Re-afforestation and water conservation in drylands

Guideline for Students and Researchers

March 2014

Preface

Tree planting in the drylands posses a big challenge to farmers in arid and semi-arid areas. There is therefore need for better technical information to promote tree planting in water deficient soils. This guideline was compiled based on the results of research activities jointly conducted by Japan International Forestry Promotion and Cooperation Center (JIFPRO) and Kenya Forestry Research Institute (KEFRI). The series of research activities, including literature review as well as field studies, were conducted from the year 2009 to 2014 with the support from the Forestry Agency of Japan.

This guideline demonstrates a better way of re-afforestation in arid and semi-arid areas and the following sections items have been described in a comprehensive manner.

1) The relationship between water and forest (trees)
2) New method for the selection of potential distribution range of trees were introduced, and a result of the trial were described
3) Typical technologies necessary for re-afforestation in arid and semiarid-area
4) Characteristics of 15 drought-tolerant tree species

This publication has been prepared as guideline for students and researchers.

We hope and trust that the guideline will be useful for students and researchers who are involved in research activities on re-afforestation in arid and semi-arid lands.

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Chapter 1. Introduction

In arid and semi-arid area, vegetation is prone to deterioration due to human activities which lead to deforestation, land degradation and desertification that directly and indirectly affects water resources Reforestation and afforestation in such regions will not only contribute to natural environment conservation, but also to improvement of rural community livelihood by production of building materials and fuel wood. Further, in the long term, restoration of forest vegetation can improve soil properties contributing to the local water balance by flood control in rainy season and mitigation of drought in dry season. Thus re-afforestation is a very important and effective environmental measure.

However, at the same time, re-afforestation causes an increase of water consumption due to evapotranspiration from newly established forests. Therefore increase in re-afforestation decreases the water resource in arid and semi-arid area further, resulting in shortage of water for daily life and agricultural production. In addition, the decrease of river flow may affect the ecosystem of river basin, which is likely to damage their biodiversity and adversely affect community livelihoods.

Therefore, there is a great demand to improve re-afforestation technologies that can promote restoration and management of forests and increase the available amount of water while preserving the water environment. However, a high amount of water consumption by afforestation using species such as *Eucalyptus* introduced to increase the local timber production has led to a serious concern that the groundwater level is decreasing. Mesquite species introduced to restore degraded lands has grown in to thick forests and spread even to agricultural lands and water paths other than the target areas due to its strong environmental tolerance and high productivity and this impedes agricultural production in some cases. Thus, planting methods are not the only challenge in the arid and semi arid areas but also forest management after planting. Destruction and degradation of forests, have led to increase in desertification and water shortage, are caused by excessive man-made stresses from longstanding deforestation and land development in huge forest area. Capacity building and cooperation with local communities are essential for restoration and conservation of forests. For this purpose, it is necessary to propose re-afforestation and management methods that benefit the lives of the local residents, to change in attitude of the local residents and to enhance their capabilities.

An experimental field study was conducted on re-afforestation and its management in arid and semi-arid area in Kenya where desertification and water shortage have become increasingly serious, with the collaboration of local community members. The aim was to develop appropriate re-afforestation and management practices taking into account short-term negative effects of forest tree planting on the local water balance.

Based on the keywords "Water Consumption by Trees", this guideline provides overview of issues in re-afforestation in arid and semi-arid areas, outcomes of previous studies on re-afforestation, and it describes re-afforestation and management techniques aiming at sustainable use of water resources.

Section 1. Strategies for Water Sharing

In dry land ecosystem, many plant species can coexist by using the wisdom of sharing water resources under severe water stress in harsh environment. In arid areas , intra- and inter-specific competition for water is acute and intense due to the lack of water. Although the wisdom of sharing water resources for coexistence under water stress must come into play in such environment, the competitive exclusion principle means that two species using the same niche cannot coexist. This is a fundamental principle in ecology (Gause, 1932). Therefore, plants that seem to be able to share water basically use different water resources. There are various types of water resources and a specific strategy is necessary to use each water resource type; it is not possible to use many types of water resources with only one strategy. At the same time, the water environment in arid areas does not allow one species to evolve with many strategies. In scientific terms, wisdom in ecology is a life history strategy. Each plant species can employ species specific strategy to secure a water source but it can use only a part of water resource and, as a result, they can coexist as a member of the arid land ecosystem in a volume appropriate for the amount of available water.

There are three possible strategies for plants to survive water shortage: drought tolerance; use of unique water source; and utilizing water leftover by other plants.

1) Drought tolerance

In cases of water shortage, morphological modification of above ground plant parts and functional adaptation are the most effective way of drought tolerance. The most typical morphological measure to tolerate desiccation is the thick and small leaves with thick cuticle layer to inhibit the transpiration loss. To improve the water-use efficiency, plants adopt control of stomata opening and enhancement of photosynthetic rate as functional adaptation. Decreasing water potential of leaves to absorb limited amount of water faster than other plants do is likely to cause cavitation in xylem (air bubbles formed in vessel become a cavity inhibiting the hydraulic function). Adjustment of the vessel diameter, which affects the water flow efficiency, is one of the effective countermeasures against cavitation in xylem (Tateno, 2003). Further, storage of a good amount of water in plant tissues is an effective measure to cope with the drought stress.

2) Using unique Water Source

The key to secure a unique water resource that is not used by other plants is the capacity of morphological and functional adaptation of root system. Osmoregulation to increase the water absorbing power by decreasing the osmotic potential of epidermal cells of root is employed in almost all plants as an effective way to respond to acute water stress. In addition, plants with both lateral and tap roots can transport soil water via roots across soils of different water contents, which is referred to as “Hydraulic Redistribution” (HR). HR makes possible exclusive use of underground water and/or surface water. Lateral roots in the ground surface may exploit dew condensation water, and some plants are capable of pooling an amount of water larger than the maximum water amount that can be retained in surrounding soils by forming an intense root system like a mat near the ground surface (Mooney *et al.*, 1980). Trapping fog by using aboveground part is also an effective strategy to secure a unique water source.

3) Utilizing water leftover by other plants

There are a limited number of environmental conditions under which plants can share water with other plants or be parasitic on other plants. When deep groundwater is transported to the surface layer, other plants may exploit such hydraulically lifted water faster. When fog is trapped by branches of a tree and then dropped to the ground, other plants on the ground surface may exploit the water first. Although most of these cases of water sharing are limited, utilizing water leftover seem to be fairly common.

Section 2. Strategies to Use Various Water Sources

The origin of water used by plants is rain water. In the process in which rain water flows down the slope, rain water become to various water sources such as river water and underground water. All plants struggle for their water sources by their properties and have strategies as countermeasures.

1) Rain water

The mean annual precipitation over the ground surface of the world is 880mm. This is enough for grassland to grow at above 5°C of the annual mean temperature and conifer forest can be established below 5°C. However, spatial distribution of rainfall is not homogeneous; the world's highest record is over 10000mm/year while some regions have experienced no rainfall for years (Fig. 1) (UNEP, 1997).

In a rich environment with sufficient water and temperature, forest with high biodiversity can be formed. However, when water supply becomes short, competition becomes severe and forest structure starts to deteriorate. Canopy can be closed only when the rainfall over the crown projection area is higher than the evapotranspiration from the crown. The larger the rainfall amount is than the necessary amount, the more vertically complex the canopy becomes. The optimum state of such condition is the tropical rainforest where the tree height exceeds 50 meter and multilayer canopy is formed. In contrast, when the rainfall over the land covered by crowns becomes less than the evapotranspiration, plants have to absorb water from an area broader than the area covered with their own crowns and competition over water among neighbors is started. As a result, crowns grow apart from each other and the forest becomes an open forest (Photo 1) where sunlight can reach the ground surface through the spaces within the canopy. This promotes evaporation further and water shortage is accelerated and the air and soil become dry. Most forests in arid and semi-arid area are under such conditions.

When rain water wets leaves only, plants cannot use it to grow. For water to be used for plant bioactivities, it must infiltrate downward into the soil and then be absorbed by the root system. Only a part of rain water that reaches the ground surface infiltrate into the soil while most of it flows down over the ground surface (surface runoff). The more effectively the forest floor can infiltrate this runoff, the more efficiently the rain water is used. Generally, forests can improve the infiltration capacity of soil by litter fall (organic matters). However, such capacity of soil formation is weak in open forests and therefore the proportion of runoff water out of the rainfall is high, resulting in dry soil. Most plants that grow in arid areas have capacity to extend their roots deep in order to use stable water sources in deeper soil layer (Wei *et al.*, 2011). However, tree planting and forest management must not be designed based on the amount of water in deep soil layer where soil water cannot be recharged by rain but based on the amount of available rain water by using measures to promote infiltration of runoff into the ground, e.g. micro-catchments (De Pauw, 2008).

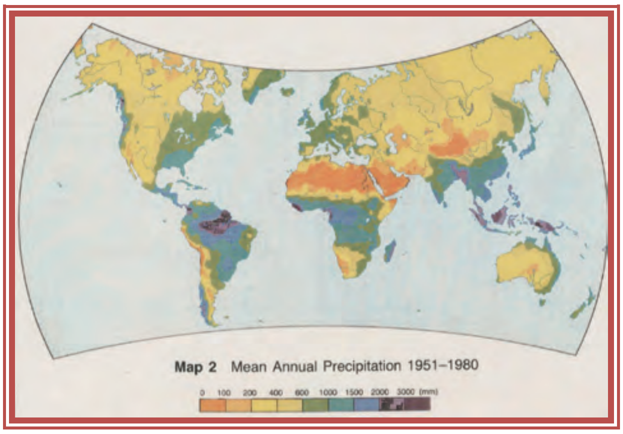


Fig. 1: Mean annual precipitation (UNEP, 1997)

Photo 1: Open forest of Elm trees
Hunshandake Desert (China)

Rainfall is temporally distributed heterogeneously hence it is not the same in every year. In humid areas, vegetation is never damaged severely even if there is less rainfall, so the fluctuation of rainfall is not a serious problem. However, arid area is the marginal area for vegetation, because of high frequency of severe drought that may destroy the vegetation completely (Fig. 2). Annual plants can survive even such severe drought and establish almost the same level of vegetation after drought, because they can start from seeds in every spring and grow according to the rainfall of the year. Central Asia and Sahel Strip suffer from severe drought every few years and harsh environments for perennial arbors and therefore grass plants can dominate. In other words, grassland ecosystem is caused by temporal heterogeneity of rainfall (Fig. 3). However, if perennial arbors are killed by drought, a large amount of plant biomass accumulated for years is lost and the ecosystem is forced to change substantially.

Even in such an environment, perennial trees can survive through drought on sand dune where only sparse vegetation can be supported normally but sufficient amount of water is retained (Photo 2). The level of variation of soil water content during drought determines the vegetation structure. Stabilization of soil water content or prevention of soil from becoming drier than the threshold for tree growth must be taken into account for maintenance of forests in arid and semi-arid areas.

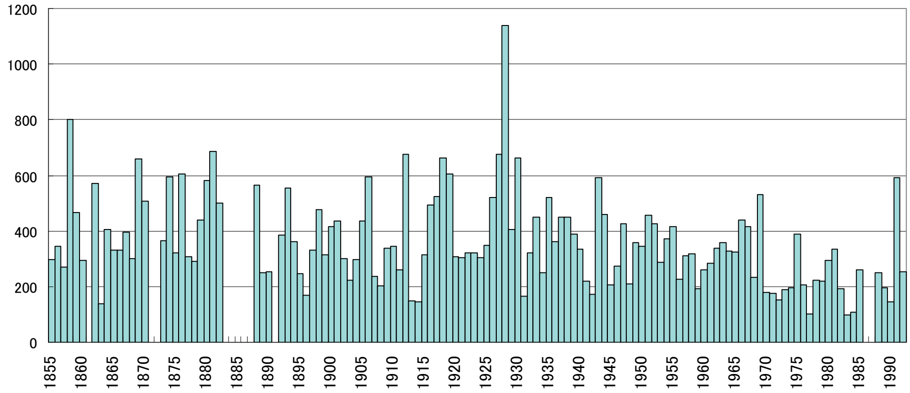


Fig. 2: Annual variability of the precipitation (Saint-Louis, Senegal)

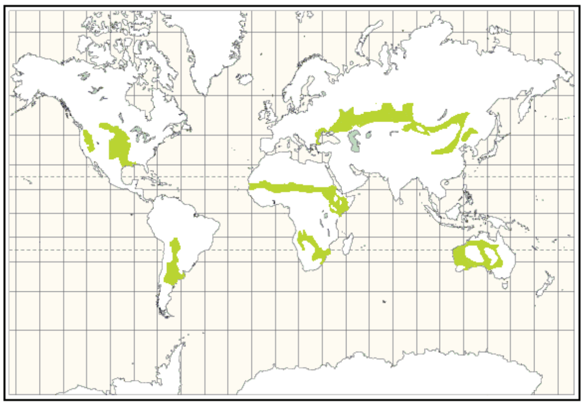


Fig. 3: Distribution of grassland in the world

Photo 2: Shrub forest existing on the top of dune Hustai National Park (Mongolia)

2) River Water

When rain water flows over the ground surface, it becomes a river that can reach to distant places quickly. With such river water, vegetation can be established even in a desert with no rain. In Central Asia, there are many rivers derived not only from rain water but also from glacier-fed water and their amount of flow has increased due to global warming. Accessible river water is a valuable source in arid areas. One of the big forests in arid area is the riparian forest of *Populus euphratica* (Euphrates Poplar) along Tarim River that crosses the Taklamakan Desert. Along the Hoarusib River in Namib Desert with annual rainfall of 50 mm, acacia forests are established and many kinds of wildlife such as elephants, lions and giraffes inhabit this forest. Although river water is a relatively stable water source, not many plants can effectively exploit this water resource. Therefore, most of *P. euphratica* forests are pure forests.

Amount of river flow also varies from year to year and season to season; the Tiva River flowing beside the Tiva Pilot Forest in Kenya has a large amount of flow in the rainy season but almost dries up during the dry season (Photo 3). Although even a riparian forest undergoes a strong water stress, most of them can survive and maintain their forest structure for long time. Generally, plants composing a forest in arid area are hard to die. *P. euphratica* is also a diehard plant (Yoshikawa *et al.*, 2007). During drought, leaves at the tip of tree crowns die (dieback) to reduce the total amount of leaves to the level that can be maintained by the available water (Photo 4). When drought ceases, the trees extend their branches again with more leaves but it can only restore to the original size. So tree height is always within a certain range of height. On the other hand, the stem diameter continues to grow steadily and these trees finally become stocky shape. For example, average height and DBH of *P. euphratica* in Ejina Oasis are 9 m and 40 cm, respectively (Monda *et al.*, 2008). For plantation in arid and semi-arid area, tree species that can steadily survive by flexibility of leaf size (eg. leaf volume) such as *P. euphratica* and *Juniperus* spp. (Juniper) are appropriate rather than species that are good loser to water stress such as *Cryptomeria japonica* (Japanese Cedar) and *Chamaecyparis obtusa* (Japanese Cypress).

Photo 3: State of the Tiva river during the rainy season and the dry season
(Tiva, Kitui Country. Eastern Province, Kenya)

Photo 4: Die-backed *Populus euphratica* (Euphrates Poplar) by drought condition

3) Ground Water

The origin of ground water is rain that has infiltrated and stored in to the soil, or is advecting slowly in the water saturated soil layer (where soil pore spaces are fully filled up with water from the upper reaches). Being free from evaporation, the amount of ground water is considerably stable. However, the longer the time that water remains under the ground, the higher the salinity hence lowering the water quality.

Plants that depend on the ground water are called "Phreatophyte" (Goudie & Wilkinson, 1987). The well-known tree is date palm (*Phoenix dactylifera*) (Photo 5). It maintains large crown on a sterile dry land and stands gallantly, giving an impression that the tree successfully survives the harsh environment of desert. Mesquite (*Prosopis* spp.) planted on a large scale for combating desertification is also a typical phreatophyte. A record of the deepest root of phreatophyte is 68 m below the ground surface, which was confirmed during well digging in Kalahari Desert (Canadell *et al.*, 1996). In order for roots to extend deep into dry soil to where rain water cannot reach, a special strategy (hydraulic redistribution) as mentioned later is necessary. Particularly, how fast a small seedling can access the ground water after germination is a determinant factor for survival of a phreatophyte. In other words, the key issue in establishment of a tree seedlings is whether roots can extend to the ground water quickly before the rain water that enabled germination dries up.

Phto 5: Date palm is one of the phreatophyte

By the analysis of stable isotope ratio of soil water, ground water and water in bundles of *Sabina vulgaris* (Savina Juniper, an evergreen conifer), *Artemisia ordosica* (Ordos Wormwood, deciduous shrub), and *Salix matsudana* (Chinese willow, deciduous arbor) inhabiting in the Mu Su Desert in the north-central China, remarkable difference in source of water was confirmed among these sympatric trees that inhabit in the same area. *S. vulgaris* absorb both soil water and ground water from all soil layers, and is therefore able to secure water in all seasons. *A. ordosica* can use only soil water within 0 to 50 cm below the ground, because it can wait for rain during a short rainy season. *S. matsudana* (Chinese willow, deciduous arbor) does not use shallow soil water to 1.5 m depth, but can use soil water and ground water in deeper layers.

Hydraulic redistribution (HR) which is the soil water transportation via roots has been recognized (Richards and Caldwell, 1987) for various kinds of taxonomic groups and life forms under many kinds of environment (Leffler *et al.*, 2995). After cessation of transpiration, soil water passively moves via roots between soil layers along the gradient of soil water potential. For example, when the surface soil becomes wet after little rain and the deep soil remains dry, plants having both lateral and tap roots absorbs rainwater from the surface soil by lateral root and transports it via tap root and releases it into deep dry soil during nighttime (Fig. 4). Although plants cannot extend their roots to the ground water level dozens of meters below the ground surface after one rainfall occasion, they may transport a small amount of rainwater from the surface to the deeper soil layer by HR and exclusively use the water to extend their tap roots up to the ground water. Then phreatophyte cannot exist without HR (Burgess *et al.*, 1998). In addition, transportation of rainwater on the ground surface into deep layers by HR reduces the amount of water loss due to evaporation in daytime and this increases the rainwater use efficiency (Caldwell *et al.*, 1998; Oliveira *et al.*, 2005).

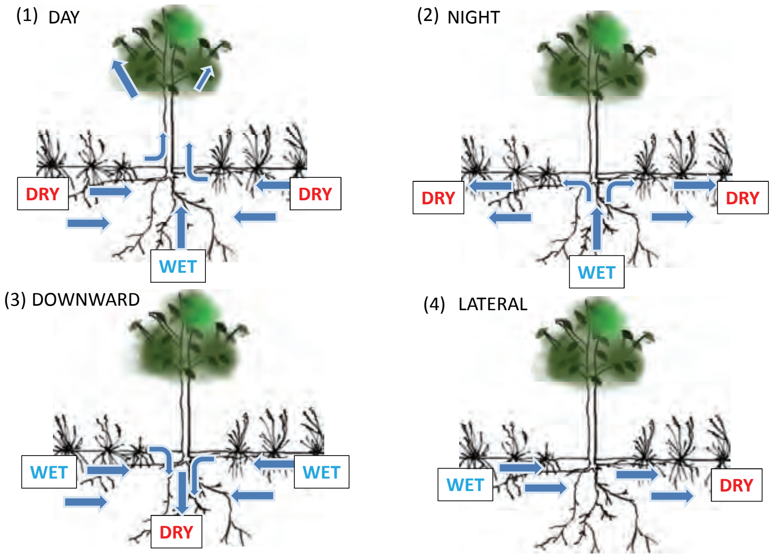


Fig. 4: Water transfer by three types of HR
(1) Water transfer in the daytime, (2) HL in the nighttime, (3) transfer to downward – HD, (4) Horizontal transfer – HR

However, HR is not always effective for all plants having HR capacity. When the surface soil layer becomes dry due to lack of rainfall, phreatophyte lifts up soil water by tap root and extracts water from lateral roots into dry surface soil layer during nighttime. If shallow-rooted plants are absent in the vicinity, such hydraulically lifted up water can be used for transpiration in daytime by HR plants, but shallow-rooted herbaceous plants in the vicinity can also get leftovers of the soil water (Ludwug *et al.*, 2003).

Although HR capacity is an important factor for selection of plants suitable for agroforestry, quantitative assessment of HR capacity is not enough (Meinzer *et al.*, 2004) and therefore development of silviculture methods taking advantages of HR capacity has not yet been started. More so, the effects of tree planting on crop growth must be revealed further in terms of soil moisture transportation.

4) Fog and Dew

As most fog generation is determined by hydrological conditions and geography, fog occurs frequently only in limited locations. However, the frequency of fog is more stable than that of rain. Fog-dependent forests have been established in coastal desert such as Namib Desert, Baja California Peninsula where climate is dry but fog occurs frequently (Kimura, 2005). On the Red Sea side of the Arabian Peninsula, dense forests of *Juniperus procera* are maintained at mountaintop above 2000 m by frequent and dense fog from the Red Sea (Photo 6). In some cases, lichen (*Usneaceae*) is formed on dead branches to trap fog (Photo 7). Water trapped on the tree leaf surface is directly absorbed through the cuticle layer. After water falls down to the ground as water drops, both trees and grasses growing on forest floor uses trapped fog moisture with severe competition.

Dew condensation water is also a stable and effective source of water. Dew on leaves is largely taken into the plant directly (Photo 8) but it may fall down to the ground as water drops or be formed directly on the ground surface. Such water is lost quickly due to evaporation after sunrise, but is also a valid water source if absorbed before dawn. If water saturation deficit (shortage of water) within a plant caused by transpiration in the previous day is not recovered by the next morning, dew condensation water on the ground can be absorbed by lateral roots before the first sunlight of the dawn. Most of plants growing on sand dune therefore, have long lateral roots spreading on the ground surface (Photo 9).

As it is not easy to quantify amount of water supplied from fog and dew, importance of these water sources has not yet been fully evaluated. In the future, development of re-afforestation methods that can promote usage of fog and dew as one of the important water sources in arid area is desired.

Photo 6: Fog generated in the Juniper (*Juniperus* spp.) forest (Saudi Arabia)

Photo 7: Beard Lichen epiphyte on a Juniper branch

Photo 8: Water that had condensed on leaves Savin Juniper (Inner Mongolia, China)

Photo 9: Roots extending crawling on ground (Inner Mongolia, China)

Section 3. Water-Use Efficiency

One of the key indicators of water use by plants is WUE (water-use efficiency). WUE refers to the primary production per unit water consumption. The higher the WUE of the plant is, the more efficiently the plant can perform photosynthesis with less water. The natural selection generally influences plants of higher WUE in arid environment (Fischer and Turner, 1978). Therefore the higher WUE of *S. vulgaris* than those of *A. ordosica* and *S. matsudana* in the Mu Su Desert (O'Leary, 1978) indicates the high adaptability of *S. vulgaris* to arid areas. In areas where a certain amount of rainfall is expected like in the Mu Su Desert, deciduous shrub trees like *A. ordosica* place priority on accelerating photosynthesis rather than increasing WUE in order to concentrate the production of photosynthesis on a short term by using the rain water. Once the rainy season ends, *A. ordosica* sheds its leaves quickly in order to reduce the loss of water. *S. matsudana* has also a distinct property; it does not supress water consumption, but its leaf growth period is longer than for *A. ordosica*. Water resources necessary for this type of growth largely depend on expanded root system, which can absorb water from a wide range. The capacity of root growth which elongates much deeper into the soil than the height growth of above ground part can guarantee adaptation to unreliable environment in arid areas.

Section 1. Selection of appropriate tree species

Selection of appropriate tree species suitable for a given natural environment is imperative in order to make forest establishment successful. The key to success of afforestation in tropical semi-arid areas is selection of highly drought-tolerance tree species. Selection of indigenous tree species should be prioritized for sustainable forest management to ensure effective use and conservation of water resources. In case of introduction of useful exotic tree species, trees must be managed based on water-use properties of each species.

Except in cases where special budget as part of a governmental policy or external support is provided, individual farmers take the primary responsibility for re-afforestation. Therefore species selection should also be based on the farmers' needs. Often, "multi-purpose trees" are preferred for re-afforestation as they meet multiple needs of the farmers. As trees are often planted as part of agroforestry, it is necessary to understand properties of respective trees and consider planting and management methods to reduce crop-tree competition over water.

In tree selection, it is important to focus on tree species that are on the verge of depletion by exploitation as fuel wood and also tree species retained intentionally by farmers for traditional use. Therefore, table that describes properties and use of trees that have highly drought-tolerant among them is provided at the end of this guideline.



Photo 10: Tree species that have been planted willingly in semi–arid areas of Kenya
Left: *Eucalyptus* sp., Center: *Grevillea robusta*, Right: *Melia volkensii*


Photo 11: Charcoal burning for sale and fuel wood for domestic use
Fuel wood is an important energy source in the area where supply of alternative sources of energy is underdeveloped

Section 2. Fifteen highly drought-tolerant tree species

This guideline provides descriptions of properties and management methods for 15 species that have adapted well in arid and semi-arid areas.

The descriptions of each species are summarized in the table and listed at the end of this guideline.

Section 3. Selection of site for re-afforestation

1) Suitable planting areas from a Macro Perspective

a. Introduction

Determination of suitable planting sites for selected tree species has been largely depending on accumulated experiences of farmers and knowledge of scientists. However, in order to promote re-afforestation activities strategically and effectively in wide areas, development of tools to identify and present "Potential habitat" is required. An analysis was conducted in order to identify the "Potential habitat" based on existing weather factor information and actual distribution data recorded for each tree species. The "Potential habitat" in Kenya for 19 species were identified on a trial basis and the results are presented in this guideline.

b. Analyzed tree species

A total of eighteen tree species that have been planted preferentially in arid and semi-arid areas and for which past research papers are available were targeted for this "Potential Habitat" analysis. The species include both indigenous and exotic tree species namely: *Acacia senegal*, *Acacia tortilis*, *Acacia xanthophroea*, *Azadirachta indica*, *Balanites aegyptiaca*, *Combretum acleatum*, *Combretum collinum*, *Combretum molle*, *Combretum shumannii*, *Eucalyptus camaldulensis*, *Eucalyptus globulus*, *Eucalyptus saligna*, *Faidherbia albida*, *Melia volkensii*, *Senna siamea*, *Senna singuneana*, *Senna spectabilis* and *Tamarindus indica*.

c. Method for the analysis

The distribution map for each tree species provided in the "Useful Trees and Shrubs for Kenya" published by "World Agroforestry Centre" and WORLDCLIM's "BIOCLIM weather factor data" were used for this analysis. The correlation among them was analyzed by using "Classification Tree Model" to identify the "Potential habitat" (Fig. A-1-1). The prediction accuracy of the model was determined based on ROC (Receiver Operating Characteristic) analysis (Fig. A-1-2).

d. Procedure of the Analysis

The land of Kenya was divided into 20 sq km grids at first and 1,440 meshes were acquired. Then data on the presence of respective tree species extracted from the "Useful Trees and Shrubs for Kenya" were mapped on each mesh and shown as "Presence Maps" (Fig. A-1-4 (Left side)). Nineteen weather factors of BIOCLIM (Fig. A-1-3, Table A-1-1) distributed into meshes of the same scale, then compared with the "Presence Maps" and analyzed by "S-Plus". Then the correlation value was calculated and the "Classification Tree Model" was indicated.

In the next stage, "Suitable habitat" and "Marginal habitat" were determined and mapped by ROC analysis using the cut-off point as a reference point to determine presence or absence of distribution (Fig. A-1-4 (Right side)). The meshes with distribution probability of lower than 0.01 were categorized as "Potential non-habitat" as it was determined that distribution is hardly from the view point of statistics.

e. Interpretation of the maps

"Suitable habitat" and "Marginal habitat" were regarded as the "Potential habitat" for forest establishment of respective tree species.

Among them, the "Suitable habitat" are regarded as environments with high distribution probability and suitable for survival of respective tree species. General planting method is deemed possible except in case where there are special limitations such as soil conditions that may compromise the survival. The "Marginal habitat" are regarded as areas with low distribution probability where additional requirement(s) must be met to ensure survival. In these areas it is deemed necessary to include management measures for planted trees e.g. introduction of micro-catchments to improve soil moisture condition, while taking account the existence of other limitations such as soil properties.

f. Factors to consider in Potential Habitat Analysis

To understand the correlation between tree species distribution and weather factors in more details and improve the accuracy of the "Potential habitat" determination, it is important to use more existing distribution data and finer meshes.

For the present study, 20 sq km meshes were used because the plots in the base data were consistent with the size. However, if more data are available and a more detailed analysis is required, 1 sq km meshes should be used.

Ideally, there should be more observation points for species presence/absence in each grid, but sufficient study data does not exist for commercially minor or exotic tree species.

For these reasons, this analysis should be perceived as exploratory.

g. Results of the analysis

Interpretation of the data was tried on the assumption that under the above-mentioned limitations. The results of the interpretation of factors are described below. Generally, details are analyzed by extracting items of higher distribution probability indicated by the "Classification Tree Models", and identifying weather factors influencing the figures and their values. But, in this analysis data were interpreted by comparing the map showing "Potential habitat" with the map of BIOCLIM weather factors with high degree of the Deviance Weighted Score (DWS) (Table A-1-2).

- The limiting factor of 3 *Eucalyptus* species was interpreted as the amount of annual rainfall. *Eucalyptus saligna* is the most resistant species to drought and the areas with annual rainfall of ≥401 mm are "Potential habitat", and the areas with ≥801 mm rainfall are "Suitable habitat". The second most resistant species among them is *E. camaldulensis*, and the areas with annual rainfall ≥801 mm are "Suitable habitat" for this species, whereas areas with >1,000 mm rainfall are "Suitable habitat" for *E. globules* (Fig. A-1-4 (10)-(12), Fig. A-1-3 (BI 12)).

- For *Acacia senegal*, "Potential habitat" include areas with annual rainfall ≥401 mm and mean temperature of <27.5 °C in the wettest quarter. Areas with the average temperature of between 17.6 °C to 27.5 °C are designated as "Suitable habitat" (Fig. A-1-4 (01), Fig. A-1-3 (BI 01, 08, 12)).
- For *Melia volkensii*, the conditions with mean temperature of between 17.6 °C to 22.5 °C in coldest quarter were identified as "Potential habitat" with the temperatures for "Suitable habitat" ranging between 20.1 °C to 22.5 °C (Fig. A-1-4 (14), Fig. A-1-3 (BI 11)).
- For *Acacia tortilis* and *Balanites aegyptiaca*, the temperature is regarded as the primary limiting factor. For *A. tortilis*, the conditions with mean temperature of ≤25.0 °C in warmest quarter are required for "Potential habitat" and it must be <20.0 °C for "Suitable habitat" (Fig. A-1-4 (02), Fig. A-1-3 (BI 10)). For *B. aegyptiaca*, the conditions with minimum temperature of ≤15.0 °C in coldest month is regarded as "Suitable habitat" in addition to the conditions with annual mean temperature ≤22.5 °C (Fig. A-1-4 (05), Fig. A-1-3 (BI 01, 06)).
- For *Acacia xanthophloea*, the maximum temperature of warmest month must be <35.0 °C for "Suitable habitat". Also, the conditions with mean temperature of driest quarter as ≤20.0 °C and annual rainfall of ≥801 mm constitutes "Suitable habitat" (Fig. A-1-4 (03), Fig. A-1-3 (BI 05, 09, 12)) .
- For *Combretum schumannii*, the conditions with annual mean temperature of between 22.5 °C to 30.0 °C, and rainfall as ≥301 mm in wettest month are designated as "Potential habitat" (Fig. A-1-4 (09), Fig. A-1-3 (BI 01, 13)).

h. Challenges

The analysis was conducted by using rough meshes and under the limited number of existing presence/absence data. Therefore, some areas were categorized as the "Potential habitat" and not in the "Suitable habitat", according to the analysis results despite being plotted in the "Presence Maps". In addition, we must note that the result of this trial does not mean that the area determined as the "Suitable Habitat" are only the area each species can grow. This analysis is based on the current presence data from existing literature. Probability of the existence of the area where there is no experience of planting despite that each species can grow cannot be denied. There is also a probability of the existence of the area where each species was lost due to some reason despite being once well distributed in the area. Therefore, the result of this trial does not deny the possibility of growth of each species in the area where it was determined as the "Potential non-habitat", especially in the area surrounding the areas where distribution is actually confirmed.

In the future, it is expected that more accurate prediction will be possible by planting respective tree species in the areas surrounding the areas regarded as the "Potential habitat" and accumulating the data. In addition, for detailed identification of the "Marginal habitat", it is also important to accumulate information about site factors that are conducive for growth of each tree species.

2) Suitable planting areas from a Micro Perspective

a. Natural environmental factors

Even within a limited range, water retention capacity of soil varies depending on micro-topography, soils types and vegetation. Generally, lands suitable for growth of trees are also suitable for growth of crops and in such lands agricultural production activities are generally prioritized. If extra lands under weather and soil conditions similar to productive crop lands are available, they can be used as optimal planting sites. In addition, it is expected that lands that are not suitable for agriculture due to other conditions such as land slope angle despite the same weather and soil conditions with crop lands are proactively utilized for forest establishment.

For the lands with low agricultural productivity due to water shortage, tree planting can be practiced using measures such as micro- catchments. It is also important to consider whether soil with poor water retention capacity can be improved by mixing it with organic matters. There is need to consider whether profits gained are proportional to the investment costs.

Although fruit trees can be grown in arid and semi-arid areas, it is advantageous to grow them in lands where there are water sources such as small rivers, considering annual fluctuation of rainfall amount and the need for stabilization of yields.

For some tree species, it is imperative to select areas with less risk to termites' damages which are more prevalent in the drier environment.

b. Social factors

Accessible areas where it is easy to plant and maintain the trees planted with less effort are desired as a location for tree planting by farmers. A low risk of illegal cutting is also an important requirement. If watering is necessary for plant growth, it is indispensable to acquire water use rights through obtaining a thorough understanding of the local community.

Tree planting to demarcate boundaries of own land, and also to prevent livestock browsing can also be strong incentives for local residents to plant trees.

Local community members can also be important actors in promoting re-afforestation activities. Tree planting on the mountain ridge to prevent soil erosion in agricultural land, protection of river bank, and also to generate fund for management and maintenance of public facilities and schools is an important activity in which community could participate. In such cases, it is required that if the land is communal, common perceptions are shared among the community members. There is need to establish systems for provision of labor and fair distribution of profits in promoting tree planting by local communities.

Section 4. Comparison of Properties between Acacia senegal and Melia volkensii

In the Tiva Pilot Forest of KEFRI-Kitui Regional Research Centre, various types of experimental stands have been established with the support of JICA. Among these experiments are, plant physiological studies and studies on forest stand density effects for *Acacia senegal* and *Melia volkensii*.

1) Comparison of drought tolerance through plant physiological studies

(1) *Acacia senegal*'s maximum daytime transpiration rate that indicates the degree of water loss from stomata is less than half of *M. volkensii*. Thus, drought tolerance of *A. senegal* is stronger than that of *M. volkensii*, which is said to have strong competitiveness over water than other plants (Mulatya *et al.*, 2002).

(2) Although no significant difference was observed in power of water absorption of leaves, it is determined that *A. senegal* may photosynthesize with less moisture (Mizobuchi, 2013).

(3) In dry season when water resources becomescarce, both *Acacia* and *Melia* defoliate to prevent loss of water from their leaves (Broadhead, 2000).

(4) How deep plants can absorb water from the soil layer is an important factor to determine their drought tolerance. According to a study on water depth for absorption by 11-years *A. senegal* and for 15-years by *M. volkensii* using stable isotope, it was estimated that water is absorbed from much deep soil layers, at least deeper than 1 m. It was therefore implied that both species have a root system that can obtain necessary water from the soil in deep layer for long period without rain in the dry season.

2) Effect of differences of density on growth

a. *Melia volkensii*

Effect of tree density on survival, height and diameter growth of *M. volkensii* were evaluated in four spacing (2.5 x 2.5 m, 3.0 x 3.0 m, 3.5 x 3.5 m, and 4.0 x 4.0 m) experimental stands that were established in November 2002. *Melia* trees turned 11-years old in November 2012. The change of survival rate is shown in Fig. 5. Although survival rate decreased in all the density plots from 2007 through 2010, no change has been observed since 2010. As at 2012, although the tree height was approximately 8 m in any density plots, the Diameter at Breast Height (DBH) showed a large value in order; 11.0 cm, 12.4 cm, 12.8 cm and 13.6 cm in accordance with increase in spacing (Fig. 7, 8, Table 1). Both tree height and DBH increased most rapidly during the first 3 to 4 years after planting, and then the growth increment sharply decreased.

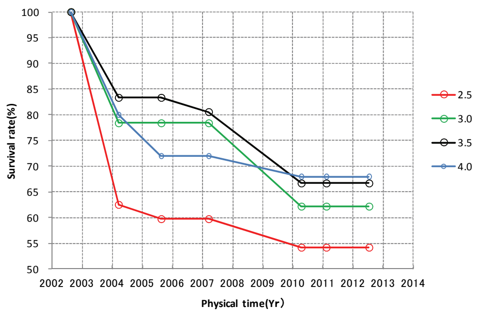


Fig. 5: Trends in survival rate of *M. volkensii*

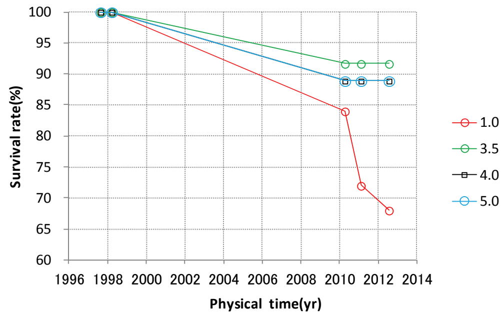


Fig. 6: Trends in survival rate of *A. senegal*

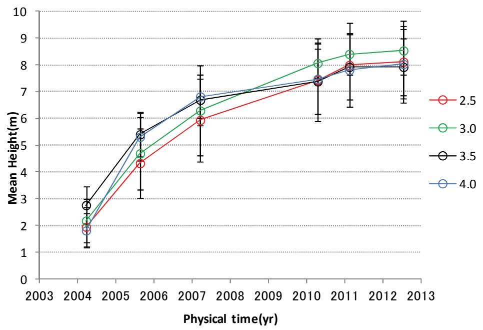


Fig. 7: Trends in growth of tree height of *M. volkensii*

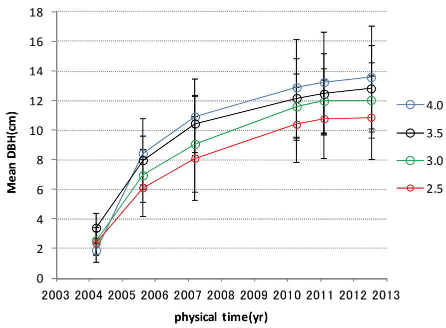


Fig. 8: Trends in growth of DBH of *M. volkensii*

Table 1: Survival ratio, height and diameter growth of *M. volkensii* in each spacing stand

Measurement Year,month	Spacing (m)	Plot size	Number of planted	Number of trees	Number of trees	Height(m) mean±S.D	max	min	DBH(cm) mean±S.D	Max	min	Basal area
2004,Jun	2.5	23x20	1636	45	978	1.9 ± 0.7 a	3.2	0.2	2.4 ± 0.8 a	3.9	0.9	0.4
	3.0	19x17	1120	29	898	2.2 ± 0.8 a	3.5	0.2	2.5 ± 0.9 a	4.1	1.0	0.4
	3.5	22x22	784	30	620	2.8 ± 0.7 b	3.8	0.9	3.4 ± 1.0 b	5.1	1.2	0.6
	4.0	21x18	667	20	529	1.8 ± 0.6 a	3.1	0.7	1.9 ± 0.8 a	3.4	1.0	0.1
2005,Nov	2.5	23x20	1636	43	935	4.3 ± 1.3 a	6.5	0.3	6.1 ± 1.9 a	9.4	1.6	2.9
	3.0	19x17	1120	29	898	4.7 ± 1.3 ab	6.2	1.2	7.0 ± 1.8 ab	9.5	1.9	3.4
	3.5	22x22	784	30	620	5.4 ± 0.8 b	6.8	3.0	8.0 ± 1.6 c	9.8	2.6	3.2
	4.0	21x18	667	18	476	5.3 ± 0.9 b	6.3	3.0	8.4 ± 2.4 bc	11.5	2.9	2.9
2007,Jul	2.5	23x20	1636	43	935	5.9 ± 1.5 a	8.7	1.6	8.1 ± 2.8 a	12.4	0.4	5.4
	3.0	19x17	1120	29	898	6.3 ± 1.7 a	7.9	1.4	9.1 ± 3.2 ab	12.8	0.6	6.6
	3.5	22x22	784	29	599	6.7 ± 0.9 a	8.1	4.0	10.4 ± 1.9 b	13.1	3.8	5.3
	4.0	21x18	667	18	476	6.8 ± 0.8 a	8.2	5.1	10.9 ± 2.6 b	14.3	4.4	4.7
2010,Jun	2.5	23x20	1636	39	848	7.4 ± 1.5 a	10.0	2.4	10.4 ± 2.5 a	14.6	3.5	7.6
	3.0	19x17	1120	23	712	8.1 ± 0.8 a	9.2	5.9	11.6 ± 2.2 ab	15.2	6.1	8.2
	3.5	22x22	784	24	496	7.4 ± 1.2 a	9.2	4.2	12.2 ± 2.7 b	15.5	3.8	6.0
	4.0	21x18	667	17	450	7.5 ± 1.3 a	9.2	3.1	12.9 ± 3.3 b	17.6	5.1	6.2
2011,May	2.5	23x20	1636	39	848	8.0 ± 1.6 a	10.7	3.1	10.8 ± 2.6 a	15.1	3.6	8.2
	3.0	19x17	1120	23	712	8.4 ± 0.8 a	9.4	6.3	12.0 ± 2.2 ab	15.6	6.8	8.7
	3.5	22x22	784	24	496	7.9 ± 1.2 a	9.6	4.6	12.5 ± 2.8 b	16.3	3.8	6.3
	4.0	21x18	667	17	450	7.8 ± 1.4 a	9.4	3.3	13.3 ± 3.4 b	18.0	5.2	6.6
2012, Oct	2.5	23x20	1636	39	848	8.2 ± 1.5 a	10.7	3.4	11.0 ± 2.8 a	15.6	3.6	8.6
	3.0	19x17	1120	23	712	8.6 ± 0.8 a	9.8	6.4	12.4 ± 2.3 ab	16.1	7.2	9.2
	3.5	22x22	784	24	496	7.9 ± 1.0 a	9.2	5.8	12.8 ± 2.9 b	17.0	3.8	6.7
	4.0	21x18	667	17	450	8.0 ± 1.3 a	9.8	4	13.6 ± 3.5 b	18.6	5.2	6.9

b. *Acacia senegal*

Effect of tree density on survival, height and diameter growth of *A. senegal* were evaluated in four spacing (1.0 x 1.0 m, 3.5 x 3.5 m, 4.0 x 4.0 m and 5.0 x 5.0 m) experimental stands that were established in November 1998. *Acacia* trees turned 15-years old in November 2012. The change of survival rate is shown in Fig. 6. In 1.0 m plot it decreased to 84% in 2010 and further decreased to 72% and 68% in 2011 and 2012 respectively, while in other density plots decreased to around 90% and then became stable. As at 2012, the tree height was approximately 6 m in all density plots. Although the observed annual average growth increment was 30 to 40 cm, some trees decreased in height hence it can be concluded that growth in height almost stopped (Fig. 9). With increase in spacing, the DBH showed large values of 4.2 cm, 9.1 cm, 9.3 cm and 10.9 cm. In 3.5 m and 4.0 m square espacements, no significant difference was observed in the survival rate, tree height and DBH, but in 5.0 m x 5.0 m plot, the DBH was larger than in other plots and the stem diameters increased vigorously (Table 2).

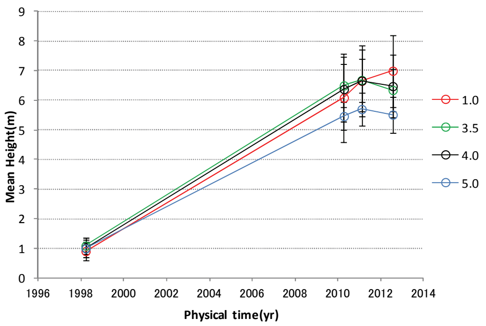


Fig. 9: Trends in tree height of *A. senegal*

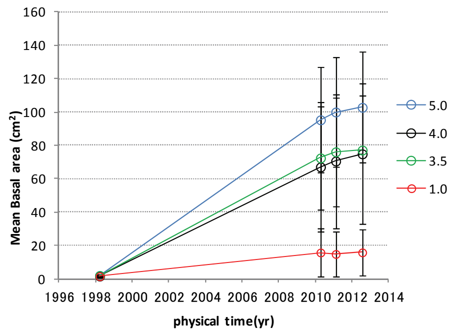


Fig. 10: Trends in growth of mean basal area of *A. senegal*

Table 2: Survival ratio, height and diameter growth of *A. senegal* in each spacing stand

Measurement Year,month	Spacing (m)	Plot size (m)	Number of planted trees(N/ha)	Number of trees (N)	Number of trees (N/ha)	Height(m) mean ± S.D	Height(m) max	Height(m) min	Basal area(cm^2) mean ± S.D	Basal area(cm^2) Max	Basal area(cm^2) min	DBH(cm) mean±S.D	DBH(cm) Max	DBH(cm) min	Basal area (m2/ha)
1998,Jul	1.0	5x5	10000	25	10000	0.9 ± 0.3 a	1.7	0.5	1.5 ± 0.6 a	3.1	0.4	1.4 ± 0.3 a	2.0	0.7	1.5
	3.5	11x8	1364	12	1364	1.1 ± 0.3 a	1.6	0.6	2.0 ± 0.6 a	3.1	0.8	1.6 ± 0.2 a	2.0	1.0	0.3
	4.0	9x10	1000	9	1000	1.0 ± 0.3 a	1.6	0.5	1.7 ± 0.7 a	3.1	0.8	1.4 ± 0.3 a	2.0	1.0	0.2
	5.0	11x11	744	9	744	1.0 ± 0.2 a	1.3	0.7	2.0 ± 0.8 a	3.1	0.8	1.6 ± 0.3 a	2.0	1.0	0.1
2010,Jun	1.0	5x5	10000	21(0)	8400	6.1 ± 1.5 ab	7.8	2.5	15.8 ± 14.5 a	51.7	2.5	4.1 ± 1.8 a	8.1	1.8	13.3
	3.5	11x8	1364	11(2)	1250	6.5 ± 0.7 a	7.6	5.1	72.4 ± 30.7 b	127.0	19.1	8.8 ± 1.8 b	11.0	4.9	9.1
	4.0	9x10	1000	8(1)	889	6.4 ± 1.1 ab	7.7	4.8	67.1 ± 38.9 b	133.1	21.2	8.7 ± 3.0 b	13.0	4.0	6.0
	5.0	11x11	744	8(2)	661	5.5 ± 0.5 b	6.3	4.7	95.3 ± 31.7 b	133.8	40.1	10.5 ± 2.4 b	13.1	6.4	6.3
2011,May	1.0	5x5	10000	18(0)	7200	6.7 ± 1.2 a	8.1	3.9	14.9 ± 13.5 a	52.8	2.0	4.1 ± 1.6 a	8.2	1.6	10.7
	3.5	11x8	1364	11(2)	1250	6.7 ± 0.7 a	7.8	5.3	76.1 ± 32.6 b	133.2	18.9	9.0 ± 1.9 b	11.5	4.9	9.5
	4.0	9x10	1000	8(1)	889	6.7 ± 1.1 a	8.1	5.4	70.6 ± 40.0 b	138.9	22.4	9.0 ± 3.0 b	13.3	4.2	6.3
	5.0	11x11	744	8(2)	661	5.7 ± 0.6 a	6.5	4.8	100.0 ± 32.6 b	147.4	51.5	10.8 ± 2.3 b	13.7	7.1	6.6
2012.Nov	1.0	5x5	10000	17(0)	6800	7.0 ± 1.2 a	8.5	4.0	15.9 ± 14.1 a	54.1	1.8	4.2 ± 1.7 a	8.3	1.5	10.8
	3.5	11x8	1364	11(2)	1250	6.3 ± 0.7 ab	7.2	5.1	77.2 ± 32.7 b	134.7	19.6	9.1 ± 1.9 b	11.5	5.0	9.6
	4.0	9x10	1000	8(1)	889	6.5 ± 1.0 ab	7.8	5.2	74.9 ± 42.1 b	149.6	27.2	9.3 ± 3.0 b	13.8	4.5	6.7
	5.0	11x11	744	8(2)	661	5.5 ± 0.6 b	6.5	4.9	102.8 ± 33.3 b	153.9	56.9	10.9 ± 2.3 b	14.0	7.4	6.8

Section 5. Water Management in the Re-afforestation Site

1) Soil moisture environment in the re-afforestation site

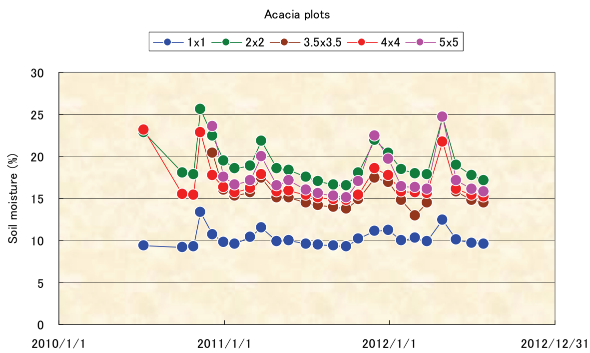
The value obtained by subtracting the evapotranspiration amount from rainfall amount is called "Available Renewable Freshwater Resources" and is regarded as the theoretical upper limit of available water resources. However, soil moisture is more important in terms of water environment in re-afforestation site. Available soil water varies with rainfall and evapotranspiration, and has significant influence on plant growth. It is known that the proportion of evapotranspiration in rainfall amount is relatively high in forest than bare lands and grass lands, and the depth of water to be absorbed by the root system varies with tree species, the vegetation conditions also affect the soil moisture.

In terms of water management in semi-arid lands re-afforestation, the goal is to use the limited amount of rain water efficiently for tree growth. Although it is not easy to achieve this goal, the relationship between forests and soil water in Kenya's semi-arid areas is introduced in this section to illustrate how trees and soil water correlate.

In this study, soil moisture was measured using the device called "profile probe" (Delta-T Devices Ltd. Type PR6) in each study plot set in the natural stand and spacing trials of *Melia volkensii* and *Acacia senegal* and bare lands (grass lands) within nursery of KEFRI-Kitui Regional Research Centre's Tiva Pilot Forest. The study was started in June 2010 and additional measurements taken from November 2011. Besides measurements at Tiva, soil moisture assessment using the same method started for 3 tree species (*Melia volkensii*, *Eucalyptus camaldulensis* and *Gmelina arborea*) in the Matinyani experimental station under KEFRI Kitui Center where WUE, growth and survival of these tree species are being evaluated.

Measurement of vertical profile of soil moisture was basically conducted at the interval of one month. Changes in water content in spacing trials of *Acacia* and *Melia* at depth of 10, 20, 30, 40, 60, and 100 cm are indicated in Fig. 11 and Fig. 12. The relation between planting density and average water content is not so simple, but the average water content of the plots with the shortest planting interval (1 m x 1 m for *Acacia* and 2.5 m x 2.5 m for *Melia*) is the lowest.

Figure 13 shows the measurement results (average water content) for 3 tree species at the Matinyani experimental station. Although the three species were planted in the same density (4 m x 4 m) at the same time (December 2007), soil in *Eucalyptus* stand was consistently drier than soil in *Melia* stand throughout the study period. The tree height difference between *Eucalyptus* and *Melia* was already remarkable (Photo 12) though only 5 years after planting in December 2007, and such difference in growth rate was thought to be influencing the soil moisture.



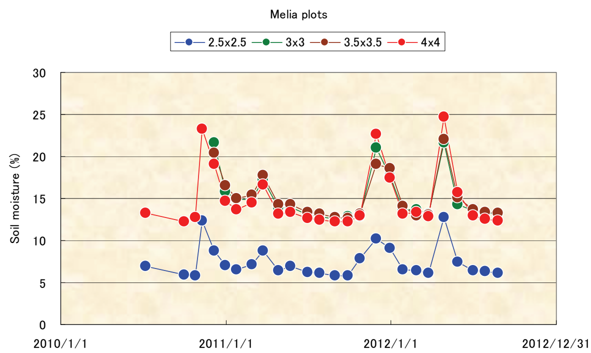


Fig. 11, 12: Seasonal change of the average water content (Soil depth between 10–100cm)
(Spacing trials of *Acacia*, from July 2010 to July 2012) (Spacing trials of *Melia*, from July 2010 to July 2012)

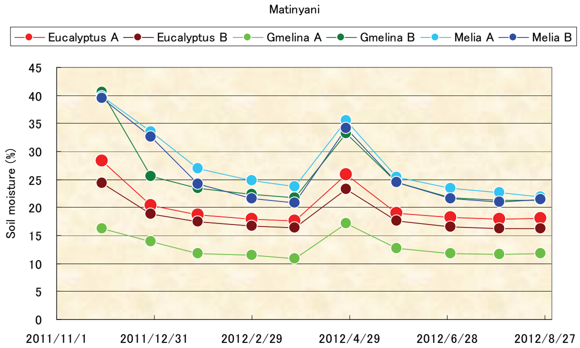


Fig. 13: Seasonal change of the average water content (Matinyani experimental site, from Nov. 2011 to Aug. 2012)

Photo 12: *Eucalyptus* and *Melia* stand in Matinyani *Eucalyptus* (left), *Melia* (right) (Feb. 2013)

As soil moisture also varies depending on micro-topography and soil properties, the above results cannot be applied broadly without discretion. However, these data imply that soil moisture may vary depending on tree species planted at the same density. Results have also revealed that species like *Melia* which hardly dries the soil relative to *Eucalyptus* may dry the soil if plantedat close spacing.

2) Water catchment and water saving methods in the re-afforestation site

Water conservation is important especially in arid and semi-arid areas where not only plant growth but also human lives are affected by water shortage. Re-afforestation activity in arid areas must therefore be carried out carefully. Basically, plantation size and the number of trees should be determined on the basis of water consumption of the forest at the time of forest maturity. Effective use of rain water is also an important measure to increase biomass at the time the forest has matured. To ensure high survival rate of the planted trees, it is important to keep the soil moisture condition appropriate for plant growth during the period in which root system is not well developed.

For this purpose, there are 2 possible measures in particular, “Water-harvesting” and “Water-saving”.

(1) Water-harvesting technologies

Water-harvesting technologies are used to collect surface water and overflow water, and let it infiltrate into the soil and increase the water amount available to plants. Besides harvesting water, micro-catchments also prevent soil erosion.

Table 3 describes features of various water-harvesting technologies and their areas of application. Contour ridge, bench terrace and fanya juu are applied to large areas including agriculture production, while the others are basically applied to individually planted trees. Selection and application of water-harvesting technologies should be determined by the; geography, precipitation, soil properties, plantation size, available labor force, and availability of materials, among other factors.

Table 3: Characteristics and applicable area of each water–harvesting technology

	Types of water catchment		Slope	Annual rainfall	Agro-forestry	Labor requirement	Remarks
1.	Negarim		flat - gentle	Feasible even 150mm below	difficult	slightly large	have high adaptability to severe arid condition
2.	Half-moon MC						
a)		W-shape MC	gentle	200-750mm	possible	slightly large	most adaptable to arid condition among 3 types
b)		V-shape MC	gentle	200-750mm	possible	small	correct run-off water on one point
c)		U-shape MC	gentle	200-750mm	possible	small	improve soil moisture in wide range (comparison with other 2)
4.	Contour ridge		gentle	(200) 350-700mm	optimum	large	mainly use to agro-forestry
5.	Bench terrace		gentle – steep (20-50%)	100-600mm	optimum	very large	mainly use to agro-forestry adaptable to steep terrain
6.	Fanya-juu		gentle (5-20%)	700mm or more	optimum	large	mainly use to agro-forestry
7.	Circular MC		basically flat	basically watering	possible	small	periodically watering is basic requirement
8.	Big hole		flat - gentle	500-600mm (in Myanmar)	possible	slightly large	effective in root development as well as soil moisture retention

a. Half-moon micro-catchment

A micro-catchment is constructed by preparing a semi-circle shaped mound to collect surface runoff water into it. The open part of the half-moon should face the top of the slope. Soil inside the mound is scooped out and heaped up on the mound part. Size and design of the mound is determined by the slope, precipitation and target plants, but, in general a 3- m diameter mound is used for tree planting. The typical height of the mound is 15 - 20 cm, but this should also be adjusted according to the slope of the land (Fig. 14).

This technology can be applied in areas with rainfall of 200 to 750 mm. Although ideal slope of ≤2% for optimal water harvesting efficiency, it is also possible to apply in areas with a slope of ≥5% by increasing the height of the mound. This technology can be applicable with relatively less labor.

Despite that it is categorized as "Half-moon", various shapes including U-shape, V-shape and W-shape are used depending on rainfall amount and slope condition. Since U-shape promotes water infiltration into a wide area of land, it is expected to benefit plants other than the planted trees (Fig. 16). V-shape is effective in concentrating water on one point, and it is suitable for tree planting in areas with severe dry conditions. W-shape consists of connected V-shape mounds in a row along the contour line to harvest all surface runoff and is used in extremely dry areas (Fig. 17). Since surface runoff is collected from wider area than other types do, the mound of this type becomes weak structurally. Use of other types is recommended in the area where rainfall per incident is a lot.

Regular maintenance and repair of the mounds is necessary after rainy season. The mounds can be made more stable by using materials like pebbles. The structure must be maintained for at least 2 or 3 years until planted trees can use water at the groundwater level.

The position for planting trees should be determined according to characteristics of the tree species to be planted and soil properties (Fig. 15). In general, trees are planted inside the mound where water is concentrated. However, tree species such as *Melia volkensii* that are prone to root rot should be planted outside of the mound.

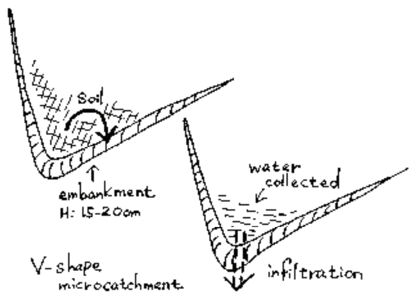


Fig. 14: Proceeding & concept of MC

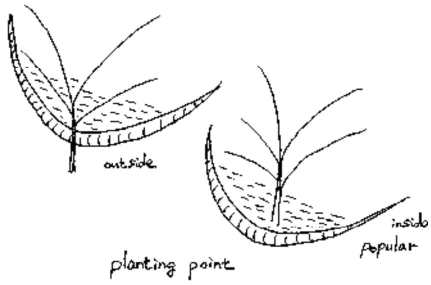


Fig. 15: Planting point

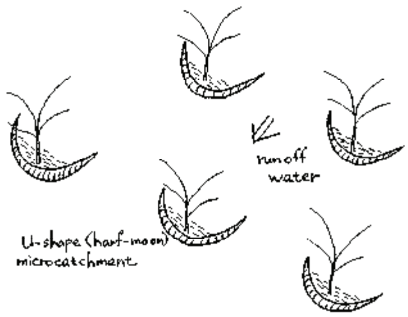


Fig. 16: An arrangement of U-shape MC

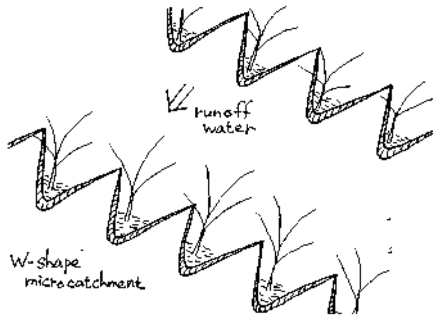
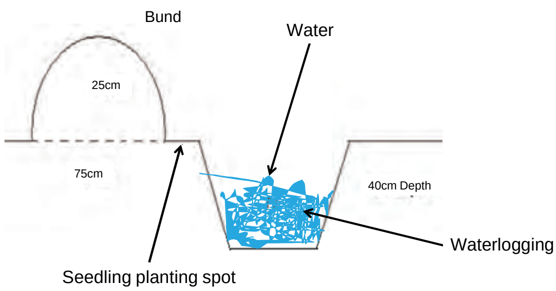


Fig. 17: An arrangement of W-shape MC

b. Negarim system

For this technology, square or rhombic compartments separated by mounds are established (Photo 13). A hole is dug at the lowest part of each compartment to store the water. The size of each compartment is determined by the number of trees to be grown per unit area and as influenced by the rainfall amount. Typical size of each compartment is 10 to 100 m^2, with size increasing with rainfall decrease. For the water storage section, the area of 1 m^2 is dug down to a depth of 40 cm and the removed soil is used for constructing the mound (Photo 14, Fig. 18). The one side of the water storage section has ramped part where trees are planted. This technology is applicable in the areas with annual rainfall amount ≤150 mm, and can be applied on land of slope up to 5%. However, because the runoff water in each compartment is concentrated on one point, this system is not suitable for agriculture use.



Negarim water catchment

Photo 13: An arrangement of Negarim MC (Previous pager left)

Photo 14: Concept of Negarim MC (Left)

Fig. 18: Structure of Negarim MC (Previous pager right)

c. Contour ridge system

For this technology, ditches are excavated along the contour line of the slope in order to store water (Photo 15). The removed soils are heaped on the lower part of the slope below the ditches where trees can be planted. Typical depth of the ditch is 30 to 45 cm, and interval between ditches is 10 to 15 m. This is primarily used for tree plantation within agricultural lands for the purpose of ensuring water supply to crops (Fig. 19).

This technology is effective for areas with annual rainfall of 350 to 700 mm and may be applied in regions with annual rainfall of about 200 mm if tree planting is the primary purpose. The interval between ditches is determined by slope and rainfall amount. If the rainfall of the area is extremely low and the primary purpose is tree planting, the trees should be planted on the upper side of the ditches. If the water flows in a lateral direction, the ditch will be divided into several sections by embankments.

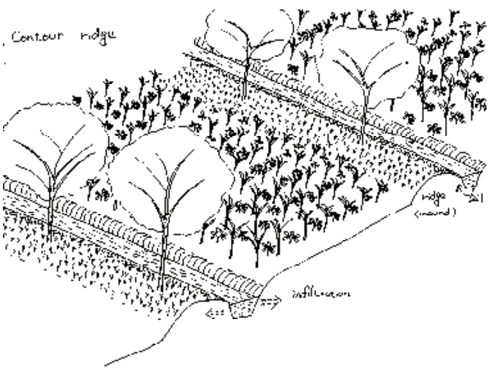


Fig. 19: Concept of contour ridge

Photo 15: An example of contour ridge

d. Bench terracing

This technology is used to promote infiltration of surface runoff by reshaping the land into terraces in steep terrains. It is used in areas with annual rainfall of 100 to 600 mm, and slopes of between 20% to 50%. The primary objective for applying this technology is for agriculture and trees are planted to protect the terrace edge (Fig. 20, Photo 16). Although the earthwork volume is large and a lot of labor and funds are required, the terrace is established as a permanent structure. This technology therefore should be introduced if appropriate benefits can be realized over a long time.

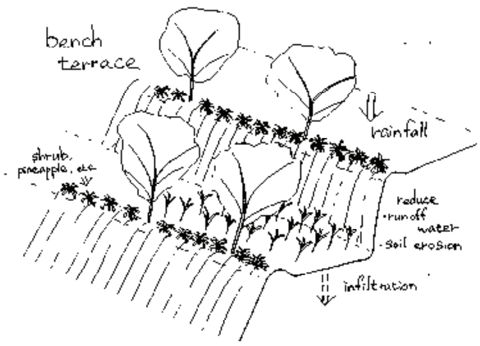


Fig. 20: Concept of bench terrace

Photo 16: An example of bench terrace

e. Fanya-juu terracing

Fanya-juu is a Swahili term means "throwing the soil on the upper side". This is an improved version of "Bench terracing". Ditches are excavated along the contour line, and removed soils are heaped up on the upper side of the slope. Ditches are 50 to 60 cm in width, 60 to 100 cm in depth on the upper side of the slope, and 50 to 60 cm in depth on the lower side (Photo 17, 18). Mound should be built to the size of 1 m in width and about 50 cm in height. Ridges are established along the contour line of the terrace section in order to promote runoff infiltration and to store water in the ditch so as to maintain soil moisture for long term use. This technology can be used in areas where annual rainfall is 700 mm or higher, and the slope is 5% to 20%.

Photo 17: An example of Fanya-juu terracing

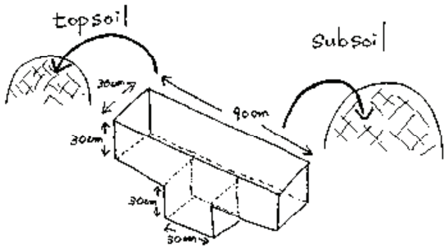
Photo 18: A variation of Fanya-juu terracing

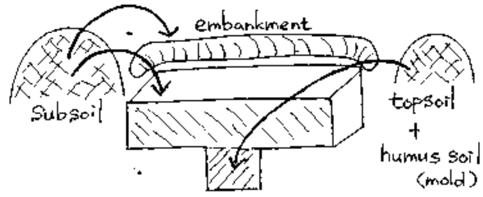
f. Circular micro-catchment

With this technology, planted trees are encircled by a circular mound and water is pooled inside the mound (Photo 23). This technology is primarily applied for fruits production within flat land where watering is possible. Diameter of the circle is generally determined by the spread of tree canopy. Combining this micro-catchment with mulching can improve water retention.

g. Large-scale planting pit

By making planting pit larger, the amount of water maintained in soil can be increased. In the case of semi-arid area in Myanmar, the planting pits were made by digging 2 m x 50 cm to a depth of 50 cm, and then digging down 30 x 30 cm at the center to an additional depth of 80 cm. This is effective not only for long-term maintenance of soil water obtained during rainy seasons, but also for promotion of early development of the root system to the groundwater level (Fig. 21). Large size seedling of about 1 m in height will be planted in each pit.





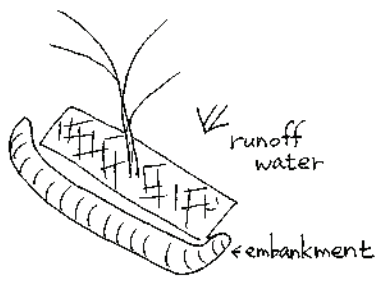


Fig. 21: Large-scale planting pit

Upper left: Installation of large-scale planting pit

Upper right: A proceeding to backfill

Left: Water harvesting and infiltration

(2) Water-saving technologies

a. Tillage (Soil plowing)

Traditionally, tillage is practiced in various regions for improvement of soil physical properties, suppression of weeds, and preventing capillary water loss. Since it promotes runoff infiltration, tillage is also regarded as one of the water harvesting technology. However, tillage has risks of reducing soil organic matter and increasing soil erosion which can be mitigated by addition of organic matter and considering it applicability depending on slope. For trees, soil under the range of canopies should be plowed up to 30 cm in depth (Photo 19, 20).

b. Mulching

Mulching is a technique for controlling evaporation of soil moisture from soil surface by covering soil surface with either tree branches, grasses, stones or pebbles (Photo 21). Mulching also helps to adjust the temperature variation within soil and provides an environment suitable for plant growth. Where organic materials are used, mulching also adds organic nutrients.

Mulching is generally an effective technique during stages where development of tree canopies is still in progress. However, there is a risk of plant mulches sheltering termites. Hence, of this technique should preferably be avoided for tree species vulnerable to termites and in areas where termites' damages frequently occur.

c. Cover plants

Plants covering the soil surface are expected to reduce evaporation from the soil surface. However, this also poses a risk of causing water competition among trees. Therefore, the plants that spread wide leaves horizontally across the soil surface like "creeping beans" is suitable to use (Photo 22).

Photo 19: An example of Tillage (for fruit trees)

Photo 20: An example of Tillage (for agro-forestry)

Photo 21: Example of mulching (Left: sawdust, Right: twigs)

Photo 22: Green gram
(a form suitable as a cover plants)

d. Complete weeding

This is a technique that was developed during Social Forestry Training Project and verified during the Social Forestry Extension Model Development project, technical cooperation projects implemented by JICA and KEFRI in Kenya. Weeds are uprooted to reduce their competition for water with trees and also to reduce capillary water loss from the soil. *Azadirachta indica* first year growth is reportedly 4 times higher in complete weeded plots than in slash weeded plots. Growth difference was continuously maintained in some test plots. Floor plants provide the covering effect on the soil surface, whereas complete weeding poses a risk of soil erosion and loss of nutrients as with tillage (soil plowing). Complete weeding should not be applied in sloping lands. Spot weeding should be done around the trees in such site.

e. Direct sowing and direct use of cuttings

Tree nurseries consume a large amount of water especially during dry seasons. Therefore, it is important to consider direct seed sowing and use of cuttings for direct planting for tree species that are adaptable to these techniques. This is effective for saving on labor and seedling production costs (soil, plastic pot, etc.).

Direct sowing has been reported to be applicable for species such as *A. nilotica*, *A. senegal*, *S. siamea*, *A. indica*, *Balanites aegyptiaca*, *Moringa oreifera* and *Ziziphus mauritaniana*. Pre-treatment to promote germination is required for some of the species, and sowing must be done at the appropriate season. Countermeasures must be taken against water and light competition with weeds and damages by livestock browsing.

Direct planting of cuttings is a technology that has already been adopted for hedges of *Euphorbia tirucalli*, *Gliricidia sepium* and *Commiphora* species such as *Commiphora africana*. There are many cases where thick and long branches are used to allow the trees to serve as hedges in early stages. However, trees that are propagated by use of stem cuttings cannot develop taproot but develop shallow lateral roots instead. In order to avoid water competition with crops, the use of root cuttingsis preferred to general method such as potted seedling.

(3) Watering and irrigation

a. Watering

In some cases, circular micro-catchments are installed for watering of fruits trees (Photo 23). This is applicable to the trees that can generate high profits in short time considering the initial investment and running costs. As a certain amount of water is consumed by watering, consensus building among community members is required before the application of this method.

Photo 23: Circular micro-catchment

Photo 24: Watering by PVC tube

PVC tubes and plastic bottles are used as small-scale facilities for watering (Photo 24). These can be applicable only to easily accessible areas because regular management is required.

b. Irrigation

Local consensus building among community members living in the downstream areas is essential depending on their land use systems. This is not a practical technique except in the case where it is to be implemented by government department/ ministry. In the long term, where water is limited, there is a risk of soil salinity.

3) Re-afforestation and forest management techniques suitable for drylands

This section describes re-afforestation and management techniques in tropical arid and semi-arid areas.

(1) Raising high quality seedlings

In semi-arid areas, seedlings are often grown as potted seedlings under favorable conditions such as sufficient watering and shading in the nursery. Acclimatization of the seedlings to strong light and drought are required before planting, to make them drought-tolerant.

To improve their drought tolerance, hardening off the seedlings is done at least 2 weeks before planting through water rationing (to 1/2 to 1/3 of the normal amount) and increasing the solar radiation (if seedlings are covered). Through these processes, root system development within the pots is promoted and the balance between aboveground parts and underground parts (T-R ratio) will be improved to ideal ratio. Strengthening of stem and leaves, and development of cuticle layer are promoted and this makes the seedlings more drought tolerant and highly resistant to pests and diseases (Fig. 22).

Although sunken beds are often used in arid and semi-arid areas to maintain soil moisture in pots (Photo 25), thickened taproots sometimes will develop into the soil. A situation that makes it necessary to cut thick roots must be avoided as much as possible to ensure high survival rate. The positions of the pots should be changed on a periodical basis and root pruning should be done by cutting roots extending outside of the pots before they grow thick.

Photo 25: A typical seedbed in arid area

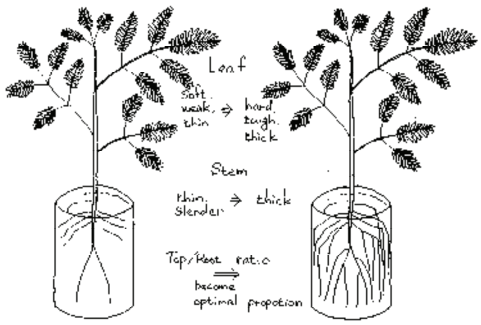


Fig. 22: Benefit from hardening treatment

(2) Planting methods

a. Planting density

Planted trees compete with other plants such as weeds for water, but also start competing with each other several years after planting. In arid and semi-arid areas, it is difficult to have closed canopy forests, and therefore re-afforestation plan should be designed with wider spacing from the early stage.

There are differences in water consumption by tree species, annual precipitation in the planting site, and water retention capacity of soil. It is therefore practically difficult to determine planting intervals without good understanding of these factors. KEFRI reported that 5 m x 5 m planting interval is adequate for *Melia volkensii* (KEFRI, 2010) and this spacing which gives 400 trees per hectare showed the most prominent diameter growth among the spacing trials in Tiva Pilot Forest. For *Grevillea robusta* and *Senna siamea* that are recognized as low drought tolerance tree species, approximately same or smaller number of trees should be planted in comparison with *Melia*. *Acacia* species with high drought tolerance can survive under a relatively higher density. *Acacia* trees with planting density of 1 x 1 m in Tiva endured the severe drought in 1992.

In testing growth of *Prosopis* species in agroforestry system in India, it was reported that it is optimal to control the stand density to 833 trees ha^{-1} for 2 to 3- year old stand and to 208 trees ha^{-1} for 12- year old stand, without significant decrease in crop yields.

b. Planting hole

Typical size of a planting hole is from 30 cm diameter x 30 cm depth to 45 cm x 45 cm, and holes within this size range are generally used in drylands region of Kenya. According to the survey result among farmers with experiences in planting, the size of planting hole was not considered as a decisive factor affecting the survival rate.

In a case study in central arid zone in Myanmar (annual rainfall amount: 800 mm, dry season: 7 months), large planting holes were reported to improve survival rate to nearly 100%. If soil in the planting site is heavy clay and tends to be solidified in dry seasons and the planting hole is small, plant's root system cannot extend to surrounding soil and sufficient growth cannot be expected. In such cases, the planting hole must be larger.

Planting holes should be dug before the end of the dry season. This is to ensure sufficient water infiltration to the bottom of planting holes at the start of the rainy season. Another reason is that there is a concern that hole digging may take a long time if the number of trees to be planted is large.

c. Planting

Tree planting should generally be carried out as soon as possible when adequate moisture has accumulated in the soil to ensure long growth period for planted seedlings and to promote sufficient root development and attain high survival rate. Normally, adequate moisture is thought to be achieved after a cumulative rainfall of 100 mm. However, long duration between rainfall events in arid and semi-arid areas complicates the decision as to when adequate moisture is achieved. Soils in arid and semi-arid areas are generally fine and poor in water retention hence organic matters should be put at the bottom of planting holes to improve its water retention capacity.

Planting work should be carried out carefully. Fine roots suffer damage when planting and this will be a significant factor that decreases the survival rate in arid areas. To improve the survival rate, cut off branches leaving the top 2 or 3 branches to ensure good balance between evapotranspiration and water absorption in broad-leaved trees.

d. Watering planted trees

Arid and semi-arid areas have limited water resources so securing water for domestic and agricultural use is a priority. It is therefore difficult to secure extra water for planted trees especially in the dry season. Re-afforestation sites are generally located away from water sources and it is practically difficult to develop irrigation system or carry water to each site. Re-afforestation success will therefore depends on selections of drought tolerant tree species, growing healthy seedlings, planting the seedlings at the beginning of the rainy season, and securing a sufficient growth period during the rainy season.

Watering is done when sufficient growth period has not been secured due to delay in out planting and when the rains are too low to attain the standard accumulative amount of 100mm. For trees planted around human dwellings domestic waste water can be used for watering them. In such cases, watering at the regular intervals is more preferable for promoting root development rather than watering every day with small amounts of water.

(3) Management and maintenance of planted trees

Re-afforestation programmes in arid and semi-arid areas are always faced with the risk of forest fires and damages due to livestock browsing.

Main causes of forest fire are: fires used for clearing land for agriculture and grazing; fires used for hunting; and other accidental fires. Fires can easily spread to dried grasses and branches of shrubs in the dry season. Effective countermeasures against forest fires include: removal of combustible material such as dried undergrowth, and installation of firebreak (streaky weeding or streaky planting of trees hard to burn) along the ridge line for fire prevention. Since most causes of forest fire are man-made, it is important to create awareness of local residents and obtain cooperation of local communities regarding forest fire prevention. It is also important to establish systems for monitoring and firefighting.

Grazing of cows and goats has been a traditional practice by the local community, hence it is difficult to prohibit by law. Browsing is a serious problem affecting management and maintenance of planted sites. The most reliable measure is to enclose each planting site by fence but this cost is high and is not practical. As with forest fire, it is necessary to obtain understanding and cooperation among local residents and make rules of grazing taking measures to secure livestock feedstuff such as by planting of fodder trees. It is important to set rules among local residents through discussion in order to enhance management and maintenance of planting sites. Tree planting in arid and semi-arid area should be carried out by local farmers as intended by Kenya government policies, and immediate countermeasures are promotion of tree planting using agroforestry systems in agricultural lands and on land boundaries where management and maintenance are relatively easy.

(4) Felling cycle and timing

a. Felling cycle

In order to get the benefit efficiently, it is important to make a good management plan based on proper knowledge of demands and commodity standards in each region. In the case study in Kitui, Kenya, the market value of coppiced *Eucalyptus* is generated when the sprout attains 8cm diameter, and the sprout can be felled in 3-year cycle.

b. Felling time

Although the market value, time and fluctuation of demand are significant factors to determine felling time, it is recommended to focus attention on water competition with crops if trees are planted within agricultural lands. It is known that pollarding and pruning reduce the total root volume and also limit its stretching range. Pruning before starting of the dry season is expected to mitigate the water competition with crops in the dry season.

Thinning is generally applied to increase biomass but in the case of drylands agroforestry thinning can be regarded as a technology to mitigate the water competition with crops. Felling of trees before the start of the dry season can also be regarded as an effective technique to reduce water competition with crop in the dry season. Especially for the plantation of semi-deciduous trees and evergreen trees, this application can be presumed as effective. When applying this technology, it is important to determine the number of trees to be felled considering the negative effect of increased evaporation of soil moisture caused by direct rays of the sunlight.

Section 6. Tree Planting by Agroforestry Approach

1) Agroforestry and water management

Securing good site for planting trees is a significant challenge to farmers not only in arid and semi-arid areas but also other areas because preferable natural conditions are generally allocated to agriculture by priority. In the areas where there is high risk of trees getting damaged due to livestock browsing and illegal cutting among other deforestation activities, farmers want to grow and manage trees in the site within their eyeshot. As a result, agricultural lands and its surroundings are often selected as tree planting sites. Technologies that optimize tree-crop production are required and such technologies are commonly referred to as agroforestry.

a. Features of agroforestry

Agroforestry is not a mere combination of different production activities, but what is to be adopted in order to comprehensively generate some kind of benefits not achieved by any mono-culture system. There is no fixed format of agroforestry and various forms are adopted according to purposes, natural, social and economic conditions.

b. Positive and negative effects of tree planting in agricultural lands

Although agroforestry is adopted to generate some kind of benefits, combinations of production activities for different objectives have risks of negative effects in some cases.

Expected positive effects of agroforestry include: provision of shades; efficient use of light; improvement of micro-meteorology/micro-climate; prevention of soil erosion; improvement of soil; increase of biomass per unit area; effective use of space; inhibition of overgrowth of weeds; provision of shades by trees; and provision of manure from livestock dung.

Negative effects of agroforestry include: competition for water, light and nutrients; risk of allelopathy; containment of plant toxins; browsing and trampling by livestock; and risk of being a host of disease and pest.

Competition over water between trees and crops is a significant issue for agroforestry especially in arid and semi-arid areas and measures to avoid or mitigate it are needed.

2) Agroforestry niches

According to a questionnaire survey conducted in Kenya, there are not many sites dedicated to tree planting except wood lots, farm forests or private plantations. Since most farmers own limited land, trees are planted within the homesteads or compound, in crop lands and grazing land as hedges and land boundaries.

3) Tree planting in agricultural lands

Tree planting in agricultural lands is adopted to generate profits as much as possible in limited land areas, and this is regarded as a typical style of agroforestry.

In positioning of trees and crops, there are various forms. However, planting patterns can be categorized into four: planting along the contour line for prevention of soil erosion; planting at certain intervals for improvement of microenvironment by leafy shades; planting of trees and crops in rows as alley cropping; and planting of trees concentrated on fixed sections (Photo 26-30). The biggest problem in tree planting in agricultural lands is decreased yields of crops due to water shortage caused by competition between trees and crops. However, there are also positive effects on crop growth such as prevention of soil erosion, improvement of runoff water filtration in to the soil, and improvement of microenvironment by leafy shade. Management techniques are necessary for success in any form of agroforestry system. Agroforestry system should be designed considering items such as: appropriate planting layout of trees to fully achieve the intended effects (prevention of soil erosion, etc.); planting intervals; tree species selection; effective use of space and soil moisture by means of mixed planting; density control (tree thinning, etc.), branch pruning, and root pruning.

Photo 26: A typical agro–forestry style
(Gentle slope; native trees + hedges + crop)

Photo 27: Tree planting by setting a compartment
(*Eucalyptus* + maize + other crops)

Photo 28: A typical agro-forestry
(Flat terrain; trees + green gram)

Photo 29: Hedge planting of *Grevillea robusta*

Photo 30: Intercropping under *Eucalyptus*

Important properties required for trees to grow well under agroforestry system are absorption of water primarily from soil depth different from that of crops; expected soil improvement effects by coexistence with nitrogen fixing bacteria; and a high capacity to supply organic nutrients. For plants used as hedge-row important factors for species selection include: promotion of surface runoff infiltration in to the soil and prevention of soil erosion; ease of planting and management; fast growth and benefits as fodder trees.

Tree spacing and the number of trees that can be planted are limited by the rainfall amount. In case of *Melia volkensii* planting in Kenya, 5 m interval is observed in Mbitini area, Kitui Country with annual rainfall below 900 mm (agro-climatic zone[*1)] V-2; mean annual temperature: 21 to 23°C) while 15 to 20 m interval is observed in Mutomo area, Kitui Country with annual rainfall of about 450 mm (agro- climatic zone V-1; 23 to 29°C) (Photo 31, 32). For the former case, the land owner explained that the original interval was 3 m but it was changed later to secure crop yields. The number of trees that can be grown on a given land size varies depending on differences in geography, weather, soil conditions and accumulated experiences of farmers.

Photo 31: An example of spacing for *Melia volkensii* (1)
Spacing: 5x5m
(Annual rainfall: 900mm below, mean a. temp.: 21–23 °C)

Photo 32: An example of spacing for *Melia volkensii* (2)
Spacing: 15–20 x 15–20m
(Annual rainfall: around 450mm, mean a. temp.: 23–29 °C)

Introduction of water harvesting techniques such as micro-catchments to promote water harvesting and infiltration of surface runoff water in to the soil, and planting of trees with root system in different development depths (water-use depth) are also important factors for effective use of soil moisture. Installation of micro-catchments is also effective for prevention of surface soil loss.

*) Concept and map of the Agro-climatic zone in Kenya is indicated at the end of this guideline.

4) Competition over water between crops and trees

a. Reality of competition

According to result of research, the effects of water competition on crop yields are much greater than those of shading in arid and semi-arid areas. Through the observation of crop yield when crop were intercropped with *Grevillea robusta* in Kenya, there were no effects of planted trees on crop yields for the first 2 years, but afterwards significant reduction of crop yields was observed. Maize yield was only a halved even in years of unusually high rainfall. A similar study with *Melia volkensii* revealed a yield decline of more than 50%, and negative effects on yields was confirmed in the range within 13 m from *M. volkensii* trunk.

In JICA's technical cooperation project in Kenya, maize and beans were intercropped with the width of 1 m (vegetation covering ratio by crops: 25%), 2 m (50%) and 3 m (75%) among *S. siamea* trees was planted at the intervals of 4 m (maize were planted in a reticular pattern at the intervals of 33 cm, and beans were sowed at the intervals of 16 cm between them). As a result, despite the crop yields in 50% crop acreage doubled compared to 25%, yields in 75% crop acreage presented no significant difference from 50% and negative effects on the growth in height of *Senna siamea* were observed. In this case, it was estimated that possibility of intercropping with the planting intervals of trees of 4 m is limited within 2 years.

b. Techniques to mitigate water competition

i. Thinning, Coppicing, Pruning and Pollarding

Competition for water by plants can be controlled by reducing plant biomass. Water consumption by planted trees can be regulated by reducing transpiration from leaves and limiting the range within which the root system is extending. Techniques to reduce transpiration include Thinning, Coppicing, Pruning and Pollarding. These techniques are commonly carried out to produce fuel wood, poles and fodder. These operations should be undertaken before the onset of the dry season to reduce water competition with crops during dry season. These management practices are applicable to evergreen and semi-deciduous tree species.

In Coppicing, sprouting capacity significantly varies with tree species. Although *Acacia* species are generally said to be poor in coppicing, some reports argue it is possible in some *Acacia* species. Since many of *Acacia* are important for fuel wood, it is important to research on conditions that may promote their coppicing. Even species for which coppicing is possible, sprouting capacity might decrease in the thickened portion. Generally, the portion of ≤10 cm in diameter maintains high sprouting ability. In the first felling, stem will be cut at 20 to 30 cm above ground height (Fig. 23). In the case of *Eucalyptus camaldulensis* coppicing in a semi-arid area in Kenya, sprouts grown to ≥8 cm in diameter were picked at 3-year cycle for pole production.

"Pruning" is applied in order to increase the value of wood in general. If high value-added timber production is the main purpose, branches should be pruned while they are still thin (Fig. 25). Generally, it is recommended to cut off branches up to two third of the tree height.

For "Pollarding", the trunk will be used as timber in the future, so the top branches are cut at the height of 1.5 to 2 m avoiding livestock browsing damages on sprout (Fig. 24). Grown sprouts are used as poles and fuel wood. Young sprouts and leaves may be used as livestock feedstuff depending on tree species.

ii. Root pruning

Root pruning mitigates water competition with crops. Roots are mostly pruned at 30 to 50 cm away from the trunk and at depths of 30 to 50 cm (Fig. 26). Roots are pruned by excavating trench which can be back-filled or be used as a water storage pit.

Root pruning inhibits the growth of planted trees therefore, this technique should be undertaken in consideration of economic impact caused by tree growth reduction. However, in some cases trees whose roots are pruned have revealed better growth rate than unpruned trees. This is likely to be as a result of rejuvenation of more efficient roots immediately after the pruning.

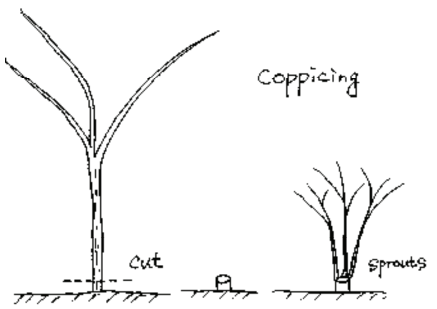


Fig. 23: Procedure for coppicing

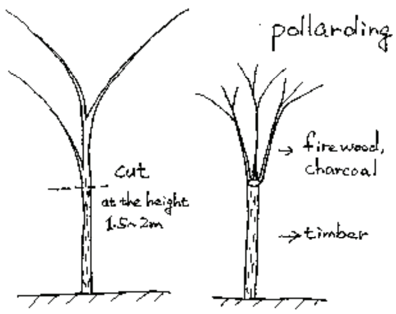


Fig. 24: Procedure for pollarding

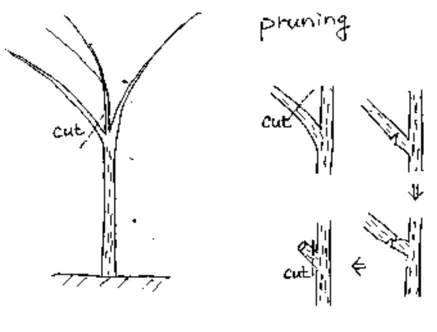


Fig. 25: Procedure for pruning

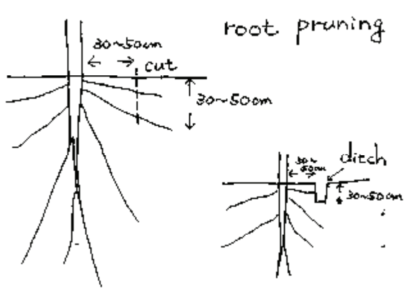


Fig. 26: Procedure for root pruning

Photo 33: Pollarding of *Lannea* sp.

Photo 34: Coppicing of *E. camaldulensis*

Photo 35: Pollarding of Mango trees

iii. Cultural control techniques to avoid water competition

Designing of spatial layout of plants (underground part)

As mentioned in an earlier part of this guideline, plants are segmented by using water at different depths under natural circumstances. By grasping the properties of root distribution of target plants and positioning them suitably, it may be possible to ensure effective use of the limited soil moisture and thereby increase the profit per unit area.

Crops such as pigeon pea, sorghum and pearl millet extend their roots vigorously at the depth of 2 m, 90 cm and near the ground surface, respectively. Maize develops its roots down to the depth of 75 cm from the ground surface while green gram and cowpea develop their roots deep and wide. Trees such as *A. nilotica* are deep-rooted and *Eucalyptus* species are generally known for development of the root system in horizontal directions along with its taproot. Tree species that can survive in arid areas are deep-rooted; however, there have been no in-depth study on these species except for a few species. Regarding water competition with crops, tree species that extend their roots horizontally in a vigorous way like *Eucalyptus*, must be avoided or given special management attention.

Designing distribution of growth period

Required growth period varies depending on crops; green gram can mature in 3 months, whereas pigeon pea matures in about 10 months. Effective use of soil moisture according to seasonal changes is possible by determining the crops that require a long growth period assuming a standard water shortage condition in the dry season, and planting early maturing crops in the rainy season.

5) Tree species suitable for agroforestry

Agroforestry is often expected to provide various forestry products for basic needs of local residents in the limited land area hence “Multipurpose trees” are positively selected. Such trees are sources of not only timber but also fuel wood, food, medicine, fodder, bee forages as well as functions of improving the environment (leafy shade and soil preservation) which are much prized. Planting many tree species rather than a single species is preferred to reduce the risks associated with mono culture.

During land preparation, indigenous tree species are often retained and there is no doubt that such species are already adaptable to the local environment. The choice of which species to spare should also be guided by tree utilization by local communities. This fact indicates that those trees are worth to be left without cutting despite the negative effect on water competition with crops.

Farmers who mainly plant *Melia volkensii* (for timber production) in semi-arid areas in Kenya (annual rainfall: about 450 mm, mean annual temperature: 23 to 29°C) have deviced a way of increasing diversity by planting other species such as; *Azadirachta indica* (timber and medicine), *Tamarindus indica* (timber and fruit), *Mangifera indica* (fruit) and *Annona senegalensis* (fruit tree). Also, they retaining useful indigenous trees species such as; *Acacia tortilis* (feedstuff and bee forage, etc.), *Sterculia* spp. (timber and fiber), *Adansonia digitata* (fruit and fiber), *Comiphora* spp. (timber), *Berchemia discolor* (fruit) and this shows their usefulness to the farmers.

Photo 36: *Acacia tortilis*

Photo 37: *Berchemia discolor*

Photo 38: *Combretum* sp.

Photo 39: *Adansonia digitata*

Photo 40: *Sterculia africana*

Photo 41: *Tamarindus indica* (planted)

Photo 42: *Senna siamea* (planted)

6) Planting in other areas than agricultural lands

a. Hedge planting

Thorn plants and toxic trees can be planted densely as hedges enclosing agricultural lands for prevention of livestock and human intrusion. Due to ease in establishment, *Euphorbia tirucalli* was planted for this purpose in Africa in the past. However, due to the risk of accidental ingestion of toxic sap by children and limited usage, the use of the species has declined. Thorn plants popularly used in Africa are *Dovyalis caffra* and *Acacia* species.

Characteristics required basically for such trees to be planted are: possibility of propagation by cuttings; tolerance to pruning; high adaptability to dense planting and ease in management. Preferential selection of tree species that can be used for other purposes such as for fuel wood and fodder is necessary for livelihood improvement.

Live fence species are densely planted, hence they have a negative effect on soil water. However, the number of trees to be planted may be reduced by using tree species whose branches can be raddled with those of neighboring trees. Tree species for which pruning and pollarding are possible should be selected. If the inside of the hedges is an agricultural land, additional management such as root pruning is required to prevent reduction of crop yields.

Photo 43: Hedge planting (*Euphorbia tirucalli*)

Photo 44: Direct planting of cuttings (*Euphorbia tirucalli*)

Photo 45: Fence of deadwood

b. Tree planting on Land Boundaries

In areas where land registration and administration system is incomplete, clarification of boundaries to third parties is the most important concern for land owners. Since trees are long-lived, they can be planted for boundary demarcation. In such cases, dense planting such as hedge line is not required. Therefore, planting intervals can be adjusted according to rainfall amount and financial status. Existing useful trees may also be used for this purpose.

For new planting, tree species are selected in consideration of the possibility to use them for timber and fuel wood. As with hedges' case, if the inside area is an agricultural land, to mitigate the water competition with crops, root pruning and branch pruning is required.

c. Tree planting within the compound (homestead)

Routine management of trees in the homestead is easy, therefore tree species whose value is commensurate with inputs used are often selected for this site. Improvement of living environment (leafy shade) and contribution to landscaping are also the selection criteria. Trees of high value such as timber trees, fruit trees and ornamental trees are preferentially planted within the compound/homestead. Water harvesting by micro-catchments and watering with a PVC tube should be applied depending on rainfall amount.

Photo 46: Boundary planting (*Grevillea robusta*)

Photo 47: Boundary planting (*Comiphora* sp.)

d. Tree planting in Grazing Land

For tree planting in grazing land, special care about water competition with other plants is not an important factor. Instead, consideration should be given to whether the area has sufficient rainfall amount for sound growth of planted trees. Micro-catchments structures cannot be maintained over a long period because they are frequently trampled by livestock. Since the grazing land is located away from residential areas, tree species that can endure extensive management must be selected.

Photo 48: Enclosure for grazing prevention

Planting of trees useful as source of fodder is required and criteria for selection include: high nutrition value; livestock's preference; absence of toxin and high coppicing ability.

Protection by fences is necessary after planting until trees develop firm roots and grow enough as fodder trees for livestock (Photo 48).

1. Capacity building on accurate information

From household interviews done in 2010 among 90 farmers (in Eastern Province, Kitui Country in Kenya) on farmers' perception about forests and water relationship, the majority of the residents noticed the positive effects of tree plantation on the water catchment. However most of them believed some false information such as re-afforestation can increase rainfall and raise the ground water level. Native species including *Acacia* spp., *Lannea* spp. and *Ficus* spp. and other species like *Grevillea robusta*, *Jacaranda mimosifolia* and *Tamarindus indica* were believed to have such positive effects, while only *Eucalyptus* spp. was thought to have adverse effects on water catchment (Josephine Musyoki, Pauline Bala, 2011, unpublished work). From the results of previous studies, about 70% of the farmers considered that *Melia volkensii* planted for agroforestry in their croplands can grow without competition or eliminate competition with crop if pruning is performed appropriately.

It was noted that there is lack of precise knowledge on the relation between water and trees (except *Eucalyptus*) hence dissemination of accurate information and knowledge is necessary. However, quality of guidance provided by forestry extension specialists is still not enough. Capacity building of residents is necessary for giving precise information about the function of re-afforestation on the local water resource, such as increase of water infiltration rate of forest soil, repression of evapotranspiration from forest floor and better rainwater use efficiency relative to bare lands. The lack of information poses challenges in designing appropriate agroforestry systems. It is important to establish a system (networks or platform) where those who are actually involved in on-site tree planting activities collect and accumulate hands-on information and share such information with local communities. Public research institutes should package their research findings on tree planting and management such that they are accessible to the local community members as much as possible.

2. Re-afforestation decreases the amount of available water

A forest can conserve water as a green dam, which can be effective for water storage, but cannot increase the rainfall (Hino, 2005). Besides, the water available to the downstream must be decreased by re-afforestation in upper reach because of a large amount of water consumption for evapotranspiration. When re-afforestation is done in bare land of Loess Plateau and evapotranspiration increases by 10 %, the amount of river flow is expected to decrease by 9 % (Zhang *et al.*, 2008). It is necessary to make it clearly known among the local community members concerned with re-afforestation in arid and semi-arid areas to restore vegetation has to exploit a large amount of water to maintain forest for long time. It could therefore decrease available water for other uses.

3. Water resource conservation

As water is used for various purposes and is essential for human life, re-afforestation techniques that can conserve water resources and minimize water loss from plantation areas should be developed.

Planted seedlings use only a small amount of water, but the water consumption increases continuously as trees grow big. As trees grow over many years, without any control of tree growth or leaf biomass, the water that flows out from the forest will continuously decrease for long period and a large amount of water is necessary for their transpiration until harvest. Therefore, re-afforestation should be designed in accordance with available water and management should be aimed at controlling water consumption for a long period so that the local water balance can be maintained.

4. Proper forest structure for wood production

From the mountain areas of Kenya, farmers were forced to move to arid low lands due to the increase in population and the immigrants planted trees around their settlement as they have done in their original area. These trees consumed a large amount of water which increased the pressure on the water resource and failed to harvest their agricultural production (Rumley *et al.*, 2006).

Re-afforestation should be conducted after clarifying the aim of forest production such as suitable size and form of timber and quantity of woody products. In other words, the desirable forest structure and its re-afforestation management methods must be proposed comprehensively taking into account of demands of residents, amount of local water resource, and physiological and ecological properties of planted trees.

5. Techniques appropriate to maintain stand density in low level

As forests in arid and semi-arid area play important roles in enhancing community livelihoods by supplying fuel wood and timber and contributing to environmental conservation e.g. soil protection, appropriate density control being most suitable for the aim of forest production is necessary. Sometimes it is also important to suppress timber production by well-timed control of tree density, because low stand density is not always preferable for the conservation of forest environment. In low-density stands, evaporation from the forest floor is promoted by strong solar radiation. Shrub forest can conserve soil condition by dense vegetation and produce fire wood. On the other hand, open forest can produce high quality wood material. Development of techniques appropriate to control stand density at low level in arid and semiarid area are necessary for the water resource conservation through a variety of researches. However, there have been no general research outcomes on low density control that are broadly applicable to different tree species.

6. Consideration for micro-scale differences in site condition

Even in wet area such as Japan with enough rainfall for tree growth, site conditions for re-afforestation largely vary with locations (upper or lower part of the slope and sides of the Sea of Japan or Pacific Ocean) and, as a result, tree species for plantation and their management methods also widely vary. Similarly, as conditions in arid and semi-arid area also largely vary with small differences in undulation and slope direction, tree species and management must be adopted in consideration of the difference in micro site conditions.

Annual rainfall in arid and semi-arid area largely varies from 10 mm to 800 mm (Yoshikawa *et al.*, 2004). Variation of rainfall significantly influences the changes in soil moisture content after plantation establishment. For example, if *Robinia pseudoacacia* (black locust) is planted in lands with sufficient amount of rainfall over 600 mm in annual average, the water retention capacity of soil is improved as the planted trees grow. On the other hand, planting of this tree species in arid area where drought occurs frequently will cause soil aridification (Jin *et al.*, 2011).

7. <u>The right tree in the right place</u>

Although the total amount of water is not sufficient in arid and semi-arid area, there are various forms of available water sources and many kinds of plants can inhabit with various life history strategies to enable them to use different water sources.

To secure a wide range of alternative selection of tree species appropriate for planting under different site conditions, growth characteristics of as many plant species as possible should be revealed. Very long period of management is necessary to achieve planting objectives because of slow rate of tree growth. Furthermore various types of tree form and forest structure are established depending on different procedures during long management period. Therefore long-term prospect is necessary for the selection of planting tree species.

8. <u>Monotonous and large scale plantation is impractical</u>

In order to mitigate the human pressure on remaining natural forests, tree plantation should be proactively promoted.However large-scale and monotonous plantations in arid and semi-arid areas should be avoided to conserve water resources, because of the difficulty to make consideration for the micro difference of site conditions.

However, large-scale plantations in arid and semi-arid areas should be done with a lot of precaution considering conservation of water resources. Most of the monotonous and large-scale re-afforestation in the northern China caused a drying up of the Yellow River due to the lack of consideration of local water balance. Moreover, most of them were conducted in degraded crop lands and mountainous barren land which were unsuitable for re-afforestation. Therefore any attempt of large-scale re-afforestation simply aiming to increase a forest biomass for carbon fixation poses a great risk of water source depletion and is not appropriate in arid area (Cao *et al.*, 2010).

To make matters worse, some big re-afforestation projects have succeeded to establish beautiful but tentative and small forest vegetation, which gives an impression that re-afforestation is possible even in a degraded barren land if a proper management is performed. However these short-term and small-scall outcomes should not support large-scale and long-term re-afforestation policies in arid and semi-arid area (Cao *et al.*, 2010) without a lot of precaution.

9. <u>Robustness under harsh and dry environment</u>

As the rainfall largely varies across years in arid and semi-arid area, forest structure and tree properties must have some drought tolerance for their sustainability.

Therefore re-afforestation techniques must focus on the securement of robustness of forest vegetation under harsh environment by the coordination of forest water consumption with the control of leaf biomass (=water loss from forest) based on the selection of tree species that can adjust its leaf biomass by itself (dieback) when there is low rainfall or during drought.

10. Difference between agroforestry and re-afforestation

Tree plantation should be started in consideration of the relation between forest and human life. Therefore, a completely different point of view of forest management is required between agroforestry tree planting within the compound and tree plantation established in the rural farms away from the settlement area.

Trees planted within the compound can be protected from illegal harvesting and livestock browsing hence maintaining a stable forest environment for tree growth. On the other hand, for re-afforestation in rural farms away from homestead has prerequisites such as low risk of illegal cutting. There are also other essential requirements such as selection of tree species suitable for extensive management and consideration of countermeasures such as fences to prevent livestock grazing. The most important concern for re-afforestation in such sites is the profits of grown trees and timbers. On the other hand, trees for agroforestry need to have positive effects on crops and to conserve and improve agricultural land conditions. There are clear differences between agroforestry in cropland and re-afforestation as concerns the management methods including tree species, planting density and management practices such as pruning. Re-afforestation in rural area requires consideration on water environment in scale of plantation area to eliminate adverse effects of tree growth on local water balance. On the other hand, trees for agroforestry are required to have positive effects on crops to conserve and improve conditions of farmland. Because agroforestry requires consideration on crop production to minimize adverse effects on yields of crops grown under planted trees.

11. Issues in agroforestry

Agroforestry is a result of compromise between forestry and crop production by segregation and competition over water. Apart from timber production, tree species used for daily life are often planted. Management techniques appropriate for tree species which are important for livelihood of residents but minor in commercial sense are less developed. For example, ecological and physiological properties of minor tree species are also less understood; distribution and capacity of water absorption of the root system that significantly affect interspecific competition for water with crops have not yet been revealed. However, a bottleneck of dry land agroforestry is the lack of crucial information about growth properties of respective tree species and management techniques appropriate for tree production that ensures effective use of space and water resources. It is necessary for the management of agroforestry to have consideration of the effect of tree growth on soil water in re-afforestation area which must be depressed as trees grow big.

12. Conclusions

New method of forest management which aims to conserve local environment and to develop human life is necessary to base on the precise information such as re-afforestation should depress the amount of available water both in the lower reaches and the concerned forest.

The selection of tree species and the execution of forest management are completely different between agroforestry and re-afforestation which support crop production and water resource cultivation, respectively.

As it is easy to consider unfamiliar environment to be a simple and monotonous condition, the necessity to select the right tree in the right place is hard to accept for re-afforestation in unfamiliar arid and semi-arid area. Even for the local residents who do not have any information about such delicate selection of tree species for re-afforestation around their residence shows a tendency to make simple and monotonous forest.

To secure a wide range of alternative selection of tree species being appropriate for re-afforestation objectives under different site condition, growth properties and way of nursing and cultivation of as many tree species as possible should be revealed.

Water in dry lands is an indispensable currency which can preside over all lives including human society.

Forest management based on the maintenance of local water balance is the fundamental issue for appropriate wood production corresponding to the initial objectives of sustainable development of forestry under persistent water consumption. New systematized techniques for re-afforestation in dry lands are desired to establish and to maintain the open forest with adequate tree density control. Especially to clarify the effects of tree density on the forest development, many kinds of forests which have precise past management history are necessary to compare growth properties under many kinds of site conditions. Then it is the issue of dry land forestry which should be started immediately, because a long time is necessary to establish suitable experimental forests.

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Annex 1

Determination of potential planting area

by

"ROC analysis" and "Classification tree models"

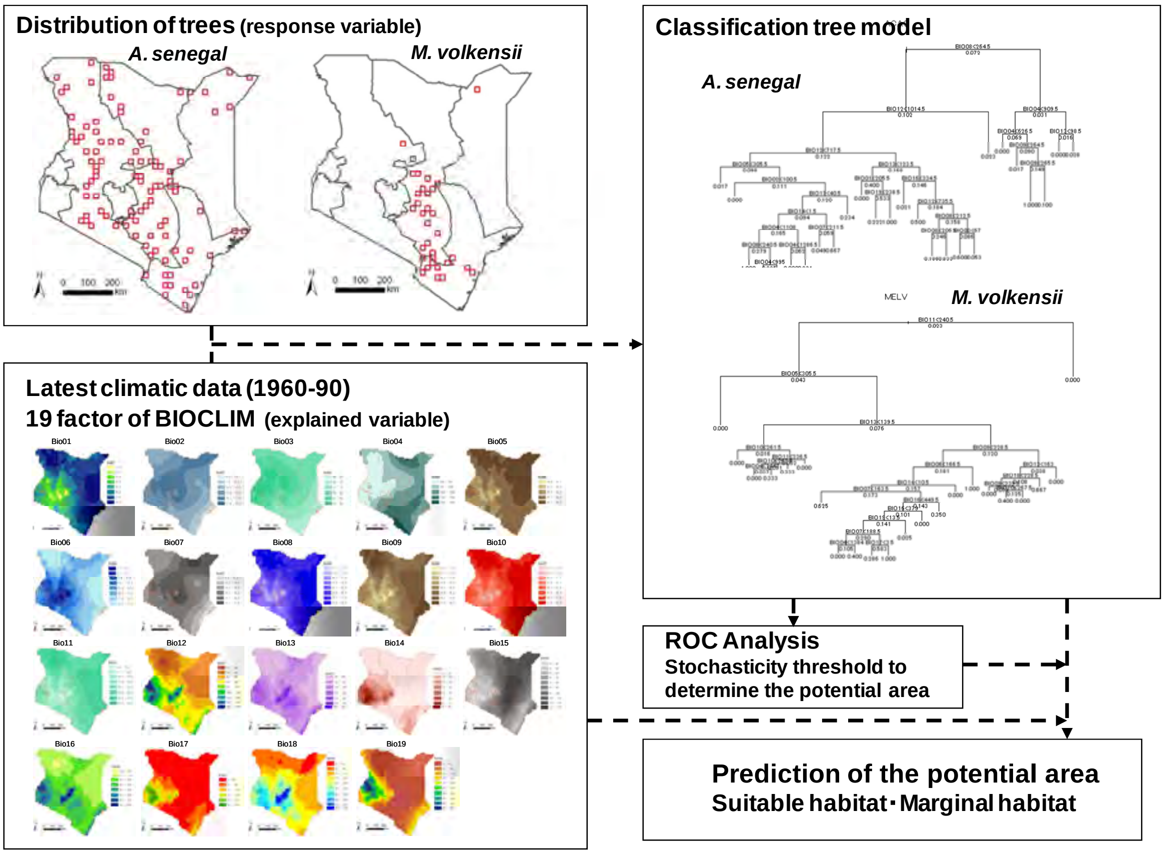
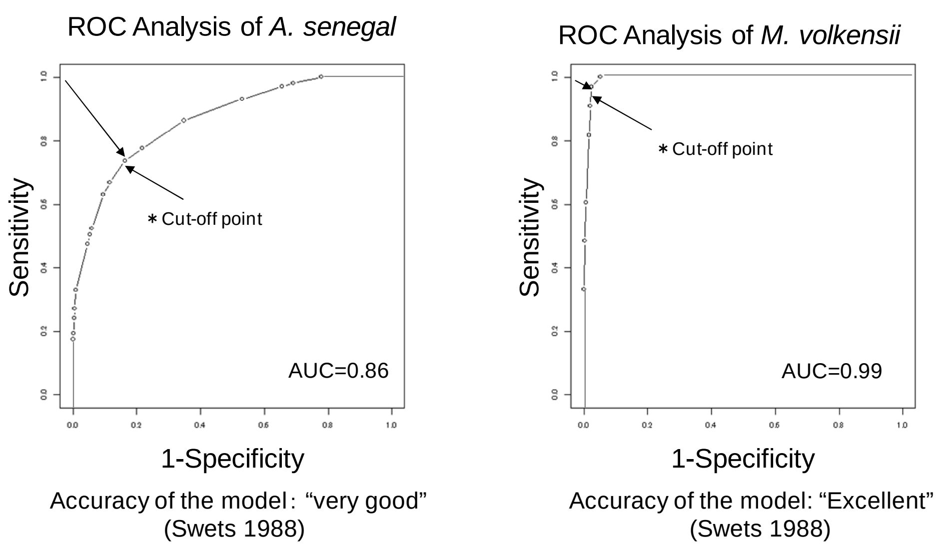


Fig. A–1–1: Flowchart for analysis

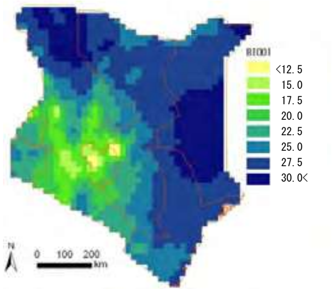


Suitable Habitat: The area where has much feasibility more than the cut-off point

Marginal Habitat: The area where has feasibility between 0.01 and cut-off point

Fig. A–1–2: Verification of the accuracy of the classification tree model and its feasibility threshold value

Fig. A-1-3: Map of 19 climatic factors by BIOCLIM and map of topography (altitude)



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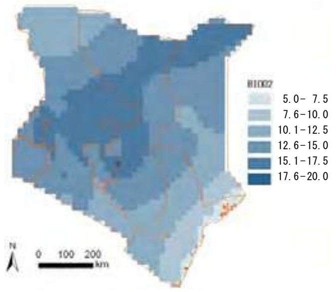

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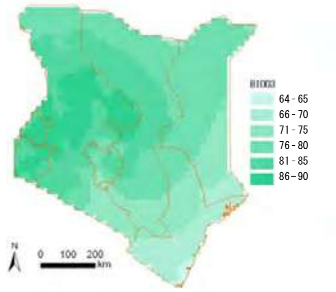
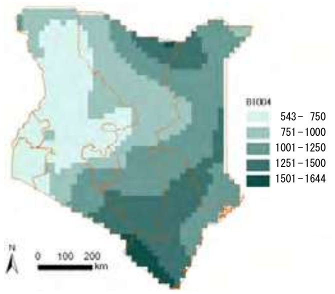
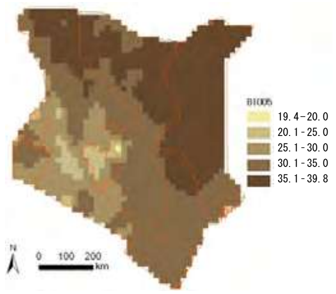


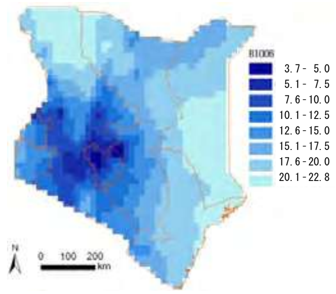
BI 03



BI 04



BI 05



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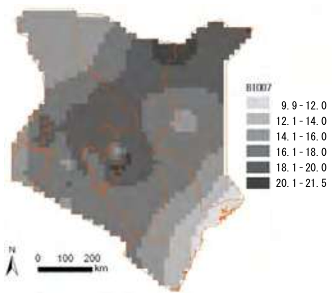
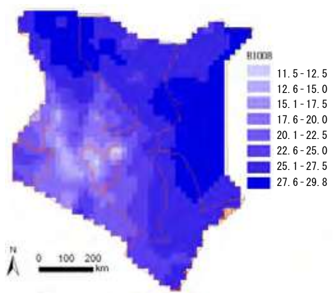
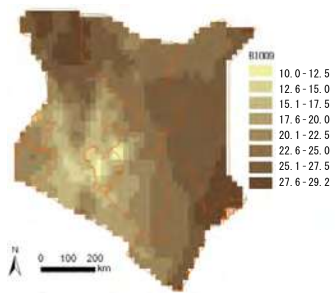


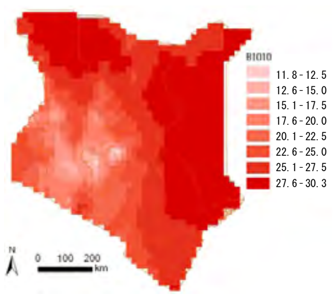
BI 07



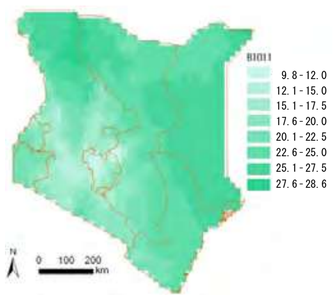
BI 08



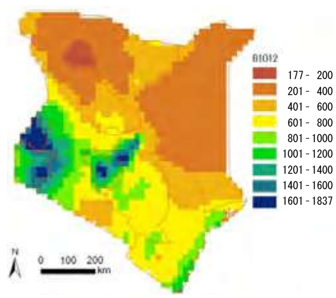
BI 09



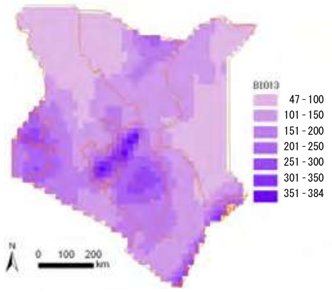
BI 10



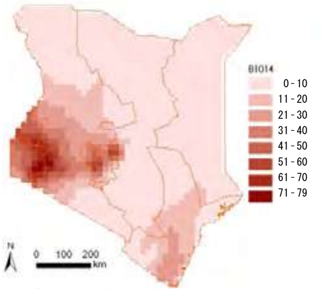
BI 11



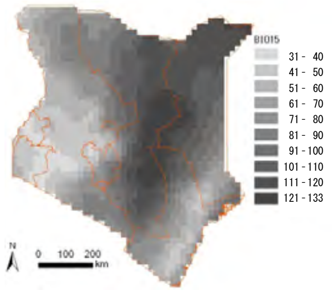
BI 12



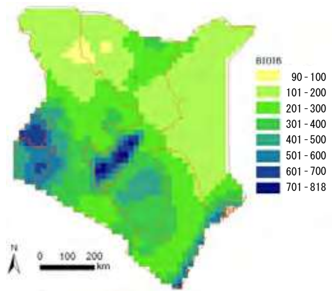
BI 13



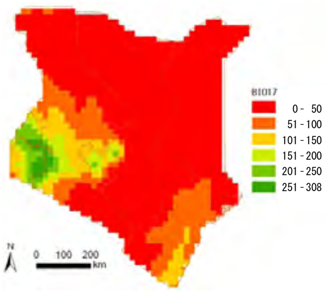
BI 14



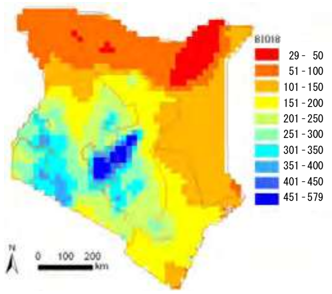
BI 15



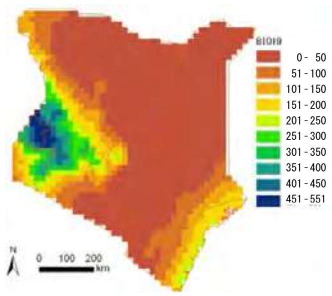
BI 16



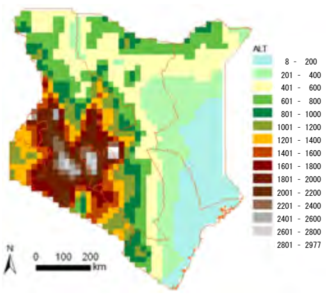
BI 17



BI 18



BI 19



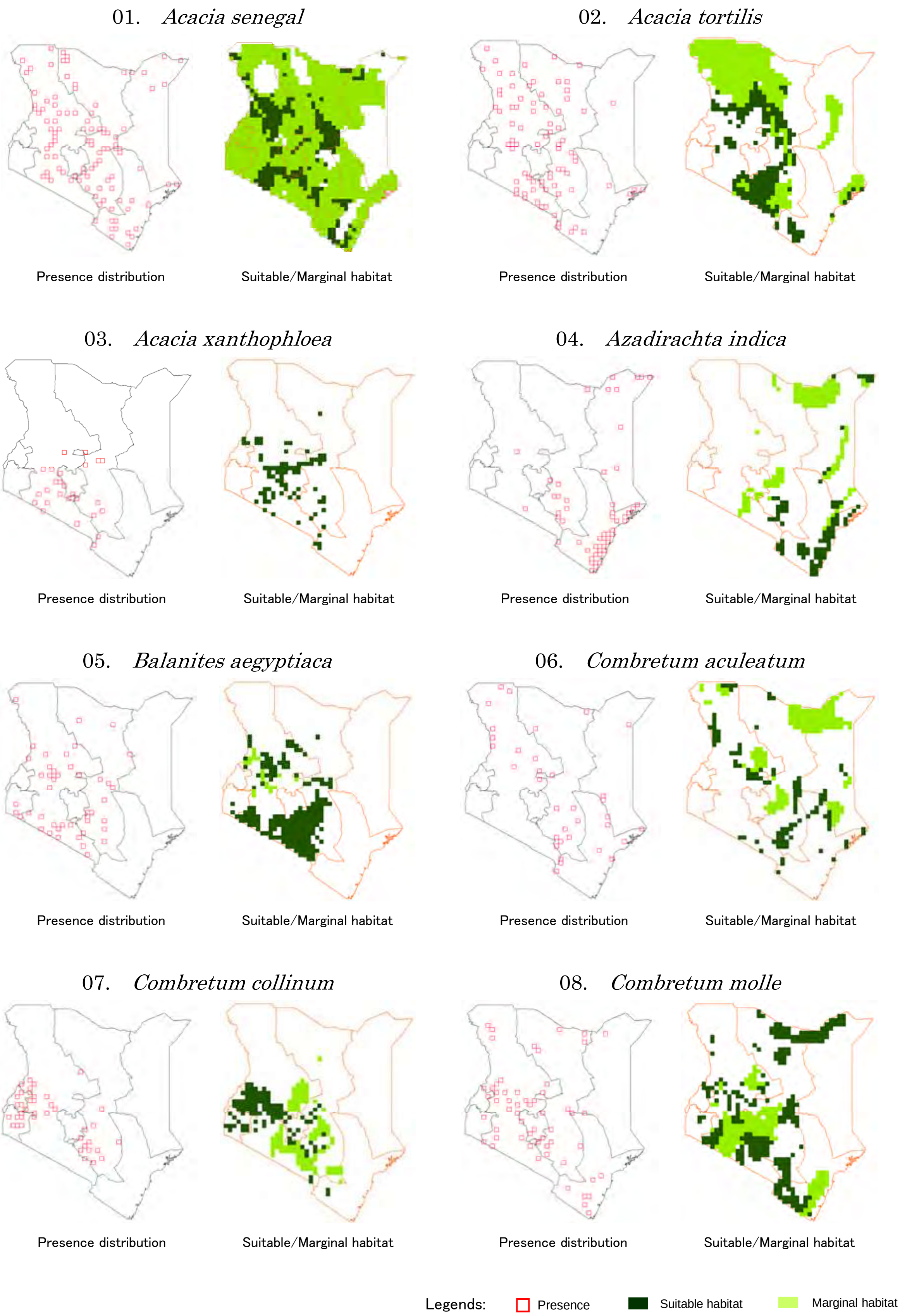
Altitude

Table A-1-2: Nineteen climatic factors of BIOCLIM

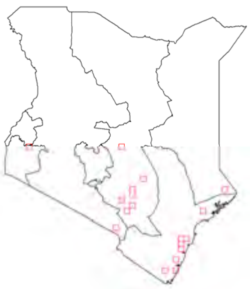
	Climatic Factor
BI01	Annual Mean Temperature
BI02	Mean Diurnal Range (Mean of monthly (max. temp. – min. temp.))
BI03	Isothermality (BI02 / BI07) (* 100)
BI04	Temperature Seasonality (standard deviation * 100)
BI05	Max. Temperature of Warmest Month
BI06	Min. Temperature of Coldest Month
BI07	Temperature Annual Range (BI05 – BI06)
BI08	Mean Temperature of Wettest Quarter
BI09	Mean Temperature of Driest Quarter
BI10	Mean Temperature of Warmest Quarter

	Climatic Factor
BI11	Mean Temperature of Coldest Quarter
BI12	Annual Precipitation
BI13	Precipitation of Wettest Month
BI14	Precipitation of Driest Month
BI15	Precipitation Seasonality (Coefficient of Variation)
BI16	Precipitation of Wettest Quarter
BI17	Precipitation of Driest Quarter
BI18	Precipitation of Warmest Quarter
BI19	Precipitation of Coldest Quarter

Fig. A-1-4: Present distribution and Suitable/Marginal habitat of each tree species



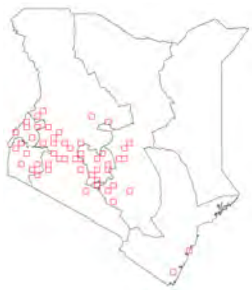
09. *Combretum shumannii*



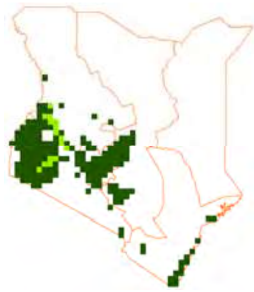
Presence distribution

Suitable/Marginal habitat

10. *Eucalyptus camaldulensis*

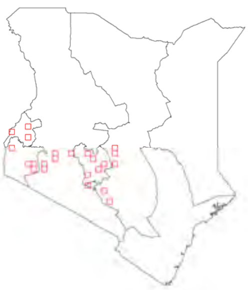


Presence distribution



Suitable/Marginal habitat

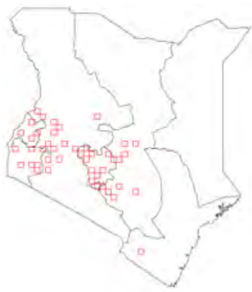
11. *Eucalyptus globulus*



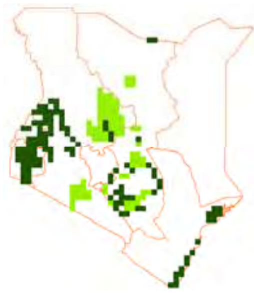
Presence distribution

Suitable/Marginal habitat

12. *Eucalyptus saligna*

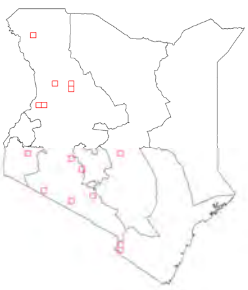


Presence distribution

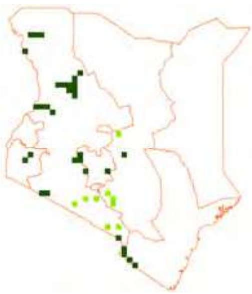


Suitable/Marginal habitat

13. *Faidherbia albida*

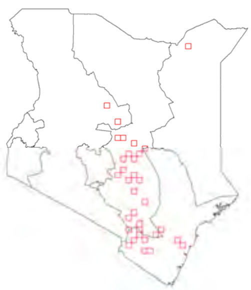


Presence distribution

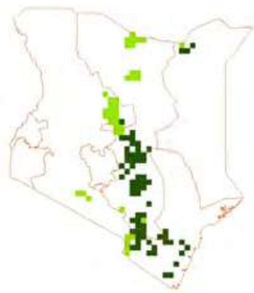


Suitable/Marginal habitat

14. *Melia volkensii*

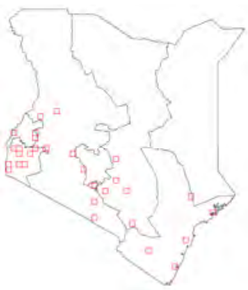


Presence distribution



Suitable/Marginal habitat

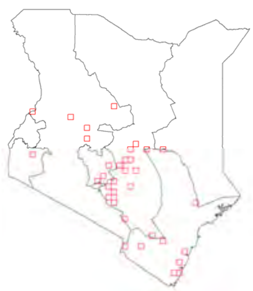
15. *Senna siamea*



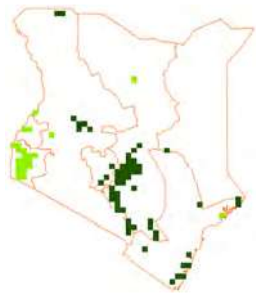
Presence distribution

Suitable/Marginal habitat

16. *Senna singuneana*



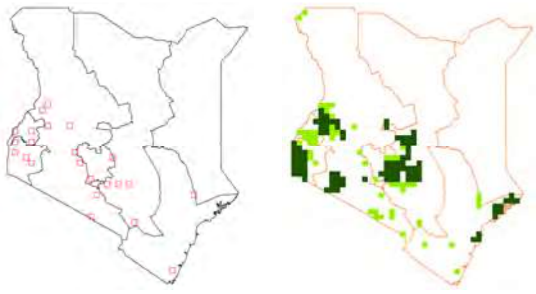
Presence distribution



Suitable/Marginal habitat

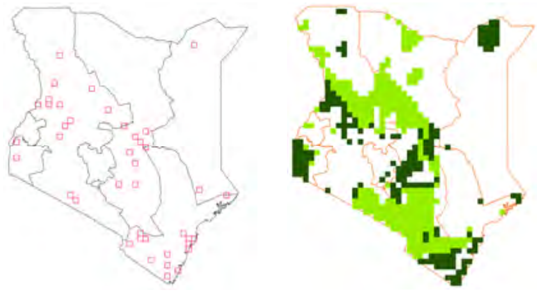
Legends: Presence Suitable habitat Marginal habitat

17. *Senna spectabilis*



Presence distribution　　Suitable/Marginal habitat

18. *Tamarindus indica*



Presence distribution　　Suitable/Marginal habitat

Legends: Presence　Suitable habitat　Marginal habitat

Table A-1-2: Deviance Weighted Score (DWS)

DWS (%)	Bioclim parameters																		
	BI 01	BI 02	BI 03	BI 04	BI 05	BI 06	BI 07	BI 08	BI 09	BI 10	BI 11	BI 12	BI 13	BI 14	BI 15	BI 16	BI 17	BI 18	BI 19
Acacia senegal	2.7	2.8	4.2	**14.5**	3.2	0.0	3.6	**20.2**	10.9	0.0	0.0	14.2	3.0	3.3	0.0	9.0	3.7	0.0	4.9
Melia volkensii	0.0	0.0	0.0	4.7	**16.5**	6.2	7.4	0.0	7.1	7.0	**20.0**	0.0	12.2	2.0	0.0	6.0	3.4	2.7	4.8
Acacia nilotica	2.0	0.0	0.0	9.2	**29.4**	0.0	4.0	0.0	2.7	7.3	0.0	**20.5**	2.4	0.0	13.1	3.0	3.1	0.0	3.3
Acacia tortilis	0.0	3.3	0.0	**15.9**	0.0	7.7	10.1	0.0	3.5	**19.7**	0.0	0.0	5.8	14.6	6.0	2.7	5.5	5.2	0.0
Acacia xanthophloea	0.0	0.0	0.0	3.0	12.5	2.6	3.1	0.0	**31.0**	0.0	0.0	**27.1**	0.0	2.3	0.0	3.7	5.5	9.3	0.0
Azadirachta indica	1.9	**36.1**	3.9	**14.1**	5.8	3.3	6.2	4.0	0.0	1.1	0.0	5.4	0.0	3.6	9.8	0.0	5.0	0.0	0.0
Balanites aegyptiaca	6.1	**10.1**	0.0	7.6	8.5	**38.9**	3.1	0.0	0.0	7.5	0.0	3.4	0.0	2.9	0.0	5.4	2.8	3.9	0.0
Combretum aculeatum	7.6	3.7	4.2	9.1	0.0	4.1	9.4	4.0	3.6	0.0	3.5	8.2	0.0	**13.8**	3.7	4.5	0.0	**16.0**	4.5
Combretum collinum	0.0	4.7	0.0	9.4	3.7	2.7	0.0	3.3	5.3	3.4	0.0	3.6	9.0	0.0	0.0	3.3	0.0	**40.5**	**11.1**
Combretum molle	12.1	4.3	8.1	**15.9**	0.0	**28.8**	3.0	0.0	2.2	0.0	0.0	11.2	14.3	0.0	0.0	0.0	0.0	0.0	0.0
Combretum schumannii	**33.4**	8.7	0.0	0.0	7.3	0.0	0.0	2.4	0.0	2.3	0.0	4.8	9.4	0.0	5.5	**23.2**	3.1	0.0	0.0
Eucalyptus camaldulensis	4.1	3.0	0.0	**10.1**	3.3	0.0	2.6	0.0	3.5	**10.1**	3.4	**49.7**	6.3	0.0	0.0	0.0	0.0	0.0	4.0
Eucalyptus globulus	0.0	3.0	4.3	4.2	0.0	0.0	7.3	0.0	4.5	0.0	0.0	**48.9**	0.0	0.0	0.0	**17.3**	7.7	2.8	0.0
Eucalyptus saligna	0.0	0.0	3.2	0.0	0.0	0.0	6.8	0.0	0.0	4.9	7.3	**45.8**	4.8	2.0	0.0	8.5	0.0	**13.9**	2.8
Faidherbia albida	0.0	0.0	0.0	**28.2**	0.0	0.0	**15.5**	0.0	0.0	0.0	0.0	15.0	9.2	0.0	0.0	0.0	8.8	8.6	14.9
Prosopis chilensis	5.2	13.7	0.0	**20.3**	3.8	6.4	**14.7**	0.0	17.4	0.0	0.0	0.0	0.0	0.0	11.5	4.1	0.0	3.0	0.0
Senna siamea	3.4	0.0	0.0	**13.1**	**33.7**	2.3	0.0	5.9	0.0	0.0	0.0	3.0	7.0	0.0	5.6	8.4	3.6	3.7	10.4
Senna singuneana	10.6	3.9	0.0	12.1	0.0	6.5	0.0	0.0	0.0	0.0	7.9	**18.1**	**27.8**	0.0	0.0	9.5	0.0	3.8	0.0
Senna spectabilis	6.1	0.0	0.0	7.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	**26.6**	13.9	8.8	0.0	**14.0**	0.0	12.5	10.5
Tamarindus indica	7.4	3.4	0.0	6.8	**27.6**	2.5	4.9	0.0	0.0	0.0	7.8	4.6	3.9	0.0	9.2	**11.1**	4.7	0.0	6.2

BI 01　Annual Mean Temperature
BI 02　Mean Diurnal Range (Mean of monthly (max temp − min temp))
BI 03　Isothermality (BIO2/BIO7) (* 100)
BI 04　Temperature Seasonality (standard deviation *100)
BI 05　Max Temperature of Warmest Month
BI 06　Min Temperature of Coldest Month
BI 07　Temperature Annual Range (BIO5-BIO6)
BI 08　Mean Temperature of Wettest Quarter
BI 09　Mean Temperature of Driest Quarter
BI 10　Mean Temperature of Warmest Quarter
BI 11　Mean Temperature of Coldest Quarter
BI 12　Annual Precipitation
BI 13　Precipitation of Wettest Month
BI 14　Precipitation of Driest Month
BI 15　Precipitation Seasonality (Coefficient of Variation)
BI 16　Precipitation of Wettest Quarter
BI 17　Precipitation of Driest Quarter
BI 18　Precipitation of Warmest Quarter
BI 19　Precipitation of Coldest Quarter

Tree species that has high drought-tolerance

1) 15 highly drought-tolerant tree species and its characteristics

- *Acacia nilotica* (L.) Del. (subsp. Nilotica)
- *Acacia senegal* (L.) Willd.
- *Acacia tortilis* (Forssk.) Hayne
- *Acacia xanthophloea* Benth.
- *Azadirachta indica* A. Juss.
- *Balanites aegyptiaca* (L.) Del.
- *Combretum* spp. (*C. aculeatum*, *C. collinum*, *C. molle*, *C. shumannii*)
- *Eucalyptus camaldulensis* Dehnh
- *Eucalyptus saligna* Smith
- *Faidherbia albida* (Del.) A. Chev.
- *Gliricidia sepium* (Jacq.) Walp.
- *Grevillea robusta* A. Cunn. ex R. Br.
- *Melia volkensii* Guerke
- *Senna siamea* (Lam.) Irwin et Barneby
- *Tamarindus indica* L.

2) List of highly drought-tolerant tree species distribute in Kenya

Acacia nilotica (L.) Del. (subsp. *nilotica*) (Fabaceae)

General description

Moderate-sezed evergreen tree, with a short , thick and cylindrical trunk, growing to a height of 25 m. It has considerable variation with nine subspecies presently recognized, three occurring in the Indian subcontinent and six throughout Africa. (1).

Environmental reqirements

Altitude	0-1340 m a.s.l. (1)
Mean annual rainfall	200-1270 mm (1)
Soils in natural range	Grows on a wide variety of soils, thriving on alluvial soils, black cotton soils, heavy clay soils, and can tolerate poorer soils. (1)
Soil water regimes	Drought resistant and occurs in plain, flat or gently undulating ground and ravines (1). The subspecies nilotica is adapted to periodic flooding followed by extended droughts (2).
Suitable site for planting	Strong light requirement. Grows best on alluvial soils in ravine areas subject to periodic inundation (1) but also grow well on heavy, clay soil with a pH range of 5 to 9 (2).
Root system	Forms a deep and extensive root system on dry sites, the tap root developing first and then the laterals, which become compact and massive, but on flooded sites the root system is largely lateral (3).

Phenology and Ecophysiology

Phenology

The trees generally lose their leaves during the dry season, though riverine subspecies can be almost evergreen.The flowers are bright yellow and borne on globe-shaped flower heads. The flowers are sweetly scented and appear near the beginning of the rainy season. Flowering is prolific, and can occur a number of times in a season. Often only about 0.1% of flowers set pods. The nutritious pods retain their seeds at maturity and are dispersed by animals (2).

Ecophysiology of water use

According to the experiment comparing water use of four species (*Acacia nilotica, Albizia procera, Azadirachta indica and Eucalyptus camaldulensis*) grown in pots in a green house, water consumption by one year old *Eucalyptus* was more than three times that of by *Acacia* and *Azadirachta*. However, water use efficiency was found as 0.32 g L^{-1}, 0.48 g L^{-1}, 0.16 g L^{-1} and 0.77 g L^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively (6). *A. noltica,* also other two native species, showed traits of low water comsumption and small biomass production in comparison with *E. camludulensis*.

Benefit and Products (1, 2)

Reclamation: In India, this species is used on degraded saline and alkaline soils.
Medicine: It is used for stomach upset and pain, the bark is chewed to protect against scurvy, an infusion is taken for dysentery and diarrhoea.
Poison: The aqueous extract of the fruit, rich in tannin (18-23%), has shown algicidal activity against*Chroccoccus, Closteruim, Coelastrum, Cosmarium, Cyclotella, Euglena, Microcystis, Oscillatoria, Pediastrum, Rivularia*, and etc.
Food: Tender pods and shoots are used as a vegetable, and roasted seed kernels are sometimes used in Sudan for food flavouring. Air-dried seeds contain crude protein and are eaten raw or roasted in India in time of acute food scarcity.
Fodder: The crude protein content of the leaves is 14-20%, and 11-16 % for the highly palatable pods. Pods and shoots are used as forage for camels, sheep and goats, especially in Sudan, where it is said to improve milk from these animals.
Apiculture: The fragrant flowers are popular bee forage.
Fuel: The calorific value of the sapwood is 4500 kcal/kg, while that of the heartwood is 4950 kcal/kg. This valuable source of firewood and charcoal has been used in locomotives, river steamers and small industries. In India and Pakistan riverine plantations are managed on a 15-20 year rotation for fuel wood and timber.
Tannin or dyestuff: The pods have been used for tanning in Egypt for over 6 000 years. The inner bark contains 18-23% tannin, which is used for tanning and dyeing leather black.

Tree Management

Planting and weeding

The species will tolerate only light frost, but is extremely resistant to drought and heat. It is also tolerant of saline soil. Young trees coppice well, and the species can be propagated from truncheons, root suckers and cuttings.But the subspecies *nilotica* coppices very weakly (1). Some subspecies can be invasive (and can be extremely invasive in exotic habitats). The species can be direct seeded or established by seedlings. In the nursery long poly-tubes (20 x 7 cm) should be used so as not to restrict rapid tap root growth. Frequent root pruning is advised. Nursery grown seedlings are usually planted out after six months, but in some cases stay in the nursery for up to a year. Establishment varies depending on the site. Seedlings are shade intolerant(2). Young seedlings are said to require full sun and frequent weeding(1).

Agroforestry

In the Central plain of Indian subcontinent*A.nilotica* grow naturally in the agricultural fields and forms an important agroforestry system. It was reported that*A. nilotica* generally reduced crop yield under its canopy and this reduction varies with distance from the tree trunk. Crop production depend upon distance from tree trunk and tree canopy size. Reduction in grain yield was maximum (30%) under the large tree canopy and lowest (12%) under the small tree canopy due to decreased availability of light by 44 to 62% under the canopy that resulted in slow photosynthetic rates and growth(4). However, when the tree is felled after the completion of rotation cycle (>12 years) grain yield increased 126% for the first cropping season and 30 % for the fifth cropping season at 1 m distance from the tree stump and declined with distance(5). These results suggest that the crop may exploit the greater amount of nutrients to increase productivity, if the tree canopy is open to facilitate greater light availability.

When intercropped with *A. nilotica* ssp. *nilotica* in semi-arid Nigeria, sorghum showed heavily depressed yields (1).

Plantations for timber production

Since the time of the Pharoahs, large timber trees have been exploited from the riverine forests of the Nile. Sapwood is yellowish-white and heartwood reddish-brown, hard, heavy, durable, difficult to work, although it takes a high polish. Because of its resins, it resists insects and water, and it is harvested for boat making, posts, buildings, water pipes, well planking, ploughs, cabinet work, wheels, tool handles, carts, mallets and other implements. It is an attractive wood, good for carving and turnery. Sudan forests have been managed on a 20-30 year rotation producing termite resistant timber especially suitable for railway sleepers(1).

In irrigated plantations in the Sind and Punjab, 10-15 seeds are spot sown at 2 x 3 m spacing on the tops of trenches. They are thinned to three to four seedlings after three to four months. Further thinning occurs at five year intervals. Rotations are 20-25 years. In the Thal desert, Pakistan (where there is 250 mm annual rainfall), promising growth resulted from irrigation at ten day intervals. Growth rates varied considerably depending on the sites, with maximum mean annual increment of 13 m3 /ha at 20 years old and 10.5 m3 /ha at 30 years recorded (2).

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(2) Royal Botanic Gardens, Kew. *Acacia nilotica* (acacia) http://www.kew.org/plants-fungi/Acacia-nilotica.htm
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Acacia senegal (L.) Willd. (=*Senegalia senegal* Britton) (Fabaceae)

General description

Small deciduous tree, usually branched from the ground, growing to a height of 5-12m with a trunk up to 30 cm in diameter. Native to semi-desert regions of Sub-Saharan Africa, as well as Oman, Pakistan, and northwestern India (1).

Environmental reqirements

Altitude	100-1,700 m a.s.l. (1)
Mean annual rainfall	300-450 mm (1)
Soils in natural range	coarse-textured, deep sandy soils to dry, rocky soils, slightly acidic to moderately alkaline (1)
Soil water regimes	Drought and heat resistant (6), tolerates seasonal inundation (4), intolerant to to water-logging (1)
Suitable site for planting	Mainly sandy soils with pH 5-8, but also grows well in cotton soil , requiring strong light (1, 6). Gum production is better on poor soils and higher in stressed trees (1).
Root system	Deep rooted, when water is only available at great depth, deeply penetrating tap roots can develop up to 30 m in depth (6).

Phenology and Ecophysiology

Phenology

The tree usually flowers during the rainy season and loses its leaves during the dry season (1, 6).

In Tiva Experimental Forest (Kitui, Kenya), it flowring peak is in February-March and July-August in the end of dry season. Most fruits ripen in July-August. Leaves flush mostly in the rainy seasons (December-January and March-April), and turn red from December reaching its peak in January to February. Canopy coverage reaches 60 - 80% in December and March-April and decreases to 40 - 55 % in Junaury-February and May-November. Radial growth occurs twice a year in October-early December and late December-mid January.

Ecophysiology of water use

Occasional favourable rainy seasons trigger explosive natural regeneration. This explains the occurrence of large even-aged stands on sandy soils with no apparent capacity to retain water. The species also grows in thick stands on alluvial soils in depressions that have collected fine alluvial material (4).

Benefit and Products

Gum or resin: Gum arabic exudes from the duct of the inner bark; it is tapped in the hot season (May-June) when the trees are stressed. Tapping commences after leaf fall and ceases during the colder months of the dry season. Gum nodules form in 3-8 weeks, exuding from the former broken abscission scars. Annual yields stand at 188-2856 g for young trees and 379-6754 g for older trees (7-15 years). Gum production is excellent on poor soils and higher in stressed trees(4).

Food: The seeds are dried and preserved for human consumption as a vegetable(1).

Fodder: Leaves and pods are browsed by sheep, goats and camels. Crude protein values are 20% for leaves, 22% for green pods, and 20% for dry pods (expressed as a percentage of dry matter)(1).

Apiculture: Bees seek the nectar from the flowers. Honey amber in colour, with a mild aroma and granulates rapidly(1).

Fuel: An excellent fuelwood, the calorific value is estimated at 3000 kcal/kg. The dense wood also yields charcoal(1).

Fibre: The long, flexible surface roots yield a strong fibre used for cordage, ropes and fishing nets(1).

Timber: The heartwood is almost black and takes polish well. It is used for making carts and Persian wheels, sugar cane crushers, agricultural implements, horse girths and tool handles. Essential oil: Seeds contain fat (khakhan), which is used both for medicine and for soap making. Medicine: Roots are used to treat dysentery, gonorrhea and nodular leprosy(1).

Tree Management

Planting and weeding

Weeding should be immediate in the season following planting and for the following 2 growing seasons. Seedlings are rather slow growing with initial annual increments of 30-40 cm. Protection of young trees from livestock browsing is essential (1).

Microcatchment water harvesting was introduced by the SOFEM Project* and v-shaped cactchments are more registant to erosion than w-shaped ones (9). Soil moisture contents increase in the the microcatchments preventing surface runoff of rainwater (8).

Agroforestry

Today, *A. senegal* is grown primarily for gum, but plays a secondary role in agricultural systems, restoring soil fertility and providing fuel and fodder. It is a highly suitable tree for agroforestry systems, widely grown in combination with watermelon, millets and forage grasses (1). The study on nitrogen fixation of three varieties of *A. senegal* revealed their ablity to fix nitrogen from the air in their natural ecosystems.The species, hence, can be utilized as plantations in agriculture and land rehabilitation programs (5, 7). In Sudan, it is grown in 'gum gardens' for gum as well as to restore soil fertility. A traditional bush-fallow system is followed with a 20-year rotation during which time it is grown for 15 years. Agricultural crops are grown for five years (millet, sesame, sorghum, groundnuts), followed by five years with young, unproductive *A. senegal* trees, which later produce gum during the last 10 years of the rotation. Corresponding to this rotation, 1/4 of the land is kept in agricultural crops, 1/4 in young unproductive trees and 1/2 in productive trees (1).

Plantations for timber production

For firewood production, trees can be cut on a rotation of 20 years using coppice with standards, lopping up to 50% of the lower crown in rainy season. Seedlings are rather slow growing with initial annual increments of 30-40 cm. For firewood production, trees can be cut on a rotation of 20 years using coppice with standards, lopping up to 50% of the lower crown in rainy season. Wood yields of 120-190 cubic metres per hectare, with annual increments of 0.5-1.0 cubic metres per hectare have been recorded (1).

Plant spacing experiment in Tiva Experimental Forest (Kitui, Kenya) showed that height growth of trees were not differed among the spacings until 14 years of age when it seems to reach its peak. At 15 yeas old, the mean tree height in 5 m x 5 m spacing (height 5.5 m tall) was significantly lower than that in 1 m x 1m spacing (height 7 m tall). and reached almost its peak (ca. 12 m) at 10 years old. Total stand volumes were not diffrent among the spcings. On the contrary, stand basal area and mean stem volume were significantly small in 1 m x 1 m spacing than other spaccings. From the view point of timber production at 15 years of age, the spacing 5 m x 5 m seems to be best with most stems >= 11 cm in dbh.

* The Social Forestry Extension Model Development Project (SOFEM: 1997-2002) by Japan International Cooporation Agency (JICA)

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(2) Beentje, H. J. (1994) Kenya Trees, Shrubs and Lianas. National Museums of Kenya, Nairobi, Kenya, 722pp.

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Acacia tortilis (Forssk.) Hayne (Fabaceae - Mimsoideae)

General description

Small to medium-sized evergreen tree or shrub that grows up to 21 m tall; well-developed multiple boles support a flat-topped or rounded, spreading crown (1).

Environmental reqirements

Altitude	0-1000 m (1)
Mean annual rainfall	100-1000 mm (1)
Soils in natural range	The tree favors alkaline soils and grows in sand dunes, sandy loam, rocky soils and other soils that drain well. It also does well on light brown, sandy soil with little or no calcium carbonate, and pH ranges of between 7.95-8.30 (1).
Soil water regimes	*A. tortilis* is drought resistant, can tolerate strong salinity and seasonal waterlogging (1).
Suitable site for planting	*A. tortilis* generally forms open, dry forests in pure stands or mixed with other species. It grows fairly well even on shallow soils less than 25 cm deep (1).
Root system	The long taproot and numerous lateral roots enable it to utilize the limited soil moisture available in the arid areas (1). *A. tortilis* behaves as a phreatophyte, with aquifers as deep as 40 -50 m or more (6).

Phenology and Ecophysiology

Phenology

A. tortilis is an evergreen tree and a hermaphrodite. In India, trees flower between May and June and fruit by mid July, and in Nigeria flowers appear in May-June and fruits in July (1).

Ecophysiology of water use

A. xanthophloea showed greater (40 kg d^{-1}) water use compared to *A. tortilis* trees of comparable sizes (20 kg d^{-1}) during favorable conditions of soil water availability (SWC). Decline in SWC reduced water use and the onset and rate of decline in sap flux was determined by the rooting depth (2).

Benefit and Products (1, 4)

Fodder: It is an important source of fodder for cattle in India, West Africa, Somalia and Ethiopia. Foliage and fruits form important browse. A 10-year-old A. tortilis yields about 4-6 kg dry leaf and 10-12 kg pods per year(1). Pods and leaves have a good level of digestible protein (mean = 12%) and energy 6.1 MJ/kg dry matter, as well as being rich in minerals. Seeds are high in crude protein (38%) and phosphorus, an element usually scarce in grasslands(4).
Fuel: Fuel: *A. tortilis* starts producing fuelwood at the age of 8-18 years, at the rate of 50 kg/tree. Its fast growth and good coppicing behaviour, coupled with the high calorific value for its wood (4400 kcal/kg), make it suitable for firewood and charcoal.
Poison: *A. tortilis* is a powerful molluscicide and algicide. The fruits are placed in fish ponds to kill the snail species that carry schistosomiasis, without affecting the fish.
Medicine: The dried, powdered bark is used as a disinfectant in healing wounds; in Senegal it serves as an anthelmintic. In Somalia the stem is used to treat asthma. Seeds are taken to treat diarrhoea.
Tannin or dyestuff: The bark is reported to be a rich source of tannin.
Boundary, barrier or support: The thorny branches are suitable material for erecting barriers.

Tree Management

Planting and weeding

Plantation by direct seeding of treated seeds should always be preferred in order to avoid the trauma of transplanting and disturbing the tap-root that grows about ten times faster than the stem(6).

The plant assumes shrubby growth and must be widely spaced for the lateral root growth. Planting is done in pits 60 cm deep dug at a spacing of 5 x 5 m and filled with weathered soil. If raised as a windbreak, 3 rows are planted spaced at 9 x 10 m, and 50 gm/plant of ammonium sulphate is applied at watering time. Plants grow to about 1.5 m in 2 years, should be protected from grazing and mulching should be practised. 2 weedings in the 1st year and 1 in the 2nd year are considered sufficient(1).

Containerized seedlings may be planted at about 10 months when 0.5 m to 1 m tall, in pits 60 cm^3. Recommended spacing is 3×3 m to 5×5 m, on sites with deep, sandy soil. Young plants in plantations as well as natural regeneration require protection from browsing for 3 to 5 years. Mature plants tolerate heavy browsing. Suppression of weed competition is essential initially(5).

Agroforestry

Studies conducted on its nitrogen-fixing ability, photosynthetic efficiency, seedling morphology and drought resistance have shown that it is relatively a better species than *Prosopsis juliflora* (1).

Poor herbaceous growth under *A. tortilis* has been reported. In India clusterbean, cowpea and mothbean are said to have failed when planted in association with *A. tortilis*. However, yields of mungbean, and sorghum have been shown to increase when lateral roots of *A. tortilis* are trenched (1). Probably through hydraulic lift by *A. tortilis*, which improves the water status of the upper soil layers and allowing water access by shallow rooted plants (3). On an average the full grown canopy of *A. tortilis* at the spacing of 4x4 m allowed 55% of total Photosynthetically Active Radiation which in turn increased Relative Humidity and reduced under canopy temperature to -1.75°C over the open air temperature. *Cenchrus ciliaris* (buffelgrass or African foxtail grass) attained higher height under the shade of *A. tortilis* (3). *A. tortilis* is a good shade tree for people and for silvipastoral agroforestry uses in arid areas. It is not good for intercropping or near farmland due to wide, shallow roots. Useful for sand dune stabilization, shelterbelts along canals and roads, and in sandy arid areas. It is recommended for semiarid areas on sandy soils with low rainfall, for fuelwood production. Plantations have been established in India (5).

Plantations for timber production

The timber is used for planking, boxes, poles, moisture-proof plywood, gun and rifle parts, furniture, house construction and farm implements. The wood is moderately soft, not very strong, and is readily attacked by decay-causing fungi and insects. It should be promptly converted after felling and subjected to rapid drying conditions (1).

Eleven-year old trees in deep sandy soils at Jodhpur averaged 6.4 m tall and 14 cm DBH. In shallow sandy loams over hardpan at Pali, India, 7-year old trees (98% survival) averaged 4.8 m tall, and 10 cm DBH. In sanddunes at Barmer, India, 5-year old trees averaged 3 m tall, 7 cm DBH. An average tree yields 6 kg pods of which 2.6 kg is clean seed. One tree is said to yield 14–18 kg pods and leaves per year in India (Muthana and Arora, 1980). *Acacia tortilis* has been reported to yield giraffe forage at 5 MT/ha/yr(7).

Firewood harvested as needed, but 10-year rotations are suggested. A 12-year-old plantation in India yielded 54 MT/ha fuel, suggest, annual returns of 4.5 MT/ha, not a bad return for the desert(7).

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=118 http://www.worldagroforestry.org/treedb/AFTPDFS/Acacia_tortilis.pdf

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(7) James A. Duke. 1983. Handbook of Energy Crops (*Acacia tortilis* (Forsk.) Hayne) http://www.hort.purdue.edu/newcrop/duke_energy/Acacia_tortilis.html

Acacia xanthophloea Benth. (Fabaceae - Mimsoideae)

General description

Large tree, 15-25 m tall, with a crown that is somewhat spreading, branching fairly up the trunk (5). Large tree with a flat crown and light foliage (2).

Environmental reqirements

Altitude	600-1200 m (2)
Mean annual rainfall	
Soils in natural range	*A. xanthophloea* is mostly found on sandy soil.
Soil water regimes	*A. xanthophloea* grows in semi-evergreen bushland and woodland in areas with a high groundwater table and often forms dense stands in seasonally flooded areas (5).
Suitable site for planting	*A. xanthophloea* grows near swamps, riverine forests or at lakesides and is able to tolerate several degrees of frost (5).
Root system	*A. xanthophloea* probably has most of their roots located within the upper soil layers, which dried out quickly soon after the rains (3). This species does not have an aggressive taproot, but because of its large size it should not be planted close to buildings (5).

Phenology and Ecophysiology

Phenology

Flowers are hermaphroditic. Development from flower to fruit takes 4-6 months. In southern Africa, flowering occurs from September to November while fruiting is from January to April. Despite the production of a large number of flowers, there is often poor fruit development (1).

Ecophysiology of water use

A. xanthophloea showed greater (40 kg d^{-1}) water use compared to *A. tortilis* trees of comparable sizes (20 kg d^{-1}) during favorable conditions of soil water availability (SWC). Decline in SWC reduced water use and the onset and rate of decline in sap flux was determined by the rooting depth (3).

Tree Management

Planting and weeding

A. xanthophloea is easily grown from seed (5).

Planting out should be done carefully so that the long taproot is not damaged(5).

Agroforestry

Birds often build their nests on the *A. xanthophloea* branches, promoting the biodiversity of the site. The tree is recognized as a stabilizer of swamplands, riverbanks and dams (6).

Trees are planted as live fences (5).

Plantations for timber production

A. xanthophroea wood has density of the wood: 0.532 g/cm^3, calorific value of wood 4.4 kj/g and calorific value of charcoal 7.9 kj/g, and it showed relatively high value compared with other Acacias and other fuelwood tree species (4).

A. xanthophloea is one of the fastest-growing thorn-tree species in southern Africa, with a growth rate of 1-1.5 m/year. It can withstand lopping (5).

Benefit and Products (1, 5)

Wood: The wood is hard, heavy and is valuable as timber but should be seasoned before use, as it is liable to crack. It is also used for poles and posts.
Fodder: Foliage and pods provide food for livestock.
Fuel: The species is used as fuelwood although it produces a gum that leaves a thick, black, tarlike deposit when burnt.
Medicine: The roots and powdered bark of the stem are used as an emetic and as a prophylactic against malaria.
Agroforestry: It is a nitrogen fixing species that can be used as shade intercropping tree in agroforestry systems, where the thorny habit is also utilized as live fences.
Apiculture: Trees produce good bee forage (5).

(1) Forest & Landscape, University of Copenhagen (2010) Seed Leaflet No. 151 (*Acacia xanthophloea*)
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(5) World Agroforestry Centre (2014) Agroforestree Database http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=125
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Azadirachta indica A. Juss. (Meliaceae)

General description

Small to medium-sized tree, usually evergreen, up to 15 (30 max.) m tall, with a round, large crown up to 10 (20 max.) m in diameter; branches spreading; bole branchless for up to 7.5 m, up to 90 cm in diameter (1).

Environmental reqirements

Altitude	0-1500 m (1)
Mean annual rainfall	400-1200 mm (1)
Soils in natural range	It grows on a wide variety of neutral to alkaline soils but performs better than most species on shallow, stony, sandy soils, or in places where there is a hard calcareous or clay pan not far below the surface. It grows best on soils with a pH of 6.2-7 (1).
Soil water regimes	It quickly dies in waterlogged soils (1).
Suitable site for planting	*A. indica* is said to grow 'almost anywhere' in the lowland tropics. *A. indica* requires large amounts of light, but it tolerates fairly heavy shade during the 1st few years (1).
Root system	Being drought resistant with a well-developed root system capable of extracting nutrient from the lower soil levels, it is a suitable tree for dune-fixation (1).

Phenology and Ecophysiology

Phenology

A. indica is a usually evergreen tree. The flowers bisexual or male on same tree, white or pale yellow, slightly sweet scented. *A. indica* trees may start flowering and fruiting at the age of 4-5 years, but economic quantities of seed are produced only after 10-12 years. Certain isolated trees do not set fruit, suggesting the occurrence of self-incompatibility. The flowering and fruiting seasons largely depend on location and habitat. In Thailand for instance, the flowers and fruits throughout the year whereas in East Africa (with pronounced dry and wet season) flowering and fruiting are restricted to distinct periods. Fruits ripen in about 12 weeks from anthesis and are eaten by bats and birds, which distribute the seed. They can live for over 200 years (1).

Ecophysiology of water use

According to the experiment comparing water use of four species (*Acacia nilotica, Albizia procera, Azadirachta indica and Eucalyptus camaldulensis*) grown in pots in a green house, water consumption by one year old *Eucalyptus* was more than three times that of by *Acacia* and *Azadirachta*. However, water use efficiency was found as 0.32 g L^{-1}, 0.48 g L^{-1}, 0.16 g L^{-1} and 0.77 g L^{-1} for *Acacia, Albizzia, Azadirachta* and *Eucalyptus* respectively (6). *A. indica,* also other two native species, showed traits of low water comsumption and small biomass production in comparison with *E. camludulensis*.

Neem appears to be a highly mycorrhizal-dependent species. The intensity of infection varies with availability of water. The deep-rooted growth habit along with vesicular-arbuscular mycorrhizal (VAM) infections of desert vegetation may be a survival mechanism in competition for water and nutrients with shallow-rooted and fast-growing plant species (3).

Tree Management

Planting and weeding

Broadcast seeding on ploughed land does not yield good results. The seed would readily germinate on top of the soil, but should be slightly buried to reduce damage from insects and rodents. Thinning is carried out later, in order to leave one seedling every 8 m (2).

Weeding of *A. indica* plantations in dry areas is essential, as the tree cannot withstand competition, especially from grasses. It responds well to chemical and organic fertilizers. Trees coppice freely, and early growth from coppice is faster than growth from seedlings. *A. indica* withstands pollarding well, but seed production is adversely affected when trees are lopped for fodder (1).

Agroforestry

Intercropping *A. indica* with pearl millet, *Pennisetum glaucum*, has given good results in India (1).

A traditional agricultural practice involves the production of 'neem tea'. The seeds are dried, crushed and soaked in water overnight to produce a liquid pesticide that can be applied directly to crops. Crushed seed kernels are also used as a dry pesticide application, especially to control stem borers on young plants (1).

Because of its low branching, it is a valuable asset for use as a windbreak (1).

Plantations for timber production

A. indica is a species of the mahogany family, and although it has some of the characteristics of a cabinetry wood, its grain is rough and does not polish well. The wood is, nevertheless, used to make wardrobes, bookcases and closets, as well as packing cases because its insect repellent quality helps to protect the contents from insect damage. The main stem of the tree is also widely used to make posts for construction or fencing because the wood is termite resistant. The density of the wood is 720-930 kg/cubic m at 12% mc (1).

Plantation in 8 x 8 m pits is recommended. Usually deep parallel furrows 8 m apart are used (2).

Benefit and Products (1)

Food: Fruits are eaten fresh or cooked, or prepared as a dessert or lemonade-type drink. The young twigs and flowers are occasionally consumed as vegetables.
Fuel: Charcoal made from *A. indica* wood is of excellent quality and the wood has long been used as firewood. Its oil is burned in lamps throughout India.
Tannin or dyestuff: Tree bark contains 12-14% tannins. This compares favourably with conventional tannin chemicals.
Lipids: *A. indica* oil has long been produced in Asia on an industrial scale for soaps, cosmetics, pharmaceuticals and other non-edible products. The seed oil yield is sometimes as high as 50% of the weight of the kernel.
Poison: Extracts from leaves and other tissues acts as an insect repellant, inhibiting feeding, and disrupting insect growth, metamorphosis and reproduction. Formulations based on *A. indica* do not usually kill insects directly but alter their behaviour in significant ways to reduce pest damage to crops, and reduce their reproductive potential. Azadirachtin affects insect physiology by mimicking a natural hormone. It has been shown to affect egg production and hatching rates.
Medicine: Neem has proved effective against certain fungi that infect humans. Various parts of A. indica have anthelmintic, antiperiodic, antiseptic, diuretic and purgative actions, and are also used to treat boils, pimples, eye diseases, hepatitis, leprosy, rheumatism, scrofula, ringworm and ulcers. Leaf teas are used to treat malaria.

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(3) K. Bala, A.V. Rao & J.C. Tarafdar (1989) Occurrence of VAM associations in different plant species of the Indian desert, Arid Soil Research and Rehabilitation, vol. 3: 391-396

Balanites aegyptiaca (L.) Del. (Balanitaceae)

General description

Multibranched, spiny shrub or tree up to l0 m high. Crown rounded, dense with long stout branchlets (1).

Environmental reqirements

Altitude	0-2000 m (1), up to 1000 m (4)
Mean annual rainfall	250-1200 mm (1), 250-400 mm (4)
Soils in natural range	The soils in its range tend to be deep sands, sandy clay loams, sandy loams or clays (1).
Soil water regimes	The tree is drought and fire resistant, and withstands up to 2 months flooding in areas near a river but it cannot tolerate prolonged water logging (2).
Suitable site for planting	It has wide ecological distribution; however, it reaches its maximum development as an individual tree on low-lying level alluvial sites with deep sandy loam and uninterrupted access to water (1).
Root system	

Phenology and Ecophysiology

Phenology

Balanites aegyptiaca is an evergreen tree (3). Flowering behaviour varies. There is no definite time for flowering in the Sahel, although flowering most likely takes place in the dry season. The 1st fruiting is at 5-8 years, yields increasing until 25 years of age for the tree. The fruit apparently takes at least 1 year to mature and ripen. Birds and mammals eat the fleshy and edible fruit, discarding, regurgitating or evacuating the stone (1).

Tree Management

Planting and weeding

Requires weeding and protection from browsing up to the initial fruiting period (at least 3 years). Weeding is important due to slow growth, as high grass can compete for light. Weeds can also impede regeneration and grass fires can destroy young plants. It coppices vigorously. Roots spread far, and throw up suckers at a considerable distance from the trunk (5).

Coppices and pollards well and can regenerate after lopping and heavy browsing. Where fruit is the principal interest, pollarding and coppicing for obtaining fodder are seldom employed (1).

This tree suffers from repeated locust and beetle attack and a high degree of parasitic infestation (1).

Agroforestry

As a thorny tree, this tree is useful for fencing to demarcate the land. Cut branches are used to make livestock enclosures (1).

Traditionally it has been, and still is, actively managed. It is planted in agroforestry along the banks of irrigation canals and as a boundary marker. The tree attracts numerous insect species and could be used in agroforestry as a trap tree. *B. aegyptiaca* is worth considering for difficult sites, where water is the main limiting factor (5).

The usually evergreen behaviour potentially makes *B. aegyptiaca* an attractive element to introduce into shelterbelts, although because of its slow growth, it is not suitable as a principal species (1).

Plantations for timber production

The wood is hard, durable, worked easily and made into yokes, wooden spoons, pestles, mortars, handles, stools and combs. The wood saws cleanly and easily, planes without difficulty to a smooth finish and is easy to chisel. The timber has traditionally been a minor product. The usually small log size and the prevalence of stem fluting makes sawmill processing difficult (1).

Benefit and Products (1)

Food: The fleshy pulp of fruit is edible. The fruit is processed into a drink and sweetmeats in Ghana, an alcoholic liquor in Nigeria, a soup ingredient in Sudan. Young leaves and tender shoots are used as a vegetable. The flowers are a supplementary food in West Africa. Flowers are sucked to obtain nectar.
Medicine: Roots is used to treat malaria, against oedema and stomach pains, and as an emetic. Bark infusion is used to treat heartburn. Wood gum is used to treat chest pains. The bark is used to deworm cattle in Rajasthan.
Fodder: The fresh and dried leaves, fruit and sprouts are all eaten by livestock. Kernel meal, the residue remaining after oil extraction, is widely used in Senegal, Sudan and Uganda as a stock feed. The tree is lopped for fodder in India.
Fuel: The wood produces considerable heat and very little smoke, making it particularly suitable for indoor use. It produces high-quality charcoal and the nutshell is suitable for industrial activated charcoal. The calorific value is estimated at 4600 kcal/kg.
Fiber: A strong fiber is obtained from the bark.
Lipids: The kernels produce edible oil used for cooking. Its free fatty acid content is low.

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=279 http://www.worldagroforestry.org/treedb/AFTPDFS/Balanites_aegyptiaca.pdf
(2) International board for plant genetic resources/Royal Botanic Gardens Rome (IPGRI) (1984) Forage and browse plants for arid and semi-arid Africa, 101-102.
(3) Von-Maydell H-J. (1984) Arbres et arbustes du Sahel: leurs caractéristiques et leurs utilisations. Eschborn: GTZ, p. 531
(4) Danida Forest Seed Centre (2000) Seed Leaflet No. 21 (Balanites aegyptiaca (L.) Del.), DANIDA
(5) D. A. Hines and K. Eckman (1993) Indigenous multipurpose trees of Tanzania : Uses and economic benefits for people
http://www.fao.org/docrep/x5327e/x5327e0m.htm#balanites aegyptiaca

Combretum spp. (Combretaceae)

- *C. aculeatum* Vent., *C. collinum* Fresen, *C. molle* R.Br. ex G.Don, *C. shumannii* Engl.

General description

A scrambling shrub up to 0.5-4 m in height with virgate branches, or scandent to 8 m (*C. aculeatum*) (1). A small to medium-sized, semi-deciduous tree 4-18 m in height, with a rounded or flat, heavy crown (*C. collinum*) (1). A shrub or small, graceful, deciduous tree 3-13 m high. Branching heavy and drooping, giving a rounded or flat-rounded, sometimes oval, crown (*C. molle*) (1). A tall tree, to 20m, leaves dense, drooping, crown narrow (*C. shumannii*) (3).

Environmental reqirements

Altitude	0-2300 m (*C. molle*) (1)
Mean annual rainfall	900-1200 mm (*C. molle*) (1)
Soils in natural range	Sandy or loamy soils (*C. aculeatum*) (1). It has a wide edaphic adaptation growing on alluvial soils and sandy, stony or clay soils (*C. aculeatum*) (2).
Soil water regimes	
Suitable site for planting	*C. aculeatum* is found in dry savannah, thickets on dry soils and is sometimes riverine (1). *C. collinum* occurs at medium to low altitudes in open woodlands (1).
Root system	

Phenology and Ecophysiology

Phenology

The yellowish-white fragrant flowers are bisexual, with greenish to dark red sepals. Flowering occurs at the end of the dry season and during the rainy season. A tree can bear flowers and ripe fruit simultaneously (2). In Sudan flowering occurs from March to June and fruits from July to October (1) (*C. aculeatum*).

C. collinum is a semi-deciduous tree. In southern Africa, flowers are often produced with the previous season's leaves in August to October, and fruiting occurs from January to August (1).

C. molle is a deciduous tree. Flowers appear before the leaves and are attractive to insects, which probably pollinate them. Flowering in southern Africa occurs from September to November; in Zambia, between July and October; fruit ripens between June and September (1).

Tree Management

Planting and weeding

C. aculeatum is a tree to respond to coppicing (3).

C. collinum is a slow-growing tree to respond well to coppicing, lopping and pollarding (1).

C. molle produces root suckers (3). *C. molle* is a slow-growing tree to tolerates to lopping and coppicing (4).

C. shumannii is a slow-growing tree to respond to lopping, coppicing (3).

Plantations for timber production

The timber of *C. collinum* is fairly hard, not very durable, has an interlocked grain and a course texture. It is used for wagon building, canoes and tool handles (1).

C. molle wood is hard, coarse, brittle when dry and rots easily. It is said to be reasonably termite resistant and is suitable for implement handles, poles, stools, construction and fence posts (1).

The very durable heartwood is termite resistant and used a great deal at the coast for carving *C. shumannii*) (3).

Benefit and Products (1)

Fodder: The plants provides browse for livestock in Senegal, Sudan and northern Kenya (*C. aculeatum*).
Fiber: The lianous branches are supple and are used in Kenya to make donkey panniers and wicker baskets for holding milk vessels (*C. aculeatum*).
Medicine: The plants is used as diuretic and purgative. It is also used in Burkina Faso and Senegal for leprosy. The boiled roots are taken in Kenya for stomach upsets (*C. aculeatum*). Roots are boiled and the decoction drunk warm as treatment for dysentery and snakebite (*C. collinum*). Boiled root decoction is used to induce abortion and treat constipation, leprosy, headaches, stomach pains, fever, dysentery, general pains, swellings and as an anthelmintic for hookworm. The bark exudes a gum that can be used to treat wounds, or crushed dried or fresh leaves can be used for the same purpose.(*C. molle*).
Apiculture: Flowers produce good nectar for honey (*C. collinum*). Flowers attract bees and make good forage for honey production (*C. molle*).
Fuel: The wood is a source of firewood and makes very good charcoal (*C. collinum*). The wood burns slowly, giving intense heat, and is suitable for firewood and production of high quality charcoal (*C. molle*).
Tannin or dyestuff: A red dye can be obtained from the leaves and yellow dye from the roots (*C. molle*).

(1) Orwa et. Al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=556 http://www.worldagroforestry.org/treedb/AFTPDFS/Combretum_aculeatum.pdf (*C. aculeatum*)
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=558 http://www.worldagroforestry.org/treedb/AFTPDFS/Combretum_collinum.pdf (*C. collinum*)
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=566 http://www.worldagroforestry.org/treedb/AFTPDFS/Combretum_molle.pdf (*C. molle*)

(2) Millennium Seed Bank Project (2007) Seed Leaflet No. 127 (*Combretum aculeatum* Vent.), DANIDA

(3) P. Maundu and B. Tengnäs (2005) Useful Trees and Shrubs for Kenya, Technical Handbook No.35, p. 159 (*C. aculeatum*), p. 160 (*C. collinum*), p. 161 (*C. molle*), p. 162 (*C. shumannii*), World Agroforestry Centre

(4) D. A. Hines and K. Eckman (1993) Indigenous multipurpose trees of Tanzania : Uses and economic benefits for people, Cultural Survival Canada and Development Services,
http://www.fao.org/docrep/x5327e/x5327e0r.htm#combretum molle*

Eucalyptus camaldulensis Dehnh (Myrtaceae)

General description

Commonly grows to 20 m tall, occasionally reaching 50 m, with a trunk diameter of 1 (max. 2) m. In open formations has a short, thick bole and a large, spreading crown. In plantations has a clear bole of 20 m with an erect (1).

Environmental reqirements

Altitude	0-1500 m (1)
Mean annual rainfall	250-2500 mm (1)
Soils in natural range	Grows best on deep, silty or loamy soils with a clay base and accessible water table. It is one of the species found to be most tolerant to acid soils (1).
Soil water regimes	Tolerates waterlogging and periodic flooding (1).
Suitable site for planting	Under natural conditions, *E. camaldulensis* occurs typically along watercourses and on floodplains. It grows under a wide range of climatic conditions, from temperate to hot and from humid to arid zones. The length of the dry season may vary from 0 to 8 months (1).
Root system	

Phenology and Ecophysiology

Phenology

Time of flowering in natural stands depends on the geography of a given location. Seeds ripen about 6 months later. *E. camaldulensis* does not develop resting buds and grows whenever conditions are favorable (1).

Tree Management

Planting and weeding

Seeds, long lived when sealed in dry cold storage, are usually started in nursery containers, then transplanted to the field (as close as 2 x 2 m for firewood). Extensive weeding may be mandatory(2).

Poor competition ability with weeds and the development of an open crown necessitate frequent weeding, up to 3 times a year, until the canopy closes 3-5 years after planting. A thinning of less than 700 stems/ha at 5 years provides posts, poles, fuelwood and pulpwood, leaving the better trees for the production of other products, such as sawn timber after 10 years. Coppices readily. Application of 100 g of NP or NPK (3:2:1) fertilizer to each tree at planting to assist establishment and early growth is common(1).

Agroforestry

With its light crown, *E. camaldulensis* is well suited for growing in arable fields. Intercropping maize with trees planted at 5 x 5 m gives satisfactory yields(1).

Plantations for timber production

Because of its great strength and good durability, the wood is suitable for many structural applications, for example, railway sleepers, poles, posts, floorings, wharves, ship building and heavy construction(1).

Seedling growth may exceed 3 m per year for well-adapted provenances on favourable sites(1).

Some provenances coppice well for six or more rotations, on good sites, plantations are managed on coppice rotations of 7–10 years(2).

According to NAS (1980a), annual wood yields or 20–25 m3/ha in Argentina, 30 m3 from Israel, 17–20 from Turkey in the first rotation, and 25–30 in subsequent coppice rotations. On poor arid sites, yields are only 2–11 m3 (ca 1–5 cords) on 14 or 15 year rotations. Litterfall ran about 3.6–5.8 MT/ha/yr in an Australian redgum swamp (Briggs and Maher, 1983)(2).

According to the phytomass files (Duke, 1981b), standing biomass in an Israeli plantation is ca 110 MT/ha. At Calistoga, California, this was calculated to yield 4.3 m3/ha/yr or 2 cords and total energy yields of 15,000,000 kcal/ha/yr (Standiford and Donaldson, 1982)(2).

Termites and aphids and rodents may be troublesome to the tree, and both physical and chemical measures are used to control them (1).

Benefit and Products (1)

Apiculture: *E. camaldulensis* is a major source of honey, producing heavy yields of nectar in good seasons. The honey is light gold and of reasonable density with a distinctive flavour.
Fuel: The firewood is suitable for industrial use in brick kilns but is not preferred for domestic use because it is too smoky and burns too fast. However, it makes good-quality charcoal.
Fiber: *E. camaldulensis* is used for pulp and paper production. It is also planted for hardboard, fiberboard and particleboard.
Medicine: The oils are used as an inhalant with steam and other preparations for relief of colds and influenza symptoms. Because of its refreshing odour and its efficiency in killing bacteria, the oil is also used as an antiseptic.
Essential oil: Some tropical provenances of E. camaldulensis are rich in 1,8-cineole leaf oil and are potential commercial sources of medicinal-grade eucalyptus oil.

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=760 http://www.worldagroforestry.org/treedb/AFTPDFS/Eucalyptus_camaldulensis.pdf

(2) James A. Duke. 1983. Handbook of Energy Crops (*Eucalyptus camaldulensis* Schlecht.)
http://www.hort.purdue.edu/newcrop/duke_energy/Eucalyptus_camaldulensis.html

Eucalyptus saligna Smith (Myrtaceae)

General description

Tall tree, 30-50 m in height, with a diameter at breast height of up to 2 m. Exceptional specimens grow 65 m tall and attain a diameter of 2.5 m. The trunk is generally of excellent form, straight and clear of branches for 1/2 to 2/3 of the total tree height (1).

Environmental reqirements

Altitude	0-1100 m (1)
Mean annual rainfall	800-1800 mm (1)
Soils in natural range	Best development occurs on good quality, alluvial sandy loams. Other soils include Podsols and volcanic loams. Soils it prefers are generally moist but well drained (1).
Soil water regimes	Although it can tolerate short dry periods, best growth is achieved on sites with a high rainfall well distributed throughout the year (1).
Suitable site for planting	The preferred climate is warm temperate to subtropical with a mild dry season of not more than 4 months. *E. saligna* is a light-demanding tree (1).
Root system	

Phenology and Ecophysiology

Phenology

E. saligna is a heterophyllous and it has juvenile and adult phases. Seed production commences when the tree is about 7-8 years old (1). Flowering and fruiting occur throughout the year (2).

Tree Management

Planting and weeding

This fast-growing, light-demanding tree is highly sensitive to competition from weeds during the 1st 2 years, and therefore measures to control emerging weed growth must be carried out several times. The rapid early growth allows *E. saligna* to dominate competing vegetation (1).

Plantations for timber production

E. saligna has proved to be highly suited for short-rotation plantations in tropical montane regions(1).

The heartwood has a density of about 900 kg/cubic m, is easy to work and polishes. It is an important general-purpose hardwood in Australia, and is favoured for construction, flooring, cladding and paneling(1).

Stands grown for timber are thinned to about 50% of the original stem density when trees are 5-8 years old. Additional thinning is carried out every 8-10 years thereafter. At a rotation of about 35 years, the final thinning, which should be done when the trees reach marketable age, should leave approximately 70-120 stems/ha. Rotations of 6-10 years are used for producing fuelwood and pulpwood(1).

A 4-year old stand in Brazil had standing biomass of 56 MT/ha (38 aboveground, 8 litter, and 10 belowground). But annual biomass productivity was estimated at 15–17 MT/ha. Fenton et al. (1977) report wood yields of 19 m3/ha/yr(3).

Benefit and Products (1)

Essential oil: The essential oil yield is 0.3-0.5%.

Apiculture: *E. saligna* is not reliable as a honey producer. It is however useful in stimulating colonies and may be helpful in queen-rearing and re-stocking programs. The honey is strongly flavoured, rather dark and frequently lacks density. It does not store well.

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=812 http://www.worldagroforestry.org/treedb/AFTPDFS/Eucalyptus_saligna.pdf

(2) Kenya Forest Research Institute, Tree Seed Information Leaflet, Leaflet No. 10 (*Eucalyptus saligna*)

(3) James A. Duke. 1983. Handbook of Energy Crops (*Eucalyptus saligna* Sm.)
http://www.hort.purdue.edu/newcrop/duke_energy/Eucalyptus_saligna.html

Faidherbia albida (Del.) A. Chev. (Fabaceae - Mimsoideae)

General description

One of the largest thorn trees reaching 30 m in height, with spreading branches and a rounded crown (1). Large tree to 30 m in height, 1m in diameter; normally only one stem (2).

Environmental reqirements

Altitude	270-2700 m (1)
Mean annual rainfall	250-1200 mm (1)
Soils in natural range	Coarse-textured well-drained alluvial soils (1). *F. albida* is successful in sandy alluvium and sandy clay in the West African Sahel and on alluvial soil in Eastern and Southern Africa (9).
Soil water regimes	It tolerates seasonal water-logging and salinity but cannot withstand heavy clayey soils (1). Though faring best on sandy soils, it will tolerate heavier soils with some waterlogging (10).
Suitable site for planting	*F. albida* grows on the banks of seasonal and perennial rivers and streams on sandy alluvial soils or on flat land where Vertisols predominate. It thrives in climates characterized by long summers, or a dry season with long days (1).
Root system	Roots of *F. albida* were distributed through the weathered rock, down to a depth of 7 m, and vanished in the vicinity of a permanent water-table (4).

Phenology and Ecophysiology

Phenology

The plant has an 'inverted phenology'. Deciduous in the wet season and foliated in the dry season. The flowering of individual trees is often not uniform. First flowering occurs in the seventh year and subsequent flowerings occur 1-2 months after the start of the dry season for up to 5 months. Ripe fruit falls towards the end of the dry season. The seeds are dispersed by animals, which eat the pods (1). In some areas flowering may occur twice in a year. Not all trees flower every year. In East Africa seeds mature in July-October (2).

Ecophysiology of water use

The tree does not conserve moisture but is effective in obtaining water for transpiration, as amply demonstrated by its vegetative vigor in the dry season, in the total absence of rain, when temperatures are high, humidity is low, and evapotranspiration is at a maximum. To achieve this, its root system has a taproot that grows very rapidly and will reach the water table if it is within range; depths of about 40 m have been recorded (Lemaftre 1954). When on its preferred sites, notably in association with water, the species prefers deep sandy soils easily exploited by its root system (11).

Benefit and Products (1)

Fodder: The leaves and pods are palatable to domestic animals and an important source of protein for livestock in the dry season.

Apiculture: For bee-keepers, it has the advantage of producing flowers at the end of the rains while most of the sahelian species flower just before or during the rains. It therefore becomes the main source of pollen and nectar at this time.

Fuel: The plant stems are used as fuelwood. The calorific value is estimated at 19.741 kJ/kg of dry wood. Charcoal yields are as low as 17%.

Medicine: The bark and roots are widely used for either externally or internally against respiratory infections, digestive disorders, malaria and other fevers. The bark is used to clean teeth and an extract is used for toothache in humans and eye infections in livestock.

Shade or shelter: F. albida is maintained and protected on farms to shade coffee and to provide shade for livestock in the dry season.

Reclamation: The plant's spreading root system offers excellent protection to the banks of watercourses.

Tree Management

Planting and weeding

F. albida can be propagated by direct sawing (3). Generally, the physical scarification techniques gave better results than the control and the hot water treatment. The 15-mm sowing depth gave significantly better results than the 10-mm treatment, due partially to less predation by mice and ants (5). Direct seeding can be recommended provided that seeding is done when the soil is moist to a depth of over 50 cm. Weeds must be suppressed and the site must be adequately reparated to encourage rapid taproot development (6). Air pruning of *F. albida* seedlings, induced by desiccation of root meristems emerging at the base of containers, was successfully achieved in the nursery. This is better than standard nursery techniques (7).

Pruning in the 2nd year to about half the tree height may be needed to control low branching. Repeated pruning during periods of average biomass production stimulates leaf production. It can be pruned twice a year. Resulting regrowth is especially vigorous in the 1st year but decreases as exploitation continues; trees show stress at the end of the 6th year. Regular lopping (once every 3-4 years) removing 0.4-0.5m³ of foliage (or 35% of the total volume) at the start of the growing season is recommended. The tree responds well to coppicing (1).

Agroforestry

Feed-value analyses have revealed that pods and leaves are rich in parietal content. Leaves, pods, and seeds contain respectively 200, 150, and 260 g TP kg-1 of dry matter (8). According to FAO (1980) a full grown tree can produce more than 100 kg pod/yr. Felker (1978) notes that pod yields range from 6–135 kg/tree (10).

Results of the crop trials conducted by the CFU to demonstrate the yield benefits of growing crops under canopies of mature *F. albida* trees have shown that yields of maize grown under canopies of *F. albida* were significantly higher than those of maize grown outside canopies in all the four regions of Zambia where the trials were conducted and in the four agricultural seasons during which the trials were conducted. The average yield of maize under the canopies of *F. albida* was about 5.0 metric tonnes per hectare compared to an average of about 2.0 metric per hectare for maize grown outside canopies of *F. albida*. No statistically significant differences were observed between yields of cotton, soya bean and groundnuts grown under and outside canopies of *F. albida* (9). Yield increases under *Acacia albida* (*F. albida*) correlate with a several fold increase in soil N and organic matter, coupled with improved soil water-holding capacity (10). In mesic Sahelian regions (400–600 mm/yr), yields of millet, peanuts, and sorghum are increased from ca 500 to ca 900 kg/ha/yr by growing under the canopy of *Acacia albida* (Felker, 1978) (10).

Branches lopped for fencing compounds and livestock enclosures (1).

Plantations for timber production

Trees have reached 2 to 4 m after only 3 or 4 years growth (10).

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=1 http://www.worldagroforestry.org/treedb/AFTPDFS/Faidherbia_albida.pdf

(2) Danida Forest Seed Centre (2000) Seed Leaflet No. 28 (*Faidherbia albida* (Del.) A. Chev.), DANIDA

(3) P. Maundu and B. Tengnäs (2005) Useful Trees and Shrubs for Kenya, Technical Handbook No.35, p. 234, World Agroforestry Centre

(4) O. Roupsard, A. Ferhi, A. Granier, F. Pallo, D. Depommier, B. Mallet, H. I. Joly and E. Dreyer (1999) Reverse phenology and dry-season water uptake by *Faidherbia albida* (Del.) A. Chev. in an agroforestry parkland of Sudanese west Africa, Functional Ecology 13, 460-

(5) P. Beckman (1992) Direct Seeding Experiments with *Faidherbia albida* in an Arid Environment, *Faidherbia albida* in the West African Semi -Arid Tropics, 137-138, ICRAF

(6) S.A.N. Samba (1992) Regeneration of *Acacia albida* with Direct Seeding, *Faidherbia albida* in the West African Semi -Arid Tropics, 139-140, ICRAF

(7) M.I Cisse and A.R. Kone (1992) The Fodder Role of *Acacia albida* Del: Extent of Knowledge and Prospects for Future Research, *Faidherbia albida* in the West African Semi -Arid Tropics, 29-37, ICRAF

(8) D. Louppe and N'Klo Ouattara (1992) Growth of *Faidherbia albida* in Nurseries: Standard Production Techniques or Air Pruning?, *Faidherbia albida* in the West African Semi -Arid Tropics, 141-143, ICRAF

(9) V. Shitumbanuma (2012) Analyses of Crop Trials under *Faidherbia albida* –Results of Crop Yields for the 2010/2011 Agricultural Season and Overall Summary of Yields and Yield Trends from 2008 to 2011-, University of Zambia

(10) James A. Duke. 1983. Handbook of Energy Crops (*Acacia albida* Del.) http://www.hort.purdue.edu/newcrop/duke_energy/Acacia_albida.html

(11) P.J.Wood (1992) The Botany and Distribution of *Faidherbia albida*, *Faidherbia albida* in the West African Semi -Arid Tropics, 9-17, ICRAF

Gliricidia sepium (Jacq.) Walp. (Fabaceae)

General description

Small to medium-sized thornless tree up to 10-12 (15) m high.Branching frequently from the base. Bark is smooth, varying in colour from whitish grey to deep red-brown. Trees display spreading crowns. Native to seasonal dry forest of Central America (2).

Environmental reqirements

Altitude	0-1200 m a.s.l. (2)
Mean annual rainfall	600-3500 mm (1) 900-1500 mm (2)
Soils in natural range	Pure sand to deep alluvial lake-bed deposits. Soils are acidic (pH 4.5-6.2); however, where parent material is limestone, the soils are slightly alkaline (1).
Soil water regimes	Prefers freely draining soils and tolerates seasonally impeded drainage. It tolerates brief flooding, but areas prone to waterlogging should be avoided (2).
Suitable site for planting	Best in deep, medium-textured, well drained, fertile soils, with near neutral acidity. It tolerates rocky (shallow or skeletal) soils that are high in available calcium, and soils with textures from sands to clays (2).
Root system	Roots propagated from cuttings are shallow and laterally extensive. Seedilings develop taproots but it is unclear if the taproots endure throughout the life of plant. (3).

Phenology and Ecophysiology

Phenology

Flowering and fruiting may begin as early as the end of the first growing season and almost always begins by the fifth growing season. Flowering occurs during the dry season, depending on the local climate. If rainfall is evenly distributed throughout the year, flowering may occur at any time, irregullarly throughout the year, but in lower quantities compared with seasonal climates (3).

Gliricidia is largely deciduous in the dry season. To prevent leaf loss at this time, cut at the end of the rains and again at 8 weeks into the dry season. A final cut at 16 weeks into the dry season may be possible (2).

Ecophysiology of water use

According to an examination of soil water, crop yield and fine roots of 3–4 year-old *Grevillea robusta* and *Gliricidia sepium* growing in association with maize in semiarid Kenya during the long rains of 1996 -1997, plots containing *G. sepium* trees always contained more tree roots than plots containing *G. robusta* trees and *Gliricidia* was more competitive with maize than *Grevillea*. Overall, *Gliricidia* reduced crop yield by about 50% and *Grevillea* by about 40%. There was less soil moisture in plots containing trees than in control plots. Plots containing *Gliricidia* trees contained less soil water than plots containing *Grevillea* trees (4).

Benefit and Products (1, 2)

Fodder: Leaves are rich in protein and highly digestible, and low in fibre and tannin, which improve animal production (both milk and meat) when *G. sepium* is used as a supplement.
Apiculture: The flowers attract honeybees (Apis spp.).
Fuel: Often used for firewood and charcoal production. The calorific value of a 5-year-old tree is 4550 kcal/kg.
Medicine: Crude extracts have been shown to have antifungal activity. Reported to be expectorant, sedative and suppurative. Madre de cacao is a folk remedy for alopecia, boils, bruises, burns, colds, cough, debility, eruptions, erysipelas, fever, fractures, gangrene, headache, itch, prickly heat, rheumatism, skin tumours, ulcers, urticaria and wounds.
Erosion control: Hedgerows in alley cropping serve to suppress weed growth and control erosion.
Nitrogen fixing: The tree is capable of fixing atmospheric nitrogen. As a green manure, *G. sepium* increases soil organic matter; it aids in recycling of soil nutrients as it produces much litter.

Tree Management

Planting and weeding

The tree tolerates only light shade.Seedlings that are planted in heavy shade can survive but will not grow. Seedlings that have been suppressed by shade for even 3-4 years will recover and grow rapidly if the sheltering overstory is removed (2).

Agroforestry

Gliricidia is a popular shade or nurse tree for crops including coffee, tea, cacao, pepper, passion fruit, and vanilla, in many varied spatial arrangements. Spacing of about 10 x 10 m interspersed with crops such as coffee and cacao is common. The shade trees are pruned seasonally to maximize benefit to the understory crop, and to minimize competition for water and nutrients. It has been intercropped in alley cropping systems with maize, cassava, taro, cucurbits, and other food crops. In such systems, pruning *Gliricidia* back regularly provides mulch for the crops and controls competition by the *Gliricidia* for light, water and nurients (3).

Pruning and pollarding are the main management activities. Pruning at 0.3-1.5 m will stimulate leaf production. Pollarding at 2 m or above is recommended for optimal wood biomass production. Coppicing is used where the primary objective is fuelwood production. *Gliricidia* has been shown to tolerate lopping and browsing (1).

According to an examination of phenological patterns in relation to climatic conditions in the bimodal rainfall regions of Kenya to identify factors which dictate the intensity of competition between trees and crop, *G. sepium* exhibited a period of low leaf cover during the long dry season and did not regain full leaf cover until mid-way through the short rains. *G. sepium* during the short rains would decrease competition for water with adjacent crops, but is also likely to decrease tree growth (5).

Wood production

Fuelwood plantations in Central America are typically established with Iooo-5000 trees/ha for rotations of 5y ears. In Asia, fuelwood plantations are set out at 1 x 1 m to 2.5 x 2.5 m spacings for pruning at 1-or 2-year intervals. Fuelwood yields from stands harvested every 2-3 years are I0-20 mJ/ha. Wood production from a living fence has been reported at 9 mJ /km. On intermediate quality sites in Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica, and Panama, annual fuel wood increment reached a peak of 4.5 kg/tree at 2 years of age, although cutting usually takes place on rotations of 5-8 years.

The wood is light to dark olive-brown, very hard and heavy, strong, coarse-textured, with an irregular grain. It seasons well and takes ah igh polish. It is highly durable, and valued for house construction and corner fence posts. Declining availability of the prime economic species in timber market has led to the introduction of Lesser-Used-Species (LUS). *G. sepium* has potential to be a major LUS timber and could substitute some economic species in timber market od developping countries (6).

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Grevillea robusta A. Cunn. Ex R. Br. (Proteaceae)

General description

Medium-sized to large tree 12-25 (max. 40) m tall; crown conical, dense, with branches projecting upwards. Bole straight, branchless for up to 15 m, up to 80 (max. 120) cm in diameter, usually without buttresses (1).

Environmental reqirements

Altitude	0-2300 m (1)
Mean annual rainfall	600-1700 mm (1)
Soils in natural range	Establishes well in riverine habitats, on alluvial soils that are free of waterlogging and mildly acid to neutral. Loam soil is preferred. It also occurs on clay loam and sand (1).
Soil water regimes	The species can stand up to 6 months of drought (1).
Suitable site for planting	Rainfall distribution has a summer maximum in the natural range, but *G robusta* also grows well in climates with a winter maximum or a bimodal rainfall regime (1). Prefers light, well-drained soils, mildly acid to neutral. Light demanding (7).
Root system	A deep rooting system causes little interference with shallow-rooted crops, and it can be successfully intercropped with banana, tomato and other agricultural crops (1).

Phenology and Ecophysiology

Phenology

In its natural range, the species is semi-deciduous, shedding most of its leaves in the dry season. The tree first flowers when about 6 years old. In its natural range, flowering occurs over a few weeks in October-November, but when planted in equatorial latitudes, flowering is sporadic throughout the year or absent. The flowers are bisexual, and pollen is shed before the stigma becomes receptive. The period from fertilization to fruit maturity is about 2 months (1).

Benefit and Products (1)

Apiculture: The golden flowers are attractive to bees, making it an important honey plant. *G. robusta* honey is dark amber, of high density with a pronounced flavour.
Fuel: *G. robusta* is popular for firewood and charcoal. It is also used to fuel locomotives and river steamers, power boilers and small industries. The calorific value of sapwood is about 4800 kcal/kg, while that of heartwood is 4950 kcal/kg.
Fiber: Mean fiber length is about 1.5 mm and width about 26 μm; the wood is suitable for pulping.
Gum or resin: By virtue of their solubility, viscosity and relatively high resistance to hydrolysis, *G. robusta* gums may have some industrial applications.
Shade or shelter: This is a well known shade tree in coffee and tea plantations. Its spreading branching system makes it ideal for windbreaks or shelterbelts against wind-induced mechanical damage, high rates of transpiration and surface evaporation.

Tree Management

Planting and weeding

Seedlings are planted out when they are 30cm tall (4-6months)(8). Outplanting is done 6-8 months after sowing when plants are 20-30 cm. Weeding is necessary for the first 1-2 years after planting(9).

Agroforestry

G. robusta regrows well after complete defoliation following pruning and pollarding, which can be carried out repeatedly to yield wood and to regulate shading and competition with adjacent crops(1).

The above-ground biomass and grain yield of understorey crops were not significantly affected by the presence of *Grevillea* during the first two years, but were greatly reduced in subsequent years and the yield of maize was decreased to less than 50% of the sole crop values(5). *G. robusta* reduced maize yield by 36% close to the tree rows at Thika, Kenya, whereas yield reductions were negligible adjacent to *Paulownia fortunei* (6). However, in a case study in Kenya indicating that agroforestry treatments of *G. robusta* were able to utilize off-season rainfall, comprising 16% of the total annual rainfall, and residual water remaining in the soil profile after the cropping period (2). In case study in Kenya, the farmers using root pruning were convinced from the positive effect on the water competition. But, most of the farmers questioned and did not prune the roots because they feared the effects on the tree growth(7). Competition between *G. robusta* and maize for soil water stored near the surface was unavoidable, although pruning reduced its impact; complementary use of water by the trees and crop would only have been possible if alternative sources of water were available (3). Careful consideration of the tradeoffs between the loss of crop production and the additional value provided by tree products is essential (2).

Plantations for timber production

In Kenya, the trees have been pruned and pollarded repeatedly to produce firewood and poles,and will eventually be harvested as saw logs (1).

Grevillea yields a medium-weight hardwood with a density of 540-720 kg/cubic m at 15% moisture content. The timber has economic potential. It is easy to work with hand and machine tools. The wood is used in making railroad ties, plywood, panelling, air-freight cases and furniture, parquetry, turnery, boat building, interior trim, cabinet work, parquet flooring, boxes, toys and novelties(1).

Moderate to fast growing. When climate and soil are suitable and weed competition is not severe, annual height and diameter increments of at least 2 m and 2 cm, respectively, are usually achieved for the 1st few years in row planting on farms (1).

A plant density of 800-1200 trees/ha is recommended for plantations. Seedlings are normally planted at a spacing of 2.5-3 x 3-4 m (1).

For firewood production, rotations of 10-20 years are applied and annual volume increments of 5-15 cubic m/ha may be expected. A growth reduction after 20 years is reported(1).

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Melia volkensii Guerke (Meliaceae)

General description

Open crowned deciduous tree, hight 6-25 m tall and dbh 25 cm in common at mature stage, distributes naturally in semi-arid zone of Ethiopia, Somalia, Kenya and Tanzania (1, 10) .

Environmental reqirements

Altitude	350-1,700 m a.s.l. (2)
Mean annual rainfall	300-800 mm (1)
Soils in natural range	sandy, clay, shallow stony (1)
Soil water regimes	Requires moist, well-drained soils (3) Intolerant to black cotton soils or areas prone to water-logging (2)
Suitable site for planting	sandy/loamy soils with good drainage (2)
Root system	Deep rooted, cuttings are more shallowly rooting than seedlings, and have higher competitivity (7)

Phenology and Ecophysiology

Phenology

It remains green most of the year except for short spells when it sheds its leaves twice a year just before flowering (1,10) .

In Tiva Experimental Forest (Kitui, Kenya), it flushes new leaves at the start of rainy season (March-May, Octovber-December) and canopy coverage reaches 60 - 80%. Then coverage decreases to 40 - 55% during dry season (Januay-February, June-October). Leaf mass depends on a precipitation. Stem growth increases after leaves unfolded in March and October. Seeds form and remain on the tree between March and August in Kibwezi, Tsavo and Kitui (10).

Ecophysiology of water use

M. volkensii showed high specific hydraulic conductivity and growth, with no symptoms of die-back, implying that a mechanism associated with the deciduous habit results in drought avoidance by reducing the re-quirement for water during the dry season (6).

Benefit and Products

Environmental conservation: One of the most important potential uses of *M. volkensii* is greening the environment through land reclamation, environmental conservation in arid and semi-arid areas (10).
Fodder: The tree comes into leaf and is pruned for fodder towards the end of the dry season, a time when fodder is extremely scarce. The fruit pulp is reported to contain almost 10% crude fat and over 12% crude protein; the mature leaves are reported to contain over 5% crude fat and 21% crude protein (1).
Apiculture: The flowers are said to provide excellent bee forage (1)
Timber: The wood is easily worked and shaped, making it suitable for making acoustic drums, containers and mortars. The coarse-textured heartwood with a density of around 0.62 works easily, planes well, is durable and extremely termite and decay resistant comparing favourably with Ocotea usambarensis, *Vitex keniensis* and *Khaya* species. The timber is valued locally for door and window frames, doors shutters, rafters, poles and furniture (1).
Medicine: The bark of the *Melia volkensii* is used as source of medicine. This tree is used by the Taita community to cure pains and aches in the body. The bark is boiled and a very small amount is taken while the root bark extract is used as an anti-cancer due to production of limonoids (10).
Fuel: The firewood produces an unpleasant smoke, and the tree is said to produce poor quality charcoal (1).

Tree Management

Planting and weeding

Planting holes are at least 45 cm square and 45 cm deep (2, 9). The ideal planting season in the eastern drylands of Kenya is during October - December rains (2). Microcatchment water harvesting was introduced by the SOFEM Project* and v-shaped cactchments are more registant to erosion than w-shaped ones (9). Soil moisture contents increase in the the microcatchments preventing surface runoff of rainwater (8).

SOFEM Project also intoroduced complete weed control (with 2-3 weedings per season within the first three years) which is essential to promote survival and growth of young Melia (2, 9).

Agroforestry

To reduce tree-crop competition, the use of seedlings rather than cuttings is recommended. If cuttings are used, alternative methods such as root pruning need to be considered (7). Propagation method of *M. volkensii* from seed has been developped and described by KEFRI (2, 10). The tree tends to develop heavy lateral branching, trees are grown well dispersed in cropland at a spacing exceeding 10-15m. Its effect on adjacent crops is minimized by regular crown pruning and a wide range of crops can be grown right up to the stem (4).

When the crown is fully developed, it is thinned heavily each year to reduce shading on underplanted crops like sorghum and millet. This operation is carried out in the dry season to provide clear conditions at planting time. Pruning with the flush of new leaves and fruits coincides with the time when fodder is scarce. Some farmers pollard their trees, however,many farmers believe that pollarding induces rot and is counter-productive (1).

Plantations for timber production

The recommended spacing is 5 m by 5 m. Melia, in its initial stages, does not compete with agricultural crops as it has a light crown and intercropping is possible for 3-4 years. However, under plantation, only short crops such as beans are suitable to plant in the first year since taller crops such as maize shade the tree (2).Melia produces timber in shorter rotations than any other timber species in the drylands of Kenya and the tree can be harvested for timber in 12-15 years (2). It coppices well and is fast growing with a rotation of 10-15 years.In some districts in Kenya, however, Melia was found to produce poles in less than 3 years and timber in less than 5 years from coppiced stems (5). SOFEM recommends pruning from the 1st year onwards to maintain a clean straight bole (9).

Plant spacing experiment in Tiva Experimental Forest (Kitui, Kenya) showed that height growth of trees were not differed among the spacings and reached almost its peak (ca. 12 m) at 10 years old. The best timber production at 10 years of age was obtained from 4 m x 4 m spacing with 80 % of trees >= 7 cm in dbh.

* The Social Forestry Extension Model Development Project (SOFEM: 1997-2002) by Japan International Cooporation Agency (JICA)

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Senna siamea (Lam.) Irwin et Barneby (Fabaceae - Caesalpinioideae)

General description

Medium-size tree growing up to 18 m tall, with a straight trunk of up to 30 cm in diameter. The bole is short. The crown is usually dense and rounded at first. Later it becoming irregular and spreading with drooping branches (*S. siamea*) (1).

Environmental reqirements

Altitude	0-1200 m (*S. siamea*) (1)
Mean annual rainfall	400-2800 mm (*S. siamea*) (1)
Soils in natural range	*S. Siamea* performs best on deep well-drained fertile soils with pH 5.5-7.5, but will grow on degraded lateritic soils provided drainage is not impeded. The species is intolerant of saline soils (1).
Soil water regimes	*S. siamea* will grow only when its roots have access to groundwater, and the maximum length of the dry period should not exceed 4-8 months. (1).
Suitable site for planting	*S. siamea* will grow in wide range of climatic conditions but is particularly suited to lowland tropics with a monsoon climate. Its light requirements are high (1).
Root system	The root system consists of a few thick roots, growing to considerable depth, and a dense mat of rootlets in the top 10-20 cm of soil, which may reach a distance of 7 m from the stem in 1 year and eventually a distance up to 15 m. (1).

Phenology and Ecophysiology

Phenology

S. siamea is an evergreen tree. The flower clusters are upright at ends of twigs with many bright yellow flowers. *S. siamea* starts flowering and fruiting at the age of 2-3 years. Once established, it flowers precociously and abundantly throughout the year (1).

Ecophysiology of water use

Moisture conservation measures (trenching, microcatchments) help establishment and growth for S. siamea planted in semi-arid areas (1).

Tree Management

Planting and weeding

S. siamea can be propagated by seeds, stumps and nursery-grown seedlings (2).

Weeding is necessary in the 1st 1 or 2 years of growth.

Agroforestry

Although not a nitrogen-fixing tree, S. siamea has been increasingly used in alley cropping systems, largely because of its coppicing ability and high biomass production (1).

S. siamea is grown as a shade tree along roads and in cocoa, coffee and tea plantations. It is also planted as a dense windbreak and shelterbelt (1). It is pruned into hedgerows and used as a live fence around food crops (1). Although not a nitrogen-fixing tree, S. siamea has been increasingly used in alley cropping systems, largely because of its coppicing ability and high biomass production (1).

S. siamea issuitable for shelterbelt plantations, but not as shade tree in agroforestry because of root competition (2).

Plantations for timber production

S. siamea yields a medium-weight to heavy hardwood with a density of 600-1010 kg/m³ at 15% mc. The wood is hard to very hard, resistant to termites, strong, durable. The dark heartwood of S. siamea, which is often nicely figured, is used for joinery, cabinet making, inlaying, handles, sticks and other decorative uses. The wood has also been used for poles, posts, bridges, mine poles and beams (1).

Planting density for *S. siamea* varies according to use. In fuelwood plantations, spacing ranges from 1 x 1 m to 1x 3 m. In hedges used for alley cropping or as a shelterbelt, spacing between plants in the row should be 25-50 cm. A clear bole volume of 77 m/m³ after 15.5 years and a mean annual increment of wood of 20-35 m/ha are observed in a 10-year-old plantation. For the production of fuelwood and charcoal, plantations are generally pollarded or regenerated by coppice leaving 2-3 shoots/stump after 1 year (1).

S. siamea is hardly used in afforestation in the Sahel, but in the Sudanian ecozone it is a rather fast growing species for the production of pole timber and fuelwood, regenerates vigorously by coppicing, rotation of 4-7 years for pole production. When in appropriate size suitable for furniture, turnery and cabinet work ; poles and posts are widely used (2).

Benefit and Products (1)

Fuel: The dense, dark-coloured wood of *S. siamea* makes good fuel, although it produces some smoke when burning. The energy value of the wood is 22 400 kJ/kg, and the density is 600-800 kg/m³. The wood was formerly preferred for locomotive engines. Its charcoal is also of excellent quality.

Fodder: *S. siamea* is widely grown for fodder. The alkaloids and other secondary plant compounds in the leaves, flowers and pods are highly toxic to non-ruminants, such as pigs and poultry, and these animals should be kept away from *S. siamea* plantations.

Tannin or dyestuff: All parts of *S. siamea* can be used for tanning. The concentrations of tannin vary slightly from 17% in the leaves to 9% in the bark and 7% in the fruits.

Erosion control: When *S. siamea* is used as a hedgerow, it effectively increases topsoil infiltration, reducing runoff and combating soil erosion.

Soil improver: Leaves of *S. siamea* are used as green manure, and a well-grown tree can yield 500 kg/year of fresh leaves. It forms ecto-mycorrhizae and provides very useful mulch, especially in alley-cropping systems.

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Tamarindus indica L. (Fabaceae - Caesalpinioideae)

General description

Large evergreen tree up to 30 m tall, bole usually 1-2 m, up to 2 m diameter. The crown dense, widely spreading, rounded (1). Tamarindus is a monospecific genus (1).

Environmental reqirements

Altitude	0-1500 m (1)
Mean annual rainfall	350-2700 mm (1)
Soils in natural range	It grows in most soils but prefers well-drained deep alluvial soil (1).
Soil water regimes	Water logging conditions, swamps and often flooded areas should be avoided (5). It should not be planted in low areas where the roots may become waterlogged (4).
Suitable site for planting	It grows well over a wide range of soil and climatic conditions, occurring in low-altitude woodland, savannah and bush, often associated with termite mounds. It prefers semi-arid areas and wooded grassland, and can also be found growing along stream and riverbanks (1).
Root system	Being a deep rooted phreatophyte in the semi-arid bioclimates it is very resistant to storms, to fogs and to slight saline spray in coastal districts (5). Its extensive root system contributes to its resistance to drought and wind (1).

Phenology and Ecophysiology

Phenology

T. indica is an evergreen tree. Flowering generally occurs in synchrony with new leaf growth, which in most areas is during spring and summer. The flowers are hermaphroditic bisexual. *T. indica* usually starts bearing fruit at 7-10 years of age, with pod yields stabilizing at approximately 15 years. Fruit are leathery, nutritive pods that do not dehisce until they have fallen from the tree, while the seeds are hard and smooth and therefore hard to chew (1).

Benefit and Products (1, 3)

Food: The ripe fruit of the sweet type is usually eaten fresh, whereas the fruits of sour types are made into juice, jam, syrup and candy. Fruit is marketed worldwide in sauces, syrups and processed foods. The juice is an ingredient of Worcestershire Sauce and has a high content of vitamin B. The flowers, leaves and seeds can be eaten and are prepared in a variety of dishes. Flour from the seed may be made into cake and bread (1). The brown, short-haired, sausage-like fruits contain an acidic pulp which is a much-prized ingredient of confectioneries, curries and pickles (3).

Fodder: The foliage has a high forage value, though rarely lopped for this purpose because it affects fruit yields.

Apiculture: Flowers are reportedly a good source for honey production.

Fuel: Provides good firewood with calorific value of 4 850 kcal/kg, it also produces an excellent charcoal.

Tannin or dyestuff: Both leaves and bark are rich in tannin. The bark tannins can be used in ink or for fixing dyes.

Medicine: The bark has astringent effect. The bark and young leaves may also be used to relives sores, ulcers, boils and rashes by incorporating into lotions or poultices. Leaf extracts are a common ingredient in cardiac and blood sugar reducing medicines. A sweetened decoction of the leaves is good against throat infection, cough, fever, and even intestinal worms.

Tree Management

Planting and weeding

Plantations may be established by direct sowing along cleared lines. It coppices well (4). The tree can also be grown easily from cuttings, or by shield-budding, side-veneer grafting, or air-layering (6).

Spacing may be 33 to 65 ft (10-20 m) between trees each way, depending on the fertility of the soil. With sufficient water and regular weeding, the seedlings will reach 2 ft (60 cm) the first year and 4 ft (120 cm) by the second year (6).

Weeding is required during the first year, with hoeing around the trees until they are well-established (4).

Size control measures include close spacing (about 500 trees/ha) and pruning to rejuvenate the fruiting wood. The trees also respond to coppicing and pollarding. When establishing a pure plantation, spacing should be at least 13 x 13 m (1).

The most serious pests of the tamarind are scale insects, mealy-bugs, and a borer (1).

Agroforestry

The tree may remain productive of fruits until it reaches old age, yielding up to 150 kg/tree or over 2 t/ha a year (1). A mature tree may annually produce 330 to 500 lbs (150-225 kg) of fruits (6).

T. indica is not very compatible with other plants because of its dense shade, broad spreading crown and allelopathic effects (1). *T. indica* has been tested as an agroforestry species in India but although the reduction in crop yield is less that e.g. with teak, the spreading crown makes it little compatible with other species. The dense shade makes it more suitable for firebreaks as no grass will grow under the trees (2). *T. indica* is not recommended as a shade tree due to allelopathic effects on understorey plants. It is used along roads and for boundary plantings (4).

It is used also as a firebreak and planted at spacings of 2.5×2.5 m or 3×3 m for firewood plantations (4).

Plantations for timber production

The wood is hard and very heavy with purple-brown heartwood that is used for furniture (2). Growth is generally slow and seedling height increasing by about 60 cm annually. The juvenile phase lasts up to 4-5 years, or longer. Young trees are pruned to allow 3-5 well-spaced branches to develop into the main scaffold structure of the tree. After this, only maintenance pruning is required to remove dead or damaged wood (1).

The tree is long lived, over 200 years in some cases. The suggested rotation for timber is 50 to 60 years (4). In some countries it is planted at a spacing of 5×5 m, which may be thinned to 10×10 m as the trees mature; linear spacing is 10 to 15 m (4).

(1) Orwa et al. (2009) Agroforestry Database 4.0, World Agroforestry Centre
http://www.worldagroforestry.org/treedb2/speciesprofile.php?Spid=1589 http://www.worldagroforestry.org/treedb/AFTPDFS/Tamarindus_indica.pdf

(2) Danida Forest Seed Centre (2000) Seed leaflet No. 45 (*Tamarindus indica* L.)

(3) Royal Botanic Gardens, Kew. *Tamarindus indica* http://www.kew.org/plants-fungi/Tamarindus-indica.htm

(4) D. A. Hines and K. Eckman (1993) Indigenous multipurpose trees of Tanzania : Uses and economic benefits for people
http://www.fao.org/docrep/x5327e/x5327e1m.htm#tamarindus indica*

(5) CIAT/FAO, Grassland species profiles (*Tamarindus indica* L.) http://www.fao.org/ag/agp/AGPC/doc/gbase/data/pf000172.htm

(6) J. Morton (1987) Fruits of warm climates, p. 115-121 (Tamarind) http://www.hort.purdue.edu/newcrop/morton/tamarind.html

2) Highly drought-tolerant tree species distribute in Kenya

No.	Scientific Name	Family	Ecology				Description			Wood				Food				Fodder		Environmental factor				Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	Information on seed and seedlings *9)		Tiva natural stand *10)	Origin	Remarks
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)				DANIDA	KEFRI			
1	*Acacia brevispica*	Fabaceae (M) *12)	II – VI			0–2,100		Sh – St	5m	F						x		x	x					x	x					I	
2	*Acacia drepanolobium*	Fabaceae (M)	II – V		500–1,300	1,300–2,400		Sh – St	6m	B						x	x	x	x					x	x					I	
3	*Acacia elatior*	Fabaceae (M)	IV – VII			0–1,750		Tt	25m	B	x	x	x			x		x	x	x			x		x					I	
4	*Acacia gerrardii*	Fabaceae (M)	III – V			1,300–2,200		Mt	15m	B	x	x	x			x	x	x	x	x			x							I	
5	*Acacia mellifera*	Fabaceae (M)	I – VI		400–900	0–1,800		Sh – St	9m	B	x		x			x	x	x	x		x		x	x	x	○	○		○	I	VII (riverine)
6	*Acacia nilotica*	Fabaceae (M)	III – VI	4–47	500–1,000	0–2,500		St	6m	B		x	x			x	x	x	x	x	x		x	x	x	○	○			I	
7	*Acacia paolii*	Fabaceae (M)	VI – VII			100–1,250	D	Sh – St	4.5m	F						x	x	x	x						x					I	
8	*Acacia polyacantha*	Fabaceae (M)	III – IV		200–800	0–1,900		Mt	18m	B	x		x			x	x	x	x		x	x	x			○		○		I	
9	*Acacia senegal*	Fabaceae (M)	III – VII	–4–48	300–450	200–2,200		Sh – St	9m	B		x	x			x	x	x	x		x		x	x		○	○			I	
10	*Acacia seyal*	Fabaceae (M)	III – V	18–28	150–900	0–1,650		Mt	10m	B		x				x	x	x	x				x	x	x		○	○		I	
11	*Acacia tortilis*	Fabaceae (M)	IV – VII	23.4–31.3	100–1,000	600–2,300		St	5–8m	B	x	x		x		x	x	x	x	x	x	x	x	x	x	○	○	○		I	
12	*Acacia xanthophloea*	Fabaceae (M)	III – V		—	600–2,100		Tt	25m	B	x	x				x	x	x	x			x	x		x	○	○	○		I	
13	*Acrocarpus fraxinifolius*	Fabaceae (C) *11)	II – V			1,900	D – SD	Sh – St	10m	F	x		x						x	x		x	x							I	
14	*Adansonia digitata*	Bombacaceae	II – VI		300–900	0–1,300	D	Tt	20m					x	x	x	x	x	x			x	x	x		○	○			I	
15	*Adenium obesum*	Apocynaceae	III – VI			0–1,500	D	Sh	2m							x		x	x			x		x	x					I	
16	*Albizia amara*	Fabaceae (M)	IV – VII	10–47	400–1,000	500–2,000	D	Mt	15m	B	x	x	x			x	x	x	x		x	x	x	x	x					I	
17	*Albizia anthelmintica*	Fabaceae (M)	III – VI	＞40	400–1,000	0–1,350	D	Sh – St	4m	F	x					x		x	x	x			x	x					○	I	
18	*Albizia glaberrima*	Fabaceae (M)	III – IV			0–900	E	Mt – Tt	15–30m	B	x							x		x			x							I	
19	*Albizia gummifera*	Fabaceae (M)	II – IV		—	0–2,400	D	Tt	20m																	○		○		I	
20	*Allophylus africanus*	Sapindaceae	III – IV				E	Sh – St	6m																					I	
21	*Anacardium occidentale*	Anacardiaceae	I – IV					Mt	15m																					E	Coastal area; Brazil, Callibean
22	*Annona senegalensis*	Annonaceae	I – III	17–30	700–2,500	0–2,400		Sh – St	6m																					I	
23	*Antidesma venosum*	Euphorbiaceae	III – IV		850–1,000	0–1,900		Sh – St	6m	F			x	x		x			x	x		x		x						I	
24	*Areca catechu*	Arecaceae	III – V			1,500–5,000		Palm	30m						x	x					x			x						E	South East Asia
25	*Azadirachta indica*	Meliaceae	I – VI	＞40	400–1,200	0–1,500	E	Mt	20m	B	x	x	x			x		x	x	x	x	x	x	x		△	○	○		E	India
26	*Balanites aegyptiaca*	Balanitaceae	IV – VII	20–30	200–800	250–2,000	E	Mt	10m	B	x	x	x	x	x	x	x	x	x	x			x	x	x	○	○		○	I	
27	*Balanites glabra*	Balanitaceae	IV – VI			1,400–1,800	E	Sh – St	2–4m				x	x				x		x	x			x	x					I	
28	*Balanites rotundifolia*	Balanitaceae	VI – VII		150–400	50–1,350		Sh – St	2–5m	B		x	x	x		x		x	x		x			x	x					I	
29	*Balanites wilsoniana*	Balanitaceae	II – IV			0–1,200		St	6–12m	B	x	x	x	x			x	x	x											I	
30	*Bauhinia variegata*	Fabaceae (C)	II – IV			–2,200	SD	St	6m	F	x		x		x			x		x	x	x		x						E	India, Tropical Asia, China
31	*Berchemia discolor*	Rhamnaceae	V – VII	14–30	250–1,200	0–1,600	SD	Sh – Tt	18m	B	x	x	x	x		x	x	x	x	x		x	x	x		○				I	
32	*Bombax rhodognaphalon*	Bombacaceae	II – IV			0–350		Tt	36m		x		x	x		x	x			x		x	x	x						I	Coastal
33	*Borassus aethiopum*	Arecaceae	III – IV			0–1,400		Palm	25m		x	x	x	x	x		x					x		x						I	Coastal
34	*Boscia angustifolia*	Capparidaceae			200–800	up to 2,100																				△			○		
35	*Boscia coriacea*	Capparidaceae	VI		300–500	100–1,500	E	Sh – St	2–6m	F	x		x	x		x		x	x	x				x						I	

No.	Scientific Name	Family	Ecology				Description			Wood				Food				Fodder		Environmental factor				Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	Information on seed and seedlings *9)		Tiva natural stand *10)	Origin	Remarks
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)				DANIDA	KEFRI			
36	*Boswellia microphylla*	Burseraceae	VI – VII			250–400	D	Sh – St	5m	F							x							x						I	
37	*Boswella neglecta (B. hildebrandtii)*	Burseraceae	VI – VII		250–600	200–1,350		Sh – St	5m	F	x		x			x	x	x						x						I	
38	*Brachystegia spiciformis*	Asteraceae	III – IV			0–350	D	Mt – Tt	8–25m	B	x	x				x	x			x			x	x						I	
39	*Buddleja polystachya*	Longaniaceae	II – IV			1,000–3,000		Sh – St	4–5m	B	x					x		x	x			x		x	x					I	
40	*Cadaba farinosa*	Capparidaceae	IV – VI	29	200–500	0–1,900	E	Sh – St	5m	F					x	x	x	x						x						I	
41	*Cajanus cajan*	Fabaceae (P) *13)	III – V	18–38	600–1,000	0–1,800		Sh	2–3m	F				x				x	x		x		x							E	South East Asia
42	*Calliandra calothyrsus*	Fabaceae (M)	IV – VI			0–1,900		Sh	4–6m	F			x					x	x	x	x	x	x							E	Central America
43	*Callistemon citrinus*	Mytraceae	I – IV				E	St	6m	B						x			x			x	x							E	Australia, New Zealand
44	*Capparis tomentosa*	Capparidaceae	III – VI		–	0–2,100		Sh	3m	F														x	x					I	
45	*Carissa edulis (C. spinarum)*	Apocynaceae	II – V		500–1,800	0–2,500	E	Sh	5m					x	x	x	x	x	x			x		x	x					I	
46	*Casimiroa edulis*	Rutaceae	II – IV	18	–	1,200–2,400	E	Mt	12m	F				x					x				x							E	Central America
47	*Cassia abbreviata*	Fabaceae (C)	V – VII	27	1,400	0–100	D	Sh – St	10m	F	x	x				x						x		x						I	
48	*Casuarina cunninghamiana*	Casuarinaceae	I – IV	13–29	500–1,500	0–2,200	E	Tt	30m	B	x	x						x		x	x	x	x							E	Australia
49	*Casuarina equisetifolia*	Casuarinaceae	I – IV	10–35	200–3,500	0–1,400	E	Tt	20m	B	x	x	x					x		x	x	x	x	x		○	○	○		E	South East Asia, Australia
50	*Celtis africana*	Ulmaceae	I – VI			1,150–2,400	D	Mt	12m	B	x		x					x		x										I	
51	*Cocos nucifera*	Arecaceae	I – IV					Palm	20m	B	x	x	x	x			x			x		x		x						E	natulalized
52	*Combretum aculeatum*	Combretaceae	V – VI		–	0–1,350	D	Sh	4m	F				x		x		x	x					x			○			I	
53	*Combretum collinum*	Combretaceae	II – V		–			Sh – Mt	10m	B		x				x			x					x	x	○				I	
54	*Combretum molle*	Combretaceae	II – V		–	150–2,300	D	St	5–7m	B	x	x	x			x			x		x		x		x					I	
55	*Combretum schumannii*	Combretaceae	III – V			0–1,200		Tt	20m	B	x	x	x			x			x		x		x							I	
56	*Commiphora africana*	Burseraceae	IV – VII		400–1,000	300–800	D	Sh – St	10m	F			x	x		x	x	x				x		x	x		○		○	I	
57	*Commiphora eminii* subsp. *zimmermannii*	Burseraceae	II – IV		600–1,000	0–1,750		Mt	5–18m	F	x		x			x		x		x	x			x	x					I	*C. zimmermannii*
58	*Commiphora myrrha (C. coriacea)*	Burseraceae	VI – VII		230–400	220–800		Sh – St	5m	F			x	x		x		x		x				x	x					I	
59	*Commiphora rostrata*	Burseraceae	V – VII		200–400	80–1,050	D	Sh – St	4m				x		x	x	x	x						x	x					I	
60	*Conocarpus lancifolius*	Combretaceae	V – VI				E	Tt	20m	B	x	x	x					x	x	x	x	x	x							E	Coastal area; Somalia
61	*Cordeauxia edlis*	Fabaceae (C)	V – VII		-400	300–1,000		Sh	3–4m	F				x				x	x		x		x	x	x					E	Coastal area ; Ethiopia, Somalia
62	*Cordia monoica (C. ovalis)*	Boraginaceae	II – IV					Sh – St	6m	B	x	x	x	x		x		x	x	x				x	x					I	
63	*Cordia sinensis (C. gharaf, C. rothii)*	Boraginaceae	III – VII			0–1,400	D	Sh – St	3–12m	F	x	x	x	x		x	x	x	x					x						I	
64	*Cordyla africana*	Fabaceae (P)	III – IV				D	Tt	9–25m		x	x	x	x						x										I	Coastal area
65	*Crateva adansonii*	Capparidaceae	III – V			550–1,500	D	St	3–10m	B			x	x	x	x		x	x			x		x						I	
66	*Croton megalocarpus*	Euphorbiaceae	III – IV	11–26	800–1,900	1,200–2,450	D	Tt	35m	B	x	x				x			x	x		x	x	x	x	○		○		I	
67	*Cupressus lusitanica*	Cupessaceae	II – III	12–30	800–1,500	1,000–4,000	E	Tt	35m	F	x	x								x		x	x	x	x	○		○		E	Mexico, Guatemara
68	*Cussonia holstii*	Araliaceae	III – IV			1,500–2,500		Mt	15m		x		x			x		x	x	x										I	
69	*Dalbergia melanoxylon*	Fabaceae (P)	II – VI	18–35	700–1,200	0–1,350		Sh – St	7m	B	x	x	x			x		x	x				x			○				I	
70	*Delonix elata*	Fabaceae (C)	V – VII	27	580	100–1,200	D	Sh – Mt	15m		x	x	x	x		x		x	x	x		x		x		○				I	

No.	Scientific Name	Family	Ecology				Description			Wood				Food				Fodder		Environmental factor				Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	Information on seed and seedlings *9)		Tiva natural stand *10)	Origin	Remarks
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)				DANIDA	KEFRI			
71	*Delonix regia*	Fabaceae (C)	II – IV	14–26	> 700	0–1,600	D – SD	Mt	15m	F									x	x		x				○		○		E	Madagascar
72	*Dicrostachys cinerea*	Fabaceae (M)	II – VI					Sh – St	8m	F			x					x	x			x	x	x						I	
73	*Diospyros mespiliformis*	Ebenaceae	IV – VI			20–1,100		Mt – Tt	25m	B	x		x	x		x	x		x	x		x								I	
74	*Diospyros scabra*	Ebenaceae	V – VI			900		Sh – St	7m	F	x		x	x		x		x	x	x				x						I	
75	*Dobera glabra*	Salvadoraceae	IV – VII		100–600	0–1,500	E	St	4–7m	F	x		x	x		x	x	x		x				x		○				I	
76	*Dodonaea angustifolia*	Sapindaceae	II – IV		450	0–2,800		Sh – St	2–8m	F		x	x			x			x			x	x	x		○				I	
77	*Dombeya rotundifolia*	Sterculiaceae	II – IV			900–2,200	D	Sh – St	8m	F	x	x	x			x	x	x	x	x	x	x	x	x						I	
78	*Dovyalis caffra*	Flacourtiaceae	II – IV		—	1,200–2,000	E	Sh	3–5m					x		x						x			x	○	○	○		E	Southern Africa
79	*Elaeodendron buchananii*	Celastraceae	III – IV					Tt	20m	B	x					x				x	x		x							I	
80	*Erythrina abyssinica*	Fabaceae (P)	II – V			900–2,250	D	St – Mt	6–12m	F	x		x			x			x		x	x	x	x						I	
81	*Erythrina burtii*	Fabaceae (P)	IV – V			950–1,750	D	Mt	5–15m		x		x							x			x							I	
82	*Erythrina melanacantha*	Fabaceae (P)	V – VI			300–1,300	D	Tt	12m		x		x					x		x		x	x							I	
83	*Eucalyptus camaldulensis*	Mytraceae	II – IV	3–40	250–2,500	0–1,600	E	Tt	30m	B	x	x							x	x		x	x	x		○		○		E	Australia
84	*Eucalyptus globulus* ssp. *globulus*	Mytraceae	I – IV	12–18	500–1,500	0–3,100		Tt	55m	B	x	x				x			x				x	x		○				E	Australia
85	*Eucalyptus grandis*	Mytraceae	II – V	–1–40	100–1,800	0–2,700																						○		E	Australia
86	*Euclea divinorum*	Ebenaceae	II – VI	17	700	0–2,500		Sh– St	3–5m	F	x		x			x			x	x				x						I	
87	*Euphorbia candelabrum*	Euphorbiaceae	IV – V			1,100–2,200		Mt	15m	F	x		x			x			x	x				x	x					I	
88	*Euphorbia tirucalli*	Euphorbiaceae	II – VI		—	up to2,000		Sh – St	8m	F						x		x	x	x				x	x					I	
89	*Faidherbia albida*	Fabaceae (M)	IV – VII	18–30	200–900	500–2,000	D	Tt	30m	B	x	x	x	x		x	x	x		x	x		x	x		○	○	○		I	reverse phenology
90	*Faurea saligna*	Proteaceae	III – IV		500	2,200–3,100	D	Sh – Tt	20m	B	x	x				x			x			x	x	x		○				I	
91	*Ficus benjamina*	Moraceae	II – IV				E	Mt	10–20m	F										x		x								E	India, Malaysia, Indonesia
92	*Ficus sur (F. capensis)*	Moraceae	II – IV				D	Tt	20m	F	x		x	x		x		x	x	x	x	x	x	x						I	
93	*Ficus sycomorus*	Moraceae	II – VII	0–40	250–1,200	0–2,000	SD	Tt	25m	F	x		x	x		x	x	x		x	x	x	x	x						I	riverine in dry area
94	*Ficus thonningii (F. dekdekana)*	Moraceae	II – V			0–2,100	E	Tt	20m	F				x		x		x		x		x	x	x	x					I	
95	*Flacourtia indica*	Flacourtiaceae	III – V	4–48	500–2,000	0–2,400	D	Sh – St	3–5m	B	x	x	x	x		x	x	x	x						x	○				I	
96	*Flueggea virosa (Securinega vilosa)*	Euphorbiaceae	II – V			120–2,000	D	Sh	1–3m	B			x	x		x		x						x						I	
97	*Garcinia livingstonei*	Guttiferae	II – V		—	0–1,900	E	Sh – St	2–10m	F		x	x	x		x		x		x	x	x		x		△				I	
98	*Garcinia volkensii*	Guttiferae	III – IV					St	8m				x			x				x		x		x						I	
99	*Gliricidia sepium*	Fabaceae (P)	III – VI			0–1,600		St	8m	B		x	x					x	x	x	x	x	x		x					E	Central America, Mexico
100	*Grevillea robusta*	Proteaceae	II – V	14–31	600–1,700	0–3,000	SD	Tt	20m	B	x	x						x	x	x	x	x	x			○	○	○		E	Australia
101	*Grewia bicolor*	Tiliaceae	III – VI		400–900	0–1,800		Sh – St	2–10m	F		x	x	x		x		x		x				x		○			○	I	
102	*Grewia plagiophylla*	Tiliaceae	III – V					Sh – St	7m			x	x	x		x				x		x		x						I	
103	*Grewia tembensis*	Tiliaceae	III – V		500–800	250–2,200		Sh	4m	F			x	x		x		x							x					I	
104	*Grewia tenax*	Tiliaceae	V – VII		200–1,000	0–1,250	D	Sh	4m	F			x	x		x		x	x					x						I	
105	*Grewia villosa*	Tiliaceae	IV – VII		200–800	0–1,500	D	Sh	3m	F		x	x	x		x		x		x				x		○			○	I	VII (riverine)

No.	Scientific Name	Family	Ecology				Description			Wood				Food				Fodder		Environmental factor							Information on seed and seedlings *9)				
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)	Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	DANIDA	KEFRI	Tiva natural stand *10)	Origin	Remarks
106	*Harrisonia abyssinica*	Rutaceae	II – V					Tt	25m	B	x	x	x			x			x		x	x	x	x						I	
107	*Hyphaene compressa*	Arecaceae	II – VII			0–1,000		Palm	25m	F	x	x	x	x			x			x			x	x	x					I	
108	*Jacaranda mimosifolia*	Bignoniaceae	II – V	20	900–1,300	up to 2,200	D	Tt	20m	F		x	x						x	x		x	x			○		○		E	Brazil
109	*Kigelia pinnata*	Bignoniaceae	II – V		500–1,500	0–2,200	SD	St	9m	B	x	x	x			x	x	x	x	x		x	x	x						I	*K. africana, K. aethiopum*
110	*Lannea alata*	Anacardiaceae	V – VI		400–600	below 1,500	D	Sh	1.5–4m	F				x		x		x						x						I	
111	*Lannea rivae (L. floccosa)*	Anacardiaceae	IV – V			300–2,000	D	Sh – St	1.5–6m					x		x	x			x				x	x					I	
112	*Lannea schimperi*	Anacardiaceae	II – IV				D	St	7m	B	x	x	x	x		x	x			x			x	x						I	
113	*Lannea schweinfurthii*	Anacardiaceae	III – V			0–1,800		Sh – Mt	20m	B	x		x	x		x	x	x	x	x				x	x					I	
114	*Lannea triphylla*	Anacardiaceae	IV – VI			340–1,400	D	Sh – St	5m		x			x		x	x	x						x	x					I	
115	*Lawsonia inermis*	Lythraceae	V – VII	19–27	200–4,200			Sh – St	4m	F		x	x			x	x	x	x				x	x	x	○				I	
116	*Lecaniodiscus fraxinifolius*	Sapindaceae	II – VII					St – Mt	5–18m	B			x	x		x			x	x				x						I	VII (rivirine)
117	*Lepisanthes senegalensis*	Sapindaceae	II – V			0–1,900	E	St – Tt	6–21m	B	x	x	x	x		x				x				x						I	
118	*Leucaena leucocephala*	Fabaceae (M)					E	Sh – Mt	5–20m	F						x		x	x	x	x		x	x						E	*L. glauca, latisiliqua* ; C. America
119	*Lippia kituiensis (L. ukambensis)*	Verbenaceae	III – V			400–2,600		Sh	3.5m																					I	
120	*Maerua decumbens*	Capparidaceae	IV – VI					Sh	1–3m					x		x														I	*M. subcordata, M. edulis*
121	*Mangifera indica*	Anacardiaceae	II – V	19–35	500–2,500	0–1,200	E	Mt	10–15m	F	x		x	x			x	x	x	x	x	x	x	x						E	VI, VII (riverine); India, Burma
122	*Manihot glaziovii*	Euphorbiaceae	I – V		600–700	600–700	D	St	8m									x		x	x	x								E	Brazil
123	*Manilkara mochisia*	Sapotaceae	V – VII			0–1,200		Sh – Mt	3–20m	B	x	x	x	x		x		x	x											I	
124	*Manilkara sansibarensis*	Sapotaceae	II – IV			0–300	E	Mt	25m	F	x		x	x		x				x				x						I	
125	*Manilkara sulcata*	Sapotaceae	II – IV			0–1,000	E	Sh – St	3–6m	F	x		x	x		x														I	
126	*Margaritaria discoidea*	Euphorbiaceae	II – IV			0–2,000	D	Tt	25m	B	x	x				x														I	*Phyllanthus discoideus*
127	*Melia azedarach*	Meliaceae	II – V	23–27	350–2,000	0–1,800	D	St	5–6m		x	x	x			x			x	x		x					○			E	Asia, Australia
128	*Melia volkensii*	Meliaceae	V – VI		300–800	350–1,680	D	Mt	15m	F	x					x		x	x	x	x		x			○	○	○		I	
129	*Meyna tetraphylla*	Rubiaceae	III – VII					Sh	2–4m					x		x								x	x					I	VII (rivirine)
130	*Mimusops kummel*	Sapotaceae	III – IV			500–2,250	E	Tt	35m	B	x		x	x		x	x			x										I	
131	*Mimusops obtusifolia (M. fruticosa)*	Sapotaceae	IV – VII			0–400	E	Mt	15m	B	x	x	x	x		x														I	VII (rivirine)
132	*Mkilua fragrans*	Annonaceae	II – IV			0–450		Sh – St	8m	F		x				x						x		x						I	
133	*Monodora grandidieri*	Annonaceae	II – IV			0–400		Sh – St	6m				x			x														I	
134	*Moringa oleifera*	Asclepiadaceae	III – VI	12.6–40	＜350	0–1,450	D	St	10m					x	x	x	x	x	x	x			x	x	x	○	○			E	India
135	*Moringa stenopetala*	Asclepiadaceae	V – VII	24–30	500–1,400	450–1,200		St	9m	F				x	x	x				x		x				○				I	VII (riverine)
136	*Morus alba*	Moraceae	II – V			up to 2,000				F				x	x			x	x	x	x	x	x		x					E	China
137	*Newtonia buchananii*	Fabaceae (M)	II – VI		—	600–2,200	D	Tt	40m	F	x							x		x		x	x			○		○		I	
138	*Newtonia hildebrandtii*	Fabaceae (M)	IV – VI			100–1,000		Tt	25m	B		x	x			x														I	
139	*Ormocarpum kirkii*	Fabaceae (P)	IV – VI					Sh – St	2–9m	F			x			x		x				x								I	
140	*Osyris lanceolata*	Santalaceae	II – IV			900–2,550	E	Sh – St	1–6m	F	x	x	x	x		x	x				x	x		x						I	

No.	Scientific Name	Family	Ecology				Description			Wood				Food			Fodder		Environmental factor								Information on seed and seedlings *9)				
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)	Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	DANIDA	KEFRI	Tiva natural stand *10)	Origin	Remarks
141	*Ozoroa insignis* subsp. *reticulata*	Anacardiaceae	II – IV			0–2,200	SD	Sh – St	14m	B	x		x			x				x				x						I	*Heeria reticulata*
142	*Pandanus kirkii*	Pandanaceae	I – V					St	4–8m							x						x	x	x						I	Coastal area
143	*Pappea capensis*	Sapindaceae	II – V			1,050–2,400	SD	St	6m	B	x	x	x	x		x	x	x	x	x		x		x						I	
144	*Parkinsonia aculeata*	Fabaceae (C)	III – V	to 36	200–1,000	0–1,300		Sh – St	5–8m	B						x		x	x	x	x	x	x		x	○				E	Tropical America
145	*Parinari curatellifolia*	Chrysobalanaceae	III – IV		700–1,500	0–2,100		Sh – St	15m	B	x	x		x		x			x	x				x						I	
146	*Pavetta crassipes*	Rubiaceae	II – V				D	Sh – St	7m							x		x	x											I	
147	*Persea americana*	Lauraceae	II – V	−4–40	300–2,500	up to 2,200	E	St	10m		x			x					x	x				x						E	Central America
148	*Phoenix dactylifera*	Arecaceae	VII	−15–50	100–300	up to 1,500		Palm	20–30m		x	x	x	x		x	x	x		x		x	x	x						E	riverine; Middle East etc.
149	*Phoenix reclinata*	Arecaceae	II – VII			0–2,600		Palm	15m	F	x			x			x		x			x	x	x						I	
150	*Piliostigma thonningii*	Fabaceae (C)	I – IV	20	700–1,400	0–1,850	D	St	3–5m	B		x		x	x	x	x	x	x	x	x	x	x	x	x	○				I	*Bauhinia thonningii*
151	*Pistacia aethiopica*	Anacardiaceae	III – IV			800–2,400	E	Sh – St	3–15m	F		x	x			x	x		x			x		x						I	
152	*Pithecellobium dulce*	Fabaceae (M)	III – VI					Sh – St	4–15m	F		x		x			x	x	x	x	x		x	x	x					E	Latin America
153	*Plectranthus barbatus*	Labiatae	I – IV					Sh	1–4m							x						x		x	x					I	
154	*Populus ilicifolia*	Salicaceae	III – VII				SD	Tt	30m	F		x	x					x				x	x							I	Riverine all area
155	*Prosopis chilensis*	Fabaceae (M)	IV – VII			0–1,500		Sh – St	8–15m	B	x	x		x	x			x	x	x	x			x	x					E	Chile, Argentina
156	*Prosopis juliflora*	Fabaceae (M)	II – VII	14–34	50–1,200	0–1,500		Sh – St	6m	B	x	x	x	x	x	x		x	x	x	x		x		x		○			E	Central America, Mexico
157	*Psidium guajava*	Mytraceae	I – V	15–45	1,000–2,000	0–2,000	E	St	8m	F			x	x		x	x	x	x	x	x	x		x	x					E	South and Central America
158	*Raphia farinifera*	Arecaceae	II – IV			up to 1,400		Palm	25m								x							x						I	
159	*Rhamnus staddo*	Rhamnaceae	II – IV			1,400–2,900		Sh – St	5m	F			x			x	x													I	
160	*Rhus natalensis*	Anacardiaceae	I – V		—	0–3,000		Sh – St	8m	B	x			x		x		x		x		x		x						I	
161	*Rhus tenuinervis*	Anacardiaceae	IV – V		500–800	900–1,850		Sh – St	6m	B				x		x		x		x				x	x					I	
162	*Salvadora persica*	Salvadoraceae	V – VI		—	0–1,500	E	Sh – St	3–7m					x		x		x	x	x	x		x	x		△				I	
163	*Sapium ellipticum*	Euphorbiaceae	II – IV					St – Mt	20m	B	x		x			x		x		x		x								I	
164	*Schinus molle*	Anacardiaceae	III – V			0–2,400		Mt	15m	B						x	x		x	x	x	x		x						E	Peru, Andes
165	*Sclerocarya birrea* ssp. *caffra*	Anacardiaceae	III – V		200–1,370	500–1,600	D	St – Mt	10–18m	B	x	x	x	x		x	x	x	x	x			x	x		○	○			I	
166	*Scutia myrtina*	Rhamnaceae	II – IV			0–2,700		Sh	6m					x		x		x		x										I	
167	*Senna siamea (Cassia siamea)*	Fabaceae (C)	III – IV	20–31	400–2,800	0–1,800	E	Mt	20m	B	x	x				x			x	x	x	x	x	x		○	○	○		E	South East Asia
168	*Senna singueana (Cassia singueana)*	Fabaceae (C)	IV – V	25–30	500–1,000	0–2,400		St	4–5m							x								x						I	
169	*Senna spectabilis (Cassia spectabilis)*	Fabaceae (C)	II – IV	15–25	800–1,000	up to 2,000	D	St – Mt	10–20m	B		x	x						x	x		x	x			○				E	Tropical America
170	*Sesbania sesban*	Fabaceae (P)	I – IV	10–45	500–2,000	350–1,900	D	St	8m	F		x				x		x		x	x		x	x						I	
171	*Sideroxylon inerme (S. diospyroides)*	Sapotaceae	III – IV					Sh – St	12m		x	x		x																I	
172	*Solanesio mannii*	Asteraceae	III – IV			0–2,600		Sh – St	10m	F						x		x				x		x	x					I	*Crassocephalum mannii*
173	*Spirostachys venenifera*	Euphorbiaceae	III – VI			0–1,450		St	5–7m		x	x	x			x														I	
174	*Steganotaenia araliacea*	Apiaceae			—	up to 2,000																							○		
175	*Sterculia africana*	Sterculiaceae	V – VI			below 600	D	St	5–12m		x								x			x		x						I	

No.	Scientific Name	Family	Ecology				Description			Wood				Food				Fodder		Environmental factor							Information on seed and seedlings *9)				
			Agro-climatic Zone	Annual temp.	Annual rainfall	Altitude	Description *1)	Description *2)	Tree height	Firewood, Charcoal *3)	Timber, Furniture, Construction	Poles	Others *4)	Edible Fruit, Nut, Seed	Vegetable, Edible leaves/roots	Medicine	Others *5)	Fodder	Bee forage	Shade	Soil conservation	Ornamental, Roadside tree	Others *6)	Others *7)	Live fence, Dead fence	Potencial of seed supply *8)	DANIDA	KEFRI	Tiva natural stand *10)	Origin	Remarks
176	*Sterculia appendiculata*	Sterculiaceae	V – VII				D	St	40m		x		x	x		x				x		x		x						I	
177	*Sterculia foetida*	Sterculiaceae	V – VII		—																										
178	*Strombosia scheffleri*	Olacaceae	III – IV			1,200–2,300	E	Tt	30m	B	x		x							x										I	
179	*Strychnos henningsii*	Longaniaceae	III – V			0–2,300		Sh – St	6m			x	x			x	x								x					I	
180	*Strychnos spinosa*	Longaniaceae	III – IV			0–1,800	SD	Sh – St	2–5m	B	x			x		x		x		x		x		x						I	
181	*Syzygium cordatum*	Mytraceae	II – IV			0–2,500	E	Mt	8–15m	B	x		x	x		x	x	x	x	x		x		x						I	
182	*Syzygium cumini*	Mytraceae	II – IV		＞1,000	0–1,800		Mt	15–18m	B	x	x	x	x		x		x	x	x		x	x	x						E	India, Tropical Asia
183	*Tamarindus indica*	Fabaceae (C)	III – V	＞47	350–1,500	0–1,500		Tt	30m	B	x	x	x	x		x	x	x	x	x		x	x	x			○			I	
184	*Tamarix nilotica*	Tamaricaceae	V – VI			0–1,050	E	Sh – St	6m	F		x	x							x		x	x							I	
185	*Terminalia brownii*	Combretaceae	IV – V		500–1,300	700–2,000	SD	St	7–13m	B	x	x	x			x		x		x	x	x	x	x		○	○		○	I	
186	*Terminalia mantaly*	Combretaceae	III – V		—	0–2,000		St	10m											x		x								E	Madagascar
187	*Terminalia orbicularis*	Combretaceae	V – VI			100–1,500	D	Sh – St	6m	F	x		x			x		x				x		x						I	
188	*Terminalia prunioides*	Combretaceae	V – VI		450–900	0–1,200		Sh – St	3–10m	B	x	x	x			x		x					x			○				I	
189	*Terminalia spinosa*	Combretaceae	IV – V					St	15m	B	x	x	x			x		x							x					I	
190	*Thespesia danis*	Malvaceae	III – VII					Sh – St	1–6m	F		x	x	x		x		x		x		x	x	x						I	riparian in dry areas
191	*Thespesia garckeana*	Malvaceae	III – V		600–800	500–1,500	SD	Sh – St	3–10m	F	x	x	x	x		x		x	x	x		x	x	x						I	*Azanza garckeana*
192	*Thevetia peruviana*	Apocynaceae	III – V					Sh – St	4m							x				x	x		x		x					E	Central and South America
193	*Thylachium thomasii*	Capparidaceae	III – IV			0–1,300	E	Sh – St	5m					x	x	x				x										I	
194	*Tipuana tipu*	Fabaceae (P)	III – IV			1,200–2,200	SD	Sh – Mt	20m	B	x	x							x	x	x	x	x							E	Bolibia, Brazil
195	*Tithonia diversifolia*	Asteraceae	II – IV			550–1,950		Sh	1–3m							x		x			x	x	x	x	x					E	Central America
196	*Toona ciliata*	Meliaceae	III – IV			0–1,800	SE	St	10m	B	x					x				x		x	x	x						E	Tropical Asia, China, Himalayas
197	*Trema orientalis (T. guineensis)*	Ulmaceae	II – IV			up to 2,200		Sh – St	12m	B		x				x		x	x	x	x	x	x	x						E	Asia
198	*Trichilia emetica*	Meliaceae	II – V			0–1,450	E	Mt – Tt	15–30m	F	x	x	x			x		x	x	x	x	x	x	x						I	riverine in dry area
199	*Vangueria apiculata*	Rubiaceae	III – IV			900–2,500	D	Sh – St	6m	F			x	x						x		x								I	
200	*Vangueria infausta*	Rubiaceae				0–2,450	D	Sh – St	8m	F		x	x	x		x		x	x	x		x								I	*V. rotundata, V. tomentosa*
201	*Vangueria madagascariensis*	Rubiaceae	II – V			0–2,400	D	Sh	4–6m	F		x	x	x		x			x	x		x								I	
202	*Vitex mombassae*	Verbenaceae	II – IV			0–450	D	Sh – St	3–6m	F		x	x	x					x	x		x								I	Coastal
203	*Vitex payos*	Verbenaceae	III – IV		650–850	0–1,600	D	St	8m	F		x	x	x						x		x				○				I	
204	*Ximenia americana*	Olacaceae	IV – V			0–2,000		Sh – St	4m	F	x	x	x	x		x		x	x					x	x					I	
205	*Xylopia parviflora*	Annonaceae	III – IV			0–250		Mt	24m	F	x	x				x														I	
206	*Zanthoxylum chalybeum*	Rutaceae	V			0–1,500	D	Sh – St	8m	B	x	x	x			x	x	x						x						I	*Fagara chalybea*
207	*Zanthoxylum usambarense*	Rutaceae	III – IV			1,400–2,500		Sh – St	5–8m		x		x			x								x	x					I	*Fagara usambarensis*
208	*Ziziphus abyssinica*	Rhamnaceae	III – IV			400–2,000	SE	Sh – St	3–6m	B	x	x	x	x		x		x	x	x				x	x					I	
209	*Ziziphus mouritaniana*	Rhamnaceae	III – VII			0–1,800		Sh – St	10m	B	x	x	x	x		x		x	x	x	x		x	x	x					E	North Africa, Asia
210	*Ziziphus mucronata*	Rhamnaceae	IV – VI			0–1,950		Sh – St	8m	B		x	x	x		x	x	x	x	x		x			x					I	

Remarks 1) : This list has compiled based on the information from "Useful trees and shrubs for Kenya", World Agroforestry Centre. Tree species adaptable to Agro-climatic Zone IV to VII was selected.

Remarks 2) : Some information missing in the "Useful tree and shrubs for Kenya" was complemented by the information mentioned in the "Agroforestre Data Base 4.0", World Agroforestry Centre

Remarks 3) : The information about "Potencial of seed supply" picked up from "Revised Seed Catalogue", October, 2005, Kenya Forestry Seed Centre, KEFRI (Kenya Forest Research Institute)

Remarks 4) : The information about "Information on seed and seedlings" picked up from "Tree Seed Information Leaflet", KEFRI & "Seed Leaflet", DANIDA (Danish International Development Agency)

***1)** Description: D = Deciduous, E = Evergreen, SD = Semi-Deciduous, SE = Semi-evergreen (Semi-Deciduous and Semi ever green is due to the short of each period)

***2)** Description: Sh = Shrub, St = Small tree, Mt = Medium-size tree, Tt = Tall tree, Palm = Palm

***3)** Firewood, Charcoal: F = for Firewood, C = for Charcoal, B = for both purpose

***4)** Others (Wood): Posts, Beehives, Tools, Tool handles, Shafts, Carvings, Utensils, Walking stick, Bow, Arrow, Farm implements

***5)** Others (Food): Seasonings, Flavoring, Drink, Soup, Edible oil, Gum, Inner bark, Jam, Syrup

***6)** Others (Environmental factor): Mulch, Nitrogenfixation, River bank, Sand stabilization, Windbreak

***7)** Others: Fibre, Weaving, Rope, Thatch, Roofing, Mats, Baskets, Regin, Gum, Glue, Latex, Tannin, Dye, Ceremonial, Toothbrushes, Boundary marking, Veterinary medicine, Toxin, Insecticide, Repellent, Cosmetic, Soap, Perfume, Oil, Brooms

***8)** Potencial of seed supply: Potencial of seed supply by the Kenya Forest Tree Seed Centre, KEFRI

***9)** Information on seed and seedlings : Presence of leaflet information about seed and seedlings

***10)** Tiva natural stand: Tree species confirmed in the Tiva Pilot Forest, Kitui District, Eastern Province, Kenya

***11)** Fabaceae (C) = Fabaceae (Caesalpiniaceae)

***12)** Fabaceae (M) = Fabaceae (Mimosaceae)

***13)** Fabaceae (P) = Fabaceae (Papilionaceae)

Annex 3

Agro-climatic zone of Kenya

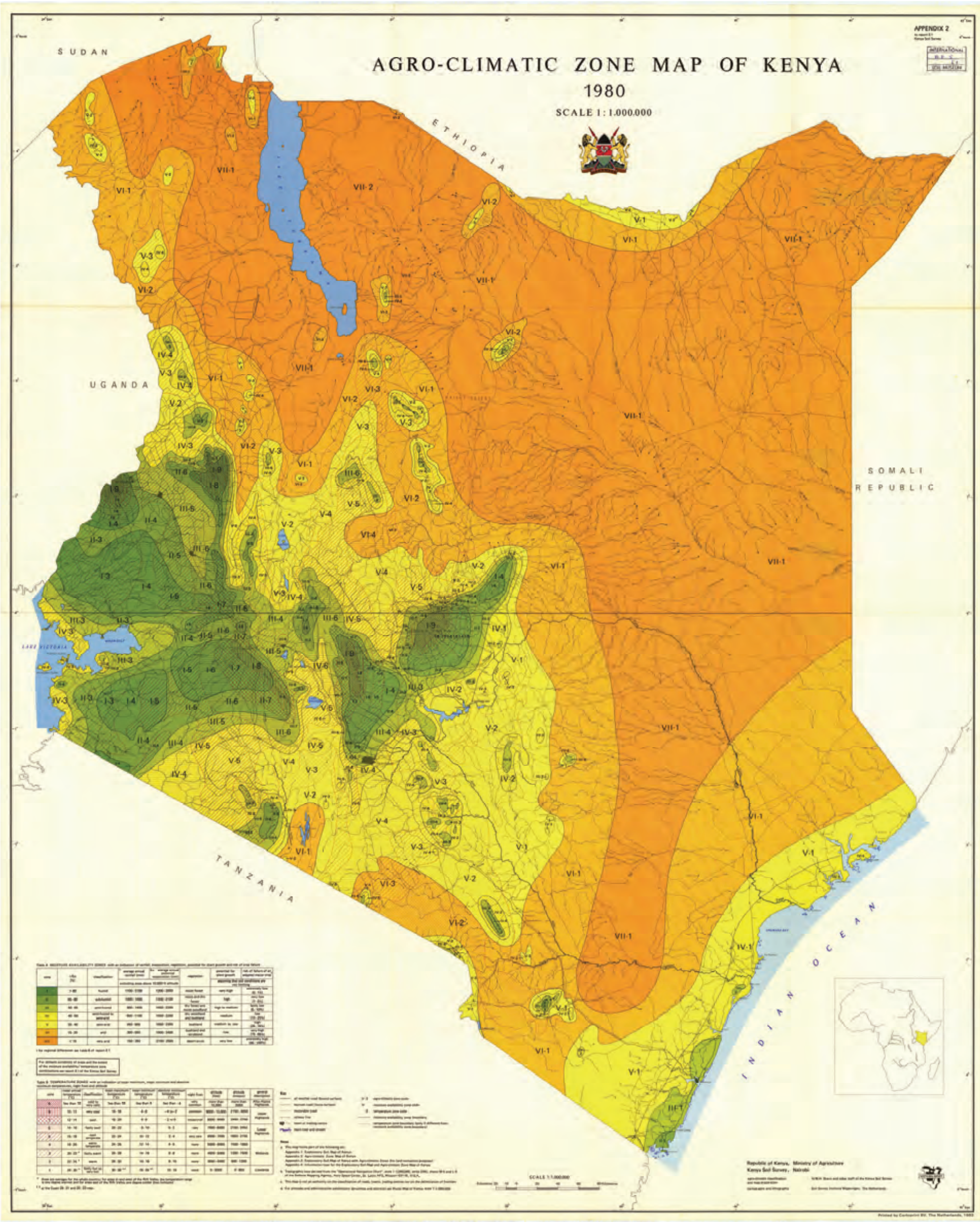

Fig. A-3-1: Agro-climatic Zone Map of Kenya

(Ministry of Agriculture, Kenya, 1980 (Organization at the time in 1980))

Published at the web site:

http://eusoils.jrc.ec.europa.eu/esdb_archive/eudasm/africa/lists/cke.htm

Table A-3-1: MOISTURE AVAILABILITY ZONES with an indication of rainfall, evaporation, potential for plant growth and risk of crop failure

zone	r/E0 (%)	classification	average annual rainfall (mm) - r	average annual potential evaporation (mm) - E0	vegetation	potential for plant growth	risk of failure of an adapted maize
			excluding areas above 10,000 ft altitude			assuming that soil conditions are not limiting	
I	> 80	humid	1100 – 2700	1200 – 2000	moist forest	very high	extremely low (0 – 1%)
II	65 - 80	sub-humid	1000 – 1600	1300 – 2100	moist and dry forest	high	very low (1 – 5%)
III	50 - 65	semi-humid	800 – 1400	1450 – 2200	dry forest and moist woodland	high to medium	fairly low (5 – 10%)
IV	40 - 50	semi-humid to semi-arid	600 – 1100	1550 – 2200	dry woodland and bushland	medium	low (10 – 25%)
V	25 - 40	semi-arid	450 – 900	1650 – 2300	bushland	medium to low	high (25 – 75%)
VI	15 - 25	arid	300 – 550	1900 – 2400	bushland and scrubland	low	very high (75 – 95%)
VII	< 15	very arid	150 - 350	2100 - 2500	desert scrub	very low	extremely high (95 – 100%)

Table A-3-2: TEMPERATURE ZONES with an indication of mean maximum, mean minimum and absolute minimum temperature, night frost and altitude

zone	mean annual temperature (°C)	classification	mean max. temperature (°C)	mean min. temperature (°C)	absolute min. temperature (°C)	night frost	altitude (feet)	altitude (meters)	general description
9	less than 10	cold to very cold	less than 16	less than 4	less than -4	very common	more than 10000	more than 3050	Afro-Alpine highlands
8	10 - 12	very cool	16 - 18	4 - 6	-4 to -2	common	9000 - 10000	2750 - 3050	Upper highlands
7	12 - 14	cool	18 - 20	6 - 8	-2 to 0	occasional	8000 - 9000	2450 - 2750	
6	14 - 16	fairly cool	20 - 22	8 - 10	0 - 2	rare	7000 - 8000	2150 - 2450	Lower highlands
5	16 - 18	cool temperature	22 - 24	10 - 12	2 - 4	very rare	6000 - 7000	1850 - 2150	
4	18 - 20	warm temperature	24 - 26	12 - 14	4 - 6	none	5000 - 6000	1500 - 1850	Midlands
3	20 - 22 *	fairly warm	26 - 28	14 - 16	6 - 8	none	4000 - 5000	1200 - 1500	
2	22 - 24 *	warm	28 - 30	16 - 18	8 - 10	none	3000 - 4000	900 - 1200	
1	24 - 30 *	fairly hot to very hot	30 - 36 **	18 - 24 **	10 - 16	none	0 - 3000	0 - 900	Lowlands

* these are averages for the whole country; for areas in and west of the Rift Valley the temperature range is one degree warmer and for areas east of the Rift Valley one degree colder than indicated

** at the Coast 28 – 31 and 20 – 23 resp.

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