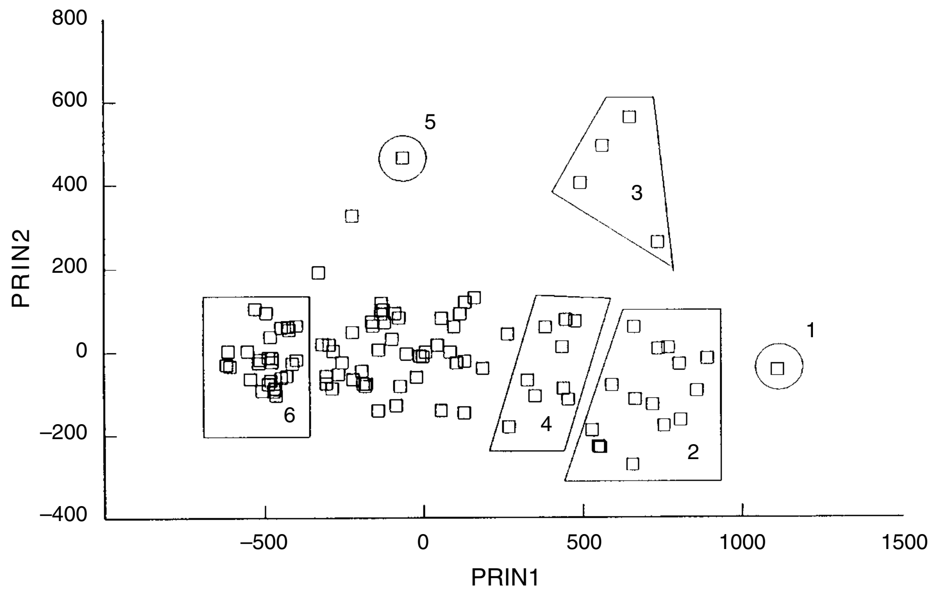

Figure 1. Graph of 105 accessions of *S. sesban* plotted against the first 2 principal components of the covariance matrix using the real values of the attributes (explaining 97% of the variance). PRIN1 = the first principal component; PRIN2 = the second principal component.

variables in the equation gave comparable and significant r^2 values ranging from 0.84 to 0.89 for the different proportions of the biomass. These were higher than estimates based on equations with either height (r^2 = 0.67–0.78) or diameter (r^2 = 0.79–0.81). Further, the estimations for the wood and total biomass yields are slightly better than for the leaf biomass yields (Table 5).

Plots of the residuals (observed minus estimated values) and the dependent variables did not show any appreciable lack of fit (Figure 3). The regression lines with the estimated yields for Model 1 are given in Figure 4.

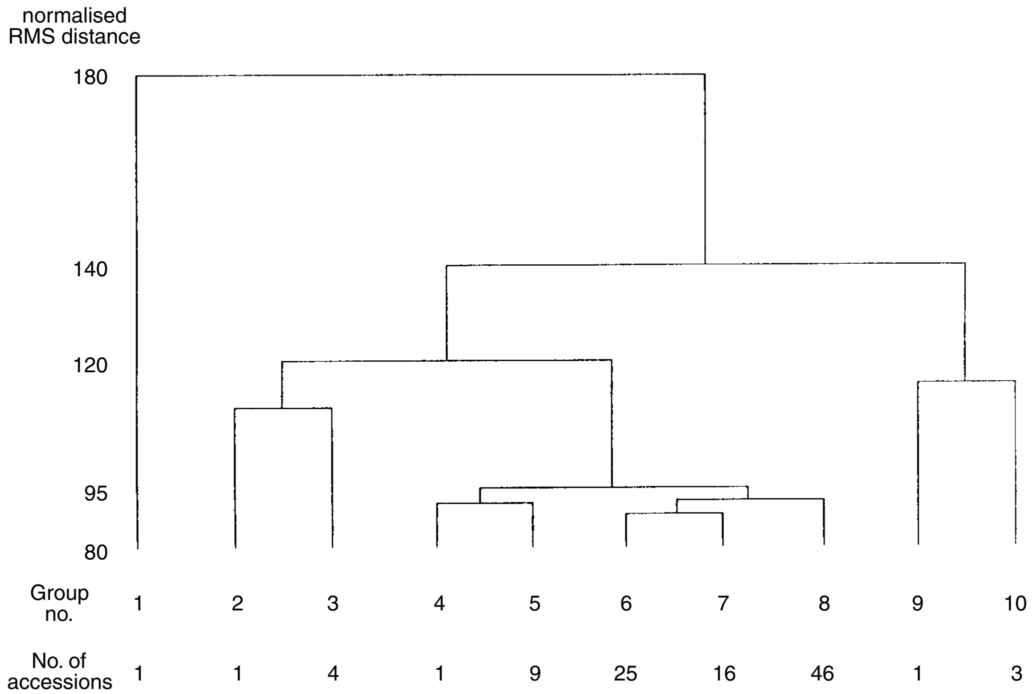

Figure 2. Dendrogram of the agronomic classification of the 108 *S. sesban* accessions, based on the average linkage algorithm using standardised values. Height of the clusters indicates the normalised root mean square (RMS) distance between the joined groups.

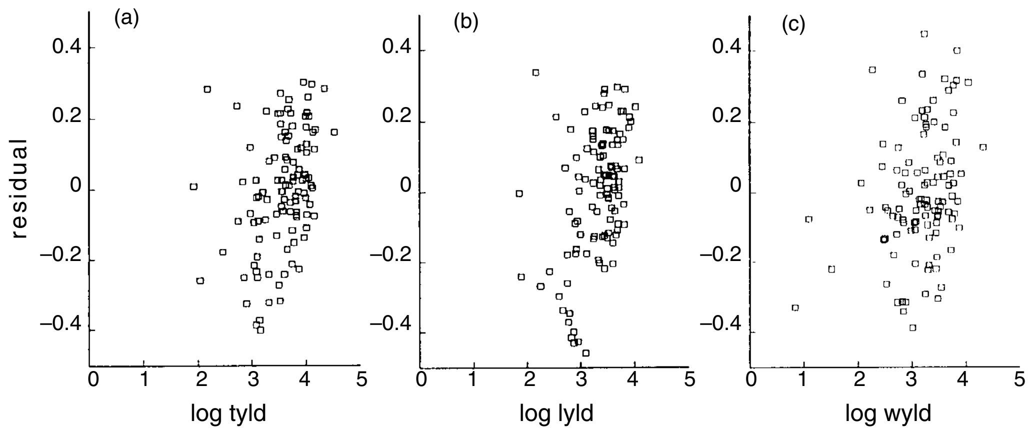

Figure 3. Graphs of the residuals and the logarithm of the total (a), leaf (b) and wood (c) dry matter yields for *S. sesban* using Model 2.

Table 5. Predictive equations for the estimation of biomass yields in *S. sesban* accessions.

Model 1: log y = a + b log d^2h[1]

Dependent	a	b	r^2	EMS[2]	Significance level
log tyld[3]	0.35	0.72	0.87	0.026	0.0001
log lyld	0.32	0.65	0.84	0.027	0.0001
log wyld	–0.50	0.86	0.87	0.040	0.0001

Model 2: log y = a + b log d + c log h

Dependent	a	b	c	r^2	EMS	Significance level
log tyld	–0.90	1.20	1.25	0.88	0.025	0.0001
log lyld	0.02	1.24	0.77	0.84	0.027	0.0001
log wyld	–3.18	1.21	2.01	0.89	0.034	0.0001

[1]d = diameter (mm); h = height (cm).
[2]EMS = Error Mean Square.
[3]tyld = total dry matter yield (g); lyld = leaf dry matter yield (g); wyld = wood dry matter yield (g).

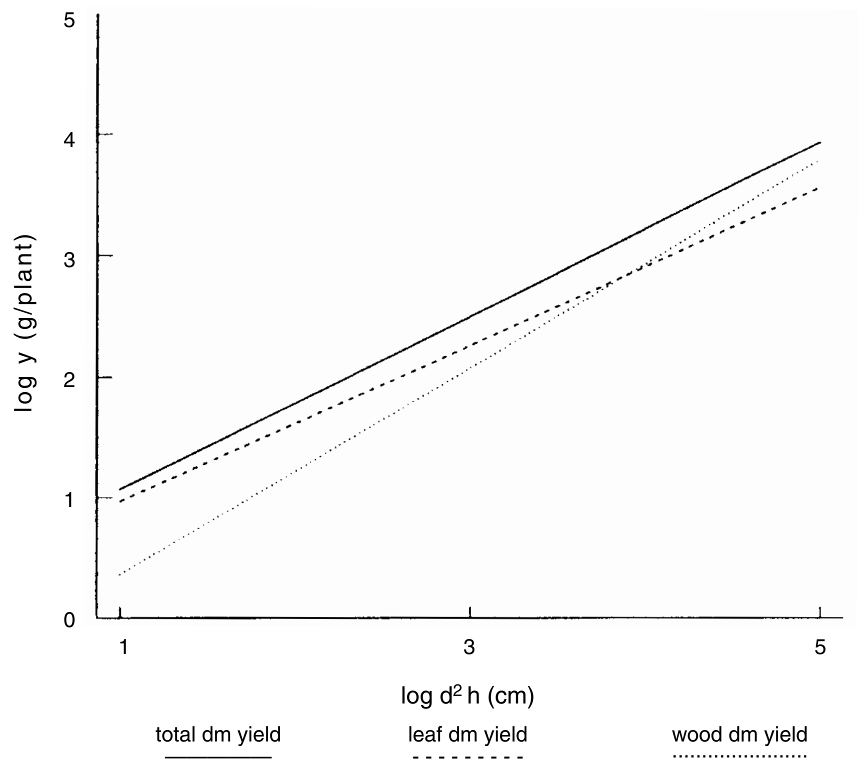

Figure 4. Regression lines for the dry matter yields for *S. sesban* using Model 1.

Discussion

Classification

The accessions showed a large variation in dry matter yields per plant after the first and second cuts. This was reflected in the outcome of the PCA with the observed agronomic characters (Table 3), which was dominated by these 2 attributes. Several accessions had a rapid early growth with a total dry matter production between 10–20 t/ha. However, as observed in an earlier experiment (J.H. Heering 1995), many accessions could not sustain their high level of production and the yields were therefore markedly lower at the second cut. The accessions in Group 3 are of interest in this respect because they also maintained high productivity at the regrowth cut (Figure 1).

The average linkage algorithm performed on the standardised values of the characteristics divided the collection into 10 clusters, which will be discussed below. At the first dichotomy, one accession (ILCA 15368) was split from the remainder because of its very high yield at the first harvest with an average DM yield of 3470 g per plant (Figure 2). At the second dichotomy, 4 accessions were separated from the remaining group because of their very low yield at the first cut (average 66 ± 58 g DM per plant), consisting mainly of leaf material. One accession (ILCA 1229) was early flowering, whereas the others were late flowering. Next, 5 accessions were detached because of their relatively high yield at the first cut (average 1124 ± 100 g DM) and very high yield at the regrowth cut (mean 64 ± 174 g DM per plant). The accession 15036 could be distinguished from the remaining 4 because of its fast growth rate after 6 months with an average height of almost 5 m per plant. At the next dichotomy a group with 10 accessions, all belonging to the varieties *sesban* or *bicolor*, was separated from the others, belonging to the variety *nubica* because of their higher thousand-seed weights. Of these 10, the accession number 15024 formed a separate group because of its very high yield after 6-months growth (2272 g DM per plant). The remaining 87 accessions were divided into 2 groups of 46 and 41 accessions, respectively, of which the first group had a lower dry matter production. The latter group was divided into 2 clusters; one containing 16 accessions which are late flowering and seeding and another consisting of 25 early flowering accessions.

Biomass estimation

High and significant correlations were found between plant dry matter yields after 6 months and height and diameter, justifying the inclusion of these characters in the biomass estimation equations. The dry matter biomass estimation gave good results for both equations. The equations which included both diameter and height provided a more accurate estimate of dry matter yield than those that used these parameters separately. Higher r^2 values were obtained for total and wood biomass production estimates than for the leaf biomass. This fact was also reported by Otieno *et al.* (1991). Now that this study has shown the relationship between height, diameter and biomass yield, the next step will be to develop biomass estimation tables that can be used for *S. sesban* at different sites and ecosystems. In this respect it is, however, important to note that leaf production can show major fluctuations over time and place and, as stated by Stewart *et al.* (1992), the relationship between height, diameter and biomass production should therefore mostly be used for the estimation of wood production in different environments.

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Appendix 1. Origin and group allocation after cluster analysis on the morphological and agronomic characters for the *S. sesban* collection.

ILCA No.	Origin[1]	Latitude	Longitude	Altitude (m)	Annual rainfall (mm)	Group allocation		
						Morphological characters		Agronomic characters
						SAS[2]	PAM[3]	SAS
920	TZA				1200	6	1	8
988	RWA	02°17′S	030°14′E	1400		7	1	8
1177	TZA			360	895	6	5	7
1178	TZA	06°22′S	037°18′E	430	544	7	5	6
1179	TZA	06°21′S	037°15′E	680	544	6	5	8
1180	TZA			900	544	7	5	7
1188	TZA	08°05′S	037°47′E	1520	626	4	4	8
1189	TZA			1300	672	4	5	7
1190	TZA			1060	672	7	4	7
1191	TZA			1050	672	4	4	7
1192	TZA			1080	672	7	4	8
1193	TZA			1060	672	7	4	8
1194	TZA			1180	883	7	5	8
1195	TZA			1550	1154	7	5	8
1198	TZA			1380		7	4	8
1200	TZA			1350		7	5	8
1201	TZA			1810		7	2	6
1203	TZA			800		7	2	7
1208	TZA			800		4	5	8
1214	TZA			975		7	2	8
1215	TZA			780	977	4	2	8
1216	TZA			780	977	7	5	8
1221	TZA			1120		7	4	3
1228	TZA	01°51′S	031°39′E	1200	972	7	1	6
1229	TZA	01°11′S	031°44′E	1110	2040	4	4	9
1231	TZA			1090	2040	7	1	8
1232	TZA			1090	2040	7	1	8
1236	TZA			1300		7	4	8
1237	TZA			1280	972	6	1	3
1238	TZA			1280	972	6	1	8
1246	TZA			1100		6	4	10
1250	TZA			1080	1002	6	1	8
1256	TZA			1400		6	4	8
1259	TZA	04°02′S	035°46′E	1000	1074	6	5	7
1261	TZA			940	1074	7	4	7
1262	TZA			920	1074	7	4	8
1264	TZA			940	809	7	4	8
1265	TZA			910	809	7	5	6
1275	TZA			600		6	3	6
1276	TZA	04°19′S	037°30′E	600		7	5	8
1280	TZA	04°19′S	037°30′E	600		6	3	6
1281	TZA	04°22′S	038°02′E	400		7	5	8
1282	TZA	04°22′S	038°02′E	400		6	3	6
1283	TZA	04°22′S	038°02′E	400		7	5	7
1284	TZA	04°22′S	038°03′E	400		6	3	6
1285	TZA	04°38′S	038°45′E	400		7	3	6
1286	TZA	04°38′S	038°04′E	400		7	5	8
1287	TZA	04°46′S		400	611	6	3	6
1288	TZA	04°48′S	038°12′E	390	611	6	3	6
1289	TZA	04°55′S	038°17′E	385	611	6	5	6
1290	TZA			350	611	6	3	6
1291	TZA			220	1321	6	3	6
1292	TZA			235	1321	7	4	6
1293	TZA	04°33′S	037°41′E	625		6	3	7
1294	TZA	04°33′S	037°41′E	625		7	3	3
1295	TZA	04°33′S	037°41′E	625		7	5	6
1296	TZA	04°33′S	037°41′E	625		6	3	6
1297	TZA	04°33′S	037°41′E	625		7	5	6
1298	TZA	04°33′S	037°41′E	625		6	4	6
1299	TZA	04°33′S	037°41′E	625		6	5	6
1300	TZA	14°34′S	056°19′W	410	1230	7	5	6
1301	TZA	04°33′S	037°41′E	625		7	5	6
1302	TZA	04°33′S	037°41′E	840		7	5	6
1303	TZA	04°33′S	037°41′E	700	858	7	4	8

ILCA No.	Origin[1]	Latitude	Longitude	Altitude (m)	Annual rainfall (mm)	Group allocation		
						Morphological characters		Agronomic characters
						SAS[2]	PAM[3]	SAS
1304	TZA	04°33′S	037°41′E	710	858	7	4	3
2000	ETH	08°21′N	039°05′E	1750		7	1	6
2007	ETH			1320		7	4	8
2012	ETH			2100		4	1	10
2021	ETH	05°22′N	039°32′E	1420	700	7	4	8
2024	ETH	05°28′N	039°29′E	1470	700	7	4	7
2055	ETH	10°58′N	036°25′E	1700	1500	3	2	8
2057	ETH	10°59′N	036°23′E	1740	1500	6	2	8
2066	ETH	10°58′N	036°22′E	1700	1500	5	2	8
2069	ETH	11°08′N	036°03′E	1200	1200	6	2	8
2076	ETH	09°57′N	038°19′E	1400	1000	4	4	8
9043	ETH	07°05′N	038°30′E	1680	970	7	4	7
9164	ETH	07°56′N	038°43′E	1550	700	7	5	7
9265						7	5	—
10375	ETH	06°06′N	037°37′E	1200	900	7	5	8
10379	ETH	06°25′N	037°22′E	1470	900	7	2	8
10381	ETH					6	2	8
10521	ETH	06°50′N	037°45′E	1925	1300	6	5	8
10639	ETH	07°45′N	036°34′E	1640	1700	7	1	8
10865						7	4	7
13144	KEN	00°35′N	034°34′E	1450	1900	6	2	10
13261	KEN	00°01′S	034°44′E	1200	1300	6	2	8
13444	ETH	05°13′N	039°46′E	1650		3	4	8
13491	ETH	06°08′N	037°35′E	1860	1500	6	5	8
13516	ETH	06°24′N	037°06′E	1150	1500	7	5	8
13887	NER	12°15′N	002°23′E	270		6	5	8
14014	ETH					7	1	8
15018	TWN					2	—	5
15019	ZAR					6	3	6
15020	KEN					2	—	5
15021	UGA					7	1	8
15022	RWA					7	1	8
15023						2	—	5
15024	IND					2	—	4
15025						2	—	5
15036	UGA					6	4	2
15037	EGY					2	—	5
15077						2	—	5
15364	KEN	00°44′S	036°26′E	1890	615	6	2	7
15368	KEN	00°22′S	036°05′E	1730	860	6	5	1
15525						6	1	7
16841	EGY	25°16′N	032°30′E			1	—	5
16842	EGY	25°41′N	032°24′E			1	—	5
16843	EGY	25°44′N	032°39′E			2	1	5

[1] EGY = Egypt; ETH = Ethiopia; IND = India; KEN = Kenya; NER = Niger; RWA = Rwanda; TZA = Tanzania; TWA = Taiwan; UGA = Uganda; ZAR = Zaire.
[2] SAS = group allocation after cluster analysis using the average linkage algorithm in SAS.
[3] PAM = group allocation after cluster analysis using the partitioning around medoids algorithm.

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