CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

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Water Use Efficiency in Industrial Tree Species in Ghana

BACHELOR'S THESIS

Prague 2019

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CZECH UNIVERSITY OF LIFE SCIENCES PRAGUE

Faculty of Forestry and Wood Sciences

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Forestry

Thesis title

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Objectives of thesis

Several crops imported worldwide are known due to its enormous water consuption, e.g. bananas (Musa sp.). With the transport of fruits abroad the most important natual resource – water – is being exhausted. The problem is good known in agriculture but poorly reflected in forestry. The goal of this bachelor thesis is to analyse data about water use efficiency among the most important tree species exported from Ghana, their impact on soil properties and the whole ecosystem.

Methodology

Water use efficiency (WUE) is defined as a ratio of biomass produced and transpiration. WUE is used as a important determinant of yield under stress and as a component of drought resistance. This bachelor study will be based on literature research and compilation of gained facts about the WUE of main exported tree species from Ghana. Next to the WUE the bachelor thesis will be focused on the ecophysiological traits e.g. allelopathy of commercial tree species which can negatively influence the survival of indigenous ecosystems.

The proposed extent of the thesis

30-40

Keywords

alelopathy, ecophysiology, foreign wood trade, teak, water use efficiency

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Recommended information sources

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Expected date of thesis defence

2018/19 SS – FFWS

The Bachelor Thesis Supervisor

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Electronic approval: 19. 11. 2018
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Prague on 30. 03. 2019

Declaration

I hereby declare that I have done this thesis entitled ‘‘water use efficiency of industrial tree species in Ghana’’ independently, all texts in this thesis are original, and all the sources have been quoted and acknowledged by means of complete references and according to Citation rules of the FFWS.

Prague, April 2019

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Ernest Gyamfi.

Acknowledgements

My greatest gratitude goes to the almighty God for seeing me through this programme successfully. I wish to express my profound gratitude to my supervisor doc. Ing. Ivana Tomášková, Ph.D of the Faculty Forestry and Wood Sciences at Czech University of Life Sciences, Prague, for the supervision and above all the inspiration that made this project a reality. I am indebted to all lecturers and members of the Faculty who taught me various subject or helped me in various ways in the course of my studies. I appreciate the kind of support and friendly attitude you showed me throughout my studies.

In addition, I wish to thank my entire family especially my parents Mr and Mrs. Tweneboah Koduah and my uncle Mr. Sampson Gyamfi. I thank you all very much for the kind of moral and financial support you have provided me all these years of my stay in the Czech republic. Finally, to all my classmates who contributed one way or the other to ensuring the completion of this work, I say thank you and God bless you.

Abstract

In recent times water use efficiency of plants has become an important concept of discussion both to agronomists and foresters because of the continual depletion of water as a resource due to global climatic changes. Forest vegetation are becoming more drier than before due to sustained increase in temperature. The aim of this work was to compile and review available scientific literature on the water use efficiency of some selected industrial tree species in Ghana along with their physiological traits. Among such physiological traits were anatomy of leaves and stems, root structure, the type of photosynthesis, transpiration rate, fertilization, pollination, germination, seed dormancy, adaptation to biotic and abiotic stress, drought tolerance, biochemical composition etc. Unfortunately, not much information about these aforementioned traits were found due to the limited research on these natives although they are of high commercial value. A big knowledge gap was found with respect to the physiology of these tree species compared to crop plants. Most of the research done on these native species were old and have not been reviewed in a while. This lack of current knowledge has resulted in failure of many forest restoration and plantation program. The domesticated tree *Tectona grandis* was found to be the most promising in terms water use efficiency probably because of its ability to growth in a wide range of climatic and edaphic conditions. This work has brought to light the need to pay attention to research of these high valued commercial species.

Keyword: *Tectona grandis*, physiology, transpiration, drought, edaphic, plantation.

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List of abbreviations

WUE	Water use efficiency
WUE_i	Intrinsic water use efficiency
A_N	Net assimilation rate
g	Stomatal conductance
E	Transpiration
P_N	Net photosynthetic rate
Δ	Carbon isotope discrimination
TE	Transpiration efficiency
IUCN	International Union for Conservation of Nature
FACE	Free Air CO_2 Enrichment
CAM	Crassulacean Acid Metabolism
PROTA	Plant Resource of Tropical Africa
PVC	Polyvinyl chloride
Ψw	Leaf water potential
HFZ	High Forest Zone
SZ	Savannah Zone

1.0 Introduction and literature review

1.1 Introduction

Water use efficiency has been extensively studied in many arable crops due to their ability to consume large amounts of water but same cannot be said of tree species in tropical Africa. Some work on this subject of has been done on certain tree species but mostly on those found in the northern hemisphere of the world and hence there is some amount of information on such species. This subject of water utilization by plants is well known in agriculture but poorly understood in forestry. This work therefore seeks to study extensively literature available on water use efficiency in tropical tree species with focus on industrial tree species in Ghana.

Water use efficiency (WUE) is used as an important determinant of yield under stress and as a component of drought resistance. Knowledge of this subject has helped immensely in improving the productions of crop plants in agriculture. This study is based on literature research and compilation of gained facts about the WUE of most important tree species in Ghana. The other part of this work will cover certain aspects of the chosen species' botanical, ecological demands, anatomy, physiological traits and their industrial use. Forestry makes an important contribution to the economy of Ghana and therefore it is important that ways are found to maximize the production of wood in these industrial tree species. Water utilization is an important factor in the growth and wellbeing of a tree and such an in-depth knowledge of the WUE of these species will help improve wood production in terms of biomass.

There are many tree species in the forests of Ghana but only a few are exploited for commercial purposes. These trees are exploited because of their commercial values which is principally timber. The most important industrial tree species in Ghana include *Tectona grandis* (teak), *Milicia excelsa* (odum), *Triplochiton scleroxylon* (wawa), *Khaya ivorensis* (African mahogany), *Ceiba pentandra* (onyina), *Terminalia ivorensis* (emery), *Terminalia* *superba* (ofram), *Entandrophragma cylindricum* (sapele), and many other lesser known species. Many of these trees are also used for restoration and reforestation efforts. Just a few species are grown on commercial scales for products other than wood. Two of such species that will be covered in this work are *Hevea brasilensis* (rubber tree) tree and *Elaeis guineensis* (oil palm).

The term water-use efficiency is a measure of productivity in plants that has long been of interest to agronomists, foresters and ecologists (Bacon 2004)**.** In forestry systems, water-use efficiency is a critical link between wood production and water management. Understanding the impact of leaf characterisics and soil water availability on gas exchange and WUE of trees in natural forests, plantations and agroforestry systems in dry areas is very important in improving the utilisation of limited resources. Two main types of water-use efficiency are mostly described; at the whole-plant level which is normally called water use efficiency of productivity or integrated water-use efficiency (mmol C mol^{-1} H_2O) and at the leaf level commonly referred to photosynthetic or instantaneous water use efficiency. Physiologically, we can evaluate WUE by the equation; CO_2 assimilation rate/Transpiration rate (WUE=A/E) expressed in mmol CO_2 mol^{-1} H_2O.

At the whole plant level, WUE is defined as plant dry matter production per unit of water loss via transpiration. It is evaluated by determining the rate of Carbon (C) accumulation in dry matter relative to cumulative water loss (mmol C mol^{-1} H_2O) or evaluating the ratio of the total dry matter to evapotranspiration kg^{-1} H_2O. A research conducted in tropical C3 tree species showed large variations in observed $TE_{C.}$ 1.6 mmol C mol^{-1} H_2O was recorded for teak (*Tectona grandis*) and 4.0 mmol C mol^{-1} H_2O for a legume, *Platymiscium pinnatum*. Determinations of Transpiration efficiency of carbon gain (TE_C) usually integrate over several weeks to months, and are based on gravimetric measurements of dry matter accumulation and plant water loss, in combination with elemental analyses of the C mass fraction of plant dry matter. Significant variation in whole-plant WUE have been observed in different genotypes of the same species (Cernusak et al. 2006) **.**

At the leaf level, two types of WUE can be evaluated according to Medrano et al. (2015), intrinsic water-use efficiency (WUEi) which is defined as the ratio between net CO_2 assimilation rate (A_N) and stomatal conductance to water vapour (g) measured in unit of μmol CO_2 mol^{-1} H_2O, and instantaneous water use efficiency defined as the ratio between A_N to transpiration (E) measured in mmol CO_2 mol^{-1} H_2O. Intrinsic water-use efficiency (WUE_i) of plants is measure of photosynthetic activity by the evaluation of carbon fixation and stomatal conductance through the leaf-level coupling of CO_2 and water fluxes. A general but variable increase of WUE_i in conditions of elevated atmospheric CO_2 has been seen in long-term studies (Saurer et al. 2014). Amongst all the abiotic stresses in the environment, water limitation may be considered to be the most important in evaluating productivity and growth in plants. In addition, plant water utilization and growth are strongly affected by climate changes and CO_2 concentration in the atmosphere. The most intriguing aspect is the fact that an increase in CO_2 concentration above normal levels is usually associated with an increase in photosynthesis and a reduction in transpiration ultimately enhancing water-use efficiency, plant growth and productivity (Hsiao & Jackson 1999).

Knowledge of the relationships between photosynthetic,transpiration rates and chlorophyll content may help to explain differences in growth rate, productivity and WUE between species and growth environments (Muthuri et al. 2009). Such information is not available for most of the native tree species mentioned above. On an integrated time scale, water-use efficiency is usually estimated from leaf carbon isotope discrimination, where integrated WUE and carbon isotope discrimination are inversely correlated. The process of photosynthesis in plants involves the fixation of carbon from the atmosphere into the leaves. In the majority of plants (C3 plants), during the fixation, the naturally occurring stable isotope ^{I3}C is discriminated against relative to the more abundant ^{12}C. The discrimination occurs because of the different diffusion rates of ^{13}C and ^{12}C across the stomata and the fractionation by the C3 enzyme, ribulose bisphosphate carboxylase. Farquhar et al. (1982) developed theory which predicted that this discrimination will be least in those C3 plants that fix the most carbon per unit amount of water transpired, i.e. in those that have the greatest WUE. The carbon isotope discrimination ($\Delta^{13}C$) is expected to correlate negatively with WUE_i (Farquhar & Richards 1984) and has been commonly used as an indicator of WUE_i in several tree species including a research study of water use efficiency in poplar (Thiec 2013).

2.0 Objectives

Several crops imported and exported worldwide are well known due to their enormous water consumption, e.g. bananas (Musa sp.). For instance, with the transport of fruits abroad, one of the most important natural resource, water is being exhausted. The problem is extensively studied in agriculture but poorly understood in forestry. The goal of this bachelor thesis is to compile and analyse available data on the physiological traits of trees that relates to water use efficiency amongst the most important tree species exported from Ghana, their impact on soil properties and the whole ecosystem.

3.0 Methodology

Water use efficiency (WUE) is defined as a ratio of biomass produced and transpiration. WUE is used is an important determinant of yield under stress and as a component of drought resistance. This bachelor study will be based on literature research and compilation of gained facts about the physiological traits that may help understand WUE of main exported tree species from Ghana. Next to the WUE the bachelor thesis will be focused on the ecophysiological traits e.g. drought tolerance and allelopathy of commercial tree species which can negatively influence the survival of indigenous ecosystems.

4.0 Literature review

4.1 Water Use Efficiency in Plants

4.1.1 Definitions of WUE

Water loss in plants is an inevitable consequence of photosynthesis, where CO_2 diffuses into the leaf and flux out water (i.e. leaf gas exchange). Minimizing water loss while maximizing CO_2 uptake (i.e. increasing water use efficiency (WUE)) is a key physiological mechanism of plants adapted to low water availability (Gindaba et al. 2005;Choat et al. 2006) especially in arid or semi-arid areas where water is a limited resource. Water-use efficiency (WUE) is defined as a ratio of biomass accumulation, expressed as carbon dioxide assimilation (A), total crop or tree biomass (B), or crop grain yield (G), to water consumed, expressed as transpiration (T), evapotranspiration (ET), or total water input to the system (I). The time-scale for defining water-use efficiency can be instantaneous, daily or seasonal. Water-use efficiency is normally written mathematically as a function of these three variables. For instance the symbols WUE(A, T, i) is commonly used in literatures to refer to water-use efficiency expressed as the ratio of carbon dioxide assimilation to transpiration for an instantaneous measurement (Sinclair et al. 1984).

4.1.2 Units of Measurements of WUE

WUE may be expressed in several different units depending on the method of estimation and the scale at which it is being measured. WUE can be measured at different spatial and temporal scales. It may be short (the ratio between net photosynthesis and stomatal conductance; intrinsic WUE (Medrano et al. 2009) or long (based on the composition of stable carbon isotopes ($\delta^{13}C$) (Farquhar & Richards 1984)). WUE may be estimated at the leaf level or at the whole plant level. Units include mmol CO_2 mol^{-1} H_2O for $WUE_{i,}$ (mmol C mol^{-1} H_2O) for TE_c at whole plant level (Cernusak et al. 2006) or Dry matter (DM) kg^{-1} H_2O for dry matter to evapotranspiration ratio (Kocacinar & Sage 2005).

4.1.3 Estimation of WUE

Ripullone et al. (2004) estimated WUE in three different ways. They calculated (WUEi) from gas exchange measurements on individual plants as the ratio of maximum carbon assimilation at saturating light (Amax) to leaf transpiration rate (E) (Dang et al. 1991; Zhang & Marshall 1994). Long-term water-use efficiency (WUET) was calculated, per pot, as the ratio between amount of total dry mass produced between the beginning and end of the growing season and water transpired during the same period, calculated by the equation, $ET = I - (ES + \Delta WS)$ where ET is transpiration, I is water added, ES is evaporation from the soil and ΔWS is the change in soil water content over the time interval. Based on ΔWS values of three pots containing no plants, ES was found to be negligible. WUET was also estimated based on C-isotope discrimination (Δ) analysis of leaf dry matter. This parameter provides an estimate of WUE integrated over the period of leaf structural carbon fixation (Osorio & Pereira 1994). The relationship between WUE and Δ arises through their independent linkages to the ratio of internal to ambient CO_2 concentrations (Ci/Ca).

$$\Delta = a + \frac{(b-a)Ci}{Ca}$$

$$\text{WUE} = \frac{Ca(1 - Ci/Ca)}{1.6v}$$

where Ci is intercellular CO_2 concentration, Ca is ambient CO_2 concentration, a is the fractionation occurring as a result of diffusion of CO_2 in air (4.4%), b is the net fractionation mainly caused by Rubisco in C3 plants (27%), and v is the water vapor pressure difference between the intercellular spaces and the atmosphere (Ripullone et al. 2004).

4.1.4 Factors Affecting WUE

4.1.41 Leaf Anatomy and Arrangement

The size of a leaf, its color, orientation, and its topology influence the amount of light intercepted and its radiation. Small and thick leaves are associated with drought tolerance and high transpiration efficiency (TE). TE is defined as the ratio of the total biomass produced to the amount of water transpired. In many crop species, leaf size decreases with water deficit and leaf expansion is one of the most sensitive processes to water stress. Leaf thickness also tends to increase in many crop species in response to water deficit, particularly genotypes with greater drought tolerance and higher TE. Increasing leaf thickness is associated with water conservation. Increasing leaf thickness will increase the boundary layer thickness and, hence, decrease the rate of evaporation from the leaf. Leaf thickness also contributes to higher TE through an increase in A_N due to greater abundance of photosynthetic apparatus.Topological features such as pubescence and glaucousness are associated with drought tolerance and high TE in xerophytes, and many plant species adapted to semiarid environments. Day time changes in leave positioning can also affect the transpiration ratio as has been shown for a number of crop species. Some crop plants reduce the rate of absorbing solar radiation under situations of high irradiance by movement of the leaves to avoid direct solar radiation (Bramley et.al 2013)**.**

4.1.42 Stomatal Behavoir

The very low transpiration ratios of CAM plants can be explained by their singular stomatal behavior when growing under water stress. Under these circumstances, the stomates open at night and fix CO_2 in malic acid, causing a gradient with the atmosphere and flux into the leaf. The stomates close during the day and the CO_2, absorbed at night is then assimilated by the C3 pathway in the almost complete absence of transpiration. Current thinking also attributes an important role to stornatal behavior in differentially controlling the transpiration and assimilation rates of C3 and C4 as well as CAM metabolism plants, and Cowan (1984) has simulated the stomatal response which would minimize TE under different weather and soil moisture conditions. The mechanisms by which stomates respond to these conditions are now thought to consist of a feedback mechanism governed by the water content of the plant (Raschke 1975) and a "feedforward" mechanism coupled to the water content of the atmosphere.

4.1.43 Root Structure

The root system structure of a palnt affects its capacity for water and nutrient uptake from the soil. Root systems of different species show a high degree of phenotypic adaptions in response to environmental conditions. The root system is a major limitation to gas exchange and consequently TE because it forms the largest resistance to water flow in the plant. Hydraulic conductivity of the roots needs to be high enough to supply the leaf with sufficient water to maintain leaf hydration so stomata can remain open. High root hydraulic conductivity will also minimize the drop in water potential needed to drive water uptake from the soil and transport it to the shoot. The process needs to be coordinated with stomatal opening or else the plant may lose water to the soil when it becomes extremely dry or excessive water loss to the atmosphere if the vapor pressure deficit is high (Bramley et al. 2013).

4.1.44 CO_2 Concentration

Plants respond directly to rising atmospheric CO_2 (ca) concentration through increased net carbon assimilation (A_N) and reduced stomatal conductance (gs). These fundamental physiological responses lead to increased intrinsic water-use efficiency (WUEi = A_N/gs) and reduced transpiration (T) at the leaf level (Knauer et al. 2017). Results from three free-air CO_2 enrichment (FACE) experiments demonstrated that C3 plants growing in CO_2-enriched air (ambient CO_2 + 200 ppm; 50% increase in ca) showed concurrent significant reductions in gs and increases in photosynthesis, which resulted in an increase of 68% in WUEi, and an unchanged ci/ca (Ainsworth & Long 2004).

4.1.45 Carbon Metabolism

The major plant characteristic associated with differences in TE is their carbon metabolism pathway. The lower transpiration ratio found in C4 plants can be attributed to their ability to continue photosynthesis at CO_2 concentrations which are one-third to one-fifteenth ofthose needed to sustain the process in C3 plants (Stanhill 1986). The C4 biochemical pathway, in which the first products of photosynthesis are C4 carboxylic acids, and specific bundle sheath anatomy of leaves enable higher rates of photosynthesis than the C3 biochemical pathway. As C4 plants frequently, but not always, have lower stomatal conductances, the TE of C4 species is considerably greater than that of C3 species when directly compared in the same environment.

C4 plants on the other hand are usually adapted to growth in more warmer and water limited conditions than C3 plants in order to achieve a similar WUE due to the greater vapour pressure deficits in the drier environments. CAM plants usually have high values of TE because of their ability to open their to open their stomata and takes up CO_2 in the dark when vapor pressure deficits and water loss are minimal. Carbon is stored as malate in CAM inside the mesophyll cells which is then converted into usable carbohydrates using sunlight. Even though the photosynthetic pathway in CAM plants is the most efficient in terms of water utilization, it results in a lowwer production of biomass as its generally observed in species adapted to living in arid conditions (Bramley et al. 2013).

4.1.5 Importance of WUE in Plant Physiology Research

Water use efficiency is recognized as an important determinant or measure of productivity in crop plants and has been used recently at the ecosystem level. Ecologists commonly use the ratio of ecosystem fluxes such as NPP net ecosystem productivity/exchange (NEP/NEE), or gross primary productivity (GPP) to water loss (ET or transpiration; as a measure of WUE. Agronomists use WUE as an index to determinant of yield under stress and as a component of drought resistance. In areas of water scarcity, it helps breeders to choose suitable genotypes of crops or trees that are well adapted to water limited conditions. Foresters use WUE index to select tree species with increased biomass in water deficit conditions (Malone 2017). WUE provides a significant scope for altering the specific environmental conditions that reduce photosynthesis and yield. Another in using WUE especially WUEi is that the ratio of A/gs is rather constant over a wide range of stomatal conductance and the relationship is fairly linear except with very wide-open stomata where the stomatal limitation to photosynthesis decreases (Bacon 2004b).

4.2 General Overview of Ghana’s Forest

Ghana is endowed with a vast forest cover of about 23.9 million hectares of which 15.7 million savanna forest zone (SZ) in the north and the remaining 8.2 million ha which is the tropical high forest zone (HFZ) covers the southern part. The high forest zone is characterised by abundant farmlands and forest reserves consisting of the ever green and semi-deciduous forests with many subtypes (Hawthorne & Abu Juam 1995). The HFZ is the main source of the country’s timber production. The savanna is characterised by an open canopy of trees and shrubs with a ground layer of grasses (Hall & Swaine 1981). The savanna zone covers about 9.4 million ha producing predominantly wood fuel. A transitional vegetation zone exists between the HFZ and the SZ, and is characterised by a mixture of savanna vegetation and dry forest.

Deforestation poses a great threat to the forest in Ghana as deforestation is estimated to occur at a rate of about 65,000 ha per year. The main cause of deforestation is the conversion of forest lands into farms lands to produce food to sustain the growing population. Other important factors include illegal logging activities, mining, constructions of roads and infrastructures, bad farming practices and wild fires. Agricultural fields, secondary forest patches and trees around settlements covers a greater part of the off-reserves (Mayers et al. 1996). In the year 2010 the off-reserve for timber production was estimated at about 350,000 ha (FAO 2010). Many commercial timber species are found in these off-reserve areas. In 1996, it was estimated to have a stock volume of about 268 million m^3 of timber. Almost half of the timber harvested came from off-reserves in the early and late 90’s areas, but this has drastically reduced in recent years (Hansen & Treue 2008). However, efforts are been made to regenerate lost forest by various plantation programs initiated by government and private organisations.

4. 3 Teak (*Tectona grandis*)

4.3.1 Botanical Description and Distribution of Teak

Tectona grandis is one of three species in the genus Tectona belonging to the family Lamiaceae. The other two species are, *Tectona hamiltoniana* and *Tectona philippinensis*. It is the most popular commercially known timber species in the tropics and subtropics parts of the world due to its valuable high yielding timber. It is a native species to India along, Thailand, Myanmar, and Laos (Kaosa-ard 1989) and has also been successfully naturalised in many South America and in many African countries including Ghana. Teak is the most planted timber species in Ghana and accounts for about 70% of all forest plantations (Owusu & Osei 2011).

4.3.2 Ecological Demands of *Tectona grandis*

Teak is a strong light demander requiring between 75 to 100% of the full sunlight for successful growth. It is also sensitive to frost and drought. In its natural ranges, it tolerates temperature as low as 2 °C to as high as 48 °C and total annual rainfall from 750 to 5000 mm (Vaishnav & Ansari 2018). It coppices and pollards vigorously and escapes damages from frost and drought. The variability in teak is largely due to the occurrence of cross-pollination which helps the species to survive in the different sites (Palanisamy et al. 2016).

4.3.3 Industrial Uses of *Tectona grandis*

Teaks excellent properties makes it useful for a wide range of purposes such as exterior and interior joinery, window and door frames, flooring, cabinet work, garden furniture, decking, boat building, bridges and railway (Borota 1991). In Ghana Teak is cut into poles for carrying electric cables, telephone lines and street lights. Many parts of the teak tree have potent medicinal properties because of the presence of different alkaloids, flavonoids and phenolic compounds. Preparations from the leaves are used in traditional medicine to cure biliousness, bronchitis, tuberculosis and urinary infections (Nidavani 2014).

4.3.4 Leaves of *Tectona grandis*

The leaf is simple, opposite, broadly elliptical or obovate, acute or acuminate, coriaceous, possessing minute glandular dots as shown in figure 1 below. Leaves have a leathery feel, glabrescent above, hairy and scabrous below and is pinnately veined (Palanisamy et al. 2005). Figure 2 is a picture showing a monocultue plantation of teak in Ghana.

Figure 1 Leaves of *Tectona grandis*

Source: http://tropical.theferns.info

Figure 2 Plantation of Teak

Source: http://tropical.theferns.info

4.3.5 Root System of *Tectona grandis*

In deep soils teak develops a taproot, becomes the main water supplier and also makes it resistant to winds. In more-shallow soils teak develops with age several very strong superficial roots, which are concentrated in the upper 50 cm of the soil and may extend up to 20 m from the stem, ensuring its stability. Abundant fine absorbent roots form on young teak plants in the uppermost soil layer during the wet season, but largely die off in the dry season and are replaced by new roots that develop in the deeper layers, provided soil aeration is adequate (White 1991).

4.3.6 Nutritional Demands of Teak

Teak thrives best on soils that are neutral, or slightly alkaline, so the most favourable soils for growth and development usually have a pH of between 6.5–7.5. Sudhakara et al in 2001 reported that stand basal area and volume increment increased with foliar N, P, K and Ca concentrations. Using Diagnosis and Recommendation Integrated Systems (DRIS), Drechsel and Zech (1994) concluded that N, Ca and P were most deficient on the high productive sites of Benin, Liberia, La cote devoir, Nigeria and Togo while in 45% of all stand there was relative excess of aluminium. Teak is a calcicolous species and requires a relatively large amount of calcium in the soil for growth and development (White 1991).

4.3.7 Pollination of Teak

T. grandis is 96-100% self-incompatible. The species is hermaphroditic and pollinated by insects such as black ants, horse flies, and particularly by bees. Fruits mature about 4 months after fertilization. Premature shedding of fruit is a problem. Up to 60% fruit set has been reported following cross-pollination of teak. The individual flower has a 1-day cycle; optimum pollination period is between 1130 h and 1300 h (Orwa et al.2009).

4.3.8 Germination of Teak seeds

Seeds from dry and moist climates differ in the rate at which it can germinate. Almost all teak seeds however, displays some degree of dormancy, making it difficult to germinate uniformly and adequately. The reason for the delay in the germination of teak seed has been attributed to the thick pericarp, which does not soften sufficiently for the embryo to be released (Kadambi 1972). Therefore, pre-treatment of the seeds is essential before sowing.

4.3.9 Effects of Water Stress on Photosynthesis and Transpiration in *Tectona grandis*

Tectona grandis is sensitive to changes in water availability. In the early stages of development water scarcity significantly reduces photosynthetic rates and consequently retards growth of young teak trees. Limited water availability during early stage of Teak plantation establishment results in failure of many reforestation efforts (Tripathi et.al 2017). In an experiment where seedlings of teak were exposed to water stress by withholding watering continuously for 3 weeks. The growth rates of the plants in both the experiment and those in the control group with regards to height and developing leaves in length were unaffected during the first week without watering but they were decreased by about 50 % during the second week and became negligible during the third week of water stress treatment. The rate of leaf production and internodal elongation was also decreased in plants experiencing 2 weeks of water stress. However, after rewatering, these plants regained growth potential and exhibited high rates of leaf expansion and plant growth comparable to those of well-watered plants in the control group.Net photosynthetic rate (P_N) of plants subjected to water stress for 2 weeks was similar to that of well-watered plants. On the contrary, P_N of plants subjected to water stress for 3 weeks was reduced in the afternoon. Also, gs and E of plants experiencing 3-week water stress were decreased in the afternoon. Soon after rewatering, P_N, gs and E reached similar values to those of well-watered plants. This relative decline of growth parameters under water deficit conditions shows a significant sensitivity of teak to drought (G.Rajendrudu & C.V.Naidu 1999).

4.3.10 Biochemical Compounds in Teak

Teak is well known for its durability and resistance to decay and fungal attacks. A large number of different phytochemicals have been isolated and identified from *Tectona grandis*. Table1 below gives summarized details of the chemical constituents of teak. In determining the main factors influencing the decay resistance (Roh Werkst et al. 2006) concluded that planting site, fungal species, radial position and extractive content of home garden teak influences the resistance to decay. According to Rudman and Da Costa (1959) and Simatupang et al. (1996) tectoquinone (2-methylanthraquinone) has insecticidal properties especially termite resistance. Myo Aung (1988) characterized the teak methanol extractives by HPLC and detected the 2-methyl anthraquinone tectoquinone. The hydrophobicity, antioxidant properties and oily nature of teak wood were mainly due to Caoutchouc compound (Simatupang et al 1998). A research was conducted to determine the major compound giving teak its resistance to decay and their results showed naphthoquinone to be the major compound which determines the decay resistance (Roh Werkst et al. 2006).

Table 1 Details of secondary metabolite constituents of *Tectona grandis*

SECONDARY METABOLITES	CHEMICAL COMPOSITION	PART OF TREE
Phenols and phenolic acids	TG1, 2, 3 and 4, Gallic acid Ellagic acid, Acetovanillone, E-isofuraldehyde, 3-hydroxy-1-(4-hydroxy-3,5-dimethoxyphenyl) propan-1-one, evofolin A, and syringaresinol	Leaves
Norlignans	3-methoxylign-7-ene-9,7’-lactone), Tectonoelin B (or7Z)-9’nor-3’,4,4’-trihydroxy-3,5- dimethoxylign-7-ene-9,7’-lactone), medioresinol, 1-hydroxypinoresinol, lariciresinol, balaphonin and zhebeiresinol	Stem, leaves, seed and wood
Flavonoids	Rutin and quercitin	Leaves
Anthraquinones	Possible anthraquinone moieties for dyeing property	Leaves
	Apocarotenoids: tectoionols A and B	Seed, leaves
Glycosoides	Steroidal glycoside: beta-sitosterol-beta-D-[4'-linolenyl-6'-(tridecan-4'''-one-1'''-oxy)] Glucuranopyranoside	Stem bark
	Quinones: 9,10-dimethoxy-2-methyl anthra-1,4-quinone. 1,4-anthraquinone, tectoquinone, lapachol, dehydro-a-lapachone, tecomaquinone I.	Heart wood Leaves
Alkaloides	Naphthoquinone and anthraquinone derivatives	
	Naphthotectone and anthratectone	
Steroids	Steroidal compounds, squalene, polylsoprene, cr-tolylmethyl ether, betulinic acid	Heart wood
Fatty esters	7'-hydroxy-n-octacosanoyl n-decanoate, 20'-hydroxy eicosanyl linolenate and 18'-hydroxy n- decanoate	Stem bark

(Nidavani & Karvekar 2010)

4.4 *Triplochiton scleroxylon* (African whitewood)

4.4.1 Botanical Description and Distribution

Triplochiton scleroxylon locally known as Wawa in Ghana is a tree of the genus Triplochiton and belonging to the family Malvaceae. It is native to the West and Central African forest zone. It is commonly planted in its natural area of distribution mostly in Côte d'Ivoire, Ghana and Nigeria. Currently, it is economically the most important timber species of Ghana and Cameroon, making up about 70% of the volume of timber products exported from Ghana (Burkill 2000).

4.4.2 Ecological Demands of *Triplochiton scleroxylon*

Triplochiton scleroxylon is characteristic for semi-deciduous forest, where it often grows gregariously, but it can sometimes be found in clearings in dense evergreen forest and in dry forest. It occurs up to 900 m altitude in regions with an annual rainfall of up to 3000 mm, but is most abundant at 200–400 m altitude and in areas with an annual rainfall of 1100–1800 mm and two rainy seasons. It requires more fertile, well-drained, ferruginous soils with light or medium texture and acid to neutral pH. It does not thrive in waterlogged areas and in general avoids swamps. It is a light-demanding pioneer species. Seedlings may be very abundant in forest gaps of larger sizes, and the tree is characteristic of secondary forest (Poorter et al. 2004).

4.4.3 Uses of *Triplochiton scleroxylon*

Wood from Wawa is commonly used for interior joinery, panelling, moulding, furniture, boxes and crates, sculptures, matches, pencils, peeled and sliced veneer for interior and exterior parts of plywood, fibre and particle boards, and blockboard. It is of great importance for house building, for beams, posts and planks, and construction in general. The wood pulp can be used to produce paper of moderate quality.The leaves serves as a source of traditional food in Côte d'Ivoire and Benin. It is also applied in traditional medicine to treat oedemas and as an analgesic. Sawdust from the tree is used for the production of edible fungi (Pleurotus spp.). The trees are often grown in cocoa plantations to serve as shade tree (Irvine, 1961).

4.4.4 Stem and Leaves of *Triplochiton scleroxylon*

The leaves are simple palmate, mostly 5-7 lobed, about 8cm long and 10cm wide as shown in figure 3. The margin is entire, cordate and glabrous with a petioloe of about 4cm long. The stem of the tree is usually straight and unbranched up to about 25m and sharp extensive buttresses (illustarted in figure 4) extending to 8m up the trunk (Oteng-Amoako 2006).

Figure 3 Leaves of *T. scleroxylon*

Source: http://www.westafricanplants.senckenberg.de

Figure 4 Buttress system of *Triplochiton scleroxylon*

Source: http://www.westafricanplants.senckenberg.de

4.4.5 Pollination, Dispersal and Germination in *Triplochiton scleroxylon*

It is known that that flower initiation is associated with changing temperature in *Triplochiton scleroxylon*. The fragrant flowers open late in the day and wither within 18 hours. They are pollinated by insects. Cross pollination is needed for the production of viable seed. Fruit production is irregular however mast production occurs with intervals of several years. Fruit development extends into the start of the rainy season, and is frequently impaired by pests such as the fruit-boring weevil *Apion ghanaensis* and other pathogens including the smut fungus Mycosyrinx sp. The fruits are dispersed by wind. It is propagated using stumps and seed but seed production is sporadic and unpredictable with short viability. Germination of seed is epigeal and takes about 6 to 15 days with a germination rate of about 55% (Taylor 1960).

4.4.6 Nutrient Application and Photosynthetic Rate in *Triplochiton scleroxylon*

Smith et al. 2012 studied the effect of nutrient treatment on photosynthetic rate per unit leaf area and other parameters of stock plants in *Triplochiton Scleroxylon* as shown in table 2 and found a significant positive correlation between nutrient application and photosynthetic rate per unit leaf area. A similar trend in carbon gain was found in the cuttings 8 days after harvesting and before roots had emerged. However, the magnitude of the response was less in the cuttings than in the stock plants. Cuttings harvested from stock plants receiving the high nutrient application rate had around 1.5 times higher assimilation rates, whereas leaves on these stock plants had 2.5 times higher assimilation rates compared with the corresponding values in the low nutrient treatments. Leaves of cuttings from stock plants subjected to the highest nutrient treatment had significantly higher nitrogen concentration and lower starch concentration but no difference in total carbohydrate concentration compared with values in the other nutrient treatments (Smith et al. 2012)

Table 2 Effects of nutrient application rate on leaf gas exchange rates and associated environmental variables for *T. scleroxylon* stock plants and cuttings after 8 days in the propagator and prior to root emergence.

Stock Plants	1: Zero	2: Low	3: Medium	4: High
Assimilation rate (µmol m^{-2} s^{-1})	3.46 a	3.51 a	5.54 b	5.69 b
Stomatal conductance (mmol m^{-2} s^{-1})	265 a	261 a	347 a	327 a
Transpiration rate (mmol m^{-2} s^{-1})	2.97 a	2.90 a	3.44 a	3.12 a
Leaf temperature (°C)	27.86 a	27.60 a	28.08 a	28.10 a
Air temperature (°C)	28.96 a	28.82 a	29.11 a	28.95 a
Cuttings before root emergence				
Assimilation rate (µmol m^{-2} s^{-1})	0.80 a	1.64 ab	1.53 ab	2.07 b
Stomatal conductance (mmol m^{-2} s^{-1})	69 a	151 c	82 ab	138 bc
Transpiration rate (mmol m^{-2} s^{-1})	0.86 a	1.13 a	0.84 a	1.27 a
Leaf temperature (°C)	24.03 a	23.78 a	24.18 a	24.42 a
Air temperature (°C)	24.86 a	24.38 a	24.57 a	24.94 a

Source: (Smith et al. 2012)

4.5 *Milicia excelsa* (African Teak)

4.5.1 Botanical Description and Distribution of *Milicia excelsa*

Milicia excelsa is a large dioecious and deciduous tree native to sub-Saharan Africa and belongs to the family Moraceae. The other species *Milicia regia* in the genus is very much similar to the former. *Milicia excelsa* is sold under the trade name ‘Odum’ in Ghana or ‘iroko’ in Nigeria. In Ghana it is moderately distributed in all the different forest types except in the wet evergreen forest (Oteng-Amoako 2006).

4.5.2 Ecological Demands of *Milicia excelsa*

Milicia excelsa is mostly found in areas having an average annual temperature of 25–35°C and an average annual rainfall of 1150–1900 mm. It is considered a pioneer species, demanding intense light and cannot grow under deep shade (Jøker 2002). For instance in young secondary forest, it cannot compete with climbers and shrubs. Although *Milicia excelsa* grows on a large variety of soils, it is reported to be rather demanding with respect to soil fertility, especially the presence of potassium (K) and phosphorus (P). It is considered to be an indicator of fertile soil suitable for farming purposes. It prefers well-drained soils and does not thrive on soils with poor drainage (Bolza & Keating 1972).

4.5.3 Uses of *Milicia excelsa*

The highly valued wood is used for construction work, shipbuilding and marine carpentry, framework, trucks, draining boards, outdoor and indoor joinery, stairs, doors, frames, panelling, flooring and profile boards for decorative and structural uses (Oteng-Amoako 2006). In traditional medicine concoctions are prepared from different parts of the tree illness such as cough, asthma, heart trouble, lumbago, abdominal pain, oedema, ascites, dysmenorrhoea, gonorrhoea and rheumatism. It also has an aphrodisiac and purgative effect (Mshana et al. 2000). The species also plays an important role in controlling erosion and improvement of soil fertility by fixing nitrogen in the soil. The leaves are coomonly used as mulch and also an important source of shade and someimes used as an ornamental tree (Ofori 2007).

4.5.4 Leaves, Bark and Roots of *Milicia excelsa*

In young trees the leaves papery to leathery and green above (as shown in figure 5), paler and hairy below; older leaves often become bright yellow, serrulate at the margin, simple, alternate, 9-20 x 5-10 cm, broadly elliptic or ovate, very shortly acuminate, usually glabrous above and beneath except for minute hairs between the network of veins. Most leaves have about 15 pairs of thick parallel, upcurving, pale-coloured lateral nerves, very prominent beneath and looped close to the margin; ultimate veins thick and forming a rectangular mesh of veins that are conspicuous on the under surface; base subcordate; apex shortly acuminate; edge finely toothed; stalk 2.5-6 cm, stout and glabrous (Berg 1982).

Figure 5 Leaves of *Milicia excelsa*

Source: http://www.mpingoconservation.org

The bark of the tree is characteristically dark grey or pale in colour and exudes a thick and milky or latex when cut or damaged. The surface roots are often prominent red to red-brown with yellow lenticels (Berg 1982).

4.5.5 Germination and Seed Dispersal

Milicia excelsa is mostly propagated by seed. Seeds are commonly dispersed by birds and bats (Osmaston 1965) Germination of the seeds is epigeal, Iight-dependent and it takes 2 to 3 weeks to germinate with a germination rate of about 90% when seeds are fresh. Percentage germination was reduced in the dark only for three small-seeded species that are common in forest soil seed banks: Musanga cecropioides, Nauclea diderrichii and *Milicia excelsa* in a research conducted to evaluate the effects of light on germination of forest trees in Ghana (Kyereh et al. 1999).

4.5.6 Effects of Water Deficit on Photosynthesis and Transpiration in *Milicia Excelsa*

In a study performed in Ghana to determine growth performance of *Milicia Excelsa* populations under water stress at seedling stage, significant reduction in height, root length, leaf area, and dry matter production, plant water status were observed. The seedlings showed significant variations in their P_N, Gs, and E under the different water treatments. Lowest values of P_N, Gs, and E were observed for all seedlings under water stress condition as shown in table 3 below. On average 45% and 59% reductions in height growth and biomass production, respectively, occurred under water stress. Photosynthetic rates, stomatal conductance, and transpiration rate were also severely reduced in all the seedlings under water stress condition (Appiah 2013).

Rao et al. (2008) also made similar observations. Other studies reported similar trends for woody angiosperms, Eucalyptus microtheca (Li & Wang 2003) , Hopea odorata Roxb, Mimusops elengi (Zainudin 2003), and African nightshades (Muthomi 2009). Reductions observed in the growth traits and gas exchange parameters of seedlings are common occurrences in water deficit plants which are often shown as ways of withstanding drought (Agong et al. 2005).

Table 3 Net photosynthesis (PN), stomatal conductance (Gs), transpiration (E) of M. excelsa seedlings from three (3) populations subjected to two watering regimes

Watering treatment	**Population**	**P_N (μmol m^{-2} s^{-1})**	**Gs (mol m^{-2} s^{-1})**	**E (mmol.m^{-2} s^{-1})**
25% field capacity	AHW-1	4.16 (0.25)	33.75 (2.42)	0.44 (0.05)
	KK-6	5.40 (0.40)	36.00 (3.95)	0.63 (0.08)
	EMH-1	3.93 (0.26)	32.14 (2.50)	0.44 (0.07)
100% field capacity	AHW-1	4.47 (0.21)	37.25 (2.41)	0.55 (0.06)
	KK-6	8.55 (0.23)	92.66 (2.28)	1.16 (0.04)
	EMH-1	7.75 (0.35)	81.25 (3.42)	1.04 (0.08)

Source: (Appiah 2013)

4.5.7 Growth Traits and Leaf Ater Potential Under Water Stress in *Milicia Excelsa*

Growth of *Milicia excelsa* like many other plants in general is reduced by water deficit conditions.Several experiments have shown the association of plant growth with water stress as water is an essential resource for plant growth. In a similar experiment performed in *Milicia excelsa* revealed similar results. There was significant differences in seedling height (SH), total leaf area (TLA) , root length (RL) and total biomass (TB) in *Milicia excelsa* populations under different water regimes. All the growth traits tended to be significantly lower for all seedlings under the water stress condition as shown in the table 4. Leaf water potential (Ψ) for all seedlings were also low under high water stress (Appiah 2013).

Table 4 Growth traits of (M. excelsa) Iroko seedlings under water stress.

Trait	Watering Treatment	Population		
		AHW-1	KK-6	EMH-1
Seedling height (cm)	25% field capacity	23 (1.20)a A	20 (1.20)a B	21(1.20)aC
	100% field capacity	31 (1.21)b	46 (1.20)b	41(1.20) b
Total leaf area (cm^2)	25% field capacity	1105 (153.6)a A	1015 (152.1)a B	924 (151.5)a A
	100% field capacity	2259 (154.0)b	3213 (152.3)b	2332 (153.6)b
Root length (cm)	25% field capacity	23 (0.91)a A	19 (0.92)a B	21 (0.92)a B
	100% field capacity	27 (0.90)b	22 (0.91)b	24 (0.93)b
Total biomass(g)	25% field capacity	6 (0.86)a A	4 (0.89)a B	6 (0.88)a A
	100% field capacity	10 (0.87)b	18 (0.88)b	15 (0.89)b
Leaf water potential	25% field capacity	-2.05 (0.27)a A	-2.82 (0.20)a B	-2.08 (0.23)a A
	100% field capacity	-1.45 (0.26)b	-1.81 (0.23)b	-1.52 (0.20)b

Source: (Appiah 2013)

4.5.8 Insect Infestation in *Milicia excelsa*

Harvesting of *Milicia excelsa* is mainly done by selective cutting from the natural forest, however, replacement has proven to be insufficient to match the high rate of exploitation mainly due to its susceptibility to Phytolyma gall attack . According to IUCN , Milicia species is categorized as one of the endangered valuable timber species. Attempts to regenerate *Milicia* species on commercial scales have been limited by *Phytolyma lata* attack on the young plants which eventually leads to gall formation and dieback of the plant. Phytolyma activity interrupts plant physiological processes causing growth reduction and killing the seedlings in most cases. Control of Phytolyma pests through the use of chemical pesticide has been found ineffective due to its hidden nature. Use of companion crops or mixed planting has been reported by several authors as a potential tool for insect pest management (Amaka et al. 2017).

4.5.9 Biomineralization in *Milicia excelsa*

Milicia excelsa (Iroko) as an oxalogenic tree tree has the ability to facilitate carbonate precipitation in tropical oxisols where such accumulations are not expected due to the acidic nature of these types of soils.This unique process is linked to the oxalate-carbonate pathway, which increases soil pH through oxalate oxidation (Cailleau et al. 2011).The system is considered as a net carbon sink because carbonate accumulation involves only atmospheric CO_2 and Ca from $CaCO_3$-free sources. Approimately one ton of mineral carbon was found in and around an 80 year old iroko stump in Ivory Coast which proves he existence of a mineral carbon sink related to the iroko ecosystem (Cailleau et al. 2004). In iroko trees, large accumulations of are present from blocks of 1.5 m wide to micro- and nano-scale forms because of a peculiar oxalate–carbonate biogeochemicalcycle. This cycle demonstrates that calcium oxalate produced by both plants and fungi can be transformed into $CaCO_3$ by bacteria (Braissant et al. 2002).

4.6 *Hevea brasiliensis (*Rubber tree)

4.6.1 Botanical Description and Distribution of *Hevea Brasiliensis*

The natural rubber tree is native to the Amazon rain forest and also occurs naturally in many parts of south America such as Basil, Colombia, Peru, Bolivia and Venezuela. The rubber tree was introduced to Ghana in the late 1800s in the Aburi botanic gardens in the Eastern Region as an ornamental plant. Rubber tree is a deciduous, monoecious tree that belongs to the family Euphorbiaceae. It is an important member of the genus Hevea. It is of major economic importance because its sap-like extract known as latex can be collected and is the primary source of natural rubber. Latex is a cellular fluid consisting of a suspension of natural rubber (cis-polyisoprene) hydrocarbon particles, represented by the formula $(C_5H_8)_n$ in an aqueous medium. Root system is well-developed and has a taproot measuring about 1-2 m long and laterals spreading to about 10 m. The trunk is usually straight, cylindrical and without buttresses. The bark is smooth and pale to dark brown in colour. Inner bark is pale brown, with abundant white latex. Leaves alternate or subopposite at apex of shoot, trifoliate, petioles long with apical glands as seen in figure 6. Leaflets are elliptic or obovate, 4-50 cm x 1.5-15 cm, entire and pinnately veined (Westphal & Jansen 1989). Figure 7 shows the process of latex tapping in a rubber farm.

Figure 6 Foliage of rubber tree showing the leathery surface

Source: http://jayaneththi.blogspot.com

Figure 7 Collecting rubber *Hevea brasiliensis* in a rubber plantation in Ghana

Source: http://www.heliotropicmango.com

4.6.2 Ecological Demands of Rubber Tree

Rubber is a crop well distributed in the lowland tropics where the average daily temperature is about 26-28°C. Lower temperatures slow stem enlargement, prolongs tapping time, and decreases amount of latex produced. Therefore for optimal growth, rubber should be planted at lower altitudes not exceeding 500m. It requires a minimum annual rainfall of 2000mm for growth in plantation. Apart from sandy soils and soils with concrete pans the crop does well in all types of soils. Marshy areas should be avoided since the crop cannot withstand water logging. Rubber can also tolerate a 2 -3 months drought period in some areas. Rubber prefers a well drained and deep soil with enough water due to its deep root system. It is less demanding with regards to its nutrient requirements and as such can survive of sites that do not support growth of crop plants (Westphal & Jansen 1989).

4.6.3 Uses of Rubber Tree

It is cultivated mainly for its latex which is used in the production of natural rubber. The latex can be processed into latex concentrate, sheet rubber or block rubber and the sold to manufacturers as natural raw rubber. Natural raw rubber is mainly used in tyre production which accounts for about 60-70 % of the total world volume of natural rubber produced and for the manufacturing of consumer products such as footwear, sports goods, toys, gloves, latex threads, catheters, condoms etc. The tree itself can also be sawn to give rubber wood (timber). Furthermore, rubber wood can also be burnt to produce fuel charcoal. Seeds contain a semi-drying oil that can be used in making paints and soap (Westphal & Jansen 1989).

4.6.4 Unique Bark Characteristics of Rubber Tree

The bark of the rubber tree is different from most trees in that it has a unique arrangement of layers from the outside toward the inner most part of the bark involving a cork layer, hard bark and a soft bark respectively. The soft bark is made up of longitudinal rows of sieve tubes and latex vessels. Latex vessels are modified sieve tubes. These latex vessels are produced from the cambium in concentric rings as cells which fuse longitudinally while the cross walls disappear. Latex vessels found in the stem, branches and leaves are interconnected. The latex-vessel cylinders are oriented in a clockwise manner at an angle of about 3.5° to the vertical. This explains why tapping cuts are made from upper-left to lower-right. Latex is produced as an exudate when the bark is cut or tapped. The content of the latex vessel is largely dependent on important feature such as the diameter of the vessels, the number of vessels per ring and the number of rings in the soft bark (Westphal & Jansen 1989).

4.6.5 Latex from the Rubber Tree

Latex is made up of a colloidal suspension of rubber particles in an aqueous serum. It is produced in the cytoplasm of specialized cells known as lactifers whose main metabolic fucnction is production of latex using sucrose as a precursor molecule (Carr 2014).The rubber content of rubber in latex may between 25% and 40%. Natural rubber normally has a high viscosity when freshly prepared and may be approximately between 55 and 90 centipoise. In storage and during transit, the viscosity of natural rubber increases to 70-100 centipoise depending on the duration. Currently 10 species are identified in the genus Hevea but only *H. brasiliensis, H. guianensis* and *H. benthamiana* produce usable rubber while the latex of other species is undesirable because of its high resin and low rubber content (Westphal & Jansen 1989).

4.6.6 Germination and Growth of Rubber Tree

Germination of seeds usually takes place 7-10 days after sowing. Seedlings and buddings exhibit growth periodicity. Terminal buds of main stems produce long internodes with leaves clustered towards the end of them. The shoot pushes out vertically, slowly for 2-3 days, then rapidly before tailing off for 1-2 days. Both self- and cross-pollination is carried out by small insects. Self-incompatibility occurs in some clones. Only a small proportion of female flowers set fruit and afterwards many of the fruitlets are shed (Westphal & Jansen 1989).

4.6.7 Drought Tolerance and Photosynthesis in Rubber Tree

Some clones of rubber tree are known to be relatively drought tolerant than others due to their ability to main higher leaf water potential by reducing stomatal conductance when water is limited. Stomata are only found on the lower surface of the leaf at densities from 280 mm^{-2} to 700 mm^{-2}. A research in south India by Rao et al. (1990) compared leaf water potential of two clones during the summer period under the same conditions of water availability and temperature, and found one clone to have a leaf water potential of -1.3Mpa and the other -2.4Mpa demonstrating their variation in drought tolerance. The xylem vessels of rubber trees in water limited conditions stress are vulnerable to cavitation particularly in the leaf petiole. Stomatal closure is important in limiting cavitation. Clones differ in their susceptibility to cavitation. Cavitation occurs in the xylem of the leaf petiole at water potentials in the range −1.8 to −2.0 MPa. Clones of rubber tree were shown to differ in single leaf net photosynthetic rates, particularly at low light intensities. Some clones were identified as having higher WUE_i others and as being less dependent on stomatal conductance than on the capacity of the mesophyll to regulate photosynthesis (Nataraja & Jacob 1999). Light inhibition of photosynthesis can occur particularly in young plants during the early stages of growth when the leaves of young rubber plants are often fully exposed to incoming light at levels beyond the light capacity for photosynthesis. That is greater than 1000 μmolPAR m^{-2} s^{-1}; PAR levels can reach 2000–2500 μmol m^{-2} s^{-1} in tropical areas. Light-induced inhibition of photosynthesis together with shade adaptation by the exposed leaves probably explains why early growth of rubber is enhanced by shade or intercropping (Rodrigo 2007;Senevirathna et al 2003).

4.6.8 Diseases and Pests Affecting Rubber Tree

There are many diseases and pests that affect rubber tree. The most important fungal species in South-East Asia known to cause root disease are *Rigidoporus lignosus* , *Ganoderma pseudoferreum* and *Phellinus noxius* causing white, red, and brown root disease respectively. They cause much destruction and total tree losses in new plantings and replanted areas of rubber. In Ghana the major root diseases control is carried out against white root rot (*Fomes lignosis*). Infected trees show yellowish leaf coloration and eventually die. Hence proper control of these diseases during pre-planting and post-planting is essential. Important fungal leaf diseases are *Colletotrichum* and *Oidium*, causing secondary leaf fall, *Corynespora* (leaf spot) and *Phytophthora* (leaf fall). In rubber plantations in Ghana the fungus (Corynespora cassicola) attacks tree leading to premature fall of all leaves. Bird's eye spot disease caused by *Helminthosporium heveae* is also common, but is confined to the nursery. The most damaging and most feared leaf disease is South American Leaf Blight (SALB) caused by *Microcyclus ulei*. It is limited to South and Central America. Infected trees lose their leaves after every new flush resulting in dieback and ultimately the death of the trees. Underground and aboveground pests are important and require attention at all stages of rubber growth. They include termites (*Coptotermes curvignathus*) and grubs of certain *Melolonthis* beetles. Among the aboveground pests, yellow tea mite (*Hemitarsonemus latus*) and thrips (*Scirtothrips dorsalis*) are commonly present in nurseries, where they cause defoliation of tender leaflets. One physiological condition known as brown blast or dryness is also very common. The initial symptom is increased production of watery latex, followed by a drying up of part or whole of the tapping cut. The cause is still unknown but is generally speculated to be as a result of excessive tapping (Westphal S& Jansen 1989).

4.7 *Entandrophragma cylindricum* (Sapele)

4.7.1 Botanical Description and Distribution of *E. cylindricum*

Entandrophragma is a genus consisting of several species distributed across tropical regions of Africa. It belongs to the family Miliaceae and is related to *Lovoa*, *Khaya* and *Pseudocedrela*. It is widespread, occurring from Sierra Leone east to Uganda, and south to DR Congo and Cabinda (Angola) and moderately found in moist semi-deciduous forests in Ghana (Oteng-Amoako 2006). It is is a premium species with high production and export. In 2004 it was reported to be a vulnerable species by IUCN.

4.7.2 Ecological Demands of *E. cylindricum*

E. cylindricum is most common in semi-deciduous forest, particularly in regions with an annual rainfall of about 1750 mm, a dry period of 2–4 months and a mean annual temperature of 24–26°C. However, it can also be found in evergreen forest. It prefers well-drained sites. *E. cylindricum* is characterized as a non-pioneer light demander. Natural regeneration is often scarce in natural forest, but logging operations creating gaps may promote regeneration, larger gaps appearing more favourable (Bolza & Keating 1972).

4.7.3 Uses of *E. cylindricum*

The wood, usually traded as 'sapele' is highly valued for flooring, interior joinery, interior trim, panelling, stairs, furniture, cabinet work, musical instruments, carvings, ship building, veneer and plywood and construction work.The bole is traditionally used for dug-out canoes. Wood that can not be valorized as timber is used as firewood and for charcoal production (Oteng-Amoako 2006).

4.7.4 Leaves of *E. cylindricum*

As shown in figure 8 below, the leaves are alternate, clustered near ends of twigs, paripinnately compound with 10–19 leaflets; stipules absent; petiole 5–13 cm long, flattened or slightly channelled, often slightly winged at base, rachis 7–17 cm long; petiolules 1–6 mm long; leaflets opposite to alternate, oblong-elliptical to oblong-lanceolate or oblong-ovate, 4–15 cm × 2–5 cm, cuneate to rounded and slightly asymmetrical at base, usually short-acuminate at apex, papery to thinly leathery, almost glabrous, pinnately veined with 6–12 pairs of lateral veins (Oteng-Amoako 2006).

Figure 8 Leaves of *E. cylindricum*

Source: korupplants.myspecies.info

4.7.5 Growth and Development of *E. cylindricum*

In natural forest conditions, seeds germinate abundantly but there is high seedling mortality. Usually less than 1% of seedlings reach 10 cm stem diameter. Growth rate is slow, 20–40 cm per year. Root development also takes considerable amount of time. Light shade is required up to 2 years of age but afterwards require gradual exposure to more light. They can thrive for several years in the shade without significant growth, but when there is enough light as a result of gap opening further growth resumes. Fruits usually open while on the tree and the seeds are dispersed primarly by wind. Seed production is rather sporadic. Fresh seeds have a high germination rate of about 90% but they tend to lose their viability quickly, normally within 3 weeks. Epigeal germination occurs within 14–26 days after sowing. The tree is liable to attacks by insect defoliators, shoot borers, fruit and seed pest (Oteng-Amoako 2006).

4.7.6 Secondary Metabolites of *E. cylindricum*

Several phytochemicals have been isolated from this species. Most important amongst them are discussed in this section. The compund named entandrophragmin has been isolated from the heartwood and bark. It has shown high toxicity to tadpoles. The bark also contains several acyclic triterpenoids known as sapelenins. Extracts from the bark showed inhibitory effects on the reproduction of the maize weevil *Sitophilus zeamais*. The tannin present in the bark has been used experimentally to produce tannin-formaldehyde resin which can be used as lacquer. The essential oil from the bark has been analyzed for trees originating from Cameroon and the Central African Republic. The major constituents were γ-cadinene (9–23%), α-copaene (7–22%) and T-cadinol (18–28%) (Zollo et al. 1999). The seeds contain about 45% oil. The fatty acid composition of the oil is characterized by the presence of about 50% cis-vaccenic acid, a rare isomer of oleic acid that can be used in the industrial production of nylon-11 (Kleiman & Payne-Wahl 1984).

4.8 *Elaeis guineensis* (Oil palm)

4.8.1 Botanical Description of *Elaeis guineensis*

The oil palm, *Elaeis guineensis* is a monoecious tree and one of only two species in the genus Elaeis. The oil palm is single-stemmed and is unable to produce suckers. The apical bud produces the long, feather-shaped leaves, one by one, in a regular sequence. *Elaeis guineensis* is indigenous to the tropical rainforest belt of West and western Central Africa between Guinea and northern Angola. In Ghana it is commonly found in the forest ones in the southern part. The abundance of oil palm groves throughout the forest zone is attributed to early domestication.

4.8.2 Ecological Demands of oil palm tree

Oil palm is a heliophile plant of the humid tropical lowlands. It is most common at the edges of swamps and along river banks, where competition from faster growing tree species is limited. It reaches its maximum photosynthetic activity only under bright sunshine and unrestricted water availability. Under such conditions palms have a single unopened leaf at any time, while several of such ‘spear leaves’ can be observed on palms suffering from drought or other abiotic stress factors. Generally, climatic requirements for high production are: well distributed rainfall of 1800–2000 mm, high air humidity, and at least 1900 hours of sunshine per year. Optimum mean minimum and maximum monthly temperatures are 22–24°C and 29–33°C, respectively. Under conditions of higher annual water deficits (prolonged dry season) or mean minimum monthly temperatures below 18°C, growth and productivity are severely reduced. Oil palm can grow on various soils povided it is well drained with no signs of permanent waterlogging but it can also fairly tolerate short periods of flooding. It also tolerates relatively high soil acidity (pH 4.2—5.5).

4.8.3 Uses of Oil Palm

Two types of oil are extracted from the fruits of Elaeis guineensis: palm oil from the mesocarp and palm-kernel oil from the endosperm. Palm oil is used for a large variety of edible products, such as cooking oils, margarine, vegetable ghee, shortenings, frying and bakery fats. Unrefined red palm oil is an essential ingredient of the West African diet. About 10% of all palm oil, the inferior grades in particular and also refining residues, is used to manufacture soaps, detergents, candles, resins, lubricating greases, cosmetics, glycerol and fatty acids. Palm oil is employed in tin plating and sheet-steel manufacturing. Epoxidized palm oil is used as plasticizer and stabilizer in PVC plastics. Palm oil and more particularly its methyl- or ethyl-ester derivatives have potential as biofuel for diesel engines.

4.8.4 Leaves, Stem and Roots of Oil Palm

Leaves arranged spirally, pinnately compound, up to 8 m long, sheathing; sheath tubular at first, later disintegrating into an interwoven mass of fibres, those fibres attached to the base of the petiole remaining as regularly spaced, broad, flattened spines; petiole 1–2 m long, channelled above, bearing spines; leaflets 250–350 per leaf, irregularly inserted on the rachis, linear but single fold, 35–65 cm × 2–4 cm, pulvinus at base, with thick wax layer on upper and semi-xeromorphic stomata on lower surface. bole erect, cylindrical, up to 75 cm in diameter, but thicker at the swollen, often inverted cone-like basal part, rough and stout due to adhering petiole bases during the first 12–15 years, slender looking and smooth in older palms. root system adventitious, forming a dense mat with a radius of 3–5 m in the upper 40–60 cm of the soil, some primary roots directly below the base of the trunk descending for anchorage for more than 1.5 m, roots with pneumatodes under very moist conditions.

4.8.5 Growth and Development

Pollination is primarily by insects but may aslo be accomplished artificificially as its often done in plantations to increase fruit sets. After harvesting oil palm seeds are dormant. Germination starts with the appearance of a white button at one of the germ pores of the endocarp, which develops within 4 weeks into a seedling but still connected to the seed endosperm by a haustorium. Subsequent leaves gradually change from lanceolate to pinnate over a period of 12–14 months., Leaves on seedlings have no spines and are less xeromorphic than adult leaves. The base of the stem becomes swollen and adventitious primary roots develop from it. In the first 3–4 years, lateral growth of the stem dominates, giving the palm a broad base up to 60 cm in diameter. After that, the stem starts growing in height, 20–75 cm per year, at a somewhat reduced diameter. The rate of height increment and rate of leaf production appear to be independent.

4.8.6 Leaf Water Potential and Gas-Exchange Parameters in Oil Palm Under Water Stress

Suresh et al. (2010) studied the physiological response of oil palm in water deficit conditions and found that oil palm seedlings tolerated water stress by regulating *g*s which in turn helped in maintaining positive values of photosynthetic rates with reduced stomatal opening along with lower leaf water potential (Ψw). Ψw in oil palm seedlings showed significant differences between two treatments on 12th day after imposition of water stress. The Ψw was –3.6 MPa at 24th day after imposition of stress, which was associated with P_N of 0.05 μmol m^{-2} s^{-1} due to stomatal closure. The P_N at the start of experiment was 6.10 μmol m^{-2} s^{-1} and progressively decreased to 0.05 μmol m^{-2} s^{-1} at 24 days after imposition of water stress. Stomatal conductance (*g*s) was significantly reduced from 8th day onwards after imposition of stress. The stomatal closure occurred at 24th day after imposition of water stress in water-stress treatment and consequently reached values close to zero. E at start of the study was 0.13 mmol m^{-2} s^{-1} which progressively declined to 0.01 mmol m^{-2} s^{-1} on 24th day after imposition of water stress. The Ψw in water-stressed oil palm seedlings recovered from –3.6 MPa at 24th day after water stress to –2.8 MPa at 4th day after rehydration and reached similar value to that of control at 12th day after rehydration. P_N, *g*s, and *E* also followed similar trend as that of Ψw in stressed oil palm seedlings after rehydration. The results also show that oil palm seedlings posses physiological plasticity during water stress and its subsequent recovery after rehydration.

4.8.7 Negative Impact of Oil Palm Plantation on the Environment

Deforestation is one of the key problems oil palm plantations pose to the environment in Ghana and in all areas where the tree is planted on commercial scales. Forest lands are constantly been cleared for the purpose of oil palm plantatons. The conversion of natural forests for oil palm plantations has been associated with the loss of biodiversity, including a decline in populations of very important species. The loss of forest consquently results in soil ersion, drying up of water bodies, pollutions etc. Oil palm is considered a relatively poor replacement for natural tropical forest. Current research shows that it ranks behind planted forest, agroforest, and community woodlots in terms of the number of species it can support. Forest conversion and plantation establishment are also significant sources of green house gas emissions. The conversion of tropical rainforest to oil palm plantations is estimated to result in a carbon debt of 610 Mg of CO_2 ha^{-1} which would take between 86 to 93 years to regain (Obidzinski et al. 2012).

5.0 Results

Many important observations were made through this compilation research studies which will pave way for further studies. After I went through a lot of scientific literature to learn about the WUE and ecophysiological traits of native tree species in Ghana, not much was found. It was observed that less work has been done concerning the physiology of tree species. Available information was from studies conducted many years ago and have not been investigated further. There was lack of in-depth and updated information on pure native species and in areas where literatures exist were based on generalisations from studies done in other exotic tropical species. One such important data base is PROTA (Plant Resource of Tropical Africa) which provides summarized information about tree species in Africa concerning their geographical distribution, botanical and anatomical description, ecological demands, silviculture etc but information on physiological processes like photosynthesis, transpiration, WUE, germination, adaptation to stress were limited. Big knowledge gaps were observed during the studies. Many researches done on native species do not provide concrete and quantitative data. For instance, one studies about *Milicia excelsa* on drought tolerance cited in this work used three different populations of the species to evaluate the variation of drought tolerance amongst genotypes of the same species. However, no information was given about the genotypes or populations (for e.g. if the populations were from higher altitudes, different forest types, artificial or natural regeneration). In addition, this species is known to have the ability to fix nitrogen in the soil and hence its presence is an indicator of soil fertility but no literature was available that provides information about the type of bacteria involved in the nitrogen fixation or how much nitrogen it can fix. WUE is a neglected to topic in forestry in Ghana as no information was found on water utilisation of commercial timber species. This and many other observations were observed that needs further research to fully understand the biology of these native species.

6.0 Discussion

Selection of suitable plant species based on their ability to use water efficiently has become an issue of much importance dry regions to save limited water resources (Nazemi et al. 2019). Knowledge about the physiology and ecological demands of a plant is very important to its management for maintaining its survival and to improve production as in the case of crop plants and timber species. In forestry systems, water use efficiency has become an important link between wood production and water management (Cernusak et al. 2006). Knowledge about how tree species utilise water in the phase of water limitation is important in selecting genotypes that could cope with the expected drier global climate in the near future. Trees that are able to maximize biomass production in water limited conditions will be more desirable especially in the dry semi-deciduous forests in Ghana. In this regard *Tectona grandis* could be a promising tree. Amongst the species reviewed in this work it's the only tree that has adapted to growth both in the high forest and savannah zone where a much harsher climate and poorer soil conditions exist. However, its productivity is lesser in the savanna than in the high forest (Nunifu 1997). In an attempt to compile knowledge and fact on the water use efficiency of the industrial tree species in Ghana, a big knowledge gap was found. There is very little scientific information on the WUE or related physiological traits such as drought tolerance, photosynthesis, transpiration, vulnerability to biotic and abiotic stress and adaption to changing climatic conditions. Many important tree species in west Africa are going extinct or threatened due to overexploitation. Replacement alone is not enough to match rate of exploitation and hence leading to an unsustainable production. Many native tree species are being exploited for their valuable timber in Ghana in an unsustainable manner largely due to lack of strict law enforcement on the harvest of timber from reserves and partly due to the lack of knowledge of the physiology and ecological demands of native tree species that helps in their regeneration to match the rate of exploitation. Many restoration and plantations efforts of individual tree species have failed due to the lack of sound understanding of the ecophysiological traits and wrong silvicultural practices. The available literature is scanty, very old and unrevised. Little attention is paid to research in forestry while current research focuses on tree crops such as cocoa and cashew.

7.0 Conclusion

Water is an essential resource needed for the sustainability of forests but in the near future where a much hotter and drier climate is expected globally, water will become a limited resource. In the phase of such climate change it is important to address the issue of efficient water utilization by tree species in other to maintain forest for both production and ecosystem services. More research needs to be done on native timber species in Ghana regarding their ecophysiological traits and more importantly their water use efficiency in order to be able to select species and genotypes that will be capable of adapting to water limited environments.

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