Value Chain Review and Recommendations for High Potential Drylands Timber Species *Melia volkensii*

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Abstract

Melia volkensii Gürke (Mukau in Kamba, Mukowe in Taita-Taveta, Bamba in Cushitic languages) is a high potential hardwood species of the Meliaceae family, indigenous to the Arid and Semi-Arid Lands (ASALs) of Kenya, Ethiopia, Southern Somalia, and Tanzania. In Kenya it is found growing naturally in Northern and Eastern Kenya, as well as the Westernmost fringes of the Coast.

Over the past twenty-plus years, *M volkensii* has been subject to numerous research & development programs, led by a diverse group of entities, from international development funds to grassroots organisations, to explore further its potential as a high grade timber species for ASALs. Alongside investments in growing and breeding the species, a significant amount of literature has been published on the subject. But while research is often focused on a portion of the value chain, especially related to propagation, there is a limited amount of reports that gives an overall picture of species' value chain, potential for further growth and obstacles to achieve it.

Commissioned by Gatsby Africa, this report is aimed at summarising the state-of-the-art of all major research and development on *Melia volkensii* across its value chain, re-assessing its potential for large scale commercial across ASALs in Kenya. Combining the literature available with field visits and modelling work, the report analyses the entire value chain, from genetic resources to marketing of wood products, with particular focus on those areas that are little covered by existing literature.

For ease of reading, the report is structured to provide the reader with high level results and recommendations first, while detailed results and analyses are covered in subsequent sections.

Summary of Results and Recommendations

Overall, the value of *Melia volkensii* as a species, and what decades of work and investment have generated, are evident. As shown in the results of the Unit Economic modelling, the potential for this species is promising, both in strengthening livelihoods and economic prosperity across large areas of agriculturally marginal land, and in contributing to sustainably addressing the wood deficit Kenya is facing on high value timber.

Despite this evident potential, widespread uptake of *Melia volkensii* both at a small and large scale is being hindered by a number of physical and technical obstacles, on the backdrop of an exhausted natural resource based. These can be broadly summarised as follows:

1. **Knowledge Gaps & Unclear Expectations:** varying and contradictory growth expectations and vague silvicultural recommendations make optimal growing of *Melia volkensii* a difficult task, especially for non-technical growers, as well as a high risk investment.
2. **Low Accessibility & High Costs:** lack of economies of scale restricts the production of quality (i.e. improved) seedlings at affordable prices, hindering uptake from growing, and/or channeling it onto low quality, undesirable material.
3. **Low Popularity outside its native range:** despite a long tradition of using *Melia volkensii* in furniture, its timber remains relatively unknown outside its native range. While current resource base and supply volumes at present would not be able to support a Country-wide market, increased popularity and demand would reasonably increase attractiveness of growing the tree commercially.
4. **Exhausted Resource Base:** decades of unregulated harvesting from the wild has left little commercial timber scattered over a large area, while also degrading the genetic wealth of the species. This situation makes large scale planting the only sustainable way of increasing *M volkensii* timber adoption across Kenya.
5. **Mono-cropping vs Agroforestry:** comparison with traditional commercial forestry crops, grown as monocrops and assessed using traditional metrics — e.g. Eucalypts, where MAI values typically range above 20 — has most probably not helped *M volkensii*'s reputation, whose MAIs hardly reach 10 $m^3ha^{-1}y^{-1}$. Based on our research, we argue that drawing such comparisons is misleading, as *M volkensii*'s potential is greatest when incorporated into Agroforestry systems, whereby revenue streams are diversified and timber harvesting is merely one of

different components. This potential is demonstrated in the Transformation Pathway Section, where comprehensive Unit Economics of different planting systems are presented.

The results and recommendations reported here are preliminary and only indicative: research and investment should be continued in the areas highlighted in this report as gaps. But even more than research, entrepreneurship and plantings should be unlocked to generate tangible results and experience onto which we can further improve the *Melia volkensii* argument.

In the paragraphs that follow, high level results of the research, and specific recommendations for continuing the work are given. In the 'Methods' and 'Detailed Results' sections more details on how these recommendations were developed are given, such as data analyses and results from field visits. Finally, in the 'Transformation Pathway & Unit Economics' section details on how the Excel models were developed are provided.

Planting Material and Germplasm: Results & Recommendations

Overall, *M volkensii* planting material is available to private investors, at both a small and medium scale, but availability shrinks significantly if requirements include a competitive price vis-à-vis other popular commercial species, and improved germplasm. High seedlings prices — esp. F1 material, and difficulties in obtaining large quantities thereof appear to be the main bottle neck preventing a more widespread uptake from smaller and larger prospect growers alike. At the same time, from our initial analysis, a much larger production of improved material could be attained in the short term, thanks to over a decade of efforts by KEFRI and JICA to set up productive seed orchards of improved material.

The following are the recommendations for continued investment in this area:

- In general use of F1 is highly recommended, and natural seed collected from the wild should be avoided as much as possible whenever planting has a commercial objective.
- An in-depth analysis on current production capacity and actual utilisation thereof would shed light on potential bottle necks at the seedling production stage. Especially on F1 material this is key to understand the scale of planting that could be attained in the short term
    - Our initial estimates are that current seed production utilisation from the existing F1 Orchards is a mere 28%, and that over 12m seedlings could be

produced if the full seed production of a single orchard were to be harnessed.

- Based on the scale attainable, larger commercial nurseries should be established to unlock economies of scale and bring the seedling cost down to competitive prices, unlocking greater uptake.
- Economies of scale at a seedling production level are even more critical due to *M volkensii*'s renowned laborious seed extraction process and low germination rates.
- KEFRI's work on thirds generation (F2) seed material is excellent news and should be monitored and supported.

Silviculture & Yield: Results & Recommendations

Melia volkensii shows remarkable variability between sites, and whilst a significant amount of research and development has gone into improving silviculture practices for *M volkensii*, there continues to be gaps in recommendations, as well as contradicting growth expectations. Generally, silvicultural regimes, including thinnings, are little covered by the literature, which often identifies them as an area for increased research and experimentation.

A prime example of knowledge gap resulting in contracting expectations set by the literature can be found in diameter growth projections. In its publications on Melia cultivation guidelines, CADEP-SFM/KFS (2018) suggests that an average DBH of 30 cm at 18 years can be achieved, both when planting at 200 or 400 SPH. At the same time, Gyokusen (2021, published by KEFRI-KFS), developed growth equations suggesting the average diameter at year 20 is 17.3 cm. Moreover, Jan Vandenabeele from Better Globe Forestry suggests that a DBH of at least 40cm, and a branch-free height of 6m, by the age of 16 to 20 years is obtainable through proper silviculture.

We find that lack of clear growth expectations is a significant obstacle in the widespread uptake of *M volkensii* as a timber species. Even more worrying is the potential setting of unrealistic expectations, which may stain the species' reputation, increase perceived risk, and consequently hamper adoption. Especially due to *M volkensii* being a relatively new species in the commercial forestry domain — and quite a variable one too, — clear silvicultural recommendations based on growing objectives are key when promoting widespread commercial uptake.

Another example of where the literature might be setting unrealistic expectations can be found in the definition of Site Indices, which for *M volkensii* are mainly based on rainfall (Gyokusen, 2021), with a prominent role typically also given to soil and altitude. In contrast with this, our research seems to show that planting density, germplasm and silvicultural treatments have a much more prominent and definitive impact on growth quality and yields than soil, elevation or even rainfall.

Due to the limited nature of our data collection, we are not in a position to propose growth equations, and our intention is certainly not to completely discard rainfall, soil and elevation as growth factors. What we set forth is simply that on more than the traditional factors, others — namely planting density and germplasm — might well be the most impactful ones in the achievement of high yields in *Melia volkensii* silviculture.

In this light, our general recommendation is to run significantly more research and data collection than done for this report, especially for the later stages of growth, and develop equations for various planting systems, from agroforestry to monospecific plantations. At the same time, we recognise that the amount of older sites for data collection is limited, and many new trials should be run to fill in the missing parts. We therefore give some initial high level indications based on the research carried out:

- Contrary to what the literature comments, to maximise diameter growth, low planting density is paramount, and not rainfall.
- While the literature usually recommends planting at 400–625 SPH and perform multiple thinnings, our recommendation is to plant from the start at very low densities — ≤200 SPH, — to avoid thinning operations while ensuring good diameter growth and unlocking the potential for multiple revenue streams in agroforestry systems.
  - Spacings of 6x6 to 7x7 (SPH of 256 or less) are recommended for monospecific plantings, while planting in rows spaced 5x15–20–25 seems to work well for agroforestry.
  - The main challenge with agroforestry systems currently seems to be damage to the trees, especially by livestock during the dry season.
  - While traditional knowledge and recent trials seem to demonstrate low levels of competition between *M volkensii* and the common crops in the growing area, more research and trials should be run to identify the most suitable combinations.
- Regarding thinnings, our view is that it is not economical nor practical to conduct thinnings on *M volkensii*, especially for non-technical growers:
  - High seedling cost makes it expensive to thin out up to 50% of the trees planted.
  - Low appreciation for small diameter *M volkensii* roundwood makes it hard to

market the thinnings.
  - Generally, the technical skills and good timing required for proper thinning is lacking in the private small growers sector, while even larger growers might struggle to keep up with such intensive regimes.
- Silviculture-wise, pruning and debudding are critical activities to obtain a clear bole for sawn timber; our finding is that clear bole height is easily controlled up to 5–6 meters, by pruning repeatedly.
  - Over-pruning is nonetheless a risk and could stunt growth.
  - Heavy pruning techniques for the release of fodder to the ground (e.g. pollarding) might be an excellent solution and even promote diameter growth but should be trialed further.
- As mentioned, *M volkensii*'s full potential could be unlocked in agroforestry systems as opposed to traditional monocrop forestry plantations.
  - Such systems seem to better suit this species' need for low densities for fast growth.
  - Agricultural revenue streams complement timber sales and allow for longer (>10 years) rotations.
  - Using MAIs to compare monocropping with agroforestry is misleading and should be avoided.

Resource Base: Results & Recommendations

The *Melia volkensii* resource base is, by its nature, rather scattered across a very large area, making it difficult to both assess its size and health, and access it. What seems to be clear is that the natural resource base has been largely depleted over decades of unregulated exploitation. Planted resources do exist but, judging from the literature and our site visits, they are limited in extent and generally poor in quality.

Widespread commercial adoption of *Melia volkensii* timber will require significant efforts and time to replenish the resource base. In this regard, an initial recommendation is made to trial remote sensing to assess the actual extent of the resource base, and identify potential existing *M volkensii* hotspots for conservation as well as tracts of land for rehabilitation through planting.

Processing and Marketing: Results & Recommendations

At the present state, the low availability of mature trees for processing is likely to make significant marketing and processing investments undesirable or at least untimely. At the same time, the potential is there for *Melia volkensii* to gain a sizeable share in Kenya's high end timber market, should volumes and quality improve significantly. Market stimulation would help to demonstrate the potential at hand and strengthen the case for increased adoption of *Melia volkensii*, while marginal improvements on Processing operations even at present scale could go a long way in reducing waste and increasing the appeal of the current timber supply.

On Marketing, the following are the condensed recommendations brought forward:

- Complete marketing research by exploring current knowledge and popularity of *Melia volkensii* among traders and wood workers outside the growing regions, and in particular in the Nairobi metropolitan area.
- At the appropriate time (vis-à-vis the expansion of plantings), conduct market stimulation work to introduce this species in the market, where not known.
- Similarly, experimentation on new and innovative product applications outside the traditional ones, such as flooring, will help in strengthening the *M volkensii* case to prospect growers, while improving the economics through introducing optimisation.
- For the same reasons, new wood properties testing should be considered, especially taking into consideration the age and provenance of the tested samples, to ensure that short rotations suffice in yielding mature timber.

On the wood processing side, while a centralised processing site is unlikely to be suitable due to the distributed nature of the resource, significant improvements in recovery rates and dimensional accuracy could be obtained through the adoption of upgraded mobile technology. Low recovery rates imply high wastage on a precious and limited resource, while low dimensional accuracy reduces the potential for the product to appeal larger manufacturers outside the native geography. Recommendations are therefore made to:

- Explore the potential for larger traders or growers' associations to adopt improved processing capacity (the specific setup of which can be based on the specific adoption pathway selected);
- While it is currently assumed that single band saws or circular saws can be adopted for *M volkensii*, due to the timber being relatively stable, such assumptions should be validated through sawing tests before investment proposals and recommendations are distributed.
- Simple wood processing investment options should be modelled out based on the test results.

Transformation Scenarios Modelling

Excel modelling was carried out to do a preliminary validation of some of the macro-hypothesis that emerged from the research carried out for this report; in particular:

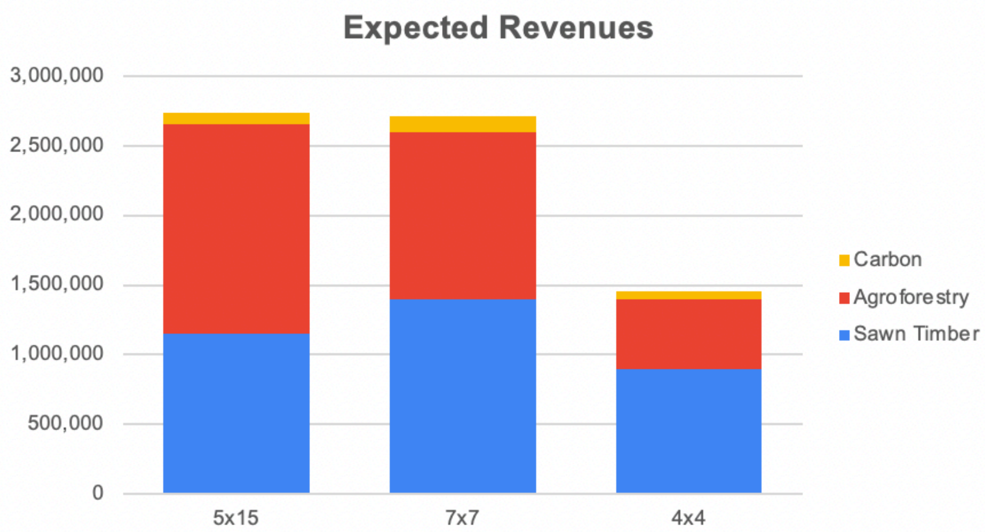
1. *M volkensii*'s potential is greatest when planted at low density and integrated into agroforestry systems.
2. *M volkensii* could eventually satisfy a significant portion of Kenya's demand for high grade sawn timber, without requiring an unrealistic amount of land.

Unit Economics

The two main objectives of the unit economics modelling are to further explore the potential for *M volkensii* to be adopted in agroforestry systems as opposed to the traditional mono-crop, dense plantations, while exploring whether profits could be made by growing the species in such way.

The results, which are preliminary and involve a long series of assumptions (➔ `Unit Economics Excel Modelling` Section), are reported in the table and graph below.

Scenario	Profit Margin (all activities)	Profit Margin (Forestry only)
5x15m rows	65%	16%
7x7m grid	55%	12%
4x4m grid	-3%	-67%



The key takeaways from these results are:

- Very low density planting can be profitable, thanks to both increased diameter growth, and sustained revenues from agricultural activities. But even without the latter, growing *M volkensii* in this fashion is able to generate profits.
- High density planting, despite a higher value of m^3Ha^{-1} and MAI, does not appear to be profitable, due to small diameters and increased costs of planting and maintenance. Additionally, lower agricultural revenues are estimated due to increased canopy cover.

Low planting density (≤200 SPH) appears to be providing three key advantages, which in turn can have a positive impact on profitability:

1. Increased diameter growth thanks to low levels of competition;
2. Decreased planting and silvicultural costs (fewer trees to maintain, which is costly for *M volkensii*);
3. Ability to carry out medium to high intensity agricultural activities during most (if not all) the rotation.

Agricultural activities, as can be seen in the preliminary results below, might ultimately be as significant as Sawn timber in terms of revenues generated. Carbon revenues did not include Soil Organic Carbon, which may be significant depending on the type of management applied.

Results	Description	5x15		7x7		4x4	
Summary		Row planting Agroforestry		Grid planting Agroforestry		Traditional high density monocropping	
Overall Profit		**1,768,358**		**1,483,059**		**-39,700**	
Profit Margin		65%		55%		-3%	
Total Revenues		**2,740,812**		**2,710,117**		**1,455,145**	
Sawn Timber	–	1,150,956	42%	1,401,380	52%	893,627	61%
Agroforestry	Based on avg net revenues	1,500,000	55%	1,200,000	44%	500,000	34%
Carbon	Excludes certification, sales costs	89,856	3%	108,737	4%	61,518	4%
Total Costs		**972,454**		**1,227,058**		**1,494,845**	
Silviculture		171,529	18%	244,698	20%	749,688	50%
Harvest & Haulage		156,293	16%	190,299	16%	121,349	8%
Processing		385,548	40%	469,435	38%	299,348	20%
Sales		97,009	10%	118,116	10%	75,320	5%
Contingency	20% added on all costs	162,076	17%	204,510	17%	249,141	17%

These results are only preliminary and theoretical: they can only be validated through extensive practical implementation. Our recommendation is to point this in the direction that is most promising based on this modelling work.

Transformation Scenario

Based on the Unit Economics presented above, a potential pathway was developed for *M volkensii* to participate to sector-level transformation by satisfying a significant portion of the near future Furniture and Joinery markets demand.

Demand growth modelling was carried out for the year 2050, and a market share target of 15% was set for *M volkensii* sawn timber (~65,000 m^3 out of a total demand estimate of ~430,000 m^3); export demand and non-furniture applications were added on top, totalling ~114,000 m^3.

Utilising the 5x15 and 7x7 scenarios, high-level requirements for Hectares to be cultivated were calculated based on the specific productivity of the two scenarios. Below are some preliminary results, showing that between 57,000 and 80,000 Ha would be required to sustainably satisfy the estimated annual demand of 114,000 m^3 of *M volkensii* timber. Of these between 3,800 and 5,000 Ha would need to be harvested annually, depending on the planting scenario adopted.

Scenario Modelling	Description	5x15	7x7	
M volkensii Demand (2050)	Domestic and some export	**113,922**	**113,922**	*m3 sawn boards*
Cultivation Requirements				
Required Hectares under cultivation		**79,268**	**57,870**	*Ha*
Annual Harvest requirements		5,285	3,858	*Ha*
Rotation length	See UE tab for details	15	15	*m3/Ha*
Annual Harvest requirements		**284,806**	**253,161**	*m3 roundwood*
Roundwood Yield (end of rotation)	See UE tab for details	54	66	*m3/Ha*
Sawn Timber Yield	See UE tab for details	22	30	*m3/Ha*

Our assumption is that land requirements of this order of magnitude are plausibly available in Kenya, where as much as 80% of the landmass — 46×10^6 Ha approximately — is considered to be Arid or Semi-Arid. Establishment of Agroforestry systems involving planting of *Melia volkensii* and hay production at this scale would generate an estimated 50 to 58M$, excluding potential carbon revenues.

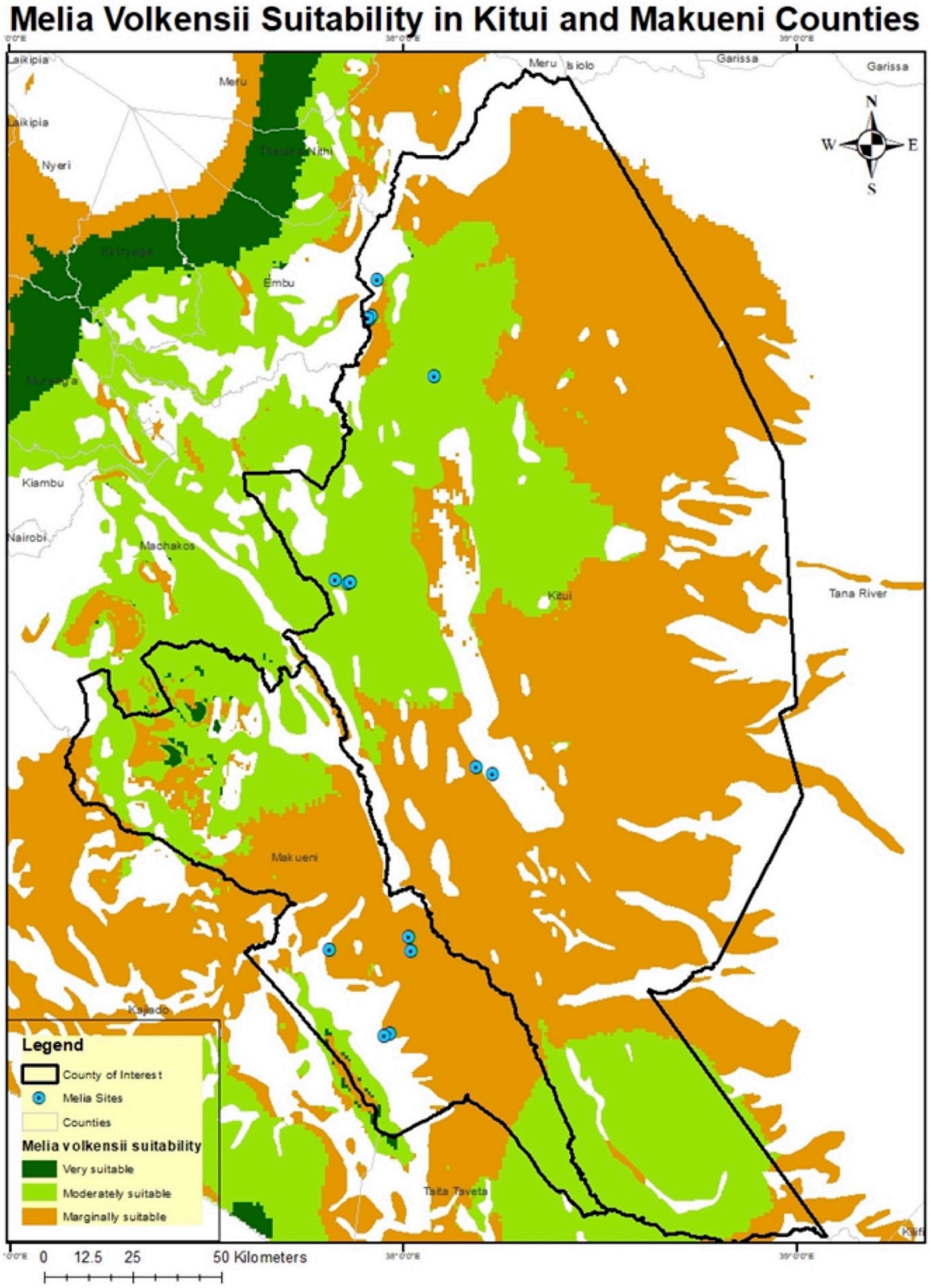
As a next step, a detailed analysis of extent of land available and suitable for growing *M volkensii* at a National scale is recommended. More details on modelling assumptions can be found in the `Unit Economics Excel Modelling` Section.

Methods

Sites visited and Site Suitability

For the production of this report 14 *Melia volkensii* woodlots were visited across Kitui and Makueni Counties. As per the *Melia volkensii* suitability map and Site Species Matching Tool (SSMT) developed by Gatsby Africa (Annex 2), most sites visited fell in what are considered marginally and moderately suitable areas. The temperature zones ranged between 2 and 3 - (Sub-tropical), while moisture Availability Zones were either V – Semi arid or IV – Semi-humid to semi-arid. Soil suitability ranged between S1, S2 and S4. S1 soils were mainly Chromic Luvisols and Ferralo-chromic. All sites were found in an altitude range of 700 to 1100 m asl. In the map and table below we report the surveyed sites' location and details.

Name	Suitability	Alt masl	Comments	Soil_FAO	Soil	TZ	MAZ	Site_Class	TZ_climate	MAZ_zone	MAT_oC	MMmax_ oC	MMmin_o C	Nat_Veg	Landform	Geology
Better Globe Nursery	Not suitable	707		chromic Cambisols	S4	2	V	2-V-Pd3	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Dissected erosional plains	
Better Globe Plantation in Kiambere	Marginally suitable	725	2011 plantation, 4*4 m spacing	chromic Luvisols	S2	2	V	2-V-Um21	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower middle-level uplands	
Simon Mull (BGF Farmer)	Not suitable	766	2018 plantation	chromic Cambisols	S4	2	V	2-V-Pd3	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Dissected erosional plains	
KEFRI Kibwezi	Marginally suitable	815		chromic Luvisols	S1	2	V	2-V-Ul18	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower-level uplands	
Kituku, Kibwezi	Marginally suitable	821	2005 plantation. 100 acres	chromic Luvisols	S1	2	V	2-V-Ul18	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower-level uplands	
Beatrice, Mutomo	Marginally suitable	870	2010 plantation	chromic Luvisols	S1	2	V	2-V-Ul18	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower-level uplands	
Jacob, Mutomo	Not suitable	912	Woodlot High gravel. S4 or NS in soil microfine assessment.	humic Cambisols	S4	2	V	2-V-H14	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Hills and minor scarps	Undifferentiated basement systems rocks (predominantly gneisses)
Grace, BGF Farmer	Moderately suitable	920	2017 plantation	chromic Luvisols	S2	2	IV	2-IV-Um21	Sub-tropical	Semi-humid to semi-arid	22 - 24	31 - 33	14 - 16	Dry woodland and bushland	Lower middle-level uplands	
Jackson Kioko Maasai	Marginally suitable	972	Very good soil observed.	chromic Luvisols	S1	2	V	2-V-Ul18	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower-level uplands	
Martha Kalia, Makindu	Not suitable	992	Hard pan on top soil	calcic Cambisols	S4	2	V	2-V-A10	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Floodplains	
Peter, Kibwezi	Marginally suitable	1002		chromic Luvisols	S1	2	V	2-V-Ul18	Sub-tropical	Semi-arid	22 - 24	31 - 33	14 - 16	Bushland	Lower-level uplands	
KEFRI, Tiva	Moderately suitable	1011		ferralo-chromic/ferric /orthic Acrisols	S1	3	IV	3-IV-Um19	Sub-tropical	Semi-humid to semi-arid	20 - 22	30 - 31	Nov-14	Dry woodland and bushland	Lower middle-level uplands	
KEFRI, Kibwezi	Moderately suitable	1030		ferralo-chromic/ferric /orthic Acrisols	S1	3	IV	3-IV-Um19	Sub-tropical	Semi-humid to semi-arid	20 - 22	30 - 31	Nov-14	Dry woodland and bushland	Lower middle-level uplands	


Melia Volkensii Suitability in Kitui and Makueni Counties
Laikipia
Meru
Isiolo
Garissa
Garissa
Nyeri
Embu
Kirinyaga
Kiambu
Nairobi
Machakos
Kitui
Tana River
Makueni
Kajiado
Taita Taveta
N
S
W
E
Legend
County of Interest
Melia Sites
Counties
Melia volkensii suitability
Very suitable
Moderately suitable
Marginally suitable
0 12.5 25 50 Kilometers

Detailed Research Results

This section contains the detailed research results from which the summary results and recommendations were developed.

Accessibility of Germplasm and Quality Varieties

The available *Melia volkensii* planting material can tentatively be classified into three categories:

1. First generation (F1) improved seed material from KEFRI;
2. Seed collected from established plantations (either KEFRI's plus trees & F1 plantation and privately owned plantations established from natural sources);
3. Seed from natural and unknown sources.

Additionally, second generation (F2) seed supply is expected in the course of this year 2022.

KEFRI F1 Germplasm

Melia volkensii is a newly improved species with the F1 generation of improved seeds available. Genetic improvement of the tree began in 2008 at Kitui regional centre with the support of JICA. Two seed orchards were established starting 2012 with each orchard having a size of approximately 11 hectares divided into 6 blocks each planted with 100 Melia tree families of 5 ramets each at a spacing of 6x6 m, making a total of 3,000 trees per orchard.

The F1 improved seeds are available from KEFRI seed centre at a limited supply. KEFRI gives priority to use of the improved seeds in their nurseries and only sells the balance, which has led to demand being higher than the supply at KEFRI seed centres. This apparent shortage of F1 seeds for private tree growers and investors appears though to be partially artificial, as KEFRI's seed collection from the orchard is done to meet its own performance targets, which are well below the orchards' production. This leads to the bulk of the seed supply being left on the trees.

Although detailed production statistics are not available, KEFRI orchards supervisors shared collection target of approximately 2,000 Kg of nut per year per orchard. Using KEFRI's tree production estimates of 50 Kg of nut per year for a well producing tree (i.e. 200 Kg of fresh fruit), we estimate the potential annual production capacity for each of the two orchards to be at around 7,200 Kg of seed (50 Kg of nut equals ~4 Kg of fruit, see ratios on page 12; we discounted 40% of production to account for poorly producing trees). If our estimate is accurate — a more detailed analysis of KEFRI's production data is needed to confirm this hypothesis, — we would conclude that KEFRI's current collection target is only 28% of the production capacity. Translating this into number of seedlings, using 3,500 as the number of seeds per kg of seed, and 50% as a conservative germination rate, we estimate that KEFRI's current seedling production (if collected seeds are fully utilised) is 3.2m seedlings per year, compared to the potential of over 12m.

Moreover, KEFRI appears to have access to more tracts of land for the expansion of seed orchards and progeny trials, as orchards currently occupy a mere 22 Ha of the over 400 Ha of available land in Kibwezi alone.

To conclude, from these initial calculations, the current F1 seed production capacity at KEFRI's seed orchards is potential as high as 24 million seedlings per year. We estimate this number to be several factors larger than the current, or medium term future demand, as shown in the "Transformation Pathway" section.

KEFRI Production and Prices

KEFRI's bulk of F1 seed supply is dedicated to seedling production in their own nurseries in Kitui and Kibwezi. We were not able to estimate production volumes for either of these nurseries, and although production is constant throughout the year, its scale might be fairly limited.

KEFRI's F1 seed can be purchased at the nurseries for 6,000 Ksh per Kg, containing approximately 3,000 seeds, while F1 seedlings are sold for 70 to 80 Ksh (a significantly higher price tag when compared to the 40–50 Ksh per seedlings most commercial and privately owned nurseries sell for, as well as what other species are being sold at at KEFRI's nurseries).

KEFRI Melia volkensii orchard in full bloom in Tiva, Kitui County

Natural, Wild and Unknown Seed Sources

Other than KEFRI's F1 sources, the majority of *M volkensii* seed collection and seedling production is carried out by a diverse pool of private individuals, farmers and investors, all of which collect seeds from either wild trees or established plantations and woodlots. It is hard to differentiate between seeds collected from plus trees and/or from plantations established from plus trees versus seeds collected from wild or not particularly good form trees. Exception made for larger players such as Better Globe Forestry and the Kituku family who collect seeds from own plantations and have the required forestry skills to discern good from poor form trees, it is safe to estimate that most small players do not perform particular selection of mother trees for their seed collection. This would lead to a large portion of *M volkensii* seed and seedling production to come from poor or non plus trees.

It also seems that more and more private players have started raising seedlings for their own purposes. Due to this, we have not identified any medium or large, professional and commercial tree nurseries focused on *M volkensii* in the Kitui/Kiambere/Kibwezi areas, despite the growing demand. Instead, small nurseries seem to be common. This setup, despite having some advantages, is currently preventing economies of scale from being achieved. *M volkensii* is a difficult tree to propagate, with a lengthy process required for seed extraction coupled with low germination rates. These challenges currently put the cost of raising a seedling at around 20–25 Ksh, pushing the average retail price at an average of 40 Ksh (Luvanda et.al, 2017 quotes a Benefit cost ratio of 1.87): a price too high for most private farmers and prospect tree growers, as well as for potential large scale players (compare with the average price for a Eucalyptus or Cypress seedling of 15–25 Ksh).

Additional notes on Seed extraction and productivity

Melia volkensii seed extraction has been extensively covered in the produced literature, we will therefore recommend readers to consult the shared bibliography. We will only limit ourselves to reporting some key productivity numbers:

- The ratio of Melia nut to Melia fruit is 1:0.24 roughly (50 Kg of Melia fruits would produce 12 Kg of Melia nuts);
- The ratio of Melia seed to Melia nuts is 1:0.08 approximately, which means that to produce 1 Kg of seed one needs 50 Kg of fruit. 50 Kg is also the estimated fruit production of a mature and healthy *M volkensii* tree. Other estimates (BGF) point at 69 Kg of dried fruit, or 82 Kg of wet fruit to produce 1 Kg of seed.
- 1 Kg of seed roughly translates into 3,500 individual seeds; a 50% germination rate is typically estimated by players in the sector.

Growth & Yield

Field data collection for this report was extremely limited (13 sites only), and it did not include full height measurements (only clear bole heights): we are therefore not in a position to propose new Site Indices or growth equations. Nevertheless, what we gather from the data collected, is that the rainfall, soil and altitude do not show to be prominent parameter impacting growth, as the literature has been arguing. Au contraire, planting density, germplasm and silvicultural practices appear to play a prominent role in both rates and quality of growth.

Planting Density

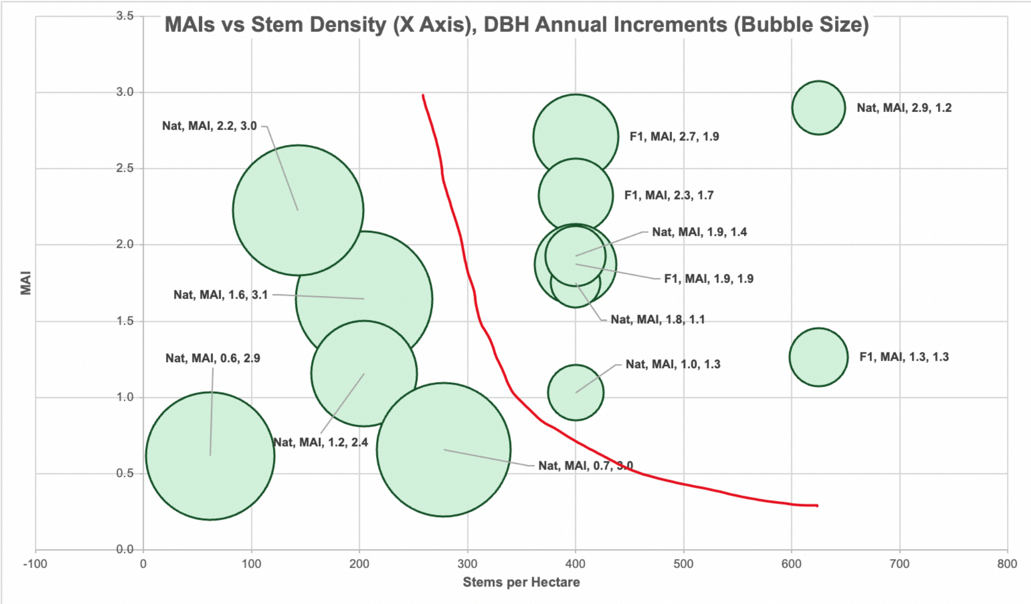
M volkensii has a wide-spreading crown which requires a large area if competition is to be avoided. Competition appears to stunt growth, often resulting in an almost complete halt in diameter growth, even in young plantations.

While the common practice, backed up by the literature, seems to focus on relatively dense spacings such as 4x4 (625 SPH, Gyokusen, 2021), 5x5 (400 SPH, CADEP-SFM /KFS, 2018), or even 3.5x3.5 (Kimondo and Ouma, 2005) as the ideal planting densities, our view is that such will most likely restrain *M volkensii*'s growth, already at a young age, unless multiple thinnings are to take place (see the Thinning section for more details on this). Additionally, arguments for larger spacings are to be found in conjunction with the opportunities for adopting *M volkensii* into agroforestry systems, which both our field visits and the literature point to its potential for improving the profitability of growing this species.

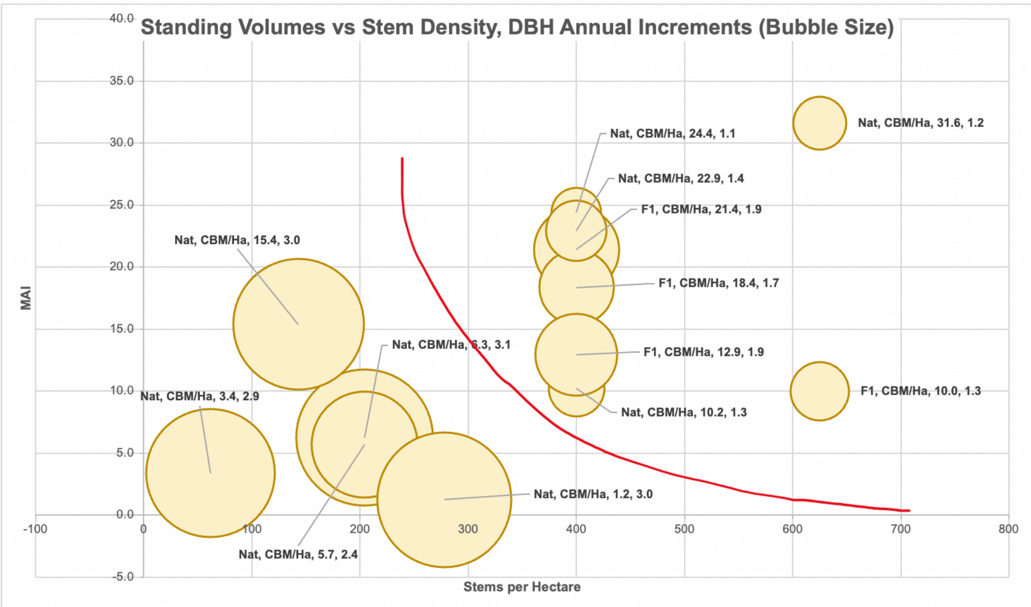
Diameter Growth at different Planting Densities

If we assume that clear, furniture grade sawn timber is the primary objective of planting *M volkensii*, diameter growth is possibly the most important parameter to assess the its success. In this section, we show, through data collected on a series of plots across Makueni, Machakos and Kitui Counties, how planting density significantly affects diameter growth.

The charts below show calculated MAIs for the plots sampled during the site visits, which were plotted against stems per hectare and annual DBH increments (represented by the bubble size). As can be appreciated, lower SPH values correspond to the faster diameter growth, and DBH increments of ≥2 cm y^{-1} can only be found in either plots with very low stems per Ha (SPH <400), or plots with low standing volumes (<10 CBM Ha^{-1}; i.e. young plantations).



MAI by DBH Increments, Spacing



Standing Volumes by DBH Increments, Spacing

The only plots defying this observation are those planted with F1 material from KEFRI (the three bubbles with F1 marked on them): these demonstrate DBH increments of 1.7 to 1.9, with an SPH value of 400. Nevertheless, once must note that all the four F1 progeny trials visited are relatively young (<8 years of age), and it is likely that if the density is not reduced diameter growth will start plateauing.

A similar note should also be made for the Better Globe Forestry plantation of Kiambere, the datum at the top right side of graph. While its MAI value of 2.9 $m^3Ha^{-1}y^{-1}$ and 31.6 m^3Ha^{-1} of standing volumes — the highest values recorded, — occur at a high density of 625 SPH and can make it appear as an attractive result from a pure biomass perspective, it should be noted that it is not ideal for sawn timber purposes, as diameter growth was hindered by competition (13.2cm average DBH at 11 years of age). The resulting DBH increment of 1.2 cm y^{-1} is likely to decrease further if thinnings are not performed.

To conclude, if sawn timber is the desired outcome of the planting, our recommendation is to plant at densities lower than 400 stems per hectare. More specifically, for pure plantations, a spacing of 6x6 seems to be giving good results, while a 7x7 experiment is being trialed by Kituku with F1 material and should be kept into consideration. Alternatively, agroforestry systems with *M volkensii* planted in rows are also a recommended system; in these a spacing of 6 meters between trees and 15 to 25 meters between rows seem to be performing well. However, we should note that most sites visited were still at a young age, and there is currently no information on older plots with such wide spacings. More research and monitoring of growth should be conducted to cover the later years of the rotation and ensure that 6x6 does not require thinning later on.

Smallholder Farmer agroforestry woodlot in Kibwezi: planted at below 200 SPH, the average diameter was measured at 20cm at 7 years of age.

MAI as a Metric for M volkensii

Lower densities will naturally lead to low values of standing volumes, as well as mean annual increments per hectare (MAI). Such low values might make *M volkensii* look uncompetitive when compared to other commercial species grown at higher stocking rates. Because the objective for growing *M volkensii* is furniture grade, high value sawn timber, comparing MAI and Standing Volumes with other species is not entirely relevant. It is therefore suggested that metrics such as MAI are put into context before being presented, even more so when *M volkensii* is planted in agroforestry systems.

Calculations

In the table below we report the summary of calculations used for the analyses presented here.

Region	Location	Plot Name	Plant Material	Spacing	Year	Age	DBH	Height	DBH Incr	Ht Incr	CBM	SPH	Surv %	CBM/Ha	MAI*	Comment
Kiambere	Kiambere	BGF Kia-1	Nat	4x4	2011	11	13.2	4.6	1.2	0.4	0.1	625	85%	31.6	2.9	
Kiambere	Kiambere	Simon	Nat	7x7	2019	3.8	11.7	4.3	3.1	1.1	0.0	204	70%	6.3	1.6	Best performing, involved landuse change
Kiambere	Kiambere	Grace	Nat	7x7	2017	4.9	11.8	3.8	2.4	0.8	0.0	204	70%	5.7	1.2	
Kitui	Tiva	TIVA F1	F1	5x5	2014	7.9	15.3	3.5	1.9	0.4	0.1	400	85%	21.4	2.7	
Kitui	Tiva	TIVA F1-2	F1	5x5	2014	7.9	13.4	4.0	1.7	0.5	0.1	400	85%	18.4	2.3	
Kitui	Tiva	TIVA NAT	Nat	5x5	2012	9.9	12.6	2.4	1.3	0.2	0.0	400	85%	10.2	1.0	
Kibwezi	Orchard	KEFRI KIB F1-1	F1	5x5	2015	6.9	12.8	3.0	1.9	0.4	0.0	400	85%	12.9	1.9	
Kibwezi	Orchard	KEFRI KIB F1-2	F1	4x4	2014	7.9	10.5	2.1	1.3	0.3	0.0	625	85%	10.0	1.3	
Kibwezi	Kituku	Kituku 1	Nat	5x5	2008	14	15.8	3.8	1.1	0.3	0.1	400	85%	24.4	1.8	
Kibwezi	Kyulu	Martha	Nat	6x27	2017	5.5	16.0	3.5	2.9	0.6	0.1	62	80%	3.4	0.6	
Kibwezi	Kyulu	Peter	Nat	5x14	2015	6.9	20.4	4.3	3.0	0.6	0.1	143	80%	15.4	2.2	
Mutomo	Jacob	Jacob-1	Nat	5x5	2020	1.9	5.8	2.0	3.0	1.1	0.0	278	80%	1.2	0.7	Best performing: both heght, diam, m3/Ha
Mutomo	Beatrice	Beatrice-1	Nat	5x5	2010	12	16.3	3.5	1.4	0.3	0.1	400	80%	22.9	1.9	

Note: Standing volumes and MAIs calculated for clear bole volume **only**.

In performing the calculations, the following assumptions were made to calculate merchantable volumes:

- Taper: 0.5 cm/m;
- Survival: 70 to 85% depending on site, based on observations.

Germ-plasm

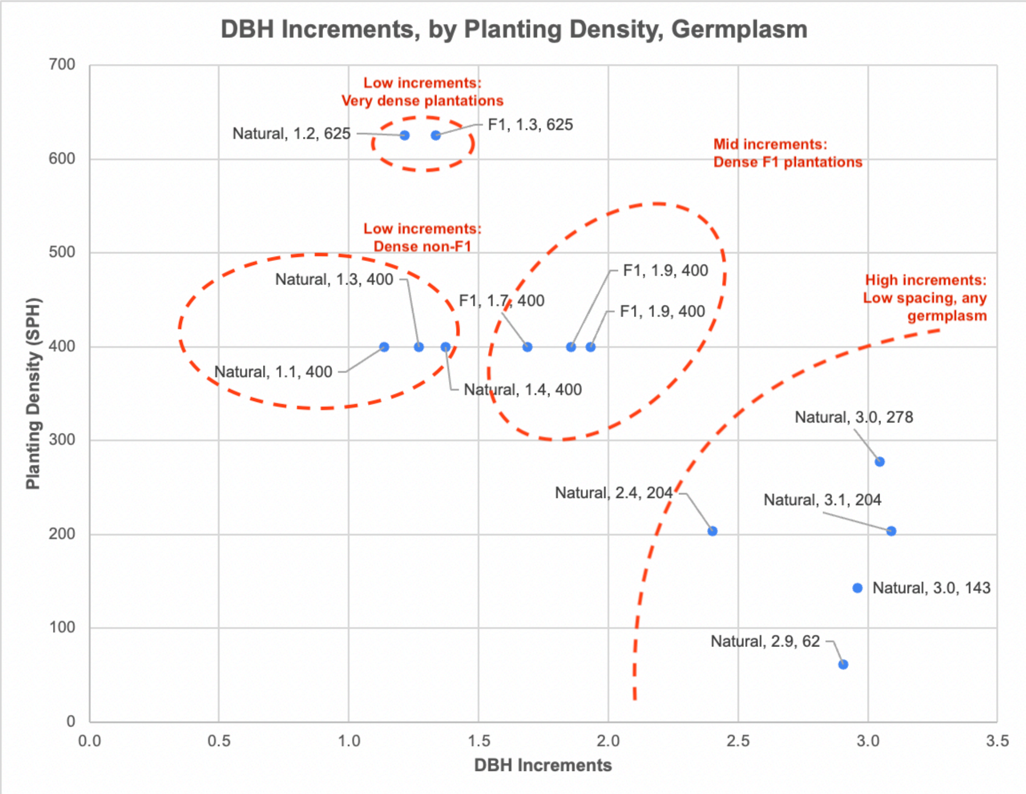
Utilisation of improved planting material from KEFRI's tree breeding program shows positive impacts on growth vis-à-vis sites established using material collected from the wild. All F1 sites measured are KEFRI progeny trials in Kitui and Kibwezi. The chart below correlates DBH increments with Germ-plasm used and planting density.

While planting density is clearly determining factor in diameter growth, utilisation of F1 material shows positive impacts at medium to high densities. From the chart below we can quite clearly distinguish three clusters:

1. High DBH increments (>2.0): these were recorded in sites with very low planting densities of less than 300 SPH, even if the material used was collected from the

wild;

2. Low DBH increments (1.0 to 1.5): these were recorded in sites with very high densities of above 600 SPH regardless of germ-plasm origin, and/or medium to high densities of around 400 SPH with non-F1 material;
3. Mid DBH Increments (1.5 to 2.0): these were recorded in sites with mid to high densities of around 400 SPH but using F1 material.



DBH Increments by Planting Density and Germ-plasm

Our conclusion from the data collected is that F1 germ-plasm allows for a faster diameter growth even under relatively dense spacings (5x5) where naturally collected material is much more likely to stunt.

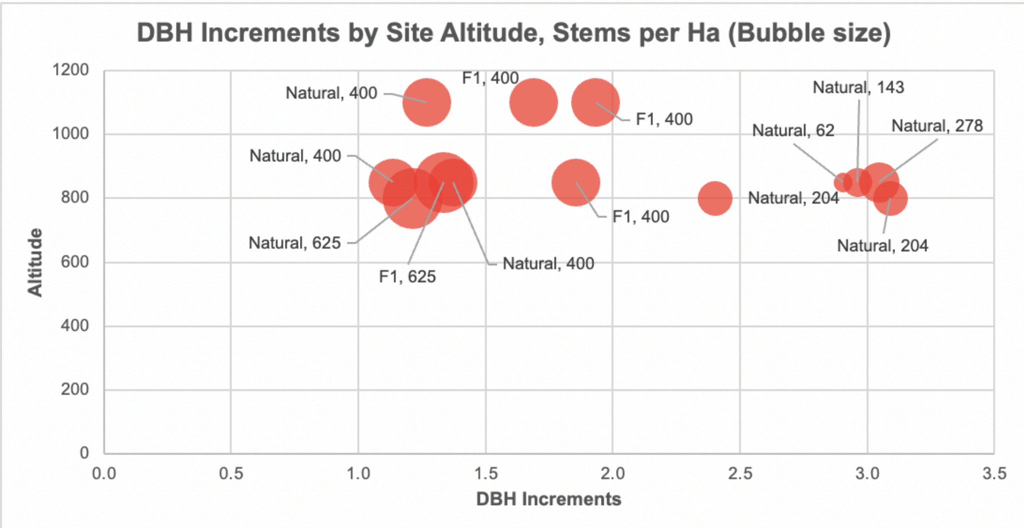
Nevertheless, planting density seems to be a more decisive factor than germ-plasm — at least at this stage of the tree breeding: from our data, densities higher than 400 SPH seem likely to result in stunted diameter growth regardless of germ-plasm, in the same way in which low densities can achieve high growth even with naturally collected planting material.

Elevation

Similar to germ-plasm is the elevation's impact on growth. From our data collection and analysis, there seems to be an clear impact from an elevation perspective, with sites falling within *M volkensii*'s natural distribution elevation range performing marginally better than those planted outside of it. Similar to germ-plasm though, even for elevation it seems that Planting Density is ultimately the highest impacting factor.

Observing the data shown in the chart below, we can again identify three distinct clusters:

1. A first cluster of high performing sites is associated, as expected, with the low planting densities (<300 SPH); all are also sitting at elevations slightly above 800 masl, therefore within *M volkensii*'s natural range.
2. A mid range cluster (DBH increments of 1.5 to 2.0) of sites at SPH of 400, at both in-range elevations and out-of-range ones (1,100 masl), all performing comparably.
3. A poor performing cluster of sites (DBH Incr < 1.5) associated with high and very high densities (≥400 SPH) at both 800 and 1,100 masl.



DBH Increments by Site Altitude, Planting Density

From these data we derive that altitude is potentially a factor, but it does not seem to be significant, at least whenever it is kept within or reasonably close to the natural distribution range. Instead, planting density, and then germ-plasm are more decisive when it comes to growth rates. These are initial findings, and the data collected is very limited: more research should be carried out before ruling out altitude as a factor in *M volkensii*'s growth.

Silviculture

In this section we review the current knowledge on silvicultural practices implemented on *M volkensii* and spell out recommendations.

Thinning

As we have seen in the Growth and Yield section, competition between *M volkensii* trees is a major obstacle in recording good diameter growth, and should therefore be prevented. Thinning as an operation is aimed exactly at that, and numerous papers suggest to perform it multiple times on *M volkensii* throughout the rotation length.

While thinning is effective in reducing the density and therefore competition, there are arguments against it, which in the specific case of *M volkensii* are, in our view, large enough not to recommend it as a practice.

Costs & Benefits

Thinning is considered an expensive operation in forestry, which can be — at least partly — offset by the sale of the small diameter material extracted. In the case of *M volkensii*, it appears from both desktop and field research that there is not a large market for small diameter *M volkensii* material. The immature wood is yellowish and of low density, and while Stewart et al. (1994) mention small diameter material being used in traditional constructions, and being termite resistant even at a young age, it seems that this material does not make it outside of household consumption. Stewart also mentions it not being appreciated for fuelwood due to unpleasant smelling smoke, and making poor charcoal.

Technical Skills, Knowledge, Timeliness

Thinning operations are fairly technical, requiring both knowledge and skills to select out trees, as well as good timing. With *M volkensii* being planted by a large number of individual growers, often knowledgeable about agriculture but not forestry, it might unrealistic to expect quality and timely thinning operations to be implemented.

Moreover, there seems to still be little knowledge around what type of thinning regime is recommended for *M volkensii*. The existing literature only suggests a number of different regimes, often involving multiple extractions, but it is evident that little formal experimentation has been carried out to identify the most efficient ones.

On the timeliness of thinnings, an outstanding question remains on *M volkensii*'s responsiveness to late thinnings. In many commercial species, late thinnings are not effective as once growth has been stunted by competition, trees are no longer able to take advantage of newly freed up space. This is may or may not be true for *M volkensii*, and there seems to be some indication of its ability to recover after late thinnings (Vandenabeele, personal communication). This is yet to be backed up by data, and it is therefore recommended not to thin late — or even more to plant at low enough densities so as to avoid thinning altogether.

Lastly, with *M volkensii* being a demanding species in terms of silviculture, especially on pruning and debudding, it could be more economical to (a) reduce labour where possible, and (b) avoid extracting trees after care and labour has been put into them.

Cost of Seedlings vs Cost of Land

As we mentioned, proposed thinning regimes differ, but on average a reduction of around 40–50% of stand density is anticipated. With cost of seedling being mentioned as a barrier to entry for most private growers, it might not be advisable to recommend a regime that involves such a large percentage of thinning. This becomes even more relevant in a Dryland context where larger tracts of land are generally available with low opportunity costs.

In conclusion, due to the high cost of seedlings, the expensive and technical nature of thinning operations, the low value of *M volkensii* thinnings, the relatively high maintenance requirements of this species, the lack of clarity around recommended regimes, and finally the generally lower levels of discipline in attending to silvicultural regimes for non-professional tree growers (we haven't seen any evidence of thinning practices in any of the sites visited), our view is that thinnings should be avoided by adopting planting densities and do not require them. As we have seen in the previous section, densities lower than 400 SPH, and even close to 200 SPH can be adopted from planting, ensuring good diameter growth without requiring thinning.

Agroforestry Systems and Yields

The literature tends to agree on *M volkensii*'s potential in agroforestry systems. Older studies such as Stewart et al. (1994) report the species being commonly planted in large spacings (10–15m) by smallholder farmers within their cultivated fields. Newer studies such as Wekesa et al. (2012) affirm that "the highest profitability [in growing the species in smallholder setups] was achieved when intercropped with green grams at initial stages of establishment accompanied with value adding into timber". The value of *M volkensii* adoption in agroforestry is shared by other authors, including

BGF, and evidence on the ground confirms these hypothesis. Nonetheless, some authors such as Mulatya (2005) seem to affirm the opposite, reporting high tree-crop competition, although variability between crops and tree management does lead to varying results[1].

M volkensii's potential in agroforestry builds on two main considerations:

- Favourable tree - crop interactions;
- High diameter growth at very low spacing.

On tree to crop interaction there is an unfortunate lack of scientific studies confirming this hypothesis, and we can only rely on evidence on the ground and traditional practices adopted by farmers. The literature (Stewart et al., 1994) only reports farmers' positive experiences in intercropping the tree with "all grown crops" (dependent on the adoption of pruning techniques to reduce the shading effect of canopies). Leaf litter is usually considered beneficial for soil health, potentially increasing yields, while the tree's deep rooting nature reportedly results in low interference ploughing and tilling activities. More research should be carried out to verify these hypotheses and further investigate these interactions.

From our field visits, most intercropping appeared to be carried out with grass and livestock keeping. Planting *M volkensii* at 100 to 200 SPH, whether scattered or in rows distanced 6 x 15–25–30m. All were reporting good results, especially in the Kibwezi area, where an average DBH as high as 20cm was attained in one plot at only seven years of age.

BGF Plantation in Kiambere, at 11 years old the average diameter is below expectations due, likely due to high planting density — 625 SPH — and no thinnings.

Intercropping appears to be feasible also at relatively high densities but for a limited number of years. Farmers plant green grams in 5x5 plantations for the first 5 years, thence switching to grass and grass seeds. In such setups KFS (Njigoya, 2018) suggests that 4,000 Kgs of cowpeas can be harvested per hectare per year for the first 6 years from planting time, for an annual revenue of 320,000 Ksh year^{-1}. Once canopy closes, green grams and other crops are not feasible any longer, but grass maintains potential. Average yields of grass even in more mature, dense *M volkensii* plantations ranger between 70–90 bales of hay per acre, sold at 250–300 Ksh (Kibwezi). Harvest can be done twice a year, leading to an achievable revenue of up to 50,000 Ksh $acre^{-1}$ $year^{-1}$.

A private Kibwezi farmer's Melia volkensii agroforestry woodlot: trees planted in rows for hay production.

Grass seeds are another potential, albeit for an international market mainly, which may be out of reach of most growers. Seeds sell at 800 Ksh/Kg, and a farmer in Kibwezi reported harvesting 12t from the 200 acre farm ≈ approx. 60 Kg/acre, for a revenue of 48,000 Ksh/acre, which can be added on top of that of grass.

David Kituku, a prominent M volkensii grower in Kibwezi, explaining agroforestry to the Gatsby Africa team, together with KEFRI representatives.

Overall, agroforestry shows the highest potential for *M volkensii*, as it matches the species low density requirements and lower levels of competition with other crops. It is also the most advisable system for small holder private farmers who cannot afford a lack of revenue until the end of the tree's rotation.

Height growth, Pruning and Debudding

The literature is consistent in identifying in *M volkensii* a tendency to produce a conspicuous crown, with many branches, often detrimental to both diameter and height growth. When planted for commercial purposes, pruning and debudding have been identified as operations to counter this natural tendency and stimulate height growth and the production of a clear bole.

Our observations were in line with the literature in noticing that *M volkensii*'s height growth is well correlated to pruning techniques, in a way that allows, depending on site conditions and within limits, an almost artificial control over it. While height growth seems to be dependant to some extent on site quality, soil fertility and possibly soil depth, KFS progeny trials as well as private woodlots demonstrate how a clear bole can be obtained if pruning is carried out diligently and timely. In the absence of pruning, boles will unlikely reach length of over 2 meters, while 4.5 and up to 5–6 can be obtained thanks to pruning and debudding schedules. These are often labour intensive, and require some degree of technical skills and tools. BGF recommends 10 pruning sessions to be carried out within the first 4 years of age, allowing to obtain a clear bole of 5+ meters and a DBH of 10cm; the correlation between pruning and DBH growth is unclear: BGF's 11-year-old woodlot we visited in Kiambere did show us an average bole height of 4.6m but a diameter of only 13.2cm — we are however unsure of what the diameter was at age 4.

At the same time, we have noticed a potential negative impact of pruning on growth, resulting from increased stress wherever it was taken too high up, damaging the crown. On of KEFRI's Tiva progeny trial was pruned too high and diameter growth seemed to be negatively impacted. This shows there is more experimentation and trials to be carried out to understand full implications of pruning on *M volkensii* growth and stem form.

Agroforestry Pruning Techniques: Lopping, Topping

In agroforestry, heavy pruning techniques are adopted to release large amounts of fodder onto the ground, whether for livestock grazing or to increase organic matter onto the soil. Of these, the two most common techniques adopted on *M volkensii* in Kenya's surveyed counties are lopping and topping. Lopping is distinguished from regular pruning in that branches are not cut from the base, but from a distance. Also, it is not always done starting from the lower part of the tree, and can be more haphazard. Topping involves severing the entire crown of the tree at the point where branching starts. While all tree species can be lopped or topped, the growth rate of certain ones can be retarded, and stresses might be created even leading to the death of the tree. On the other hand, such techniques potentially have positive impacts on the tree form, stimulating in some cases the diameter growth, and even improving the taper of the bole. From field observations, lopping and topping of *M volkensii* is a relatively common sighting on private farms, as it seems to be used mainly for fodder production during the dry season. *M volkensii* seems to take lopping and topping relatively well, but more trials and data should be collected to verify the impacts on growth and tree form.

Resource Base

M volkensii being an indigenous tree self-propagated in the wild, the resource base should distinguish from natural, wild resources and planted ones. Unfortunately, on either the amount of information is extremely scarce, limiting our ability to understand the extent — let alone the quality — of the *Melia volkensii* trees available for felling. This lack of information, together with anecdotal reports, point to the natural resource base being largely depleted (at least of the commercially valuable trees), with a high potential for genetics degradation in the wild. Commercial forestry ventures should therefore focus on planted resources only.

Natural Resource Base

Melia volkensii's native range is large, covering a significant portion of Kenya, as well as small portions of Tanzania and Somalia. In the wild *M volkensii* is not often found to be gregarious, and isolated trees are more common than pure stands. This being said, *M volkensii* has been targeted for felling for a relatively long time, achieving large volumes in the past 10 to 20 years, when it reached a peak. According to wood workers in Kitui, the flow of *M volkensii* timber has since decreased significantly, together with the sizes. The Zombe Workshop supervisor reported that in the early 2000s *M volkensii* was being traded in the same sizes wild Mahogany from the Congo is being traded in currently, while today only small sizes are available, and in limited quantities. These reports point to an overexploitation of the natural resource base, especially of the larger, better form trees, leading to genetic degradation other than lack of commercially valuable stems (Muchiri et al., 2005; Odee et al., 2005). Today, in Kitui, most *M volkensii* timber traded seems to come from planted and/or semi-managed trees within private properties. The heavy presence of yellow sapwood and the small sizes of the timber traded point to farmers felling young, often immature trees.

Due to the overexploitation, the extremely large range of distribution of the species, and its non gregarious growing habit, it would be difficult to run full inventories of the wild resource base. Leveraging on Remote Sensing technology could be the only cost-effective way to run such an exercise, although the deciduousness of the tree could pose technical challenges. Whether the exercise is run or not, it does not seem probably that large amounts of wild, commercially valuable trees outside (or even inside) of protected areas will be found.

Artificial Resource Base.

Melia volkensii has been planted and managed by farmers as an agroforestry trees for decades, if not centuries. Its termite resistant timber is appreciated locally and a favourite for door and window frames as well as other furniture. In the past 20–30 years, thanks to significant investment, research and planting have been scaled up, led by KEFRI and JICA, whom, today possibly own the largest amount of planted *Melia volkensii* trees. Other than these government-led efforts, only one other larger player exists: Better Globe Forestry, a forestry company. BGF has so far established over 300 Ha of *M volkensii* in the Kiambere region and another 700 Ha in the Coastal Region. It also features an outgrowers program that provides additional planting potential. Similarly, Komaza Forestry Ltd, a commercial forestry business and former NGO has also established a significant amount (3,700 Ha in total) of *M volkensii* plantations in the form of half-acre woodlots, although just outside of the native range.

Both these players, while having commercial interests, have not yet started felling, processing or selling their resource base. Commercial planting and felling of *Melia volkensii* is therefore almost purely delivered by smaller, private investors: mainly Makueni, Kitui or Machakos residents, farmers or middle class employees living or having strong ties in rural areas. While rather unique, Mr Jonathan Kituku, a farmer from Kibwezi, is a prime example of private investment in *M volkensii* commercial planting. Albeit receiving significant support from KEFRI, Mr Kituku has established over 200 acres of *M volkensii* for commercial purposes, although it seems than rather than felling the trees themselves, most of Mr Kituku's revenues come from intercropping of grass and legumes within the his plantations.

Grower	Ha under cultivation	Comments
KEFRI	50–100 (?)	Not commercial
Better Globe Forestry	1,000 Ha (of which 700 Ha in Lamu)	Not entirely commercial: not harvesting, not thinning
Komaza	3,700 Ha (Kilifi, Kwale)	Not harvesting yet
Private growers	Data lacking	Appear to be the only real commercial planters, need to identify growers' groups or associations
Natural Resources	Data lacking	Likely only very few, uncommercial volumes, mostly in protected areas

Dense Melia volkensii planting by BGF cover the landscape in Kiambere: despite the species' popularity, such a sighting are rather unique across the growing regions.

To conclude, as for the natural resources base, even the artificial one is of a very scattered nature, with large tree planters being less active in the felling of the tree — whether because of following investors' interests or for leveraging on the agroforestry value of this species. Supply of timber is therefore coming from a myriad of growers establishing small woodlots in their properties, or managing the natural resources found therein. Similarly to the natural resource base, nothing close to a full inventory exists, and Remote Sensing technology seems to be the only cost-effective solution to resolve this knowledge gap. Finally, albeit anecdotal in its nature, observations from our site visits point to planting of *M volkensii* among private growers far from having reached its full potential: especially when compared to Eucalyptus and Grevillea plantings from Central, Nyanza and Western Kenya, *Melia volkensii* still has a long way to go before becoming a popular crop.

Timber Processing & Marketing

In a previous section we mentioned the literature covering extensively the first steps in this species' supply chain — seed collection and propagation in particular, — while successive steps receiving less and less attention the farther down the supply chain one goes. Timber processing and marketing are therefore areas little covered by literature and possibly still far from the being included in research and development plans for *M volkensii*. This is understandable based on what has been said in the previous section — i.e. the volumes available for cutting being very limited, — coupled with the timber already having a very good reputation amongst those who know it.

That being said, there is ample room for improvement in these areas, especially when widespread commercial uptake is being targeted. The four areas that we consider requiring most attention are as follows:

- Product uses, Timber Properties and Market Feedback;
- Market size and distribution;
- Harvest and Processing capacity;

Product uses, Timber Properties and Market Feedback

M volkensii timber is a popular timber species in its native range, much appreciated by woodworkers, furniture manufacturers. as well as end users, for its beautiful and stable grain, colour, workability, and not least its termite resistance. Woodworkers report it being easily seasoned, taking sanding and varnishing well. It is compared to, and is being essentially substituted by "Mahogany" (African Mahogany, prob Khaya spp), both for its appearance and workability. Mahogany is a relatively new product in Kenya as a whole, and even newer in the Melia growing counties, being introduced to compensate a lack of suitable Melia timber in terms of maturity and sizes. Woodworkers report preferring Melia over Mahogany, due to having the same workability and aesthetic properties, being traded at a fraction of the Mahogany price, and finished products using either timber attracting similar if not the same prices in the market.

The most popular product utilisation for *M volkensii* timber are doors and door frames, thanks to its termite resistance, followed by beds and general furniture (coffee tables, chairs, etc). These are traditional products being produced with *M volkensii* timber, and little innovation seems to be carried out in terms of expanding the possible offer. Opportunities for innovation have been sported by one private player, Mwaduka Joseph, who has been producing flooring and roof shingles successfully in the recent past. Currently he is not producing and we have not come across any other players using *M volkensii* for non-traditional products. There was no notice of the timber being used for structural applications, perhaps due to its apparent higher value.

Melia volkensii furniture produced by a small woodworkshop in Mutomo. Knots from poor silviculture can be observed.

When compared to other commercial timber species, *M volkensii* is much preferred over Blue Gum (Eucalyptus spp), Pine or Cypress, on account of both properties and price. *M volkensii* has in fact a reputation of being a high quality timber for high end applications, therefore not easily substituted by rougher or less pleasant timber such as Eucalyptus and Pine.

Timber Properties

From a technical perspective, the suitability of *Melia volkensii* in competing with renowned species for structural and furniture applications has been looked at by assessing strength characteristics and properties. Results of this exercise were shared by Oduor (2013) in an article in Miti Magazine, which compared *M volkensii* with *Milicia excelsa* (Mvule), *Tecnona grandis* (Teak) and Congolese Mahogany (*Khaya spp*), concluding that on average it compared favourably with all these species, thus being eligible for substitution on most applications. Additional characteristics such as workability, ease of seasoning, stability and natural resistance to decay and termite attacks make it standout.

These results are in line with the general assessment made through the literature and site visits. They also do not come as surprise when taking into consideration that the genus Melia belongs to the *Meliaceae* family, to which numerous prized timber species belong as well, such as *Swietenia* (the genuine mahogany from the tropical Americas), *Lovoa* (another African genus dubbed "mahogany" in trade language), as well two of the compared genuses, *Milicia* and *Khaya*. The genus *Azadirachta* (to which the "Neem tree" belongs) is also part of this family, and while little known commercially, it has become a substitute for a number of overexploited carving species, as well as a preferred species for furniture making in the Coast of Kenya.

One reservation we would like to bring forward with the test results shared by Oduor is that no mention is made on the provenance and age of the used samples. From our field visits, premature felling of trees is a common practice, resulting in substandard sapwood content, whereas the timber of Mahogany and Mvule typically comes from mature individuals, several decades old, harvested from the wild. Adoption of *Melia volkensii* as a commercial species entails short rotations of a maximum 20 years. In testing the timber, one should therefore take age into consideration: tests should be performed on different age trees, in order to ensure that recommended rotation lengths suffice in producing mature, stable timber for structural and furniture applications alike.

Market Size and Distribution

M volkensii's value chain once a tree has reached maturity is run mostly by informal entrepreneurs who scout standing trees or timber from landowners and distribute to a network of hardware stores. A general dearth of mature trees, and informal nature of the supply chain, lead to supply trickling into secondary processors, wood workshops, at inconstant rates, despite a reportedly stable demand and willingness to pay. Additionally, poor processing technology and inadequate farmers' technical knowledge bring on further inefficiencies (Muthike and Githiomi, 2020).

Low supply volumes, together with dimensioning and quality of the supply, are according to our observations the key limiting factors in serving a market that would otherwise be theoretically large, based on timber characteristics and ability to substitute expensive and environmentally disastrous Mahogany timber.

Supply Volumes

Field observations and interviews with hardware store owners clearly identify supply volumes as the main challenge. *M volkensii* timber is not easily available, and waiting times can be rather long, especially for specific orders and dimensions. It is rather hard to estimate the total volumes of timber traded, as it is used by a multitude of small wood workshops. Zombe, in Kitui, is one of the largest, as well as a traditional believer in *Melia volkensii* for high end furniture manufacturing. Zombe's owner, despite its preference for this species, reports it satisfying only 5% of his monthly consumption (500–600 feet out of his total 10,000 feet consumption). Other hardware store owners worked on much smaller consumptions of *M volkensii* timber. Low volumes are being substituted by Mahogany for high end products, or Eucalyptus spp for lower end product.

The low volume of timber supplied appears to prevent the species from exiting its native range, as it does not seem to be able to satisfy internal demand. For this reason, no marketing research has been so far conducted outside the Counties of Kitui, Makueni and Machakos, although recommendations for running a survey and collect information in the Nairobi furniture market are made, to assess the potential for *Melia volkensii* to satisfy a portion of the capital's market, while substituting Mahogany and other imported or illegal timbers.

Supplied Dimensions, Quality

Dimensions supplied to manufactures are mainly the common dimensions: 3x3, 4x3 and 6x1 or 2. No larger dimensions are commonly available due to the degradation of the resource base. Lengthwise too, woodworkers complain of the timber being traded in short lengths, down to 7 feet, which make their work harder and less efficient.

In terms of quality, *M volkensii* timber is not graded and all the material is traded as one grade. This can be of good quality, but is often affected by defects, the most common of which consist in either silviculture-related defects — such as knots, resin pockets, and immature timber due to premature felling, or processing-related ones — such as wane, undersizing and poor dimensioning. Premature felling results in the presence of bright yellow sapwood, both unappealing to customers' eyes, and prone to termite damage. Processing-related issues such as poor dimensional accuracy leads to the raw material being under-dimensioned after planing, creating wastages and inefficiencies in the production processes. Due to the various defects in the timber, a portion of the supply is reportedly rejected by the larger players and fed to smaller woodworking shops who produce less high end products. In general though, many of these defects are currently accepted by secondary processors, as there is very little supply of defect-free grades available.

Melia volkensii bed produced by Zombe, in Kitui. Some yellow sapwood is visible: while undesirable, it is rather common across the available supply.

Same as the volumes, even the quality of the supply of *M volkensii* timber has reportedly degraded over the past two decades or so, very likely due to the overexploitation of the natural resource base of older, and better form trees.

Prices

Below an overview of the prices quoted in Kitui and Kibwezi for *Melia volkensii* timber, in March 2022. All prices in Kenyan Shillings, per foot, if not otherwise specified.

Size	*M volkensii*	DRC Mahogany	Source
3“x3”	70 (Kitui), 50 (Kibwezi)	320 (Nairobi)	Zombe, Kitui; Furniture lady, Kibwezi
4“x2”	80 (Kitui), 50 (Kibwezi)	n/a	Zombe, Kitui
6“x1”	70 (Kitui), 50 (Kibwezi)	n/a	Zombe, Kitui
12“x2”	n/a	900	Zombe, Kitui
Bed, 4’x6’	9,000	15,000	Zombe, Kitui
Std Door Frame	4,500	?	Kituku, Kibwezi

Harvest and Processing Capacity

M volkensii is dedicated almost entirely to sawn timber for general woodworking and furniture applications. For this reason it is being traded almost entirely in sawn timber form, in the dimensions described in the section above.

Due to the distributed nature of the resource base, the timber is often cut on the site of the felling, and extracted as sawn boards. It is typically performed by entrepreneurs or brokers, who purchase standing trees from farmers, or harvest in the wild. The processing technology adopted is therefore limited to mobile options that can be taken to the growing site. This is usually limited to chainsaws and we have not observe or heard of mobile mills being adopted, although it is possible that some are in operation. On the contrary, some timber traded in a wood workshop in the town of Mutomo was carved manually with a machete into a plank, chainsaws not being available to the grower.

The quality of the cut is therefore generally poor to extremely poor, leading to both very low recovery rates during primary processing, and high wastage (or poor quality finished products) at secondary processors' level. These latter ones are particularly negatively affected by the poor dimensional accuracy, which negatively impacts their economics. Poor recovery rates at primary processing instead are likely to affect the brokers or — most likely — the farmers, who might see their revenues decline accordingly. An in-depth analysis of the value chains should be run to assess the damages of poor quality practices at processing; at the moment, due to the high demand, the inefficiencies and defects presented seem to get accepted by the market, as they do not seem to be preventing trading from happening.

M volkensii Transformation Pathway & Unit Economics

In this section details of the calculations and assumptions made in the development of the Unit Economics and Transformation Pathway model are given.

Unit Economics Excel Modelling

An Excel model was developed to assess Unit Economics for various planting regimes, in order to compare a traditional monocropping setting with the proposed agroforestry plantings at very low densities. The Excel model is available as an attachment to this report. Below is an overview of how the calculations were carried out, and any assumptions made.

Modelling Structure & Background

The basic unit utilised for the modelling is **1 hectare** of land, planted with *M volkensii*, F1 material.

Three different planting scenarios were modelled out and compared, the main different being the spacing:

1. **5x15** meters apart (in rows), equivalent to 143 SPH;
2. **7x7** meters apart (as a grid), equivalent to 204 SPH;
3. **4x4** meters apart (as a grid), equivalent to 625 SPH;

For all three scenarios growth was modelled out based on a 15 year rotation involving agricultural and carbon revenues to be generated on the same Hectare where the trees are grown. Harvest and Haulage, Processing and Sales costs were also calculated.

Growth & Yield

Diameter and height growth for the three scenario was calculated for a rotation of 15 years. For the 5x15 and 7x7 scenarios, growth was calculated based on height and diameter increments estimated based on the data collected for this report. We remind the exiguity of the dataset utilised, and lack of substantial data especially for the years past the 10th. For the 4x4 scenario growth estimates from Gyokusen (2021) were used.

Revenues

To fully account the agroforestry potential of *M volkensii*, and to capture the ability of running multiple activities concurrently on the same piece of land, three basic revenue streams were included in the model:

1. Sawn Timber Sales
2. Agricultural Revenues
3. Carbon Revenues

Sawn Timber Sales

This is the actual sale of *M volkensii* sawn timber grown on the land. Sales were assumed as carried out on a wholesale basis to secondary processors (i.e. furniture manufacturers) in the Nairobi area. Three different grades were estimated coming out of the sawing operations, priced at a competitive market rate based on current (2022) sawn timber prices, as shown in the table below. Moreover, an average distance of 250 Km from the sawing operations to Nairobi was estimated, with a cost of transportation and a cost of running sales operations.

Grade	Kes/m3	Kes/BF
Clear WOS, RST	84,746	200
Joinery WOS, RST	55,085	130
Utility WOS, RST	29,661	70

Agricultural Revenues

Agricultural revenues were estimated using annual revenue figures net of all agricultural costs. These figures were estimated based on data collected in the field, and assuming that only the most basic activity (hay production) is carried out; other, more sophisticated, activities can be built on top and add onto the revenues.

Both light-touch and intense revenues were used, to account for the increased light competition in the denser scenarios as the trees mature:

- Net annual revenues of intense agricultural activities: 100,000 Ksh y^{-1};
- Net annual revenues of light agricultural activities: 40,000 Ksh y^{-1}.

These figures are considered conservative and representative of light engagement in agricultural activities.

Carbon Revenues

Carbon revenues were estimated based on the following assumptions:

- Issuable certified credits were estimated using the long term (30 y) average sequestration based on the 15y rotation chosen in the modelling.
- Baseline is assumed to be agricultural activities with no significant carbon sequestration in biomass.
- Only biomass carbon included (above- and below-ground).
  - Soil Organic Carbon current excluded for now: while this could be significant it depends on what agricultural activities were carried out in the plot.
  - Carbon sequestered in Harvested Wood Products also excluded.
- A price of 15$/tCO2e was used for the modelling.
- Carbon sequestration is gross of emissions generated by the operations, including and not limited to the use of fertilisers.

Costs

The model was developed to factor in all costs associated with planting, maintenance, harvest and processing of the timber, up to sales operations. No costs associated with land acquisition, security and/or infrastructure was included. Details of the cost figures can be obtained in the Excel model.

Silviculture Costs

Broadly, the following assumptions were made:

- Survival rate estimated at 90% after blanking. Blanking of 20% planted seedlings was included.
- Fertiliser, pesticide applications for 3 years after planting.
- Weeding for 5 years after planting.
- Pruning and debudding to be carried out 12 times during the rotation.
- No thinnings, clearfelling at year 15.

Harvest & Haulage Costs

These were calculated based on an extraction cost and an average distance to be travelled to the processing site for sawing.

Processing Costs

Three different processing options were modelled out: chainsaw cutting, small Woodmizer line, and an industrial large scale line. The mid scenario (Woodmizer line) was chosen as the most appropriate for the comparison. Costs, efficiencies, CAPEX required and other factors were calculated using Gatsby Africa's sawmilling model.

Transformation Scenario Modelling Assumptions

For the modelling of the various components of this analysis, the following assumptions made:

Current Sawn Timber demand for furniture and joinery sectors was derived by comparing various reports, including Africa Forest Forum (2016), EPZA (2005), World Bank (2016).

For the total 2050 demand, the following CAGR values were used:

Period	CAGR	Source
2007–2013	10%	World Bank (2016)
2016–2030	8%	Reduced value from World Bank (2016)
2030–2050	1%	Own estimate

All other assumptions are found in the Excel model attached (`M volkensii Economics v1.2`). Productivity and cost values are calculated using the Unit Economics model presented in the previous section.

Bibliography

CADEP-SFM, KFS (2018). Guidelines to Growing *Melia volkensii* in the Dryland Areas of Kenya. Nairobi.

Cheboiwo J., Commercial Forecast of Timber Industry in Kenya (2018)

Gyokusen K. (2021) Growth curve of *Melia volkensii* in Arid and Semi-arid Lands (ASALs) of Eastern Kenya

Kamondo, B. M., Kimondo, J. M., Mulatya, J. M., & Muturi, G. M. (2004). Recent Mukau (*Melia volkensii*, Gurke) Research and Development. In Proceedings of the First National Workshop, KEFRI Kitui Regional Research Center. November (Vol. 16).

Kamondo, B. M., Kariuki, J. G., Luvanda, A. M., Muturi, G. M., & Ochieng, D. (2018). Guideline on Production, Distribution and Use of Improved Melia Seed and Seedlings in the Drylands of Kenya. KEFRI, Kenya.

Kimondo, J., & Ouma, G. (2005). Performance of *Melia volkensii* at different spacing in Tiva, Kitui district. Recent Mukau (*Melia volkensii* Gurke) Research and Development, 16, 39.

Kimondo J., Management of melia plantation. KEFRI (2018)

Luvanda, A. M., Musyoki, J. K., Cheboiwo, J. K., Wekesa, L., & Ozawa, M. (2015). An assessment of the socio-economic importance of *Melia volkensii* based enterprises in Kenya.

Muchiri, D., & Mulatya, J. (2005). Survey of *Melia volkensii* plus trees in the Eastern and Coastal provinces of Kenya. Recent Mukau, 17–22.

Mulatya, J. M. (2005). A review of *Melia volkensii* tree-crop interactions in eastern Kenya. Recent Mukau (*Melia volkensii* Gurke) Research and Development, 16, 41.

Muok, B., Mwamburi, A., Kyalo, E., & Auka, S. (2010). Growing *Melia volkensii*: A guide for farmers and tree growers in the drylands. KEFRI Information Bulletin, (3), 20.

Muthike, G. M., & Githiomi, J. K. (2020). Value chain analysis of farm grown *Melia volkensii* (Gurke) timber in the South Eastern Dry lands of Kenya.

Muturi G.M., Improved *Melia volkensii*

Njigoya J., *Melia volkensii* enterprise/ cost- benefit analysis. Kenya Forest Service (2018)

Nowak, S. (2010). Inventory of problems in the cultivation of Jatropha curcas and *Melia volkensii* at Kiambere, Kenya. Hogeschool Gent Lid van De Associatie Universiteit GENT.

Odee, D. W., Runo, M. S., Gicheru, J., & Muluvi, G. M. (2005). Genetic structure of Kenyan populations of *Melia volkensii* inferred from random amplified polymorphic DNA (RAPD) analysis. Recent Mukau, 12–16.

Oduor, N. (2013). Evaluating Mukau wood: Looking at the properties of *Melia volkensii*, compared to mahogany, teak and mvule. Miti Magazine April-June 2013.

Stewart, M., & Blomley, T. (1994). Use of *Melia volkensii* in a semi-arid agroforestry system in Kenya. The Commonwealth Forestry Review, 128–131.

TAKANO K., Outline of Capacity Development Project for Sustainable Forest Management in Kenya (CADEP-SFM) (2018)

Tedd, J. (1997). Perception, management and usage of *Melia volkensii* by farmers: A case study from the Kibwezi district, Kenya (Doctoral dissertation, University of Nottingham).

Vandenabeele J., Kimondo, J. COMMERCIAL FORESTRY IN SEMI-ARID KENYA The case of *Melia volkensii* (2014)

Wekesa, L., Muturi, G., Mulatya, J., Esilaba, A., Keya, G., & Ihure, S. (2012). Economic viability of *Melia volkensii* (Gurkii) production on smallholdings in drylands of Kenya. Int. Res. J. Agric. Sci. Soil Sci, 2, 364–369.

1. In particular, Mulatya (2005) studies *Melia volkensii* interaction with Maize, and reports competition being mostly sunlight driven.