Determining the climatic suitability of *Khaya senegalensis* for plantations in Australia

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Abstract

An existing profile of the climatic requirements for *Khaya senegalensis* plantations was compared to the climatic conditions of 20 successful *K. senegalensis* trial and plantation sites in north Queensland, 21 in the Northern Territory and 4 in Sri Lanka. The climatic profile for the species was revised if there were more two or more successful trial/plantation environments with climatic values outside the limits of the existing profile. The revised climatic profile was used with the Ausgrd climatic program to show areas climatically suited for plantations of the *K. senegalensis* in Australia.

Key words: *Khaya senegalensis*, climatic interpolation, species-site matching

Introduction

Khaya senegalensis (Desr.) A. Juss. (dry zone mahogany or African mahogany) has shown good potential for commercial timber production in farm forestry plantations in the seasonally dry tropics of northern Australia (Sun and Dickinson 1997, Bristow 2004). In the Northern Territory it was first planted around Darwin as a street tree in the late 1950s (Robertson 2002). In Queensland, it has been planted for mine-site rehabilitation purposes at Weipa since the early 1970's (Nicholson 1985). Since then, it has shown good growth, excellent survival and generally reasonable stem form in numerous plantation trials established in the top-end of the Northern Territory and at Weipa in Queensland, as well as in a number of other plantings in northern Queensland and northern Western Australia (Bristow 2004). In addition, it has generally proven resistant to attack by termites, including the giant termite (*Mastotermes darwiniensis*) (Whitbread *et al.* 2003), and is known to be less susceptible to attack by some species of tip moth/shoot borer (*Hypsipyla* species) than many other *Meliaceae* species (da Silva *et al.* 2004). It also produces a timber suitable for high value end uses, such as quality furniture, that is well regarded in the international timber trade (CAB International 2000).

In its natural habitat *K. senegalensis* is often found individually, dispersed in natural vegetation and secondary forest. It grows mainly in the riverine forests and deciduous savannah woodland, where it is a smaller tree reaching heights of 15 m to 24 m with a diameter of up to about 1 m. However, on more fertile deeper soils it can grow up to more than 35 m high and up to 1½ m in diameter (CAB International 2000).

The natural range of *K. senegalensis* is in Africa between 8° and 15° N in a discontinuous band extending from the Atlantic Ocean eastwards towards the Indian Ocean (CAB International 2000), as shown in Figure 1. Countries that its range extends into in northeast tropical Africa include Chad and Sudan; in east tropical Africa include Uganda; in west-central tropical Africa include the Central African Republic; and, in west tropical Africa include Benin, Cote D'Ivoire, Gambia, Guinea, Guinea-Bissau, Mali, Niger, Nigeria, Senegal, Sierra Leone and Togo (USDA-NRCS 2004). In technical terms its natural phytogeographical distribution includes both the 'Sudanian Regional Centre of Endemism' and the 'Guineo-Congolia/Sudania Regional Transition Zone' (White 1983).

Within its zone of occurrence its distribution is discontinuous (Jøker and Gaméné 2003). Its habitats vary in altitude from 0-1800 m asl with rainfalls varying from about 400 mm to more than 1700 mm per year (World Agroforestry Centre 2004) and with dry seasons lasting from 4 to 8 months (CAB International 2000; Jøker and Gaméné 2003). Although it generally prefers moister sites, it is reputedly one of the most drought-tolerant *Khaya* species (Jøker and Gaméné 2003).

It is recognised that an integrated approach to research on *K. senegalensis* as an exotic plantation species would facilitate development of the forest industry in the top end of the Northern Territory along with some other areas of northern Australia (Bristow 2004). An essential component of such research involves defining the climatic requirements of the species for successful plantations and identifying areas that meet these requirements.

A profile of the climatic requirements for plantations of *K. senegalensis* has been provided by Booth and Jovanovic (2000) and CAB International (2000). It is based on climatic information from both the species' natural range and a report on successful plantings of the species in China. The objective of this current study is to examine climatic parameters from sites of successful trials and plantings of the species in Australia (Northern Territory and Queensland) and Sri Lanka, with a view to improving on the published profile of the species' climatic requirements. With the revised profile, climate interpolation relationships will be used to identify locations exhibiting similar climatic conditions across northern Australia that might be potentially suitable for the establishment of successful *K. senegalensis* plantations.

Methodology

Existing climatic description

A description of the climatic conditions of *K. senegalensis*'s natural range was given by CAB International (1998) as: annual precipitation of 650-1300 mm in summer; a dry season lasting for 4-8 months; and, an annual mean temperature of about 24°C. Based on that information, an early profile of the climatic requirements for plantations of *K. senegalensis* was provided by CAB International (1998). However, that profile excluded many climatic environments known to be well suited for the species (Booth and Jovanovic 2000). A revised climatic profile was subsequently prepared by Booth and Jovanovic (2000), based on both the species' natural range and some successful plantings of the species as an exotic. This profile is given in Table 1.

Booth and Jovanovic's (2000) profile was used with the 'Ausgrd' program to produce a map of the areas in Australia that are climatically suitable for *K. senegalensis*. The Ausgrd Australian climatic mapping program is a Windows-based program, which has data for approximately 400,000 locations representing a regular grid across Australia (Booth and Jovanovic 1991; Booth 1996). Figure 2 shows locations with all six climatic range values within these limits indicated in green (or light grey when printed in black and

white) whilst locations with values outside the limits are indicated in red (or darker grey when printed in black and white).

Analyses of climate at successful trial sites

Estimates of climatic parameters were obtained for 45 successful *K. senegalensis* trial and plantation sites known to the authors of this report. The categorisation of a trial or plantation as being 'successful' was based on subjective judgement. If growth was relatively good (also judged subjectively), or where growth was only fair but was considered likely to have been inhibited by sub-optimal management, then the trial/plantation was deemed to be successful. The sites included 20 in north Queensland, 21 in the Northern Territory and 4 in Sri Lanka (Table 2). The climatic data obtained for each site was based on the nearest meteorological station and/or local records.

The ranges for the six climatic parameters given by Booth and Jovanovic (2000) were then compared to the parameters for the 45 successful trial/plantation sites. Where appropriate, the climatic profile was revised if there were more two or more successful trial/plantation environments with climatic values outside the limits provided by Booth and Jovanovic (2000). The revised profile of the climatic requirements for plantations of *K. senegalensis* was then used with the Ausgrd climatic program to produce a revised map of areas climatically suited for the species in Australia.

Results and Discussion

The trial and plantation sites surveyed covered a wide range of geographical locations and climatic environments (Table 2). The highest elevation site of those surveyed in this study was only 300 m asl, which is relatively low given that natural habitats of this species in Africa extend up to altitudes about 1800 m asl (World Agroforestry Centre 2004). Although there are many sites in Queensland and Sri Lanka at elevations far exceeding 300 m that have climate parameters within the range given by Booth and Jovanovic (2000), no reports could be located of trials or plantations of the species from such environments.

In Queensland, 3 of the sites surveyed had mean annual rainfalls below 700 mm. In contrast, 2 large plantings of about 12 years of age near the town of Kurunegala in Sri Lanka were growing very well where the mean annual rainfall is about 2100 mm. Whilst these latter sites have no dry season (i.e. rainfall every month averages > 40 mm), some of the Queensland and Northern Territory sites have dry seasons of up to seven months. The profile of the climate for successful *K. senegalensis* plantations provided by Booth and Jovanovic (2000) indicates mean annual rainfalls in the range of 700–1750 mm and dry seasons of 2–8 months. Given the excellent growth in Sri Lanka at 2100 mm and that rainfall in some parts of the species' natural habitat exceeds 1700 mm, modification of the rainfall range to 650–2100 mm would be appropriate. As many tree species native to seasonally dry habitats can encounter disease problems in humid lowland environments lacking distinct dry seasons, it was decided to leave the range for the duration of the dry season unchanged until more trial and/or plantation results are available. Results from recently established trials and plantings in wetter climates in Sri Lanka should soon help to determine the species' suitability for year round moist tropical environments.

The mean annual temperatures for all the 45 sites surveyed were approximately within Booth and Jovanovic's (2000) range. However, at several sites the mean minimum temperature of the coldest month was well outside their given range for this parameter of 11–19 ^{o}C: 3 of the Queensland sites had values below this range whilst all 4 Sri Lankan sites had values above this range (Table 2). With respect to the

mean maximum temperatures of the hottest month, many of the Queensland sites were below Booth and Jovanovic's (2000) range. Thus, extending the range of mean temperature of the coldest month to 10–23 ^{o}C, and mean maximum temperature of the hottest month to 29–40 ^{o}C was considered appropriate.

Taking into account the above modifications, a revised climatic profile for successful plantations of *K. senegalensis* can be specified, as shown in Table 3. Using these parameters with the Ausgrd program produced a revised map of climatically suitable areas for the species in Australia as shown in Figure 3. Though the differences between the areas of suitability indicated on two maps (i.e. Figures 2 and 3) are subtle at the scale of the map shown, they nonetheless important. The revised climatic profile expanded the area recognized as potentially suitable to include: additional areas to the north of Broome in Western Australia; areas to the east of Derby in Western Australia; the Cobourg Peninsula and the eastern tip of Melville Island in the Northern Territory; the tip of the Gove Peninsula in the Northern Territory; areas around Cooktown and in its hinterland in Queensland; and, substantial additional coastal areas from around Townsville southwards to around Rockhampton in Queensland. Along the Western Australian coast the new southern limit is just to the north of Broome and along the Queensland coast the southern most limit is at about Gladstone. In the Northern Territory the limit south down the Stuart Highway is about mid-way between Daly Waters and Elliot.

In using the revised climatic profile for site-species matching it is important to recognise its limitations. The climate data obtained for most of the sites surveyed are long-term average data that do not reflect year-to-year variations. Similarly, the map developed (Figure 3) is also based on long-term averages. Problems might be experienced if *K senegalensis* is established during periods of severe drought in areas deemed climatically suitable by long-term averages. Separate to drought, evaporation can also be an important factor in determining climatic suitability; two locations receiving similar mean annual rainfalls may experience different plant water availability because they experience different evaporation rates. Unfortunately though, this factor could not be included in this study as good quality estimates for this parameter were not available for many of the sites surveyed.

Soils and nutrition, silviculture, provenance/seed source variation and landuse issues can also be critical to the success of forest plantations within any given climatic environment. On many sites in north Queensland, irrigation is also often conducted for the first few years to assist early plantation establishment. In this study however, such factors were not included. Even though some soils information is available for many of the sites surveyed, it was decided not to incorporate this due to the complexity of combining climatic and soils data.

Given that natural habitats of *K. senegalensis* cover a wide range of climatic conditions, particularly with respect to rainfall (i.e. mean annual rainfall range of 400 mm to more than 1700 mm), it may be that it has significant provenance variation with respect to climatic adaptability. Unfortunately though, the original provenance origins (i.e. in Africa) of the planting material for most of the sites surveyed in this study are unknown with the exception of the Northern Territory plantings. Indeed, surveys of published literature indicate that very little information has yet been published about provenance and genetic variation for any traits within this species (see CAB International 2000). This important topic seems an imminently worthy subject for future research.

Conclusions

The revised description of the climatic requirements for successful plantations of *K. senegalensis* developed here will assist in selecting sites potentially suitable for the species in Australia and elsewhere. However, climatic conditions are just part of what needs to be considered for matching species to sites –

soils, silviculture, pest and diseases, end product objectives, land use priorities, abiotic risks and other factors also need to be carefully consideration. It is always recommended that species be evaluated in small scale trials/trial plantings in a particular region before large-scale commercial planting programs are initiated.

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Table 1. Climatic parameters for successful plantations of *Khaya senegalensis* provided by Booth and Jovanovic (2000).

Climatic parameter	**Requirements for successful plantations**
Mean annual rainfall	700 – 1750 mm
Rainfall regime	summer; winter
Dry season duration	2 – 8 months
Mean annual temperature	22 – 31 ºC
Mean maximum temperature of hottest month	32 – 40 ºC
Mean minimum temperature of coldest month	11 – 19 ºC
Absolute minimum temperature	> 5 ºC

Table 2. Ranges of geographic locations and climatic parameters for successful *K. senegalensis* trials and plantings surveyed for this study.

Region	No. of sites	**Geographic range** Latitude	longitude	altitude	mean annual rainfall	**Climatic range** length of dry season	mean max. temp. of hottest month	mean min. temp. of coldest month	mean annual temp.
Queensland	20	12°32'S to 20°04'S	130°51'E to 132°40'E	6 to 300 m	660 to 1780 mm	5 to 7 months	28.4 to 34.8 °C	9.9 to 18.8 °C	21.3 to 27.1 °C
Northern Territory	21	11°43'S to 14°36'S	141°51'E to 148°12'E	10 to 220 m	970 to 1780 mm	4 to 7 months	33.8 to 37.7 °C	13.2 to 14.9 °C	26.7 to 27.3 °C
Sri Lanka	4	6°44'N to 8°21'N	80°23'E to 81°06'E	80 to 180 m	1450 to 2100 mm	0 to 5 months	32.0 to 36.0 °C	20.7 to 23.0 °C	27.0 to 28.5 °C

Table 3. Revised climatic parameters for successful plantations of *Khaya senegalensis*.

Climatic parameter	Requirements for successful plantations
Mean annual rainfall	650 – 2100 mm
Rainfall regime	Summer; winter, bimodal
Dry season duration	2 – 8 months
Mean annual temperature	22 – 31 ºC
Mean maximum temperature of hottest month	29 – 40 ºC
Mean minimum temperature of coldest month	10 – 23 ºC
Absolute minimum temperature	> 5 ºC

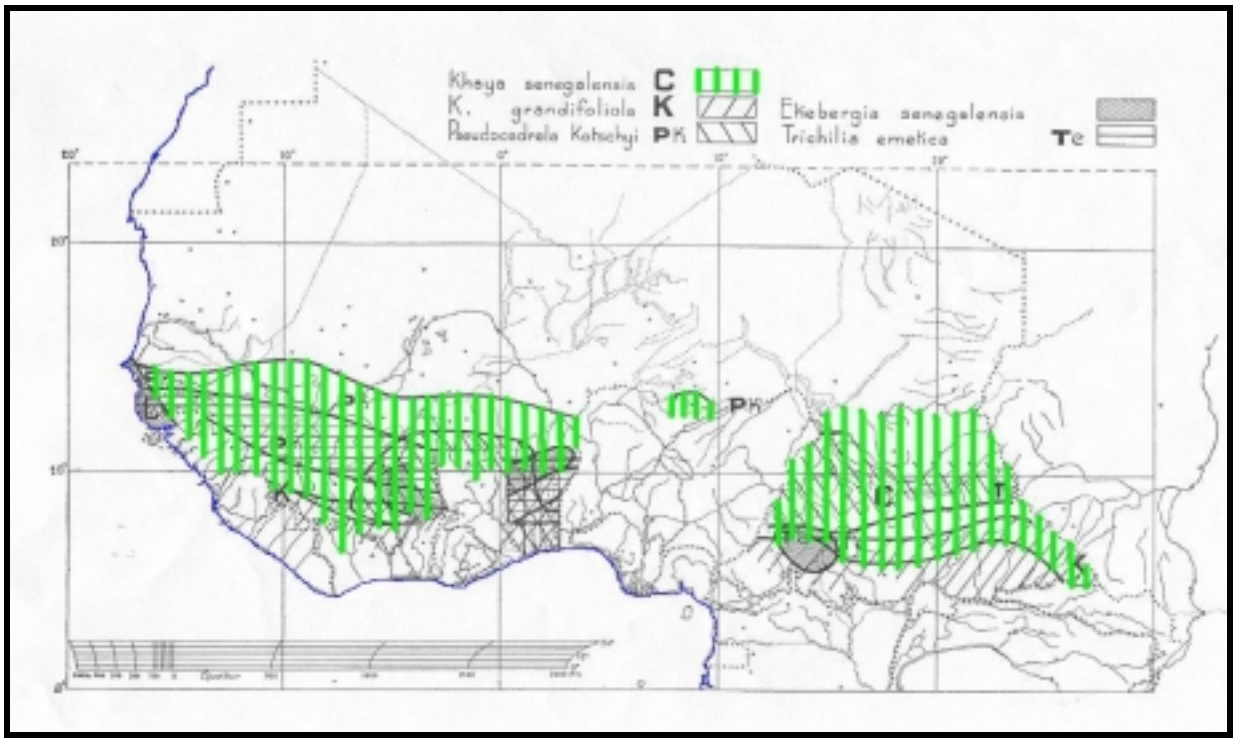


Figure 1. Approximate natural range of *Khaya senegalensis* in Africa (courtesy of Antoine Kalinginaire, ICRAF).

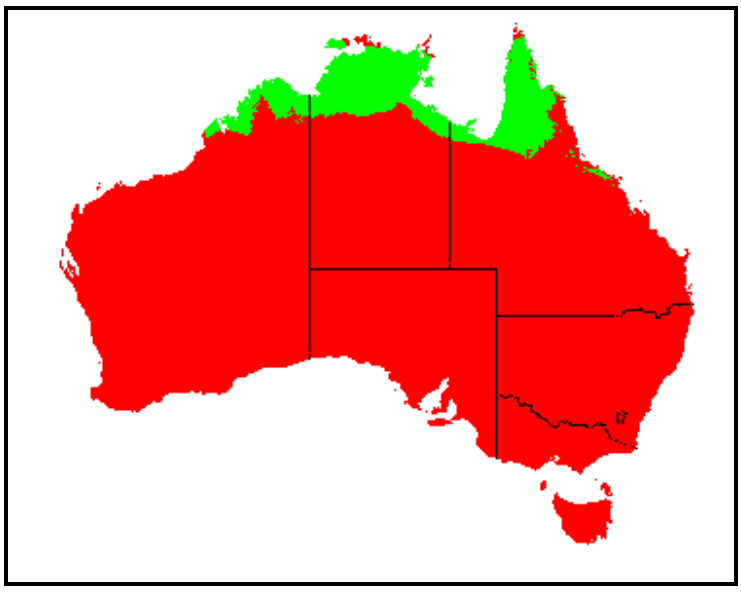
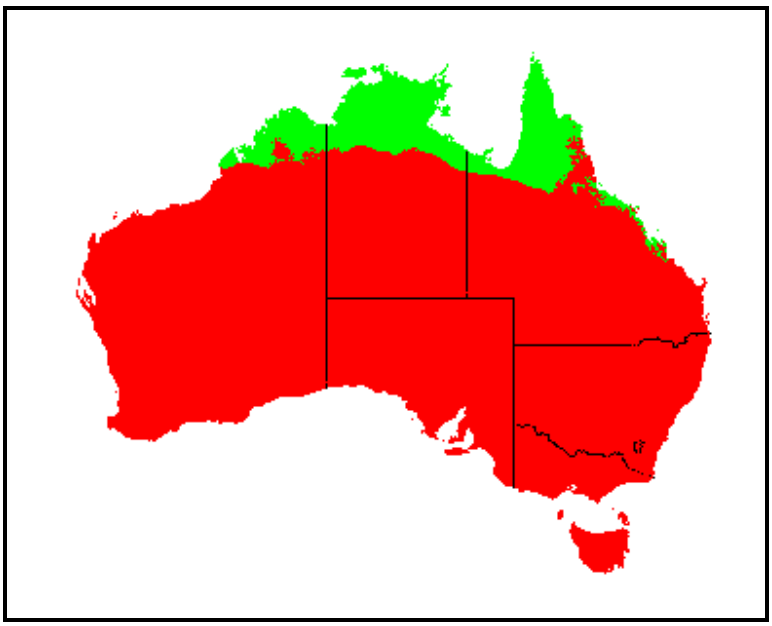


Figure 2. Climatically suitable areas for plantations of *Khaya senegalensis*, shown in green (or shown in light grey when printed in black and white), based on the climatic description developed by Booth and Jovanovic (2000).



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