

Distribution of *Acacia senegal* (L.) Willd. (Fabaceae) in Uganda and its relationship to climatic factors

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Abstract

The aim of the study was to map the distribution of *Acacia senegal* and its infraspecific taxa in Uganda and predict its suitable range of occurrence based on climatic factors. The distribution of the infraspecific taxa was analysed for richness, diversity, turnover and reserve selection. Regression analysis was performed to understand the relationship between distribution of the species and climatic variables. Georeferenced species occurrence points were superimposed over temperature and vapour maps. Areas with highest taxa richness, diversity and turnover were mapped and found in the Lake Kyoga basin. The species shows preference for the northern region of the study area with dissimilar climatic pattern from the southern region and the superimposition supported findings. Variety *kerensis* exhibited narrower climatic, altitudinal and distribution range preference. Temperature seasonality, maximum temperature of warmest month, temperature annual range, mean temperatures of warmest and driest quarters had the highest coefficients of determination ($r^2 > 0.7$) hence most important in influencing species distribution. The most appropriate locations for *in situ* conservation and for germplasm collection to ensure maximum diversity is secured are found in Wabisi-Wajala, Kiula, Kyalubanga, Bajo, Kasagala, Kabwika-mujwalanganda, Maruzi, Moroto and Napak Central Forest Reserves. The study recommends ecological studies to understand status of *A. senegal*.

Key words: *Acacia*, diversity, *in situ*, occurrence, richness, Uganda

Résumé

Le but de cette étude était de cartographier la distribution d'*Acacia senegal* et de ses taxons infrasécifiques en

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Ouganda et de prédire quel habitat est le plus approprié en fonction des facteurs climatiques. La distribution des taxons infrasécifiques fut analysée pour la richesse, la diversité, le turn-over et la sélection de réserve. Une analyse de régression fut réalisée pour comprendre la relation entre la distribution de l'espèce et des variables climatiques. Des points géoréférencés d'occurrence de l'espèce furent superposés sur des cartes de température et de vapeur. On a cartographié les endroits où la richesse des taxons, leur diversité et leur turn-over sont les plus élevés et ils se trouvent dans le Bassin du Lac Kyoga. L'espèce marque une préférence pour la partie nord de la zone d'étude qui présente un schéma climatique différent de la région sud, et la superposition confirme ces résultats. La variété *kerensis* présente une préférence climatique, altitudinale et de distribution plus étroite. La saisonnalité des températures, la température maximale du mois le plus chaud, la variation annuelle de la température, la température moyenne des trimestres les plus chauds et les plus secs avaient les coefficients de détermination les plus élevés ($r^2 > 0,7$), ceux qui étaient donc les plus importants pour leur influence sur la distribution de l'espèce. Les sites les plus appropriés pour la conservation *in situ* et pour la collecte de germoplasme, pour s'assurer qu'un maximum de diversité est sécurisé, se trouvent dans les réserves forestières de Wabisi-Wajala, Kiula, Kyalubanga, Bajo, Kasagala, Kabwika-Mujwalanganda, Maruzi, Moroto et Napak. L'étude recommande de faire des recherches écologiques afin de bien comprendre le statut d'*A. senegal*.

Introduction

The ever increasing world population is exerting tremendous pressure on the natural ecosystems leading to either depletion of the biological resources therein or even total loss of an entire ecosystem. This is leading to loss of many

important species whose potential has been little tapped. Coupled with the emerging climate change effects, it is more compelling than ever before that more knowledge is generated on the little known and the underutilized but in many respects socioeconomically and ecologically important species. One such species is *Acacia senegal* (L.) Willd. whose superior gum dominates the international trade (Fagg & Allison, 2004). The species is known to have a wide distribution in tropical and subtropical Africa (Ross, 1981; Brenan, 1983). Four varieties have been described within this species but with significant contradictions on the delimitation (Brenan, 1959, 1983; Hassan & Styles, 1990; Mulumba & Kakudidi, 2009). A number of the few herbarium specimens collected from Uganda, for example, and held in different herbaria (Fagg & Allison, 2004) have not been assigned to their respective infraspecific taxa because of taxonomic difficulties brought about by the wide variability in the species (Brenan, 1983). The varieties described include var. *senegal* Brenan, var. *kerensis* Schweinf. var. *rostrata* Brenan and var. *leiorhachis* Brenan. The variety *senegal* is known to occupy a belt stretching from west Africa to eastern Africa, whereas var. *kerensis* is more limited to eastern Africa (Brenan, 1983). The varieties *leiorhachis* and *rostrata* occur in eastern Africa and southern Africa (Brenan, 1983; Fagg & Allison, 2004). However, the distribution of the species together with its diversity at infraspecific level and the relationship between diversity-distribution and climatic factors in Uganda have not been studied before. Recent studies using numerical taxonomic principles (Mulumba & Kakudidi, 2009) identified and improved the delimitation of three taxa within the species across its range in Uganda, namely var. *senegal*, var. *leiorhachis* and var. *kerensis*. Based on this recent delimitation, this study was intended to:

- 1 map the diversity distribution of *A. senegal* in Uganda;
- 2 use climatic variables to predict the range of occurrence and suitability for the different *A. senegal* infraspecific taxa in Uganda;
- 3 identify hotspots for *in situ* conservation of the diversity as well as areas with complementary levels of diversity for future-targeted collection of germplasm and ecological studies.

Material and methods

Sampling

Preliminary desk and field surveys were undertaken during the period January–June 2007 to establish the extent of

occurrence of the species across the country. A total of 19 study sites were identified representing the variable climatic conditions as exemplified by the different vegetation and ecosystem types (Langdale-Brown, Osmaston & Wilson, 1964) as well as the latitudinal and longitudinal extent of the species occurrence in Uganda. At each site, sampling was done along a linear transect of 5 km and 10–15 individuals were sampled from each site. A total of 218 individuals were sampled, and geographical coordinates were taken for each individual. The individuals were assigned to their respective infraspecific taxa using the field guide (Mulumba & Kakudidi, 2009) and further field observations. Six groups emerged: three as variants of var. *senegal*, two of var. *leiorhachis* and var. *kerensis* as a single recognizable group.

Data analysis

Data were analysed using DIVA-GIS version 5.2 software (Hijmans *et al.*, 2005).

The 'extent' was defined as X-axis = 29.10° to 35.10° and Y-axis = -1.48° to 4.52° to cover the whole of Uganda, and 'resolution' of the grid was defined as 0.2 resulting into 30 rows by 30 columns in the grid.

Based on the six infraspecific groups of *A. senegal*, the analysis included richness, turnover, diversity, reserve selection and prediction of occurrence. Richness was estimated using the incidence-based Chao 2 estimator (Chao, 1987). Turnover, a measure of the rate at which the taxa assemblages change in space, hence indicating how different a number of nearby areas are (Hijmans *et al.*, 2005), was calculated for each grid cell using Whittaker's measure of beta diversity; $\beta_w = (S/\alpha) - 1$, where S was equal to total number of taxa and α as the average number of taxa in the grid cells considered. Diversity was estimated using the Brillouin and the Shannon indices (Magurran, 1988). Reserve selection, a procedure that identifies the least number of cells that capture the entire diversity was undertaken based on algorithm described by Rebelo (1994).

Prediction of distribution pattern for the different taxa and their likely range of occurrence or climatic suitability in Uganda was modelled based on 19 climatic variables using Bioclim (Hijmans *et al.*, 2005). Using SPSS version 11.0, the distribution of the species based on presence/absence was regressed over the 19 climatic variables based on 32 locations. Sixteen of the locations had a recorded presence of *A. senegal*, and the other 16 were surveyed but the species could not be located. This was (i) to verify whether there was any correlation between

the climatic variables and the distribution of the species and (ii) to identify the most important climatic variables in influencing distribution of the species. The geo-referenced species occurrence points were further superimposed on to existing vapour pressure and maximum temperature maps from Atlas of Uganda (UGANDA Dept. of lands and Surveys, 1962) to further ascertain species occurrences and climatic variables relationship.

Results

Richness, diversity and turnover

Figure 1 shows the areas with the highest richness to be concentrated in the central region of the country around the Lake Kyoga basin. The areas include the districts of Apac (Maruzi County), Nakasongola (northern part of Buruli County) and Masindi (extreme south east of Kibanda and north east of Buruli Counties) with up to five taxa followed by Luwero and Kamuli districts with up to four taxa. Apac, Nakasongola and Masindi districts possess the highest diversity followed by Kaabong in north-eastern Uganda (Figure not shown). The districts of Masindi (Buruli and Kibanda Counties, Kayunga (Bbaale County) and Kamuli (Budiope County) had the highest turnover. Two areas that are complementary in capturing maximum diversity of the species in Uganda have been identified and one, with most diversity, is located in parts of Masindi (Kibanda County), Apac (Maruzi County) and Nakasongola districts (32.01°–32.50°E and 1.51°–1.97°N), while the second is in Karamoja area covering parts of Moroto and Kotido districts (34.01°–34.49°E and 2.49°–2.97°N).

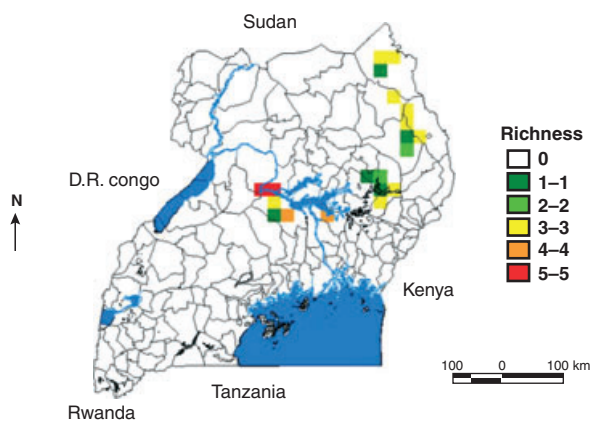


Fig 1 Simple richness of *Acacia senegal* in Uganda

Climatic variables and species occurrence

Acacia senegal occupies a belt falling within an annual temperature range of 15.7–32.9°C and a wide annual rainfall regime ranging from 674 to 1265 mm (Table 1). The driest month of the year across the belt is January with a moisture regime as low as 8–33 mm, and it is the hottest month (29.3–32.9°C) after February in most locations. The driest quarter of the year is December–February with a moisture regime of 45–131 mm of rainfall. The coldest month of the year is August but with temperatures above frost levels (>14°C). Regression analysis showed that all the eleven temperature-based variables (see Table 2) had high correlation coefficients ($r > 0.6$) and subsequently high coefficients of determination ($r^2 > 0.4$) and therefore important in influencing the occurrence of *A. senegal* in Uganda. The most significant though were temperature seasonality ($r^2 = 0.778$), maximum temperature of warmest month ($r^2 = 0.800$), temperature annual range ($r^2 = 0.760$), mean temperature of the warmest quarter ($r^2 = 0.741$) and mean temperature of the driest quarter ($r^2 = 0.740$), hence most important in influencing the species distribution in the country. Of the eight precipitation-based variables, precipitation of the wettest month, wettest quarter as well as overall annual precipitation had low correlation coefficients ($r \leq 0.4$) and subsequently very low coefficients of determination ($r^2 \leq 0.2$). On the other hand, precipitation of the driest month, driest quarter and warmest quarter had high coefficients of determination ($r^2 > 0.4$). These findings were further supported by the apparent difference in the vapour pressure and maximum temperature regime (Figs 2 and 3) between the southern part of the country where the species was not located and the central and north-eastern part where the species is abundant. The two maps reveal the

Table 1 Values of selected climatic variables across the *Acacia senegal* belt in Uganda

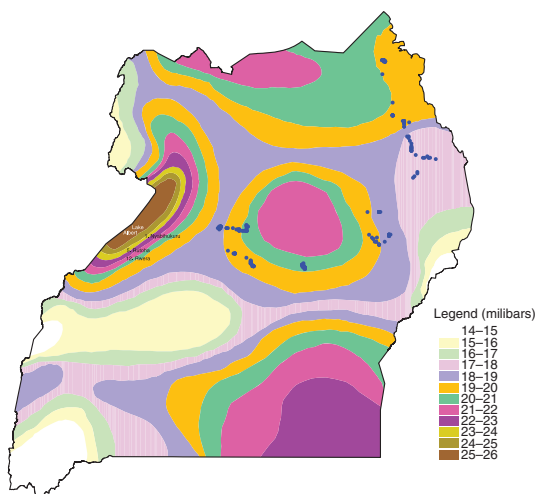
Variable	Lowest	Highest
Precipitation of driest month (mm)	8	33
Precipitation of driest quarter (mm)	45	131
Annual precipitation (mm)	674	1265
Minimum temperature of driest month (°C)	16.0	17.6
Maximum temperature of driest month (°C)	29.3	32.9
Minimum temperature of coldest month (°C)	14.8	16.9
Maximum temperature of coldest month (°C)	24.9	28.4
Annual temperature (°C)	15.7	32.9

Table 2 Climatic variables used in the *Acacia senegal* study in Uganda

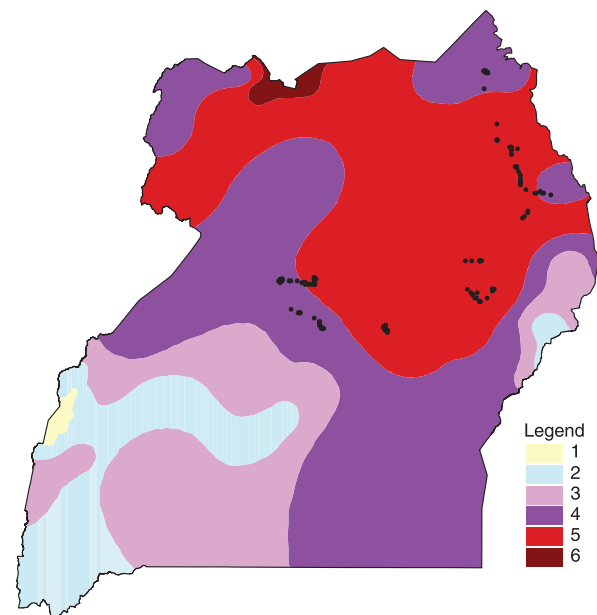
Variable
Annual mean temperature
Mean monthly temperature range
Isothermality
Temperature seasonality ^a
Maximum temperature of warmest month ^a
Minimum temperature of coldest month
Temperature annual range ^a
Mean temperature of wettest quarter
Mean temperature of driest quarter ^a
Mean temperature of warmest quarter ^a
Mean temperature coldest quarter
Annual precipitation
Precipitation of wettest month
Precipitation of driest month ^a
Precipitation seasonality
Precipitation of wettest quarter
Precipitation of driest quarter ^a
Precipitation warmest quarter ^a
Precipitation coldest quarter

Source: DIVA climatic data – Worldclim_5 m.

^aVariables with high coefficients of determination ($r^2 > 0.7$) and ($r^2 > 0.4$) for temperature-based and precipitation-based, respectively.

**Fig 2** *Acacia senegal* collection points superimposed over vapour pressure regimes of the different parts of Uganda

preferred vapour pressure range to be 17–20 mbar and the preferred maximum temperature range to be 27.5–32°C agreeing with the study findings.

**Fig 3** *Acacia senegal* collection points superimposed over annual maximum temperature regime (°C) of the different parts of Uganda. Legend: 1, 20.0–22.5; 2, 22.5–25; 3, 25–27.5; 4, 27.5–30; 5, 30–32.5; 6, 32.5–35

Prediction of infraspecific distribution

The predicted range for occurrence of the species agrees with previous studies (Mulumba & Kakudidi, 2009; Katende, Birnie & Tengnas, 1995; Obua *et al.*, 2006) that the species mainly occurs in Nakasongola, Luwero and Karamoja area. However, the important areas located in Masindi, Kamuli, Kumi, Bbaale and Hoima are being clearly delimited for the first time.

Acacia senegal var. *kerensis* occurrence is limited within the districts of Kotido and Kaabong. The variety occurs at an elevation of over 1200 m, unlike the other taxa that occur at much lower elevation. The variety also appears to thrive best in conditions of lower minimum and maximum annual temperature (15.7–16.9°C and 27.1–29.0°C, respectively) and a lower and narrower mean annual precipitation range (674–732 mm) compared to the rest of the taxa. The variety *senegal* (variant 1) distribution is limited within the districts of Apac (Maruzi), Kamuli (Budioppe) and Kumi. On the other hand, variant 2 of variety *senegal* (Fig. 4) and var. *leiorhachis* (variant 1) have the widest distribution range although the latter does not occur in Kotido, Kaabong, Kamuli and Kumi. Variety *senegal* (variant 3) prefers Moroto and Kotido but

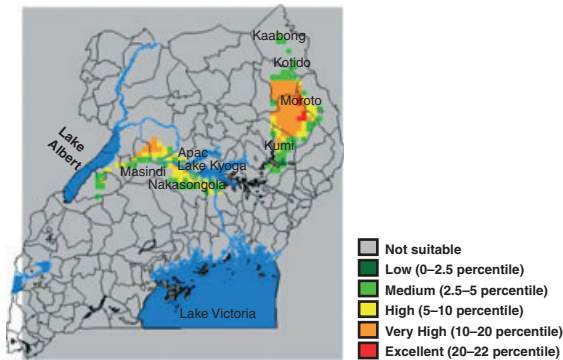


Fig 4 Predicted range of occurrence for *Acacia senegal* variant 2

with patches in Hoima and Masindi. The variety *leiorhachis* (variant 2) has its main range of occurrence in the districts of Nakasongola and Luwero.

Discussion

Because of the wide distribution of *A. senegal* from Africa to the Indian subcontinent, only generalizations have been made before about the climatic conditions across its range (Fagg & Allison, 2004). This study provides the specific climatic variables that prevail where the species is found in Uganda. The study has shown that occurrence of *A. senegal* in Uganda is, to some extent, influenced by each of the eleven temperature-based variables investigated but most important of them being temperature seasonality, maximum temperature of warmest month, temperature annual range, mean temperature of the warmest quarter and mean temperature of the driest quarter. Overall, the species prefers a minimum annual temperature range of 15.7–17.5°C and a maximum annual temperature of 27–32.9°C. On the other hand, although the species was found to occupy a precipitation range of 674–1265 mm, among the precipitation-based variables investigated, precipitation of the driest month, driest quarter and warmest quarter were found to be most important in influencing occurrence. These findings explain the absence of the species in parts of the country (particularly the southern part of the cattle corridor with similar land use systems) where one would have easily assumed its occurrence. The altitudinal range for the species is between 1040 and 1492 masl. Variety *kerensis* occupies almost exclusively the higher elevation locations above 1260 m, hence a lower minimum annual temperature and also a more arid region as found in Turkana and Isiolo regions of Kenya

(Fagg & Allison, 2004). Nevertheless, the minimum temperatures of the belt of >14°C may imply that the species avoids colder areas because of its frost sensitivity (Barnes *et al.*, 1996). Although the highest population density of *A. senegal* is known to occur in north-eastern Uganda (Obua *et al.*, 2006), which is also considered to be part of the Somali-Masai regional centre of endemism (Fagg & Allison, 2004), richness, diversity and turnover are higher in the central regions of the country.

Although some overlaps are observed in the predicted ranges, location preference for the different infraspecific groupings (high percentiles) is observed. Subsequent studies are required to understand the performance of the different taxa in relation to gum production and quality, among other parameters, in their preferred environments as well as when grown in similar ones. This is particularly important to substantiate the available limited information that gum arabica produced from Uganda differs in several respects from, for example, typical commercial Sudan samples (Anderson & Weiping, 1992) and that the quantity and quality may differ significantly by source location and by variety (Chikamai *et al.*, 1996; Fagg & Allison, 2004).

The two complementary areas in capturing maximum diversity, which have been delimited by this study, stand out to be the most important for *in situ* conservation of the species. At the same time, the same areas are the most important for targeted germplasm collection for *ex situ* conservation. Several existing forest reserves are located in these two areas and they include Wabisi-Wajala, Kiula, Kyalubanga, Bajo, Kasagala, Kabwika-mujwalanganda, Maruzi, Moroto and Napak Central Forest Reserves. It is recommended therefore that a status assessment of *A. senegal* and related ecological studies be undertaken in these forest reserves to generate the necessary information for guiding the conservation and sustainable utilization plans for the species. Also, information on the importance of these reserves in relationship to *A. senegal* diversity and distribution needs to be provided to the decision makers and managers of these entities. However, bearing in mind the pressure on these forest reserves (Ministry of Water, Lands and Environment, 2001; The National Environment Management Authority, 2004/2005; National Forestry Authority, 2008; Obua, Agea & Ogwal, 2010) leading to degradation coupled with the unfolding climate change challenges, complementing this *in situ* conservation with collecting the diversity and securing it in arboreta as well as seed genebanks is recommended.

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