SCIENTIFIC EVIDENCE IN SUPPORT OF UNITED NATIONS EASTBOURNE MVULE PROJECT FOR CARBON CAPTURE

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A. SCIENTIFIC EVIDENCE FOR MVULE'S HIGHLY EFFICIENT CARBON SEQUESTRATION

In recent years considerable research has been conducted on the special oxalogenic properties of *Milicia excelsa* (known in East Africa as mvule and West Africa as iroko). The carbonate-oxalate pathway of this tree species has proved to be a newly identified and neglected carbon sink. Below are key research papers amongst the increasing number of scientific studies on the special role of Mvule as an efficient agent for long-term carbon storage.

Sources:

1. **Braissant, Olivier, et al. (2004).** ***Biologically induced mineralization in the tree Milicia excelsa (Moraceae): its causes and consequences to the environment.*** **Geobiology 2(1) DOI:** 10.1111/J.1472-4677.2004.00019.x University of Neuchâtel, Institutes of Geology and Botany. (Note: In recent years considerable research has been conducted on the special oxalogenic properties of *Milicia excelsa* known in East Africa as mvule and West Africa as iroko. The carbonate-oxalate pathway of this tree species has proved to be a newly identified and neglected carbon sink).

   "(The) abundance of carbonate minerals within *M. excelsa* testifies to the fact that the inorganic sink is of great significance to the terrestrial carbon cycle… the sustainability of a carbon pool is also an important point: time residence for organic matter and mineral carbon in soil are at least 10^1-10^3 years and 10^2-10^6 years, respectively. Biologically induced mineral carbon sinks are undoubtedly more efficient for carbon sequestration than soil organic matter".

   In terms of rate of carbon capture the following calculations are given for an 80 year old tree, bearing in mind that *M.excelsa* trees over 200 years old have been located. ".. calculations using soil and tree carbonate titrations suggest at least 1500 kg of $C_{mineral}$ is trapped during the life of a single *M.excelsa* tree (c.500kg inside the tree and c.1000kg in surrounding soils). This value is equivalent to a sequestration of 18.25 kgC yr^{-1}." (Note: lifespan here is taken as 80 years whereas *Milicia excelsa* can grow for over 250 years and continues to sequester carbon exceeding 3.5 tonnes $C_{mineral}$ for very mature trees).

(**<u>NB Update by Ian Elgie</u>**. Personal communication with Dr. G. Cailleau 3/10/2019. A re-evaluation of the data through C14 dating of age of trees has reduced $C_{mineral}$ rates of capture to 160kg for tree and 460kg for soil for 80 yr. old tree. The new total of 620kg $C_{mineral}$ would equate to a carbon capture rate of **2.273 tonnes CO^2 per tree over 80 yrs. from inorganic carbon alone**). Note: this could be a low figure as over 1 tonne of mineral carbon (= 3.664 tonnes CO2) has been found in the stump and soil around an Mvule tree of 80 years in age (see ref. 2 below).

2. **Guillaume Cailleau, Olivier Braissant & Eric P. Verrecchia. (2004).** ***Biomineralization in plants as a long-term carbon sink*** <u>Naturwissenschaften</u> 91: 191-194**. "**Carbon sequestration in the global carbon cycle is almost always attributed to organic carbon storage alone, while soil mineral carbon is generally neglected. However, due to the longer residence time of mineral carbon in soils (10^4–10^6 years), if stored in large quantities it represents a potentially more efficient sink…. The system is considered as a net carbon sink because carbonate accumulation involves only atmospheric CO_2 and Ca from Ca-carbonate-free sources. Around one ton of mineral carbon was found in and around an 80-year-old iroko stump, proving the existence of a mineral carbon sink related to the iroko ecosystem. Conservation of iroko trees and the many other biomineralizing plant species is crucial to the maintenance of this mineral carbon sink.
3. **Cailleau, G., Braissant O., & Verrecchia E.P. (2011). Turning sunlight into stone: the oxalate-carbonate pathway in a tropical tree ecosystem. <u>Biogeosciences</u> 8:1755-1767.** (Doi:10.5194/bg-8-1755 2011). The research suggests that the iroko ecosystem can act as a long-term carbon sink, as long as the calcium source is related to non-carbonate rocks. Consequently, this carbon sink, driven by the oxalate carbonate pathway around an iroko tree, constitutes a true carbon trapping ecosystem. Details also given of the role of termites, saprophytic fungi and bacteria in breaking down the decaying plant tissues further adding to the carbon sink.

4. **Cailleau, G., et al. (2014). Detection of active oxalate-carbonate pathway ecosystems in the Amazon Basin: Global implications of a natural potential C sink. <u>Catena</u>. Vol 116, May 2014, pp.132-141.** Comments on the oxalate-carbonate pathway (OCP) as being widespread in the plant world and, therefore a potential important source of C sink in Amazonia. However, indications are that carbonate accumulated under African *Milicia* ecosystems is 3 to 4 times greater than in Amazonian soils.

5. **Ferro, Katia Imeria. (2012).** ***The impact of oxalogenic plants on soil carbon dynamics – formation of a millennium carbon storage as calcium carbonate.*** Univ. of Neuchâtel. Dr. Sc Thesis.
   (<u>Note</u>: Dr. Ferro indicates in her study that earlier researchers/authors "have found that this oxalogenic tree-soil system runs like a pump, driving carbon from the atmosphere to the hydrosphere through the pedosphere and, therefore, inscribes it in the global carbon cycle."
   Her research provides details of the carbonate-oxalate pathway in *M.excelsa* and the following observations:
   p116. "Although the maximum lifetime of a *M. excelsa* tree is unknown, trees of about 250 years are frequently cited or studied in the Central African Republic".

"Normally, *M. excelsa* stumps remain in place after the tree is cut, as a result of deforestation and wood trade. Their biodegradation is difficult, due to the intrinsic properties of lignin and the high carbonate content of wood, which makes it practically impenetrable to normal chainsaws. Nevertheless, termites are able to grind M. *excelsa* stumps allowing the release of oxalate and carbonate into the soil environment."

p119. "Chemical changes in soils due to the oxalate - carbonate pathway indicate a pH increase and an accumulation of alkaline cations (Ca and Mg), which can improve soil fertility. Consequently, plantations of biomineralizing plants would not only enhance CO_2 retention and capture in soils but also increase agronomical productivity."

Section 1.7.4 p15.
"Regarding the rapid increase of the atmosphere and the potential problems due to the greenhouse effect caused by this gas, the challenge is now to slow down the CO_2 in the air. There are two different ways: reduction of emissions and looking for stocks. The M. excelsa system is a natural pump for atmospheric CO_2 allowing the formation of the oxalate- carbonate pathway with the result of a long-term carbon stock in soil in the form of carbonate".

6. **Pons, S. et al. (2018). *Biocontrolled soil nutrient distribution under the influence of an oxalogenic-oxalotrophic ecosystem*. Plant and Soil, Vol.452, Issue 1-2, pp.145-160.** (Note: refers to the usefulness of the *Milicia excelsa* in increasing the nutrient value of soils to benefit agroforestry and in this study *Coffea arabica*).

7. **J.A. Ugwu and A.A. Omoloye. (2015). *Perception on the Constraints to Propagation of Iroko (Milicia excelsa)* (WELW) C.C. BERG in South West Nigeria. Research Journal of Forestry, 9: 48-5** DOI: 10.3923/rjf.2015.48.57
Notes that "Despite the potential of *M. excelsa*, there is little or no propagation of this plant and the regeneration from the wild cannot commensurate (*sic*) the demand for *Milicia* timber in Africa. International Union for Conservation of Nature (IUCN) has placed *Milicia* in their red list as endangered species."

8. **Luc Durrieude de Madron. (2003). *Diametrique du bele de l'Iroko.* Bois et Forets des Tripiques no. 275 (1).** The article has several charts on the annual growth of *Milicia excelsa*.

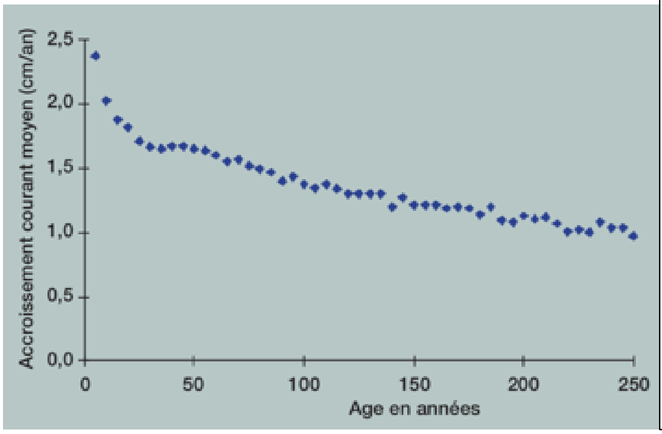


Figure 1.
Mean diameter growth cm/yr. of 46 Iroko (Mvule) trees by age in years.
Notes:

- Even with very old trees (>250yrs) substantial growth is maintained.
- Trees can reach 50m in height and 2.5m diameter.
- In the timber trade minimum exploitable diameter (MED) is 80cm for Iroko (reached on average in 130 years.

(**IDE note**: See survey below on Biomass Calculations by Onefeli, A.O.et al. (2012)). Also see **St. Mary's survey**, Bukedea, Uganda for growth rates at 80yrs).

9. **Aragno M., Verrecchia E. (2012).** ***The Oxalate-Carbonate Pathway: A Reliable Sink for Atmospheric CO_2 Through Calcium Carbonate Biomineralization in Ferralitic Tropical Soils*** In: Satyanarayana T., Johri B., Anil Prakash (eds) **Microorganisms in Environmental Management**. Springer, Dordrecht. Abstract: "Calcium carbonate has a residence time in soils in the order of $10^{4–6}$ years. Therefore, sequestration of atmospheric carbon as $CaCO_3$ is almost irreversible, as compared to organic carbon. Calcium oxalate, a metabolite often accumulated in plants, is chemically highly stable. However, it is readily oxidized by oxalotrophic bacteria, with simultaneous alkalinisation and biomineralization of calcium carbonate, which eventually accumulates in soil. In tropical countries, on mainly acidic, non-calcareous soils, this represents a significant sink for atmospheric CO_2: **at the present rate of increase, one full-grown Iroko tree may stabilize concentration of CO_2 in the air column above a 2,400 m^2 surface**. This process may be applied in reforestation and agroforestry, as well as in conservation and sustainable development of tropical forests and soils. (**Note**: In 2005 Dr. Cailleau *et al*. first observed large accumulations of limestone in African ferralitic soils under certain tree species, particularly the Iroko tree. In such soils, the pH under the tree was distinctly alkaline, reaching values between 8 and 9, whereas the soil at a distance was acidic with values <6).

10. **Onefeli, A.O. et al. (2012). Volume predictions for Milicia excelsa (Welw C.C. Berg) trees in selected institutions in Ibadan, Oya State, Nigeria**. J.Agric.Sci.Env.2012, (1):26-38. Useful data on growth rates on one of the most iconic trees in southern Nigeria, concluding that M. excelsa showed a very wide variation in their growth characteristics, as illustrated in Table 3 below.

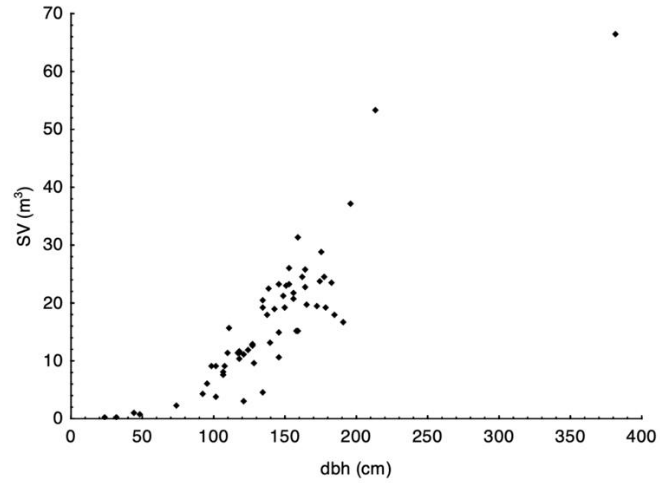
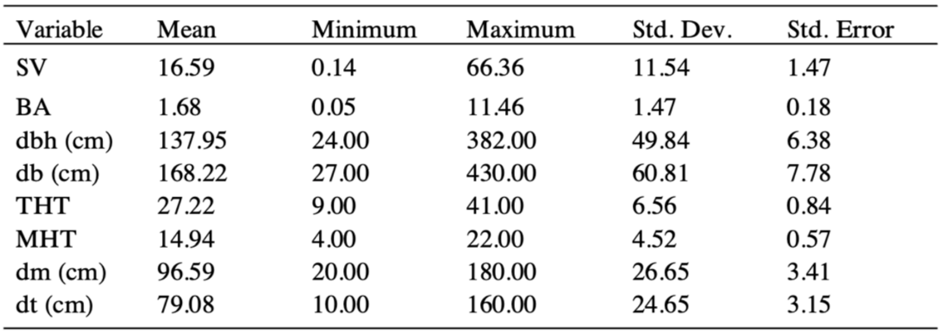


Figure 2: Scatter plot showing relationship between the stem volume (SV) and the diameter at breast height (*dbh*)

Table 3: Summary of Statistics of growth variables



Variable	Mean	Minimum	Maximum	Std. Dev.	Std. Error
SV	16.59	0.14	66.36	11.54	1.47
BA	1.68	0.05	11.46	1.47	0.18
dbh (cm)	137.95	24.00	382.00	49.84	6.38
db (cm)	168.22	27.00	430.00	60.81	7.78
THT	27.22	9.00	41.00	6.56	0.84
MHT	14.94	4.00	22.00	4.52	0.57
dm (cm)	96.59	20.00	180.00	26.65	3.41
dt (cm)	79.08	10.00	160.00	24.65	3.15

11. **Gatz-Miller, Hannah S., et.al. (2022). Reactive transport modelling the oxalate-carbonate pathway of the Iroko tree. Investigation of calcium and carbon sinks and sources**. Geodema. Vol.410, 15 March 2022, 115665. https://doi.org/10.1016/j.geodema.2021.115665.

12. For general comprehensive notes on *Milicia excelsa* visit website: https://uses.plantnet-project.org/en/Milicia_excelsa_(PROTA)

B. SCIENTIFIC EVIDENCE ON BENEFITS OF COMPANION PLANTNG with *M. excelsa*

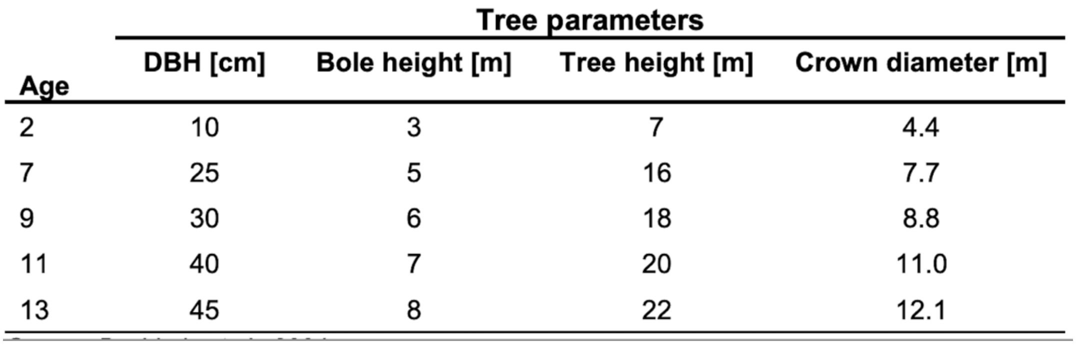
The papers below indicate the physiology, biomass and carbon capture potential of the two key companion species identified for planting with Mvule. Scientific studies on the status of Terminalia superba as an oxalogenic tree is still awaiting although other Terminalia in the genus have been identified as oxalogenic e.g., *T.bellirica* and *T.oblonga*.

Companion Species 1: *Maesopsis eminii* (Musizi)

General: Indigenous tropical tree, fast growing light-demanding pioneer species, semi-deciduous (deciduous under severe drought), density 370-480 kg/m^{-3}; dbh @ maturity 50-180cm; height @ maturity 40m, branch ageing (self-pruning) 10-35m, unbuttressed, lateral & deep tap root, shade intolerant from one year.

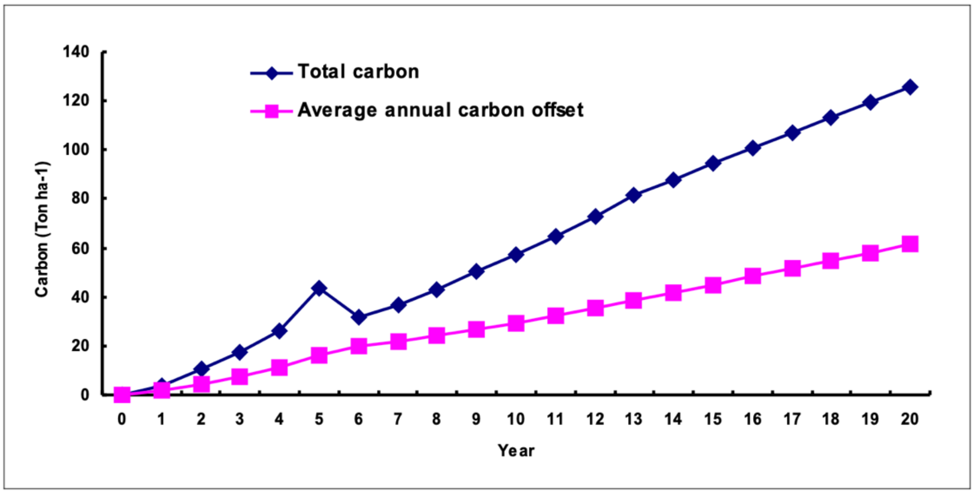
1. **Buchholz T. et al. (2004). *Maesopsis eminii* - a challenging timber tree species in Uganda - a production model for commercial forestry and smallholders. Paper presented at a IUFRO conference, Lugo, Spain.15p.** This technical specification explores the carbon sequestration potential of Maesopsis and benefits to farmers. In woodlots described rotations are 12-20 years for timber, with high quality fuel wood harvesting in early years. Some farmers are using Maesopsis for provision of shade under coffee and banana land use systems. It has long been established that shade coffee yields better and is of superior quality than the conventional un-shaded coffee. Other products and services from Maesopsis woodlots include fodder (fruits), support to honey production, and restoration of positive environmental and ecological functioning in heavily degraded areas. Such functions include: runoff and soil erosion control, micro- climatic modifications, and increased terrestrial biodiversity (e.g. birds).

Table 1: Maesopsis growth in its optimum range.



Age	Tree parameters			
	DBH [cm]	Bole height [m]	Tree height [m]	Crown diameter [m]
2	10	3	7	4.4
7	25	5	16	7.7
9	30	6	18	8.8
11	40	7	20	11.0
13	45	8	22	12.1

Figure 2 carbon accumulation under sole M.eminii woodlots.



The above graph is for a plot of 50 Maesopsis eminii trees after thinning. The graph indicates at 20yrs 125 tonnes carbon sequestered by 50 trees after thinning. (**IDE note**: This equates roughly to 2.5 t/C/per tree = 9.2t/C02/per tree at 20 yrs.

2. **Buchholz T. et al. (2010). Modelling heliotropic tree growth in hardwood tree species – A case study of Maesopsis eminii**. <u>**Forest Ecology.**</u> **V260, 10, pp 1656-1663.** Emphasises the genetic feature of strong apical dominance which results in fast straight bole development relative to branches. Useful growth data for 285 sampled trees of known ages 1.5yrs to 38 yrs by dbh and height.

M.eminii Growth Rates (adapted from Table 1, p.1658).

No of trees in survey	Age (yrs)	Mean dbh cm	Annual Growth cm	Mean height m	Annual growth m
24	1.5	8.4	5.6	5.5	3.7
47	4	20.5	5.1	13.1	3.3
29	5	21.4	4.28	12.3	2.5
32	6	13.1	2.18	11.5	1.9
26	7	26.3	3.8	17.1	2.4
30	8	29.6	3.7	17.9	2.2
8	9	38.4	4.3	18.9	2.1
31	37	40.6	1.1	30.1	0.8
29	38	49.3	1.3	33.9	0.9
256					

DOI: 10.1016/j.foreco.2010.08.001

3. **Epila, J. (2016). Ecophysiological assessment of drought vulnerability of the African tropical tree species *Maesopsis eminii* Engl.. PhD Thesis, Ghent University, Belgium. ISBN-number: 978-90-5989-958-2.** The study investigated the drought coping strategies and mechanisms of the African pioneer semi-deciduous tree species *Maesopsis eminii*. The species was chosen because of its economic and ecological importance in tropical Africa. It is used as timber, for crop shade, to limit erosion, as medicine, as medium for mushroom culture, as source of edible oil, as a road-side ornament and as firewood and fodder and in general for enrichment planting. Deciduous, light demanding species are considered to be able to better cope with forecasts of increasing drought stress in tropical Africa with climate change.

4. **Epila, Jackie, et al. (2017). The ecology of Maesopsis eminii Engl. in tropical Africa African Journal of Ecology DOI: 10.1111/aje.12408**. Comments on the functional traits allowing M. eminii to grow under a wide range of site conditions, having both deep taproots and an intricate mat of lateral roots that permeate the subsoil, allowing the species to explore resources (nutrients and water) from both shallow and deep soil layers supporting its fast-growing and competitive habit.

5. **Telli-Nelson, et al. (2008). Tree growth and management in Ugandan agroforestry systems: effects of root pruning on tree growth and crop yield.** Tree Physiology, v.28, Issue 2, Feb.2008. Pp 233-242. https://doi.org/10.1093/treephys/28.2.233 (IDE comment: useful data on root pruning of *M. eminii* to assist under-canopy crops, with little effect on overall growth of tree).
6. **Okorio, J., et al. Comparative performance of seventeen upperstorey tree species associated with crops in the highlands of Uganda.** Agroforest Syst 26, 185–203 (1994). https://doi.org/10.1007/BF00711210 (**IDE comment**: Trials were established at three sites in Uganda to test the suitability of multipurpose trees (MPTs) as upperstorey in crop lands to provide poles, small timber, and fuelwood. *M.eminii* (with average growth rates of 1.8-2.7m annually) showed an average of 60% decline in understory crop yields without root pruning. But with root pruning crop yields increased by up to 52%.

Companion Species 2: *Terminalia superba* (Limba).

1. **Maitre, Henri-Felix and Don Wijewardana. (2004).** ***Conservation and Provenance Plantings and Integrated Pest Management to Sustain Iroko Production in West Africa*** **(Ghana). ITTO PROJECT PD 3/95 Rev.2 (F).** (Note: useful information on difficulties in establishing *Milicia* plantations due to control of *Phytolyma lata*, cf. community plantings. Sapling spacing of 4m x 4m with mix of *Terminalia superba* has been found to give good results.

2. **Bosu, Paul P. et al. (2006)**. ***Survival and growth of mixed plantations of Milicia excelsa and Terminalia superba 9 years after planting in Ghana***. Forest Ecology and Management 233 (2-3): 352-357. DOI: 10.1016/j.foreco.2006.05.032. "Iroko (*Milicia excelsa* and *M. regia*) is a valuable hardwood from the humid tropics of Africa and, is currently under threat of extinction because of over-exploitation and poor regeneration. Attempts to establish Milicia plantations in Africa have been hampered by gall-forming psyllids of the genus Phytolyma. This study investigated the impact of Phytolyma on Milicia planted in 11:89, 25:75, 50:50, and 100:0%

mixtures (by stem numbers) of *M. excelsa* (high-risk species) and *Terminalia superba* (companion species). At the forest site, *M. excelsa* survival was 10% in the short season plantation and 30% in the long season plantation. Mean diameter and mean height were significantly higher in the long season plantation than in the short season plantation 2.4 cm versus 0.43 cm diameter respectively, and 295 cm versus 74 cm in height. However, neither survival nor growth was influenced by density of Milicia in a plot. Survival of Milicia was even lower (6.3%) at the agricultural site (short season only). Survival and growth of *T. superba* were relatively higher than that of *M. excelsa*. The mean overall diameter growth of *T. superba* was significantly higher at the agricultural site than at the forest site. Shade from *T. superba* appeared to reduce psyllid galls on *M. excelsa*, though crop tree growth was slow, with the best mean height attained being 400 cm at 8–9 years in 50:50 mixtures. Continuing experiments will involve thinning and-or pruning *T. superba* so that low levels of galls and reasonably rapid growth of *M. excelsa* will be achieved. (Note: 4m x 4m spacing proved successful in other studies).

(**IDE Comment**:

a. On companion planting. Given the scientific evidence, together with the local favourable conditions in eastern Uganda, the UNA Eastbourne, has within the Mvule Project for Carbon Capture, the goal of planting equal number of seedlings of the species *Terminalia superba* and *Maesopsis eminii*. Both these fast-growing trees grow well with *M. excelsa* and are popular with communities to meet short-term and medium-term fuelwood and timber needs.

b. On *Phytolyma lata* (gall) infestations. **Ian Elgie's (IDE)** field observations in Sironko district Uganda November 2019, support the view that although not a cause of significant mortality, infection can reduce main stem height. Evidence (also supported by the NFA Mbale) suggests that infected seedlings will suffer slower growth rates and changes in stem morphology but can recover within a few years (sample: 4 adjacent Mvule which after 7 years the only gall infected Mvule was 47% shorter than fastest growing Mvule). It can be further noted that historically *Phytolyma lata* has been identified as a continuing problem for *M.excelsa* commercial plantings throughout tropical Africa. IDE suggests that the large merchantable stem from natural forests which are not so typical in deforested areas, where shorter stem size to bifurcation point, is due to the relative absence of gall fly in these closed canopy forests.

3. **De Ridder, Maaike et al. (2010). The potential of plantations of *Terminalia superba* Engl.** & **Diels for wood and biomass production (Mayombe Forest, Democratic Republic of Congo.** Ann.For.Sc.67, 501. DOI: 10.1051/forest/2010003. Main survey was of limba (*T.superba*) trees 50-58yrs old. Buttress height N=2365 trees (72% of buttresses higher than dbh. Mean DAB (Diameter Above Buttress 202.5cm.) Buttress height increases with age of tree. 23yr old limba reached DAB of c37cm (indicating fast early growth). Bole height (N= 265 trees) mean 25.2m. Total tree height (N=128 trees) mean 31.5m Note: mean ratio Bole Height: Total Tree Height = 0.78: 1.0 indicating some 80% of trunk has commercial value. Mean AGB 4.1-4.4 tonnes/tree. After Groulez & Wood (1984) 14-18yr had bole heights of 17-21m (growth rate of 0.8 to 1.2m/y^{-1}). High natural self-pruning capacity giving high % of valuable stem timber. Small branches & leaves c.3% of total AGB. Note: limba has

small crown as percentage of AGB cf. other species, i.e., about 20% in young trees declining to 9-11% in older limba.

4. **De Ridder, M. et al. In the heart of the limba tree (Terminalia superba Engl. & Diels): detection methods for heart rot and false heartwood**. (nd). Older trees may suffer from hollowing and brittle heart (limba noir). (**IDE Comment:** The UNA Eastbourne Mvule Project plants T. superba as a medium rotation tree 16-20 yrs. for timber well before heart rot will occur).

C. SCIENTIFIC REFERENCES ON BIOMASS CALCULATIONS & CARBON CONTENT

1. **Charve, J. et al. (2005).** ***Tree allometry and improved estimation of carbon stocks and balance in tropical forests.*** **Oecologia 2005, Vol.145, Issue 1, pp87-99.** Detailed consideration of interspecific variation and the adaptive significance of wood C content of AGB. Suggested that for tropical hardwoods in natural forests, a mean biomass-C conversion factor of 47.4% is currently the most reliable, analytically supported value for wood C content (revising the IPCC conversion factor of 49%). Mentions the lack of detailed studies on below ground biomass (BGB) and carbon, which is generally estimated to be 24-37% of AGB.
2. **Charve, J. et al. (2014).** ***Improved allometric models to estimate above ground biomass in tropical trees.*** **Global Change Biology (2014) doi: 10.1111/gcb.12629.** Paper analysed a global database of harvested trees at 58 sites, spanning a wide range of climatic conditions and vegetation types. When studies using trunk diameter, total tree height and wood specific gravity were included in the AGB (above ground biomass) model as covariates, a single model was found to hold across tropical vegetation types. Wood specific gravity was an important predictor of AGB. Several allometric models discussed, with model 4 as the most appropriate if tree height, DBH and wood density available. Mentions that in many allometric models tree height has been absent as in closed canopy forests it is difficult to measure accurately.

3. **Henry, M., et al. (2011).** ***Estimating tree biomass of sub-Saharan African forests: a review of available allometric equations*****. Silva Fennica 45(3B): 477–569.** This study contains a comprehensive database of allometric equations for SSA. The various equations found in the database reflect the variability in volume and biomass of different ecological zones, tree species, ages, management types and sites found in SSA. This work highlights important gaps in researchers' ability to use equations for estimating biomass and C stocks in the various ecological zones and countries found in SSA. The use of species-specific biomass equations, rather than volume and generalised equations, are encouraged. The equations reported different tree compartments, including the stem wood and bark, stump, thin and gross branches, leaves and roots. Because it is difficult to measure the volume of the leaves or thin branches, the volume equations did not consider all of the tree compartments but focused on the bole and the merchantable compartments. Merchantable volume excluded non- merchantable aboveground compartments such as treetops, branches, twigs, foliage, stumps (sometimes excluded) and roots. On the other hand, biomass equations often considered more compartments that have fodder (leaves) or firewood (twigs) purposes.

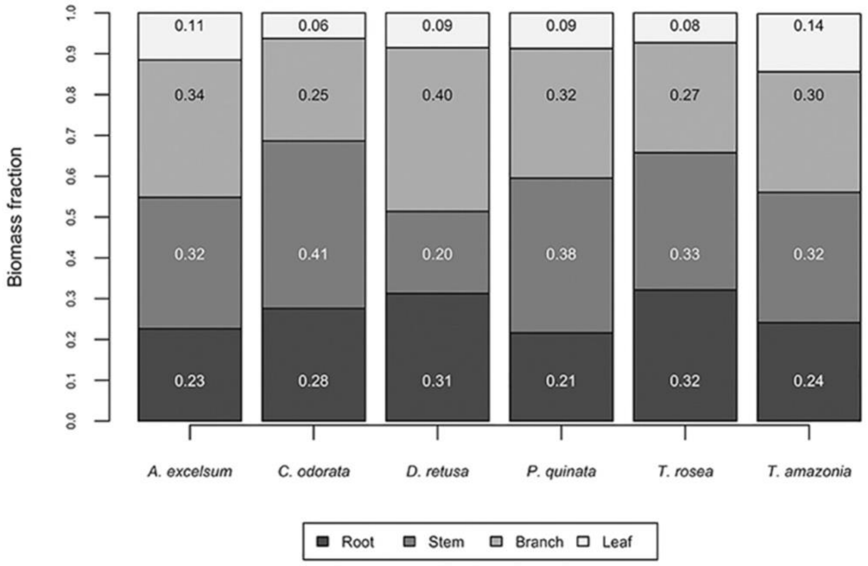
4. **Onefeli, A.O. et al. (2012). Volume Prediction for Milicia excelsa trees in Selected Institutions in Ibadan, Oyo State, Nigeria. __Agric.Sci. Env__. 2012, 12(1):26-28.** The study identifies majority of M. excelsa trees (61 sampled) in city of Ibadan are on institutional grounds as they have been protected from felling. The study showed that stem volume of M. excelsa can be predicted from db and dbh by using the equation given with reasonable precision. Of the 61 trees 26.2% were distributed in the 105.1 to 130cm class, 24.6% in the 130.1 to 155cm class with few in the extreme diameter class. The majority of the trees (73%) were in the diameter range 105.1 to 180cm. 3.3% were in diameter class 205.1 and above, with one specimen having a dbh of 382cm and db of 430cm and 41m THT and MHT of 21m. Below extract from Table 3 Summary of Statistics of growth variables p30.

__Variable__	**__Mean__**	**__Minimum__**	**__Maximum (61 Iroko trees)/ Milicia excelsa__**
SV (m^3)	16.59	0.14	66.36 (Stem Volume)
dA (m^2)	1.68	0.05	11.46 (Basal Area)
dbh (cm)	137.95	24.00	**382.00 (**Diameter breast height 1.3m)
THT (m)	27.22	9.00	41.00 Total Tree Height
MHT (m)	14.94	4.00	22.00 Merchantable Tree Height (ie.to bifurcation)
dm (cm)	96.59	20.00	180.00 Diameter middle (mid-stem)
dt (cm)	79.08	10.00	160.00 Diameter top (top of main stem)

(**__IDE comment__**. One mvule specimen in Ibadan was recorded with a dbh of 3.82m which is exceptional and indicates a longevity of hundreds of years).

5. **Sinacore, K. et al. (2017) Unearthing the hidden world of roots: Root biomass and architecture differ among species within the same guild. __PloS one__** vol. 12,10 e0185934. 12 Oct. 2017, doi:10.1371/journal.pone.0185934. Species differences in foliar biomass ranged from 6-14% of total tree biomass; branch biomass allocation ranged from 27-40%; stem biomass ranged from 20-41%. An average of 26.7% of total biomass was allocated to roots (excluding fine roots). Ref. is made to other studies (e.g., Vogt et al – see below) which suggest fine roots can account for a significant amount of total biomass: 8%, 1-2% and 7-14% of total biomass for broadleaf deciduous, broadleaf semi-deciduous and broadleaf evergreen tropical trees. See Fig 4 below for biomass fraction with tree components.

Fig.4: Biomass fraction with tree component.



IDE Note: The six tropical species studied from Panama include are mostly pioneering species and deciduous and evergreen trees of medium to high wood density. As large fast-growing trees A.excelsum & T.amazonia would probably be closest to M.excelsa,T.superba and Maesopsis eminii of the 6 species identified.

6. **Waring BG, Powers JS. (2017). Overlooking what is underground: root:shoot ratios and coarse root allometric equations for tropical forests. Forest Ecology and Management** 385**: 10-15. DOI: 10.1016/j.foreco.2015.11.007**. Details the efforts to determine the ratio between BGB of coarse roots to the AGB of leaves, branches and stems (shoots). Considerable range in R:S ratios with average of 0.53, concluding that BGB of coarse root stocks in tropical forests can exceed AGB, with older trees generally having higher R:S ratios.

   Note: Research by R.B.Jackson et.al. (1996) "A global analysis of root distributions for terrestrial biomes" which concluded that tropical evergreen forests have the highest BGB stocks in comparison to other biomes. https://doi:org/10.1007/BF00333714

7. **Vogt, Kristiina A. et al (1996). Review of root dynamics in forest ecosystems by climate, climatic forest types and species**. **Plant and Soil 187: 159-219**. Comments on fine roots (dia <2mm) which generally contribute <2% of total biomass (TB). However, in broadleaf tropical forests fine roots varied from 1-8% of TB and roots from 7-34% of TB. (Table 1).

D. ABOVE GROUND BIOMASS & STEM ROT

Numerous scientific papers all point to the overestimation of Above Ground Biomass (AGB) (>9%) and therefore efficiency of carbon capture of a wide variety of tree species in a variety of biomes. Stem rot or hollowing is caused by fungal, termite attack and fire. Rotting trees are returning CO2 back to the atmosphere. Some species of trees can be more susceptible. Surveys show % of trees affected by hollowing is considerable e.g. 65% (Marra 2019); 66-89% (Royal Society 2014); 54% (Heinnemann 2015). Hollowing generally increases with age of tree – as measured by the dbh. (See Fig 5. below from Nogueira 2006), Important to emphasise the *Milicia excelsa* even with dbh > 200cm rarely shows hollowing due to its high resistance to fungal decay and termite attack. Companion species *T.superba* and *M.eminii* planted under the Mvule Project for Carbon Capture also are relatively free of hollowing).

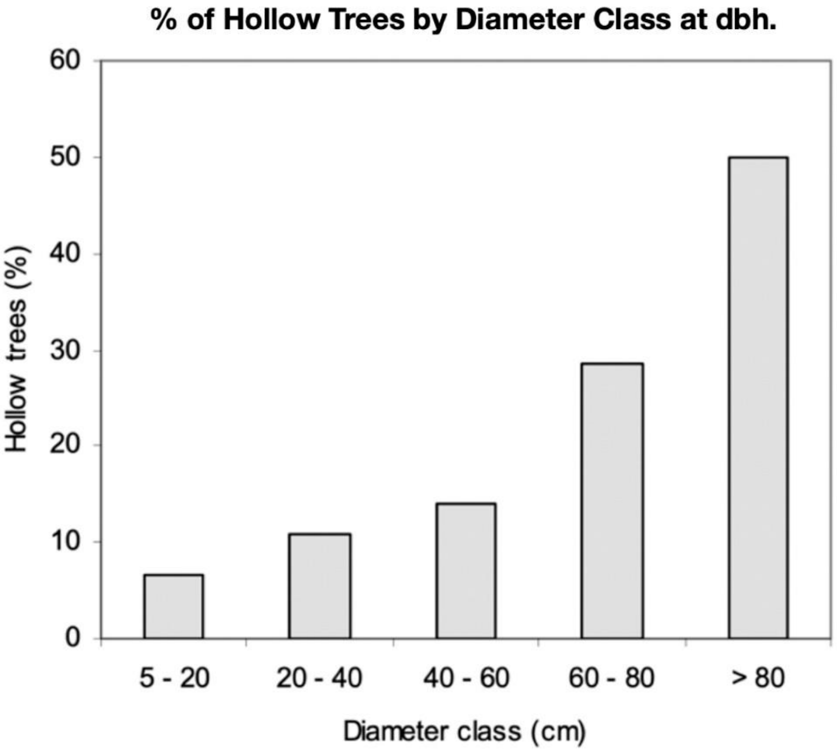
1. **Marra, Robert E. et al. (2019) Tomography: An Innovative Technique for Assessing Forest Carbon Storage.** Earth & Environment, Engineering & Tech. Tree damage caused by wood-decaying fungi means that forests store less carbon than previously thought. As forests play a vital role in sequestering atmospheric carbon, knowing the extent of hollowing has important implications in the fight against climate change. Using the pioneering non-invasive sonic tomography, a survey of common hardwood trees in USA showed 65% of trees had hollowing with as much as 36.7% of the stem hollow.

2. **Royal Society (2014). Why are so many trees hollow?** Royal Society Biology Letters. 1 Nov 2014. https://doi.org/10.1098/rsbl.0555. The paper discusses two hypotheses to explain the widespread extent of hollowing. Surveys of savannah woodland in Australia have found hollow cores (a phenomenon called *piping*) in 66–89% of trees of different species; on average, hollow cores extended to 50% of the total diameter. A study in the Amazonian rainforest found 37% of trees from a broad range of species to be piped. The paper also mentioned that trees with large lateral branches need a solid stem to compensate for the stress on the trunk and would therefore not be expected to have hollow stems. (IDE comment: This is the situation with *M. excelsa* – a tree with large heavy branches which has no hollowing, although the common oak with relatively large lateral branches does suffer hollowing with ageing).

3. **Heinemann, K.D. et al. (2015). Evaluation of stem rot in 339 Bornean tree species: implications of size, taxonomy, and soil-related variation for aboveground biomass estimates.** Biogeosciences, 8 Oct. 2015, 12, 5735–5751, 2015 https://doi.org/10.5194/bg-12-5735-2015 Survey of stem rot of sample of 3180 trees of 339 species in Borneo showed that on average AGB was reduced by 7% on account of stem rot. % of stem rot increased with DBH but not necessarily severity. 13% of sample had stem rot at 10-30cm DBH and 54% at >50cm DBH.

4. **Brigitte, Aya et al. (2014). The dynamics of hollowing in annually burnt savanna trees and its effect on adult tree mortality**. Plant Ecology. Jan. 2014 v.215, Issue 1, pp.27-37. **Findings:** For species resistant to hollowing, tree mortality was rare; alternatively, for species prone to hollowing, whole trees died quickly and before the most severe hollow classes could be observed.

5. **Nogueira, Euler Melo et al. (2006). Volume and biomass of trees in central Amazonia: influence of irregularly shaped and hollow trunks**. Forest Ecology & Management. v. 227, issues 1-2, 15 May 2006 pp. 14-21. https://doi:10:1016/j.foreco.2006.02.004 Findings: From survey of large number of trees in Amazonia sampled in each class based on the diameter distribution of a large inventory. For large trees (DBH ≥50 cm) total basal area was overestimated by 30%. (IDE comment: *M.excelsa* has a straight bole with little or no buttressing- so basal overestimation would be at a minimum for this species of tree. Note too, the table below (Fig.5) which shows how most species as the get older (greater dbh), have substantially increased % of hollowing.



Source: Fig.5 Nogueira, Euler Melo, et al (2006)

E. SCIENTIFIC PAPERS ON THE IMPORTANCE OF TROPICAL TREE PLANTING

1. **Bastin, Jean-Francois et al. (2019). *The global tree restoration potential*. Science July 2019,365 (6448): 76-79. DOI:10.1126/science.aax0848.** Photosynthetic carbon capture by trees is likely to be among the most effective strategies to limit the rise of CO_2 concentrations across the globe. Consequently, a number of international initiatives [such as the Bonn Challenge, the related AFR100, and the New York Declaration on Forests (*4*, *5*)] have established ambitious targets to promote forest conservation, afforestation, and restoration at a global scale. The latest special report by the Intergovernmental Panel on Climate Change (IPCC) suggests that an increase of 1 billion ha of forest will be necessary to limit global warming to 1.5°C by 2050. The study estimates that if we cannot deviate from the current trajectory, the global potential canopy cover may shrink by ~223 million hectares by 2050, with the vast majority of losses occurring in the tropics.
2. **IPCC (2019) Climate Change and Land.** (Draft proposal). Detailed analysis with confidence levels indicated for all performances. E.g. Section A4.5 p12. "Where forest cover increases in tropical regions cooling results from enhanced evapotranspiration (*high confidence*). Increased evapotranspiration can result in cooler days during the growing season (*high confidence*) and can reduce the amplitude of heat related events (*medium confidence*). In regions with seasonal snow cover, such as boreal and some temperate, increased tree and shrub cover also has a wintertime warming influence due to reduced surface albedo[28] (*high confidence*)."
3. **Brienen, R.J.W. et al. (2020). Forest carbon sink neutralized by pervasive growth-lifespan trade-offs.** Nature Communications 11, 4241 (2020), https://doi.org/10.1038/s41467-020-17966-z.
   Paper provides firm evidence for the existence of a universal trade-off between early growth and tree lifespan in trees with the potential to reduce,

or even reverse the global carbon sink of forests in the future. Faster growth has a direct and negative effect on tree lifespan. Growth increases across high latitude and tropical forests are expected to reduce tree lifespans and may explain observed increases in tree mortality in these biomes. Shorter lifespans will mean the benefits of these faster-growing forests might also be short-lived as forests die off sooner and end up storing less carbon. Moreover, when trees die, they slowly begin to release their carbon stores in the form of methane, a potent long-lived greenhouse gas. (**IDE comment**: This observation is less critical for the two companion species planted under the Mvule Project for Carbon Capture (*T.superba* and *M.eminii*), as they are generally harvested well before maturity whilst the Mvule (*M.excelsa*) is resilient to early mortality on account of its special features i.e. high resistance to fungal and termite attack, and on eventual destruction has a significant content of inorganic carbon which remains locked in for millennia).

4. **Bellassen, V & Luyssaert, S. (2014). Carbon sequestration: Managing forests in uncertain times**. Nature 506 (7487): 153-5. 10.1038/506153a. Comments on the uncertainty of climate models in predicting the changing CO2 sequestration rates with climate change, so necessitating several potential strategies to secure the forest carbon sink. One such strategy is conditional harvesting of timber ensuring a long-life for the wood products. (IDE comment: the harvesting of companion species with the Mvule Project (*T.superba* and *M.eminii* fulfils this role).

5. **Waring, B., et al. (2020). What role can forests play in tackling climate change?** Grantham Institute Discussion Paper #6. https://doi.org/10.25561/80271. A qualified appraisal of the benefits of planting trees, indicating too the benefits of tree planting in tropical biomes for maximum growth.

F. CLIMATE RELATED SCIENTIFIC EVIDENCE RELEVANT TO UGANDA

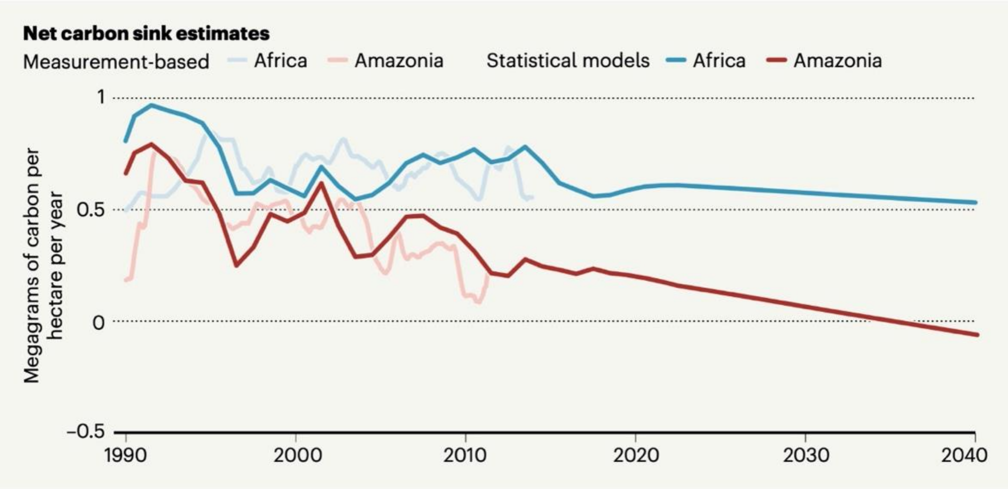
1. **World Bank Group, Climate Change Knowledge Portal (2020).** Climate Risk County Profile: Uganda. Pp. 30. Detailed information from CCKP on climate predictions for Representative Concentration Pathways: RCP2.6; 4.5; 6.0 & 8.5. "The country's weather and seasons being determined by the large-scale Indian Monsoon, Congo air mass, Indian Ocean Dipole (IOD) and the Inter Tropical Convergence Zone (ITCZ) systems. Uganda also experiences the El Nino Southern Oscillation (ENSO) phenomena, which are principal driving forces of intra-annual to inter annual rainfall variability. Specifically, the most pronounced impacts for Uganda are during the rainy season, September to December, where the El Nino is often equated to floods rather than La Nina that is often equated to droughts "(p3). (**IDE:** Data shows current Mean max ann. temp. 28.7^{O}C; mean min.ann.temp.16.2^{O}C; mean ann. precipitation 1,200mm. Predictions under RCP 8.5 (High emissions) using the CMIP5 ensemble of 32 Global Circulation Models (GCMs) as follows:

   a. Median temp. anomaly: 2020-39 = +1.0^{O}C/ 2040-59 = +1.8^{O}C/2060-79 = +2.8^{O}C/2080-2099 = +3.7^{O}C (range: +2.6^{O}C to + 5.2^{O}C with 10th- 90th percentile).

   b. Median precipitation anomaly: 2020-39 = +1.4mm/ 2040-59 = +2.9mm/ 2060-79 = +7.37mm/ 2080-99 = +13.6 (range: -26.0 to +63.1 with 10th to 90th percentile). (**IDE comment**: Compared with the two major rainforest ecosystems, i.e. the Amazon and Congo basins, Uganda has the advantage of being on a plateau with a 6-7^{O}C cooler temperature regime for its equatorial location (on account of the troposphere Environmental Lapse Rate (ERL) of 6.5^{O}C/km). Manaus in central Amazonia can expect a median monthly increase of 4-6^{O}C from current temperatures of 30.9 to 33.4^{O}C.

2. **Teskey, Robert et al. (2015). Responses of tree species to heat waves and extreme heat events.** Plant, Cell and Environment 2015, v38, 1699-1712. doi.10.1111/pce.12417. Trees are well adapted to survive transient extreme heat events, although these events reduce carbon gain and growth. Heat stress and drought stress are often linked, and each tends to amplify the stress caused by the other. Mortality from drought is far more likely than mortality from heat stress, but the severity of drought stress, and the speed of its onset, is greatly increased under high temperatures. Similarly, drought can exacerbate the effect of heat stress. (IDE Comment: IPCC 5th Assessment (2015) indicated median prediction of increased precipitation).

3. **Hubau, W. et al (2020). Asynchronous carbon sink saturation in African and Amazonian tropical forests.** Nature Vol.5795, March 2020. https://doi.org/10.1028/S41586-020-20350. Recent scientific studies have indicated that of the two major global tropical rainforest regions, Amazonia and Africa, it is the latter which is showing the greater resilience given the environmental stresses of global warming.



Source: Hubau,W. et al (2020). IDE Comment: The above graph showing estimates and projections of tropical carbon sinks for Amazonia and Africa indicate the higher estimates for Africa. The historic benefits of CO2 fertilization, leading to increasing carbon sequestration in tropical forests, is falling as a consequence of higher temperatures and droughts. African rainforests with generally higher elevations have an advantage (particularly true of Uganda at 1000m asl). Note also: "CO2 fertilized trees grow faster and die younger and therefore might not necessarily contribute to the carbon sink in the long term". (see Ramming A. Nature 579, 38-39. doi:10.1038/d41586-020-00423-8).

4. Martin J.P., Lewis, Simon L., Affum-Baffoe, Kofi et al. (2020)**. Long-term thermal sensitivity of Earth's tropical forests**. Science v.368, 6493, pp.869-874 DOI:10.1126/science.aaw7578. The research indicates that forest thermal sensitivity is dominated by high daytime temperatures which depresses growth rates and shortens the time that carbon resides in the ecosystem by killing trees under hot dry conditions. The effect of temperature is worse above 32^{o}C. However, under moderate climate change forest carbon stocks are likely to remain higher. Precipitation is also important, as increased moisture in the 'dry' season for Moist Rain Forests (MRF), can reduce thermal stress on the canopy. (**IDE comment:** Uganda's altitude keeps max. daytime temperatures well below the critical 32^{o}C

protecting forests from high temperature stress for the longer term than Amazonian and Central African rainforests).

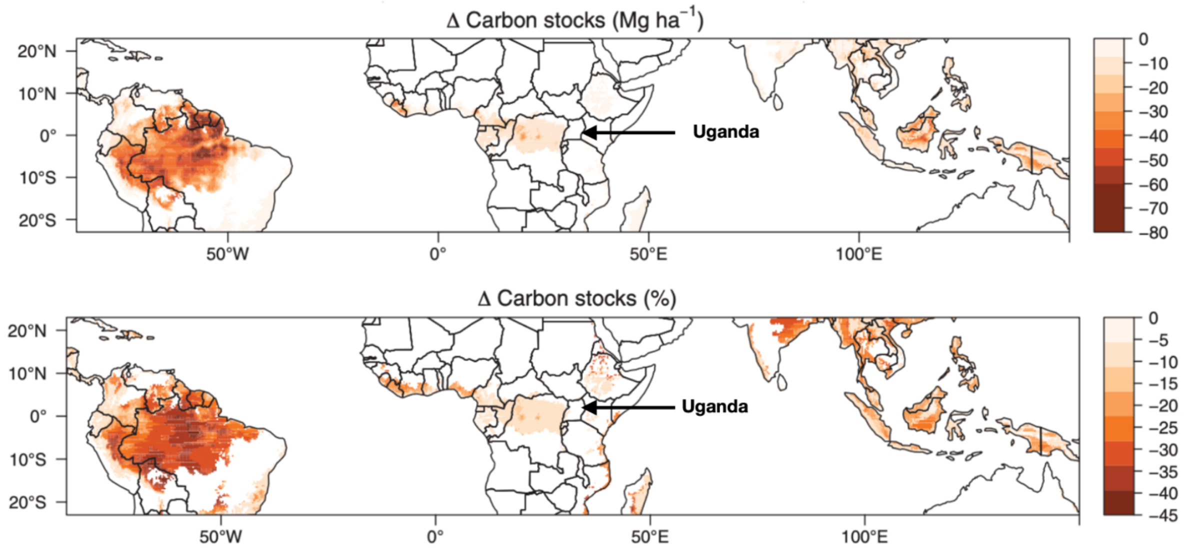


Fig. 4. Long-term change in carbon stocks due to temperature effects alone for global surface air temperature warming of 2^{0}C. Maps show the predicted absolute and relative change in tropical forest carbon stocks. Note: precipitation changes are not included as future patterns are uncertain.

IDE note: The superimposed arrows point to Uganda, where it is predicted that a rise of 2^{0}C, will have little affect on C-stocks. This may be accounted for by the positive advantage of altitude (over 1,000m asl) which gives a significant temperature amelioration.

5. **Lake Victoria Basin Commission**. (nd) **Lake Victoria Basin Climate Change Adaptation Strategies & Action Plan 2018-2023.** Pp58**.** The report distinguishes between the long rains from late March to June (MAMJ) and the short rains from early Oct to Dec (OND)**. El Niño** result in above normal rains, whilst **El Niña** in below normal rains. These two oscillations (ENSO) have occurred approx. every five years since 1970 but can vary from 2- 7 yrs. Trend analysis shows a long-term decline in precipitation for the long rains (MAMJ) with drier periods getting longer and more pronounced. Trends also indicate total rainfall in the short rains (OND) has increased and modelling suggests this trend is likely to continue.

6. **Royal Botanic Garden Kew. (2017) State of the World's Plants 2017**. Chap 7 'Climate Change: Which Plants will be the Winners?"(pp 42-49). Plant traits are identified which may help with adaptation to temperature and precipitation stress. These include: more sclerophyllous leaves (i.e. lower SLA); higher wood density; more-efficient water-use strategies and deeper roots. (**IDE comment**: the Mvule tree has at least two of these key plant traits - relatively high wood density and sclerophyllous leaves). For the report see: https://stateoftheworldsplants.com/2017/climate-change.html.

7. **Shongwe, Mxolisi E, et al. (2011) Projected Changes in Mean and Extreme Precipitation in Africa under Global Warming. Part II: East Africa.** J. of Climate, v.28, pp3718-3733. https://doi.org/10.1175/2010JCL12883.1 Draws on 12 GCMs concluding that in spite of an uncertainty in the rate of change, almost all results indicate a wetter climate with more intense wet season and less severe droughts.

8. Uganda's Climatic Advantage for tree planting in a warming climate: The charts below provide additional climate data for a better understanding of why Uganda's location, compared with the Amazon & Congo Forest basins,

can provide an advantage in the medium term to tropical moist forests carbon sequestration rates in a warming climate.

CLIMATE DATA MBALE, UGANDA

	Jan.	Feb.	Mar/	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
Av.Temp (^{0}C)	20.2	20.6	20.9	19.9	19.7	19.5	19.5	20.4	20.1	20.0	19.8	19.5
Min. Temp (^{0}C)	13.9	14.3	14.8	14.4	14.1	13.2	12.8	14.0	14.0	14.2	14.0	13.6
Max.Temp (^{0}C)	26.6	26.9	27.0	25.5	25.4	25.9	26.3	26.8	26.2	25.8	25.3	25.5
Rainfall (mm)	56	66	108	143	88	37	36	57	97	110	131	82

(Early rains: MAM) (Late rains: SOND)

ADVANTAGE OF UGANDA FOR TROPICAL TREE PLANTING
CLIMATE DATA SELECTED EQUATORIAL REGIONS

DATA ITEM	ENTEBBE (UG)	JINJA (UG)	MBALE (UG)	KINSHASA (DRC)	KISANGANI (DRC)	MANAUS (Brazil)
ALTITUDE metres asl.	1,180	1,180	**1,479**	240	447	92
Record High ^{0}C	na	na	**na**	38	36	38
Av. High ^{0}C	27	27	**26**	30	30	32
Record Low ^{0}C	na	na	**na**	10	16	12
Av. Low ^{0}C	16	16	**14**	20	20	23
Av. Rel. Humidity	80%	80%	**60%**	80%	86%	81%
Precipitation mm/pa	1,560	1317	**1,111**	1,500	1,600	2,300

1. Uganda is on the E.African plateau. A rise in altitude of 1000m asl reduces temperatures by 6.5^{o}C/km (ELR). The advantage to Mbale at around 1100m asl is >6.5^{o}C. This is important as it is predicted that tropical rainforests could experience stress, such as higher respiration of VOCs from higher temperatures and earlier tree mortality. Tree growth in the Mbale region could even benefit from a few degrees higher temperature. The IPCC 5th Assessment report also with predicts a qualified increase in precipitation for the Lakes region.
2. Precipitation in the Equatorial region is characterized by a double-maxima regime (2 wet and 2 dry seasons). Dry seasons are generally short and, in these seasons , rain can fall typically in all months (see chart below).

PRECIPITATION UGANDA
ENTEBBE, JINJA AND MBALE precipitation patterns will be similar.

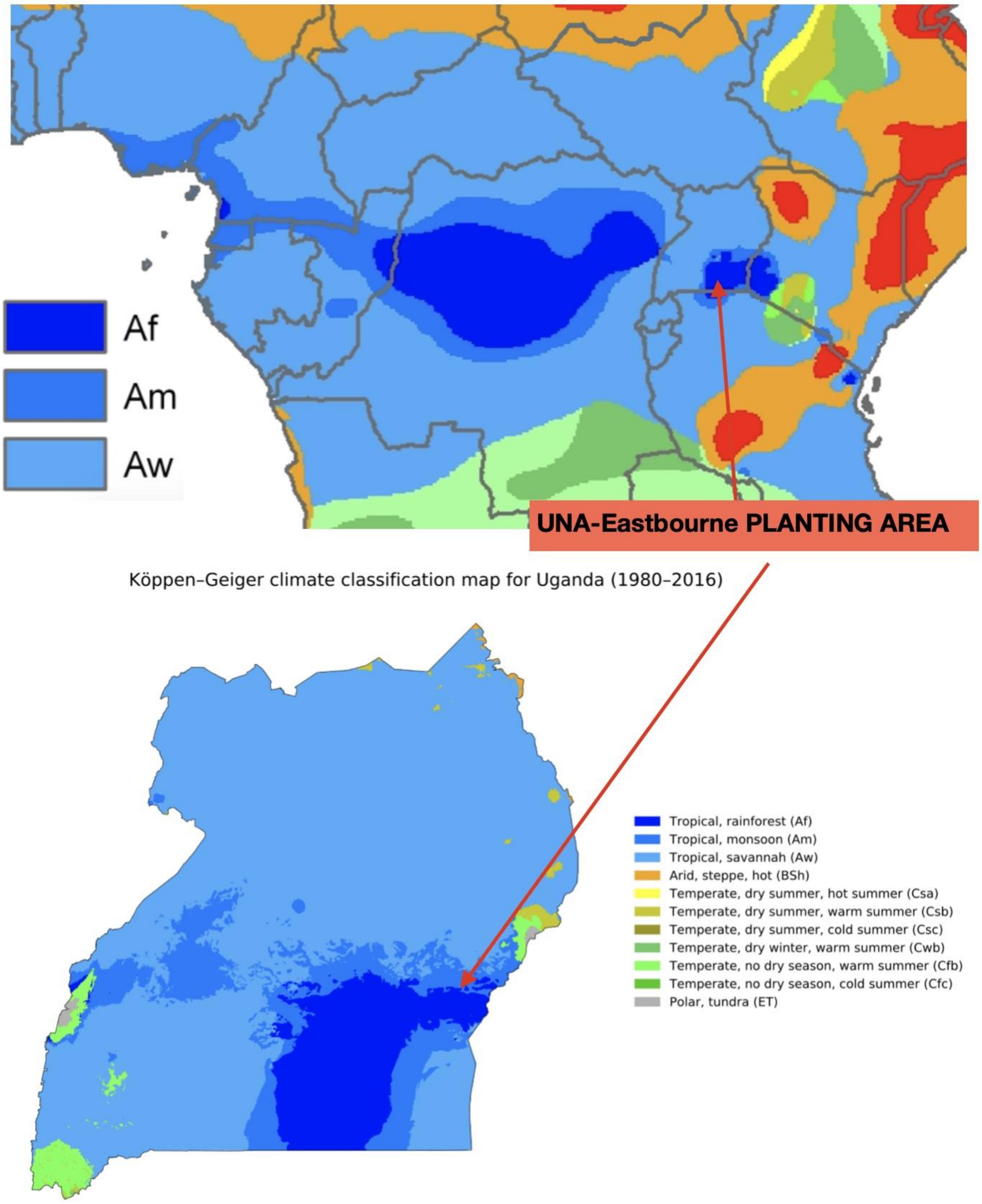
<u>The two 'wet' seasons are:</u>
"Early Rains" - April - May.
"Late Rains" - Sept-Nov/Dec.

Note: Kew Gardens State of the World's Plants. Annual.

Uganda declared as one of 7 tropical IPAS to be studied 2015-2020

The precipitation diagram for Entebbe shows on how many days per month, certain precipitation amounts are reached. In tropical and monsoon climates, the amounts may be underestimated.

UGANDA’S CLIMATE
(Köppen climate classification)



Lake Victoria Basin Climate Change Adaptation Strategies & Action Plan 2018-2023.
Lake Victoria Basin Commission. nd.

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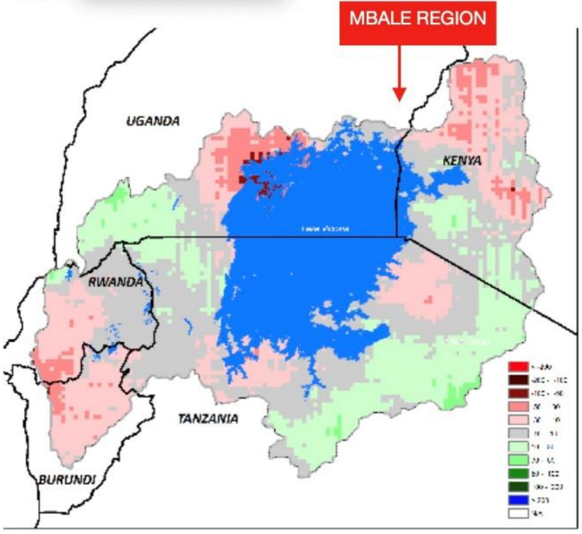


Map 3: Lake Victoria Basin MAMJ Precipitation Trends

Source: Section 2.1 of report.

Lakes Region Precipitation Changes.
The Lakes Equatorial Region has double maxima rainfall regime.
Long rains from late March to June (MAMJ)
Short rains from early Oct to Dec (OND).
Note: Mbale differs slightly.

El Niño result in above normal rains, whilst **El Niña** in below normal rains. These two ossilations (ENSO) have occured approx. every five years since 1970 but can vary from 2- 7 yrs.

Trend analysis shows a long term decline in precipitation for the long rains (MAMJ). Drier periods are getting longer and more pronounced. In contrast trends indicate total rainfall in the short rains (OND) has increased and modelling suggests this trend is likely to continue.

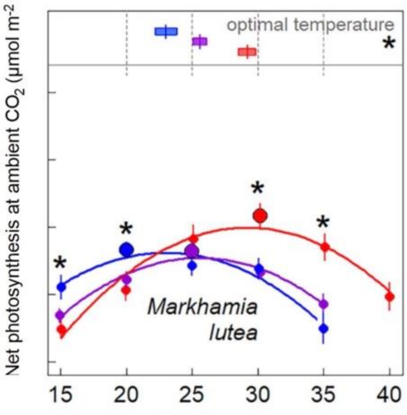
Significance for Mbale region, eastern Uganda.
Areal extension of the lower precipitation pattern indicated around the northern shores of Lake Victoria suggest the Mbale region may also suffer from falling overall precipitation in the Long Rains (MAMJ) with increased periods of droughts although indications are that intensity of rains may increase with consequent flooding. However, short rains may get longer.

9. **Scientific references to the ability of long-succession tropical trees to adapt to rising temperatures and increased drought.**
    a. **Wittemann, M. et.al. (2022) Temperature acclimation of net photosynthesis and its underlying component processes in four tropical tree species.** Tree Physiology **42(6). DOI:1093/treephys/tpac002.**
    b. **Mujawamariya, M. et.al. (2023) Contrasting warming responses of photosynthesis in early- and late=successional tropical trees.** Tree Physiology 43 (1-2). DOI: 10.1093/treephys/tpad305.

IDE Comment: Much current research is concerned with the response of tropical vegetation to increasing ambient temperatures and increased drought periods during seasonal low precipitation cycles. Although the science is uncertain in detail the diagram below from Wittemann et al. would suggest UNA Eastbourne Tri-species programme can expect increased photosynthesis rates up to ambient temp. rising from mean diurnal highs of 24°C to 30°C. However, increased drought intensity would probably negatively affect rates of photosynthesis.

EFFECT ON PHOTOSYNTHESIS FROM INCREASING EQUATORIAL TEMPERATURES

NB. *Makhamia lutea* grows at comparable sites to *M.excelsa, T.robusta* and *M.eminii*



Source: Wittemann, M. et al (2022) DOI: 10.1093/treephys/tpac002, adapted from Fig. 3. NB. Research conducted on 4 tropical hardwoods from different altitudes in Rwanda - *M.lutea* at asl 950-1800m, in mean air temp.18-23 °C.

G. EVALUATION OF TREE PROJECTS FOR CARBON SEQUESTRATION.

(IDE comment: Tree planting for carbon sequestration is a contentious issue and it is easy to be confused by statements such as “don’t plant trees – trees cause global warming”).

1. **Carton, W., & Andersson, E. (2017). Where Forest Carbon Meets Its Maker: Forestry-Based Offsetting as the Subsumption of Nature. Society and Natural Resources, 30(7), 829–843. https://doi.org 10.1080/08941920.2017.1284291**

   (IDE Comment: This article refers to the difficulties faced by large well-funded carbon offsetting organisations, in this case, ECOTRUST in Uganda, in partnership with Trees for Global Benefit -TFGB. This paper highlights the difficulties of such large-scale schemes of enlisting local communities with financial incentives for carbon sequestration. Below is an extract from the conclusion of the study, although the full article is recommended reading).

   “Under the community-based framework that Ecotrust relies on, the subsumption of nature is effectively outsourced to participating communities and farmers, who assume a stake (and the corresponding risks) in the project by benefitting from instalment payments and the value of the timber. To ensure that tree carbon is sequestered in a way that enables the production of tradeable offsets, farmers are thereby expected to live up to a specific planting, thinning and pruning regime, to keep track of exact land sizes and tree numbers, to combat pests and diseases and to base their involvement in the project on a cost-benefit estimation of tree cultivation compared to a range of alternative land uses. They are, in other words, submitted to a disciplining exercise that enforces the same logic employed in the subsumption of tree carbon, a logic that prescribes utility maximization and the rationalization of tree management for sequestration purposes. To all intents and purposes therefore, they are enlisted as ‘green custodians’ as labourers in the new carbon economy. This is not to say that the project does not bring potential benefits to participants, that it does not contribute to afforestation, or that Ecotrust is to blame for all of the projects’ shortcomings….the management practices of carbon forestry are fundamentally shaped by the requirements of the carbon market, which for all sorts of socio-economic reasons (not least widespread poverty) are often far from the reality on the ground. TFGB participants have their own priorities, time constraints and livelihood concerns that partly conflict with Ecotrust’s ideas about ‘boutique’ offset production. To the extent that this puts them into conflict with the organisation’s objectives, this has led to substantial misunderstandings and frustrations, causing large numbers of farmers to fall short of their contract requirements, with some even removing trees and leaving the project.”

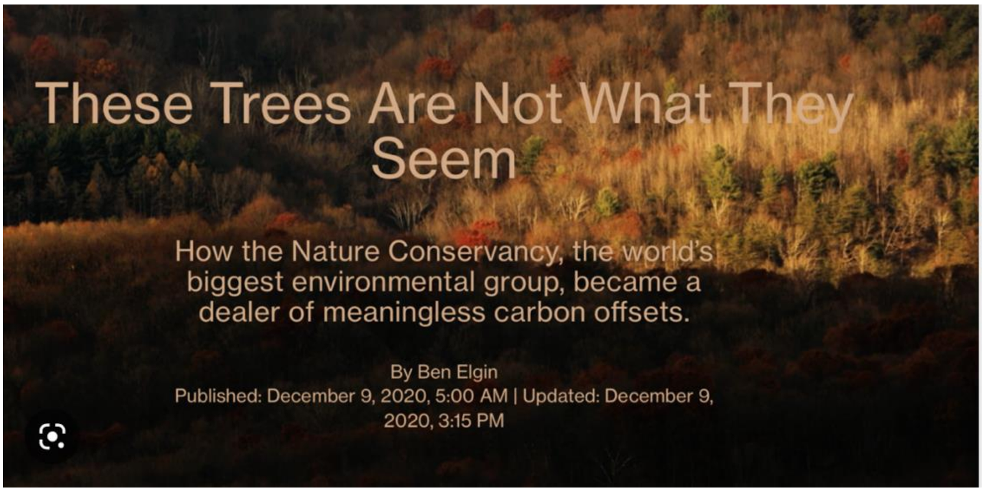
2. **UNEP (10 Jun 2019). “Carbon offsets are not our get out-of-jail free card”.**

   UNEP emphasises that projects which offset schemes support are vital: trees must be planted, existing forests and peatlands that hold and absorb carbon must be protected. However, they in themselves are insufficient as they give the dangerous illusion of a “fix” that will allow our billowing emissions to just continue to grow”.
   (IDE Comment: This is a point made by Greenpeace UK (20/05/2020) “**The biggest problem is that carbon offsetting doesn’t really work”**. **Such headlines are eye-catching but misleading.** The issue, as recognised by UNA Eastbourne, is that planting trees must not be used as an excuse for continuing with our high carbon

emissions. Tree planting is essential but must be coordinated with reductions in current carbon emission programmes by all sponsors).

3. **The problem of false claims for carbon offsetting – 'Greenwashing'.**

   To see the scale of the problem of 'greenwashing' by large corporations ostensibly offsetting their carbon footprint see the following article: '***Carbon offsets are flawed but we are now in a climate emergency***' by Fiona Harvey, The Guardian 18 Jan. 2023. See also numerous reports by Ben Elgin of Bloomberg.com, example below.



These Trees Are Not What They Seem

How the Nature Conservancy, the world's biggest environmental group, became a dealer of meaningless carbon offsets.

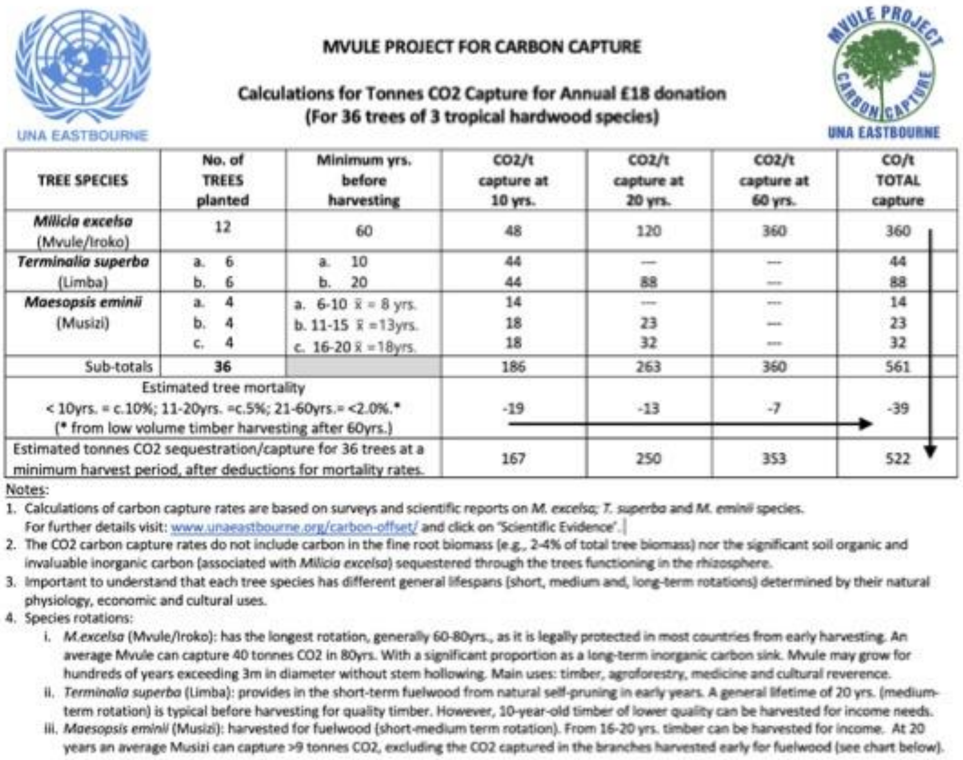
By Ben Elgin
Published: December 9, 2020, 5:00 AM | Updated: December 9, 2020, 3:15 PM

(IDE comment) Should we offset our carbon footprint by planting trees? There are several natural ways to sequester carbon to mitigate carbon footprint, such as planting mangroves, seaweed e.g., kelp, and biochar. However, planting trees remains the most widespread method. Questions which should be addressed include: which trees species, where and why? What are the potential pathogens, mortality rates, rates to maturity, planting costs and is long-term monitoring available. Please email our Chair, to discuss any of these issues in further detail (contact: ianelgie@hotmail.com).

4. **Toochi, E.C. (2018). 'Carbon sequestration: how much can forestry sequester CO2?** *Forest Res Eng Int J*. 2018;2 (3): 148-150. Doi. 10.15406/freij.2018.02.00040
   Photosynthesis permits trees to uptake CO2 from the atmosphere and convert it into organic carbon and later, through digestion and decomposition, back into CO2. A few trees, such as the *Milicia excelsa*, can also sequester CO2 and convert it into an **inorganic carbon** for millennia carbon storage.
   Average CO2 absorbed by trees is in the region of 21.6kg/yr.
   (**IDE Note**: Important that C and CO2 are not confused. The conversion ratio for C to CO2 is given as: 1:3.6663. The average figure can be misleading and should only be used with care. Tree species show a wide range of growth rates, wood densities and maturity ages and susceptibility to disease including stem hollowing which can make averages very misleading).

G. MVULE PROJECT FOR CARBON CAPTURE: TABLES & CHARTS

1. CO2 capture rates for 36 trees under Mvule Tri-Species Project



UNA EASTBOURNE

MVULE PROJECT FOR CARBON CAPTURE

Calculations for Tonnes CO2 Capture for Annual £18 donation
(For 36 trees of 3 tropical hardwood species)

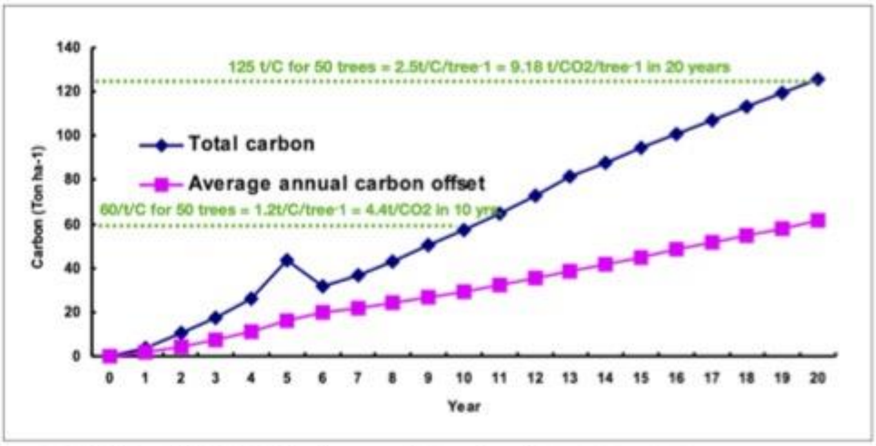
MVULE PROJECT CARBON CAPTURE UNA EASTBOURNE

TREE SPECIES	No. of TREES planted	Minimum yrs. before harvesting	CO2/t capture at 10 yrs.	CO2/t capture at 20 yrs.	CO2/t capture at 60 yrs.	CO/t TOTAL capture
Milicia excelsa (Mvule/Iroko)	12	60	48	120	360	360
Terminalia superba (Limba)	a. 6 b. 6	a. 10 b. 20	44 44	— 88	— —	44 88
Maesopsis eminii (Musizi)	a. 4 b. 4 c. 4	a. 6-10 x̄ = 8 yrs. b. 11-15 x̄ =13yrs. c. 16-20 x̄ =18yrs.	14 18 18	— 23 32	— — —	14 23 32
Sub-totals	**36**		186	263	360	561
Estimated tree mortality < 10yrs. = c.10%; 11-20yrs. =c.5%; 21-60yrs.= <2.0%.* (* from low volume timber harvesting after 60yrs.)			-19	-13	-7	-39
Estimated tonnes CO2 sequestration/capture for 36 trees at a minimum harvest period, after deductions for mortality rates.			167	250	353	522

Notes:

1. Calculations of carbon capture rates are based on surveys and scientific reports on *M. excelsa; T. superba* and *M. eminii* species. For further details visit: www.unaeastbourne.org/carbon-offset/ and click on 'Scientific Evidence'.
2. The CO2 carbon capture rates do not include carbon in the fine root biomass (e.g., 2-4% of total tree biomass) nor the significant soil organic and invaluable inorganic carbon (associated with *Milicia excelsa*) sequestered through the trees functioning in the rhizosphere.
3. Important to understand that each tree species has different general lifespans (short, medium and, long-term rotations) determined by their natural physiology, economic and cultural uses.
4. Species rotations:
   i. *M.excelsa* (Mvule/Iroko): has the longest rotation, generally 60-80yrs., as it is legally protected in most countries from early harvesting. An average Mvule can capture 40 tonnes CO2 in 80yrs. With a significant proportion as a long-term inorganic carbon sink. Mvule may grow for hundreds of years exceeding 3m in diameter without stem hollowing. Main uses: timber, agroforestry, medicine and cultural reverence.
   ii. *Terminalia superba* (Limba): provides in the short-term fuelwood from natural self-pruning in early years. A general lifetime of 20 yrs. (medium-term rotation) is typical before harvesting for quality timber. However, 10-year-old timber of lower quality can be harvested for income needs.
   iii. *Maesopsis eminii* (Musizi): harvested for fuelwood (short-medium term rotation). From 16-20 yrs. timber can be harvested for income. At 20 years an average Musizi can capture >9 tonnes CO2, excluding the CO2 captured in the branches harvested early for fuelwood (see chart below).

CARBON ACCUMULATION RATES FOR MAESOPSIS EMINII (MUSIZI)



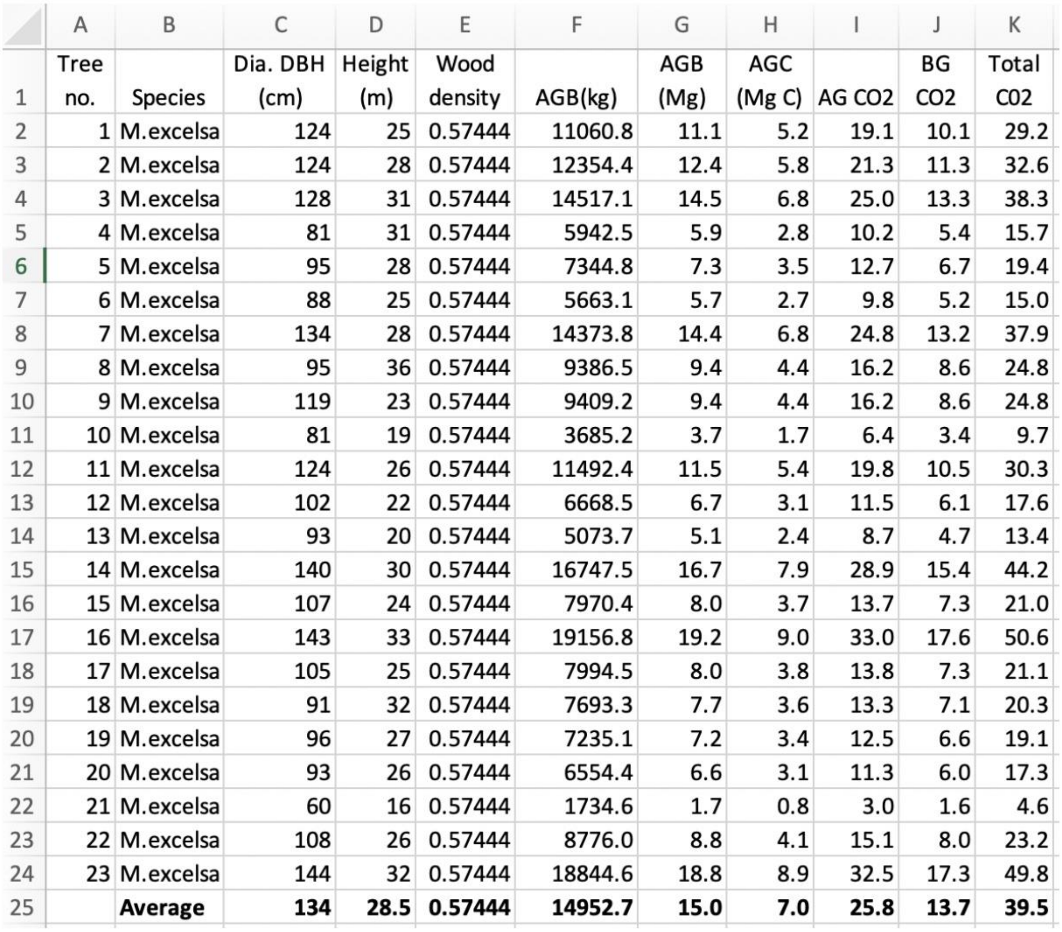
Source: Buchholz, T, et al (2004) Fig.2 "Carbon accumulation under sole M.eminii woodland.
The above chart shows carbon capture rates for 50 trees from the research of T. Buchholz, a world expert on *M. eminii*.
The green lines & text have been added to convert the carbon data into CO2 data (using conversion factor of 3.67).
Note: The carbon rate of capture is converted into CO2 capture rate by multiplying by 3.67. The green lines with text have been added to the chart to support the calculations in the table of CO2 capture rates by 36 trees of three species.
Capture rates for *Milicia excelsa* are derived from survey data and analysis from Uganda in 2020 (Click here for details).

2. Survey data from 80yr Mvule. St. Mary’s Bukedea, Uganda 2020 for Biomass and CO2 sequestration rates.

SURVEY OF RANDOMLY SELECTED 80 yr OLD MILICIA EXCELSA (N=23)

FOR BIOMASS & CO2 SEQUESTRATION

ST.MARY’S TEACHER TRAINING COLLEGE, BUKEDEA, UGANDA
January 2020.



	A	B	C	D	E	F	G	H	I	J	K
1	Tree no.	Species	Dia. DBH (cm)	Height (m)	Wood density	AGB(kg)	AGB (Mg)	AGC (Mg C)	AG CO2	BG CO2	Total C02
2	1	M.excelsa	124	25	0.57444	11060.8	11.1	5.2	19.1	10.1	29.2
3	2	M.excelsa	124	28	0.57444	12354.4	12.4	5.8	21.3	11.3	32.6
4	3	M.excelsa	128	31	0.57444	14517.1	14.5	6.8	25.0	13.3	38.3
5	4	M.excelsa	81	31	0.57444	5942.5	5.9	2.8	10.2	5.4	15.7
6	5	M.excelsa	95	28	0.57444	7344.8	7.3	3.5	12.7	6.7	19.4
7	6	M.excelsa	88	25	0.57444	5663.1	5.7	2.7	9.8	5.2	15.0
8	7	M.excelsa	134	28	0.57444	14373.8	14.4	6.8	24.8	13.2	37.9
9	8	M.excelsa	95	36	0.57444	9386.5	9.4	4.4	16.2	8.6	24.8
10	9	M.excelsa	119	23	0.57444	9409.2	9.4	4.4	16.2	8.6	24.8
11	10	M.excelsa	81	19	0.57444	3685.2	3.7	1.7	6.4	3.4	9.7
12	11	M.excelsa	124	26	0.57444	11492.4	11.5	5.4	19.8	10.5	30.3
13	12	M.excelsa	102	22	0.57444	6668.5	6.7	3.1	11.5	6.1	17.6
14	13	M.excelsa	93	20	0.57444	5073.7	5.1	2.4	8.7	4.7	13.4
15	14	M.excelsa	140	30	0.57444	16747.5	16.7	7.9	28.9	15.4	44.2
16	15	M.excelsa	107	24	0.57444	7970.4	8.0	3.7	13.7	7.3	21.0
17	16	M.excelsa	143	33	0.57444	19156.8	19.2	9.0	33.0	17.6	50.6
18	17	M.excelsa	105	25	0.57444	7994.5	8.0	3.8	13.8	7.3	21.1
19	18	M.excelsa	91	32	0.57444	7693.3	7.7	3.6	13.3	7.1	20.3
20	19	M.excelsa	96	27	0.57444	7235.1	7.2	3.4	12.5	6.6	19.1
21	20	M.excelsa	93	26	0.57444	6554.4	6.6	3.1	11.3	6.0	17.3
22	21	M.excelsa	60	16	0.57444	1734.6	1.7	0.8	3.0	1.6	4.6
23	22	M.excelsa	108	26	0.57444	8776.0	8.8	4.1	15.1	8.0	23.2
24	23	M.excelsa	144	32	0.57444	18844.6	18.8	8.9	32.5	17.3	49.8
25		**Average**	**134**	**28.5**	**0.57444**	**14952.7**	**15.0**	**7.0**	**25.8**	**13.7**	**39.5**

Formula for columns:

Col.E = Wood density of Milicia excelsa = 574.44kg/m3. (Green tree mass x specific gravity of wood).

Col F = 0.0673*(E2*((C2^2)*D2)^0.976 (Source: Charve, J. *et al*. (2014) using formula 4 (best-fit pantropical model).

Col G = F2/1000 (Kg to Tonnes)

Col H = G2*0.47 (Estimated carbon content of dry mass of wood)

Col I = H2*44/12 (Conversion Carbon to Carbon Dioxide should be C x 3.6663 in tonnes/per tree.

Col J = IPCC suggest for tropical rainforests in Africa with > 125 tonnes C ha-1 (Milicia excelsa environment) use factor 0.532 for ratio BGB to AGB.

3. Mvule DBH growth rates in Uganda cf. Central African Republic

MVULE (IROKO) GROWTH RATES

A COMPARISON OF UGANDA SURVEY DATA WITH CENTRAL AFRICAN REPUBLIC DATA

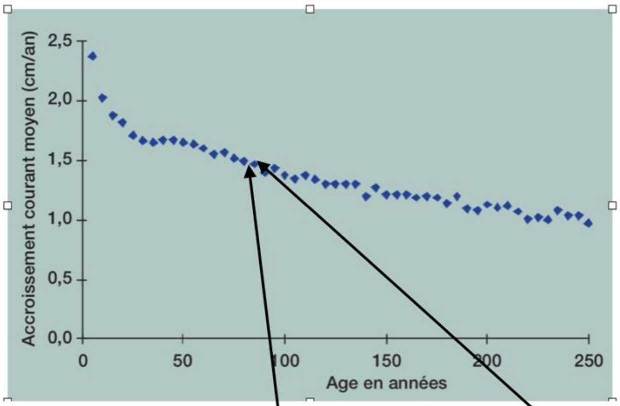


FIGURE 1
Source:
Luc Durrieude de Madron. “Diametrique du bele et de l’Iroko”
Bois et Forets des Tripiques 2003 no 275 (1)

Figure 1 shows mean diameter growth (cm/yr) of 46 iroko trees by age in years.

Note:

1. Even with very old trees substantial growth is maintained - at least 1cm/yr.
2. From two surveys carried out in eastern Uganda in Nov. 2019 and Feb 2020 it can be demonstrated that average diametric growth is consistent with that of the Central African Republic.

BUKEDEA SURVEY FEB. 2020
(ALL MVULE 80 YEARS OLD)

N =23	Diameter (cm)	Growth/yr^{-1}
MAX	144	1.8
MIN	60	0.8
MEAN	108	1.4

Note:
Survey conducted by METGE Feb.2020.

KAMUGE SURVEY NOV. 2019
(ALL MVULE 90 YEARS OLD)

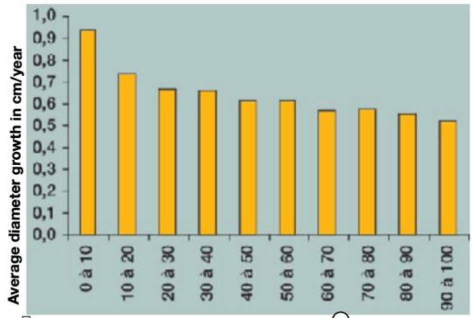
N =7	Diameter (cm)	Growth/yr^{-1}
MAX	185	2.1
MIN	105	1.2
MEAN	135	1.5

Note:
Survey conducted by Ian Elgie, 5 Nov.2019.

Above: image of Mvule lower bole, Kamuge, Uganda. Nov.2019

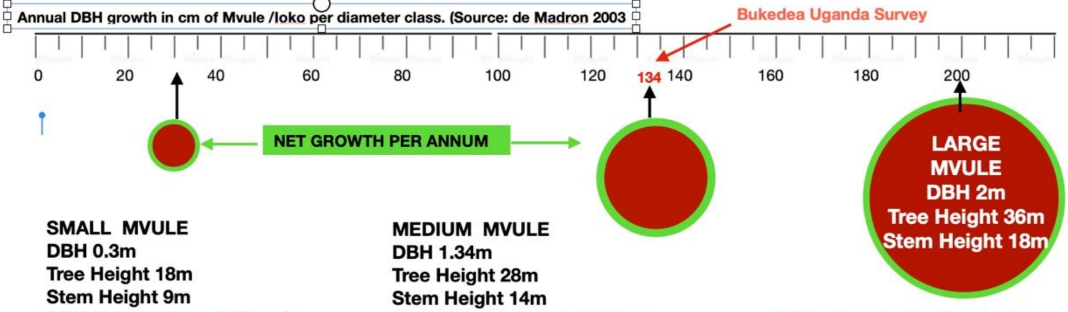
4. Mvule Stem Biomass and CO2 Sequestration.

ANNUAL INCREMENT IN TREE STEM BIOMASS (SB/kg/a) & CO2 SEQUESTRATION (CO2/kg/a)



Annual DBH growth in cm of Mvule /Ioko per diameter class. (Source: de Madron 2003

Description	Small	Medium	Large
Tree Stem height, cm	900.0	1400.0	1800.0
DBH, cm	30.0	134.0	200.0
Radius cm	15.0	67.0	100.0
Tree stem volume cm^3	636172.5	19743653.2	56548667.8
Increase in DBH/a^{-1}	0.7	0.5	0.5
New radius cm	15.3	67.3	100.3
Tree stem new volume cm^3	664038.6	19891268.8	56831764.5
Net inc. in Tree Stem volume cm^3	27866.1	147615.6	283096.8
Factor increase		5.3	10.2
(volume compared with small tree)			

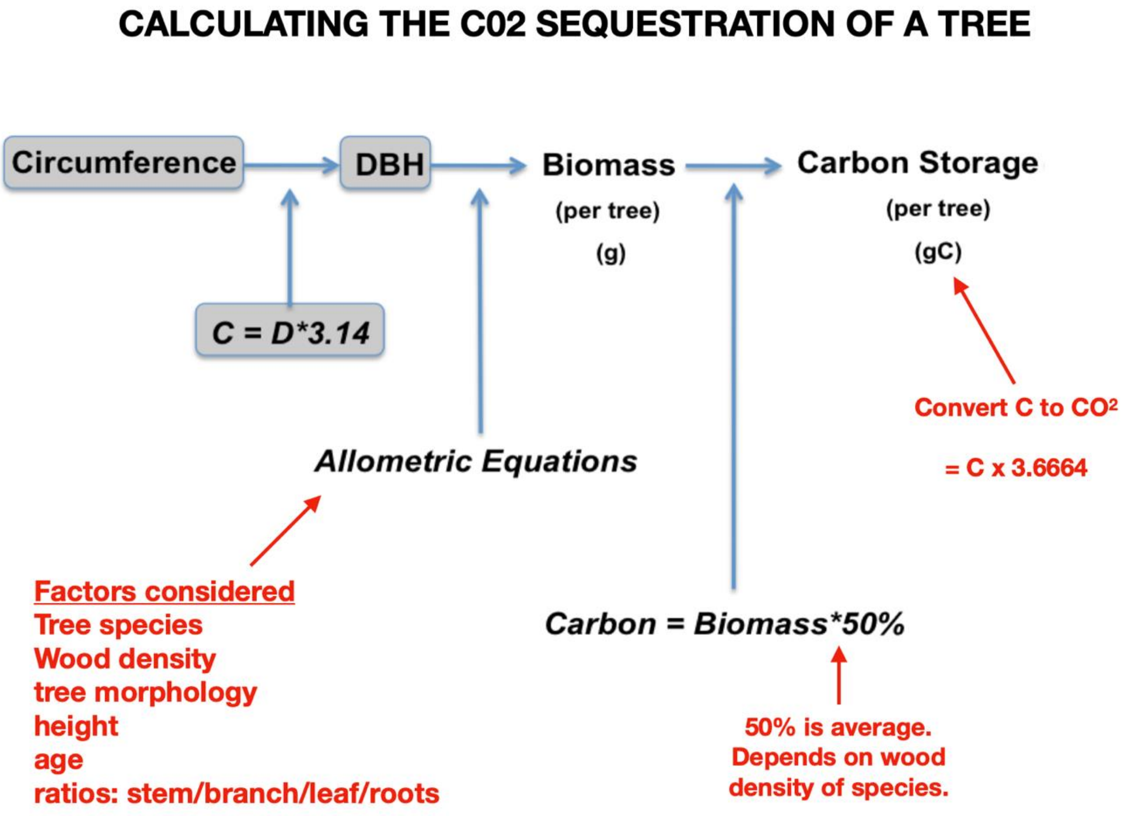


SMALL MVULE
DBH 0.3m
Tree Height 18m
Stem Height 9m
DBH Net growth = 0.70cm/a
Added SB = 27866.1cm³/a
= c.33kg CO2/a

MEDIUM MVULE
DBH 1.34m
Tree Height 28m
Stem Height 14m
DBH Net growth = 0.50cm/a
Added SB = 147615.6cm³/a
= c.176kg CO2/a

DBH Net growth = 0.50cm/a
Added SB = 283096.8cm³/a
= c.337kg CO2/a

5. Calculating the CO2 sequestration of a tree



Scientific references and comments compiled by:
Ian Elgie
Chair, UNA Eastbourne.
www.unaeastbourne.org
Last updated: 10/09/23.

For any queries contact: ianelgie@hotmail.com