The Management of *Acacia nilotica* Plantation Along the Blue Nile South of Sennar Dam Through Successive Rotation (1935-2006)

By

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A thesis submitted for fulfillment of the requirements for the Degree of M.Sc in Forest Science

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Dedication

To my devoted wife Nadia, daughters, Nehal, and Tagwa and sons Mohamed and Moas.

To my precious parents, beloved brothers and sisters

With great love

Gaffer Awad alka
Acknowledgements

A lot of thanks and praise are due to almighty Alla, who created me from nothing, provided me with health and power to study and accomplish this work. I am really impotent to sign thanks and appreciation to my supervisor Dr. Elnour Abd Alla Elsiddig, Faculty of Forestry, University of Khartoum for his valuable help, endless patience in data analysis, sincere support and encouragement through his guidance. I would like to express my thanks to Dr. Abdelazim Mirghani Ibrahim, director general, FNC, for offering this chance and sponsoring the study. I am thankful to Dr. Abdalla Gaafar Mohamed, for his most valuable help and sincere assistance. Distinctive thanks are due to Dr. Abdelazim Yassin Abdelgadir, Dr. Abdalla Mirghani, Dr. Huda Sharawi and Dr. Mohamed Awad for their generous assistance.

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Abstract

The Management of *Acacia nilotica* Plantation Along the Blue Nile South of Sennar Dam Through Successive Rotations (1935-2006)

The study considers the case of the *Acacia nilotica* forest reserve distributed along Blue Nile between Sennar and Roseirise dams. *Acacia nilotica* grows on flood basins on three topographic sites the gerf, karrb and Maya. The present study tackled successive inventory data collected from Sunt (*Acacia nilotica*) plantation in 1964, 1984, 1996 and 2006. Data was used to group the plantation into area by age classes for successive 30 years rotation of 1935-1964 and 1965-1994. Overlapping 30 years period of 1955-1984 and 1977-2006 were used for monitoring and evaluation.

The overall objective of this research is to enhance developing management plans for *Acacia nilotica* plantation that under threat of being severely disturbed so as to enhance its sustainability along Blue Nile.

The results indicated that the area by age group of the first 30 year rotation (1935-1964) had the tendency towards a sustainable management system with areas of five years age classes were close together in values. The area by age group of the second rotation (1965-1994) showed highly significant differences with a tendency towards unsustainable management system.

Disturbance of the sustainable system resulted from large area felling over time that caused increased bare land and decreased area of final felling age / group. The bare land increased from 4% in 1964 to 29% in 2007 and the 16 -30 years age / group decreased from 54% in 1964 to 28% in 2007. The young fifteen years of age group 1-15 years showed limited change between 50% in 1955 to 42% in 2006.
The results indicated expansion in bare area; shrink in planted area decreasing trends in areas of final felling crops over successive rotations. The yield of *Acacia nilotica* stands, measured in average number of tree per hectare for the final felling age group, indicated a decline from (100-125) to (50-60) tree per hectare. These changes were associated with changes in other yield factor including average DBH, average height and top height. Causes for this change were not investigated but may be attributed to changes in social aspects and industrial development that exerted pressure on the riverine forest.

The main conclusion from this study is: The present management practice of *Acacia nilotica* plantation has resulted in failure to attain sustainable production; site index and yield are always directly correlated and the application of productivity models facilitated production of top height from stumps of large trees and improved the calculation of site index values.

The study recommends that the management system of *Acacia nilotica* plantation south of Sennar Dam should be revised.
لا يوجد نص يمكن قراءته بشكل طبيعي من الصورة المقدمة.
إذا 1955 %50 لجذب زهرة 15-1 لجذب إلى ورك 2006 %50

لقد تقدر : زهرة 50% لأول مرة 5% لجذب如果我们

تظهر إلى الصغرى العمرية الجماعة التي تظهر

الوافدين الذين يقلون على الجزيرة بين

تؤدي إلى تغيير عام %50 في 1955

في تغذية 42% في 2006.

تقوم هذه الدراسة بناشئة

المساحة ونزع الزراعة

 До 100 (60-50) في (125-100) لجذب في

المساحة في الزراعة

تقتصر هذه الأشجار من

التغذية وفقا لتغيير

ارتفاع وعليه

التنمية الاجتماعية

الأحداثية بالازدهار في

التي تعود إلى صناعة

النيلية الغابات على ضغط

وهي من الصناعة والشاحن

التدريبية.

المساحة تتحقق في الدورة

الانتجية الملمَّعة بواسطة

التي تلقي عليه

تقدم ويقة مستواها وMENTS

البادئة ودعالتلابية

الوصية.

النوعية بعدها كبيرة الأشجار

الارتفاع على الحصول سهل

الانتجية النموذجية وتطبيق

القيمة حساب وتحسين

الواجعة

الشافع جنوب النيلية

إدارة نظام المرجعة

الدراسة

تحقق. 

النوعية لدوري لكونه

الشافع
CHAPTER 1

Introduction

1.1 Background

Sudan is the largest African country with an area of approximately 2.5 million square km, extending between latitude 4°N and 22°N and longitude 22°E and 38°E.

Sudan is characterized by diverse climatic conditions from desert (0 - 100 mm rainfall per annum) to savannah (200 - 850 mm rainfall per annum). The diversity of such climatic conditions in a very large country like the Sudan constitutes major problems in natural resources development and their conservation.

The country was divided administratively into 25 states, and it’s bounded on the east by the red sea and on the other sides by nine African and Arab countries. The forests and wood lands cover 17.7% of the total land area (FAO-2000).

The forests reserves constitute approximately 12.5% of the total area of the Sudan (CNS 1992 - 2002). As planned, the aim is to increase the reserved forests area up to a minimum of 25% of the area of the country. Demands of forests products mainly fuel wood and charcoal was steadily increasing during the last ten years as they are extensively used as major source of energy for more than 80% of the population (FNC 2003). The country also produces sawn timber but in insufficient quantities to meet domestic demand. Part of Sudan demand for softwood is supplied from Jebel Marra.
plantation and some imported. Paper products are also imported. The productive forests included the savannah wood lands of the central and western parts of the country dominated by various species of acacia. Sudan is the principal source of gum arabic. Sudan also is one of the world’s main producers of olibanum resin (FAO, 2000).

Sudan natural resources cover is decreasing at alarming rate. Lack of sound management and land use plans, population pressure, desertification, mechanized agriculture in dryland, traditional and shifting cultivation and fire are considered as the main factors that contribute to the decrease of forests cover (FNC, 2003).

1.2 Climate zone

The Sudan is characterized by diverse climatic condition, associated with different vegetation zones. The northern part of the country is an arid zone (latitude 14° – 23° N) characterized by very low summer rainfall. The southern part is comprised of two major divisions of the savannah regions, low rainfall wood land savannah (latitude 10° -14° N) and high rainfall wood land savannah (latitude 3° -10° N).

The annual rainfall varies between less than 100 mm in the northern desert region to more than 1200 mm in the equatorial southern region. The Sudan is divided into five ecological zones according to rainfall (Table 1.1).
Table 1.1 vegetation classifications in relation to rain fall

<table>
<thead>
<tr>
<th>Vegetation</th>
<th>Rainfall</th>
<th>Area in (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert</td>
<td>0-75 mm</td>
<td>9020800 (36%)</td>
</tr>
<tr>
<td>Semi desert</td>
<td>75-300 mm</td>
<td>50111000 (20%)</td>
</tr>
<tr>
<td>Low rainfall savannah</td>
<td>300-900mm</td>
<td>60139000 (24%)</td>
</tr>
<tr>
<td>High rainfall savannah</td>
<td>900-1500mm</td>
<td>30070000 (12%)</td>
</tr>
<tr>
<td>Flood plains mountain vegetation</td>
<td>1500-2000mm</td>
<td>20046000 (8%)</td>
</tr>
</tbody>
</table>

Source: FOSA 2001

The whole area of the central sector falls within the savannah region characterized by short period of rain fall for 3-4 months and longer dry periods for 8-9 months.

The period from November-February is characterized by cold-dry weather and from March –June hot dry weather, usually the rainy season starts from July and ends in October with a savannah type of distribution having its peak in August and with occasional showers in May. In central Sudan the following divisions of land use can be observed (Table 1.2)

Table 1.2 Land-use in Sudan

<table>
<thead>
<tr>
<th>Item</th>
<th>Area in (000 hectare)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Land area</td>
<td>237.600</td>
</tr>
<tr>
<td>Area under water</td>
<td>12.981</td>
</tr>
<tr>
<td>Forests and wood land</td>
<td>67.546</td>
</tr>
<tr>
<td>Other</td>
<td>170.054</td>
</tr>
<tr>
<td>Total area</td>
<td>250.581</td>
</tr>
</tbody>
</table>

(Source: FAO, 2005)
1.3 Population

Population has grown from approximately 10.26 million in 1956 to 25.6 million in 1993 and in 2002 the country’s population was 30.3 million. The annual growth rate has increased from 1.9% to 2.7%.

Forests products and services play crucial role in the economy of Sudan and the life of its people. Wood fuel constitutes 80% of the total national energy consumption. Almost 80% of the population depends on wood fuel for energy. Seventy percent of the people engaged in agriculture or pastoral activities, another 21% are employed in services and only 9% have jobs in manufacturing, construction, mining and civil services.

1.4 Forests resources in Sudan

Forests products play an important role in the economy of the Sudan and the life of its people. FOSA (2001) stated that about 40 tree species constitute fodder trees particularly during dry season. Wood fuel constitutes 80% of the total national energy consumption.

Forests are essential as local, national and global resources. At the local levels, communities in and around the forests are always dependent on forests products. Despite increasing substitution by alternative materials, the demands for timber continue to rise. However, the survival of forests and wood land is fundamental to the continued functioning of the environmental system (FOSA, 2001).

Gum Arabic and other tree gum are among the important foreign exchange earners, poles and sawn timber for construction and furniture are also supplied by forest.
The environmental and the social roles played by the Sudan forests are even more pronounced; forests and wood lands are first and the last defense line against desert encroachment south wards.

1.5 Riverain forests

Riverain forests lie along both banks of the Blue Nile as detached areas. They form a very unique forests ecosystem covering a vast area and of vital economic importance for the economy of the Sudan and its nature conservation. They played vital environmental roles. They provide fuel wood, poles and sawn timber for construction and furniture. They protect the Nile system and its water shed and soil against wind and water erosion. The riverain forests are contained in two main sites. The floods basin that provide the main site for Sunt growing in pure stand and upper slopes of the flood basin represent higher levels where flood is rare contain forests of mixed species including *Acacia seyal, Balanites aegyptiaca, Faidherbia albida, Ziziphus spina-christi* and others. The non –wood forests products from these forests are vital to the livelihood support of the local communities.

Riverain forests are valuable both in terms of their direct use and indirect use value.

1.6 *Acacia nilotica* (Sunt)

The forestry development plans put great emphasis on the establishment of plantation of indigenous and exotic species inside the forests reserves. Various species within the savannah region have been declared reserved wherever they regenerate successfully and their timber uses identified. Of these tree species, Sunt has been found as the most valuable timber
producing species. An ability to regenerate successfully on flooded sites along the Nile and its tributaries that satisfy most of the utilization standards make the species the most important in the economy of the Sudan (Jackson 1959).

*Acacia nilotica* (Sunt) plantations of the Blue Nile flood basins form significant resource with an area approximately 12000 hectare. The contribution of *Acacia nilotica* species to the total sawn timber production in northern Sudan is estimated at 40-50% its contribution to the production of round timber may be considered as second to the eucalyptus. The latter continues to be the major source of round timber in the Sudan. Sunt also adds substantial volume to the production of fuel wood estimated at 10-15% of the country’s total production (Elsiddig 1980)

Sunt timber is preferably used in various utilization practices including railway sleepers, heavy construction, turnery, boat building and fuel. Its proprieties are very attractive to such uses that require hard and strong mechanical proprieties (Elsiddiq and Hetherington, 1985).

Exploitation of the natural Sunt forests started at the beginning of the last century when the first sawmill was installed in 1901 for trials of railway sleeper production. However the industry of sleeper’s production due progressed very slowly. During the period 1930-1940 fairly good progress in agricultural development enhanced further railway construction that resulted in more consumption of Sunt timber for railway sleepers and wood fuel. Small scale reforestation programme of Sunt forests resulted in the first even-aged plantation in the Sudan (Jackson, 1959)
Large scale conversion of the natural crop into plantations started in 1948 (Booth 1949) since then the annual area planted with the species has been progressively increasing.

1.7 Problem Statement

The Sunt plantation extending south of Sennar dam is managed on thirty years rotation since 1935. Although the management follow guidelines and prescriptions setting targets of stocking and yield, forests are rapidly dwindling and ground vegetation has disappeared from extensive areas creating various environmental hazards, forests products scarcity and land productivity decline, in terms of age/area gradation, decrease in the number of trees per unit area, decline of the main tree size and the productivity per tree. These results are largely attributed to the management approaches currently adopted in Sudan, which are criticized as being inefficient and unsustainable. Many reports have warned about the declining of forests recourses and emphasized on the importance of quantifying and appraising the remaining resources. Sustainable management of these resources was emphasized on many occasions. Furthermore the involvement of local communities in the stand management is limited to activities at early ages of stand. People access to the stands at productive stages is prevented by law. People needs force to exercise illegal activities which might have resulted in forests degradation.

1.8 Justification

- The need for assessment of the status of Sunt forests is felt as to investigate the extent of changes
- Importance of assessing changes in stocking density, target yield etc. For future salvation program
• The need for studying the effect of degradation and deforestation of natural forest resources on Sunt forests and their management
• Since illegal access to the riverain forest reserves by the communities living near riverain is one of the major factor that disturb such ecosystem, assessment of the impact of this illegal access on management of riverain forests is badly needed

1.9 Objective
The overall objective of this research is to provide management tools for *Acacia nilotica* plantation that under threat of being severely disturbed so as to enhance its sustainability a long Blue Nile

Specific objectives
• To assess the trend models of productivity and forest cover change of Sunt along Blue Nile during successive rotations.
• To assess changing in top height, number of trees area, age gradation, average diameter of final felling trees during successive rotations.
CHAPTER 2

Literature Review

2.1 The management plan

The plan usually describes the goals of the forester and a schedule of activities for the woods. Generally the larger the forest acreage and the more different conditions of soils and tree sizes in the woods, the more details are needed in the plan (Osmaston 1968). Where there are major differences in various sections of the woods in the form of productivity classes, the needed forestry activity will likely be quite different (Husch et al. 1972). Therefore, the plan of activities will vary for each of the different major conditions found; dividing the woods into sections or compartments allows the forester to treat them separately. The plan will tell the forester when the available time will be spent for the best future returns. In other words, it sets priorities for work which needs to be accomplished (Loetsch et al. 1972).

A management plan is a tool to help the forester set goals, and assign priorities to forest management activities. Systematic planning is a step to productive forests and satisfactions gained from forest regardless of how large or how small are the acreage (Taylor 1978). The management plan facilitates monitoring and evaluation of the forest conditions and their suitability to defined management objective which can by using indicators (Miles 2004). The management goals set for the management of Sunt plantation includes timber production and protection of the Nile ecosystem (Elsiddig 2002).
The plan of actions and activates prescriptions are considered main aspects of the plan contents that all plans have in common (Osmanston 1968) but there are many things which may be made a part of a plan of action; naturally few plans will contain all of them. These other aspects are well essential to support the sustainable management and are continued in the various texts dealing with plans construction and execution (Husch et al 1972).

Maps of the property showing the boundaries and the wooded portions of the property clearly separated using time scale as age class or productivity level quality class. When the woods have been divided into several compartments for management purposes, each compartment should be shown along with the acreage and the conditions of the compartment, such as the major kinds of tree, the size-class of the trees, the site characteristics and the production potentials. Brickel (1992) profiled comprehensive description of methods of delineation map units in relation of stand inventory and management. Each stand as management unit will be inventoried in details to facilitate delineation of productivity class and levels. A description of the management compartment including the major kinds of trees, the most important size-class of the trees, some idea of the amount of merchantable volume by tree kinds and sizes, and what forestry practices are needed. The provision of detailed information and their changes over time is the mechanism for the monitoring and evaluation of stands capacity to meet objectives (Elsiddig 2002). Of particular interest will be the area/age gradation and area extent of the whole forests delineated according to area/age as indicators of a sustainable system.
For those with trees at or near mature size, information on available markets prices and product specifications should be compiled and plans for sales and contracts developed. The information on these aspects are essential for final felling crop management and production forecast. Accordingly successive inventories will qualify the management system to address criteria and indicators related to the average diameter values and production requirements (Musselman, 1992).

Mapping forest stands facilitates integration of forest boundaries with forest road that can help execution of management plans in efficient and sustainable approach. Thoughts should be given to road layout and construction so any road or trails will have permanent value for future harvests and forestry activities as well as a current sale. Roads can coincide with boundaries of major classes. Plans and activities for other values such as wildlife, water, and any other use of interest to the owner may be considered (Stoehrr 1955).

A date should be established for a review of the current plans; the date will depend upon the forest conditions and how much activity will take place in the near future. Reviewing of forest activities and there monitoring requires successive inventories to check results of activates with planned actions (Elsiddig 2002). In the case of Sunt plantation the thinning schedules every three years starting at age six years is an example (Jackson 1958).

The management of Sunt plantation on the higher slopes or the lower slopes is based on the site quality and individual tree size-class's development. The rotation age has been set at 30 years based on clear felling to mature stands 30 years of age (Jackson 1959; Foggie 1968).
2.2 Forest planning and management in Sudan

The early history of Sudan forestry is one of heavy exploitation of natural forests without reservation and rehabilitation. This type of mismanagement continued until the end of the first three decades of the twentieth century when forest management planning started. The first working plan for some Riverain forests came into operation in 1929 and a complete working plan covered the period 1929-1933 for only six reserved forests and twelve unclassified forests (Elsiddig 2002). The limited experience in management planning made the area covered by these working plans limited in area.

Agreement on reservation program was settled with the issuance and enactment of Sudan forest policy 1932 of the central and provincial forest ordinances. The policy emphasized the need for concentration management planning and wood production in side forest reserves because of the provision of protection that enhance regeneration of tree species. The first proper management plan was prepared for Riverain forests. Booth (1948) defined the approach of plan preparation as conservation plan. The objective was directed towards the continuous development of equal area of annual plantation as the basis for sustainable management. This working plan was followed by preparation of forest working plans in different areas of Sudan but very limited.

At the same time no management plans were made for the natural forests except for very few reserved natural forests. All management activities executed within the natural forest reserves are mainly concerned with protection through patrolling system. Such approaches turned the forest management into a punishing tool rather than a development mechanism
(Vink, 1987). Moreover, the few existing management plans have clearly failed to achieve their intended objectives, e.g. sustainable production of railway sleepers from the Riverain forests because they were concentrated on timber and didn’t consider the various needs and interest of different stakeholders, particularly local communities. Such management plans are not based on site understanding nor on the conditions around the forests such as people needs and the type and size of the products needed (Elsiddig 2002).

The serious error in forest uses associated with forest reserves have come about from an attempt to manage the forest on material – yield scale i.e. to plan timber cutting for human needs according to fixed rotations 15 years, 20 years or 30 years management plans, irrespective of the ecological conditions such as site quality, changing climatic condition and human induced changes. These numbers of years, present an irrelevant cycle in the whole forest functioning. There is a need for revising the conventional timber management and considering more ecologically oriented management approaches in order to consider site and site quality. Recent inventories (1986 - 1997) indicated wide variation in area/age units and variation in the average number of stems per feddan in most of the forest reserves (Elsiddig 2002). Also there is an observed decline in volumes of fuel wood produced due to lopping of tall trees and delimming (Elsiddig and Hamid 2000). *Acacia nilotica* (Sunt) has been found the most valuable timber producing species. The Riverain forests, which can be considered, as the most unique ecosystem in the world, should be managed to provide an array of uses and services while providing protection to the Nile ecosystem (Elsiddig 2002). The current decision of using the species mainly for timber
production is a decision typically based on narrow objectives and on the financial returns. Alternative uses of the forest ecosystem and the many environmental values are subsequently lost (Elsiddig and Hamid 2000). This approach for timber production as the main use may be the reason for forest degradation and productivity variation over rotation.

Forest managers are sometime challenged by the task to transform national-level goals into forest-level prescription, yet more difficulties are expected to arise from the fact that global emphasis on forest management planning is being based not only on timber production but also on values such as biodiversity conservation, carbon sequestration, wildlife and amenities (Elsiddig 2002). Considering such multiple goals assist in satisfaction of sustainability objective and maintenance of the productive capacity of the forest (Osmaston 1968).

2.3 Sustainable Forest Management (SFM)

The increasing rate of forests depletion in the Sudan has brought into focus the shortfall of traditional control of forest management systems in sustaining the forest resources. The concept of sustainable forest management implies the stewardship and use of forest resources to provide a range of direct and indirect benefits over time on sustainable basis. International initiatives and agreements and national policies require foresters to demonstrate that forestry practices satisfy the criteria of sustainability (http://www.forestresearch.gov.uk). A major step forward occurred in 1992 based on the world summit of the United Nations. As a result, the international concern was focusing on the conservation and sustainable management of forest.
The aim of sustainable forest management is to ensure that the goods and services derived from the forest resources meet present and future needs (Miles 2002). In its broadest sense, forest management encompasses the administrative, legal, technical, economic, social and environmental aspects of the conservation and use of forests to meet the present needs as well as the needs of the future generations (Helms 1998).

According to FAO, many developing countries have inadequate funding and human resources for the preparation, implementation and monitoring of forest management plans, and lack mechanisms to ensure the participation and involvement of all stakeholders in forest planning and development. Where forest management plans exist, they are frequently limited to ensuring sustained production of wood, without due concern for non-wood products and services or social and environmental values (www.fao.org/forestry).

FAO defines sustainable forest management as the stewardship and use of forests and forest lands in a way, and at a rate, that maintains their biodiversity, productivity, regeneration capacity, vitality and their potential to fulfill, now and in the future, relevant ecological, economic and social functions, at local, national, and global levels, and that does not cause damage to other ecosystems. Forest managers must assess and integrate a wide array of sometimes conflicting factors - commercial and non-commercial values, environmental considerations, community needs, and even global impact - to produce sound forest management plans.

The ecosystem approach is a strategy for the integrated management of land, water and living resources that promotes conservation and sustainable
use in an equitable way. Sustainable forest management was recognized by parties of the Convention on Biological Diversity in 2004 to be a concrete means of applying the Ecosystem Approach to forest ecosystems.

2.4 Participatory Forest Management (PFM)

The forest reforms seek to initiate a process of eliminating the fundamental causes of the depletion of forest resources through participation of various stakeholders. During recent years a number of changes in the management of forests have taken place. There is a major shift towards people oriented forest management (Wily, L. 2001).

The destruction of natural forests for agriculture, fuelwood, timber, pasture, urbanization have had an impact on many poor rural people who are dependent on forest resources for energy, fodder, food, medicine, housing etc. It is now being recognized that local communities need to be involved in establishing sustainable forest management systems and forestry authorities in Sudan are opening a number of opportunities for sustainable forest management and biodiversity conservation based on participatory approaches (Wily, L. 2000). More and more, ‘participatory’ approaches to forest governance and management are replacing intensive ‘scientific’ exploitation.

Worldwide, Joint Forest Management (JFM) has emerged as an important intervention in management of forest resources where, village groups have started to protect and reclaim degraded forest lands. The JFM seeks to develop partnerships between local community’s institutions and the forest authorities for sustainable management. The objective of JFM is to ensure
sustainable use of forests to meet local needs equitably while ensuring environmental sustainability (Wily and Gibbon, 2001).

2.5 The utilization of Sunt in Sudan

Utilization objectives of Sunt are based on timber production as recognized in the working plans (Booth, 1948; Jackson, 1958; Foggie 1968). They include:

- Production of railway sleepers.
- Sawn timber for local uses.
- Fuelwood.

Sleeper’s production consists of the Sudan railway sleeper of 2.3 meters length and 25x12.5 cm cross-sectional area, and the Sudan Gezira Board light rail sleepers of 1.2 meter length and 20x10 cm. This kind of product constitutes the most important produce of all sawn timber production from the species (Elsiddig and Hetherington, 1985). The management of the species for these production targets necessitates careful treatments of the Sunt plantation over successive periods to end at 30 years of age with the best quality log size-classes (Jackson 1958). Selection of the best quality trees of the largest 50 trees per feddan at age 12 years to be maintained as final felling trees was recommended (Jackson 1958; Foggie 1968).

Swan timber production from small sized log (25 cm at small end), and from the waste of sleepers production, includes bed units, stools, lintels for construction purposes and boat industry. Fuelwood production includes the remaining waste of sawmills and the branch wood of sizes smaller than 25 cm in diameter (Elsiddig and Hetherington 1985). These products come as second priority in the management objectives and come from small sized trees, which are not the target for final felling.
The main product, railway sleepers, constitutes the major objective of the management plan defined to be attained at thirty years rotation (Elsiddig, 1980). Jackson (1958) described the time-scale activities conducted in sequence of thinning operations every three years starting at age six years and ends up to 50 trees per feddan after the fifth thinning cycle, reached at age 20 years. The best quality trees were retained at age 20 years and maintained up to age 30 years for final felling and also constitute the site quality trees being the largest and best formed. Each of these trees constitutes a potential to be selected as top height tree for site index evaluation (Elsiddig 1980). Elsiddig (2002) defined these best trees as site indicators. Any 4-10 trees per 0.1 hectare provide a measure of the site index and the quality of the site.

2.6 Site classification

Different tree species growing on the same site or the same species growing on different sites exhibits great variability in growth and volume productivity (Carmean1975; Hetherington and Elsiddig, 1983/84). These variations stimulated the development of various concepts, methods and techniques for site evaluation and productivity assessment, (Carmean1975; Elsiddig1980). Such variations in growth and productivity provide the basis for monitoring and evaluation of difference in major products over time.

2.7 Site types and quality classes

Three site types were identified on the basis of the topography and the soil of the flood basins, and given the local names Karab Slope, Maya and Gerf slope (Jackson, 1958; Elsiddig and Hetherington, 1985; Elsiddig 2002). Polymorphic site index curves were constructed for each site type and eventually combined into two groups on the basis of their shape producing
one set of curves for the Gerf slopes and one set for the Karab and Maya (Elsiddig and Hetherington 1982).

Analysis showed that a logical grouping into classes resulted in an improvement in tree volume prediction and volume tables were prepared by Elsiddig (1980). for:
- Quality class I: all gerf slopes and karab slopes and Maya of site index 21 - 25.
- Quality class II: karab slopes and Maya of site index 17 - 20.

The site quality description in this case is first based on physical factors i.e. to geographical factor, then biological factors are based on top height measurement. Tree size-classes and saw logs production for railway sleeper's production were found to exhibit differences between quality class I and quality class II. Hence, quality classification is a measure of differences in productivity.

Productivity can also be measured indirectly by looking at how well plants are growing on different soils or topographic classes. Differences can qualitatively be evaluated based on experience. It can be understood that when this idea is applied to how well trees are growing on a site, the productivity is called site quality. The idea is that sites with the fastest growing trees have the most productive conditions (Assmann 1970).

Trees on sites with productive soils will be taller and larger in diameter than trees of the same age growing on less productive soils. For this reason top height is used as a measure for site and used for site classification. It implies that top height trees must be conserved throughout the rotation and during successive rotation to facilitate accurate site index evaluation.
selected fifty largest trees per feddan according to Jackson provided such condition.

2.8 Site Index

Site quality can be estimated by means of a site index. The relationship between the top height and age of trees on one particular site is called its site index (Schumacher, 1933 Carmean, 1975). It’s important to recognize that within a forested property of any size, there will no doubt be a good deal of variation in the soil found there and its productivity. Therefore, it’s very likely that parts of forest will have different site quality (Carmean, 1975).

Of all the indirect measures investigated, the rate of height growth has been the most practical, consistent, and useful indicator of site quality with respect to timber production. The standard practice has been to define site index in terms of the total height of the dominants, the largest and full-crowned trees in a stand. These trees capture the most light, moisture, and nutrients in a stand. Numerically, site index is the total height of the dominant trees in a stand at specified ages, 20 years in case of Sunt (Elsiddig 1980).

Since many objectives relate to volume, it is often used as a measure of density. Volume is interpreted in relation to some standard, such as the volume represented in a yield table, and is given as a percentage of stocking for a specified objective.
2.9 Site index curve

Regardless of whether the method of site definition to be used is the direct or indirect approach, a necessary perquisite is a set of site index curves. Because of this and because of the primary importance of site index in forest productivity classification and forest management, a great deal of work has been directed to methods of site index curve construction and their use in site index prediction. The original approach was graphical, based on the assumption of an anamorphic growth pattern (Bruce 1926, Bruce and Schumacher 1950). The approach is named "the harmonized curve method" as it employs a scatter diagram of the observations and harmonization of the family of curves on a proportional basis. It was very useful for long time as basis of yield studies and forest management. It is described in many textbooks of menstruation (Bruce and Schumacher 1950, Carron 1968).

Site index information has been collected for most of the major tree species. The productivity of different soils for one particular species is represented by means of a graph or curve, (Kocher and Blanc. 1996). The “site index” is the height of the trees at the index age, which can be from 16 to 30 years, depending on the site index classification system used. The curves can be constructed for sites of different site quality and show tree height growth versus tree age (Kocher and Blanc, 1996).

2.10 Estimating Site Index

Estimating the site index for forest requires finding out how fast the trees are growing. This requires knowing how tall the trees are and how old they are (Splechtan 2001). It is important to choose trees that have been dominant during their whole lifetime. This is because trees which have been...
overtopped by others will have slower growth and therefore, be shorter for their age than the dominant trees in the stand (Kocher and Blanc, 1996). It implies that selection of trees which are not dominant will under estimate the site index and accordingly under estimate the site quality (Boyer 2001).

The height of the tree can be measured fairly easily. Trees can be measured from the ground with a special instrument, known as clinometers. It can also be very easily measured by using tree measuring stick for short trees at early ages. Site index values can be presented in a graph or in tables (Elsiddig 1980). To estimate site index, the age of the site tree is taken and located on the horizontal axis of the graph. A line is drawn straight up. Then the height of the site tree is located on the vertical axis and a straight line is drawn across (Kocher and Blanc, 1996). The use of site index tables facilitates reading of site index against age value, at different ages to provide for site quality and yield in past and future (Curtis 1972)

2.11 Site Quality Classes

Site quality class, usually numbered in Roman numerical from I (best) to III (worst) is a grouping of site indexes used to determine among other things, the productivity rates for the stand. It also determines whether or not it can be zoned as (timber production zone).

In most counties, on sites (Site Class I to III), site class is also used to determine which of the compartment “Practice Rules” may apply on the forest (Kocher and Blanc, 1996).

Site quality class is a similar idea to site index, but slightly different. In general, the many different site indices for each species have been lumped
together into a series of site quality classes. These site classes are known as site class I through III. For Sunt plantation qualitative classification has been applied as Gerf, Karab and Maya. then site indeces of gerif (site index 21 – 25) are grouped as quality class I. for the karab slopes and Maya, site index (21-25) are classified as quality class I, while site index 16 – 20 are grouped as Q.C.II (Elsiddig 1980).

The most productive sites, those capable of growing the fastest trees, are grouped together into site class I, while the least productive are lumped into site class III (Kocher and Blanc. 1996). Therefore, site quality classes are usually used to compare sites within specific regions and forest types. A site class property cannot be assumed to have the same growth potential along the outer Karab slopes as a site class property in the gerf of the Riverain along the Blue Nile. While the measure of site index for forest stand is relatively straight forward, a determination of site class requires localized information to be factored (Kocher and Blanc, 1996). Because taxes and timber harvest regulations are involved, it may be needed to rely on the professional judgment of a professional forester to accurately determine the property’s site class.

2.12 Site Quality and Stand characteristics

Site quality tells how much timber a forest can potentially produce. The productivity of forest is defined in terms of the maximum amount of volume that the forest can produce over a given period. Site quality is measured as an index related to this timber productivity (Nyland. 1983). Since total volume accumulation for site assessment is not easy, top height is the alternative measure for site quality assessment.
It is very important to understand that the productivity of forest varies greatly by site. On one site very good growth may be observed, while on another site, the same species at the same age may grow poorly (Nyland, 1983). Site quality can be changed by fertilization, vegetation control or irrigation. Only highly intensive treatment can make a productive site out of a poor one (Nyland, 1983)

2.13 Density and Stocking

Density is a measurable attribute of a stand. Stand density is a measure of how many trees are growing per unit area. Together, site and density tell how much timber can be produced, as well as what kind of wood quality can be expected at harvest time (Nyland 1983). Stand density can describe how much a site is being used and the intensity of competition between trees for the site's resources (i.e., water, light, nutrients and space). At higher densities, the growth rates of individual trees slow down because there are more trees competing for the site's limited resources (Bennett 1970).

Stocking refers to the adequacy of a given stand density to meet some specified management objective. Hence, stands are often referred to as under stocked or fully stocked (Briegleb 1952, Bick ford 1957). Stocking is a relative concept - a stand that is overstocked for one management objective may be under stocked for another (Nyland 1983).
2.14 Thinning

Once trees crowd out, it is important to open stands back up as soon as possible. Thinning should be conducted in Riverain forests and should be implemented as the word “thinning from below” applies, so the end result will be closed canopy. Commercial thinning can be implemented at age 6 to 20 years, depending on the site quality (Jackson 1958).

Site quality can be measured as height that trees will reach by a certain age (usually 20 years). A good *Acacia nilotica* site might be 25 meters at 20 years. A typical forestry thinning provides space for the residual trees to grow but does not allow sunlight to penetrate to the ground; additional tree removal is, therefore, in order. Basal area is the total cross-sectional area of wood in the stand, expressed as square meter per hectare or feddan. The forestry rule of thumb is usually to thin a stand until the site index is about equal with increasing age. For Sunt, thinning stops at age 20 when 50 trees per feddan are remaining (Jackson 1958). Five thinnings used to be applied for *Acacia nilotica* plantation, namely at ages six, nine, twelve, fifteen and twenty years (Jackson 1958). By the twentieth year the crop would be reduced to fifty trees per Fadden (125/ha) at approximately 9 x 9 meter spacing (Elsiddig 2002).

All the *Acacia nilotica* plantations exist between Sennar and Demazin are managed on 30 years rotation length for the production of railway sleepers as the main management objective. To satisfy this system of management on sustainable basis, the plantations remanded in accordance to management plans which incorporate regular thinning regime and yield
prescription. Jackson (1958) recommended five thinning *Acacia nilotica* plantation, namely at ages 6, 9, 12, 15 and 20 years (Figure 5.1).

Figure 5.10 Diagrammatic illustration of thinning schedule for Sunt plantation over age 1-30 years.

At each thinning, a yield table is followed as guide for the number of trees per hectare to be left after the removal of the trees marked for thinning. At age twelve years and before executing the third thinning, it is usually prescribed that the best fifty trees per feddan (125 trees per hectare) are selected and marked as the final felling trees (Jackson 1958). It is assumed that at this age, the best recognized trees reflect the site productivity and they will remain as the site quality trees through the rotation. The trees that satisfy railway sleepers production were accordingly identified and selected
(125 tree/ha) and marked at age 12 years and that was done before the third thinning (Jackson, 1958). Thinnings continue following the management plans guidelines (Both, 1949; Jackson, 1958; Foggie, 1968). By the twentieth year the crop would be reduced to fifty trees per feddan (125/ha) at approximately 9 x 9 meter spacing. These trees are conserved and protected until age thirty years when finally felled. These 125 trees per hectare produce 150-185 sleepers per hectare (FNC records, Suki sawmill, 1960-1965). Jackson, (1958) stated that the final felling of 125 trees per hectare produced an average of 1.25-1.5 railway sleeper per tree.

With time, the practice of final felling, crop selection and marking was abandoned. At present, the final crop is usually less than fifty trees per Fadden ranging between 25 and 35 trees. This might because of heavy thinning, or that successive thinning continued beyond the age of twenty years. Ahmed (1997) observed large stumps of recently felled trees in stands approaching final felling, while small-sized trees left. This condition of selection of large trees for felling may result in reducing the top height value and the site quality.

Mukhtar (1978) stated that Acacia nilotica stands started to be over thinned since 1970 in order to satisfy the deficit of logs supply to the sawmills due to failure in logs transportation across the river (for economic reason). The average produce of railway sleepers declined to approximately 0.8 sleepers per average tree at age 30 years, with the majority of trees producing a single sleeper or nil. No more than thirty to forty sleeper feddan could be produced.
The decline of sleeper production per feddan and per tree may be due to the decline of the stem number per feddan and the reduction of average stem size of the mean tree due to abandoning of final felling crop selection and marking used to be carried out at the third thinning. The diameter at breast height of the mean tree has decline (Elsiddigg 1980). While it is at present in the range of 30-45 cm, it was in the range of 45-62 cm indicating the effectiveness of selection and marking of the final felling crop at early age of stand development (Faculty of Forestry final year students 1981-1990). Ahmed (1997), using 0.25 feddan sample plots for data collection in *Acacia nilotica* plantations along the Blue Nile, concluded that the stocking falls to the range of 25-44 trees per feddan and the DBH ranges between 37 and 48 cm.

*Acacia nilotica* is a light demander, a characteristic that requires great care in thinning practice. Heavy thinning, usually practiced at present, induced heavy branching resulting in short boles that may have large size but shorter than the standard length for the railway sleeper production. That is contrary to the situation in the past when long straight boles were obtained having sometimes twice the standard length for sleeper production.

2.15 Afforestation and silvicultural treatment

Of the various Acacia species growing in the savannah region, sunt is found to be the only species well adapted to flooded basins of the Blue Nile. It requires greater soil moisture supplies than is provided by the local rainfall, a characteristic that makes regular flooding a favourable condition for its regeneration, growth and development (Booth 1949, 1966; Foggie 1968).
On the mayas and the lower slopes of the gerif and karab of the flood basins which are seasonally flooded, sunt forms pure stands and other species is ever found to compete with it. On the upper slopes of the gerif though rarely flooded, the available moisture is enough to maintain the species growth provided that competition with other species like *Zizyphus spinacristi* and *tamarix aphylla* is eliminated (Sudan For. Dept. Ann. Rep. 1951\52-1969\70). (SFDR, 1951, 1970)

Sunt is indigenous to the region and regenerates naturally and more successfully in the flood basins than any other species so that there is no question of species choice for these sites (Booth 1966). Knowledge of these ecological characteristics of sunt has been useful in the afforestation techniques used for its plantation establishment on these sites. All plantations of the study area have been established artificially by either pit sowing or broadcasting of seeds pretreated by sulphuric acid or submerged in water. In general pit sowing is the standard establishment technique on the upper slopes of the gerif and karab which are flooded for short periods. Seed broadcasting on the other hand is the standard practice on the regularly flooded mayas and the lower slopes of the basins. Here, there is no problem of weed competition as the weeds are eliminated by the floods. On sites where pit sowing is practiced, advantage is sometimes taken of the taungya system to reduce the weeding and establishment cost. These two techniques constitute the main methods of plantation establishment. No transplant trials have been successful (Sudan For. Dept. Ann. Rep. 1951\52-1969\70). (SFDR, 1951, 1970).

The initial stocking of sunt stands at a spacing of $2 \times 2$ meters approximates 1000-1100 stems per feddan 2500 stems/ ha. Thinning usually commences
at the age of 5-6 years from the date of establishment, with subsequent thinning every three years and the last thinning is carried at age 20 years. However, the thinning intensity, the final stocking and the rotation age have been a subject of continuous discussion and trials. In the last two decades the final felling trees per hectare have been subject to variations. Earlier thinning prescriptions attempted by Booth (1949), Jackson (1959), DeeVeer (1961) did not include numerical guides except for the final crop where an average of 50-60 trees per feddan were to be retained (Ahmed 1976).

The thinning prescription of Booth (1949) was a summary of a general thinning programme as it appeared in his statement; the continuation of thinning began in 1947-1948 in immature sunt leaving trees which would produce sleeper diameter logs before the forest is cut. Jackson (1959) recommended heavy thinning for the first three thinning during the period of rapid height growth, and light thinning for the rest of the time. The first numerical guide to thinning practice in sunt stands was made by Foggie (1968) based on the provisional yield tables for sunt by khan (1964). Ahmed (1976) summarized the quantitative guide of the yield tables and outlined the method of their application.

The definition of the rotation age has also been a controversial subject. Booth (1949) recommended 35 years as the probable rotation suitable for the production of the size expected to satisfy the utilization specification for which the crop was managed. Jackson (1959) suggested that 30 years could be a suitable age. Foggie (1968) agreed with Booth (1949) on a 35 years rotation age.
2.16 Top height and diameter at breast height (DBH)

In each sample plot, DBH was measured in cm and the four large diameter trees were selected for total height measurement in meters. The average of these heights provided the average top height of the sample plot. Average top height data of sample plots were recorded for each compartment together with compartment age. Average top height and age were used to estimate site index of each plot using site index curves (Hetherington and Elsiddig, 1983/84).

This procedure was done for all compartments in Sunt forest in the study area, in order to facilitate area/age grouping and also site quality classification for Sunt compartments. DBH in each sample plot was measured for every tree and recorded against serial numbers. Measurements of DBH facilitated selection and measurement of top height trees. The values of DBH for the final felling compartments were used to provide average values and range in cm. The serial numbers provide the number of trees per hectare for these final felling compartments. In the management system each forest was divided into six to ten compartments ranging between 16.0 and 30 hectare (Jackson 1959). Each compartment, representing one year age group, was felled and regenerated the same year.

The compartment does not correspond to a site class although the flood basin constitutes three topographic sites based on the flood basin configuration as from the river bank to the clay plain (Jackson 1959; Elsiddig 1980; Eltayeb 1985). Felling and regeneration take place over the whole compartment at one year irrespective of the differences in site qualities across the flood basin. Brickel (1992) states that stand boundaries
can be defined on vegetative and topographic differences, and that it is impossible to give general rules on compartments size beyond saying that they should be as small as necessary to preserve differences meaningful to management.

Investigations in connection with the preparation of volume tables, (Elsiddig 1980; Hetherington and Elsiddig 1983\84) showed significant differences in growth trends and production potentials between two site quality classes identified on the bases of top height value across the flood basin of the Blue Nile bearing *Acacia nilotica* plantations. Stands in both quality classes are at present managed with similar objectives and on the same rotation, but they produce timber of different quality and size (Hetherington and Elsiddig 1983\84). Stand growing on quality class 1 sites meet current management objectives by producing sawlogs suitable for railway sleeper production in thirty years (Elsiddig and Hetherington 1985). On quality class 11 sites, the minimum dimensions for sleeper production are rarely achieved within thirty years period but they do produce material, which satisfies the small sized saw timber market on shorter rotation (Hetherington and Esiddig 1983\84). Studies on sunt timber quality also indicate variation in relation to site type (Dafa alla, 1998).

### 2.17 Natural vegetation tree cover

The Sudan was once the home of great forests that covered most of the vegetation and desertified areas. The tables below show the characteristics and uses of different species in the different forest regions of Sudan (Elhuri 1989).
### Table (2.1) characteristics of desert forests in Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Latitude</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Desert</td>
<td><em>Acacia nilotica</em>&lt;br&gt;<em>Acacia tortilis</em>&lt;br&gt;<em>Balanites aegyptiaca</em>&lt;br&gt;<em>Acacia seyal</em>&lt;br&gt;<em>Ziziphus spina christii</em></td>
<td>14-16 N</td>
<td>Fire wood and poles railway sleepers</td>
</tr>
</tbody>
</table>

Source: Elamin (1996)

### Table (2.2) characteristics of wood land savanna on clay forests in Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Latitude</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood land savanna on clay</td>
<td><em>Acacia mellifera</em>&lt;br&gt;<em>Commiphora Africana</em>&lt;br&gt;<em>Balanites aegyptiaca</em>&lt;br&gt;<em>Acacia seyal</em>&lt;br&gt;<em>Angiosus leocarpus</em></td>
<td>10-14 N</td>
<td>Charcoal production, furniture, boats.</td>
</tr>
</tbody>
</table>

### Table (2.3) characteristics of wood land savanna on sand forests in Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Latitude</th>
<th>Uses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wood land savanna on sand</td>
<td><em>Acacia Senegal</em>&lt;br&gt;<em>Acacia radiana</em>&lt;br&gt;<em>Dallbergia melanoxylon</em>&lt;br&gt;<em>Combretum cordofanum</em>&lt;br&gt;<em>Terminalia laxiflora</em></td>
<td>10-14 N</td>
<td>Gum production, high-grade timber for high furniture</td>
</tr>
</tbody>
</table>
Table (2.4) characteristics of high rainfall forests in Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Latitude</th>
<th>Uses</th>
</tr>
</thead>
</table>
| High rainfall wood   | *Khaya senegalensis*  
                      | *Combretum hartmannianum*  
                      | *Parkia Africana*  
                      | *Isoberlina doka*  
                      | *Angioossus leucarpus*  
                      | *Albizia zygia*  
                      | *Annona chroysophylla*  
                      | *Khaya grandifoliola*  
                      | 10-14 N  
                      | Houses construction, furniture, boats.      |

Table (2.5) characteristics of mountain forests in Sudan

<table>
<thead>
<tr>
<th>Region</th>
<th>Species</th>
<th>Latitude</th>
<th>Uses</th>
</tr>
</thead>
</table>
| Mountain forest  
1- Imatong and Dongotona  
2- Didinga  
3- The Red Sea Hills  
4- Jebbel Marra | *Hayginia abyssinica*  
                | *Podocarpus melanjianus*  
                | *Olea hastetteri*  
                | *Juniperus procera*  
                | *Olea chrysothyloa*  
                | *Dracaena ombet*  
                | *Olea chrysophylla*  
                | *Cordial africana*  
                | *Ficus sp*  
                | *Salik sasaf*  
                | *Pinus sp*  
                | 10 N  
                | Timber for development project, urban houses, furniture etc. |

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CHAPTER 3

Study Area

3.1 location and climate

The study area is located in Blue Nile and Sennar States, between latitudes 12-13° N. It includes 44 sunt forests with total areas 12000 hectar. The Snut forests are constituted of individual units with area between 500 - 1500 faddans, alternating on both sides of the Blue Nile in a narrow discontinuous strip of approximately three miles in width traversed by the Blue Nile. The northern boundary of the area is about 200 miles south of khartoum, the capital of the Sudan (Figure 3.1).

All the area falls within the savannah region characterized by short rainy season and a longer dry period (Harrison and Jackson, 1958). As the area lies within very narrow geographical limits, its climate is rather uniform. The annual rainfall variability at both ends of the area is less than 10% of the average annual rainfall of the area, falling within a range of 550-620 mm per annum (Jackson 1959).

The rainy season starts in June and ends in October with a savannah type of distribution having its peak in August. Occasional light showers fall in May. The period from November - February is characterized by cold dry weather and hot dry weather from March to June (Booth 1949, Jackson 1959).

During the rainy season, the prevailing winds are from the south east and during the dry season from the north east. The mean daily maximum
temperature is lowest in January (about 30°C day temperature) and highest in May (about 41°C day temperature).
Figure 3.1 the study area
Table (3.1) Temperature (minimum and maximum), relative humidity and rainfall for the period 1993-2002

<table>
<thead>
<tr>
<th>Year</th>
<th>m. max. low Temp. Year</th>
<th>Monthey min. high Temp. year</th>
<th>m. relative humidity %</th>
<th>Mean Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>16.6</td>
<td>35.2</td>
<td>48</td>
<td>698</td>
</tr>
<tr>
<td>1994</td>
<td>18.3</td>
<td>36.9</td>
<td>49</td>
<td>700</td>
</tr>
<tr>
<td>1995</td>
<td>21.7</td>
<td>39.5</td>
<td>46</td>
<td>695</td>
</tr>
<tr>
<td>1996</td>
<td>24.2</td>
<td>40.6</td>
<td>45</td>
<td>680</td>
</tr>
<tr>
<td>1997</td>
<td>24.8</td>
<td>38.5</td>
<td>46</td>
<td>685</td>
</tr>
<tr>
<td>1998</td>
<td>22.6</td>
<td>35.3</td>
<td>44</td>
<td>670</td>
</tr>
<tr>
<td>1999</td>
<td>21.4</td>
<td>32.1</td>
<td>45</td>
<td>674</td>
</tr>
<tr>
<td>2000</td>
<td>21</td>
<td>31.3</td>
<td>40</td>
<td>365</td>
</tr>
<tr>
<td>2001</td>
<td>20.9</td>
<td>32.5</td>
<td>39</td>
<td>625</td>
</tr>
<tr>
<td>2002</td>
<td>21.3</td>
<td>34.9</td>
<td>37</td>
<td>570</td>
</tr>
</tbody>
</table>
Figure (3.2) Water level, Sennar Dam for period 1998-2007

Figure (3.3) Water level, Roseires Dams for the period 1998-2007
3.2 configuration and floods

The unique feature of the topography of the flood basins of the Blue Nile has been created by the meandering action of the Blue Nile. The mechanism involves erosion on one bank and deposition of sand and silt on the opposite bank. Although this process is slow, it is believed to be continuous, cutting off alternating channels and creating a new river course. The cut-off channels are linked to the new river by narrow canals which become shallow due to the continuous deposition of sand and silt (Foggie 1968).

The existing flood basins of the Blue Nile, that now bear sunt crops, are believed to have been created by this meandering activity of the river. They were originally part of an old river course (Jackson 1959). The topographic features of these basins are common to all and described by figure 3.3 which represents a cross-section through a typical flood basin. The bottom of the basin, the old river bed, is locally known as maya which means a shallow depression often flooded. The basin slopes nearest to the present river are locally known as gerf slopes and the slopes adjoining the clay plains inland, as karab slopes.

The Blue Nile level starts to rise in May at the onset of the rainy season on the abyssinian plateau in Ethiopia. The level reaches its peak in August which almost coincides with the time that the monthly rainfall peak is reached. The maximum level is then maintained during August and starts falling from the beginning of September until it reaches its minimum in early May (Sennar Nile gauge reading 1998-2007). Except for exceptional years, the level rises within a range of 8-13 metres between May and August.
Figure 3.3 Diagramatic transect across a meander of the Blue Nile basin

Flooding of the basins follows the trend of the river floods. The high levels of the (gerif) and (karab) upper slopes are flooded only rarely during periods of exceptionally high floods when the river levels rise by more than 13 meters, and for very short periods. The lower slopes of the basins however are usually flooded for 1-3 months during July- September when the river levels peak. The (mayas) on the other hand are usually flooded for periods ranging between 5-12 months (SFDR, 1951, Sudan forests dept. annual rep. 1951\ 52- 1969\70). Prolonged flood periods occur in basins nearer to the Sennar dam bordering the north boundary of the area (map, appendix).

Most of the flood water comes from river through the natural canals that link the basins with the river. It has been sometimes possible to control the basin flood levels by controlling the junctions of the canals with the river.
Walls built at the canal junction with the river have been found effective in controlling undesirable flooding. A small amount of the basin floods comes from water run-off from inland.

3.3 Soils

Flowing from south to north, the Blue Nile traverses the vast clay plains of the Sennar and Blue Nile States. The soil of these plains is referred to as (cracking clays) a term that describes the cracking nature of the soil during the hot dry weather (Tothill 1946, 1948). Bunting and Lea (1962) stated that the whole of the clay plain surface between the Blue Nile and White Nile, except for the trough and grooves of the Blue Nile, is covered with a mantle of alluvial, hydromorph clay. The clay layer is believed to have been brought by the Blue Nile, during the past pluvial period, from Abyssinian high floods. The continuous weathering process by the wind and water run-off made an important contribution (Grabham 1934; Bunting and Lea 1962; Foggie 1968). The uppermost clay bed may be from 6-10 meters in depth overlying alternating layers of sandy and silty alluvial beds (Foggie 1968). Evidence of the underlying alluvial beds has been drawn from deep water wells near settlement areas. During the rainy season, the clay soil absorbs water, swells and closes the cracks. When water saturated, the clay becomes impermeable and most of the surface water is drained by run-off (Jackson 1958).

The soils of the flood basins of the Blue Nile exhibit some variations from that of the clay plains. Here the soils may be classified into three major soil groups related to the basin topographic classes. The dominant soil of the maya is typical of the dark, cracking clays believed to have been brought from the clay plains by water run-off (Foggie 1968). It is a black, clay soil
that cracks widely in the dry season. The karab slopes are eroded slopes characterized by a high content of sand and gravel exposed as a result of erosion. The gerif slopes on the other hand have deep, permeable silt deposits known to be the most fertile type of soils (Booth 1949).

The clay plain soils and the flood basins soils have been influenced mainly by weather factors. The deep underlying geological rocks of the ancient basement complex had no effect on their formation (Bunting and Lea 1962; Foggie 1968).

### 3.4 Vegetation

The natural vegetation of the study area prior to the establishment of sunt plantations can be described in relation to the topographic classes and their soil groups. Man activities through cultivation and plantation establishment may have modified the vegetation succession of the area, a situation which makes it difficult to describe the vegetation under closed canopies or areas cleared for agricultural purposes. However the type of vegetation found on areas after final fellings or under poorly stocked sunt crops is observed to have similar features to the natural vegetation described in many publications (Andrews 1948; Booth 1949; Smith 1949; Harrison and Jackson 1958).

The characteristic natural vegetation type on the northern Fung clay plains is Acacia – Balanytes savannah woodland associated with thorny bushes, scrub and annual tall and short grass (Harrison and Jackson 1958; Foggie 1968). Annual grass fires and grazing are among the many factors that contribute to the disturbance of the vegetal development of this area. However, the clearance of the land for cultivation and fuel wood production
are the dominant factors in the destruction, of approximately 37,000 acres annually (Sudan For. Dept. Ann. Rep 1951\'52; Foggie 1968, 1969\'70).

Because of the extremely limited capacity of the clay soils for available water, the occurrence of sunt on the clay plains is sporadic and confined to small catchment areas or narrow water courses periodically flooded by rain water run-off (Smith 1949). Sunt, however, attains its best development in the flood basins of the Blue Nile and its tributaries in pure stands or mixture (Harrison and Jackson 1958; Booth 1966). The natural forest type and the associated vegetation on these basins vary on the different topographic classes (Table 3.2).

On the karab slopes a mixture of acacias including sunt constitutes the forest type of the rarely flooded upper slopes. The proportion of sunt increases down the slopes towards the maya and decreases towards the clay plains (Booth 1949; Jackson 1959; Foggie 1968). The associated vegetation includes Cyprus species on the lower slopes and punicum and Aristeda species on the upper slopes.

On the gerf slopes, the upper slopes bear a mixture of species dominated by sunt while the lower slopes are characterized by pure stands of sunt. The associated ground flora includes punicum species, cassia species and beckoropsis species. Sparse bushes include *Zizyphus spina-christi* and *Tamarix aphylla* (Jackson 1959).

On the maya where prolonged flooding usually occurs, the ground flora is absent except for a sparse cover of a crickly-leaved mixture of herbs known collectively as terma. Mayas flooded for over six months are almost
bare of tree cover. The only species found as scattered trees is Sunt. Maya flooded for a period up to six months carry pure sunt stands. However there are a few mayas that may be flooded for optimum period of 3-5 months where better growth of Sunt is observed and the terma cover becomes denser.

It can be concluded from what has been mentioned above that the forest type and vegetations cover in the flood basins bear some relationship to the topography, soil and flood conditions. This relationship is clearly observed in sunt distribution and growth.
<table>
<thead>
<tr>
<th>Site types</th>
<th>Topographic features</th>
<th>Soil types</th>
<th>Vegetation</th>
<th>Dominant species</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maya</td>
<td>The bottom of the flood basin</td>
<td>Hard surface cracking clay</td>
<td>Crickly leaved hoary prostrate herbs known collectively as <em>terma</em> species</td>
<td><em>Chrosophora plicata</em>&lt;br&gt;<em>coldinia species</em>&lt;br&gt;<em>Heliotropium sp.</em>&lt;br&gt;<em>Cyprus rotandrus</em></td>
<td>Flooded for 4-6 or over 6 months</td>
</tr>
<tr>
<td>Gearf slopes</td>
<td>Slopes of the flood basin between the maya and the river</td>
<td>Predominantly silt soil with low percentage of clay and sand</td>
<td>Perennial shrubs and herbs sparsely distributed under the sun canopy</td>
<td><em>Punicum sp.</em>&lt;br&gt;<em>Cassia tora</em></td>
<td>Flooded for short period. Upper slopes rarely flooded</td>
</tr>
<tr>
<td>Karab slopes</td>
<td>Slopes of the flood basin between maya and the clay plains</td>
<td>High content of sand and gravel</td>
<td>Low slopes close to the maya have sparse vegetation similar to that found on maya. Higher slopes have a mixture of vegetation similar to maya and gearf</td>
<td><em>Punicum sp.</em> On upper slopes. Lower slopes have dense <em>Cyprus rotandrus</em></td>
<td>Flooded similar to gearf slopes</td>
</tr>
</tbody>
</table>
Chapter 4

Materials and Methods

4.1 General

The methodology is concerned with collection of primary and secondary data. The secondary data consists of information collected from records, reports and previous working plans and studies concerned with the Sunt plantation in flood basins of the study area. The source of data included the Forest National Corporation (FNC) at headquarters and at FNC offices at Sennar and Blue Nile states.

The primary data was based on the field work conducted in Sunt forest reserves along the Blue Nile based on successive inventories over the period 1935 – 2006.

4.2 Field work

Within the framework of forest inventory carried in Sunt forests along the Blue Nile, data was collected from Sunt forest reserves along the Blue Nile in forests between Sennar and Roseires dams. Data collected was based on sampling procedure carried in 2006 inventory using systematic line plot sampling. All forests were inventoried.

Sample plots were located on lines, which were systematically distributed, at 200 meters and the plots were equidistant at 200 meters along the lines. Sample plot area was 0.1 hectare giving a sampling present of 2.5%.
In addition to the data of the inventory carried in 2006, data of successive inventories were available for three measurement periods, each covering all compartments. The first measurement was data of 1964, the second data was carried in 1983 and the third data was conducted in 1996. Accordingly four sets of data were available. Two sets of data covered two rotations: 1935-1964 and 1965-1994. The other two groups represent monitoring and evaluation data; (the 1983 and the 2006 inventory data) collected in the middle of the second and first half of the third rotations. Each data set consisted of area in hectares and age in years for stocked and bare areas.

4.3 Forest Boundary survey

Forest boundary survey was carried out for forests reserve in two stages. In the first stage boundary survey was conducted following the boundary of existing forest, using compass, chain and ranging rods. Lines distances in meters and lines bearings were recorded. The data was used for drawing a map for existing forest boundary 2006.

In the second stage, use was made of the original maps, which contain location of survey stones as existing marks demarcating the original common points between survey lines. The boundary data provided means for estimation forest area and bare area. The collected data included information on compartments area, stocked area and bare areas. Data also included information of tree and sample plot measurements courting top height, DBH, and number of trees per hectare by compartment in addition to compartment age.
4.4 Data Analysis

Data was grouped into two classes and analyzed using, top height averages by sample plot and age pairs to access site index curves for Sunt plantation. The site index curve, defined by top height and age, was extrapolated to age 20 years to estimate the site index value. The site index value was then used to define the quality class (Q.C) for each sample plot. Site index values $\geq 21$ classified the plot into Q.C.I and site index values $< 21$ classified the plot into Q.C.II.

This procedure was done for every sample plot in compartments and forests of all the area between Sennar Dam and Roseires Dam using the inventory of 2006.

4.5 Area – age groups

A list of compartments was prepared and the compartment area and age were registered. The stocked area was calculated for each compartment based on the assumption that the number of stocked plots represents the stocked area of the compartment. The process resulted in data of area planted and plantation age for each compartment.

4.6 Forest cover change

Data of forest boundary survey carried for Sennar and also for all forests of the Blue Nile was used for construction of the forest map of existing cover in 2006. From data developed using the original positions of stones and survey lines, the maps were traced and change in forest area was calculated.
4.7 productivity change

The data of top height, DBH, and number of trees, by sample plots, for selected compartments at final felling stage in (2006) and similar data for same forests in first and second rotation were used to monitor the forest productivity changes. For the same compartment, top height values, site index and Q.C were estimated for selected compartments, in 2006 and from previous data at similar ages. Data of number of trees per hectare for the age classes 21 year to age class at final felling (30 years) are expected to be within 100-125 trees. Comparison was made between the number of trees at the range of age – class 21-30 years in 2006 and in time of first or second rotation. Average diameter at value and DBH range at final felling was also compared.

Data analysis was performed by two methods. First, data descriptive form was employed using tables and histograms to provide comparison between area/age trends across the rotations. In the second form, statistical comparison was made to develop objective means of comparisons.
CHAPTER 5

Result and Discussions

5.1. Plantation structure

The principle of sustainable forest yield is one of the fundamental concepts of continuous forest management necessitates that an approximately equal volume or value of timber should be cut every year (Osmaston 1968). To secure this, an approach towards a normal forest is required in which all the age classes are appropriately represented over the rotation length in approximately equal areas (Davis 1975; Taylor 1962).

The plantations of *Acacia nilotica*, along the Blue Nile flood basins, in the south of Sennar Dam, were managed over thirty years rotation for the production of railway sleepers and other small-sized sawn timber. The plantations represent an simple example of forests approaching normality during the first thirty years rotation, 1935-1964 (Table 5.1). The area of the younger crop of the second fifteen years age group during the period 1950 – 1964 constitutes 45.2% of the total forest crop area, while the older crop of the first fifteen years age group during the period 1935 – 1949, constitutes 54.8% of the forests area. The average annual area for the whole thirty years period was approximately (368) hectares within the range (297.0 – 475.0) hectares. Such range provides for controlling the balance in annual area for felling and that can always be possible by using part of the old crop as buffer during felling time in order to bring the annual felling area to equal area/age gradation (Loeschau, 1977).
The plantations were established on the basis of blocks of approximately equal areas annually felled and regenerated during the period 1935 – 1964 (Jackson 1959). The annual block area approximates one thirtieth (400 hectares) of all the *Acacia nilotica* forests area 12000 hectares along the Blue Nile, south of Sennar dam. During the felling season, the felling blocks area are distributed over many forests along the Blue Nile that in total represented the annual area allocated as felling coupes.

Table (5.1) *Acacia nilotica* age class distribution during the first thirty years rotation, 1935-1964

<table>
<thead>
<tr>
<th>Planting year</th>
<th>Age class years</th>
<th>Plantation area (\text{ha})</th>
<th>% of total area</th>
<th>Annual planting area (/\text{ha})</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Second 15 Years (young)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1960-64</td>
<td>1-5</td>
<td>1488 ha</td>
<td>12.4</td>
<td>297.6 ha</td>
</tr>
<tr>
<td>1955-59</td>
<td>6-10</td>
<td>1780 ha</td>
<td>14.8</td>
<td>356.0 ha</td>
</tr>
<tr>
<td>1950-54</td>
<td>11-15</td>
<td>1936 ha</td>
<td>16.1</td>
<td>378.2 ha</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td>5204 ha</td>
<td>43.3</td>
<td></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td></td>
<td></td>
<td>346.9 ha</td>
</tr>
<tr>
<td><strong>First 15 Years (old)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1945-49</td>
<td>16-20</td>
<td>2376 ha</td>
<td>19.8</td>
<td>475.2 ha</td>
</tr>
<tr>
<td>1940-44</td>
<td>21-25</td>
<td>1800 ha</td>
<td>15.0</td>
<td>360.0 ha</td>
</tr>
<tr>
<td>1935-39</td>
<td>26-30</td>
<td>2139 ha</td>
<td>17.8</td>
<td>427.8 ha</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td>6315 ha</td>
<td>52.6</td>
<td></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td></td>
<td></td>
<td>421 ha</td>
</tr>
<tr>
<td><strong>Bare land area</strong></td>
<td>1964</td>
<td>zero</td>
<td>481 ha</td>
<td>4.1</td>
</tr>
</tbody>
</table>

Source: 1958 inventory (Jackson 1959) and 1964 inventory of the Forest Department.

Yield continued to be regulated on the basis of annual areas (Jackson 1959; Foggie 1968; Eltayeb 1985). This situation of forests structure represented by area / age gradation satisfied a good level of sustainable
yield during the first rotation length (1935-1964) as indicated by (Table 5.1); and up to the middle of the second rotation (1965-1994) as indicated by (Table 5.2).

The average annual area during the first half of the second rotation was (268) hectare for the five - years (1970 – 1974) and was (342.8) hectare for the period (1975 – 1979).

Later, during the second half of the rotation (1980 – 1994), the annual area started to deviate from normal structure at alarming rate (Table 5.2) indicating very wide variations in the annual area planted ranging in 266.2-502.4 per five years age group.

Table (5.2) *Acacia nilotica* age class distribution during the second rotation for the period, 1965-1994

<table>
<thead>
<tr>
<th>Planting year</th>
<th>Age class years</th>
<th>Plantation area (\text{ha})</th>
<th>% of total area</th>
<th>Annual planting area (\text{ha})</th>
</tr>
</thead>
<tbody>
<tr>
<td>Second 15 Years(young)</td>
<td>1990-94 1-5</td>
<td>1131 ha</td>
<td>9.4</td>
<td>266.2 ha</td>
</tr>
<tr>
<td></td>
<td>1985-89 6-10</td>
<td>2020 ha</td>
<td>16.8</td>
<td>404.0 ha</td>
</tr>
<tr>
<td></td>
<td>1980-84 11-15</td>
<td>2513 ha</td>
<td>20.9</td>
<td>502.4 ha</td>
</tr>
<tr>
<td>Sub total</td>
<td></td>
<td>5664 ha</td>
<td>47.1</td>
<td></td>
</tr>
<tr>
<td>Average / year</td>
<td></td>
<td></td>
<td></td>
<td>390.9 ha</td>
</tr>
<tr>
<td>First 15 Years(old)</td>
<td>1975-79 16-20</td>
<td>1714 ha</td>
<td>14.3</td>
<td>342.8 ha</td>
</tr>
<tr>
<td></td>
<td>1970-74 21-25</td>
<td>1340 ha</td>
<td>11.2</td>
<td>268.0 ha</td>
</tr>
<tr>
<td></td>
<td>1965-69 26-30</td>
<td>271 ha</td>
<td>2.2</td>
<td>-</td>
</tr>
<tr>
<td>Sub total</td>
<td></td>
<td>3325 ha</td>
<td>27.7</td>
<td></td>
</tr>
<tr>
<td>Average / year</td>
<td></td>
<td></td>
<td></td>
<td>203.6 ha</td>
</tr>
<tr>
<td>Bare land area</td>
<td></td>
<td>3011 ha</td>
<td>25.2</td>
<td>221.6 ha</td>
</tr>
</tbody>
</table>

Source: 1994 inventory (FNC 1994), one feddan = 0.42 ha
The average annual area during the second half of the second rotation (1980-1994) was approximately (391) hectare falling within the range 266 – 502 hectare. For the five - years (1990 - 1994) the average annual area felled was (266.2 hectares) indicated a low rate of regeneration during the last five years of the second rotation. However, during the five years (1985 -1989) the regeneration rate was very close from the average but the regeneration rate during the five years (1980 – 1984) was the highest indicating a high rate of felling and regeneration during the same period (Table 5.2). The younger fifteen years for the period (1980 – 1994) represented 47.1% of total area of the plantation while the older fifteen years for the period (1965 - 1979) represented 27.7% of the total area of the plantation. This is in contrast to the situation in the first rotation (1935 – 1964) where the younger fifteen years plantation for the period (1950 – 1964) represented (45.2%) of the total area of the plantation while the older fifteen years plantation for the period (1935 -1949) represented (54.8%). The area of the bare land during the first rotation was only 4% of the total area of the plantation, while it was 3011 hectares at the end of the second rotation (Table 5.2).

Assessment system was used to check upon the progress of the area/age distribution during the second rotation and third rotation based on the results of an inventory conducted by the group Poulin (1984) in the middle of the second rotation and an inventory conducted by the FNC (2006) at the age of 12 years of the third rotation (1995 – 2024). The data of the 1984 inventory are presented in (Table 5.3).
Table (5.3) *Acacia nilotica* age class distribution during the 30 years period 1955-1984

<table>
<thead>
<tr>
<th>Planting year</th>
<th>Age class year</th>
<th>Plantation area \ ha</th>
<th>% of total area</th>
<th>Annual planting area \ ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>1980-84</td>
<td>1-5</td>
<td>2513 ha</td>
<td>20.9</td>
<td>502.4 ha</td>
</tr>
<tr>
<td>1975-79</td>
<td>6-10</td>
<td>1714 ha</td>
<td>14.4</td>
<td>342.0 ha</td>
</tr>
<tr>
<td>1970-74</td>
<td>11-15</td>
<td>1785 ha</td>
<td>14.9</td>
<td>349.9 ha</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td><strong>6012 ha</strong></td>
<td><strong>50.2</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td><strong>398.1 ha</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1965-69</td>
<td>16-20</td>
<td>1825 ha</td>
<td>15.2</td>
<td>365.0 ha</td>
</tr>
<tr>
<td>1960-64</td>
<td>21-25</td>
<td>1488 ha</td>
<td>12.4</td>
<td>297.6 ha</td>
</tr>
<tr>
<td>1955-59</td>
<td>26-30</td>
<td>780 ha</td>
<td>6.5</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td><strong>4093 ha</strong></td>
<td><strong>34.1</strong></td>
<td><strong>662.6 ha</strong></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>220.9 ha</strong></td>
</tr>
<tr>
<td>Bare land area</td>
<td></td>
<td>1895 ha</td>
<td>15.7</td>
<td></td>
</tr>
</tbody>
</table>

Source: 1983 inventory (Poulin 1984), one feddan = 0.42 ha

Table (5.3) shows the results of area/age distribution of five years age groups within the first and second halves of the thirty years period 1955 – 1984. From the results of the 1984 inventory (Poulin 1984), and the inventory (FNC 2006), it appears that there was more area felled than regenerated the same year as indicated by an increase in the area of the bare land (Table 5.3 and Table 5.4). The bare land increased to (1895) hectare by 1983 (Table 5.3) and to (3580) hectares by 2006 (Table 5.4). Table (5.4) indicated that the area of the older crop for the age / group (16 – 30) years were declining to 28.1% and the bare land area increased to 29.8%.
Table (5.4) *Acacia nilotica* age class distribution during the 30 years period 1977-2006

<table>
<thead>
<tr>
<th>Planting year</th>
<th>Age class year</th>
<th>Plantation area ( \text{ha} )</th>
<th>% of total area</th>
<th>Annual planting area ( \text{ha} )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Second 15 Years(young)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2002-2006</td>
<td>1-5</td>
<td>1334 ha</td>
<td>11.1</td>
<td>252</td>
</tr>
<tr>
<td>1997-2001</td>
<td>6-10</td>
<td>1002 ha</td>
<td>8.3</td>
<td>218.4</td>
</tr>
<tr>
<td>1992-1996</td>
<td>11-15</td>
<td>2724 ha</td>
<td>22.7</td>
<td>471</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td><strong>5040 ha</strong></td>
<td><strong>42.1</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td><strong>347 ha</strong></td>
<td></td>
<td><strong>380.1</strong></td>
</tr>
<tr>
<td><strong>First 15 Years(old)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1987-1991</td>
<td>16-20</td>
<td>1480 ha</td>
<td>12.3</td>
<td>365.0</td>
</tr>
<tr>
<td>1982-1986</td>
<td>21-25</td>
<td>1578 ha</td>
<td>13.1</td>
<td>297.6</td>
</tr>
<tr>
<td>1977-1981</td>
<td>26-30</td>
<td>322 ha</td>
<td>2.7</td>
<td>-</td>
</tr>
<tr>
<td><strong>Sub total</strong></td>
<td></td>
<td><strong>3380 ha</strong></td>
<td><strong>28.1</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Average / year</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>220.9</strong></td>
</tr>
<tr>
<td><strong>Bare land area</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>4093</strong></td>
</tr>
</tbody>
</table>

Tables (5.1, 5.2, 5.3 and 5.4) indicated that there is progressive changing trend in the area / age relationship over the period 1935 – 2007 with respect to the *Acacia nilotica* plantation extending between Sennar and Roseirs Dams. The areas of the younger fifteen years plantation over the period 1935 - 2007 shows fluctuation within narrow range (42.1% - 50.2%) of the total area of the plantation (Table 5.5).

The area of the older fifteen years (16 - 30 years) on the other hand declined from 52.6% in 1964 to 28.1 in 2007. The bare land gradually increased from 4.1% in 1964 to 29.8% in 2007 (Table 5.5).
Table 5.5 changing trends in area / age groups of *Acacia nilotica* planting area the period 1935 – 2007.

<table>
<thead>
<tr>
<th>Period</th>
<th>Inventory year</th>
<th>Bare land hectares</th>
<th>Percent of total</th>
<th>Plantation area hectares for the age (16-30)</th>
<th>Percent of total</th>
<th>Plantation area hectares for age group (1-15) year</th>
<th>Present of total area</th>
<th>Total area hectares</th>
</tr>
</thead>
<tbody>
<tr>
<td>1935-1964</td>
<td>1964</td>
<td>481</td>
<td>4.1</td>
<td>6315</td>
<td>52.6</td>
<td>5204</td>
<td>43.3</td>
<td>12000</td>
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<tr>
<td>1955-1984</td>
<td>1984</td>
<td>1895</td>
<td>15.1</td>
<td>4093</td>
<td>34.1</td>
<td>6012</td>
<td>50.2</td>
<td>12000</td>
</tr>
<tr>
<td>1965-1994</td>
<td>1994</td>
<td>3011</td>
<td>25.2</td>
<td>3325</td>
<td>27.7</td>
<td>5664</td>
<td>47.1</td>
<td>12000</td>
</tr>
<tr>
<td>1977-2006</td>
<td>2007</td>
<td>3580</td>
<td>29.8</td>
<td>3380</td>
<td>28.1</td>
<td>5040</td>
<td>42.1</td>
<td>12000</td>
</tr>
</tbody>
</table>
Figure (5.1) shows the changing trends of the area / age gradation in a comparative illustration taking the case of first rotation (1935 – 1964) and the second rotation (1965 - 1994). It is clear from figure (5.1) that in the first three groups of the age – classes (1-5 years, 6-10 years and 11-15 years) the change is limited to small differences in plantation areas for each group for the two rotations. Figure (5.1) shows a decrease in area for the first age group (1–5) years and increase in area for the second age group (6 – 10 years) and third age group (11- 15) year. However, the plantation area is indicating a continuous decline for each age group of the three groups (16 – 20) years, (21 -25) years and (26 – 30) years (Figure 5.1).

Figure 5.1 Trends of the area covered by age classes and change in bare land in first rotation (1935- 1964) and second rotation (1965 -1994).
The deference between the area of the age group (26 – 30) years of the first rotation and that of the second rotation is very pronounced as indicated by Tables (5.1 and 5.2) and Figure (5.1). The area of this age-group was (2139) hectare in the first rotation (Table 5.1) but was only (271) hectares in the second rotation (Table 5.2).

This ultimately resulted in large accumulated areas of bare land which was (3011) hectares in 1994 and (3580) hectares in 2006 as compared with (481) hectares in 1964. Large areas were regenerated during the 1980s and early 1990s, larger areas of young plantation for age group 1, 2 and 3 compared with that for the age group 4, 5 and 6 of the plantation areas (Table 5.2). By 1994 nearly 72.3% of the plantations is in the age group (0 – 15) years (including the bare area) and only 27.7% of the plantation area is in the age group (16 – 30) years (Table 5.5), and by 2007 the area of the age group (0 – 15) years was 71.9%. This is clearly abnormal compared with the situation shown in first rotation where young plantation area was 43.3% and that of the old plantation was 52.6% and the bare land area was only 4%.

Figure (5.2) shows the breakdown of the 12000 hectare plantation area into one year age group for the (30 – years) period (1977 – 2006). Very wide variation in annually planted area exists over the 30 years of the plantation age. Of the six age-groups, only the age-group (6 – 10) years indicates narrow variation in annual plantation areas over five years (1997 – 2001), varying in the range (170 – 280) hectare per year. Yet the areas were very much below the (1/30) of the 12000 i-e the 400 theoretical annual area. In the contrary the age (11 - 15) years indicates a very wide

Figure 5.2 One year age-group for Sunt plantation during the 30 years 1977 – 2006
(Source: FNC inventory data)

Variation in plantation areas of Sunt plantation is illustrated by aggregation of annual areas into five years age-group as shown in Figure (5.3).
Figure 5.3 Area/age gradations for the Sunt plantation area 30 years (1977 -2006)

Figure (5.2) and (5.3) indicate that large area were planted with Sunt in the middle of 1990s while very small areas were planted towards the end of 1980s.

Figure (5.2) illustrates that annual felling area is very much larger than planted area during (2001 – 2006) such that much areas were felled in the
age-group younger than 30 years. The oldest plantation was 26 years by 2006 (figure 5.2).

It is clear that the felling areas during the second period were much greater than during the first rotation.

5.2 Variation in area planted

Statistical analysis was carried out to compare between annual area planted over the thirty years rotation during 1935 – 2007. Figure (5.4) shows that significant differences were detected in annual planting areas between the first and third rotations.

Figure 5.4 Variation in annual planting areas during successive rotations (1935 – 2007). Boxes are means and bars are standard errors; Rotation 1, = 1935 – 1964, rotation 2= 1965 - 1994 and rotation 3= 1996 - 2007.
The largest area was planted during the first rotation (1935 – 1964); followed by second and then third rotation. Declining trend in annual area planted was observed from the first towards the third rotations. This indicates the disturbance in normality of area / age structure and also failure in execution of regeneration programme prescribed by the management plan. Increasing trends in bare land areas is obviously an indicator for failure in regeneration programme except in exceptional years like 1990 as show in Figure (5.2).

Figure (5.5) shows that significant differences were detected in annual planting areas as expressed per five-year age/classes through different rotations. This means that the annually planted areas were not consistently regular or strongly related to the area to be covered by the different age-classes. This may also indicate that the annual area felled (age-class 6) was not equal to annual planted area. This was reflected clearly in the variation of stocked areas between the three rotations.
5.3 Variation in density

Statistical analysis was carried out to compare between stocked areas over the thirty years rotation during 1935 – 2007 as within and between different age classes. Figure (5.6) shows that significant differences were detected between stocked areas for the different age-classes through the different rotations. This indicates the disturbance in the sustainability of the area covered by the area/age classes. The representation of age classes is not uniform over the rotation length as from 1935 – 2007 (Figure 5.2).

Figure 5.5 Variation in annual planting areas during successive rotations (1935 – 2007) as expressed in five-year age/classes. Boxes are means and bars are standard errors; Rotation 1, = 1935 – 1964. Rotation 2= 1965-1994, Rotation 3=1977-2006

$R^2=0.68$  
$P=0.0098$
Figure 5.6 Variation in stocked area between age-classes over successive rotations 1935 – 2007. Boxes are means and bars are standard error, numbers 1 – 6 represent 5-years age-classes form (1 – 5 years) up to (26 – 30 years).

Figure (5.7) shows stocked area of each five-year age-class as percent of total area. Significant variation (p=0.012) within different rotations. Such situation represents an example of forest that is deviating from the normal age/area structure as from first to third rotation.
5.4 Relationship between the bare land and stocked area by age classes

As shown in Table 5.1 to 5.4 that the bare land is continuously increasing in area through the period of the successive rotations 1935 – 2007. It seems that there is stronger relation between the trend of bare land area and the stocked area of the age-class 16 – 30 years over the three rotations. Figure (5.8) indicates that there is inverse significant \( (p=0.04, \ R^2=0.90) \) relationship between the area of the age/group (16 – 30) years and the area of the bare land as from 1935 to 2006.

Figure 5.7 Variation in stocked area of five-year age/classes as percent of total area. Boxes are means and bars are standard error, numbers 1 – 6 represent 5-years age-classes form (1 – 5 years) up to (26 – 30 years).
The bare land area was increasing from 481 hectares in 1964 to 3580 hectares in 2007 while the area of the age group (16 – 30) years was decreasing from 6315 hectares in 1965 to 3380 hectares in 2006 (Table 5.5). Equation (5.1) has (r²) value of 90% at (p<0.04). Very week relationship has been detected between the bare land and the stocked area of the age group (1 – 15) years over the successive rotations. Figure (5.9) indicates no relationship between the bare land and age group (1-15) years (R²= 0.0064)

Figure 5.8 Relationship between bare land and stock area of age between 16 – 30 years over the period 1935 – 2007
5.5 Yield regulation

The deviation of *Acacia nilotica* plantation from normal structure and failure to attain sustainable yield is also indicated by the declining production and supply of sawlogs to the government sawmills for railway sleepers production. Until 1975, the sawmills yards were fully stocked with logs annually extracted from the forests and the sawmills usually operated all the year round producing railway sleepers, small-sized sawn timber and firewood. Railway sleepers were produced at approximately 1.5-2.0 sleepers per tree at age 30 years (Jachson 1958). Recently, the
sawmills are fed directly from the vehicle transporting the logs, and the sawmill yards are empty (Final year forestry students data 1981-1990).

5.6 Site yield change

Figures (5.1 and 5.2) indicate the changes taking place with respect to areas of final felling crop. The changes were very pronounced for age groups 21-25 years and 26-30 years, with the later age-group having the minimum area recorded. Figure (5.2) shows that the age group 27-30 year has been completely lost in 2006.

It is not only the area that has exhibited changes but also other parameters are affected. The number of trees per hectare is the most affected. Table 5.6 shows the number of trees per hectare and DBH in cm, taken as average of the final felling crop at age 21-27 years. Table 5.6 indicates the variations in stocking densities, average DBH and volume for the selected compartments at age 21 – 27 years. By age 20 years and following the fifth thinning, the final felling trees (100 - 125 trees/ha) should remain and be maintained until age 30 years.

Variation in stocking densities per hectare indicate that the final felling crop has been subjected to mismanagement that caused either low stocking than (125 trees) as a result of over-thinning or on the other hand higher densities than (125 trees) indicating neglect of thinning.
Table 5.6 Stocking density, average DBH and volume per hectare for all compartments of Sunt plantations

<table>
<thead>
<tr>
<th>FOREST name</th>
<th>Compartmet No</th>
<th>Age (year)</th>
<th>No of trees / ha</th>
<th>Mean height / m</th>
<th>Mean DBH / m</th>
<th>V/h ac. m</th>
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</thead>
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<tr>
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<td>21</td>
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</table>
Table 5.7 shows the decline in stand parameters for Sunt plantation at age group of 30 years as a comparison between average values during the first rotation and that during the second rotation. The number of trees per hectare has declined from a range of (100-125) per hectare (Elsiddig, 2002) to a range of (50-60) per/ hectare tree (FNC Inventory 1996). Changes are observed in stocking density average DBH, DBH range, top height values and site quality class over time. Table (5.7) also witnessed decrease in average DBH from 44.0 cm during 1955 -1984 to 39.0 cm taken from 1996 inventory. The range has also changed from (38-60 cm) in the past to a range of (32-55 cm) in 1996.

Table 5.7 changes in productivity characters of sunt forests over time

<table>
<thead>
<tr>
<th>Character</th>
<th>Value of character</th>
<th>1996 Inventory</th>
<th>1955 -1984</th>
</tr>
</thead>
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<tr>
<td>Trees/ha</td>
<td>50-60</td>
<td>100-125</td>
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</tr>
<tr>
<td>DBH/cm</td>
<td>39.0</td>
<td>44.0</td>
<td></td>
</tr>
<tr>
<td>DBH range /cm</td>
<td>32-55</td>
<td>38-60</td>
<td></td>
</tr>
<tr>
<td>Top height/m</td>
<td>&lt; 21.0</td>
<td>≥ 21.0</td>
<td></td>
</tr>
<tr>
<td>Q .C</td>
<td>II</td>
<td>ı</td>
<td></td>
</tr>
</tbody>
</table>

Source: 1996 inventory and the inventory conducted in 1984

The decline in DBH values as average or range is a logical result of the decrease in number of stems per hectare from the range of (100-125) trees per hectare in the past to (50-60) trees per hectare at present. Changes in stand parameters over the rotations need to be investigated. However many factors may contribute to these changes. Illegal felling is a selective
felling which continues to be practiced over the period from age 20 years (final thinning) to age (25-30) years before the trees were finally felled. Illegal felling takes the best trees leaving large stumps with large diameters. Extrapolation of stump diameter to DBH values results in higher average of the estimated DBH, than the average DBH of the existing trees (Shahali 2005). This also applies to DBH range.

The need of local communities for wood products particularly firewood and building poles from Sunt forests are obtained illegally through illegal felling. People used to obtain their needs from the natural forests to avoid illegal means from sunt forest and to obey the laws. However, the natural forest cover continued to decline (Daak 2006).

People find limited sources from the natural forests and have no alternative other than forest reserves. Sunt forests are nearer to the villages extending along the Nile. The forests provide the local people with good quality wood particularly poles and small sized logs for simple furniture since 1935, the start of Sunt plantation management. The local people obtain their firewood and building poles from Sunt forests within the context of planned production system from thinning and final felling (Booth, 1949; Jackson, 1958; Foggie, 1968). With continued decline of natural forests, people,s needs have limited sources from the natural forests and the supply has to rely on forest products from sunt plantation. In fact the people needs are more than the supply provided by scheduled production from Sunt plantation. People continued to enter Sunt forests, illegally to fell trees for firewood and building poles. The illegal felling resulted in reduction of stocking density particularly the final felling trees
of the 30 years rotation that used to be maintained at 125 trees per hectare as stated by (Elsiddig, 2002).

People needs in the area are not limited to fire wood and building poles. The area between Sennar and Roseiris dams experience noticeable increasing the number of saw mills which put more pressure in sunt plantation for supply of sawlogs.
CHAPTER 6

Conclusions and Recommendations

6.1 Conclusions

- The present management practice of *Acacia nilotica* plantations has resulted in failure to attain sustainable production because of the deviation of the plantations from normal structure and the decline of the stocking of the final crop from (125) trees per hectare to 60 - 70 stems per hectare. The decline of the average DBH may also have contributed to failure of attainment of sustainability. The average production of the mean tree has declined from 1.5 to 0.8 railway sleeper at age 30 years.

- Site index and yield are always directly correlated. The decline in site index for Sunt growing in the flood basins suggests that poor management has in fact depressed growth rates.

- The application of productivity models (Elsiddig 1980, Hetherington and Elsiddig 1983/1984, Eltayeb1985), facilitated production of top height values from stumps of large trees and improved the calculation of site index values.

- The comparison between the inventory in 1935-1964, 1960-1983, 1965-1994 and 2006 indicated that the site productivity appeared to have declined and sustainability
attainment is under risk, but in reality site values remained the same while productivity declined because of mismanagements.

- The popularity of top height/age relationship as a site indicator is that top height is closely correlated with the ultimate measure of site productivity, top height and age are easily determined; top height growth is largely unaffected by stand density and Site index provides a numerical expression for site quality.
6.2 Recommendations

- Forest planning should consider the development of forest management plans that include consideration of establishment of specific area for management options, defined in Q.C.I and Q.C.II.

- A large amount of information that is useful for estimating the productive capacity of the land for same tree species (Sunt), related to the different compartments inventories can be integrated to provide a better estimate of the productivity of the various sites. This information also has some use for evaluating current and potential productivity for selected sites along the productivity gradient of top height against age.

- Execution of thinning according to schedule and involvement of the local communities in thinning execution improves the management and contributes in satisfaction of communities needs. The selection and marking of the final felling crop as the best 125 trees per hectare may contribute to sustainable production.

- Site index values use existing parameters of the trees like top height related to age is recommended to be used as measurable indicators of site and productivity.

- Estimates of site can be used to identify land that is more appropriate for different uses. Hence better land use policies and practices are encouraged.
• Exchange of information between researchers and FNC, on the results of forest and forest management research is very important to the process of planning for a sustainable forest management.

• It is recommended to use the recently developed powerful computer packages, which enable users to use the different tree growth parameters and their interaction objectively in easier manner than before, leading to more development in forest management.

• More studies are needed to explore the genuine causes of changes in Sunt stand periodicities that may have biological physical social and financial attributes.
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