Regeneration Ecology of Heglig (*Balanites aegyptiaca* (Del.))

in the Dry region West of the Blue Nile, Sudan

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Plant Ecology

Department of Environmental Science and Natural Resources

Faculty of Agricultural Sciences

(February, 2015)
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**Supervision Committee:**

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<td>Co-supervisor</td>
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Date: February, 2015
Regeneration Ecology of *Heglig (Balanites aegyptiaca* (Del.))

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<td>Internal Examiner</td>
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**Date of Examination: 9/2/2015**
DEDICATION

To

All those

Whom I love

I dedicate this work
ACKNOWLEDGEMENT

First of all I would like to thank and pray for (Allah) almighty god who gave me the will, skill and health to complete this work. I would like to express my gratitude and appreciation to my supervisor Dr. Hasabelrasoul Fadlelmula Mustafa for his supervision, guidance, criticism, strong support and encouragement, thank you Dr. for being patient with me and my mistakes, I have learned a lot from you during the period of study. I am also much indebted to the co-supervisor Professor Mohamed ELMukhtar Ballal for his contribution. My thanks are also due to Mr. Ahmed Ibrahim former manager of FNC in Sinnar State and Mr. Yahia Adam Abdullah, for their strong support and valuable help during the field study. I also thank Mr. Fathelrahman Alqasim and the staff of FNC Sinnar and Blue Nile States who helped me during my field work. Thanks are due to Mr. Abdullah Adam Osman manager of FNC in East Darfur State. I gratefully acknowledge the encouragement words of Mr. Abdullah Abdul Mahmud (Elshareef) and my college and friends, Shihab Eldein Awad Alfadel and Saiefedoula Khider. My deep and gratitude appreciation and respect to the staff of the Department of Environmental Science and Natural Resources at the Faculty of Agricultural Science of the University of Gezira. I also would like to thank Mr. Malik Kannan and the staff at the Department of Environment of the University of Gezira for their support and help. I extend my deep gratitude to my colleagues at the FNC both at River Nile State and FNC Headquarter. I thank all those who directly or indirectly assisted in this study. Special thanks are given to my parents, brothers, wife and children for their patience and support during the whole period of the study.
Regeneration Ecology of Heglig (*Balanites aegyptiaca* (Del.)) in the Dry region West of the Blue Nile, Sudan

Mohamed Ahmed Abaker Ahmed

**Abstract**

*Balanites aegyptiaca* is a multipurpose tree species of wide range of uses in terms of economic, social, and environmental aspects, but it was neglected and not given attention by the forestry authority. Concerning its existence and distribution. The objective of the study was to assess the natural regeneration of *Balanites aegyptiaca* in the dry region west of the Blue Nile. Ten villages were randomly selected and 20 villagers in each village were interviewed on their perception on the management and utilization of *B. aegyptiaca*. Natural regeneration was monitored in the field at different sites in the area between Sinnar and Damazin towns immediately after the rainy season in the year 2010. Those sites were abandoned agricultural farms, natural forests, vicinity of villages, valleys (seasonal water courses) and karab (eroded site). Random samples of 50 m in diameter each were laid on the northern, middle and southern locations of the various sites. In the sample the height and diameter at ground level were recorded for each plant of *B. aegyptiaca*. A field experiment was carried in Nawara natural forest on the dormancy of the fruit in the soil. Fresh fruits were divided into two lots; in one the fruits buried in the soil as they were and in the second the pericarp and mesocarp were removed. Burying was done during the rainy season of the year 2010 at 0 cm and 5 cm depth and each plot surrounded by metallic ring of 25 cm in diameter. Germinated, perished, and persistent fruits were calculated at the end of the rainy season. To study the effect of soil type on the regeneration, the fruits were sown in the nursery in black plastic container filled with clay soil or clay loam (eroded soil) brought from the natural domain of the species. Two forms of fruits; with and without pericarp and mesocarp were sown in the containers at August of the year 2011 and watered every two days. An experiment on effect of salinity on germination was performed used both NaCl and CaCl salts to fix different levels of salinity in the clay soil. The initial EC of the clay soil used in the experiment was 0.8 dSm$^{-1}$ and represented the control, and then five levels of salinity measured at 4 dSm$^{-1}$, 6 dSm$^{-1}$, 8 dSm$^{-1}$, 10 dSm$^{-1}$ and 12 dSm$^{-1}$ were fixed. The salts were added separately to the quantity of distilled water and magnetically shocked till all granules were completely dissolved. Then, viable fruits after removing of pericarp and mesocarp were sown in August of the year 2012 in Petri dishes of 15 cm in diameter and filled with one kg of clay soil had field capacity to 420 ml/kg. The weight of each Petri dish was measured and recorded. The salt solutions were applied once. Irrigation was applied every 48 hrs using tap water for five weeks. The amount of water applied to each dish was calculated as an equivalent of the difference in weight of the filled dish at application of irrigation water (Wet weight) and before application (Dry weight). The analysis of the questionnaire showed that the local community perceived the need of management and conservation programs to secure the natural regeneration on all sites despite the activities to collect fruits for food, lopping the branches for fodder and sometime felling the trees for wood and they were ready to participate in the programe. The results of the monitoring of the natural regeneration revealed that *B. aegyptiaca* trees thrived on all sites but newly recruited natural regeneration was lacked in the vicinity of the villages and valley meander. The fruits germinated readily when placed on the soil surface (91%) or buried to 5-cm depth (90%) whether pericarp and mesocarp removed or left intact, and completely failed in eroded soil while succeeded in clay (91%). Salinity significantly decreased the germination from above 80% at EC of 0.8 dSm$^{-1}$ (control) to less than 40% when increased to 12 dSm$^{-1}$. The study recommended that concern and attention should be given to conservation of *B.aegyptiaca* through its improving management and extension programs and reserving the lands where its natural stands occur and integrating it into agroforestry programs.
الخلاصة

يعتبر شجرة اله힐يج (B. aegyptiaca) ذات أهمية وقيمة إجتماعية واقتصادية وبيئية، وهي واسعة الانتشار، بيد أنها لم تجد الاهتمام والرعاية اللازمن مما يهدد وجودها وانتشارها. لذلك هدفت الدراسة إلى تقييم التجدد الطبيعي للشجرة غرب النيل الأزرق في الأراضي الجافة بالسودان بين سنار والدملازين، لمعرفة رؤى ومفاهيم المواطنين المحليين عن الاستخدامات المختلفة والإدارة الفنية لها، اختبرت 10 قرى و20 مستهدفا في كل قرية لإستبياناتهم. كما تم تقييم التجدد الطبيعي في الأراضي الزراعية المهجورة، الغابات الطبيعية، حمى القرى، ولوذان وأراضي الكرب في عينات عشوائية بقطر 50 مترًا بعد أن قسم موقع البحث إلى شمال ووسط وجنوب العربي. أجري في كل عينة أشجار اله힐يج الموجودة مع قياس طول وقطر كل منها. لمعرفة كمون البذرة في التربة تم تنفيذ تجربة في غابة نوارة الطبيعية في موسم خريف العام 2010 وذلك بتقسيم ثمار اله힐يج الطازجة إلى نوعين: في النوع الأول تم زراعة الثمار كما هي بدون أزالة القشرة الخارجية واللب وفي النوع الثاني تم زراعتها بعد إزالة القشرة الخارجية واللب وفي كل النوعين كانت الزراعة علي اعماق صفر و5 سم، وأقيمت الثمار بحلقات حديدية بقطر 25 سم، بنهاية موسم الخريف تم حساب عدد الثمار التي نبتت والتي لم تبتث وثمار التالفة. لدراسة تأثير نوعية التربة على إنبات ثمار اله힐يج تم زراعة ثمار ه힐يج منزوعة القشرة الخارجية واللب وأخرى غير منزوعة القشرة الخارجية واللب في أكياس سوداء مملوءة بتربة طينية وأخرى مملوءة بتربة الكرك في أغسطس 2011. لمعرفة تأثير ملوحة التربة على إنبات ثمار اله힐يج استخدم نوعين من الاشلاح: هما كلووري الصوديوم وكلوريد
الكالسيوم للحصول على مستويات مختلفة من الملوحة كانت 6، 8.6، 10.8، 12 و14.2 دسم-1. بعد ذلك تمت زراعة ثمار الهلجيل مصنوعة القشرة الخارجية واللبلبة في أوان فخارية ب قطر 15 سم مملوءة بواحد كللجم من النسبة الطينية بسعة حقلية 420 مل/كلجم وذلك بعد وزن كل إثنان فخاري على حدة وتسلسل وزنها، وكان الري يتم كل 48 ساعة لمدة خمسة أسابيع. كمية المياه المضافة لكل إثنان تعدل الفرق بين الوزن الرطب والوزن الجاف لكل إثنان. أثبتت نتائج تحليل الاستبيان أن المواطنين المحليين يرغبون في إخضاع الهلجيل لإدارة فنية للمحافظة عليه. وعلى الرغم من كثافة النشاطات المتعلقة بجمع الثمار وقطع الفروع والأشجار لجمع العلف وحطب الحريق. أثبتت النتائج كذلك توفيق الشجرة والتجدج الطبيعي في كل المواقع التي مسحبت باستثناء مجري الهوديان ومسى القرى. أشارت النتائج أيضًا على أن القشرة الخارجية واللبلبة وكذلك عمق التربة لا تؤثران في إثبات البذور حيث أثبتت تجارب الهلجيل مزالة القشرة الخارجية والللب مباشرة عند زراعتها على السطح عند مستوى عمق صفر أو 5 سم بنسبة 90%. كانت نسبة الأنبات في تربة الكرت صفرًا بينما كانت 90% في التربة الطينية. خلصت الدراسة كذلك إلى أن زيادة نسبة الملوحة في التربة تقلل من نسبة الأنبات تمار الهلجيل في كل النوعين من الأملاح المستخدمة حيث هبطت نسبة الأنبات من 84% عند أدنى مستوى ملوحة 0.8 دسم-1 (الشاهد) إلى 32% عند أعلى مستوى ملوحة 2.1 دسم-1. توصى الدراسة بضرورة إيلاء الاهتمام والرعاية اللازمة للمحافظة على الشجرة من خلال تحسين وتطوير نظام الإدارة وتكوين برامج الإرشاد وإدخال شجرة الهلجيل في نظام الزراعة الغابية.
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<td>C°</td>
<td>Degree centigrade</td>
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<td>Cm</td>
<td>Centimeter</td>
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<tr>
<td>DGL</td>
<td>Diameter at Ground Level</td>
</tr>
<tr>
<td>E</td>
<td>East</td>
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<tr>
<td>FAO</td>
<td>Food and Agriculture Organization of the United Nation</td>
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<tr>
<td>FMNR</td>
<td>Farmer Managed Natural Regeneration</td>
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<td>FNC</td>
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<td>GDP</td>
<td>Gross Domestic Production</td>
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<td>Ha</td>
<td>Hectare</td>
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<td>HCENR</td>
<td>High Council for Environment and Natural resource</td>
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<td>HDRA</td>
<td>High Desert Racing Association</td>
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<td>ICRAF</td>
<td>International Council for Research in Agro forestry</td>
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<td>IFFN</td>
<td>Integrated Fire management and Fire situation in Sudan</td>
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<td>ISTA</td>
<td>International Seed Testing Association</td>
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<tr>
<td>Kcal</td>
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<td>Kg</td>
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<td>SMI</td>
<td>Sudan Ministry of Information</td>
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<td>Mm</td>
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<td>NRC</td>
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<td>NTSC</td>
<td>National Tree Seed Centre</td>
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<td>O. P</td>
<td>Osmotic Pressure</td>
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<td>Office for the Coordination of Humanitarian Affairs</td>
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<td>PET</td>
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CHAPTER ONE

INTRODUCTION

1.1 Background

Forest cover in Sudan was estimated at 43% in 1958, 29% in 2005 and 12% in 2011 of the total area of the country that comprises 1882000 km² (Harrison and Jackson, 1958); FAO, 2005; SMI, 2011). Statistic showed that the forest cover decreased from 71, 220,000 ha in 1990 to 61,630,000 ha in 2000 and 59, 440,000 ha in 2010 (FAO, 2010). This is considered as poor coverage of the country most of it is dry. The decline was explained as consequences of expansion in agriculture, wood harvesting and free grazing accelerated by increasing variability of rainfall (World Bank, 2009).

Degradation is a process caused by complex interactions among physical biological, topographical, political, social, cultural and economic factors (Glover, 2005). It is a cumulative decline in the biological productivity and a loss of its resilience (Mustafa, 1997). The most commonly recognized main causes of land degradation include, over cultivation of arable land, removal of vegetation by over grazing, water logging, deforestation and converting land for agriculture (Glover, 2005). There are also some individual causes for degradation such as misguided government policies, lack of land tenure, concentration of herds around human settlement and watering points and clearance of marginal lands, collection of fuel wood and trampling by livestock (FAO, 1996; Hoffman and Todd, 2000). FAO (2010) estimated the annual loss of the world’s forests due to deforestation, by 130,000 km² conversion to agricultural land, harvesting of timber, unsound land management practices and creation of human settlements. According to Ayoub (1998) about 64 million ha of soils are degraded in the Sudan, 81% of the degraded area falls on the dry lands.

The first step in any forest rehabilitation is the prevention of further damage to the woody plant cover, putting limitations to marginal agricultural cropping and strong measures on fire control, stop illicit felling of trees and bush removal beside the regulation of grazing. By these measures the natural vegetation cover could be
recuperated. Under natural conditions and without negative interference from man and animals, ecological systems may regain their balance (Ahmed, 1989a). Lamprechet (1989) and Chidumayo and Frost (1996) noticed that in the tropics the degraded forests that left for a long period of time were eventually regenerated and recovered their full protective and productive functions.

Almost all the lands in the Sudan are recognized as state lands. These lands are traditionally communed, their use vested in tribal, family or village communities, but a small portion of the land, about 1%, is owned by private sector or individuals (Awad, 1971). These lands are mainly along the river's banks, and they are utilized as gardens producing vegetables and fruits to satisfy the daily needs of the people and to supply the nearby markets. Some Gum Arabic forests are reserved away from the rivers on clay plain. Live stock reared along the Blue Nile, are camels, cattle and sheep, agricultural activities vary from traditional shifting cultivation practiced by small farmers to extensive mechanized rain fed agriculture practiced by companies, government sector and individuals. The area along the Blue Nile is known as a large producer for charcoal obtained from Acacia seyal and other tree species. Along the Blue Nile banks Acacia nilotica (Sunt) forests are reserved by government to produce mainly sawn timber.

1.2 Dryland environment

It is reported that half of the world’s countries have part of their area as dryland, and that represents one third of the earth’s surface, the home of 40% of the world’s population (White et al., 2002). In Africa the drylands cover 24 million km², where as in Sudan about 1.5 million km² which represent 59% of the total area of the country stretching from east to west between latitude 10° N and 23° N. Scanty and erratic rainfall, prolonged dry season, high temperature and high evapotranspiration are the characteristics of dry lands (Le Houérou, 1980).

The drylands are diverse in terms of their climate, soil, flora, fauna and land use. There are three climatic zones of the dryland based on aridity index; the first zone is the hyper arid zone, where annual rainfall rarely exceeds 100 mm, infrequent and irregular, even sometimes no rain falls in this region for several years. This put great pressure on the scattered shrubs that dominate the zone by the high demand for fuel wood and fodder as well as heavy grazing (Heathcote, 1983). The second zone is the arid which is characterized by high rainfall variability ranging between 100 to 300
The vegetation of this region varies from herbaceous plants, shrubs and small trees, while extensive and nomadic pastoralism is being practiced (Heathcote, 1983). The third climatic zone is the semi arid, where the rainfall varies from 300 to 800 mm. Grasses, forbs, shrubs and trees are the native vegetation.

Almost 75% of the people inhabiting dry land environments live in semiarid zones, 25% in arid zones, and only 1% in hyper arid zones. (Ffolliott et al., 2002). This put great pressure on natural resources special forest cover by the high demand for food and energy, the result is that large areas covered with forests are cleaned annually, to meet people’s demand for food energy and building materials, expansion of agriculture at the expense of forests will reduce the forest areas and will lead to the disappearance of certain tree species.

In the drylands the environmental degradation reaches alarming rate causing desertification and affecting the livelihood of more than one billion people. Ibid. Over two thirds of Africa receives annual rains fall during three months with a large variation in the amount. However, rainfall is the key factor in management of the natural resources in general and trees cover in particular, because the soils of dry land cannot absorb the rain that falls in large storms, hence, the water is lost from the surface by the run-off. When the rainfall is of low intensity water can be lost through evaporation (Ffolliott et al., 1995).

The growth of plants is restricted by the fluctuations in temperatures and soil moisture Ibid. Wind in drylands moves the moist air surrounding plants and soil bodies and as a result decreases atmospheric moisture and increases evapotranspiration. Drought is one of the environmental problems in the dryland due to fluctuations in rainfall and temperature that results in shortage of water, food for people and forage for livestock. The main victim of the drought are the natural resources, special forest cover which will remain the main source for food and fodder during drought (Brooks et al., 1997).

According to Ayoub (1998) about 64 million ha of soils are degraded in the Sudan, 81% of the degraded area falls in the drylands. Deciduous and ever-green are the forms of non-succulent perennials plants dominating the drylands (Buck et al., 1999). Some plants have evolved specialized rooting systems, while others have unique leaf characteristics that allow them to withstand prolonged periods of drought. Ibid. Other plants simply loose their leaves when soil moisture conditions become too
dry. Seeds of some tree species can remain dormant in the soil for many years and only germinate under special conditions.

1.3 Environment of dryland in Sudan

The winds prevailing in Sudan are the humid south-westerly wind, that starts by the end of March and leaves the country by the end of November, succeeded by the dry north-easterly wind (Le Houérou, 1980). There are five seasons; the rainy season from mid June to September, the deferred season from September to November, the cool dry season from November to February, the hot dry season from March to May and the pre-rainy season which prevails in May and June. The mean annual temperature is 30 °c, the maximum mean daily temperature is 40 °c in summer and the minimum is 15 °c in winter. The mean relative humidity is 40% and the maximum is 75% in August and minimum of 25% in April, where as the mean annual evaporation is 5180mm and the potential evapotranspiration is 2000 mm (Le Houérou, 1988).

1.4 Efforts on conserving Balanites aegyptiaca

The efforts to meet the high demand of growing population in the country for food and energy as well as building materials put a great pressure on natural resources, specially forest resources, as have been affected directly through the cleaning of large areas for cultivation. That resulted in loss of large habitats and disappearing of some species. During the 1980s large areas covered with Balanites aegyptiaca to supply the private owned saw mills (Elfeel, 2004). Moreover, the large areas converted to mechanized agricultural schemes in central Sudan were naturally B. aegyptiaca and Acacia seyal (Del) habitats (Sulieman and Buchroithner, 2009). The over exploitation of the tree forced the FNC to make efforts being focused on halting habitat destruction. In the region it is not only B. aegyptiaca that was destroyed but other species such as Commiphora africana, Dalbergia melanoxylon, Hyphaene thebaica, Salvadora persica, Sclerocarya birrea and Sterculia setiera (FAO, 2001).

Forest laws in Sudan aim to conserve and develop forest resources. The minister of agriculture and forestry was given the right to ban cutting of endangered trees. Accordingly several decrees were issued to protect and ban the cutting of endangered tree among them that on bans cutting of B. aegyptiaca (Warag et al., 2002). Extensive extension campaigns were conducted during the 1980s and 1990s to increase the
knowledge of the local people on the danger of cutting *B. aegyptiaca* trees. FAO (2001) has identified *B. aegyptiaca* on the priority list of Africa. The species was also ranked by the National Research Council of USA among the 24 lost crops in Africa and called for efforts to develop its true potential uses and potentiality.

### 1.5 Rationale of the study

Since the decree of the forest policy and forest act in the year 1932 in the Sudan, the FNC has been acting on conserving and sustainable management of the natural forest resources, considering the high and continuous demand for wood (Elsiddig, 2007). The act granted rights and privileges for local communities living in or around the forests. Recently, as stated by forest policy of (1986), adopted the participation of people in forests management based on the concept that it may help in minimizing the problems related to forests.

In developing countries, a large amount of ecological knowledge is held by local people and has not yet been adequately integrated with formal scientific knowledge (Sinclair and Walker, 1999). Many farmers carrying out slash-and-burn agriculture manage regenerating forest as fallows before another cycle of cultivation. It is therefore likely, in some environments, that local people’s knowledge could make a major contribution to the information needed for improved methods of forest restoration. Therefore, one priority should be the recording of relevant local knowledge of forest regeneration and its integration with scientific knowledge. This may well lead to an adjustment in the priorities identified for new scientific research (Paudels, 1997).

However, in the absence of clear management practices and the absence of local people involvement in the management process natural forests reserves and forests out site reserves are subjected to heavy pressure from the local people. *B. aegyptiaca* is a promising widely distributed tree and of high value in terms of economic, social, and environmental issues. Its value arises because it is a source of fodder and foliage in the dry season, medicinal and nutritional non-wood products, wood and timber, and natural nitrogen fixation capacity. The fruits collected from the tree alone can generate to the country about 80 million dollars per year (NRC, 2008). The species is subject to continuous felling to meet peoples demand for fuel wood, building and fencing poles, timber for furniture but the most serious felling due to crop cultivation. However *B. aegyptiaca* stands are not given full attention concerning their
rehabilitation although the species is protected by law. The efforts of the FNC are still concentrated on planting three or four *Acacia* species for income revenue. Hall (1992) and NRC (2008) stated that the current conservation status of the tree could change if human and animal pressure increased sharply.

However, several studies on the chemical composition, fodder value, pharmaceutical ingredients and morphological variation were made (Mohamed, 2002; Kamal and Koskinen, 1995; El Nour, 1994; Elfeel, 2004, Abdoun, 2005, EL safori, 2009), but little is done on the natural regeneration of the species in relation to soil type, dormancy of the fruits in the soil. However, by all those threats unless management measures would be taken the tree may disappear from large areas which would lead to environmental and social impacts. Hence, launching of rehabilitation program is of utmost necessity and its success would be underlined unless provision of the relevant and valid technical information on regeneration ecology is made available and at access.

### 1.6 Objective of the study

The overall objective of the study was to assess and monitor the natural regeneration of *B. aegyptiaca* in *A. seyal* Balanites vegetation belt west of the Blue Nile south of Sinnar Dam in Sudan. The specific objectives were:

1. To assess the natural regeneration of *B. aegyptiaca* on various sites
2. To study the impact of soil type and soil salinity on seed germination of *B. aegyptiaca*
3. To investigate the perception of rural communities concerning the management and impact of *B. aegyptiaca* in their livelihood and environment
CHAPTER TWO
LITERATURE REVIEW

2.1 Botanical description and distribution of *Balanites aegyptiaca*

The species is known as desert date in English and *laloub* and *Heglig* in Arabic, belongs to the family Balanitaceae or Zygophyllceae is one of the most important tree species in the dry region of Africa. The tree is ever green, tall (15 m), single stem, multi branched, spreading spherical crown, bark dark to grey with deep vertical fissures, spines are straight, stout, rigid and up to 8 cm long, leaves compound and spirally arranged on the shoots with two separate leaflets, obviate to orbiculate, rhomboid grey green in color. Flowers, yellowish green in spikes sometimes shortened to rounded clusters. Fruits are green turning on drying to yellow or brown with different sizes and shapes. The tree flowers in November to April and fruits in December to July (El Amin, 1990) In the red sea region fruiting is recorded to occur in August (Badi *et al.*, 1989). The name *Balanites* is derived from the Greek for acorn which refers to the fruit named by Alire Delile in 1813 but before that the tree was named *Agialid* derived from the Arabic name *Heglig*. However the tree has different names in different places such as *Aduwa* in Hausa and in Swahili it is called *Mduguyu*, whereas in Amharic language the tree is known as *Bedena* (Orwa *et al.*, 2009).

It is indigenous to all dry lands south of the Sahara, extends south ward to Malawi (Hall, 1992; Schmidt and Joker, 2000; NRC, 2008). Associated woody species are *Combretum* and *Acacia spp* (Hall, 1992). However, the tree is characteristic of cracking clay soil under rainfall 500 mm and more.

In Sudan it grows in association with *A. seyal* on cracking clay soil in short grasses savannah and on sandy soils in Kordofan and Darfur regions (El Amin, 1990). It is also found on the slopes at the foot of rocky hills and fringes of iron stone regions. Booth and Wickens (1988) reported that there are plantings of the species *B. aegyptiaca* in the Cape Verde Islands, Curacao, the Dominican Republic and Puerto Rico, where the tree is considered as an exotic species introduced from its native land to these countries. Plantings have also been reported in India.

The tree is known as drought resistant species and therefore suitable for sand dune stabilization, agroforestry and reforestation in the dry zones (Ladipo, 1989).
According to it is considered as good fodder with high protein value and withstands prolonged browsing and lopping (Billore, 1990). It is also used as a trap tree in agroforestry since it attracts numerous insects (Mbuya et al., 1994). The tree is one of the priority species in the Sahel where it is cultivated with annual food crops in the traditional park land agroforestry (ICRAF, 1992). The tree is also used in the farm lands in a program called farmer managed natural regeneration (FMNR) in Niger, a program that proved cheap and rapid method of revegetation, where more than three million ha were revegetated in using this method in Niger Ibid.

The species is multipurpose tree of very wide range of uses, the fleshy pulp of the fruit is edible either fresh or dried, source of dysgenic and oil (Ladibo, 1989), its reported that the fruit pulp contains between up to 72% carbohydrates, mainly sugar plus crude protein, steroidal saponins, vitamin C, ethanol and other minerals (NRC, 2008). The seed kernel produces good quantity of oil which is used for cooking and oil making, local people in some parts of Sudan use the fresh fruit as drinkable food called (madeda) said to be good treatment for stomach pains.

The seeds are also widely used in Sudan by some religious groups as worshiping toll tool (Sebha or laloba). It is known that the seed kernel consists of 30% protein and 51% saturated oil, proportion very similar to that of sesame and groundnuts (HDRA, 2003). Mohamed (2002) found that the seed kernel of Balanites contains about 49% crude oil and 32% crude protein. Balanites fruits are considered as one of the indigenous food plants with great potential to support and strengthen livelihoods of people (Grosskinsky and Gullick, 2001). Referring to study made by the UNIDO (1983) about 400.000 tons of B. aegyptiaca fruits can be obtained from the natural forests of Kordofan, Darfur, Blue Nile and Kassala states. This quantity produces five million gallons of ethanol, 1500 tons of Carbon acid, 120 tons of mylic acid, 1200 tons of dysgenic 13600 tons of oil 2400 ton of cake 200000 tons of fuel wood and 2500 tons of residues. All these products offer net profit of about 25 million US$ per annum.

Wide range of diseases are used to be treated by different parts of the tree since are known to be rich in steroidal saponins which yield dysgenic (Pettit et al., 1991; Farid et al., 2002). Kamal and Koskinen (1995) found that the fruit mesocarp contains pregnant glycosides. The aqueous extract of mesocarp of the fruit exhibits prominent anti diabetic activity (Al shanawany, 1991) and the extract of the base is used for jaundice (Elsafori, 2009). The fruit has been used in the treatment of liver and spleen
diseases (Jain and Sharma, 2000). The fruit is used by nursing mothers as food after being mixed into porridge. It is also used in whooping cough, leucoderma and other skin diseases. Bark and the fruit extracts repel snails (NRC, 2008). Decoction of the root is used to treat malaria, edema and stomach pains. The wood gum is mixed with maize meal porridge to treat some chest pains. The bark is used against stomachaches, mental diseases, yellow fever and to treat heart burn (Both and Wickens, 1988). The maceration of the fruit and seeds is used as laxative and anthelmintic (Eltohami, 1999). Fresh twigs are put on the fire in order to keep insects away. The leaves are used for cleaning wounds. The seed is used as anti fungal, anti bacteria and as expectorant. However, Sudan could supply 50% of the world demand of dysgenic from its natural resources of Balanites tree (El Nour, 1994).

The wood is hard, durable, worked easily and smoothly which makes it widely used for tool handles, yokes, wooden spoons, pestles, handles, stools, combs, bowls, posts mortars and many households and agricultural implements (Von Maydell, 1986.). The wood is also valued for furniture as it shows no serious seasoning defects and tendency towards surface checking or splitting. It saws cleanly and easily, planes without difficulty to a smooth finish and is easy to chisel. It glues firmly and takes a clear varnish (UN-OCHA, 2009). It also good charcoal and firewood, produces considerable heat and very little smoke.

Fruits of Balanites aegyptiaca vary in shape, size and weight according to growing site. Young fruits are green and tormentose, when ripe, each containing 1 pit ellipsoid rather long, narrow drupe, 2.5 to 7 cm long, 1.5 to 4 cm in diameter. turning yellow and glabrous when mature. Pulp is bitter-sweet and edible. a brittle coat enclosing a brown or brown-green sticky pulp and a hard stone seed. pyrene (stone), 1.5 to 3 cm long, light brown, fibrous, and extremely hard. It makes up 50 to 60% of the fruit. The fruit has thin brittle epicarp, a fleshy mesocarp and a woody endocarp containing the oil seed or kernel. There are 500 to 1 500 dry, clean seeds per kg. The tree begins to flower and fruit at 5 to 7 years of age and maximum seed production is when the trees are 15 to 25 years old Hall, (1992).

2.2 Natural regeneration ecology

Natural regeneration remains the important process in plant succession (Grim, 1979; Cok, 1980 and Roberts, 1981). It is in most sites and species depends on the soil seed bank. The persistence of seeds in the soil depends on many factors such as decay, pathogens, predation and rainfall that affect germination or depletion, but the
rainfall has the substantial role (Mustafa, 1997). He also reported that the natural regeneration from seeds is successful on cleared forest sites and fallow land where the rain fall is above 600 mm. When rainfall tends to be less than 600 mm, the seeds face some difficulties in germinating naturally unless they are ingested by animals or placed on flow sites. In some conditions, weed species can arrest succession (Aide et al., 1995).

It was reported that natural regeneration could be successful where good root is developed by the native seedlings, less disturbance to soil ecology and reduction of risk to soil erosion (Kirkpatrick et al., 2010). Comparison between directly seeded seedlings and planted seedlings showed that the better growth was given by direct seeded seedlings (Goransson and Widgren, 1996). According to Mustafa (1997) in his study of the natural regeneration of A. seyal as associated species with B. aegyptiaca, the low rate of seed production, exhaustion of the soil seed bank, unfavorable hydrological or microclimatic conditions with human and livestock pressure would limit and slow down the recovery of natural dry land forests.

Fire play basic role in determining the natural regeneration dynamics by disturbing the soil seed bank (Bekker, 1989). Some of the disadvantages of natural regeneration are that less control over initial stocking and spacing, low commercial yields, no genetic improvement and the introduction of diseases resistant stock, also the delays in regeneration due to drought or inadequate seeds (Kirkpatrick et al., 2010).

In the White Nile area in Sudan, natural regeneration of B. aegyptiaca showed low rate among other Acacia species (El safori, 2009). El Nour (1994) reported that natural regeneration was possible both by natural seeding which gave (53%) and by coppicing which resulted in (47%). He also observed that coppicing occurs irrespective of the stump diameter or height.

In artificial regeneration direct sowing by seeds is the most important way to attain good results. In Kenya a preliminary trail of direct sowing of 17 different species showed that B. aegyptiaca was the best given 79% germination (Goransson and Widgren, 1996). Mustafa (1997) reported that on badly degraded lands forest regeneration is a challenging and difficult task when valuable and certain tree species are threatened to disappear, then development programs should be taken including effective protection and improving the production.
Natural regeneration is assumed to be more guaranteed under protection (El siddig, 2007). In the areas where the rain fall fluctuation is normal, seeds of favorable and threatened trees ingested by animals can be used to guarantee good natural regeneration (Ahmed, 1986). Light is the most important environmental factor affecting the processes of seedling recruitment and attribution in tropical forests (Sharma and Sen, 1975; Rincon and Huante, 1993). Seeds need more light than they receive in the forest understory to recruit new individuals (Brandani et al., 1988). According to McLaren and McDonald (2003), the proportion of seeds germinated under partial shade was less than 40% than that under full shade. It is observed that seed germination was higher under plant cover, while seedling growth is reduced under the same areas, when compared to open areas during the rainy season (Woods and Elliott, 2004). However forests can regenerate in previously forested areas once the land ceases to be used for alternative purposes such as grazing and agriculture and providing that suitable natural conditions are available (Holl, 1998).

Natural regeneration is of high important where planting cost is an obstacle, the thing that could threaten any reforestation programs. The first step in the process of stimulating forest recovery involves identifying the principle factors that are acting as barriers or as facilitators to natural regeneration, (Vallejo et al., 2003). Its success depends on how different variables of light, humidity, temperature, availability of seeds and predation act in the system that is undergoing recovery. Most of the studies have identified dispersion, competition with herbaceous plants and poor soil conditions as being the most important barriers for tree regeneration on abandoned farmlands (Holl, 1998).

Those studies also highlighted the importance of physical and biological barriers. Once these factors have been identified they can be manipulated to accelerate forest regeneration. The availability of seed source in any site will be a sign of any natural regeneration success, main source could be nearby mother trees, existence of seed dispersers such as birds, mammals, sometimes water, that could transfer seeds from place to place, lack of these sources could restrict natural regeneration possibilities to soil seed bank, when there are low numbers of birds and mammals natural regeneration may be confined to species whose seeds are dispersed by wind (Peterson and Haines, 2000).

External ecological factors such as interactions with other plants and animals, climate and disturbance like fire or landslide, are a limiting factors in any restoration
success, (Price et al., 2001). He also confirmed that the successful establishment of seedlings, the survival and growth processes that transform seedlings into saplings can be even more complex, because plant ecology, environment factors and many random events all play significant or deterministic roles.

Water is determining factor in successful natural regeneration, however optimum amount of rainfall water is necessary for seedling germination and after germination progressively large amount of water are required for seedling growth and development (Kozlowski and Pallardy 2002). However natural regeneration on natural forests mainly depends on pattern of rainfall which has a substantial role in the natural regeneration success in Sudan. Density and occurrence of the trees decreases northwards similar to pattern of rainfall (Mustafa, 1997).

Temperature is a factor that could limit seed germination and seedling growth; most of the seeds require certain temperatures to initiate out of their dormancy and the start of metabolism. The mean annual temperature for the species *B. aegyptiaca* to germinate range between 20° C and 30° C but there is possibility for the tree to occur in areas with mean temperature lower than 20°C and as high as 46°C but in some places the tree is found existing under temperature exceeding 50°C (Hall and Walker, 1991).

Both seed germination and early seedling development are influenced by light intensity, light quality and photo periods, seedlings under trees might be affected by shade and light, which would affect the site conditions (Botkin, 1992). The gap size in any forest stand which is created naturally or artificially is a key factor in natural regeneration ecology. It affects the plant growth by the impact on microclimate. However, as the gap size increases the intensity and duration of solar radiation, mean soil and air temperature also increases, while humidity decreases.

Gaps with irregular shapes, in general, have more pronounced gap-edge effects on the inner-gap environment because of increased competition for both aboveground (light) and belowground (water, nutrients) resources (Gagnon, 2004). Some tree species may regenerate better on less fertile sites because of reduced competition from the ground vegetation (Chen and Popadiouk, 2002). Generally, the environment within a gap is heterogeneous and it would influence regeneration of different species through seed lodgment, germination or survival of the seedlings.

Effect of insects on natural regeneration is by damaging tree seed, eating leaves and roots. *B. aegyptiaca* seeds were infected by borers which will reduce the number of seedling grown, however any successful natural regeneration program should
consider pest and diseases management, (Badi et al., 1989). Competition between species for light brings about not only growth and establishment of plants but also vegetation changes and succession, growth and development of plants is prevented or hampered due to high competition, it was stated that competition from other plants in the under story is one of the major factors affecting regeneration of forests, (Begon et al., 1996).

Management operations like weeding and other man made factors such as grazing, fires, cultivation are essential measures in successful natural regeneration. Studies by Ayoub (1998) concluded that overgrazing (47%), improper agricultural practices (22%), deforestation for firewood and urban demand for charcoal (19%), and overexploitation of vegetation for domestic use (13 %) prevent natural regeneration success, by removing mother trees and burning seed stock in the soil, destroying regenerated seedlings, changing species habitat.

2.3 Cultivation and forests

Agricultural production is the main source of income for 80% of the workforce, and contributes to 39% of GDP in Sudan (FAO, 2001). Natural forests in developing countries and in the savannah region of the Sudan in particular are loosing areas year by year for the expansion of agriculture. There are two types of agricultural practices in the country; conventional shifting cultivation and rain fed mechanized farming. Shifting cultivation is mainly practiced by villagers living in permanent villages around natural forests, where these farmers tend to clear an area of about five feddan (2.1 ha) called Bilad for cultivation, sometimes a single farmer may clear and cultivate more than one farm to grow different crops which increases the cleared forest areas (Mustafa, 1997). It's notable to mention that the farmer can move and clear another area due to the poor yield he obtained. However, any successive cultivation at the same area will have destructive impact on the soil and the appropriate environment for tree species to grow.

Shifting cultivation is usually followed by fire set by farmers to burn the felled wood and leaves to clean the land for sowing and that maximizes the destruction by felling mother trees expected to bear seeds for plant succession, burning the newly regenerated seedlings, and damaging of the soil minerals and the surface seeds (Badi et al., 1989) The second type of the agriculture, rainfed mechanized farming, was first started in the early 1940s in the savannah wood land with an area of 5000 ha (EL
Nagheeb, 1992). Then it expanded southwards deep to the woodland and three million ha of forest cover were lost to meet the increasing cultivation in the year 1992 (Mustafa, 1997).

Since the early 1900s, extensive areas of woodland and forests have been converted to agricultural use. Large amounts of land classifiable as woodland has been cleared in the development of large-scale mechanized rainfed farming in a number of states. This is expected to lead to negative impact on the forest sector unless the necessary measures are taken as soon as possible. Shifting cultivation is recorded to account 70% of the clearing of closed forests and 60% of the cutting of savannah forests.

Natural regeneration declines after each cycle of cultivation. Regeneration between successive periods of cultivation grows shorter and shorter, sometimes even disappears altogether. A study in Surinam showed that the indigenous species in some natural forests has largely disappeared due to lack of natural regeneration caused by the effect of shifting cultivation (Jonkers, 1987). However burning of residues in cultivation operations as one of the most important tools in achieving clean land always destroys the litter layer and so diminishes the amount of organic matter returned to the soil, the burning operations are practiced at summer when the newly natural regenerated seedlings and saplings starts growing and developing. The organisms that inhabit the surface soil and litter layer are also eliminated, as a result of fire and heat caused by burning, destroying the suitable condition for new regeneration (Izhak and Eman, 2000)

The clearing of mother trees could greatly affect the soil seed bank by removing the main seed source that is expected to enrich the soil with the amount of tree seeds that can in the future produce new regeneration. The soil seed bank is considered as the main factor determining the success of any natural regeneration. The soil seed bank is affected by fire set by farmers to clean cultivation lands. The fire destroys the trees, alters the nature of the soil, affects the soil seed bank and damages the produced seedlings. (Young et al., 1978) stated that slash and burn reduced the seed bank to less than 50% of its original size, the thing that decreased naturally regenerated area.

2.4 Grazing in forests

Sudan is known for its wealth in livestock. It was reported that 90% of the livestock in the country is under the hands of nomads and semi-nomads (World Bank,
1986), that mean herding animals and grazing is not organized in farms as found in some developed countries. This puts great pressure on the natural forests since trees and shrubs are the only alternatives feed during the dry season when there is no grasses available Ibid. According to Elsiddig (2007). B. aegyptiaca is being grazed intensively in its natural habitats at the regeneration stage. However the direct effects of grazing is trampling seedlings, pushing over small saplings, reducing stocking of the stands, changing species composition, and reducing production (Herron and Labone, 1972). The trampling made by livestock is known to compact the surface soil and damage the fine absorbing tree roots, which will reduce the tree capability to absorb water and nutrients and leads to moisture stress, increases susceptibility to insects and diseases. It is also observed that heavy grazing reduced sapling diameter growth at 25% to 50% (MacCain, 1985).

Natural regeneration was found four times more under rotational grazing as opposed to conventional grazing (Fischer, 2009). Badi et al. (1989) claimed that grazing in its absolute terms is not considerably harmful to forest, because an appreciable amount of natural regeneration can get away and grow into maturity. Anyhow, the real concern is over grazing in which the animal population exceeds the potentiality of the resources and causes severe damage to the stand. Ibid.

Over grazing is more intensive and obvious in the surroundings of the towns and villages where tree vegetation is reduced to stunted stumps or absolute bare area (FAO, 1953; Badi et al., 1989). Different types of animals vary in their grazing on the trees but goats are the worst since they prefer woody vegetation to grass or herbs Ibid. So where there is heavy grazing natural regeneration of forests is impossible Ibid.

The great effect of grazing in dryland of Sudan occurs during the summer when there is no alternative source of fodder for livestock except tree seedlings and saplings. Animals can even eat tree seeds and threatening the soil seed bank. Linhart and Whelan (1980) considered natural regeneration at some sites as a problem due to heavy over grazing, where seedlings were damaged or even eaten or killed by big animals. The soil could be compacted due to heavy load from livestock to result degradation and runoff. Osman and Idris (2012) stated that some Acacia and B. aegyptiaca disappeared under the pressure of over grazing by a large number of livestock on a small area which resulted in the deterioration of protective vegetation.
According to them, soil was compacted, water did not penetrate into the soil and regenerated seedlings were damaged or killed.

It was observed in England that grazing by field voles killed about 73% of the newly regenerated plants (Rose, 2002). Goats have a major effect on tree regeneration than any other animal because of their high propensity to brows. Cattle can cause damage by eating seedlings and trampling soil which will slow the growth of seedling through preventing water penetration. Some studies suggested that there are some advantages of grazing for natural regeneration; assisting initial establishment of seedlings by suppressing competing vegetation, transferring seeds from place to place by the movement of animal, treating the seeds through animal digestive tract and readily germinated and eliminating some grasses that can compete with seedlings.

However, total exclusion of grazing may be a mistake where there is a lack of germination and/or low densities of seedlings. Badi et al., (1989) found that hard seeds of B. aegyptiaca and Zizyphus spiniersti were palatable for goats, which resulted in widespread of their seedlings and saplings all over El Nour natural forest in Blue Nile State. However livestock in the forests is one of the whole ecosystems, the challenge is to make use of its benefits and lessen its negative impact.

2.5 Forest fire

Fire is an important factor affecting forests in general and natural regeneration in particular. Increased wildfire hazard is associated with low humidity, high fuel loads and the presence of moving grazers. In Sudan, annual wildfires are common and spread rapidly due to northeast winds and flat terrain. In Jebel Marra, about 1250 ha of Cupressus lusitanica were destroyed in the 1990s (Goldammar, 1991). Large tracts are often swept over by wildfires in central and western Sudan (Bayoumi, 2001). Growing population density escalates fire risk due to the increased demand for land and other natural resources.

The largest number of fires is human-induced, either by negligence, economic interests, and careless use of fire in agriculture and pasture lands or illegal land clearing (FAO, 2009). Fires cause great damage to the ecosystem by changing the species composition and the forest climax, destroying the trees and altering the nature of the soil which affects the soil seed bank (Badi et al., 1989). Forest fires are considered as a major problem confronting forest management. Fires occur when the
atmospheric relative humidity and the moisture content of the forest litter decreased 
Ibid.

The dangerousness of fires increases when they convert the natural stands from 
broad-leaved timber tree species to thorny acacias and finally into bush and grass 
lands (IFFN, 2001). Balanites trees are known for their resistant to fire but the risk is 
that, the fire damages the seedling stage of the tree and destroys the natural 
regenerations (Badi et al., 1989). Forest soils have its share in the damage that is 
caused by fire which burns the soil nutrients and considerable changes in structure 
and water retention capacity. It was proved that fires also can create good conditions 
for the spread of insects and fungal diseases Ibid. In some cases fire is required to 
promote seed release and seed germination. However, fire is recognized as both use 
full tool and a complex management issue. It creates an ash bed and encourages 
germination, but this is only relevant for fire adapted vegetation types (Goldammer, 

Forest fires have a negative impact on the natural regeneration system since it 
has a direct and indirect impacts on the environment. It is expected to kill naturally 
regenerated seedlings and saplings, injuries plant and reduces soil seed banks capacity 
(Janzen, 2002). These adverse impacts depend on the intensity, duration of fire and 
exposure of plants to fire. Adequate exposure is suitable for seed germination and 
noticed that most successfully established seedlings were destroyed by fire during the 
summer when the site is dry.

Where the land is greatly damaged by fire on some sites the vegetation will be 
absent for many years until the land regains its original feature. (Goldammar, 1991; 
IFFN, 2001; Bayoumi, 2001). It was stated that dry forests can naturally regenerate 
only by preventing fire in abandoned pastures where there are already seeds that were 
transferred by livestock or from soil seed bank (Janzen, 2002). Studies in Mexico 
showed that seed banks at a slash-and-burn site in a tropical deciduous forest 
decreased one day after a fire by 93% in density and 81% in richness (Miller, 1999). 
In Bolivian deciduous forests about 94% of the viable seeds destroyed after high 
intensity burn treatments (Kennard et al., 2002). Fire could be one of the main factors 
leading to deforestation and land degradation. In northern Thailand uncontrolled 
annual burning is one of the causes of forest restoration failure.
Heat from fire can alter the chemical properties of the soils and the availability of nutrients. The specific effects depend on the temperature and duration of the heat. In some cases the availability of nutrients increases with low-intensity fires, whereas with high-intensity fires soil fertility may be diminished. Soil may become temporarily impervious to water after a hot fire, increasing the amount of water runoff. Water runoff also increases after a fire because there is less groundcover and fewer trees to absorb it.

Intensity of fire may also consume soil humus and thus eliminate the growth of natural regeneration or slow it. Consumption of forest floor could change the micro environment of the upper soil layer (Eriksson et al., 2003). Removal of vegetation in open land by fire exposes the soil to wind or water erosion and hence forces the plant to change its habitat (Taylor et al., 2013).

### 2.6 Fruit and seed dispersal

Seed and fruit dispersal is a major and limiting factor in determining soil seed bank. Wind or gravity dispersed fruits mature mostly in the rainy season (Griz and Mashado, 2001), although the seeds remain dormant until the beginning of the next rainy season (Hardwick, 1999). According to (Clark, 1998) most seeds produced by a tree are locally dispersed and their declines exponentially with distance from the tree, i.e. density falls off steep with distance, approximately 10% of the seeds are dispersed over long distances, seed density gradually diminishes and extends over great distances of 1 to 10 km. Hardwick (1999) stated that, tall fruiting trees located in and adjacent to a site make the biggest contribution to the seed rain.

Bird species has been found to be highly effective in seed dispersal of forest trees, in some cases over a long distances from the seed parent tree, the presence of bird perches generally increases bird–dispersal seed rain compared to open areas (Holl, 1998). Although birds and small mammals may aid the dispersal of species, the effect of animals on regeneration of most trees is predominantly harmful, seeds being eaten and young trees damaged by browsing and fraying.

The mobility of trees varies within species and site, in open conditions light wind– born seeds may travel over 100 meter and heavy wind borne seeds may travel to tens of meters, however distances are much reduced within a stand. Heavy seeds can be dispersed by animals; most seeds of species remain close to the parent tree.
2.7 Seed predation

Predation seems to prevent germination in many types of tropical, moist and dry forests (Woods and Elliott, 2004). However, the intensity of seed predation is highly dependent on size of the seeds. Medium sized seeds (0.2–4 g) are more susceptible to rodents because they are easier to find than very small seeds, and are easier to manipulate than larger seeds. Small seeds are eaten mainly by small insects such as ants. Seed predation is also affected by land use; secondary succession, logging and pasture Ibid. Buried seeds are less predated by ants and suffered less desiccation than unburied seeds Ibid. Most studies have agreed that seed predation in cleared areas significantly limits seed availability with mortality levels ranges from 20% to 80% (Osunkoya, 1994; Hammond, 1995).

2.8 Soil and B.aegyptiaca growth

The physical, chemical and biological properties of the soil affect the plant growth. The soil texture has influences on several important soil characteristics including infiltration rate and available water capacity (Dan, 2000). Compaction and erosion affect natural regeneration. Compaction binds soil particles together so that germination restricted and root growth reduced. Good soil structure usually contains high content of organic matter. Salinity reduces moisture availability directly and harms plant growth (EL Darier and Youssef, 2003).

B. aegyptiaca occurs over wide range of environment and soil types (Badi et al., 1989; Hall, 1992). This resulted in a considerable phenotypic variation in fruits, seeds, leaves, crown shape and timing of flowering and fruiting (El Amin, 1990; Sands, 2001; Gebaur, 2002). Hall (1992) also confirmed that B. aegyptiaca is observed in relatively fertile, loamy or clayey soil of low salinity, but in the northern Sahel is widely present on lighter and drained soil. El feel (2004) observed that the soil effect on growth parameters was very highly significant in silt than in sand soils. Anyhow, it prefers valley soils but can grow in sand, loam, clay alluvial and gravel soils ( RSCU ) 1992). According to Teel (1984) B. aegyptiaca is known to tolerate heavy clay soils. Generally adapted to soil environments with low nutrient levels, (Hardwick, 2004). Soil types because of their different properties could affect survival and growth and even quality of the tree, for example soil fertility strongly affects foliage growth and shoot/ root height, high measures of shoot / root height were found on silt soils, this might be due to greater nitrogen present in silt soils (Landsberg and Gower, 1997).
Along the Blue Nile B. aegyptiaca is widely found growing on the heavy cracking clay soils associated with A. seyal. The density of the trees increases southwards (El Amin, 1990; Teel, 1984). El Nour (1994) obtained 53% of natural regeneration of B. aegyptiaca in Abu Hujar area along the Blue Nile on cracking clay soil. The clay soil increased the germination of B. aegyptiaca in Tanzania to about 60% and 52% in Kenya (Hines and Eckman, 1993).

Silt soils are also the best site for growing and distribution of B. aegyptiaca as germination increased from 41% to 60% (El feel, 2009). He also noticed that seedling growth on silt soil is faster than in sand soil.

However the natural regeneration performance of the tree is better in silt and clay soils than in sand and loamy soils, clay soil can hold water for a long time while sand and loamy soils are known to be of free drainage with very low organic contents Ibid. Similar result was observed by Hall and Walker (1991) who examined the rate of B. aegyptiaca germination on silt soil, which was raised from 33 to 61%.

The good performance of clay and silt soils, could be due to the fact that these two soil types hold moisture well, and rich of minerals, they also found that in the nature the development of the tree is on low-lying alluvial sites with sandy loam soil, where best quality trees were always found occupying river banks and valleys Ibid.

Best germination of the species B. aegyptiaca seeds were obtained in Kenya reached 79% on sandy soil, on the other hand sand soil can decrease germination, alter tree distribution, however sand soils gave low germination, when decreased germination percentage from 22% to 11% (El Nour, 1993). Elfeel et al. (2007) reported that sand soil reduced germination percentage of B.aegyptiaca seeds with 48% to 17%. Elsafori, (2009) recorded poor germination results in sandy soils of White Nile State. These poor results might be linked to some other factors affecting the germination and seedling growth and tree distribution as well, seed source, environmental and other related conditions might cause this poor results.

Generally while sand and loamy soils are known to be of free drainage with very low organic contents. Saline soils are not suitable for B. aegyptiaca growth and distribution, water absorption and essential nutrients are retarded due to the concentration of salts in the soil, which will stop the growth of seedlings and halt seed germination, or some time damaged, and being poisoned to death, affecting seedling development. Salinity and sodisity soils can reduce moisture availability directly and harms plant growth (EL Darier and Youssef, 2003).
CHAPTER THREE
MATERIALS AND METHODS

3.1 The study area

The study was conducted along the Blue Nile western bank, south of Sinnar Dam, between latitude 11.49 - 13.33 N and longitude 33.37- 34.42 E (Figure 3.1). The climate is characterized by short rainy season, July to September, with an average annual rainfall of about 500 mm. Temperature is high during the dry period; the maximum mean daily temperature is 43.8 °C in May, the minimum daily mean temperature is 13 °C in December and the mean annual temperature is 28.8 °C (Elagib and Mansell, 2000). The mean relative humidity is 40% with a maximum of 75% in August and minimum of 25% in April. The annual evaporation is 5180 mm, the potential evapotranspiration is 2000 mm (Le Houérou, 1988).

There are four distinguished soil types; the Jerf soil fringing the river meander which is fertile silt used for producing vegetables and fruits, the clay soil lies next to Jerf in depression known locally as Mayá flooded annually during the rainy season and used to manage A. nilotica forests, the Karab soil stretches out of the Mayá slope to the flat plain with crusted surface and concentration of iron oxides, and cracking clay soil extend far away from the river banks on flat plain where staple crops are grown under rainfed agricultural practices ( Figure 3.2). The area is part of the central clay plain of Sudan, characterized by its cracking clay soils, which are mostly alluvial in origin from material transported by the Blue and White Niles and their clay content is about 70% (Craig, 1991; Mirghani, 2007).

Gully erosion stripes off the fertile clay soils from the degradation clay plain forming lands known locally as karab. Karab lands are classified as marginal abandoned lands due to the poor and eroded soil they contain and are dominated by drought resistant species such as A. seyal, B. aegyptiaca, and Capparis desidua (Craig, 1991; Mirghani, 2007). A. nilotica trees dominates Mayá. There are several seasonal water sources (Wades and khors) that radiate from the Ethiopian Plateau and the Hills in Dali and Mazmoum area. These wadies are, however, seasonal carrying water during the peak of the rainy season. To the south-east of the region runs Khor Dunya from south west to north east until it joins the Blue Nile at a point at 35 km north of Ed Damazin town. North to Khor Dunya, khor Kennana, khor Galagu, Khor
Enaikleeba and khor Abu Naàma, but all are joining the Blue Nile. These khors are home for A. seyal and B. aegyptiaca.

The vegetation belt is called A. seyal–Balanites belt. Bordering Damazin from south and west is Khor Dunya forest reserve, a natural forest composed of a variety of tree species, and traversed by Khor Dunya seasonal water course. This Khor is characterized by the presence of degraded areas, natural regeneration, human activities such as agriculture, pastoralism and small settlements, and human intervention to reclaim the vegetation. Nawara natural forests adjacent to the high way of Khartoum Damazin, A. seyal and B. aegyptiaca are the dominant tree species. Tozi natural forest is also found to the west far from Blue Nile river. Gum Arabic trees A. senegal and A. seyal are mainly found in natural forests to the west of the Blue Nile on the flat clay plain in Dalli and Mazmoum area. Jabal Abu Grood natural forest is one of the forests dominated with hashab, A. senegal trees (Mirghani, 2007). There are a number of natural forests in the eastern part, for example, Okalma forest reserve which is bounded by Okalma mountain on the west and Zign mountain on the south east corner.

The livestock in the area are namely camels, cattle, sheep and goat. According to World Bank (1986) about 85% of the livestock is owned by nomads and semi-nomads who move within the savannah belt to rear their animals on the natural pastures which provide browse trees and shrubs. Settled villagers earn a considerable number of livestock that use to graze not far from the villages.

Inhabitants practice both traditional and mechanized farming to produce sorghum (Sorghum bicolor L.) and sesame (Sesame indicum L.). Traditional agriculture is practiced by the majority of the people in this area who have not enough money to introduce heavy machines (El Nour, 1994). The area of cultivation is always small about two hectares and called "bilad". The crop produced is mainly for family consumption. Shifting cultivation is widely practiced in the region where large forested areas were cleaned every year. Moreover, large areas were cleaned and cultivated with cash crops using machines to produce large amounts of crop. This is mainly done by investors and large companies but some wealthy locals are involved in mechanized agricultural practices. One mechanized farming area (mashroul) ranges between 500 to 1000 ha. (EL Nagheeb, 1992).

Forest products in the area contribute to the income of local people; collection of forest fruits, leafs for fodder, branches, wood for fuel and timber for fencing. Usually
these products are collected during the summer after crop harvest and practiced by all family members but is mainly done by women and children. Charcoal making is widely practiced by local people to produce small or medium amounts of charcoal or supplied by traders. This represent the major activity during summer.

Large areas in the natural forests reserves mainly A. seyal forests were cut annually and regularly by FNC through announced bids; here large amounts of charcoal sacks are produced. Timber is largely produced from riverine forests and A. nilotica for commercial uses, beside the collection of building pools where forests are the main source for it. Fruit collection mainly Heglig and sunt lalob and garad, nabag, aradaib and others is one of the main activities during summer, large amount of forest fruits are collected and sold in the nearby markets or transported to other places. Gum Arabic plays an important role in rural life providing a steady income to rural families especially in dry years when crops fail. Gum tapping and collection is practiced in the A. senegal and A. seyal stands (Gaafar, 2005).

The majority of the population in the study area live along the river bank, so most of the villages are located adjacent to the river, but some villages are located far from the river bank.
Figure (3.1): The study area along the Blue Nile
Figure (3.2): Cross Section in Blue Nile Basin
Figure (3.3): Distribution of targeted villages at the study area along the Blue Nile
3.2 Natural regeneration survey

A spot sampling was carried out in the field at selected sites immediately after the rainy season of the year 2010. The selected sites included: (a) abandoned agricultural farms, where the soil is cracking clay, flat topography and traditional agriculture was practiced, (b) vicinity of the villages, the area of heavy grazing, browsing and lopping, (c) Karab of the eroded sandy loam soil lies between the water courses and flat plain, (d) Wad valley with deposited silt and clay soils and (e) B. aegyptiaca stands in association with A. seyal and Acacia nubica species. The diameter of the spot was 50 m and replicated randomly three times in each location. Boundaries of the spot were marked using colored flags to prevent missing of trees or measuring trees outside the spot. B. aegyptiaca trees within the spot were counted, their shoot height and diameter at ground level were measured, using the diameter tape for measuring trees and the caliber for saplings and seedlings. In addition, measurements on lopping, pollarding of the trees and browsing on sapling and seedlings were recorded. All readings and measurements in each spot were recorded on separate sheet. The soil moisture in the five sites was measured in April, which is the driest month and are given in Table (4.4).

3.3 Germination of the seeds in the soil

Fresh seeds of B. aegyptiaca were randomly collected from trees at different sites in April 2010 from Wad el Naiel area, lat. 12° 41’N long. 34° 09’E in the region. The seeds collected were divided into two lots; each one containing 1500 seeds, in one lot the epicarp and mesocarp were removed to extract the seeds. Only healthy seeds were reserved. The other lot was kept as fresh with epicarp and mesocarp after ensuring that they were healthy. The seeds were subjected to viability test. The viability tests were based on ISTA (1996) rules that utilized both germination, Tetrazolium Chloride staining, and conducted at the National Tree Seed Centre (NTSC) of the Forest Research Center.

An experiment on seed germination was carried out in 17th June in 2010 at the onset of the rainy season, in Nawara Forest reserve in the region. The soil of the forest is black cracking clay and the average annual rainfall is around 500 mm. The dominant trees are Acacia seyal variety seyal with some scattered trees of B. aegyptiaca. The experiment was laid out in split plot design in four blocks distributed within the forest. The status of the seed, either extracted or pulped, formed the main
plot. The seeds were laid on the soil surface at 0.0 cm depth and 5.0 cm depth, and that formed the subplot. Sowing of the seeds was done in plots of 25 cm in radius. The plot was surrounded with metallic ring and contained 50 seeds. Germination of the seeds was recorded. Persistent and perished seeds were recorded at November or after the cease of the rainy season. The data were subjected to analysis of variance using MSTAT software program and the Duncan's Multiple Range Test was used to detect the significance of differences among the means.

3.4 Impact of soil type and salinity on seed germination

3.4.1 Effect of soil type on seed germination

Seeds of *B. aegyptiaca* were sown in the nursery in two soil types; clay and eroded clay loam. They were sown in August 2011 in black plastic bags of 30 x 30 cm size filled with 2.5 kg of each soil type and laid out under direct sun light in split plot design in four blocks. The two main plots allotted for the soil types and the two subplots in each main plot for the seeds either extracted or pulped. Each subplot contained ten bags. One seed was sown in each bag. The experiment was irrigated every two days in the morning. Germination in each subplot was recorded daily for 35 days. Seeds were sown in August and took two weeks to start germination and ended on day thirty five.

3.4.2 Effect of soil salinity on seed germination

An experiment on effect of salinity on germination was performed using NaCl and CaCl salts to fix different levels of soil salinity in clay soil. The initial EC of the clay soil used in the experiment was 0.8 dSm$^{-1}$ and represented the control. In addition to the control, five levels of salinity measured as EC were fixed at 4 dSm$^{-1}$, 6 dSm$^{-1}$, 8 dSm$^{-1}$, 10 dSm$^{-1}$ and 12 dSm$^{-1}$. The amounts of NaCl or CaCl salt required to prepare one liter of each of the different planned levels of salinity were calculated as given in table (3.1).
Table (3.1): Calculated amount of NaCl and CaCl required making separately one liter solution to adjust different levels of salinity in clay soil

<table>
<thead>
<tr>
<th>Adjusted salinity level (dSm(^{-1}))</th>
<th>NaCl salt required to adjust salinity level (g/l)</th>
<th>CaCl salt required to adjust salinity level (g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>4</td>
<td>1.66</td>
<td>2.13</td>
</tr>
<tr>
<td>6</td>
<td>4.97</td>
<td>3.20</td>
</tr>
<tr>
<td>8</td>
<td>6.62</td>
<td>4.26</td>
</tr>
<tr>
<td>10</td>
<td>8.28</td>
<td>5.33</td>
</tr>
<tr>
<td>12</td>
<td>9.94</td>
<td>6.39</td>
</tr>
</tbody>
</table>

The salts were then added separately to the exact quantity of distilled water and magnetically shaked till all granules were completely dissolved. Viable seeds of *B. aegyptiaca* were sown in August 2012 in pots of 25 cm in diameter and filled with one kg of clay soil having field capacity to 420ml/kg. About 18 pots were laid out in glass house yard arranged in three blocks. Each pot contained 25 seeds. The weight of each Pot was measured and recorded. Salt solutions were applied once. Irrigation was applied every 48 hours using tap water for five weeks. The amount of water applied to each pot was calculated as an equivalent of the difference in weight that can fill the dish at application of irrigation water (wet weight) and before application (dry weight). The experiment continued for five weeks. The germination started after two weeks and by the end of fifth week no germination was recorded. Parameters measured were the weekly and cumulative germination. The data were subjected to analysis of variance using MSTAT- C software program and Duncan's Multiple Range Test was used to detect the significance of differences among the means.
3.5 Perception of the local communities

A reconnaissance survey was conducted in the study area along the western bank of Blue Nile River from a point south of Sinnar Dam to the vicinity of Damazin City in the south. The survey focused on randomly selected villages along the western bank and protruded every now and then to the flat plain where traditional and mechanized agriculture are practiced. During the survey observations were made on location of the villages, community livelihood, agricultural practices, livestock, pastures, occurrence and distribution of *B. aegyptiaca* and type of the soil and data were recorded to help in writing a questionnaire format to interview some of the community groups and forests officers on *B. aegyptiaca*. Accordingly, ten villages located along the Blue Nile western bank were randomly selected for the interview (Figure 3.3). The contents of the form of the questionnaire included in details the perception of local people with respect to the planting, conservation, illicit felling, diversity of utilization, process of lopping and browsing, preference of the community regarding the forest services and participation of the community in forests management programs (Appendix 1).

In each village, 20 respondents over 40 years age were randomly chosen for interview and hence 200 respondents of both sexes were interviewed. Restriction of age to above forty year is because of accumulated indigenous knowledge they had on the species and environmental changes that have occurred. Respondents were briefed about the objectives and purpose of the study, moreover, they were assured about the confidentiality of information they give. SPSS software was used to analyze the data.
CHAPTER FOUR
RESULTS AND DISCUSSION

4.1 Natural Regeneration of *Balanites aegyptiaca*

The monitoring of the natural regeneration carried out along the study area revealed the occurrence of the *B. aegyptiaca* trees at various sizes, and hence ages, on all the sampled locations (Figure 4.1). That occurrence of trees was continuum in generation on all locations except on valley meander and at the vicinity of villages. Although respondents stated that there were regeneration in the vicinity of villages during and after the rainy season.

In the vicinity of villages the density was 90 plants per plot, about 548 plants in ha, all of the seed origin, with diameter at ground level (DGL) ranged between 7.0 to 82 cm and height ranged between 1.0 to 14 m. According to figure (4.1) dense plants were between diameter 40 cm and 60 cm. Smaller trees could be vulnerable to cutting and grazing. The consideration that there are some traditional and religious believes prevent cutting of *B. aegyptiaca* trees found at the vicinity of settlements could explain why it regenerates in the vicinity of the villages. Absence of natural regeneration at the vicinity of villages although there were big and fruity mother trees around, maybe for certain reasons; collection of the fruits by the locals and then transferring them to the markets which would reduce the stock of fruits in the area, newly seedlings that succeeded to emerge are subjected to browsing by animals during summer when there are no nearby fodder and also are cut for fencing.

The density of *B. aegyptiaca* plants on abandoned agricultural farmswas 129, about 1375 in ha (Figure 4.1), with diameter at ground level (DGL) ranged between 5.0 to 49 cm and the shoot height between 1.0 to 8.0 m. Total number of *B. aegyptiaca* seedlings counted was 270 with shoot height ranged between 10 and 75 cm. The trees were found to be young at this site and seem to be of small ages.

The results indicated that natural regeneration of *B. aegyptiaca* is possible on open land utilized as agricultural farms. El Amin (1990) and Elnour (1994) supported this result in addition to Goransson and Widgren (1996) who stated that *B. aegyptiaca* gave a high germination percentage (79 %) on abandoned agricultural lands in Kenya. The abandoned agricultural farms used in this study were previously the natural domain of both *B. aegyptiaca* and *A. seyal* species on cracking clay soils before taken
for the mechanized agricultural, This may be the reason behind the good regeneration of *B. aegyptiaca* found on this land, it means that the site is still rich of soil seed bank. Dense stands were recorded between diameter 5.0 and 25 cm while there was absence of trees between diameter 25 and 35 cm. That may relate to such activity that cut and removed all the coming regeneration at a time for to cultivate the site.

Also both figures (4.1 and 4.2) showed that the total number of *B. aegyptiaca* plants in natural forest were 192; 75 trees and 122 seedlings, with diameter at ground level ranged between 5.0 and 56 cm and shoot height ranged between 1.0 and 11 m. The experiences and studies (EL Amin, 1990; Hall, 1992) on natural distribution of *B. aegyptiaca* showed that natural regeneration is successful in association with *A. seyal* on cracking clay soils. Honu and Dang (2002). McLaren and McDonald (2003) had similar results. The nature or the growing conditions of the two species are almost the same or close to each other.

The natural regeneration of *B. aegyptiaca* was not dense as on abandoned agricultural farm because the natural forests in Sudan clay plain swept by fires every year during the dry season which reduce the number of generated seedlings and before that damaging the source of seed soil seed bank. Close to that result was stated by Okia (2010) who said that natural regeneration of *B. aegyptiaca* was insufficient in Uganda due to annual bush fires set for cleaning land for agriculture practiced on *A. seyal* sites.
Figure (4.1): Size class distribution in connect with Natural regeneration
The density of the natural regeneration of *B. aegyptiaca* on *Karab* site was 127 in a plot; 52 were trees and 75 were seedlings (Figure 4.1 and 4.2). That density was 647 plants in ha. The diameter at ground level ranged between 5.0 to 42cm the height ranged between 0.2 to 6.0 m.

*Karab* soils are known of their low content of moisture and organic matter, the thing that could determine the natural regeneration success and also the development of seedlings, but inspite of that there was considerable regeneration of *B. aegyptiaca* on *Karab*. The newly regenerated seedlings within the *karab* lands are always found on the slopes where some of the running water could be found which will form a good germination condition as the soil moisture increases, enabling the seeds to absorb enough water during the rainy season. The leashing water could probably store organic matter carried from other places in the slope, and during the running of the water heavy fruits like *B. aegyptiaca* would be dropped and stored in these slopes forming a good seed stock in the soil that is why the natural regeneration found within the *karab* lands are located on depressions within these lands.

*B. aegyptiaca* seeds treated by animal after passing its digestive tract could readily germinate when enough water staying on the slope reaches to the seeds. The high temperature found on these *karab* lands due to lack of enough water could break or weaken the hard epicarp of the woody seeds of *B. aegyptiaca* making it ready for germination when rain falls and by the end of the rainy season the deep tap root would enable the young seedlings that germinated to withstand hard conditions found on these *karab* lands by going deep into the soil for water, this will happen after the seeds germinate by the end of the rainy season when the soil is fully absorbed with water. This came in line with Elfeel (2011) that in Sudan the tree *B.aegyptiaca* is suitable for difficult sites where water is the main limiting factor in natural regeneration. The species could have developed some genetic characteristics to germinate and grow where tough and hard conditions existed. The main factors in any new regeneration on *karab* sites could be related to fruits and deep tap roots of *B. aegyptiaca* that are found on the slopes.

Natural regeneration of *B. aegyptiaca* was also found on the banks of the valley or depressions at discontinuous distribution regarding the age (Figure 4.1). It was less in density compared to abandoned agricultural farm, natural forest or village vicinity sites, and ratio of seedlings to trees was comparable (Figure 4.1). The number of trees was 28 and the seedlings was 29 in a plot; 143 and 148 in ha respectively. The
diameter at ground level of the plants ranged between 5.0 to 71 cm and the height ranged between 0.2 to 6.2m. Heavy felling and over grazing was observed at this site.

Figure (4.2): Stocking density of *Balanites aegyptiaca* trees and seedlings in 50 m-diameter plot at various growing sites
The tree is subjected to felling probably for timber and building poles due to the good quality. This may explain the few number of trees found along depressions. Besides that the valley is a good site for growing some crops during the winter due to the high fertility and moisture contents of the soil the conditions that would encourage people to clear the area from any trees so as to cultivate it. Moreover the site is suitable for grazing certainly the remains of vegetables and fruits, so the species suffers from heavy grazing, lopping and removing of saplings and young trees for fencing and firewood. It could be the need for shade during summer or while people were collecting their crops that forced them to leave some *B. aegyptiaca* trees.

The finding that natural regeneration of *B. aegyptiaca* was found on depressions and valleys banks agree with Badi *et al.* (1989) who stated that the species *B. aegyptiaca* was found growing under rainfall of 600 mm on water receiving sites such as depressions. RSCU (1992) went on the same line and recorded that *B. aegyptiaca* species prefers valley soils. Rulangaranga (1989) observations came close to the results that *B. aegyptiaca* is growing well in valleys and on river banks in depressions. The gap in the diameter distribution (Figure 4.1) could be attributed to the assumption that farmers cut the trees of medium sized as they are preferable for building poles, furniture and other uses. Trees with diameter of 30 cm and more are suitable for the private owned sawmills. In general valley banks are suitable sites for growing *B. aegyptiaca* but the clearance taking place for winter cropping would limit the success of natural regeneration and the development of trees at the site.

*B. aegyptiaca* was also regenerated in the valley meander (Figure 4.1) but all of the measured and recorded plants were trees and new regeneration was completely lacked (Figure 4.1). Results in both figures indicated that natural regeneration in the depressions, on washed sand soil, was not continuous and dense as on the other sites or facing problems; number of seedlings found was zero and total number of trees were 34. Diameter at ground level (DGL) ranged between 32 and 83 cm while the least shoot height recorded was 5 m and the highest was 13 m.

It is important to consider the limiting factors operating at all stages of the regeneration process, namely seed production and dispersal, and seedling recruitment, establishment and growth. Lacking of new regeneration at the valley meander was earlier supported by Harrison and Jackson (1958) who stated that *B. aegyptiaca* disappears in the flood region with rainfall over 700 mm.
It may be possible that the reason behind lacking of new regeneration is the lack of stock seeds; seeds being removed and washed away by running water to far distances, or being rotted, even if some seeds succeed to germinate they would not have the chance to survive because flood would submerge these seedlings to death since valleys uphold water on them for seven months, from August to February, taking into consideration that *B.aegyptiaca* fruits are said to germinate immediately when reaching soil surface. The remaining trees found in this site could be due to the chances given in some rainy seasons with low rainfall that didn’t cause floods stayed for months to the dormant seeds to germinate and survive.

There is high variability in moisture content percent ranging from 4.5% on *karab* to 20% on river meander in summer (Table 4.1) and despite of that there was natural regeneration on all sites except the vicinity of villages. This could be related to the nature of the species *B.aegyptiaca* that it is found dominating all habitats from wet sites to dry areas, that the tree can grow where high rates of rainfalls 800mm and low rainfall rates 250 mm, this could probably had some relations with the fruits and the root system of the species despite the amount of moisture content that the fruit can bear both high and low rates of soil moisture. In case of high moisture content the fruit can germinate easily and develop well into seedling, while the fruits in lowest moisture content where high soil temperature is recorded could help in breaking or weakening the hard epicarp of the fruit by heating, and then after germination the tap root would go deep to search for water during summer.

The germination of *B. aegyptiaca* on both wet and driest sites was strongly supported by Hall and Walker, (1991) and Elfeel (2011) that the tree dominates flooded areas and is also suitable for difficult sites with scarcity of water. The species could have developed some genetic characteristics to germinate and grow where tough and hard conditions existed.

Another justification for the existence of natural regeneration on all sites despite of the high variability in moisture content, that on sites of low moisture content the fruits that germinated might have been treated by animal digestive tract, and that the least amount of water would be enough for the seed to emerge and then being helped by the deep tape root to survive and develop, while for the other fruits the amount of water in the soil could act as a treatment method to treat the seeds by soaking, but the amount of water could also damage some seeds by rotting causing failure of natural regeneration. In general *B. aegyptiaca* is characteristics of various habitats
from wet to dry and this is based on its genetic characteristic, fruit and root functioning.

Table (4.1): The status of the soil moisture taken at April (Dry month) at northern (A), central (B) and southern (C) parts of the zone of the study from Sinja town in the north to Disa village in the south

<table>
<thead>
<tr>
<th>Location</th>
<th>Moisture content (%)</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
</tr>
<tr>
<td>Karab</td>
<td>3.6</td>
<td>4.8</td>
</tr>
<tr>
<td>Natural forest</td>
<td>6.7</td>
<td>4.8</td>
</tr>
<tr>
<td>Abandoned agricultural farm</td>
<td>3.8</td>
<td>6.1</td>
</tr>
<tr>
<td>Vicinity of village</td>
<td>6.4</td>
<td>6.6</td>
</tr>
<tr>
<td>Valley banks</td>
<td>8.3</td>
<td>9.8</td>
</tr>
<tr>
<td>Valley meander</td>
<td>10.3</td>
<td>13.7</td>
</tr>
</tbody>
</table>

4.2 Germination of *B. aegyptiaca* seeds in the field

There were no significant differences between the means of germination percentage due to sowing depth and form of seeds (Table 4.2). seeds with removed epicarp and mesocarp gave about 90% germination sown at either 0-cm or 5-cm depth. However, it was observed that germination was delayed for two weeks in case of the seeds sown at 5-cm depth. The high germination of the unburied seeds were unexpected compared to buried ones because I do believe that the soil moisture contents available for the buried seeds could be more conserved for long time and moreover the soil could have an action to weaken the hard coat of the seeds and hence more significant germination as compared to those not buried. However, the result seems controversial, and has supporting or denying from a considerable number of scientists. Watt and Whalley (1982) and Benevento *et al.*, (2001) supported that observation when they found that the soil depth had no any effect on seed germination but it did on emergence.
Same results were obtained by Asgharipour (2011) who found that germination decreased linearly with increasing depth of sowing. The result was also backed by the finding provided by Dalling (1995) when he investigated the tropical soil seed banks and reported that dense regeneration was obtained from soil seed bank at 1-cm and most of the seedlings emerged within six weeks. Other scientists like Woods and Elliott (2004) were opponent to that observations and results. They reported that deeper soil layers usually are moister than shallow layers and hence more likely to maintain a stable level of moisture for germination. Moreover, they said that fruits laid on the surface of the soil could suffer the drying by both sun and wind.

Anyhow, buried fruits are protected from damage by organisms and desiccation. On other hand, fruits buried deeply in the soil usually establish very few seedlings because pre-emergence mortality results from a cessation of seedling growth before it reaches the soil surface or the seeds are unable to germinate due to lack of oxygen, light and temperature (Benevento et al., 2001).

Generally seed size, time of emergence, and the type of soil determine the optimum depth of planting. The seed must be able to imbibe enough water to germinate before the soil surrounding it dried out. Deep sowing are successful in lighter soils than in heavy soils. The surface dries out quickly in sandy soils making deep sowing necessary for placing the seed in moist layer. In cold and wet soils shallower sowing are required because the oxygen concentration and temperature at greater depths may be too low for germination.

Table (4.2): Percentage of germinated seeds of *Balanites aegyptiaca* under field condition

<table>
<thead>
<tr>
<th>Sowing Depth</th>
<th>Status of Fruit</th>
<th>Mean SE ± 2.7</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Extracted¹</td>
<td>Pulped²</td>
</tr>
<tr>
<td>0-cm</td>
<td>92</td>
<td>91</td>
</tr>
<tr>
<td>5-cm</td>
<td>90</td>
<td>85</td>
</tr>
<tr>
<td>Mean</td>
<td>91</td>
<td>88</td>
</tr>
</tbody>
</table>

CV = 3.6%

No significant (p≤ 0.05) differences between the means according to DMRT.

Extracted¹ = Seeds with removed epicarp and mesocarp

Pulped² = Seeds with intact epicarp and mesocarp
The insignificant difference in germination between extracted and pulped seeds (Table 4.2) could be due to the assumption that the thin epicarp and fleshy mesocarp didn’t withstand the natural conditions and decomposed in due time to rectify any effect that could cause delay of germination. The mesocarp is easy to be liquidated by sunlight or by high temperature. Its likely to say that the time taken to remove the effect of them to delay germination is not long, within days the woody endocarp of the seed might be directly subjected to decomposition by the natural biotic and abiotic factors. Some scientists such as Tredici, (1978) obtained good results of germination when seeds of Pontetieria cordata and Comptonia peregrina sown without removing their epicarp and mesocarp.

4.3 Impact of soil type and salinity on seed germination
4.3.1 Effect of soil type on seed germination
The results given in figure (4.3) revealed clearly that the seed of B. aegyptiaca sown in clay loam soil almost completely failed to germinate nevertheless the status of removing both the epicarp and mesocarp or not. As far as the status of the seeds was concerned, it was clear that there was no any significant difference between the germination percentage of the seeds whether epicarp and mesocarp removed or not. The seeds with any status gave germination more than 90%. Clay soils hold moisture well, this helped the seed to germinate. This is supported by (Elfeel, 2009) who confirmed that soil type affected B. aegyptiaca germination.
Figure (4.3): Percentage of germinated seeds of *Balanites aegyptiaca* sown in clay and clay loam soils

Hall and Walker (1991) agreed with the above findings when they observed an increase in germination of *B. aegyptiaca* seeds from 33% to 61% on silt and clay soil. Results also came in line with Hines and Eckman, (1993) who investigated the germination of *B. aegyptiaca* seeds on clay soil in Tanzania and found that average germination reached 60%. Similar results were found by El Nour (1994) who recorded a germination of 53% on the clay plain. In Kenya a preliminary trail of direct sowing of 17 woody species on clay soil by Okia (2010) showed that *B. aegyptiaca* was the best to give 52-79% germination.

As mentioned in the previous chapter, clay loam was sampled from *karab* site. The *karab* soil was found containing high salt concentration reached 13C dSm\(^{-1}\) (Appendix 2). Therefore, the germination failure in clay loam is no doubt referred to high saline concentrations found in the soil. The primary effect of excessive salinity is that it renders less water available to seeds and plants. This is because the osmotic pressure of the soil solution increases as the salt concentration increases. The salts ions can affect seed germination through toxicity then affect the embryo germination. Also high levels of salts cause changes to soil structure resulting in compacted soils which reduces water and oxygen penetration into the soil and water drainage from the
soil. Hall (1992) had described a similar results when he stated that the tree is typical to fertile, loamy or clayey soil of low salinity. The results of zero germination obtained from clay loam soil is supported by Daffalla (2011) who reported that the cumulative germination percentage of A. senegal was reduced with the increase of salt concentration to 10 dSm⁻¹.

In the same line Ewusie (1980) indicated that the factor of high evaporation, transpiration and concentration of salts on soil surface are responsible for most emergence failures. The result also came in line with the finding of Sonaike and Okusanya (1987) who found that salinity caused loss in germination of Lufa aegyptiaca seeds at concentrations of 10 dSm⁻¹ and the germination decreased as salinity increased. Another supporting result was obtained by Palmer et al. (1969) who showed that increased salinity resulted in decreasing or absence of germinability. In Nigeria Agboola (1998) agreed with the results that low germination of 3-10% were obtained in Ceiba pentardra and Terminalia superb species, due to high saline contents.

4.3.2 Effect of soil salinity on seed germination

To verify the assumption discussed above, table (4.3) revealed the results of the experiment tested the effect of salinity on germination. It was found that the increase in the salinity was significantly decreased the germination at both salts concentration. The trend in the decrease was almost linearly related to the increase of salinity (Figure 4.4) Perhaps that might be attributed to the ability of the salts to absorb the water surrounding the fruits, osmotic retention of water or toxicity to embryo.
Table (4.3): Germination percentage of *Balanites aegyptiaca* seeds at different soil electrical conductivity (EC) levels

<table>
<thead>
<tr>
<th>EC (dSm⁻¹)</th>
<th>Germination (%) at different EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8 (control)</td>
<td>Na Cl: 84 a, Ca Cl: 82 a</td>
</tr>
<tr>
<td>4</td>
<td>Na Cl: 74 b, Ca Cl: 72 b</td>
</tr>
<tr>
<td>6</td>
<td>Na Cl: 58 c, Ca Cl: 72 b</td>
</tr>
<tr>
<td>8</td>
<td>Na Cl: 50 d, Ca Cl: 64 c</td>
</tr>
<tr>
<td>10</td>
<td>Na Cl: 40 e, Ca Cl: 45 d</td>
</tr>
<tr>
<td>12</td>
<td>Na Cl: 32 f, Ca Cl: 41 d</td>
</tr>
<tr>
<td>SE±</td>
<td>Na Cl: 0.9, Ca Cl: 1.3</td>
</tr>
<tr>
<td>CV%</td>
<td>Na Cl: 8.2, Ca Cl: 14.1</td>
</tr>
</tbody>
</table>

Means followed by different letters were significantly different at p≤ 0.01 according to DMRT

Abdelmajid (2006) supported the above result when he found that high levels of saline concentrations at 20 dSm⁻¹ resulted in zero germination for both *A. seyal* and *A. tortillis*. Omami (2005) also supported the obtained results when he stated that an increase in concentration of NaCl significantly affected seed germination of *Amaranthus hypochondriacus*, the effect increased as NaCl concentrations increased. Similar supporting results were also reported by Abari et al., (2011) who showed that NaCl and KCl salt decreased germination percentage in *Acacia oerfota* and *A. tortilis*. He also stated that germination speed and germination percentage of these *Acacia* species were significantly affected by type of the salts. Similar results of reduction in germination of plants by increasing salinity levels had been described by numerous authors (Breen et al., 1997; El-Tayeb, 2005; Hall, 1992).

It was observed while the experiment was running that the germination was delayed for two weeks at both salt types. High germination rates were recorded on the second and third week for both two salts solutions. However the rapidity in seeds germination is particularly important in adverse climatic conditions, where salinity is
aggravated by scarce and erratic precipitation. seeds germinated without delay had made use of the limited soil water pool to establish seedlings before adverse climatic conditions prevail.

![Graph showing comparative trend in germination of Balanites aegyptiaca fruits as affected by source of salinity](image)

**Figure (4.4) : Comparative trend in germination of Balanites aegyptiaca fruits as affected by source of salinity**

### 4.4 Local community perception on Balanites aegyptiaca management

Local communities play an important role in forest management in general and in trees outside forests in particular as they are closely related to forests and depend on forest products as source of food, fodder, firewood, however the local knowledge of these communities and their behavior towards trees could help in improving forest management.

#### 4.4.1 Socio-economic characteristics of the respondents

A broad range of age was covered in the study with majority of them (85%) in the class of 40 years and more (Figure 4.5a). It was aimed to interview that age because they have enough experience about the *B. aegyptiaca* and the ecological changes in the area and frequently related to the field. Those who are expected to less than 40 years were recognized to be ambitious to settle in urban areas to work or run small
businesses for cash income. These changes are characteristics of many African societies as usually rural migrate to urban (UNDP, 2009). Though, this situation supports our assumption mentioned on importance of interviewing the old age groups who possess the inherited and practiced knowledge on management and ecology of *B. aegyptiaca*.

About 98% of the respondents were males (Figure 4.5b). In these conserved communities it is not easy to meet and have conversation with women due to traditional and religious reasons. In the local communities in Sudan the separation between women and men is strongly practiced. Males in these communities were responsible for field jobs such as farming, harvesting and animal rearing, which means they were close to the tree species and could recognize any changes within the tree. However, females work on collection of fire-wood and other forest products especially collecting lalob and other fruits (UNDP, 2009). In Burkina Faso women and children harvest as much as 40kg of *Balanites* fruits per day in December and January (Okia and Agea, 2011).

Figure (4.5c) revealed that about 45% of the respondents were illiterate, and that was increased to 96% when school leavers were included. This low level of education put a great pressure on forests resources specially in combination with the poverty that could not allow the majority to send their children to the nearby villages or towns for education.

According to data given in Figure (4.5d) that about 62% of the respondents were farmers. The high numbers of farmers reflect the nature of the area where the majority of the people work in agriculture during the rainy season, forest products collection and charcoal making during the dry season. That was close to the finding provided by El Nour (1994) that local inhabitants in this area practice small scale farming and large scale mechanized farming of sorghum and sesame. Agricultural production was the main source of income for 80% of the workforce and contributed to 39% of GDP. Those who breed and rear livestock were about 8%. It is reported that about 85% of the livestock in the country is owned by the nomads and semi-nomads, that means herding animals and grazing is not organized in farms as found in some developed countries (World Bank, 1986). Consequently that put great pressure on the natural forests since trees and shrubs are the only alternatives feed during the dry season when there is no grasses available Ibid.
4.4.2 Occurrence of *Balanites aegyptiaca*

The respondents claimed that about 43% of *B. aegyptiaca* distribution is in depressions, 42% on flat sites and 15% along the river bank (Figure 4.6). References on distribution of *B. aegyptiaca* have agreed with what was mentioned by the respondents, which replied that it occurs on hard-surface-soil, slopes at the foot of rocky hills, the valleys and widely on cracking clay soils in association with *A. seyal* (Suleiman and Jackson, 1959, El Amin, 1990).

![Graphs showing demographic and socio-economic characteristics of the respondents](image-url)

**Figure (4.5):** Demographic and socio-economic characteristics of the respondents at the study site along the western bank of Blue Nile
In fact the lands in Sudan are recognized as state lands, but these lands are traditionally communal, their use vested in tribal, family or village communities, but a small portion of this land about 1% is owned by private sector or individuals (Awad, 1971). Local people at the study area don’t have the culture of registering the land that they used it as farm because they depend on shifting cultivation in most of their life.

4.4.3 Uses of *B. aegyptiaca*

About 3% of respondents interviewed had seen the importance of the tree as fodder (Figure 4.7). That could happen during the dry season when other sources could be depleted. Elseed (2002) supports that result by the report; young leaves sprouts and fruits are eaten by livestock. In Burkina Faso, *B. aegyptiaca* contributed in the dry season to 40% of the dry-matter intake by goats. The shaft remained after oil extraction is widely used as a stock feed in Senegal, Sudan and Uganda. The tree is also lopped for fodder in India (NRC, 2008). In the same figure, 5% of the respondents had recognized the tree as source of fruits Ibid. reported that the fruits of *B. aegyptiaca* has been the bases of an active trade for many centuries in many countries.

Collection of *B. aegyptiaca* fruits is one of the main operations practiced during the summer when farmers cultivate and collect their crops (Billore, 1990). UNIDO (1983) estimated that about 400000 tons of *B. aegyptiaca* fruits can be obtained from natural Heglig forests in the Sudan. About 6% of the respondents claimed that they used the tree as fuel wood (Figure 4.7). Charcoal industry is source of income for many locals, the high calorific value of the tree 4600 kcal/kg made it excellent for firewood and charcoal (Van Mayedell, 1986; Lockett et al., 2000).

Toll to 5% of the respondents believed that *B. aegyptiaca* was used in rural houses as building poles (Figure 4.7). Due to the poverty people cannot afford paying industrial building materials, though they are depending on *B. aegyptiaca* and other local material in building the huts. Other use claimed by 18% of the respondents was utility of *B. aegyptiaca* in furniture designing (Figure 4.7). Elfeel (2004) reported that large numbers of *B. aegyptiaca* were subjected during the 1980s to felling at the region to meet the high demand for timber. Using the tree for all mentioned purposes was confirmed by 64% of the respondents (Figure 4.7).
Figure (4.6): Occurrence of *Balanites aegyptiaca* along the western bank of the Blue Nile as stated by the respondents.

Figure (4.7): Uses of *Balanites aegyptiaca* as experienced by the local community along the western bank of Blue Nile.
4.4.4 Change in the status of *B. aegyptiaca*

About 89% of the respondents noticed that there was change in the status of *B. aegyptiaca* (Figure 4.8). More than 70% of those believed that the trend of change was negative; i.e. reduced the density, declined the regeneration and disappearance of the tree from the vicinity of the villages compared to the past. However, 27% of them saw that the change was of positive trend, whenever you move southwards dense stands of the species could be noticed. This is because there is sufficient grass for grazing and also people are involved in gum collection the situation that decreases the pressure on the species. Those results might pointed to future threatening of the existence of the tree. In general peoples of the local communities are experienced in monitoring changes occurring in the environment since they are close to it (NRC 2008).

![Figure (4.8) : The trend change in the occurrence of *Balanites aegyptiaca* along the western bank of the Blue Nile as stated by the respondents](image-url)
4.4.5 Management of *Balanites aegyptiaca*

It could be noticed that 67% of the respondents claimed that there were no planting programs had taken place. Despite of that, 32% thought that FNC conducted the planting programs, 6% said it is the community while 62% denied the role of both. For the contribution of the community in planting, 73% said that might contributed. Nevertheless, 87% of the respondents said that planting was done by sowing and the remaining group (13%) said that could be naturally. More than 60% believed that the density of regeneration increased.

All the community groups (100%) were ready to contribute in the conservation by preventing cutting, extension or both. The majority (88%) of the respondents claimed that they retained *Balanites* trees on their farm. The fruits collected during summer is then distributed and consumed in the villages, this thing contributed to the dispersal of *B. aegyptiaca* seeds and can add to the soil seed bank. The results presented in table (4.4) showed the participation of local communities in regeneration of *B. aegyptiaca* with their high contribution in tree planting 73% and the establishment of seedlings 37% and the management of natural regeneration 62%. These indicated that the fruit collecting enhanced seed dispersal, the local communities share in *B. aegyptiaca* conservation through preventing cutting, retaining trees in their farms bildat or even masharie and this is important for them since they benefit of fruit collection, they believe that the tree is sacred tree and must not be removed.
Table (4.4): Planting and conservation of *Balanites aegyptiaca* tree

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Status</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Existence of planting programs</td>
<td>Exist</td>
<td>33</td>
</tr>
<tr>
<td></td>
<td>Not exist</td>
<td>67</td>
</tr>
<tr>
<td>Responsibility of planting</td>
<td>Forest authority</td>
<td>32</td>
</tr>
<tr>
<td></td>
<td>Community</td>
<td>06</td>
</tr>
<tr>
<td></td>
<td>No one</td>
<td>62</td>
</tr>
<tr>
<td>Contribution of the community in tree planting</td>
<td>Contributed</td>
<td>73</td>
</tr>
<tr>
<td></td>
<td>Not contributed</td>
<td>27</td>
</tr>
<tr>
<td>Establishment of <em>Balanites</em> trees</td>
<td>Planting</td>
<td>87</td>
</tr>
<tr>
<td></td>
<td>Natural</td>
<td>13</td>
</tr>
<tr>
<td>Status of natural regeneration</td>
<td>Increasing</td>
<td>62</td>
</tr>
<tr>
<td></td>
<td>Decreasing</td>
<td>38</td>
</tr>
<tr>
<td>Contribution of the community in conservation</td>
<td>Contributed</td>
<td>52</td>
</tr>
<tr>
<td></td>
<td>Not contributed</td>
<td>48</td>
</tr>
<tr>
<td>Method of contribution</td>
<td>Prevent cutting</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>Extension method</td>
<td>29</td>
</tr>
<tr>
<td></td>
<td>Both</td>
<td>16</td>
</tr>
<tr>
<td>Trees on farm</td>
<td>Retained trees</td>
<td>88</td>
</tr>
<tr>
<td></td>
<td>Not retained</td>
<td>12</td>
</tr>
</tbody>
</table>

Discussing the results above (Table 4.4), the farmers are close to the land and can observe the pattern of regeneration of the tree either increasing or decreasing. Though, their witness could be taken in trust.

The high negative answers given by the respondents on the role of FNC in planting *B.aegyptiaca* tree because of neglecting its productive, protective and nutritive values to local communities but inspite of that its cutting was banned by law (Warag et al., 2002). The trees found growing in the natural forests, of large areas, and mostly the tree is found out site forests recognized as trees out site forests, that is way it receives little attention in planting programs. This is supported by (Elsiddig, 2003) who reported that the management activities executed within the natural forests reserves are concerned mainly with protection and patrolling However, the tree is kept to regenerate naturally due to inclusive environmental conditions. In the dry land natural regeneration is preferred than planting for its cheep and does not require more than reserving the regenerated seedlings.
According to Goor and Barney (1976) costing is a limiting factor in forest rehabilitation and plantation programs. As the tree is neglected there were no regular planting activities recorded, the tree is kept to grow naturally, that is why people could not observe any planting activities.

The majority of the respondents reported that *Balanites* is established in the field from seeds, they mean that the tree grows when fruits fall from the tree to the ground rather than direct planting by bit sowing.

The contribution of the community in protecting the tree according to the revealed results has a great role in the protection of *B. aegyptiaca* trees. This is possible for most of *B. aegyptiaca* trees found on privately owned lands and large agricultural schemes as it is difficult to cut trees without permission by the owner, unlike the public lands owned by the government and the reserved forests that are suffering from illicit felling. In some cases the protection is performed by livestock herders who recognize *B. aegyptiaca* trees as fodder during the dry season. Moreover in some places cultural believes play a great role in protecting some tree species.
CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The study revealed the following conclusions:

a) Regeneration of *B. aegyptiaca* was found on all sites in a continuous trend of various class sizes except on the vicinity of villages and in the valleys meander where juvenile natural regeneration was lacking.

b) Seeds of *B. aegyptiaca* could readily germinate irrespective of the soil depth and removal of both epicarp and mesocarp from the fruit but increasing in the salinity had resulted in low germination rate.

c) *Balanites aegyptiaca* is of vital importance to the local communities for diversity of utilization (fruits, wood, medicine, fodder and food) and they are wiling to contribute in its conservation and management.

5.2 Recommendations

More concern and attention should be taken to conserve *B. aegyptiaca* trees. That could be by:

a) Improving management program

b) Extension programs on the importance of the species

c) Reserving lands as forests where the tree exists

d) Introduction of the tree in production to encourage investment in the products for export purposes to encourage tree planting

e) Introduction of the species into agroforestry programs

f) More research on protection measures, regeneration by root suckers, dormancy of the seeds, ecology of soil seed bank, relationship between the tree and the associated species and effect of fire and grazing on seedlings at juvenile stage
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APPENDICES

Appendix (1) : Questionnaire

Self administered Questionnaire for Thesis to PhD Degree at University of Gezira Faculty of Agricultural science Department of Environmental science and Natural Resources.
Subject: Local Community Perception on *Balanites aegyptiaca* (L.) Del. (Heglig Tree) management Along the Blue Nile in Sudan:

Questionnaire serial number ........................... Date ............ village ................Respondents’ name ............respondent no. ........

1/ Socio-economic characteristics of the respondents
1- Gender
Male ............ Female ......................................

2-Social status of the respondents

3-Main occupation (livelihood source)
Farmer...........Herder...........Employer ......Merchant...........other (specify).

4- Age
20-24……25-29……30-34……35-44…45-54…55-64… 65............

5- Educational level
Illiterate……Khalwa……Primary school …Secondary….. Other (specify)

6- Occurrence of *Balanites aegyptiaca*
    a- Depressions............ 4- Government lands............
    b- Flat sites.............. 5- Communal land............
    c- River bank............

7- Uses of *Balanites aegyptiaca*
    a- Fodder..............  d-Furniture..............
    b- Building poles...........  e- All uses..............
    c- Fire wood............... 

8- Change in the status of *B. aegyptiaca*.
    a- Changed..............
    b- Not changed...........

9-Trend of change
    a- Positive..............
    b- Negative..............
10- Management of *B. aegyptiaca*.
Existence of planting program
   a- Exist......................
   b- Not exist.................

11- Responsibility of planting
   a- Forest authorization.......... 
   b- Community....................
   c- No one ........................

12- Contribution of community in tree planting.
   a- Contribute...................
   b- Not contribute..............

13- Establishment of *B. aegyptiaca*
   a- Seeds ....................
   b- Seedlings...................
   c- Natural.....................

14- Status of natural regeneration
   a- Contribute...................
   b- Not contribute..............

15- Method of contribution
   a- Prevent cutting..............
   b- Extension method...........
   c- Both.........................

16- Management of trees on farm
   a- Retain......................
   b- Not retain..................
Appendix (2): Soil analytical data.

User

A- Chemical properties

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<th>Pit Code</th>
<th>Depth (cm)</th>
<th>pH</th>
<th>E.C.dSm⁻¹</th>
<th>C/N</th>
<th>CaCO₃</th>
<th>N</th>
<th>O.C</th>
<th>Soluble cations</th>
<th>Soluble anions</th>
<th>Exch.cations</th>
<th>CEC</th>
<th>SAR</th>
<th>ESP</th>
<th>Av.P mg/kg⁻¹</th>
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<td>0.062</td>
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