Acacia tortilis 実生採種林の設置及び管理のガイドライン（概要）

ケニア政府は、東アフリカの乾燥・半乾燥地域（ASALs）における植林を JICA と協力して 30 年以上促進してきた。ASALs において、*Acacia tortilis*（以下、アカシア）は、家畜の飼料や燃料として高く評価される樹種のひとつであるが、過剰な利用状況にあり、その資源の安定供給は重要かつ喫緊の課題である。

１．背景とアカシアの育種

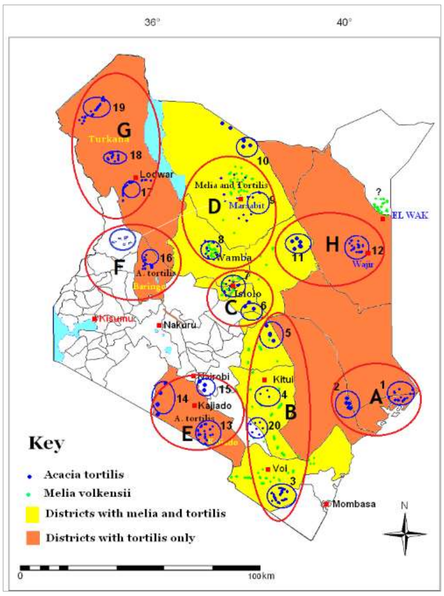
アカシアは「トゲの傘」と言われ、アフリカ地域の乾燥・半乾燥地域に最も広く生息する樹種の一つであり、サバンナ地域で優勢な樹木で、果実や葉のタンパク含量が高く、燃焼時の熱量が高いことから、動物の飼料や燃材料として重要である。アフリカから中東アラビア南部、イランにかけての乾燥地・半乾燥地、海抜０～1,000m、年間雨量 40～1,200mm、年平均気温 23.4～31.3 度の地域に自生し、砂丘、岩石地、堆積土壌など幅広く適応する。乾燥地での造林への使用に適応でき、環境ストレスに対し顕著な耐性及び広く生態的な適応力を示す。このため、アカシアの育種プログラムは、プラス木候補木の選定とともに 2012 年に開始された。

２．ガイドラインの目的

本ガイドラインの目的は、アカシアの種苗生産に必要な種子を供給する実生採種林を造成し、維持管理する技術的情報を提供することである。

３．アカシアのプラス木の選抜

アカシアの育種プログラムでは、ケニア国におけるアカシアの分布域を網羅し、かつ特定の地域に偏らないように区分された地域から、プラス木候補木(CPTs)100 個体が選抜された。選抜に際しては、樹高や胸高直径等が周囲の同種別個体と比較して優れている個体が候補木として選ばれた。



図：アカシアの分布域とプラス木選抜のための地域区分

４．アカシア実生採種林・検定林の造成

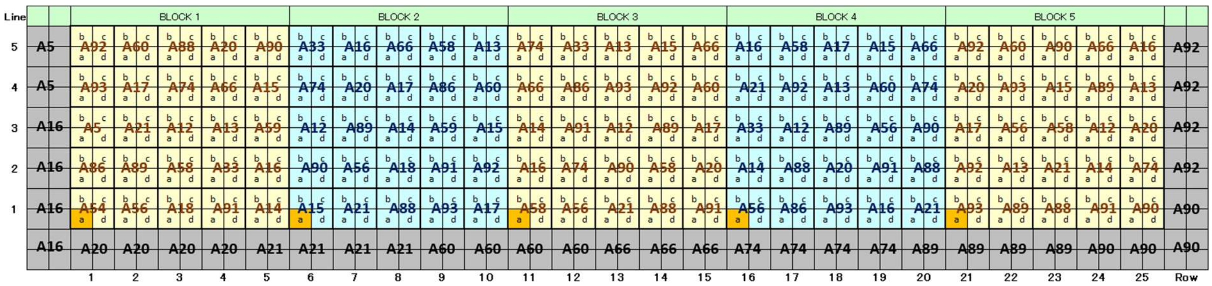
選抜されたプラス木候補木からは種子が採取され、実生採種林造成用の苗が育成された。2015 年から 2016 年にかけて、Tiva と Kibwezi に検定林を兼ねた実生採種林が造成された。その役割は次のとおりである。

(i)　成長その他の遺伝的性質を評価し、次世代を選抜するとともに、それらの性質に子孫への遺伝性があるか否かを確認する検定林。

(ii)　種子を生産する実生採種林。検定林としての各候補木の評価をもとに植栽木を選抜（劣性の候補木家系を除去）することで、生産される種子の遺伝的能力を向上させる。

実生採種林の植栽間隔は 3.5m で、１つの家系の苗木４本がまとめて植栽された。この４本のまとまりをプロットとし、隣接するプロットが同じ家系にならないように配置された。例えば、Tiva において 2015 年に造成された区画では、25 家系を用いて、ランダムかつ隣り合うプロットが同じ家系にならないように設計された。

その後、複数回の間伐を行う。初回は同じ家系プロットの中で個体の間隔を広げるため、２回目は検定林としての評価をもとに選抜改良のために行う。



図：実生採種林の配置。A 番号は家系番号、a、b、c、d はプロット内の植栽位置を表す。
灰色の行列は周囲木である。

５．アカシア採種林の管理及び間伐

実生採種林では、次の管理が適期および定期的に実施された。

ⅰ　下刈り：各雨期の後、年２回。

ⅱ　剪定・断幹

ⅲ　支柱設置

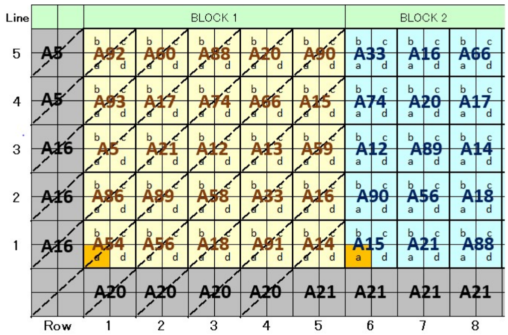
ⅳ　保護：フェンスの維持管理、パトロール、病害虫のモニタリングを含む。

実生採種林での着花と種子生産は造成後３年目に観察された。

実生採種林造成の約５年後に、日当たりを改善し、着花を促進するために 50%（2 本に 1 本）の間伐が実施された。具体的には 2015 年造成区画は 2020 年 12

月、2016 年造成区画は 2021 年 3 月に間伐された。間伐は対角線状に行われ、植栽木の間隔が拡大された。

　また、伐採された植栽木の中から 30 個体をサンプルとしてバイオマス量の測定と材質強度の測定が行われた。



図：対角線状の間伐設計。斜線の植栽位置にある木が伐倒、除去された。

６．種子生産と今後の予定

　この実生採種林は、検定林の役割も兼ねている。ひきつづき、目的とする性質である成長と繁殖（着花と着果の量）を定期的に調査する。これらのデータは、第２世代プラス木選抜のために活用される。

　第２世代プラス木が選抜された後は、選抜されなかった個体を除去する間伐を行い、実生採種林の遺伝的改良がなされる。

Guidelines for Establishment and Management of *Acacia tortilis* Seed Stands in Kenya

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November 2021

Published by: Forest Tree Breeding Center, Forestry and Forest Products Research Institute
3809-1 Ishi, Hitachi, Ibaraki 319-1301, Japan

First published on November 10, 2021

Compiled and edited by: Jason G. Kariuki, Hisaya Miyashita, Taiki Kobayashi, James K. Ndufa, Dorothy Ochieng and Josephine Wanjiku

Citation:
KEFRI and FTBC 2021. Guideline for Establishment and Management of *Acacia tortilis* Seed Stands in Kenya

Foreword

Kenya's national development program, Vision 2030, recognizes climate change as an important challenge whose impacts needs to be urgently addressed. The Vision therefore proposes formulation of programs for adaptation to climate change and combating desertification especially in the arid and semi-arid areas (ASALs) of the country. The Vision also recommends development of commercial tree planting in ASALs as one of the strategies to address climate change challenges.

Climate change, combined with increase in deforestation has adverse impacts on the country's economic development and threatens the realization of our Vision 2030 goals such as a secure environment. For over 30 years the Government of Kenya, recognizing the threats posed by climate change has collaborated with JICA in conservation and promotion of tree planting in ASALs. Through such collaboration, Kenya Forestry Research Institute (KEFRI) and Kenya Forest Service (KFS) have strengthened their capacity to implement social forestry approaches and promotion of improved techniques in tree planting in ASALs. Two dry land indigenous tree species, namely, *Melia volkensii* and *Acacia tortilis*, have been more recognized as important trees for promotion in the ASALS mainly due to their drought tolerance, fast-growth and multiple uses. *A. tortilis* provides; high quality fodder from pods that sustain and provide resilience to livestock during dry season and biomass energy. However, the species has been over-exploited for provision of firewood and charcoal leading to increased desertification of arid and semi-arid areas (ASALs). The National Forest Programme 2016-2030 and Nation Climate Change Action Plan 2018-2022 clearly stipulate 'developing drought tolerant trees for adaption to climate Change' as one of the dry land forestry programs. Kenya Forestry Research Institute (KEFRI) has been undertaking tree breeding of dryland species to promote tree productivity and consequently accelerate Kenya's attainment of 10% forest cover.

The objective of this guideline is to provide technical information on establishment and management of *A. tortilis* seedling seed stands in Kenya for improvement of the species. The guideline will provide guidance to managers on how to: select candidate plus trees, plan and establish seedling seed stands, rogue and improve seed stands, and produce seeds. The guideline is based on experiences of KEFRI researchers from JICA supported Projects on 'Developing Drought Tolerant Trees for Adaption to Climate Change' and 'Capacity Development Project for Sustainable Forest Management (CADEP-SFM)' tree Breeding component. The guideline is expected to encourage and facilitate establishment of more Acacia seed stands using more improved germplasm. It is anticipated that once improved *A. tortilis* seed is available in the country, a wide range of tree growers in drylands will adopt and undertake growing on the species on large scale for biomass energy.

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1. Background

Acacia tortilis, often called the "umbrella thorn" for its distinctive spreading crown, is one of the most widespread trees occurring naturally in arid and semi-arid areas of Africa ranging from Senegal to Somalia and down into South Africa and the Middle East occurring in Israel, southern Arabia, and Iran. The umbrella thorn is the dominant tree in many savanna communities that provides an important source of browse for both wild and domestic animals. It is also an important fuelwood species. The species occurs throughout dry Africa, ranging from Senegal to Somalia and down into South Africa. Other areas are Israel, southern Arabia, and Iran.

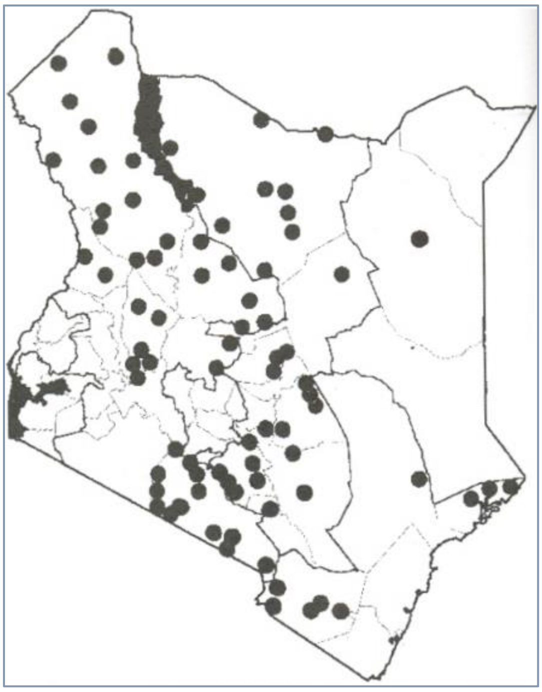


Figure 1: General distribution of *Acacia tortilis* populations in Kenya

(Source. Maundu P. and Tengnas T. (2005)).

A. tortilis also known umbrella thorn is normally found in sand dunes and rocky scarps to alluvial valley bottoms, avoiding seasonally waterlogged sites. A very drought resistant species, it the grows in areas with annual rainfall as low as 40 mm and as much as 1200 mm, with dry seasons of 1-12 months. The tree grows well in alkaline soils, sandy loams, rocky soils and other soils that drain well but will colonize saline and gypseous soils. It is a phreatophyte, relying on aquifers as deep as 40 - 50 m. *A. tortilis* and forms a deep tap root in sandy soils. On shallower soils and in arid sites, it can develop hose-pipe subsurface roots extending over twice the width of the crown.

The umbrella thorn habitat ranges from sea level to 1000 m elevation, mean annual temperature of 23.4 - 31.3 ^{o}C. However, it survives in sites where temperatures regularly reach 50 °C at mid-day and fall to near freezing at night. Older trees (>3 m tall) can withstand frosts and light grass fires. In Sudan, Kenya (Figure 1) and Tanzania, the species is often found on flat alluvial areas (Orwa *et al*. 2009). The subsp. *tortilis* is commonly found in the east Sahel and the Nile Valley, the Horn of Africa, Israel, Jordan, and the Arabian Peninsula, while subsp. *Heteracantha* (Burch) Brenan is found in Southern Africa. The subsp. *Raddiana* (Savi) Brenan is common in the Sahara, the Sahel, North Africa and West Asia, while subsp. *Spirocarpa* (Hochst ex A. Rich.) Brenan) is found in East and Southeast Africa and Namibia.

1.1 Species description

The species varies from multi-stemmed shrubs 4-8 m tall to trees up to 20 m tall with rounded crown for ssp. *raddiana* or flat-topped crown for ssp. *heteracantha* and *spirocarpa*. The presence of two thorn types, long-straight and shorter-hooked (Plate 1), distinguish *A. tortilis* from other acacia species. The alternate leaflets (usually < 1 mm wide) are smaller than those of most bipinnate acacias. White or pale-yellow fragrant flowers cluster in 1 cm diameter round heads. Flowering is prolific with up to 400 flowers/meter twig. Flowers later develop into bunches of spirally twisted, indehiscent pods (Plate 2). Straight pods also occur, though rarely. Pods vary considerably in size depending on provenance but range from 8 to 12 cm long. At Jodhpur, India (320 mm annual rainfall) average height of 20 selected 2.5-yr-old plants was 3.8 m. In Tiva, Kitui Kenya, 5-year old *A. tortilis* trees averaged 4m in height.

Plate 1: Two types of thorn and spiral twisted pods in *Acacia tortilis*

1.2 Uses

1.2.1 Forage and shade

A. tortilis is an excellent source of fodder that can survive heavy browsing. Pods and leaves have a good level of digestible protein (15 to 20%) and energy 6.1 Ml/kg DM (Le Houerou 1980) as well as being rich in minerals. Forage from the species is available throughout most of the dry season when other sources are scarce. Leaves of young trees are also browsed by livestock and wildlife, but the main value of this species is in its pods, which can be very numerous and are eaten from the ground and from low branches. When pods are mature (usually in January-February in Kenya), they are often the main source of food for cattle, sheep and goats.

In the Turkana region of Kenya, large riverine trees (called ekwar) are individually owned by families for their use. Pods are collected for sale in markets, such as in Lodwar (Turkana), both as animal and human food. Pods are also fed to lactating animals to increase milk yields. Over 90% of the tree's flowers abort and drop from the trees, providing additional important forage (Kayongo *et al*., 1983). Crude protein and digestibility coefficients of *A. tortilis* are about 18% and 46.2%, respectively.

A number of studies have quantified *A. tortilis* fodder production. Estimates of about 1 dry ton/ha/yr shoot and leaf growth was demonstrated in semi-deciduous bushland in the Tugela Dry Valley, South Africa (Milton 1983). Fodder yields from young plantations in India indicate productivity of 2.5 kg/tree/yr (at 400 trees/ha) and pods estimated at 1 kg/tree/yr by age 7 (Gupta and Mohan, 1982).

A. tortilis also provides shade for animals and under-storey plants. Some of the most palatable grass species grow beneath its canopy (Walker, 1980). In Turkana, soil nutrients and herbaceous plant productivity and diversity were significantly greater under than away from the *A. tortilis* tree canopy (Weltzin and Coughenour, 1990).

1.2.2 Fuelwood

A. tortilis is a reliable source of fuelwood and starts producing fuelwood at the age of 5 years. The species fast growth and coppicing ability, coupled with high calorific value of its wood (4,400 kcal/kg), make it suitable for firewood and charcoal (BOSTID, 1979). Its wood burns slowly and produces little smoke when dry.

The tree sprouts vigorously when coppiced and is managed for fuelwood in natural woodlands in Sudan. In plantations in India, trees are planted at 3 x 3 m spacing and coppiced for fuelwood. After 10-12 years over 50 tons/ha wood can be harvested (NFTA, 1991).

1.2.3 Other uses

A. tortilis may be used as a source of timber for light construction and carpentry. The sapwood and heartwood are white and lustrous, with the heartwood aging to reddish-brown. Growth rings are distinct and separated by brown lines. The wood is, however, moderately soft, not very strong, and readily attacked by decay-causing fungi and insects. It should be promptly converted after felling and subjected to rapid drying conditions. *A. tortilis* poles are commonly used in hut construction and for tool handles. The wood of ssp. *heteracantha* is durable if water-seasoned.

A. tortilis flowers provide a major source of good quality honey. The Turkana make porridge from pods after extracting the seed whereas the Maasai eat the immature seeds. The bark yields tannin and the inner bark cordage. Thorny branches are used for enclosures and livestock pens; roots are used for construction of nomad huts (Somali). Leaves, bark, seeds, and a red gum are used in many local medicinal concoctions. Two pharmacologically active compounds for treating asthma have been isolated from the bark (Hagos *et al.* 1987). Other medicinal uses include as a vermifuge, for skin infections, oedema and allergic dermatoses.

A. tortilis is a powerful molluscicide and algaecide. For example, in Sudan, fruits are placed in fish ponds to kill the snail species that carry schistosomiasis without affecting the fish. The dried, powdered bark is used as a disinfectant in healing wounds. In Senegal, it serves as an anthelmintic, while in Somalia the bark is used to treat asthma and the seeds to treat diarrhea.

Due to its drought hardiness and fast growth, the species is considered more useful than many indigenous species growing in the arid zone. Due to its fast growth, it is a promising species for soil erosion control, afforestation and stabilizing shifting sand dunes, refractory sites, hill slopes, ravines and lateritic soils. In agricultural production, *A. tortilis* is nodulated by beneficial microbes and hence is nitrogen fixing and thus a soil improver.

2. Objectives and Justification of Breeding *Acacia tortilis*

According to Kenya Bioenergy Strategy 2020, bioenergy resources in Kenya have not been exploited to their full potential despite numerous initiatives by numerous government and nongovernmental organizations in efforts to address issues touching on sustainable biomass production, efficient conversion/processing and use (MoE, 2020). However, for most of preferred indigenous species in arid and semi-arid lands (ASALs), increasing overexploitation of the species for charcoal production and other multiple uses such as dry season fodder, building and fencing materials without any conservation measures being undertaken such as domestication and establishment of woodlots threatens the existence of the tree resources.

A. tortilis shows remarkable tolerance to environmental stresses and wide ecological adaptability making it a suitable option for use in reforestation of degraded drylands. Its value for production of fuelwood and provision of livestock present a strong case for the species. Tree breeding can play a major role in development of superior germplasm to increase productivity of planted trees. However, tree improvement of dryland indigenous trees is limited. Since 2012, *A. tortilis* has therefore been targeted for improvement through breeding.

The *A. tortilis* breeding programme commenced in 2012 with selection of Candidate Plus Trees (CPTs), followed by seed collection from the CPTs, which was used to raise seedlings for establishment of combined progeny trials/seedling seed stands at Tiva and Kibwezi.

The general objective was to carry out breeding of *A. tortilis* to produce fast growing, drought resistant, high yielding trees for biomass energy production and for dry season fodder (pods, leaves). The specific objectives of the trial were dual, i.e. act as a progeny test and also later be converted into a seed stand. The specific objectives of the trial were dual, i.e. as a progeny test and also as a seed stand as follows:

(i) To evaluate growth and genetic parameters of Candidate Plus Trees of *A. tortilis* and to select next generation Plus Trees and to confirm that the target traits are heritable and can be expressed in subsequent generations.

(ii) To establish the seedling seed stand for seed production. And to improve the seed stand using the result of progeny test. Seedlings were used instead of clones for establishment of the seed stand because clonal propagation of the species is difficult.

Box 1: Seedling seed stands

A Seedling seed stand is a seed orchard that is used for improving genetic quality of seed and is established using seedlings instead of vegetative clonal propagation. In the design of the seedling seed stands, seedlings of same family are planted with one plot, followed by thinning of trees a number of times to retain plus trees. The first thinning is implemented within same family plots to avoid inbreeding. The second thinning is implemented in same family, based on the result of progeny test.

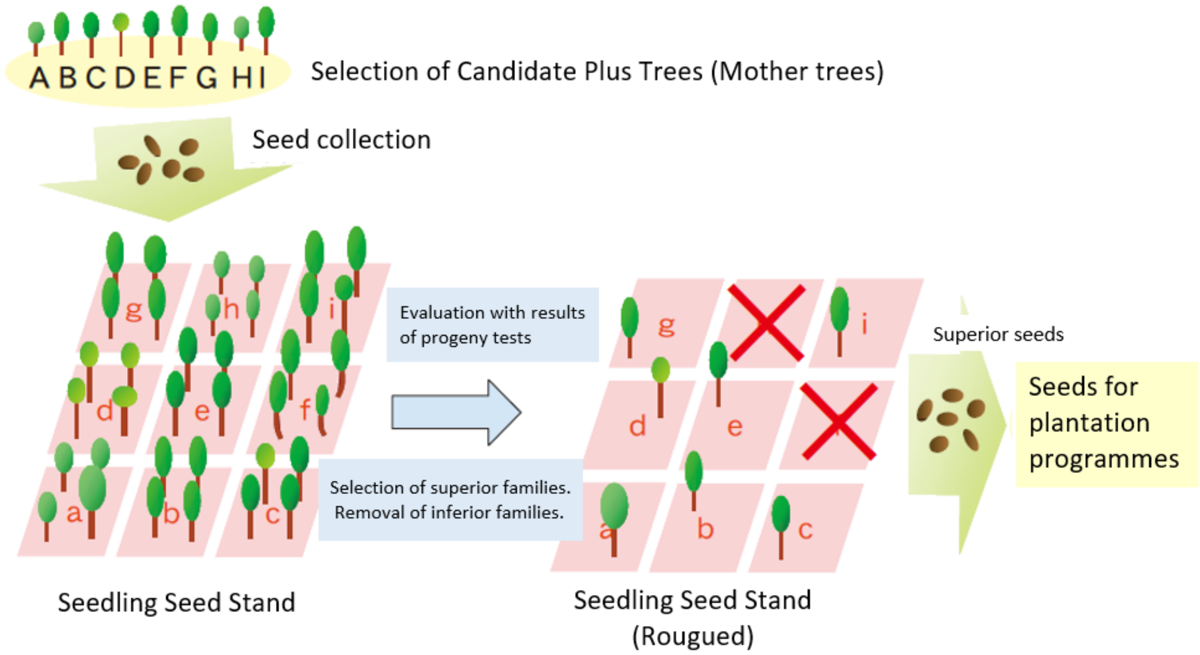


Figure 2: Method of seedling seed stand cum progeny test (FTBC 2006)

3. Objectives of this Guideline

Objective of this guideline is to provide information on establishment and management of *Acacia tortilis* seedling seed stands in Kenya. The guideline addresses various aspects including: Selection of Candidate Plus Trees; Planning and establishment of seedling seed stands; Rogueing and improvement of seed stands; and seed production. The guideline will be useful for effective management of the seed stands of *A. tortilis*.

Box 2: Principle of rogueing of seedling seed stands

When the time comes to select plus trees within the seedling seed stand, of all inferior families are removed and only trees of superior families are retained ('rogueing'). The rogueing can be done in terms of various traits in accordance with the objectives of breeding e.g. growth, hardiness to drought and diseases, pod/seed production. With rogueing the quality of seeds produced in seed stand will be improved.

4. Selection of *Acacia tortilis* Candidate Plus Trees

After evaluation of the current most common uses and probable future uses of *A. tortilis*, various criteria were adopted for selection of individual trees of the species also known as mass selection. Species population as well individual tree characteristics were considered.

Selection of Candidate Plus Trees (CPTs) of *A. tortilis* aimed at traits that will maximize the important uses and benefits of the species i.e. for biomass energy production and as a fodder, while maintaining/improving adaptability. The following criteria were used in carrying out selection of CPTs.

4.1 Selection criteria and planning

Selection of *A. tortilis* CPTs involved the following: identification and mapping of areas of occurrence of the species; delineation of transects (zones); reconnaissance within an area (transect); and preliminary selection and assessment of CPTs. The data obtained from the selection site was processed and used to do develop a final list of selected trees within individual transects. The criteria used for selection was based on local population characteristics and individual tree characteristics as follows:

Population Characteristics

Selection was done only in viable populations that allowed individual tree comparisons. Trees standing alone without any surrounding *A. tortilis* were avoided.

Individual Tree Characteristics

The following criteria were used in selection of individual CPTs

i. The trees are in the dominant or co-dominant crown class (at or above the general tree canopy level) within the immediate surrounding
ii. Superior in height and diameter growth in comparison to surrounding 5 trees (High growth vigour, biomass)
iii. High branching and high pod/flower production
iv. Large extensive crowns (crown width and depth)
v. Free from insect pests and free of any signs of diseases
vi. Not crooked or twisted stems/branches
vii. Large pod production/fruiting/flowering capacity (The local community consulted on high yielding trees)

4.2 The transects (selection areas)

Following consultations with communities in areas of occurrence of the species and a reconnaissance by the KEFRI team, the areas of occurrence of *A. tortilis* were divided into blocks for the purposes of CPTs selection (Figure 3). A block consisted of 2-4 populations from which 4-11 individual trees were selected (Table 1). Each selected CPT and its 5 surrounding/nearest *A. tortilis* trees were assessed for height, DBH, crown length, width and depth, branching habit and healthiness (see Appendix 1 – CPT assessment sheet).

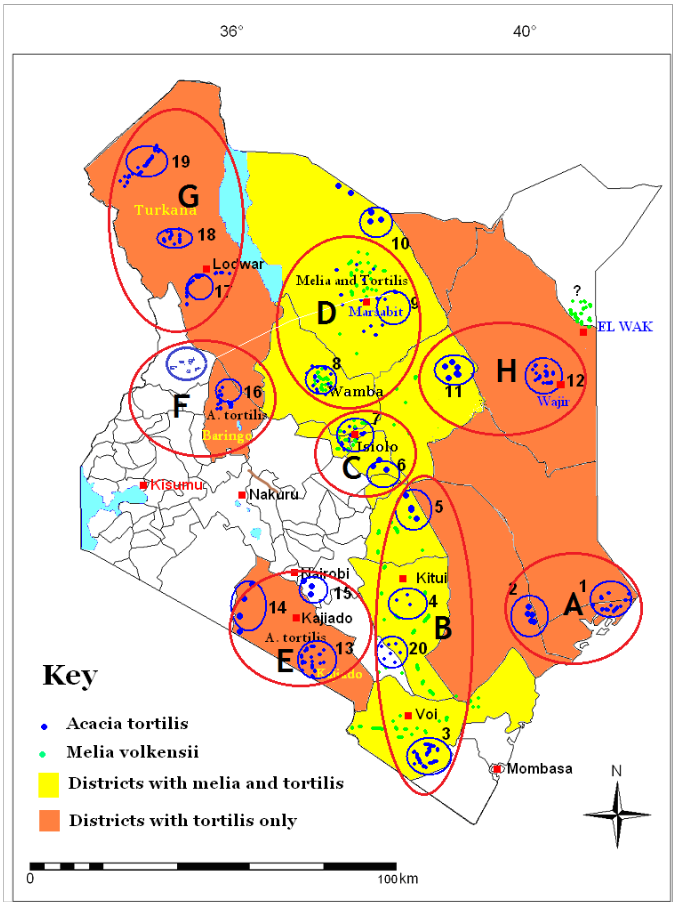


Figure 3: Distribution of *Acacia tortilis* blocks and populations for selection of CPTs
(See Table 1)

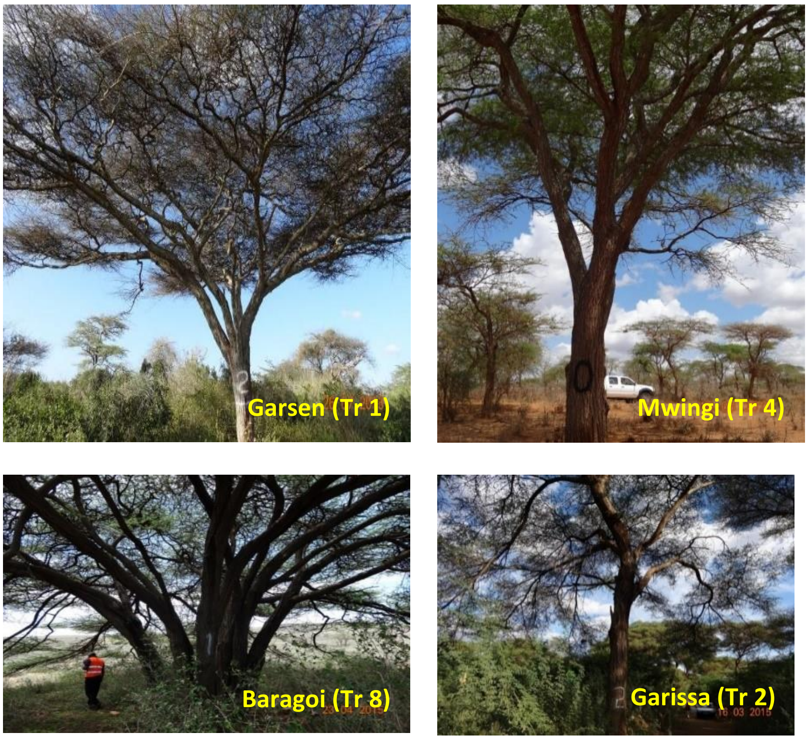


Plate 2: Examples of selected *Acacia tortilis* CPTs from various transects

Table 1: Transects from which *Acacia tortilis* CPTs were selected

Block	Transect No.	Transect Name (Tr)	No of CPTs
A	1 &2	Tana-Lamu	11
B	3	Voi-Mwatate	6
	4&5	Machakos-Mwingi	11
C	6	Isiolo-Garba	4
	7	Archers-Isiolo	4
D	8	Maralal-Wamba	8
	9 & 10	Wamba-Marsabit	8
H/A	11&12	Garissa	6
E	13	Loitokitok-Namanga	9
	14	Kajiado-Magadi	4
	15	Namanga-Kajiado	8
C	Added	Tharaka	4
F	16	Baringo	6
G	17, 18 &19	Turkana	7
B	20	Kibwezi	4
		TOTAL	**100**

5. Establishment of *Acacia tortilis* Seeding Seed Stands/Progeny trials

The seed stand/progeny trial of *A. tortilis* was established in two phases, in December 2015 and in April 2016. In 2015 seeds from only 26 families were available for establishment of the seedling stands while in 2016, seeds from 61 families were available for establishment of the stands. These were established in Tiva and Kibwezi. The establishment was through the following steps:

5.1 Seed collection

A quick seed survey was first carried out when seed setting in the regions started. Through a network of community contacts in areas where of *A. tortilis* CPTs had been selected, progress of seed development was monitored. Based on this information, the time of collection was then determined and the team embarked on seed pod collection.

Pods were collected by shaking them from the tree canopy of each CPT and collecting them on a tarpaulin placed under the tree. The pods were then packaged and labelled (indicating Transect name, tree number assigned within transect, date of collection and collector). The pods were then transported to KEFRI Seed Centre, Muguga for processing. The pods were processed through: pounding pods in a mortar to extract the seed; followed by winnowing and cleaning; and storage awaiting sowing (Plate 3). During the processing phase, strict labeling was adhered to.

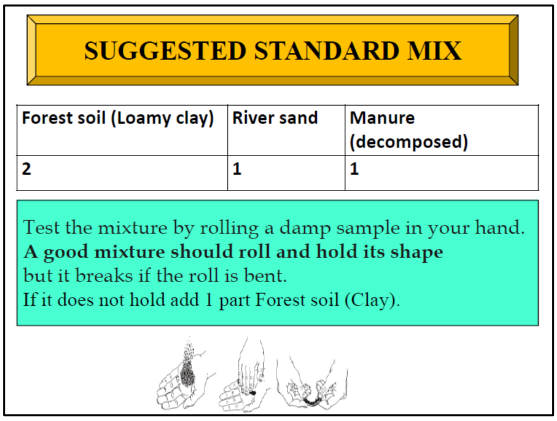
Plate 3: Acacia seed collection and processing
(a): Shaking pods from tree. (b): Packaging and labelling. (c): Extracting.
(d): Collecting pods (e): Pods on the canopy. (f): Cleaning.

5.2 Seed germination and nursery management protocol

The time of seed germination is determined by the projected planting time/season. For the current seed stands, germination was initiated 6 months before the projected planting time. For example seed sowing was done in April 2015 for the stand established in December the same year and sowing in August 2015 for the stand established in April 2016. The collected seed was pretreated as follows:

a) Dipping the seed in hot water for 30 minutes,
b) Nipping on the upper side (testa) using nail cutters,
c) Soaking seeds in cold water for 72 hours, change the water every 24 hours
d) Transfer to seed bed when radicle starts to emerge.
e) Prick out (transplant) the germinated seed into polythene tubes after about 3-4 weeks
f) The pots should be filled with a mixture of forest soil, sand and manure at a ratio of 2:1:1 (Figure 4) (See Hanaoka *et al, 2014*).

The seedlings were thereafter managed in the nursery through weeding, watering, and disease control (Plate 4). Rapid tap root growth required frequent root pruning.



SUGGESTED STANDARD MIX

Forest soil (Loamy clay)	River sand	Manure (decomposed)
2	1	1

Test the mixture by rolling a damp sample in your hand.
A good mixture should roll and hold its shape
but it breaks if the roll is bent.
If it does not hold add 1 part Forest soil (Clay).

(a): Suitable soil potting mixture for drylands

(b): Forest soil (2), sand (1) and manure (1))

Figure 4: Suitable standard potting mix for *Acacia tortilis* and other dryland tree species

Plate 4: *Acacia tortilis* seedlings at Kitui Nursery

5.3 Planting site preparation

The site planted with *A. tortilis* seed stands in Tiva and Kibwezi were initially covered by wooded bush land. Both sites are located next to Melia seed orchards both in Tiva and Kibwezi. The selected sites have slight slope and had woodland type vegetation.

Site clearing and deep ripping was done by bulldozer machine. This operation involved clearing bushes, unwanted trees, grasses and other debris. The cut materials (trash) were removed completely from the site prior to ripping operation. Ripping was done to a depth of 2 feet using a heavy duty ripper and the sites were thereafter fenced. It is important to uproot all stumps within the site (Plates 5 (a) and (b)). The following was carried out during site preparation activity:

- ***Land preparation alternative***: - If deep ripper is unavailable, site clearance can be done using manual labour, including cutting, uprooting stumps and removal of debris. The site can then be ploughed using a tractor. The aim of site preparation is to: Provide optimum conditions for root penetration and development of young Acacia trees; Improve water penetration and moisture build up (retention capacity) of the soil and, Reduce weeds and undergrowth.
- ***Staking***: - Using a pre-designed layout, staking was done at a spacing of 3.5 m x 3.5 metres. Each stick used was labelled with a tag showing the site, identity of the seedling to be planted and its position (See Plate 7).

- ***Pitting***: - Pits of 45 cm x 45 cm x 45 cm were dug after staking at the specified spacing in accordance with the pre-prepared layout of the seed stand.
- ***Backfilling***: - This was done by using the combination of charcoal dust and topsoil. The purpose of the charcoal dust is to help retain soil moisture for the seedling to withstand any adverse effect of drought.
- ***Fencing***: - For best growth, *A. tortilis* trees should be protected from browsing animals for the first three years as they are highly palatable to the game and domestic animals like goats. For this seed stand, complete fencing with the concrete post and chain link was erected to prevent browsing.

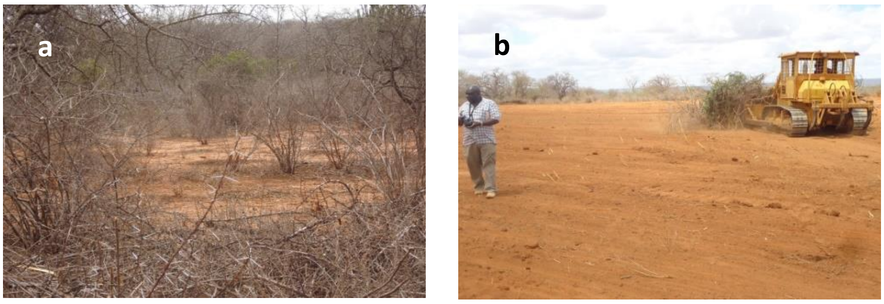


Plate 5: Acacia PTS site (a) Before clearance and (b) After clearance

5.4 Design/layout

A Randomized Block Design was used with each family being planted in plots of 4 seedlings (2 x 2 configuration) designated as A, B, C, D (Figure 5 and 6). Families were randomly allocated to each of the blocks used.

At Tiva, there were five (5) blocks and 25 families used for 2015 planting. Each block had 25 plots and 100 trees, resulting in a total 500 trees (Figure 5). For the 2016 planting, five (5) blocks and 59 families were planted. Each block had 60 plots and 240 trees, as a total 1,200 trees. They were surrounded by guard rows which consist of 460 trees (Figure 6).

Line		BLOCK 1					BLOCK 2					BLOCK 3					BLOCK 4					BLOCK 5					
5	A5	A92	A60	A88	A20	A90	A33	A16	A66	A58	A13	A74	A33	A13	A15	A66	A16	A58	A17	A15	A66	A92	A60	A90	A66	A16	A92
4	A5	A93	A17	A74	A66	A15	A74	A20	A17	A86	A60	A66	A86	A93	A92	A60	A21	A92	A13	A60	A74	A20	A93	A15	A89	A13	A92
3	A16	A5	A21	A12	A13	A59	A12	A89	A14	A59	A15	A14	A91	A12	A89	A17	A33	A12	A89	A56	A90	A17	A56	A58	A12	A20	A92
2	A16	A86	A89	A58	A33	A16	A90	A56	A18	A91	A92	A16	A74	A90	A58	A20	A14	A88	A20	A91	A88	A92	A13	A21	A14	A74	A92
1	A16	A54	A56	A18	A91	A14	A15	A21	A88	A93	A17	A58	A56	A21	A88	A91	A56	A86	A93	A16	A21	A93	A89	A88	A91	A90	A90
	A16	A20	A20	A20	A20	A21	A21	A21	A21	A60	A60	A60	A60	A66	A66	A66	A74	A74	A74	A74	A89	A89	A89	A89	A90	A90	A90
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	Row

Figure 5: Layout plot details of Tiva *Acacia tortilis* PTS/Seed stand seed December 2015 planting

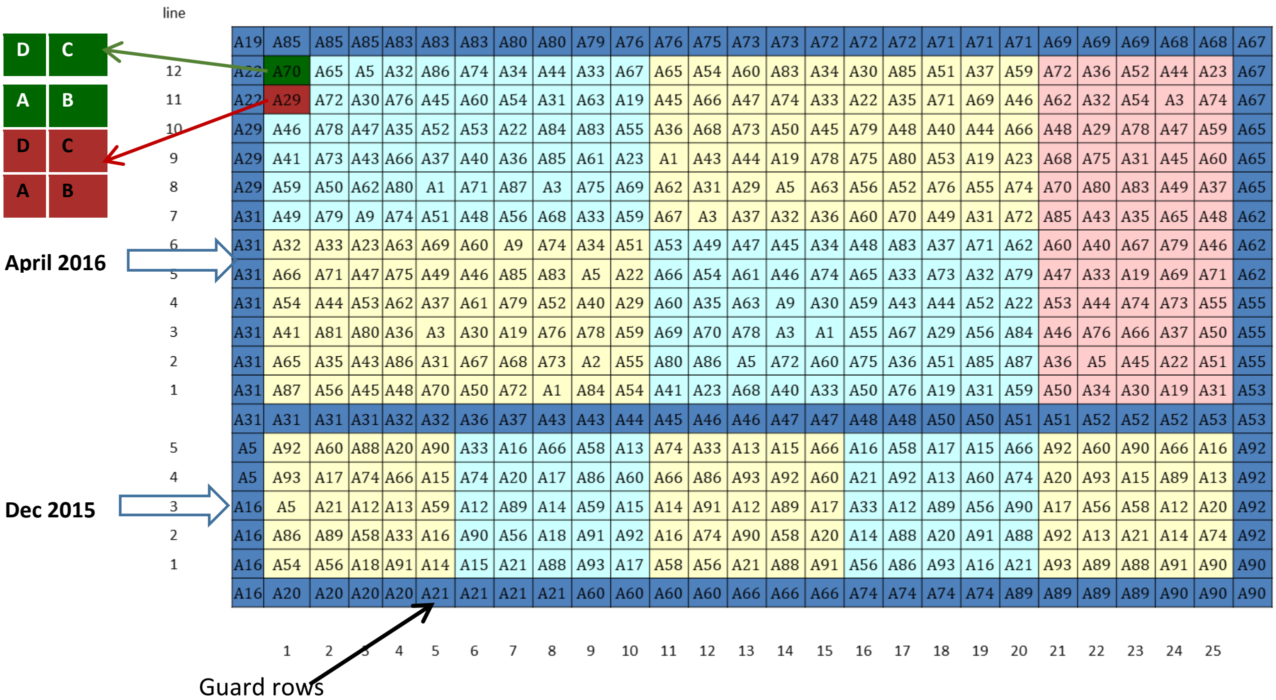


Figure 6: Seedling Seed stand of *Acacia tortilis* layout details at Tiva:

December 2015 planting: 5 Blocks, 500 seedlings, April 2016 planting: 5 blocks, 1,200; 4 seedlings per family, 460 seedlings as Guard rows = TOTAL 1,660 seedlings, 69 Families ABCD are four seedlings per family (see below for details)

At Kibwezi, there were six (6) blocks x 27 plots/block x 4 trees per plot used for 2015 planting totaling 648 trees (Figure 7) whereas in 2016, Kibwezi had eight (8) blocks divided as follows: 6 blocks had 60 plots each and each plot had 4 trees of the same family designated as A, B, C, D. The remaining 2 blocks had 63 plots each and 4 trees per family, with all eight blocks totaling 1,944 trees (Figure 8).

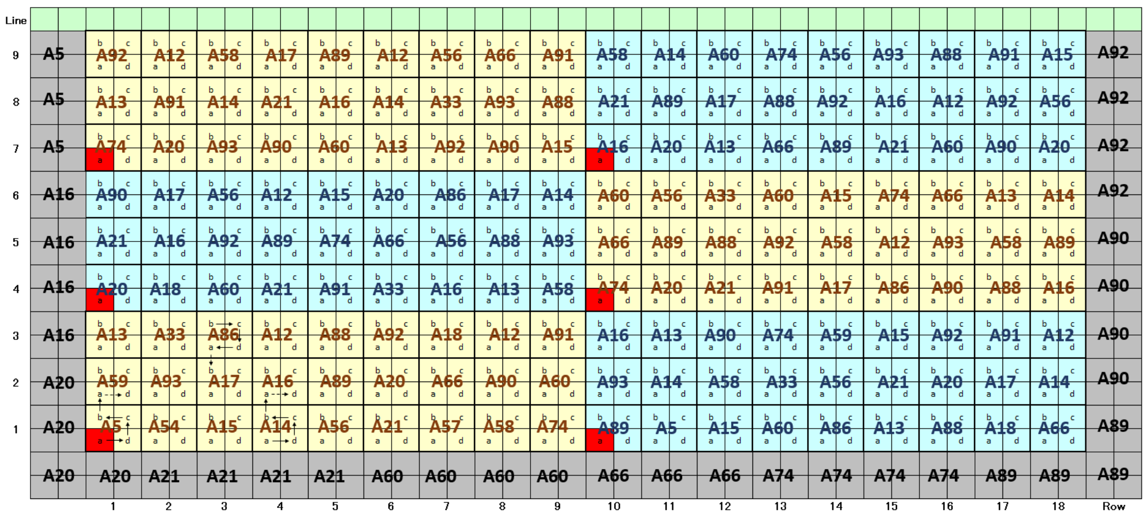


Figure 7: Acacia PTS/Seed stand detailed layout planted in Kibwezi in December 2015 with plot details

	A85	A85	A85	A85	A83	A83	A83	A83	A80	A80	A80	A79	A79	A76	A76	A75	A73	A73
27	A69	A54	A37	A32	A19	A76	A44	A85	A67	A69	A47	A45	A51	A19	A50	A35	A31	A51
26	A60	A74	A48	A46	A29	A83	A22	A45	A40	A66	A60	A36	A46	A37	A43	A44	A46	A45
25	A36	A34	A71	A66	A73	A55	A33	A74	A37	A50	A71	A53	A83	A74	A62	A60	A85	A36
24	A19	A80	A44	A75	A70	A43	A60	A36	A46	A59	A80	A68	A33	A75	A73	A48	A79	A67
23	A53	A67	A5	A31	A59	A53	A35	A31	A72	A44	A55	A54	A19	A76	A70	A47	A69	A37
22	A69	A51	A79	A50	A68	A78	A52	A65	A47	A22	A85	A67	A29	A31	A40	A71	A72	A32
21	A71	A23	A85	A45	A47	A51	A48	A50	A62	A34	A48	A65	A53	A78	A74	A65	A52	A23
20	A47	A37	A35	A34	A3	A74	A73	A19	A43	A63	A37	A45	A23	A46	A51	A55	A53	A19
19	A5	A72	A31	A75	A36	A54	A60	A45	A31	A59	A66	A49	A33	A36	A50	A37	A60	A36
18	A84	A55	A65	A83	A76	A52	A35	A23	A67	A79	A85	A52	A29	A62	A48	A47	A35	A54
17	A86	A59	A50	A69	A43	A53	A70	A5	A46	A44	A50	A47	A31	A71	A22	A75	A31	A85
16	A62	A23	A46	A80	A73	A79	A74	A75	A71	A68	A55	A19	A32	A67	A45	A79	A78	A80
15	A19	A74	A67	A60	A49	A59	A33	A62	A51	A66	A80	A74	A34	A46	A59	A74	A44	A53
14	A30	A70	A44	A78	A32	A45	A3	A83	A22	A76	A54	A78	A51	A76	A68	A47	A50	A66
13	A85	A87	A51	A22	A66	A41	A72	A30	A29	A65	A31	A37	A43	A60	A83	A19	A37	A48
12	A66	A40	A1	A29	A71	A9	A40	A48	A34	A60	A59	A1	A44	A67	A52	A72	A65	A45
11	A63	A60	A68	A48	A33	A56	A69	A36	A44	A32	A53	A36	A40	A69	A70	A5	A73	A74
10	A73	A49	A23	A67	A37	A59	A68	A74	A75	A66	A54	A5	A41	A49	A54	A29	A85	A69
9	A3	A84	A44	A62	A43	A45	A55	A86	A52	A61	A65	A35	A48	A3	A61	A1	A22	A80
8	A56	A53	A22	A30	A52	A60	A34	A63	A71	A46	A60	A85	A50	A52	A32	A45	A59	A84
7	A5	A70	A31	A76	A78	A46	A23	A49	A30	A22	A31	A51	A9	A76	A53	A62	A73	A47
6	A9	A54	A19	A50	A75	A2	A73	A9	A59	A33	A43	A41	A75	A79	A33	A78	A35	A36
5	A85	A40	A48	A35	A41	A86	A44	A40	A32	A69	A72	A47	A37	A74	A66	A51	A31	A40
4	A47	A74	A32	A55	A1	A69	A87	A19	A50	A56	A83	A48	A54	A56	A83	A72	A5	A46
3	A29	A79	A81	A51	A36	A65	A67	A37	A82	A1	A78	A45	A30	A71	A55	A23	A19	A67
2	A83	A61	A87	A68	A34	A66	A70	A53	A33	A36	A79	A80	A86	A63	A34	A87	A59	A70
1	A63	A33	A72	A38	A71	A80	A3	A29	A2	A62	A84	A76	A60	A68	A65	A33	A43	A44
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18

Figure 8: Acacia PTS/Seed stand layout planted in Kibwezi in April 2016

5.5 *Planting*

Seedlings are ready to be planted out after 3-8 months in the nursery. The labeled seedlings were transported to the planting site in crates (Plate 6a). Before transporting, each seedling was tagged with family number, predetermined planting position and site of planting (Plate 6b). A similar duplicate label had also been tagged on the stake in the field at the pre-determined position. The seedlings were placed per line (e.g. all seedlings with line 17 were placed at the beginning of each line). Staffs were then allocated to place these seedlings in their appropriate planting position within the line. A supervisor then went over each line to verify correct positioning before planting was allowed to proceed.

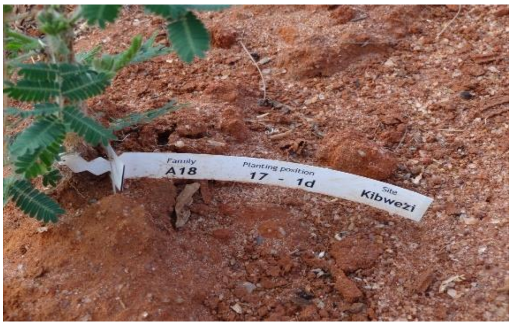
(a)  (b) 

Plate 6: (a) Preparation for transporting seedlings and (b) Tagged planted seedling Kibwezi

Table 2: No of seedlings planted for Acacia seed stands in Tiva and Kibwezi

Site	Year planted				
	2015	**2016**	**Total**	**Spacing**	**Area(ha)**
Tiva Seed Stand	500*	1200*	1700	3.5 m x 3.5 m	2.5
Kibwezi Seed stand	648*	1920*	2568	3.5 m x 3.5 m	3.6
Total	**1148**	**3120**	**4268**		

*- Thinned to half in 2020/21

6. Management of *Acacia tortilis* seed stands

The following routine seed stand management activities were carried out:

i. ***Weeding***: - Complete weeding was done in the *A. tortilis* seed stands in order to reduce competition for water and soil nutrients and therefore promote optimum growth. This was done twice a year after each rainy season.

ii. ***Pruning***: - To undertake pruning, the following equipment are needed:

- ✓ Pruning saw
- ✓ Secateurs
- ✓ Surgical spirit
- ✓ Wood glue
- ✓ Glue based fungicide (e.g. Topsin. If Topsin is not available, wood glue can be mixed with “*Swift”* fungicide)
- ✓ Cotton wool

The lower branches of the species tend to grow very fast and leaning downwards, often touching the ground (Plate 7b). Pruning was therefore done to reduce lower lateral branches which tend to hinder free movement within the stand during assessment and also during weeding. Pruning using pruning saw was done up to two-thirds of the height to open the crown. After pruning, the wounds on the tree were treated with a glue based fungicide e.g. Topsin (thiophanate-methyl) to prevent infections. During pruning process, the pruning saw was cleaned with surgical spirit after every tree.

The following considerations were taken during pruning:

- – All overlapping and crossing branches to the adjacent trees were pruned.
- – Branches nearly touching the ground or growing towards undesirable direction were cut.
- – Branches that protruding to other adjacent trees were trimmed.

iii. ***Stem support***: - Owing to initial fast growth of *A. tortilis* under plantation conditions, supporting the bending/leaning trees at the sapling stage in the Acacia seeds stands to control destruction by strong winds is necessary. The saplings were supported to maintain an upright position in order to enhance vertical growth and straight clear bole (Plate 7).

(a) (b) (c)

Plate 7: Support of *Acacia tortilis* at early ages and no support and unsupported at age 2.5 years (c))

iv. ***Protection***: - This involved protection against damage. Protection involves monitoring and maintaining fencing, patrol, insect and disease monitoring and appropriate responses.

Plate 8: *Acacia tortilis* seedling in Kibwezi six months after planting

7. Thinning of seed stands

First thinning was carried out with the objective of reducing stocking of the seed stand/progeny trial by 50%, in order to promote seed production by allowing more sunlight into the crowns.

The following activities were carried out:

i. Selection and paint marking of trees to be removed (Plate 9).
ii. From the marked tree for felling, 30 trees were further selected and spray painted with second colour at 50 cm above ground for biomass weight and wood samples.
iii. Measurement of wood density of the 30 selected trees by Pilodyn equipment (Proceq Switzerland).
iv. Felling of the 30 selected trees, debranching and measurement of fresh weight.
v. Collection of wood disks (5 cm thickness) from the 30 trees for wood density study (Plate 11). For below ground biomass the 30 trees were dug up within a radius of 2 m to a depth of 2 m and fresh weight determined.
vi. Cutting and cross-cutting and removal of all other trees felled/thinned diagonally.

Systematic thinning was carried out in November 2020 (for the seed stand planted in December 2015) and in March 2021 (for the seed stand planted in April 2016). For 2015 stand, a total of 250 out of 500 trees were thinned in Tiva and a total of 324 out of 648 trees thinned in Kibwezi. For the 2016 planting, 600 out 1,200 trees were thinned in Tiva and 972 out of 1,944 trees were thinned in Kibwezi. The trees were thinned diagonally as illustrated in the experimental layout (Figure 9). The activities were done first at Tiva, which has 5 blocks followed by Kibwezi, which has 6 blocks for the 2015 stand. The trees were felled using power saw or machete depending on size and cross cut. All stems were moved to the edges of the respective sites. After first thinning, spacing had changed from 3.5 m x 3.5 metres to 7 m x 7 metres. The diagonal spacing remained at 4.95 metres.

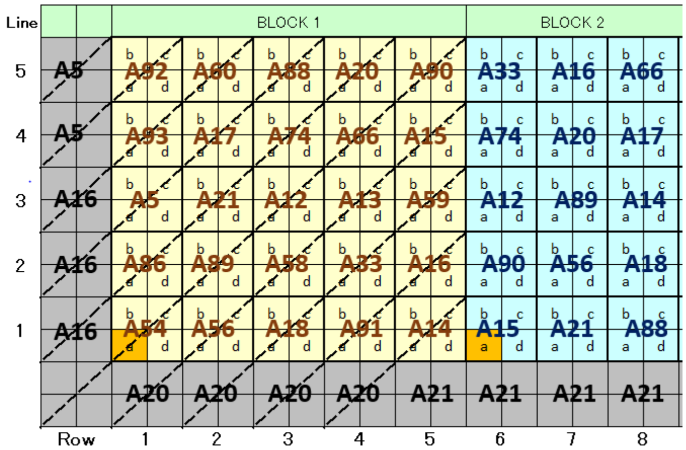


Figure 9: Diagonal thinning layout of *Acacia tortilis*

Plate 9: Paint marking for thinning

Plate 10. Wood discs collected at three trees height level

Felling – Kibwezi

Felling and clearing – Tiva

Cleared stand at Tiva

Cross cutting and disk sampling

Wood/root biomass collection

Weighing samples

Plate 11: Thinning, sample collection and weighing of *Acacia tortilis*

Plate 12: Thinned *Acacia tortilis* seed stand at Tiva

8. Flowering and Seed Production

Flowering and seed production in *Acacia tortilis* seed stands have been observed at 3 years of age in a few trees. However, while the close initial spacing (3.5 m x 3.5 m) was suitable for fast growth in height, it is probable that the close spacing was not favourable to seed production. There was also frequent branching due to overlapping of trees due to close proximity and spacing.

Plate 13: Early pod production

The seeds stands were thinned to half the original density in 2020/2021. This opened up the spacing and the effect of thinning on seed production will be closely monitored. It is expected that the thinning will stimulate seed production.

9. Way forward for *Acacia tortilis* seed stands at Tiva and Kibwezi

This being a combined seed stand and progeny test, assessment will be done on the remaining trees including an assessment of fecundity. Assessment data will be analyzed and used for selection of 2nd generation *A. tortilis* trees. After data analysis, genetic thinning will be done to improve the pollen cloud within the seed stand.

Appendix 1: *Acacia tortilis* Candidate Plus tree data sheet

***Acacia tortilis* Plus tree data sheet/Register**

Sheet No. …………………

Date ………………………..

A: GENERAL INFORMATION

1. County ……………………………………………………………………………….
2. District ………………………………………………………………………………
3. Division ……………………………………………………………………………….
4. Location ………………………………………………………………………………
5. Sub-location/Village ……………………………………………………………….
6. Ecological zone ……………………………………………………………………..
7. Transect ………………………………………………………………………………
8. Tree Reference …………………………………………………………………….
9. GPS Reference ……………………………………………………………………..
10. Altitude ……………………………………………………………………………
11. Land type/owner…………………………………………………………………….
12. Tree No. ……………………………………………………………………………

B: TREE INFORMATION

Trait	CPT	*S1	S2	S3	S4	S5
13. Height (m)						
14. Dbh (cm)						
15. D_{30} (cm)						
15. No. Branches						
16. Clear bole Ht (m)						
17. **Crown width 1 (m)						
18. Crown width 2 (m)						
19. Crown depth (m)						
19. Branch size range (cm)						

* S trees are surround comparison trees within 20 metres of candidate

** The crown width is estimated by projecting the outermost branches to the ground.

20. Crown volume:

(a) Dominant (b) Co-dominant (c) Lower canopy

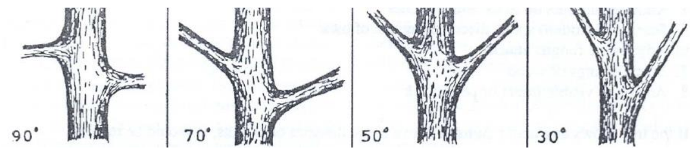
21. Tree health

(i) Sign of dead top or thin crowns
(ii) Nibbles, galls and discolouring of leaves and shoots
(iii) Major leaf not coinciding with natural shedding.
(iv) Knots or tumours on trunk and branches.
(v) Scars, soft (rotten) spots, discolouring etc. bark
(vi) Any visible fungus attack.
(vii) Insect borings of wood
(viii) Any other visible insect or pest attack
(ix) None of the above

(a) Excellent (b) Good (c) Stressed (d) Diseased

21. Dominant branch angle

(a) Acute (<45^o) (b) Medium 45-60^o (c) High (70-90^o)



22. Pests

(a) None (b) Infested

22. Observed pod/flower production

(a) Heavy (b) Medium (c) Light (d) None

23. Informant pod/flower production

(a) Heavy (b) Medium (c) Light (d) None

24. Stem form

(a). Straight (b) Medium (c) Twisted/Crooked

25. Drought index

Notes: Ideotype selection

Genetic improvement of multipurpose trees is carried out for a variety of characteristics including productivity, suitability to sites and planting systems, tree qualities for special end uses, drought and pest resistance.

The ideotype tree is, in a broad sense, a biological model which is expected to perform in a predictable manner within a defined environment. More specifically, an ideotype tree is a plant model designed to yield an improved quality and quantity of useful products than a wild plant or a conventional cultivar (Dickman 1985).

The selection will eventually define the appropriate ideotype that the breeding of *Acacia tortilis* will concentrate on.

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