A NUMERICAL CLASSIFICATION OF SOWN TROPICAL PASTURE REGIONS BASED ON THE PERFORMANCE OF SOWN PASTURE SPECIES

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ABSTRACT

The purpose of this study is to introduce a hierarchical polythetic classification analysis to delineate sown tropical pasture regions, using existing published data. The importance of the various attributes in the classification is explored and the status of the resultant groups briefly examined. The technique appears to have been successful using only 50 sites and despite the very limited comparative information available for each, a clear-cut classification into seven major pastoral types has resulted. This classification agrees well with several subjective and intuitive classifications already in existence, while making provision for types which one or other of the previous classifications do not cover.

INTRODUCTION

Orderly plant introduction aimed at providing productive and adapted pastures in the tropics and sub-tropics is a relatively new phenomenon. Unlike many situations in temperate areas of the world, where sown pastures have evolved for hundreds of years, workers in many tropical areas have had to seek out and, introduce material where sown pastures were desired. The need for realistic classification into areas of similar pastoral potential has long been recognised but as yet no global classification of sown tropical pastures using objective multivariate methods has been proposed.

It has been suggested by Davies (1960) that changes in vegetation occur at latitudes 30°N and S which makes possible the concept of the "biological tropics". Changes in the type and composition of grassland occur at these latitudes with no directly comparable changes at the solar tropics. On a global basis something like half of the pastures are in the biological tropics and occur in a wide range of environments.

Davies and Skidmore (1966) noting that rainfall has a major influence, discuss tropical pastures on the basis of humid zones, sub-humid zones, semi-arid zones and arid zones. However, this simple classification does not make allowance for tropical highland areas and the cooler sub-tropics; both areas having sown pasture species which do not occur elsewhere. Whyte (1959) presented a table of grass species adapted for cultivation to the major climatic regions of the world, and his climatic classification of the tropics and sub-tropics consists of six units: tropical semi-arid, tropical restricted rainfall, tropical extended rainfall, sub-tropical semi-arid, sub-tropical summer rainfall and sub-tropical extended rainfall. However, many of the grass species listed are only suggestions as to what may be suitable and not what are in fact extensively grown.

Philipps (1961) suggested the adoption of a complex classification which is based on climatic conditions and the associated natural vegetation. It has considerable use as a base for discussion of natural or derived pastures but has little application to those areas that are deliberately sown. Borget (1969) suggested six pastoral-climatic regions in the tropics; wet equatorial, dry equatorial, wet tropical, dry tropical, high altitude equatorial and high altitude tropical. He then outlined the major species combinations that characterize the regions. Unfortunately he does not discuss any areas > 18° latitude. Hutton (1970) distinguishes seven pastoral-climatic zones, comprising a wet equatorial zone with constant heat,

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rainfall and humidity, occurring between 5–10°N and S of the equator. Four monsoonal areas are distinguished as follows—annual rainfall of 1000–2000 mm in two rainy seasons with short dry seasons; annual rainfall of 600–1500 mm in two short rainy seasons; annual rainfall of 750–1500 mm in one fairly long rainy season with a short dry season, and an annual rainfall of 500–1000 mm with one short rainy season and a long dry season. The sub-tropical zones are characterized as humid and dry respectively. Although this classification is more meaningful than those outlined above, it again lacks a provision for a tropical highland zone.

More detailed classifications have been devised for individual countries. Ripperton and Hosaka (1942) published descriptions and maps of the pastoral zones of Hawaii. This classification is still the most useful device for describing the large range in climate, soil and vegetation types within a short distance and is the first example of pastoral zones being distinguished by sown species (Plucknett 1970). Garcia–Molinari (1952) distinguished the distribution of pasture and forage species on a topographical-ecological basis for the Caribbean area, and Davies (1960) similarly suggested eight zones for the Australian tropics.

Bogdan (1960) established a classification for Kenya in which he delineates six regions, ranging from cold areas at very high altitudes consisting of temperate zone grasses and legumes, to hot and moderately moist coastal areas growing adapted pasture plants. Moore (1970) classified the grazing lands of Australia on the basis of climate, the physiognomy of the communities and the characteristics of the common edible species, and was then able to delineate sown pasture types and outline the characteristic species. This classification is undoubtedly the best to date, as it relates to many pastoral elements such as natural vegetation, the natural grazing lands and sown pastures.

The present work represents an attempt to use objective multivariate methods to define a classification which shall be solely determined by the data rather than by the views of individual investigators. To this end 50 sites have been selected covering a wide range of tropical and sub-tropical environments; data for 46 of these sites have been extracted from scientific papers and annual reports, and for the remainder by personal observation. These data referred to the actual pastoral situation and the many reports on species in plant introduction gardens were not considered. Modern classificatory techniques have then been used to process these data.

DATA

The location of the fifty sites is shown in Figure 1. Site selection was quickly resolved for although there is an increasing interest in tropical pastures, very few of the many reported site × species interactions recorded any climatic or soil data. There are indeed many references to experimentation with various grasses and legumes throughout the tropics but as yet little follow-through work reporting long term adaptation and use of these species. Consequently only those sites which were characterized by the use of species for at least a period of five years were used in the analysis. This was taken as a measure of the adaptability of species to the environment and reduced the risk of fluctuation of species due to either a series of wet years or drought. The sites are listed and located in Figure 1, and the species are listed in Table 1 (grasses) and Table 2 (legumes).

The individual species are subjected to a complex interacting set of environmental factors, all of which are important if the plant is to complete its life cycle. The major obstacle encountered in building a numerical classification of sown pasture species, was the decision on which attributes could be profitably utilized. This was resolved when the data on each site had been collected and it was apparent that there was considerable unconformity between recorded characteristics. Whilst many sites had good climatic data, e.g. mean monthly temperatures, mean monthly rainfall, evaporation readings, etc., others had little more than mean annual

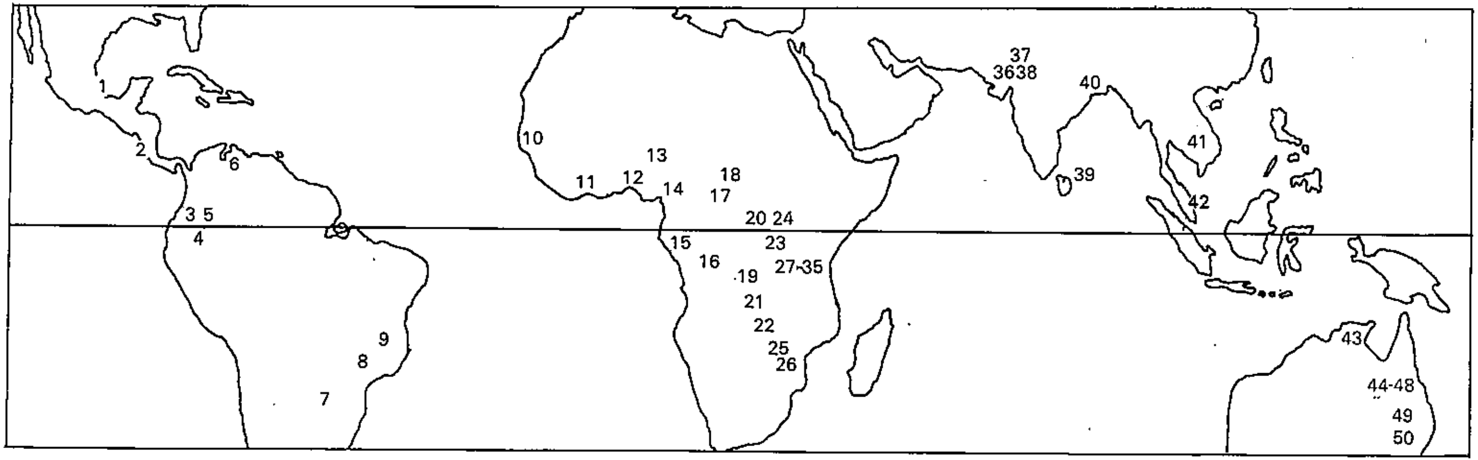

FIGURE 1
Location of sites used in the classification.

1	Cotaxtla, Mexico
2	El Capulin, Costa Rica
3	Buenaventura, Colombia
4	Popayan, Colombia
5	Palmira, Colombia
6	Barquisimeto, Venezuela
7	Corrientes, Argentina
8	Matao, Brazil
9	Sete Lagoas, Brazil
10	Bambey, Senegal
11	Bouake, Ivory Coast
12	Ibadan, Nigeria
13	Shika, Nigeria
14	Dschang, Cameroon
15	Dolisie, Congo (Brazzaville)
16	M'vuazi, Zaire
17	Sardi, Central African Rep.
18	Bouar, Central African Rep.
19	Gandajika, Zaire
20	Yangambi, Zaire
21	Keyberg, Zaire
22	Mt. Makulu, Zambia
23	Mulungu, Zaire
24	Nioka, Zaire
25	Henderson, Rhodesia
26	Marandellas, Rhodesia
27	Entebbe, Uganda
28-29	Ukuriguru, Tanzania
30	Serere, Uganda
31	Kitale, Kenya
32	Kongwa, Tanzania
33	Machakos, Kenya
34	Lyamungu, Tanzania
35	Tanga, Tanzania
36	Ahmedabad, India
37	Jodhpur, India
38	Pali, India
39	Maha, Ceylon
40	Ranchi, India
41	Vientiane, Laos
42	Kluang, Malaysia
43	Katherine, Australia
44	Kairi, Australia
45	South Johnstone, Australia
46	Ingham, Australia
47	Charters Towers, Australia
48	"Lansdown", Australia
49	Biloela, Australia
50	"Brian Pastures", Australia

TABLE 1

Grass species used in classification.

Andropogon gayanus	*Eragrostis curvula*
Andropogon tectorum	*Eragrostis superba*
Brachiaria brizantha	*Hyparrhenia rufa*
Brachiaria decumbens	*Lasiurus sindicus*
Brachiaria dictyoneura	*Melinis minutiflora*
Brachiaria mutica	*Panicum antidotale*
Brachiaria ruziziensis	*Panicum coloratum*
Cenchrus ciliaris	*Panicum maximum*
Cenchrus setigerus	*Panicum maximum* var. trichoglume
Chloris gayana	*Paspalum dilatatum*
Cynodon dactylon	*Paspalum notatum*
Cynodon plectostachyus	*Paspalum plicatulum*
Dichanthium annulatam	*Paspalum rojasii*
Dichanthium aristatum	*Paspalum virgatum*
Digitaria decumbens	*Pennisetum clandestinum*
Digitaria milanjiana	*Pennisetum purpureum*
Digitaria umfolozi	*Setaria sphacelata*
Echinochloa polystachya	*Urochloa mosambicensis*

TABLE 2

Legume species used in classification.

Alysicarpus glumaceus	*Lotus corniculatus*
Calopogonium muconoides	*Medicago sativa*
Centrosema pubescens	*Melilotus alba*
Clitoria ternatea	*Macroptilium atropurpureum*
Desmodium intortum	*Macroptilium lathyroides*
Desmodium unicatum	*Pueraria phaseoloides*
Dolichos formosus	*Stylosanthes guyanensis*
Glycine wightii	*Stylosanthes humilis*
Leucaena leucocephala	*Trifolium pratense*
Lotononis bainesii	*Trifolium semipilosum*

rainfall. Likewise with soil information, some sites were characterized by soil type, texture, structure, pH, drainage, etc., but the only common parameter over all was soil texture. Attributes finally selected were latitude, altitude, mean annual rainfall and soil texture. The length of humid season, length of dry season, and a temperature factor were calculated using the method of Papadakis (1966).

NUMERICAL METHODS

The complete attribute-set consists of 6 continuous variables (climate); one 9-state nominal attribute (soil)—these 7 attributes constitute the environmental set; and 56 binary attributes (presence or absence of plant species), constituting the floristic set. It was desired to process the environmental and floristic sets both separately and together; but different types of attribute call for different computational algorithms. The methods used were as follows:

Environmental set. The attributes were subjected to the Euclidean standardization of Burr (1968); this is equivalent, though the computational route is different, to standardizing each attribute to unit sample variance. Classification was effected by the same author's "incremental sum of squares" fusion strategy (Burr 1970), available as an option in the Canberra program MULTCLAS.

Floristic set. This was processed by information analysis (Williams, Lambert and Lance 1966); both normal and inverse classifications were undertaken and the results consolidated into a two-way table (Canberra program CENTCLAS).

Mixed environmental and floristic set. Preliminary examination of the floristic-only results indicated that the system was dominated by double-zero matches; in fact, of the 2800 entries in the floristic set, only 261 were non-zero. For the mixed set it was therefore decided to suppress double-zero matches for the floristics. An *ad hoc* FORTRAN program was therefore written. For the continuous variables the Canberra metric was used; for a single attribute this takes the general form $| x_1 - x_2 | / (x_1 \ x_2)$. The binary counterpart is the one-complement of the Jaccard measure; in the usual (a, b, c, d) notation of a 2×2 table this takes the form $(b + c)/(a + b + c)$, and ignores double-zero matches. A comparison for the nominal attribute scores 1 if two individuals are in different states, 0 if they are in the same state. The contributes of all 63 attributes were added, and divided by the number of permitted comparisons (i.e. double-zeros and missing values excluded). The resulting inter-site matrix of distance measures was classified by the "flexible" sorting strategy, with the cluster-intensity coefficient, β, set at the now usual value of $\beta = -0.25$ (Canberra program CLASS). Group means at each hierarchical fusion were examined by the diagnostic program GROUPER (Lance, Milne and Williams 1968); in presenting the results the convention will be adopted of reading the dendrogram downwards from the complete population. All computations were carried out on the Control Data 3600 computer in Canberra.

RESULTS

Environmental and floristic only

In order to examine the attribute structure of the site x species classification it was desirable that the environmental data only should first be analysed, so that the resulting classification could be compared with the mixed set and any outstanding differences highlighted. The MULTCLAS classification of the environmental data was arbitrarily truncated at the ten group level, and the first two divisions of the resultant dendrogram were regarded as jointly constituting a trichotomy. The first group defined those sites characterized by a short humid season, a long dry season and low altitude, while the second group consisted of sites with a long humid season, short dry season and low altitude. The third group consisted of sites characterized by a long humid season, short dry season and high altitude. By using solely the environmental attributes the classification in fact went little further than defining and quantifying the three major groups, and further group division in fact only generated ideas on the possible attribute contributions to the classification, and the means had to be tested against the pasture species found at the sites.

Similarly with a floristic-only analysis the domination by double-zero matches gave rise to combinations that were obviously incompatible. Only the first division of the dichotomy which separated those species obviously adapted to a long dry season from those adapted to a short dry season, appeared valid.

Mixed

The mixed classification of environmental and floristic data was arbitrarily truncated at the seven group level (see Figure 2). It is of particular interest to ascertain the extent to which the attributes have contributed to the classification; however it is impracticable to reproduce the results for all fusions, but those at the top of the hierarchy deserve attention.

The first dichotomy places major emphasis on the grass species *Cenchrus ciliaris* (A) and *Panicum maximum* (B). This division is strengthened when the major environmental attributes are considered, as the mean length of the dry season for A and B are 8.1 months and 2.6 months respectively, whilst the mean lengths of the humid season are 1.4 and 6.4 months. Whilst the two preceeding grasses may be considered the primary species for separation, it should be noted that *Cenchrus setigerus* is found only in A and *Stylosanthes guyanensis* and *Centrosema pubescens* only in B.

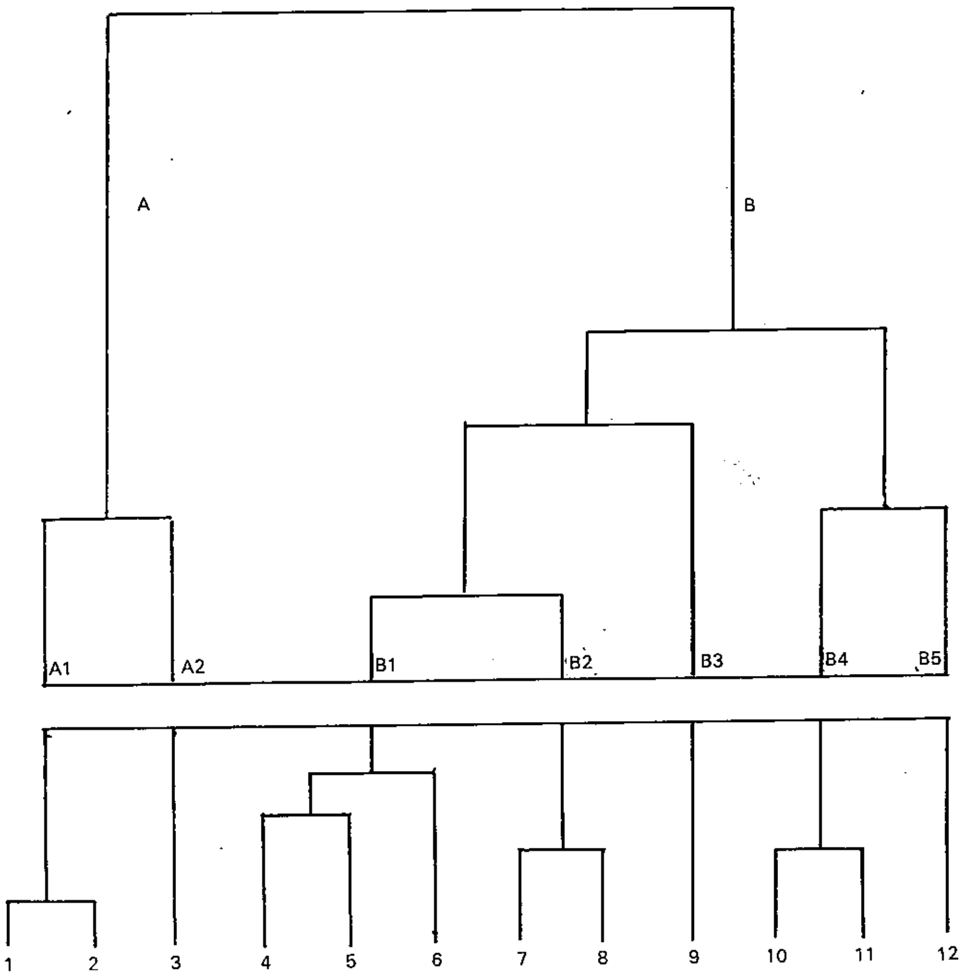

Fig. 2 CLASS hierarchy at 7 and 12 group levels

We may usefully term group A1 *tropical semi-arid*, distinguished by having *Cenchrus setigerus* growing at all sites. *Urochloa mosoambicensis* and *Stylosanthes. humilis* occur at the three Australian sites, but are absent from the Indian sites. These species have been used both experimentally and commercially in Australia for some time but have only very recently been introduced into India. Recent work at Jodhpur has validated this group by pointing out the initial value of *U. mosambicensis* as a sown species in that environment. Group A2 may be termed *sub-tropical seasonal rainfall* as the two dominant pasture species are *Medicago sativa* and *Panicum maximum* var. trichoglume. The mean latitude is 24.5° and *C. setigerus*, *U. mosambicensis* and *S. humilis* are absent.

Characterizing group B1, and designated *tropical extended rainfall*, is *Digitaria decumbens* which occurs at 72% of the sites. Although *S. guyanensis* and *C. pubescens* occur (36% and 25% respectively) they cannot be considered as the major legumes. In group B2, designated as *tropical seasonal rainfall*, *S. guyanensis* occurs at 80% of the sites and *C. pubescens* and *Melinis minutiflora* at 60% of the sites. The mean latitude is 16° and the dry season has a mean length of 3.8 months.

Pennisetum purpureum is the primary species delineating group B3 termed *equatorial extended rainfall* and it is accompanied by a very small number of other grasses. The absence of major sown species such as *M. minutiflora* and *Hyparrhenia rufa* is noteworthy.

Groups B4/B5 are representative of the high altitude tropics designated as *wet tropical highland* and *dry tropical highland* respectively. In B4 *Setaria sphacelata* is the only species common to all sites and the mean length of the dry season for the group is one month. *Desmodium uncinatum* is the only legume to occur at 80% of sites. Unlike B4, group B5 has a mean dry season length of 5.2 months and *S. sphacelata* is absent. *Chloris gayana* is the dominant grass species with *Glycine wightii* occurring at 50% of sites.

Further examination of the hierarchy at the 12 group level resulted in only minor clarification and revealed that whilst some groups could possibly be substantiated to a major group level others were non-conformist. Thus group 7 may be considered as a very uniform unit in that all sites are environmentally similar with a mean annual rainfall of 1250 mm and a dry of 4.3 months. The group falls naturally into the sudanese savanna of previous geographical classifications and is characterized by the widespread use of *Andropogon gayanus* and *S. guyanensis*. *A. gayanus* has been successfully introduced into India at a site which falls within this group. A closely related group is group 8 which has a shorter dry season and *A. gayanus* is replaced by *H. rufa*. *Brachiaria brizantha* is found at all sites within this group and the associated legume in *Calopogonium muconoides*. This may well be an indication of lower soil fertility levels to be found associated with this group as both these species, like *H. rufa*, have the ability to grow well in poor soils and are unlikely to suffer from competition from higher fertility demanding species. (Buller 1960).

Sites in group 9 are linked primarily by the occurrence of *Pennisetum purpureum*. Environmentally this group corresponds with the wet equatorial zone having a long wet season and a short dry season. It seems likely that this group may in fact mask certain socio-economic factors that are not used in the classification. *P. purpureum* is propagated by stem cuttings and requiring a high level of soil fertility would be more suited to intensive soilage production, and a high labour requirement. This speculation is strengthened by the absence of extensive grazing species such as *H. rufa*, *M. minutiflora* and *P. maximum*.

On the negative side, group 5 is open to question as it is constituted by the occurrence of only one species, *Brachiaria decumbens*, and the environmental data suggests that it should be reallocated to group 4. Likewise group 6 may be termed a non-conformist group as it includes sites which are markedly different from each other and those in other groups. This non-conformity is reflected in the floristic component of these sites which have species occurring that are not evident elsewhere.

DISCUSSION

An inherent difficulty in regional classification is the lack of uniform attributes which enable valid comparisons between them to be made. Also it is not possible to synthesise the general from the specific and a *de novo* approach is required. The classifications outlined above are all somewhat subjective and intuitive and none have used modern numerical methods in the isolation of their respective units.

The purpose of this study has been to introduce a technique for the delineation of sown tropical pasture regions, using existing published data as far as possible. Even with only 50 sites, and despite the very limited comparative information available for each, a clear-cut classification into seven major pastoral types has resulted. Moreover, this classification agrees well with the several subjective and intuitive classifications already in existence, while making provision for types which one or other of the previous classifications do not cover. The seven major groups may be designated as *tropical semi-arid, sub-tropical seasonal rainfall, tropical seasonal rainfall, tropical extended rainfall, equatorial extended rainfall, wet tropical highland* and *dry tropical highland*. The groups are summarized in Table 3.

TABLE 3

Characteristics of species composition and environmental descriptions of the groups

Group	Site	Species	Environmental Means	
A1	Jodhpur Pali Lansdown Katherine Charters Towers Bambey Barquisimeto Ahmedabad	*Cenchrus ciliaris* *Cenchrus setigerus* *Lasiurus sindicus* *Urochloa mosambicensis* *Panicum antidotale* *Stylosanthes humilis* *Clitoria ternatea*	Length of humid season Length of dry season Altitude Mean annual rainfall	1.25 months 8.6 months 192 metres 627 mm
A2	Biloela Brian Pastures	*Medicago sativa* *Panicum maximum* var. trichloglume *Chloris gayana*	Length of humid season Length of dry season Altitude Mean annual rainfall	2 months 6 months 150 metres 711 mm
B1	Matao South Johnstone Ingham Sete Lagoas Dschang Palmira Popayan El Capulin Marrandellas Corrientes Cotaxtla	*Digitaria decumbens* *Stylosanthes guyanensis* *Centrosema pubescens* *Melinis minutiflora*	Length of humid season Length of dry season Altitude Mean annual rainfall	6.4 months 1.9 months 655 metres 1596 mm
B2	Shika Ibadan Ranche Bouake Vientiane Dolisie Serere Bouar Sardi	*Andropogon gayanus* *Stylosanthes guyanensis* *Centrosema pubescens* *Leucaena leucocephala* *Brachiaria brizantha*	Length of humid season Length of dry season Altitude Mean annual rainfall	5.8 months 3.8 months 616 metres 1350 mm
B3	Yangambi Gandajika M'vuazi Tanga Buenaventura Maha Kluang	*Pennisetum purpureum* *Panicum maximum*	Length of humid season Length of dry season Altitude Mean annual rainfall	8.4 months 1.1 month 271 metres 2212 mm
B4	Entebbe Kairi Kitale Lyamungu Nioka Mulungu	*Setaria sphacelata* *Desmodium uncinatum* *Desmodium intortum* *Glycine wightii*	Length of humid season Length of dry season Altitude Mean annual rainfall	7.1 months 1 month 1441 metres 1387 mm
B5	Kongwa Henderson Machakos Keyberg Ukiriguru Mt. Makulu	*Panicum maximum* *Cenchrus ciliaris* *Digitaria milanjiana* *Chloris gayana* *Glycine wightii*	Length of humid season Length of dry season Altitude Mean annual rainfall	4.4 months 5.2 months 1240 metres 854 mm

The method adopted is a new one in pastoral classification, and it appears that further study is warranted in order to refine both the technique and the quality of the resultant classifications. It would be preferable that the study should be first undertaken within a given geographical unit which encompasses a range of climatic × soil × species combinations and where the classifications can be checked by field examination.

The number of attributes could then be expanded to include; a more detailed record of temperatures, details of rainfall on a monthly basis, soil data including pH and chemical analyses, and socio-economic factors related to the use of a particular pasture. Nevertheless, where environmental information is insufficient or too general, and where the selected environmental factors have not been correlated with the pastures, the pattern of pastoral species remains of potential value as a indicator of environmental differences. Provided that available information about the environment is not neglected, a study of species combinations offers a rapid means of classifying pastoral landscapes into units of similar habitat types.

With a further assemblage of detailed environmental data and more substantial floristic data it should be possible to construct a global classification that will aid in understanding sown pasture distribution and the profitable exchange of potential pasture species.

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