ROLE OF TRADITIONAL ECOLOGICAL KNOWLEDGE IN MANAGEMENT OF *Acacia senegal* (L.) Willd FOR GUM ARABIC PRODUCTION AND THE EFFECT OF BIOPHYSICAL FACTORS ON ITS YIELD AND QUALITY

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WEKESA CHEMUKU

A Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Award of Master of Science Degree in Environmental Science of Egerton University

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RECOMMENDATION

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DEDICATION

To my son Kevin, my wife Jackline and my parents for their support and encouragement throughout my study.

ABSTRACT

Gum arabic is a natural exudate obtained from *Acacia senegal* (L.) Willd. The levels of yield and quality of gum arabic vary depending on the variety of *A. senegal*, site conditions and in some cases how the trees are managed. However, it has not been established to what extend these factors affect the yield and quality of gum arabic. Thus, it is important to assess traditional ecological knowledge (TEK) applied in the management of *A. senegal* resources for gum arabic production and evaluate the potential yield and identify the quality of gum arabic in different varieties of *A. senegal* inhabiting different sites. The broad objective of the study was to assess TEK relating to the management of *A. senegal* for gum arabic production and the effect of biophysical factors on gum arabic yield and quality. Data on TEK in respect to the management of *A. senegal* for gum arabic production was collected using questionnaires. The effect of tapping, tree size and/or age, *A. senegal* density, soil moisture, soil temperature and frequency of gum arabic collection on gum arabic yield was studied. Gum arabic samples were collected from different *A. senegal* varieties (var. *senegal*, var. *kerensis* and var. *leiorhachis*) and physicochemical properties studied (moisture content, absolute viscosity, specific rotation, nitrogen content and pH). Data collected was analyzed using SPSS version 11.5 and Genstat version 10.0. The results showed that local communities use traditional ecological knowledge to manage natural *A. senegal* resources to sustain their livelihoods. The density of *A. senegal* varied between and within *A. senegal* varieties and influenced the average gum arabic yield per tree per season. A significant difference in gum arabic yield ($p<0.001$) was observed between tapped and non-tapped *A. senegal* trees as well as between trees' stems and branches. Tapping increased gum arabic yield by 77.42%. A decrease in soil moisture enhanced gum arabic yield while high soil temperature increased gum arabic production. Small sized trees with a basal diameter of 3.0-6.0 cm produced high quantities of gum arabic than bigger trees with basal diameters of 6.1-9.0 cm and >9.0 cm for *A. senegal* varieties *senegal* and *leiorhachis* ($p<0.001$). There were significant differences ($p<0.05$) in gum arabic moisture content (9.15%-12.09%), nitrogen content (0.17%-0.30%) and specific rotation (-21.78° to -25.52°) with respect to *A. senegal* varieties. Significant differences were also observed ($p<0.01$ and $p<0.001$) in gum arabic pH (4.24-4.58) and absolute viscosity (114.9-666 cP) respectively. Thus, the quality of gum arabic varied between *A. senegal* varieties and even within variety *kerensis*. The findings of this study showed that gum arabic yield and quality varies between and within varieties of *A. senegal* and can therefore be used for predicting yield and quality in relation to the variety and site.

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LIST OF ACRONYMS/ABBREVIATIONS

AIDS	Acquired Immune Deficiency Syndrome
ALRMP	Arid Lands Resources Management Project
ANOVA	Analysis of Variance
ARC	Agriculture Research Corporation of Sudan
ASALs	Arid and Semi-Arid Lands
BC	Before Christ
BD	Basal Diameter
CBOs	Community Based Organizations
cm	Centimeter
cP	Centipoises
CV	Coefficient of Variation
FAO	Food and Agriculture Organization
FGDs	Focused Group Discussions
g	Gram
g/l	Grams Per Litre
Ha	Hectare
HCl	Hydrochloric Acid
HHs	Households
ITC	International Trade Centre
IUFRO	International Union of Forestry Research Organizations
JECFA	Joint Expert Committee on Food Additives
KEFRI	Kenya Forestry Research Institute
Kg	Kilogram
Km^2	Kilometer Square
m	Meter
M	Molar
m.a.s.l	Meters Above Sea Level
ml	Milliliter
mm	Millimeter
N	Nitrogen
NAS	National Academy of Sciences (U.S.A)
NGOs	Non-Governmental Organizations

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NTFPs	Non-Timber Forest Products
S.E	Standard Error
S.E.D	Standard Error of Differences
S.E.M	Standard Error of Means
SEK	Scientific Ecological Knowledge
sph	Stems per Hectare
SPSS	Statistical Package for Social Scientists
TEK	Traditional Ecological Knowledge
UNEP	United Nations Environmental Programme
Var.	Variety
WHO	World Health Organization

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background information

Arid and Semi Arid Lands (ASALs) of Kenya make up 84% of Kenya's total land surface and support about 34 % of the country's human population. They account for more than 80% of the country's eco-tourism, 60% of the livestock, and up to 75% of its wildlife population (Republic of Kenya, 2002a; Republic of Kenya, 2005). In Kenya, dryland ecosystems include the tropical grassland and savannah/woodlands, the warm desert and semi-desert (Barrow and Mogaka, 2007).

ASALs are characterized by high potential evapotranspiration, exceeding twice the annual rainfall, and in some areas as much as ten times the annual rainfall (Republic of Kenya, 1992). The annual rainfall is low, ranging from 150-450 mm and rarely achieves the 60% probability of occurrence (Republic of Kenya, 1993). Rainfall is also highly variable in space and time, and often occurs as high intensity storms. As a result, considerable surface runoff is generated, which is aggravated by sparse vegetation cover. Water availability and accessibility is a constraint to production and is highly variable spatially and temporally. The mean annual temperature is high at about 28°C and the soils are poor (Sombroek *et al.*, 1982). The productivity of drylands is therefore quite low compared to the high potential areas. For instance, plant biomass per unit area of drylands is about 6 Kg per square meter, compared with many richer terrestrial systems, which have 10-18 Kg of plant biomass per square meter (Safriel *et al.*, 2002).

Kenyan ASALs are mainly inhabited by nomadic pastoralists and agro-pastoralists whose livelihood heavily depends on livestock and small-scale irrigated agriculture. The lives of these nomadic communities are often subjected to various shocks and disruptions of prolonged drought, insecurity fueled by ethnic conflict through livestock raiding and banditry resulting in great loss of livestock (Barrow, 1996). The other major challenge is lack of proper technologies suitable for management and sustainable use of dryland resources as well as poor infrastructure and declining asset levels.

The dryland ecosystems of Kenya are experiencing rapid population growth due to internal growth and migration from more densely populated higher potential areas causing environmental degradation especially in those lands bordering high potential areas (Barrow and Mogaka, 2007; Lusigi, 1984). The high current movement of people from high and medium potential areas to the fragile ASAL areas in search of settlement has led to widespread over-exploitation of plant resources (Herlocker, 1999). These people indiscriminately exploit and heavily deplete the indigenous trees and shrub species for firewood, charcoal, medicines and building poles. The clearing of woody and bushy shrub lands for conversion to agriculture and other developmental activities has led to loss of biodiversity resources, severe land degradation and threatens the economic potential and environmental security of these marginal lands.

Land use sustainability is therefore a challenge to the people living in these dryland environments. As a result, inhabitants of ASALs suffer from high levels of poverty, despite the fact that they have a rich diversity of natural resources that can be exploited and contribute to poverty alleviation (Chikamai, 1994). However, people cannot confront this problem in attempting to attain a level of sustainable land use because of their inadequate knowledge of alternative land use practices (Ffolliott *et al.,* 1995; Squires and Sidahmed, 1998). Many people have a tradition in livestock keeping and small-scale agriculture that is not always matched by a similar attitude towards other land use practices such as forestry, wildlife ranching, or ecotourism, all of which are profitable enterprises in many dryland regions of the world (IUFRO, 2004).

Vegetation is thus a key component to these nomadic communities to meet the demand for fuel wood, fodder, soil improvement through nitrogen fixation and protection of the environment. Among the most important indigenous species in the ASALs of Kenya is the *Acacia senegal*, the main species in the world producing the internationally traded gum arabic. In Kenyan drylands, *A. senegal* var. *kerensis* is the main source of commercial gum arabic, and grows naturally in the wild (Chikamai and Banks, 1993); the other varieties of *A. senegal* are var. *senegal,* var. *rostrata* and var. *leiorhachis* (Coe and Beentje, 1991). Apart from gum arabic, *A. senegal* enhances soil stabilization and soil fertility through biological nitrogen fixation thus contributing to the environmental conservation (Wickens *et al.,* 1996). The tree also provides grazing and browsing material for livestock. *A. senegal* is thus a potential solution to land degradation in the ASALs. Its promotion and utilization can offer

alternative livelihoods to the pastoralists and agro-pastoralists, contribute to soil fertility and protect these fragile ecosystems from environmental degradation.

Given that drylands of Kenya have a limited range of economic activities that could enhance livelihoods on a sustainable basis, the role of gum arabic in ASALs is one component of a number of non-timber forest products (NTFPs), which if integrated and balanced with other opportunities for dryland management can contribute to the economic well being and long-term viability of such areas. Improving gum arabic yield and quality through development of appropriate harvesting methods as well as post-harvest handling procedures is the starting point to increasing the economic viability, creating employment opportunities and sustainably improving livelihoods in these areas where majority of the people are poor.

1.2 Statement of the problem

In Kenya, the arid and semi-arid lands (ASALs) are the hardest hit by poverty. Inhabitants of these areas are nomadic pastoralists or agro-pastoralists who lack diversity of livelihood sources and continue to rely heavily on livestock production and subsistence farming. The poor pastoral and agro-pastoral communities are known to engage in environmentally degrading activities such as; overgrazing and felling of *A. senegal* trees to make charcoal or for farming despite the fact that *A. senegal* produces an internationally traded commercial product known as gum arabic. However, the level of yield and quality of gum arabic vary depending on the variety of *A. senegal*, site conditions and in some cases how the trees are managed. There is therefore need to ascertain the role of traditional ecological knowledge in the management of *A. senegal* for gum arabic production and the effect of biophysical environmental factors on gum arabic yield and quality in order to improve gum arabic quality and yield for sustainable production of high quality gum arabic obtained from the *A. senegal* trees to supplement over dependence on livestock production and subsistence farming. This will diversify income sources, reduce poverty levels and hence provide environmental security.

1.3 Broad objective

The broad objective of the study was to investigate the role of traditional ecological knowledge in the management of *Acacia senegal* for gum arabic production and the effect of biophysical environmental factors on its yield and quality.

1.3.1 Specific objectives

1. To investigate and document traditional ecological knowledge relating to *A. senegal* management for gum arabic production.
2. To determine *A. senegal* tree density and its possible effect on gum arabic yield.
3. To determine the effect of soil moisture and temperature on gum arabic yield.
4. To determine the effect of tapping on gum arabic yield.
5. To determine the quality of gum arabic from different varieties of *A. senegal*.

1.4 Research questions

1. Is there traditional ecological knowledge applied in the management of *A. senegal* for gum arabic production?
2. Does gum arabic yield differ with *A. senegal* varieties and density?
3. Does soil temperature affect gum arabic yield?
4. Does soil moisture affect gum arabic yield?
5. Does tapping method affect gum arabic yield?
6. Does the yield of gum arabic vary between the tapped tree branches and stems?
7. Is the quality of gum arabic similar in different *A. senegal* varieties?

1.5 Justification of the study

Acacia senegal that grows naturally in ASALs of Kenya is an important natural resource. Nevertheless, it is currently under utilized in Kenya though the tree holds the potential to fetch alternative sources of income for the nomadic communities and earn the country the much-needed foreign exchange through the export of gum arabic. There is therefore a need to obtain data that will promote increased gum arabic production and enhance the quality as this will contribute to poverty reduction in Isiolo District while at the same time, encourage

sustainable management of *A. senegal* tree resources, and hence conservation of the environment.

1.6 Scope and limitations of the study

This study covered a period of four months from the beginning of December 2008 to the end of March 2009 and addressed the following biophysical factors; soil moisture and soil temperature in study sites and how they affect the yield and quality of gum arabic. The tree density of *A. senegal* varieties in the experimental plots was studied and documented. The *A. senegal* varieties were classified into three size classes based on basal diameter and tapped on the main stem and branch and gum arabic yield and quality determined. Gum arabic was also collected as natural exudates from untapped trees, which acted as a control and its yield determined.

The aspects of traditional ecological knowledge (TEK) related to *A. senegal* tree resources management investigated include; traditional *A. senegal* resources conservation strategies, location of the tree resources, local tapping methods, tools used for gum arabic tapping and collection, local uses of *A. senegal*, gum arabic production seasons and cultural beliefs of the communities with respect to management of *A. senegal* trees and gum arabic collection.

The dependent variables of focus were gum arabic yield and quality while the independent variable consisted of *A. senegal* varieties, soil temperature, soil moisture, tapping, tapping position and gum arabic picking schedules.

This study had several limitations including limited funding, severe and prolonged drought. Severe and prolonged drought had a huge impact on the results regarding the yield of gum arabic such that the yield was very low than what was expected. This is because the amount of gum arabic produced in a given season is heavily dependent on the amount of rainfall immediately preceding gum arabic production season. Besides, the time allocated to carry out this study was very short and as a result, only one season of gum arabic production was assessed. To get representative gum arabic yield per tree per season, at least six production seasons should be assessed. Lastly, the experiments were conducted in the wild whereby the sample plots were accessible to local community members thus making it difficult to have controlled monitoring. This might have influenced the yield of gum arabic

collected per tree per season since the locals feed on it during dry season and therefore, they could have picked some gum from the individual *A. senegal* trees selected for this particular experiment.

1.7 Definition of terms

Acacia senegal - It refers to all the three varieties of *A. senegal*: var. *kerensis*, var. *senegal* and var. *leiorhachis* unless stated or specified.

Akol - This refers to a traditional hut in the Turkana community.

Biophysical factors - Refers to tree density, tree size, soil moisture and temperature as factors influencing physiological process of gum arabic production by *A. senegal* trees.

Ecology - The study of the interactions between organisms and their environment and in this study, it is the interaction between pastoral and agro-pastoral communities in the ASALs and *A. senegal* tree resources.

Gum arabic - A dried exudate obtained from stems and branches of *A. senegal* or *A. seyal* trees (FAO, 1999).

Gummosis - The physiological process of gum formation resulting from stress caused by desiccation and injury to the tree.

Lolsoro - A cultural belief that restrict young initiated boys in Samburu community to livestock herding and rustling thereby denying them an opportunity to participate in any other economic activity like gum arabic collection.

Manyattas/Bomas - The name given to traditional homesteads among pastoral communities.

Morans - Young boys in Samburu community who have passed through circumcision rite.

pH - The acidity or alkalinity of gum arabic solution.

Sapling - All young trees with a basal diameter (BD) of less than 3 cm.

Sonke - A specially designed tool that has a metal head fixed to a long wooden handle used for tapping *A. senegal* trees for gum arabic production.

Tapping - Injury made on the stem or branch of *A. senegal* trees by removing a small area of the bark measuring about 3 cm wide and 10 cm long using a special tool called sonke to induce gum exudation.

Traditional Ecological Knowledge (TEK)-Local people's knowledge based on experiences, informal experiments and intimate understanding of their environment and how to utilize and sustainably manage *A. senegal* resources around them.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Introduction

The African Acacias are divided into two sub-genera and two series namely sub-genus *Aculeiferum* belonging to the series Vulgares Bentham and sub-genus *Acacia* belonging to the series Gummiferae Bentham (Arce and Blanks, 2001). Sub-genus *Aculeiferum* includes the species with prickly re-curved, claw-shaped thorns such as *Acacia ataxacantha, A. dudgeoni, A. erythrocalyx, A. gourmaensis, A. laeta, A. macrostachya, A. macrothyrsa, A. mellifera, A. polyacantha* and *A. senegal (*Arce and Blanks, 2001). On the other hand, sub-genus *Acacia* includes those species with straight axillary thorns and they include *A. ehrenbergiana, A. nilotica, A. oerfota, A. seyal, A. sieberana, A. tortilis* and the naturalized neo-tropical species *A. farnesiana* among others (Brenan, 1983).

Acacia species thrive in a diverse range of habitats and environments. Hence, many Acacia species are well adapted to the semi-arid and savannah regions but equally, others survive in moist forest and riverine areas, tolerating both high pH and waterlogged soils (Coe and Beentje, 1991). Given such diversity, Acacia species have considerable potential in a range of livestock and agro-forestry systems and consequently, naturally occurring Acacia species are important in traditional pastoral and agro-pastoral systems in ASALs of Africa (Allen and Allen, 1981).

Many Acacia species form spiny and slow-growing scrub, which provides protection against soil erosion caused by wind and precipitation (Wickens *et al.*, 1996). Their tolerance of harsh conditions makes them valuable for stabilization and re-vegetation of difficult sites such as ASALs. *A. armata, A. glaucescens, A. pycnantha* and *A. suaveolens* tolerate salt spray and hence used to stabilize coastal sand dunes (Fagg and Stewart, 1994). Acacia species are important sources of fuelwood in arid and semi-arid regions (NAS, 1979).

Several species of Acacia yield gums, which are utilized to produce items of trade, either locally or internationally. For instance, *A. mearnsii* is the world's most important source of vegetable tannin whereby 35-40% of the air-dry weight of bark is extracted for leather manufacture (Mueller-Harvey *et al.*, 1987). Yields of vegetable tannin in excess of 15% are

also obtainable from other species of Acacia such as *A. albida* and *A. cyanophylla* (Mueller-Harvey *et al.*, 1987). *A. senegal* produces gum arabic that is in the form of round tears, orange-brown in colour and is of the highest quality (FAO, 1990). In fact, Sudanese gum arabic from *A. senegal* var. *senegal* sets the standard by which other gum arabic is judged because it is intrinsically of high quality with superior technical performance (Jurasek *et al.*, 1993). *A. seyal* produces gum talha, which is more friable than the gum arabic that is produced by *A. senegal*. Gum talha from *A. seyal* is intrinsically of poor quality than gum arabic since it has inferior emulsifying properties and even light-colored samples of gum talha sometimes forms dark solutions in water due to the presence of tannins and other impurities (Anderson *et al.*, 1991). Other species of *Acacia* that produces gum for local use or as minor components but of poor quality include *A. karroo*, *A. paoli*, *A. polyacantha* and *A. sieberana* (Jurasek *et al.*, 1993).

Acacia senegal is native to the Sahelian regions of Africa and the Middle East (NAS, 1979). It is one of the most common trees in Africa's arid and semi-arid savannas and occurs throughout the Sahel and Sudanese woodlands, in the Great Rift Valley and into Southern Africa (White, 1983). It is widely distributed in the drier parts of tropical Africa, from Senegal and Mauritania in the West to Eritrea and Ethiopia in the North-East and to South Africa in the south. Of the four recognized varieties, *A. senegal* var. *senegal* is the most widespread and is found throughout the area of distribution of *A. senegal* except along the west coast of central and southern Africa (Brenan, 1983). Outside Africa, it occurs in Oman, Pakistan, India, Australia, Puerto Rico and the Virgin Islands. This variety is the major source of gum arabic. *A. senegal* var. *kerensis* occurs in Ethiopia, Somalia, Uganda, Kenya and Tanzania; *A. senegal* var. *leiorhachis* occurs throughout Eastern Africa from Ethiopia to South Africa; *A. senegal* var. *rostrata* occurs in the same area as *A. senegal* var. *leiorhachis* and in Namibia and Angola, and in Oman (Brenan, 1983).

2.2 Description and ecology of *Acacia senegal*

Acacia senegal is a xerophytic plant and grows in dryland habitats. The plant tolerates water deficit and therefore able to endure conditions of prolonged drought associated with the arid region of Kenya. It belongs to the family Mimosaceae and genus Acacia. This tree is a leguminous, nitrogen-fixing tree that is a pioneer species that thrives well on sandy soils. *A. senegal* thrives well on dry rocky hills, in low-lying dry savannas and areas where annual rainfall is 250-360 mm (Bekele-Tesemma *et al.*, 1993). *A. senegal* is reported to tolerate

annual precipitation of 380-228 mm, annual mean temperature of 16.2-27.8°C and soil pH of 5.0-7.7. However, Cheema and Qadir (1973) reported that *A. senegal* grows well in soil having a pH of 7.4-8.2. The tree ranges from 100-1700 m elevation in the Sudan to 1950 m around Nakuru in Kenya (Maundu *et al.*, 1999).

A. senegal is a woody species varying in habit from a shrub about 2 m to a tree about 15 meters high. It is generally recognized by its three-hooked prickles, central one curved downwards and the two laterals more or less curved upwards, or singly, the laterals being absent and with the flowers in spikes. These characters are however shared by a number of other Acacia species and *A. senegal* forms part of this complex group of spicate-flowered acacias with prickles in threes or singly. *A. senegal* exhibits three different growth forms in Kenya, recognized as three varieties (Gachathi, 2002). Varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as presence or absence of hair on the axis of the flower spike, color of the axis, shape of pod tips, number of pinnae pairs, and occurrence of a distinct trunk and shape of the crown. Three different varieties of *A. senegal* recognized in Kenya are var. *senegal*, var. *kerensis* and var. *leiorhachis*.

Typically, *A. senegal* var. *senegal* is recognized as a tree with a flat or rounded crown and rough non-papery and non-peeling bark commonly growing on sandy alluvial loamy soils in plains or at the foot of hills in semi-humid to semi-arid areas. *A. senegal* var. *kerensis* grows as a single or several-stemmed shrub with lateral branches form near the base and with smooth yellowish-brown peeling bark on the stem. It is common on rocky hills and ridges or sandy plains in arid to the very arid areas (Gachathi, 2002).

A. senegal var. *leiorhachis* exhibits two growth forms; either as a struggling slender tree starting with a very branched bushy base then thinning out to 1-4 slender whippy erect tall stems with peeling bark or a well grown tree with open rounded spreading crown and yellowish papery and peeling bark on the main trunk. The whippy form occurs in clusters of small populations on extremely rocky gneiss-derived sandy soils in semi-arid to arid areas in plains while the tree form occurs on red deep sandy soils along drainage lines and areas with high water table (Gachathi, 2002).

2.3 Traditional ecological knowledge and *A. senegal* resources management

Acacia senegal trees in ASALs of Kenya are managed under traditional land use systems. Consequently, traditional ecological knowledge is of fundamental importance in development of sustainable management and use of *A. senegal* resources in the drylands. Traditional ecological knowledge and practices have been termed by some scholars as kind of capital that a society or a community may possess (Gadgil *et al.*, 1993). This capital is common and part of the tradition of communities. It is an important part of the lives of the rural poor and is a key element of their social capital (Mauro *et al.*, 2000).

Traditional ecological knowledge (TEK) is defined as a cumulative body of knowledge and beliefs handed down through generations by cultural transmission about the relationship of living beings including humans with one another and with their environment (Gadgil *et al.*, 1993). Most traditional institutional structures encompass indigenous resource management practices and knowledge that form a part of the socio-economic structure of any given community (Sadeeque, 1999).

TEK has been recognized as having equal status with scientific knowledge (UNEP, 1998) and has been termed as the intellectual twin to science (Deloria, 1995). TEK has much in common with scientific ecological knowledge (SEK), since both derive information from the same source, systematic observations of nature. Both knowledge systems yield detailed empirical information of natural phenomena and relationships among ecosystem components. Both SEK and TEK have predictive power, and in both intellectual traditions, observations are interpreted within a particular cultural context. This long intellectual tradition exists in parallel to Western science, yet historically; the scientific community according to Salmon (1996) has marginalized it.

There is growing research on the role of TEK in biodiversity conservation and the scientific validity of traditional ecological knowledge in achieving the objective of conservation and utilization of natural resources (Gadgil *et al.*, 1993; Sarangi, 2004). This is because such knowledge is necessary for effective communication with local people and besides, it allows research and extension activities to be appropriately targeted at locally experienced constraints.

In order to ensure sustainable production of gum arabic, communities in ASALs of Kenya have been using this knowledge to develop various *A. senegal* resource management strategies (Watson and Van Binsbergen 2008). Such strategies include locally coined management practices like nomadism, which encourage conservation of *A. senegal* trees (Watson and Van Binsbergen 2008). According to Kamau (2004), nomadism enhances tree species diversity and richness at a local scale by providing opportunities for common dryland species such as *A. senegal* to establish. Moreover, it is argued that livestock on free grazing system play a very important role in maintenance of tree diversity in ASALs through the dispersal of readily germinating seeds in their manure (Kamau, 2004). Furthermore, the local communities have formed village level institutions, which normally formulate rules, and regulations that govern the use of this important natural resource (*A. senegal*) at their disposal and oversee the effective implementation of these rules and regulations (Krishna, 2000; Balooni, 2002).

Most communities in ASALs districts of Kenya including Isiolo district especially the Samburus rely on dead wood materials to meet their domestic fuelwood demand (Chikamai and Odera, 2002; Watson and Van Bins Bergen, 2008). However, Turkanas produce charcoal, which is sold along the main highway between Isiolo town and Archers Post trading centre (Chretin *et al.,* 2008). Unfortunately, whilst charcoal production offers small returns to those that produce it, the practice is destructive to the environment and undermines conservation efforts of *A. senegal* tree resources (Chretin *et al.,* 2008). As studied by anthropologists and ethno-biologists these practices govern gum arabic resource productivity and use in terms of quantity collected, season, locality and production age and size of the tree (Gadgil *et al.*, 1992; Luvanda *et al.*, 2006). These practices not only conserve the tree resources but also serve as common good for the communities by encouraging sustainable use of the natural resource.

By tradition, *A. senegal* is a multipurpose African tree highly valued for centuries for gum arabic production. Gum arabic obtained from the tree is usually used for home consumption whereby it used as chewing gum or even eaten as food in the dry season when there is food scarcity (Watson and Van Binsbergen, 2008; Chikamai and Odera, 2002). Gum arabic is also sold commercially to Somali traders to generate income for the local communities (Chikamai and Odera, 2002, Watson and Van Bins Bergen, 2008). The tree also plays a secondary role

providing fuelwood, fencing material, herbal medicine, poles, fibers and fodder to livestock (Okunomo and Bosah, 2007, Obua *et al.* 2006, Luvanda *et al.* 2006, Chikamai and Odera 2002, FAO 1995, Wickens *et al.*1996, NAS 1979).

The communities in ASALs of Kenya have historical relationship with their lands, natural resources and environment with holistic TEK that has been developed over many generations (Chikamai and Odera, 2002). The long-term sustainable use of *A. senegal* trees depends on local people's knowledge, management and local people's ability to maintain and utilize it. The use of TEK may benefit scientific community and development agencies in providing more realistic evaluations of the role of *A. senegal* in the management of the environment and production systems in drylands of Kenya. We must therefore understand how these people in ASAL areas survive and thrive, why they do what they do, and what mechanisms both technical and social they have put in place to make use of this important tree resource base at their disposal on sustainable basis. However, the aspects of TEK related to the management of *A. senegal* such as traditional *A. senegal* resources conservation strategies, location of the tree resources, local tapping methods, tools used for gum arabic tapping and collection, local uses of *A. senegal*, gum arabic seasonality and cultural beliefs of the communities with respect to management of *A. senegal* trees and gum arabic collection have been little studied and this study endeavored to do so.

2.4 Physiology of gum arabic production by *A. senegal*

Gum arabic is a dried exudate obtained from the stems and branches of *A. senegal* (L.) Willd or *A. seyal* (FAO, 1999). *A. senegal* trees produce gum arabic during the process known as gummosis when the trees are responding to physiological stress caused by desiccation and injury. Causes of desiccation include soil water depletion and high soil heat/temperature. Gum arabic is found immediately under the bark, where it is sometimes collected in regular cavities. Usually, gum arabic is formed within the plant by metamorphosis of the cells of the inner bark. The tissues involved in the formation of gum arabic are chiefly those of the sieve and the cambiform cells (Anderson, 1995). While to some extent it is a natural change, yet it is usually looked upon as being in part a pathological production, as gummosis develops more largely upon the wounding of the trees. The attack of the *A. senegal* trees by various parasites/insects is held by some researchers to account for the

enormous production of gum arabic in these trees whereby it oozes out from the injured spots on the stems and branches of trees.

2.5 Gum arabic yield

High gum arabic production requires severe physiological stress from water depletion and heat (Anderson, 1995). Gum arabic formation has been regarded as a natural response of trees under dehydration stress to store a strongly hydrophilic form of reserve carbohydrate (Anderson, 1995). Gum arabic is formed at the time of leaf-fall and translocated to the roots even before the tree is tapped.

Gum arabic exudes from the cracks on bark of wild trees in the dry season, with little or none in the rainy season when flowers are out. Jackson (1968) stated that, in Morocco, the greatest gum arabic product is obtained in the driest and hottest weather, and from the sickliest trees. An elevated temperature appears to be essential, for cooler climates, though the tree may flourish; it yields no gum. Generally, the higher the average atmospheric and soil temperatures, the higher the yield of gum arabic. The effect of soil temperature and soil moisture on yield of gum arabic in Kenya has not been investigated thoroughly to establish the how they affect gum arabic yield and quality.

Many authors (ITC, 1972; FAO, 1978; NAS, 1979; Duke, 1981; Muthana, 1988; Badi *et al.*, 1989; Ballal *et al.*, 2005; Dagnew, 2006; Chiveu *et al.*, 2009) have presented varying estimates of gum arabic yields. These estimates contain little information on the different varieties of *A. senegal*. Yields of gum arabic from individual trees are very variable and hardly any reliable data is available. A tree, on an average, may yield 250 grams of gum arabic per annum (two seasons), although production may range from a few grams to as high as 10 kg (NAS, 1979; Dagnew, 2006) or 0.2 to 6.7 kg (Duke, 1981). Chiveu *et al.* (2009) has reported that the yield of gum arabic range between 0.66 and 0.81g/tree/season for *A. senegal* var. *kerensis* in Kenya. The highest yields are observed on individuals aged from 7 to 12 years. Yield per hectare per year ranges between 30 to 40 kg in case of open stands and as much as 100 kg in case of dense stands (ITC, 1983). Yields from cultivated trees are said to increase up to the age of 15 years, when they level off and then begin to decline after 20 years (ITC, 1983; Abdel Rahman, 2001).

Presently, the major problem facing gum arabic industry in Kenya is lack of reliable information on gum arabic yields and yields trends that can be used as a basis for monitoring gum arabic production. Consequently, there is need to evaluate quantitatively gum arabic yield by three different varieties growing in Kenyan dryland areas and in sites with different biophysical characteristics. Besides, information on how tree size and/or age affect the quantity of gum arabic produced by *A. senegal* growing naturally in ASALs of Kenya is also lacking.

Results of recent research work carried out in plantations of *A. senegal* in Sudan; shows that gum arabic production per individual tree is higher at higher tree densities (Ballal *et al.*, 2005). However, assessment of densities of *A. senegal* varieties in natural stands in Kenya has not been carried out to establish the number of stems per hectare and how the density influences the yield of gum arabic produced per individual tree per season.

2.6 Gum arabic tapping, collection and quality criteria

In Sudan, the world's leading producer, gum arabic is regularly tapped from trees, which are about 5-6 years old by making narrow transverse incisions in the tree bark in order to facilitate the exudation. Tapping utilizes a specially designed tool, the sonke. This has a metal head fixed to a long wooden handle. The pointed end of the head is pushed tangentially into the stem or branch to penetrate just below the bark, and then pulled up to strip a small length of bark longitudinally from the wood. Damage to the wood should be minimal. Several branches are treated in a similar manner at one tapping. In following years, other branches or the reverse side of the previously treated branch are tapped. The gum then dries into shiny, amber-coloured globules, which are manually collected.

However, at present, there is no formal tapping in Kenya. Only gum arabic resulting from natural exudation is collected but with impurities such as tree barks and this presents quality problem. The quality of the gum arabic can be controlled effectively at the point of harvesting (Lelon, 2008; Chikamai and Odera, 2002). According to Agriculture Research Corporation (ARC) of Sudan, gum arabic yield can be increased by 47%-60% with good management and proper tapping of the *A. senegal* trees. This study endeavored to develop appropriate tapping procedure that utilizes a special tool known as the sonke in order to improve the yield and quality of gum arabic in produced in Kenya.

Gum arabic collection takes place at intervals during the dry season. However, gum arabic yield from each individual tree rarely exceeds 300 g per harvesting season, but tapping the tree at precise periods during the dry season can induce higher and more regular yield. The colour and quality of the gum arabic exudates depend on the climatic and soil conditions of the area. Some studies have shown differences between Kenyan gum arabic and gum from other countries such as the Sudan and Nigeria in terms of specific rotation, mineral composition especially nitrogen, metal content and viscosity. This study endeavours to investigate whether the differences in gum arabic quality may be due to the differences in edaphic (soil) and environmental factors.

The gum from *A. senegal* is complex polysaccharide and contains a small amount of nitrogenous material that cannot be removed by purification. Its chemical composition varies slightly with source, climate, season and age of the tree among other factors. The gum consist of rhamnose, glucuronic acid contents, arabinose and 4-O-methyl glucuronic acid (Anderson, 1987). Gum arabic readily dissolves in water to give clear solutions ranging in colour from very pale yellow to orange-brown and with a pH of 4.5. The highly branched structure of *A. senegal* gum gives rise to compact molecules with a relatively small hydrodynamic volume and consequently gum solutions become viscous only at high concentrations (Williams and Philips, 1998).

The Joint Expert Committee on Food Additives (JECFA) of FAO/WHO revised specifications states that the quality parameters of gum arabic must be of the Sudan gum arabic from Kordofan gum belt region. The specifications of quality of gum arabic must have a moisture content of less than 15% at 105°C for granular material, specific/optical rotation of -26° to -34°, low absolute viscosity of 75-110 centipoises (cP), pH of 4.2-4.8 and a Kjeldahl nitrogen content of 0.27-0.39% (FAO, 1990).

Kenya has emerged as a new supplier of gum arabic in the world market, but the country does not meet the competitiveness and adequate supply of the commodity to the world market demand (FAO, 1995). The Kenyan gum is rated of low quality when compared with the Sudan gum in the world market according to JECFA specifications because of the high absolute viscosity problem, which is more than 110 centipoises (FAO, 1990). Quality problems as a function of site and location of *A. senegal* trees also count towards low quality gum.

The quality of gum arabic is affected by botanical origin, individual tree differences and environmental factors such as climatic and soil conditions, and harvest and post-harvest handlings (FAO, 1995). It is obvious that gum arabic from different Acacia species exhibit characteristics that are intrinsically different. Even within the same species, different varieties and individuals of different provenances produce gum with different characteristics. Recognizing these differences in the varieties and environment is important in producing gum arabic for a desired end use (Chikamai, 1997). This study seeks to confirm whether different varieties of *A. senegal* produce gum arabic of different quality.

Reports indicate that gum arabic from Kenya is dark-red in colour instead of the usual amber colour because of the uncommonly high content of iron usually exclude the gum from usage in certain processes. Moreover, Kenya's gum arabic from *A. senegal* var. *kerensis* has high nitrogen content of 0.44%, a more negative optical/specific rotation of -35° and moisture content of 14.7% (Chikamai and Banks, 1993).

A number of research scientists (Mulinge *et al.*, 1988; Chikamai and Banks, 1993; Lelon, 2008) have assessed gum arabic quality for *A. senegal* var. *kerensis* and *A. senegal* var. *senegal* growing naturally in Kenyan ASALs but information on quality of gum arabic from *A. senegal* var. *leiorhachis* is not available. Therefore, there is an urgent need to investigate the quality of Kenyan gum arabic from the three different varieties of *A. senegal* adequately to allow for its improvement.

2.7 Industrial uses of gum arabic

Gum arabic has been used for over 4,000 years. Egyptians used gum arabic as early as 2,000 B.C. in food, preparations of human and veterinary medicines, in crafts, and as a cosmetic. In Sudan, gum arabic has been an article of commerce since 100 A.D (Anderson, 1987). Gum arabic is extensively used in pharmaceutical preparations, inks, pottery pigments, watercolors, wax polishes and liquid gum. It is also used for dressing fabrics, giving luster to silk and crepe. It is used for thickening colors in calico printing (Cossalter, 1991).

Gum arabic has been used widely in the confectionery industry, where in most cases it has two important functions: to retard sugar crystallization and to emulsify the fat and keep it evenly distributed through out the product. For prevention of sugar crystallization, gum

arabic finds its greatest application in confections such as jujubes and pastilles in which sugar content is high and moisture is low. With these products, the technique of incorporating the flavors is extremely important. Usually, gum arabic is dissolved in water and the solution is filtered, mixed with sugar, and boiled. The flavor is added with a minimum of stirring to prevent formation of bubbles or opaque spots. The second function, as a fat emulsifier, is essential in keeping fat distributed uniformly throughout an oxidizable, greasy film. This property makes gum arabic extremely useful as an emulsifying agent in caramels and toffees.

The emulsification properties of gum arabic are utilized in various liquid flavor emulsions. Many citrus oils and other beverage flavor emulsions utilize the emulsification properties of the gum. When used as a flavor fixative, the superior film forming ability of the gum arabic makes it ideal for protecting the flavor from oxidation, evaporation and absorption of moisture from the air. It is equally used as a foam stabilizer and agent to promote cohesion of foam to glass.

Gum arabic's suspending and stabilizing properties are employed to suspend insoluble drugs and to prevent the precipitation of heavy metals. Its emulsifying property is used for calomine, magnesia, and kaolin suspensions and liquid petroleum and cod liver emulsions. Many cough drops and syrups utilize gum arabic because of its demulcent of soothing characteristics. Gum arabic is used as an adhesive and binder for pharmaceutical tablets as well as in their coating.

It is widely used in the baking industry for its low water absorption properties. It is cold water-soluble and has impressive adhesive properties for use in glazes and toppings. The ability of the gum to stabilize foam is used in the manufacturing of drinks. The gum is also used to clarify wine and fix tanning.

Gum arabic is an important constituent of many special purpose inks. Watercolor and quick drying inks utilize the suspending and binding properties of gum arabic. Gum arabic is also used by tannery and textile industries. The textile industries use the gum in fabric sizing and stiffening, as a binder for textile printing, in laundry as water proofing emulsions, starches, as thickening agent for silk and acetate rayon printing. In paper industries, it is used in the production of high quality paper with glossy appearance. It is also used in the plastic industry as stabilizer in polymeric emulsion and polymerization.

2.8 Conceptual framework

This study was conceptualized to look at how soil moisture, soil and atmospheric temperature as well as tapping process affect gum arabic production in terms of quality and quantity in different varieties of *A. senegal*; *A. senegal* var. *kerensis*, *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis*. These varieties occur in sites with different biophysical characteristics and therefore the yield and quality of gum arabic from different varieties may vary. TEK was assessed to provide information on indigenous knowledge regarding *A. senegal* tree resources management for gum arabic production and how this knowledge varies from scientific ecological knowledge (SEK).

Thus, Figure 2.1 illustrates the interaction among TEK, biophysical environmental factors and the tapping position and further, highlights the study's focus on the assessment of gum arabic yield and presents the indicators of gum arabic quality. Understanding and appreciating the trends in soil temperature and soil moisture content as well as the density of *A. senegal* varieties was key in achieving objectives two, three and four of this study. Evaluation of the effect of soil moisture content and soil temperature on gum arabic yield provided information on the trend of gum arabic yield at different soil moisture and soil temperature levels. *A. senegal* density assessment directed this study in estimating gum arabic yield per tree per season given the differences in the distribution patterns *A. senegal* trees per unit area while the different varieties of *A. senegal* inhabiting sites with different physical characteristics provided an insight on how varietal differences and site conditions affect the yield of gum arabic per tree per season. Moreover, the different varieties of *A. senegal* directed this study in comparing the quality of gum arabic produced by different varieties of *A. senegal*. Gum arabic oozes from both the tree branches and stems and therefore tapping sampled trees on the stem and on one selected branch made it possible to establish the average quantity of gum arabic (in grams) produced on the stems and branches of *A. senegal* and make a comparison.

TEK used in the management of *A. senegal* by local communities with different ethnic backgrounds differ and hence, to some extent has an effect on the density of these trees and consequently the amount of gum arabic produced. Different communities have varied cultural beliefs, local legislations, management strategies, utilization patterns and perception concerning *A. senegal* resources. Based on this, the study was able to answer objective

number one by looking at these aspects of TEK in relation to the management of *A. senegal* for production of gum arabic and other tree products needed to sustain livelihoods of the local communities living in areas where this resource occurs.

A. senegal varieties, soil temperature, soil moisture and tapping position (tree stem and branch) constituted independent variables while gum arabic quality and yield were the dependent variables while TEK was the intervening variable in this study.

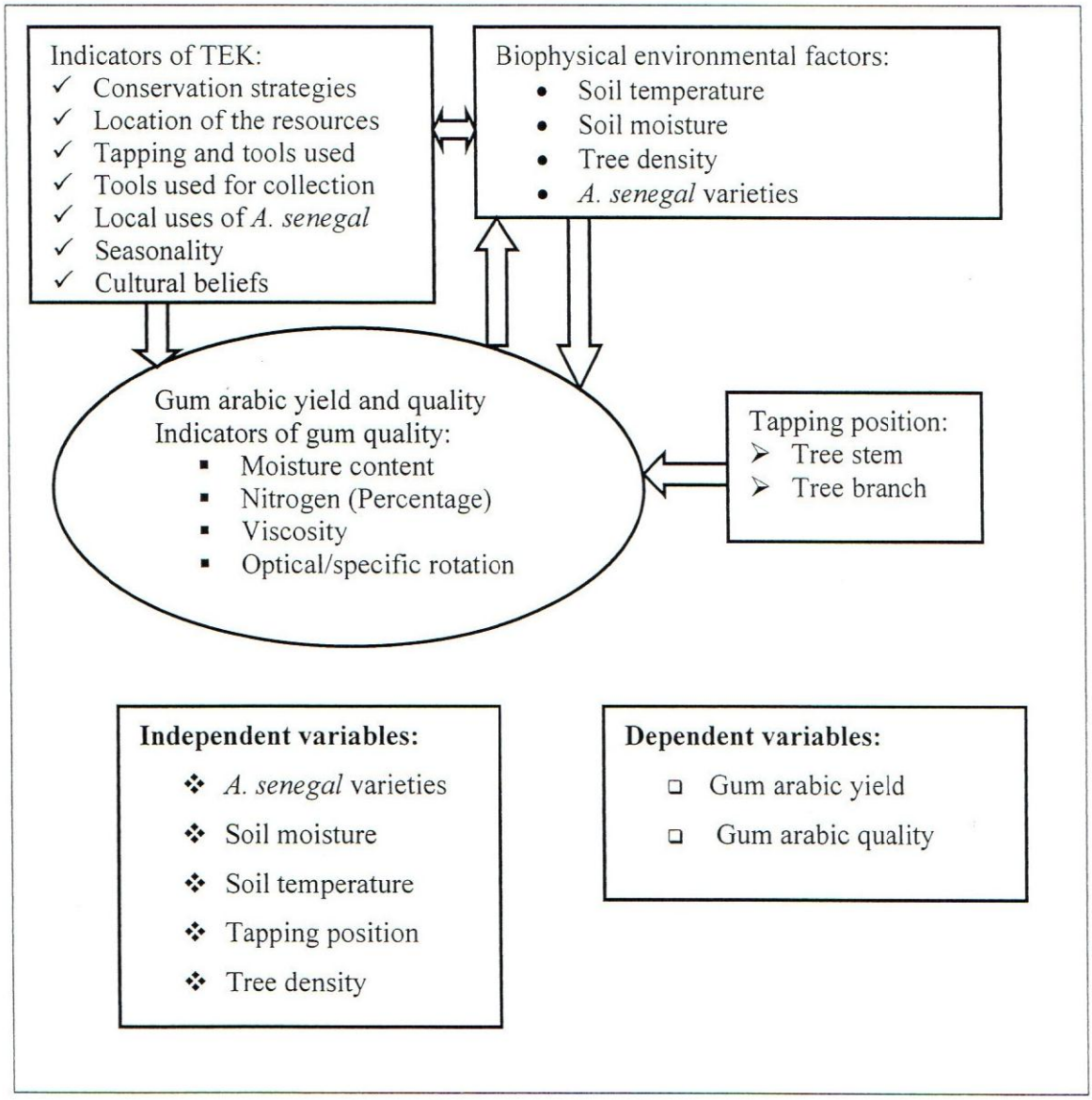


Figure 2.1: Model on the conceptual framework for the study

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Research design

This study employed both field survey and experimental research designs. Ex-post facto research design was used based on a one time cross sectional survey with data collected at one point in time. The study used naturally occurring treatments or subjects having a self-selected level of the independent variable (Kathuri and Pals, 1993). The manifestations of the independent variables had already occurred and the researcher therefore did not manipulate them.

3.2 Study area

This research was undertaken in Isiolo District. The study site was selected because of the presence of high natural population of *A. senegal* trees. Moreover, Isiolo is one of the Districts in the ASALs with high gum arabic production potential.

3.2.1 Study sites

This research was carried out in four study sites in Isiolo District; Ngare Ndare, Kulamawe, Ntumburi and Daaba, which exhibit different biophysical characteristics, were selected for the study. The selection of the four sites made it possible to compare the effect of different biophysical conditions on gum arabic yield and quality.

3.2.2 Location and size

Isiolo is one of the thirteen Districts in Eastern Province. It borders Marsabit to the North, Garissa and Wajir to the South-East and East respectively. It also borders Tana River, Nyambene and Meru Districts to the South, Laikipia and Samburu Districts to the West (Figure 3.1). It is located between Longitude 036°60'East and 039°50'East and Latitudes 00°5' North and 02°00' North. The District covers an approximate area of 25,605 Km^2. The District is divided into six administrative divisions, twenty-two locations and forty-four sub-locations (Ministry of Planning, 1989).

Most of the District is a flat, low lying plain. The plain rises gradually from an altitude of about 200 meters above sea level (m.a.s.l) at Lorian Swamp in the northern part to about 947 meters above sea level at Daaba. The altitude is highest to the south where Ntumburi site is located, about 1748 m.a.s.l. To the West towards Laikipia District where there are volcanic hills, the altitude is 987 meters above sea level and to the East towards Garba-Tulla; the altitude is 1020 m.a.s.l at Kulamawe

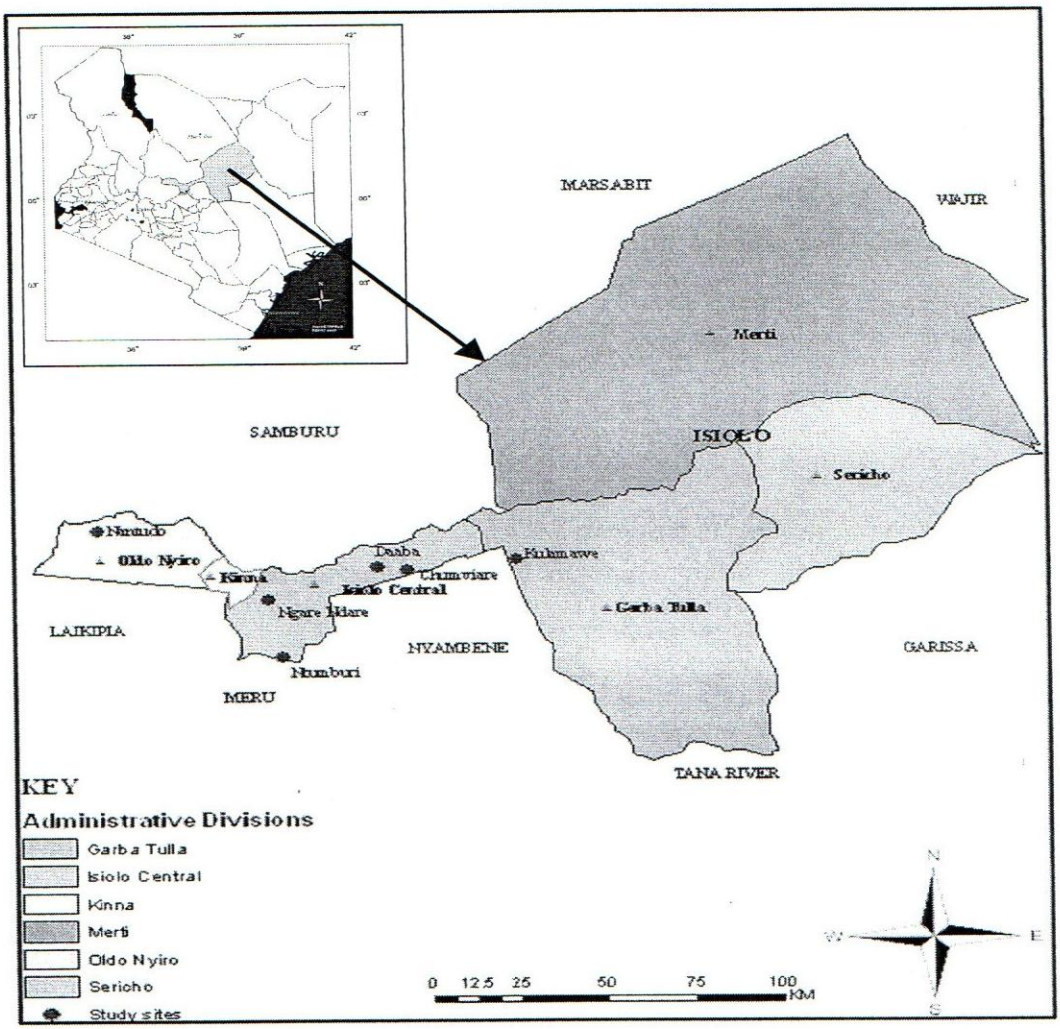


Figure 3.1: Map of Kenya showing the position of Isiolo District and the study sites

3.2.3 Population and ethnic composition

Isiolo District is inhabited by among other groups the Borana, the Somali, the Turkana, the Samburu and the Meru. Thus, the District is one of the most cosmopolitan Districts in Kenya. The 1999 census put the population of the District at 100,861 people. This was projected to rise to 112,364 by 2002. The District has about 73% of the population living below poverty

line (Republic of Kenya, 1994). The most affected are the landless, the pastoralists who have lost most of their livestock due to drought or cattle rustling, households headed by people without formal education and female headed households, AIDS orphans and handicapped people.

3.2.4 Settlement pattern

Water availability and security situation influences the District's population distribution and density. Central division is densely populated compared to other divisions due to its well developed infrastructure and is the commercial center of the District. In the other divisions, people tend to settle around permanent water sources. Other areas of high density in the District are the townships/market centers due to better security arrangements. People also settle along the river where they practice irrigation. The majority of the people move with their livestock in search of water and pasture.

3.2.5 Rainfall pattern

The District is hot and dry for most of the year. It has two rainfall seasons; the short rains, coming in October and November, and the long rains, which fall between March and May. The rainfall received in the District is scarce and unreliable. The District is arid with an average annual rainfall of 580.2 mm. The wettest months are November during the short rains with an average of 143 mm and April with an average of 149 mm during long rains. Since rainfall is erratic and unreliable, it cannot support perennial agricultural crops.

3.2.6 Temperature

High temperatures are recorded in the District throughout the year, but there are slight variations in some places due to differences in altitude. The mean annual temperature for Isiolo station, at an altitude of 1,104m above sea level is 26.6°C while in Merti, which is 300m above sea level, it is 27°C. Most parts of the District records about nine hours of sunshine per day and therefore the rate of evaporation is high.

3.2.7 Soils

The District has a combination of both metamorphic rocks and other superficial rock deposits in central division. Tertiary rocks (olive basalt) are found in the northern part of the

District. The soils are primarily sandy soils, though pockets of black cotton and red soils that can sustain agriculture exist in Central and Kinna divisions. The soils are poor over most places and are characterized by lithic soils mainly sandy clay to gravel clay, well drained, shallow, stony and rocky, and hold no water but support vegetation that remains green for long after the rain. The soils vary in color ranging from reddish-brown in Ngare Ndare to greyish in Daaba and Ntumburi and brownish in Kulamawe.

3.3 Sampling methods

Two sampling methods were employed in this study namely; socio-economic survey and experimental research design. Socio-economic survey was used to collect data on TEK while the field experiments were set up to collect data on *A. senegal* density, soil moisture, soil and atmospheric temperatures, gum arabic yield and quality. The full description of the steps followed for each of the sampling procedure is given below (Sub-sections 3.3.1 and 3.3.2).

3.3.1 Socio-economic survey

The research design of this study was conceived such that both primary and secondary data were acquired to complement each other. Secondary data was collected from previous related studies, government departmental reports, gum arabic traders and agents, CBOs, private companies and reports from NGOs. Primary data was gathered from sampled households (HHs) or homesteads from local communities in the study sites involved in gum arabic collection.

The sampling frame involved sampling casing of the nomadic pastoralists and agro-pastoralists from the District. Both stratified random sampling and purposive sampling techniques were used to select the target respondents. Stratified random sampling technique was instituted to select the representative respondents for the District whereby only the areas with high production of gum arabic were selected. The District was stratified into four main communities namely the Samburu, the Borana, the Turkana and the Somali. According to Patton (1990), purposive sampling technique was employed to select the representative respondents from each of the four communities whereby only household members actively involved in gum arabic collection were selected for interviews. Thus, within each community, 25 households were picked and respective respondents; adult males, females or children aged over 15 years and were actively involved in gum arabic collection were

interviewed using structured questionnaires. One hundred households (HHs) were interviewed to gather information mainly on the local uses of the trees and gum arabic, management and conservation strategies of *A. senegal*, constraints to gum arabic production, seasonality and local knowledge of habitats of *A. senegal*. Eight focused group discussions (FGDs) were also held.

3.3.2 Field experiments

The field experiments on tapping and soil conditions evaluation were conducted in the natural stands of *A. senegal*. Four study sites namely Ngare Ndare, Kulamawe, Ntumburi and Daaba were selected and four sample plots measuring 100m by 100m (1 ha) established, one in each site. Ngare Ndare was the study site for *A. senegal* var. *kerensis*. The Samburu community who are pastoralists principally occupies the area. Most of the trees of this variety were single stemmed but branching from close to the base. Daaba was the other study site for *A. senegal* var. *kerensis*. Most of the trees of this variety were single stemmed but branching from near the base. They were taller than those in Ngare Ndare. The site was relatively flat, slightly slope and with rocks of volcanic origin. The local community is largely the Turkana who are also pastoralists. Ntumburi was the study site for *A. senegal* var. *senegal*. These were well-formed trees with large basal diameter. Ntumburi is mainly inhabited by the Meru community who are agro-pastoralists. Kulamawe was the study site for *A. senegal* var. *leiorhachis*. This was the furthest site, located along Isiolo-Garba Tulla road and approximately 2 kilometers from Kulamawe trading centre. The site was gently sloppy and very rocky. The Borana community who are nomadic pastoralists mainly occupies the area.

3.3.2.1 Soil sampling for moisture determination

In the field, five sampling points were picked along two diagonal line transects across the experimental plot at the four corners and at the middle of the plot where the two transects met (Figure 3.2). Three trees were selected at each point and under these trees; the soil samples were collected by core method. The surface soils were first removed 5-10 cm from the level area at the points where the samples were collected. The core samplers were then driven in the soil surface far enough to fill the sampler without compressing the soil in the confined space of the sampler. The sampler was carefully removed and its content to obtain with a natural structure and soil packing as possible with a shovel placed under it to prevent the soil from falling. The soil extruding beyond each end of the sample holders was trimmed using a

sharp spatula before the sampler was closed with the lid. The core samplers were placed in the cooler box and taken to the laboratory for percentage moisture determination.

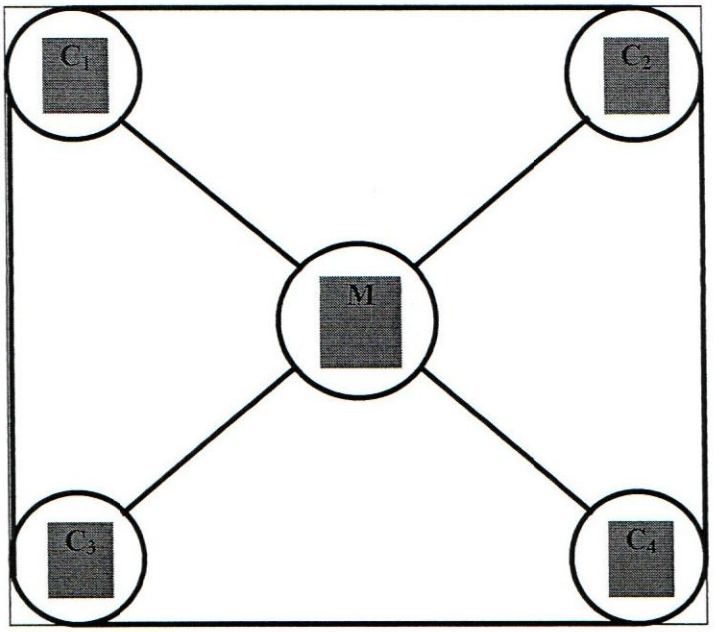


Figure 3.2: Field soil sampling design

Legend:

C_1-C_4 = Corners of the plot

M = Middle/Centre of the plot

3.3.2.2 Soil temperature measurement in the field

Since the soil was firm, nail was used to make a hole 7 cm deep into the soil for inserting the soil thermometer. A hammer was used to hit the nail in order make the hole. The nail was pulled out carefully with minimum disturbance to the soil. The thermometer was then inserted through the hole until 7 cm of the probe extended below the bottom of the guide by gently pushing the thermometer into the soil. First reading of soil temperature was recorded after 2 minutes. Second and third readings were taken at an interval of 1 minute. The thermometer was removed from the hole and wiped to clean it. The soil temperature was measured at 9.00 a.m. during each visit to the study sites. The first reading was taken at the date of tapping and thereafter at an interval of 3 weeks during subsequent gum arabic collection dates to determine dehydration stress caused by soil heat and how the heat influence gum arabic production in the study sites.

3.3.2.3 Air temperature measurement in the field

The air temperature was measured at the same time (9.00 a.m) when soil temperature was being measured during each visit to the study sites using a thermometer and recorded.

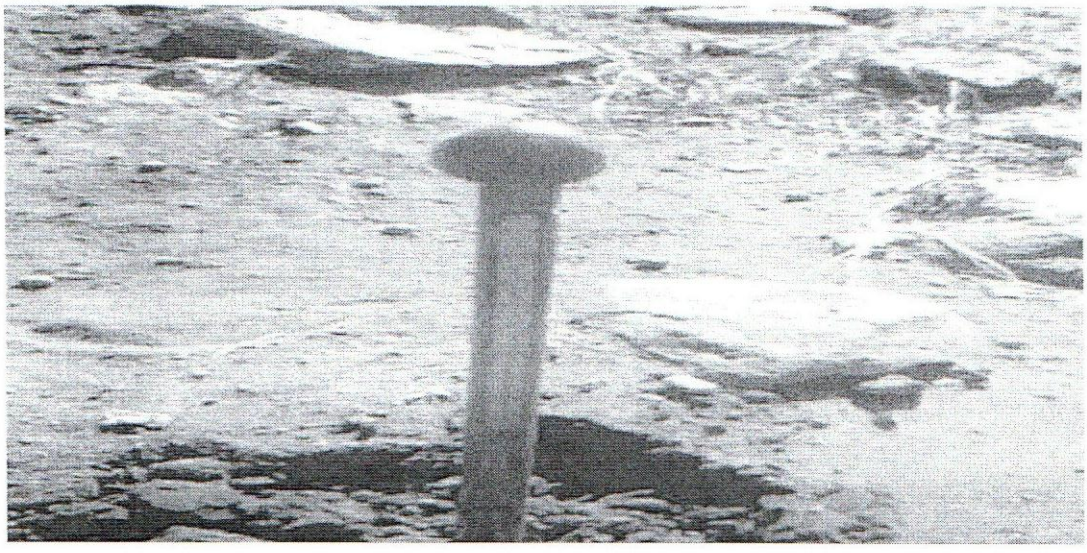


Plate 1: Soil temperature recording in sites

3.3.2.4 Tree sampling for gum arabic collection

Within each sample plot, all individual *A. senegal* trees in the sample plots were identified, counted and basal diameter (BD) measured. They were classified into three different diameter classes as follows: 3.0-6.0 cm, 6.1-9.0 cm and >9.0 cm. From each diameter class, ten trees were randomly selected by casting the dice and then tapped for gum arabic production. Further randomization was performed to select an additional ten trees from each diameter class that were left untapped as a control to replicate natural conditions under which local communities collect their gum arabic exudates. All other dryland tree species growing in association with *A. senegal* in the sample plots were identified, enumerated and their number recorded.

Tapping of the trees was done by making one incision on one selected branch and one incision on the main stem using the sonke. The incision had a length of 10-15 cm and a width of 3-cm. Gum arabic was collected after 25-30 days from the date of tapping from both the tapped and untapped trees and thereafter at a regular interval of three weeks until the end of

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dry season. Gum arabic exudates were collected from 30 tapped trees and 30 untapped trees *A. senegal* trees at each site and the quantity obtained from the stem and the branch of each tree was weighed and recorded to estimate the gum arabic production potential. In total, three collections/pickings were made.

The quality of gum arabic collected from the three varieties of *A. senegal* was determined by analyzing its moisture content (Oven dry method), optical/specific rotation (Polarimeter), absolute viscosity (Viscometer), pH (pH meter) and nitrogen content (Kjeldhal Method) in the laboratory.

3.4 Methods of soil analysis

The soil samples collected by core method were analyzed for moisture according to the procedure prescribed by Anderson and Ingram (1993) and Okalebo *et al.* (2002).

3.4.1 Determination of soil moisture

Core samples collected from the field were taken to the laboratory for moisture analysis. The fresh weight of the soil and core sampler was measured and recorded (W_2). The samples were then oven dried at 105° C for 24 hours and allowed to cool in a desiccator for 30 minutes. The soil dry weight and core sampler was then measured (W_3). The core samplers were emptied by removing the soil and their weight measured (W_1). The moisture content of the soil was calculated as a percentage of the dry soil weight as shown below:

Soil Moisture Content (%) = $W_2 - W_3 / W_3 - W_1 \times 100$

Whereby,

W_1 - Weight of core

W_2 - Weight of core + fresh soil

W_3 - Weight of core + dry soil

3.5 Methods of gum arabic quality analysis

Gum arabic was air-dried and crushed into small pieces of ≤ 2 cm^3 and analyzed for moisture content, absolute viscosity, optical rotation, pH and nitrogen content to determine its quality.

3.5.1 Determination of moisture content

A portion gum samples (2g) were weighed and their fresh weight recorded. The samples were then oven dried at 105° C for 24 hours and allowed to cool in a desiccator for 30 minutes. The oven dried gum arabic samples were weighed and their dry weight ascertained and recorded. Moisture content in gum arabic was expressed as a percentage of the weight loss from the original weight (FAO, 1999).

3.5.2 Determination of gum arabic absolute viscosity

A 25% concentration solution of gum arabic was prepared by dissolving 150g of finely ground gum arabic in 600ml of distilled water. The solution was left to stay overnight to allow complete dissolution. The absolute viscosity of gum arabic was then measured using a calibrated Brookfield viscometer model DV-II + Pro at a temperature of 25.0°C and expressed in centipoises (cP).

3.5.3 Determination of optical/specific rotation

A 1% concentration solution of gum arabic was prepared by dissolving 1 g of finely ground gum arabic in 100 ml of distilled water, allowed to stay overnight for complete dissolution. The solution was filtered with Whatman filter paper No. 42 and the optical rotation measured using a Polarimeter model ADP 410 at a temperature of 20.0°C (Chikamai and Banks, 1995).

3.5.4 Determination of nitrogen content

The nitrogen content in gum arabic was determined using Kjeldhal method as prescribed by Anderson and Ingram (1993) and Okalebo *et al.* (2002). A sample of 0.3 g of finely ground gum arabic was weighed and transferred to clean labeled digestion tubes. A digestion mixture of 4.4 ml prepared by dissolving 0.42 g of selenium (Se) powder and 14 g of lithium sulphate in 350 ml 30% hydrogen peroxide and mixed well. 420 ml of concentrated sulphuric acid was slowly added while cooling in an ice bath. 4.4 ml of the mixture was transferred to the tubes in replicates of 3 per site and placed in a block digester (Skalar Block Digester System, Model SA 5640). The digestion tubes were heated at 360°C for 2 hours until the solution is clear. The contents were allowed to cool. Subsequently, 25 ml of distilled water was added to the contents and mixed well in a 50 ml volumetric flask until no more sediment dissolved and the contents allowed to cool again and topped up to the mark with distilled water. The contents were allowed to settle and a clear solution taken from the top of the tube

for nitrogen analysis. An aliquot of 5 ml of the solution was transferred to the distillation tubes and 10 ml of 40% sodium hydroxide added for distillation. The extract was steamed immediately into 5 ml of 1% boric acid and 4 drops of mixed indicator. Distillation was continued for 2 minutes from the time the indicator turned green. The distillate was removed and titrated with 0.2 M HCl until the colour changed from green through grey to a definite pink.

Calculation of Nitrogen Content (%) in gum arabic:

N (%) in gum arabic sample = corrected ml of N/70HCl ×0.2 / Weight of sample

Whereby;

Corrected ml of N/70HCl = Burette reading – The ml of N/70HCl required for the blank.

3.5.5 Determination of pH

A 25% gum arabic solution was prepared left for overnight and the pH meter was calibrated with a standard buffer solution of known pH. The pH measurement of the gum solution was read from the pH meter and recorded (Chikamai and Banks, 1995).

3.6 Data analysis

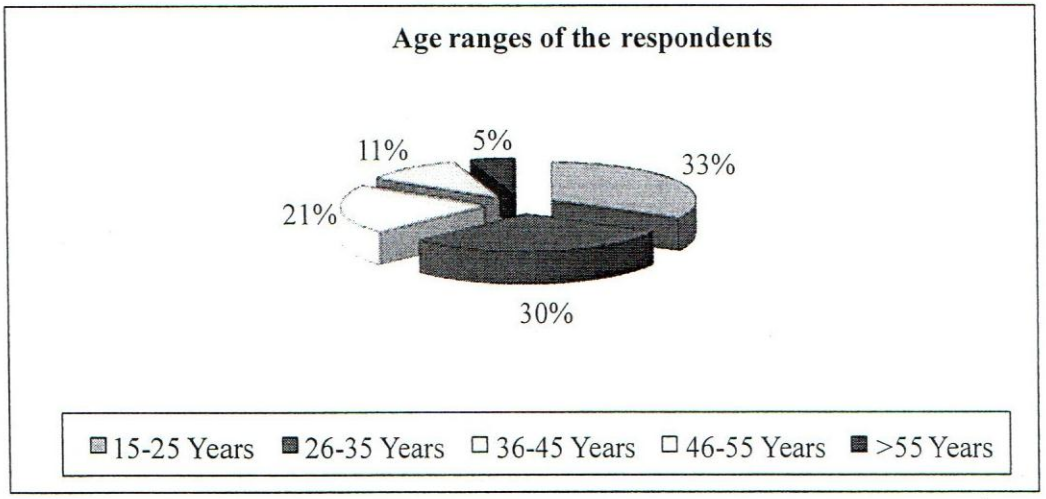
SPSS version 11.5, MS-Excel and Genstat version 10.0 were used to analyze the data. All the data collected during the survey by questionnaire responses were analysed using SPSS for descriptive statistics involving computation of percentages, sums, means, and standard deviations. The results are presented in form of tables, pie charts and bar graphs. MS Excel was used to summarize tree density data for the four study sites in the District. Kruskal-Wallis one-way ANOVA was performed to determine the significant difference in yield between sites, diameter class and pickings, followed by Least Significance Difference test ($p<0.05$, $p<0.001$ and $p<0.01$) where the F-test demonstrated significance. Two-tailed t-test was performed to test possible differences between the means of nitrogen content in gum arabic ($p<0.05$). Mann-Whitney U (Wilcoxon rank-sum) test was used to determine the differences in gum arabic yield for tapped and untapped trees and between the branches and the stems ($p<0.001$). Regression analysis was performed to determine the effect of soil moisture on gum arabic yield in the sites. Kendall's rank correlation was performed to determine the relationship between soil moisture and soil temperature, soil temperature and atmospheric temperature and soil temperature and gum arabic yield.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Age of the respondents

The age composition of those interviewed showed that 33% were youth aged between 15 and 25 years. About 30% of the respondents had age ranging from 26 to 35 years old while 21% were 36 to 45 years old. A further11% of the respondents were aged between 46 and 55 years. Only 5% of those interviewed were above 55 years of age (Figure 4.1). The stratification of respondents into various age classes was carried out to establish whether TEK applied in the management of *A. senegal* for gum arabic production was held collectively by all members of the communities irrespective of their ages or there are certain aspects of it which were the purview of specific individuals or sub-groups in a specific age group within the communities. This study established that TEK applied to the management of *A. senegal* for gum arabic production was collectively held by locals of all ages implying that TEK was transmitted from generation to generation and was not static, but dynamic, evolving over time as the communities respond to new challenges. Other related studies in the district have shown that people aged between 15 and 25 years form the majority of the population and are the ones actively involved in the management of *A. senegal* for gum arabic production as well as the collection of gum arabic (Chikamai and Odera, 2002).



Source: Field data (2009)

Figure 4.1: Age ranges of the respondents

4.2 Gender of the respondents

The gender representation for each age class of the respondents is shown below (Table 4.1). In average, of all the people interviewed, an overwhelming 75% of the respondents were women while 25% were men. This is because men spend most of the time herding livestock leaving women at home to perform household chores. Since the interviews were conducted during the day, it was uncommon to find men and boys in the homesteads as most of them had gone to look after livestock in the grazing fields. The gender of the respondents was studied to give special attention to the different roles men and women play in the management of *A. senegal* for gum arabic production, including aspects of tapping and gum arabic collection. Besides, women are important holders of TEK and they usually operate in economic niches that depend heavily on the natural resources like *A. senegal* trees to support their livelihoods (Chikamai and Odera, 2002). According to the report by Chretin *et al.* (2008), more women were interviewed than men during a similar survey carried out in Isiolo and Turkana districts as supported by the present study.

Table 4.1: Structure of the respondents by gender

	Number of respondents		Percentage (%)	
Age class (Years)	**Female**	**Male**	**Female**	**Male**
< 20	11	4	73.3	26.7
20 – 30	33	4	89.2	10.8
30 – 40	16	8	66.7	33.3
40 – 50	13	5	72.2	27.8
50 – 60	2	2	50	50
60 – 70	0	1	0	100
> 70	0	1	0	100

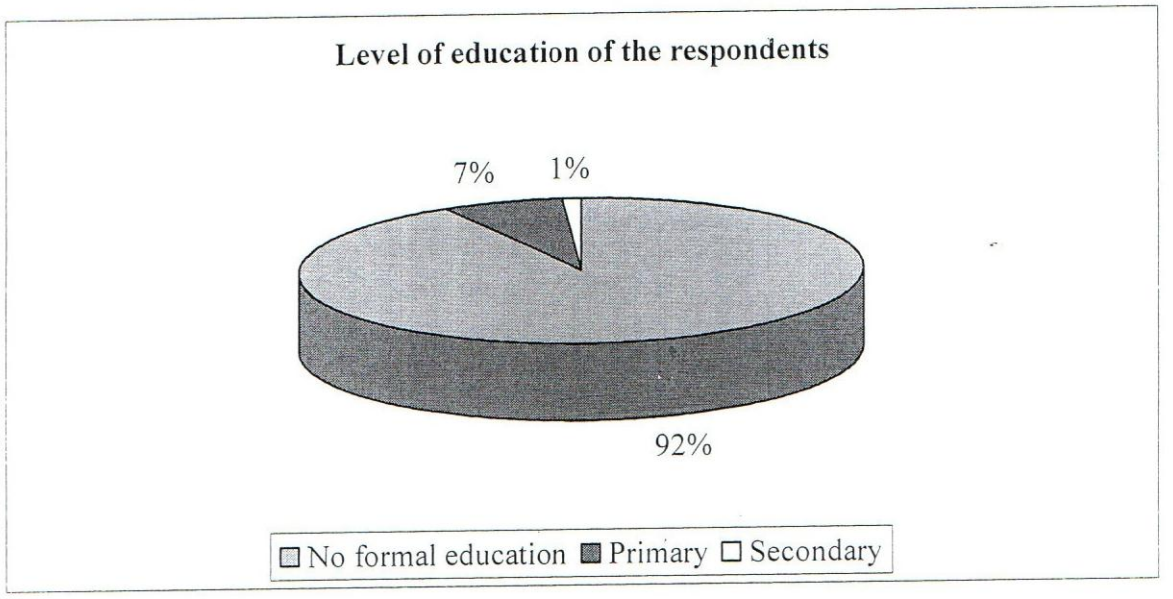
Source: Field data (2009)

4.3 Education level of the respondents

The level of education was studied because it is a vital instrument in the development of an individual and the society and begins at birth and continues until a person's last day on earth. Education can be formal, informal or non-formal. It can be traditional and indigenous, or modern and imported. It was therefore expected that when community members do not

have formal education, then they heavily rely on indigenous knowledge in the management of natural resources at their disposal including *A. senegal* trees for gum arabic production.

Regarding education level, 92% of the respondents had no formal education, whereas 7% and 1% had primary and secondary school education respectively as shown below (Figure 4.2). This study confirms the results of previous research undertaken by Chretin *et al.* (2008) in Isiolo and Turkana districts, which indicated that the Samburus and Turkañas could not be interviewed without the assistance of translators. The level of illiteracy was very high underscoring the reality that the local communities inhabiting dryland areas employ traditional ecological knowledge more often in the management of natural resources at their disposal such as *A. senegal*, the main species producing gum arabic.



Source: Field data (2009)

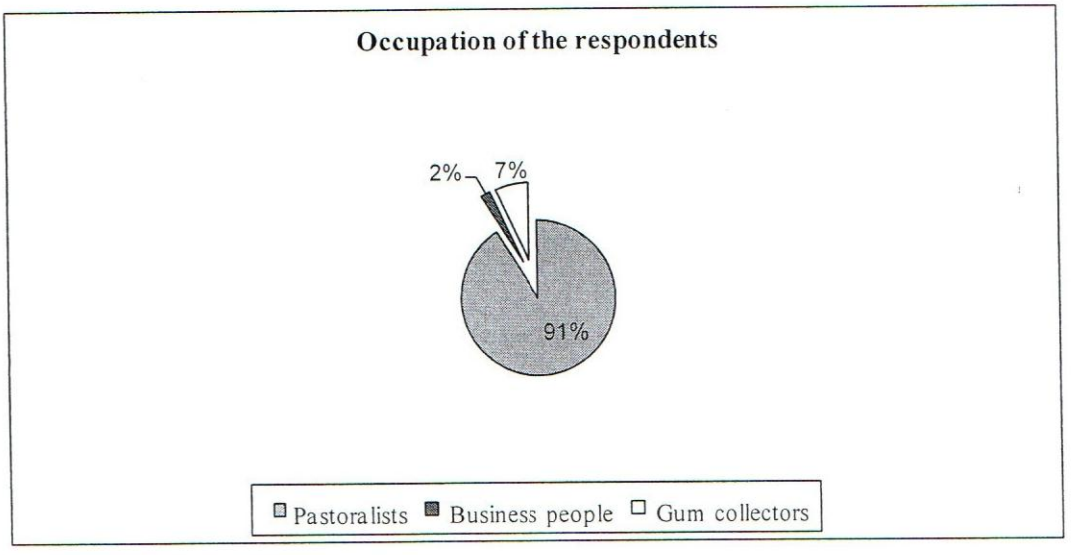
Figure 4.2: Level of education of the respondents

4.4 Occupation of the respondents

This study looked at the occupation of the local communities to ascertain their level of involvement in gum arabic collection as an economic activity. This was important because in this study, it was assumed that the traditional ecological knowledge applied in the management and conservation of *A. senegal* resources by the local communities for gum

arabic production heavily depended on their level of participation in gum arabic collection and the subsequent economic benefits they derive from it.

About 91% of the respondents practiced pastoral nomadism while 2% were business people. Some 7% of the respondents practiced gum arabic collection as their main occupation indicating that gum arabic collection was a secondary economic activity to pastoralism (Figure 4.3). Results of previous studies in Wajir District of Kenya indicated that collection of gum arabic and gum resins as an economic activity ranked second to pastoralism (Luvanda *et al.*, 2006). Furthermore, Chikamai and Odera (2002) and Chretin *et al.* (2008) reported that gum arabic collection in Isiolo district was done by the local communities as a secondary activity to pastoralism. Consequently, this study confirms that the local communities inhabiting Isiolo district are inclined more towards managing *A. senegal* predominantly for provision of fodder for their livestock rather than gum arabic production.



Source: Field data (2009)

Figure 4.3: Occupation of the respondents

4.5 Management strategies of *A. senegal* resources by the local communities

The management strategies of *A. senegal* resources by the local communities are presented in Table 4.2 below;

Table 4.2: Management strategies of *A. senegal* resources

Strategy	Response (%)
Collecting dead wood materials	65.0
Local by laws governing the community	58.0
Nomadism/temporary homesteads	57.0

Source: Field data (2009)

The study revealed that the traditional management system of the *A. senegal* trees was carried out on a sustainable natural resource conservation basis. The techniques used include mobility of livestock and people, a council of elders who report to the area chief and protect the *A. senegal* trees using cultural taboos like '*lolsoro*' used in the blessing of '*morans*', well laid down informal laws and collection of only dead wood materials mainly used for cooking.

This study established that 57.0% of the respondents moved from one place to another to allow natural regeneration of *A. senegal* trees while 58.0% adhered to community laid down legislation to conserve and manage the resource. A large portion of those interviewed (65.0%) indicated that they gathered only dead wood materials for their domestic fuel wood needs (Table 4.2) which is a positive indication of TEK conservation endeavour by the local communities.

4.5.1 Nomadism/Temporary livelihood as a management strategy

The mobility of pastoral communities and their animals is considered primarily as a strategic instrument of enhancing pastoral production units. Nomadism enables the Samburu, Turkana, Borana and Somali pastoral communities to efficiently utilize the limited and spatially located range of *A. senegal* tree resources for fodder. This enables them to mitigate the effects of periodic droughts and erratic rainfall and the ensuing pasture shortage. These communities use nomadism to cope with ecological variability and to conserve the environment. Their mode of utilization of *A. senegal* resources follows spatial and temporal patterns of resource distribution. The communities roam from one point to the other to ensure that the land is replenished for the future utilization. In light of this, nomadism directly enhances the growth of this arid lands tree and hence this study confirms previous reports by Kamau (2004) and Watson and Van Binsbergen (2008).

The practice of frequent movement of camps among pastoralists and agro-pastoralists often results in higher *A. senegal* tree germination especially in the campsites. This is because the seeds are scarified when they pass through the digestive system of livestock and taking advantage of the high organic fertilizer on the campsites, the seeds germinate rapidly and grow better. Thus, nomadism facilitates the dispersal of seeds of *A. senegal* trees and hence enhances regeneration of these arid lands vegetation. The grazing areas sprout up with all forms of vegetation including the gum trees shortly after the rainy season. Moreover, it was commonly observed that the localities of livestock enclosures, where animal wastes are deposited, after the nomads occasionally abandon the facility when they move, have all different species of acacias growing during the rainy season. This restrictive customary practice of managing *A. senegal* resources and other related dryland tree species is a conscious environmental protection and management effort.

4.5.2 Management of *A. senegal* through community by-laws

The Samburus, Turkanas, Somalis and Boranas sustainably integrate livestock production and the *A. senegal* resource management. These trees are protected because they are perceived as valuable resources and they make a heedful effort to control their exploitation through laid down local legislations. No trees or parts of the trees may be cut when the trees are still alive. No herding sticks or tent poles are cut from *A. senegal* trees. Clearly, these restrictions are instituted in order to ensure survival of the trees in these areas for continued gum arabic production. Among the Turkanas, the construction of their traditional houses (*akol*) does not pose a serious deforestation threat to these trees because only small sticks from the branches and fiddles are used. The *A. senegal* trees that are seen to be obstructing livestock routes are gently pruned. In the absence of such environmental protection local legislation and wise management of these resources, these areas would have been degraded long time ago. Krishna (2000) and Balooni (2002) reported that local communities in ASALs have a set of rules and regulations that govern the management, conservation and utilization of natural resources at their disposal as supported by this study.

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4.5.3 Dead wood collection as a management strategy

Collection of wood for firewood can be destructive in the ASALs especially when it is collected from live trees. Fuelwood collection varied significantly in the different communities. Among the Samburus, the Somali and the Borana communities, only dry fallen dead wood was collected for fuelwood and this concurs with an earlier report by Chikamai

and Odera (2002). This was done to protect the trees against destruction that could otherwise occur if live trees were cut to meet domestic fuelwood needs. However, the case is different among the Turkanas who are actively involved in charcoal production to earn alternative income. The charcoal is sold to the neighbouring trading centres like Ngare Mara and Isiolo town to earn alternative income during severe drought. This destructive practice threatens gum arabic production in these areas and should be discouraged. Chretin *et al.* (2008) confirmed that majority of the Turkanas residing at Ngare Mara which neighbors Daaba are more involved in charcoal burning than gum arabic collection even though the activity is illegal and can be detrimental to the environment.

Thus, encouraging the local communities to engage in gum arabic collection can significantly improve pastoralists' livelihoods by offering alternative income, conserve *A. senegal* trees thereby contributing towards sustainable management of natural resources and hence environmental conservation. This could result from the development and improvement of the gum arabic sector in Kenya in terms of yield and quality gum by training the locals on sustainable harvesting methods together with good post-harvest handling procedures of the gum.

4.6 Local uses of *A. senegal* trees

Acacia senegal trees were found to be remarkably useful to the local communities because of the products and services they derive from the trees (Table 4.3). Among the respondents, 99.0% said they got fodder form *A. senegal* trees and 98.0% said they got all firewood from the same tree. Further, 89.0% of the respondents indicated that they obtained traditional medicine from the tree while 88.0% of those interviewed were in consensus that gum arabic is used as human food. Again, 41.0%, 29.0% and 12.0% of those interviewed said they got fencing materials, poles and fibres from these trees respectively.

Table 4.3: Uses of *A. senegal* trees as stated by farmers

Use	Response (%)
Fodder	99.0
Fuel Wood	98.0
Medicine	89.0
Human food (Gum arabic)	88.0
Fencing	41.0
Poles	29.0
Ropes/Fibers	12.0

Source: Field data (2009)

Acacia senegal trees were important source of fodder in all the study sites in the District especially during dry season when pasture is very scarce. Mainly goats, sheep and camels feed on the pods of these particular trees while cattle and donkeys browse on the leaves of the trees. The tree is also used for fencing, fuel wood, poles and fibre production. Fencing of Manyattas and livestock sheds is mainly done using the branches that are pruned from *A. senegal* trees. Turkanas in Chumviare and Daaba were cutting down the tree for charcoal production leading to deforestation and environmental degradation. On the other hand, the Samburus in Ngare Ndare and Nantudo are not involved in charcoal production and consequently, they do not cut down *A. senegal* trees but instead conserve the trees for gum arabic production. Hence, gum arabic production potential is not threatened in Ngare Ndare and Nantudo. Gum arabic is consumed in its raw form as a food supplement especially during severe food scarcity period. The tree is an important medicinal species for treatment of backache and pain in the body joints. The bark is used in the treatment of stomach related illness. These outlined uses of *A. senegal* in this study conform to reports about the use of the species by several authors including NAS (1979), FAO (1995), Wickens *et al.* (1996), Chikamai and Odera (2002), Obua *et al.* (2006), Okunomo and Bosah (2007) and Luvanda *et al.* (2006).

4.6.1 Evaluation of local uses of *A. senegal* in sites

Generally, fodder, fuel wood, human food and traditional medicine were the main products derived from *A. senegal* trees in all the study sites. All the respondents (100%) in

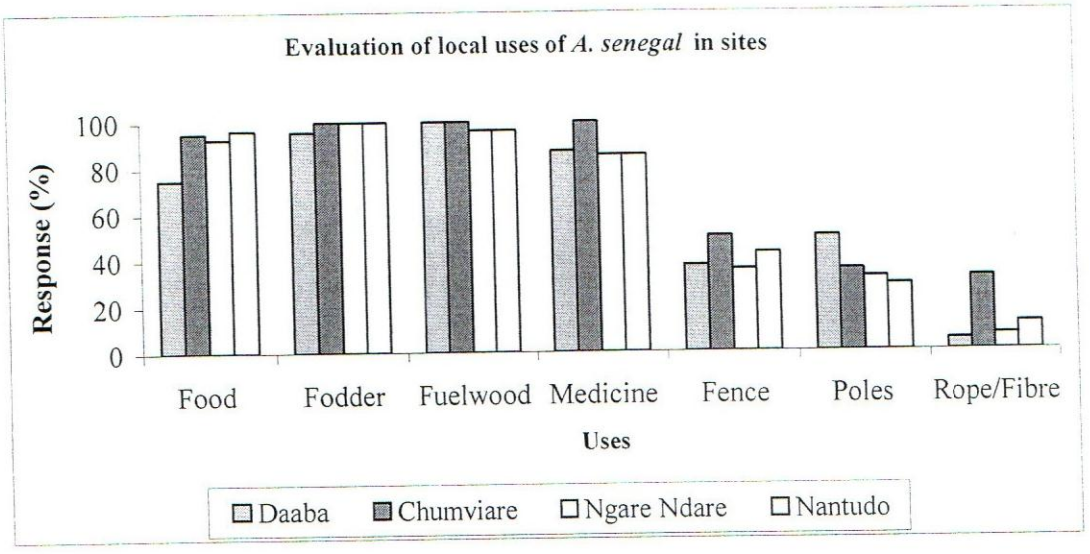
Chumviare and Daaba obtained firewood from *A. senegal* trees and a further 96.0% in Ngare Ndare and Nantudo. Furthermore, 100% of those interviewed in Chumviare, Ngare Ndare and Nantudo got fodder from the trees. An extra 96.0% of the respondents in Daaba got fodder from *A. senegal*. It was evident that the tree was crucial for the communities in meeting their demand of fodder and fuel wood (Figure 4.4).

The tree was an important medicinal species in all the sites as attributed to 100% of the respondents interviewed in Chumviare and 88.0%, 86.0% and 85.0% of those interviewed in Daaba, Ngare Ndare and Nantudo respectively consented that the tree has medicinal value. Gum arabic is used to treat backache and pain in the body joints. Besides, the bark of the *A. senegal* trees is used to treat stomach related illness.

Moreover, the tree was a significant source of human food during famine in the study sites but to a varying degree. The local communities feed on gum arabic as reported by 96.0% of the interviewees in Nantudo. Additionally, 95.0%, 93.0% and 75.0% of the respondents in Chumviare, Ngare Ndare and Daaba respectively alluded that they rely on gum arabic to feed themselves and their families during severe drought to supplement other food sources.

Fibers/ropes were not common products obtained from these trees with only very few farmers in the four localities got this for their home use with Chumviare having the highest number of farmers utilising the tree for fibre making followed by Nantudo and Ngare Ndare respectively. Daaba had the least number of respondents who obtained fibres/ropes from gum arabic trees. The Turkana community in Daaba use fiddles from *Acacia tortilis* for constructing their traditional houses and fencing livestock enclosures. However, the use of fiddles is supplemented by poles obtained from *A. senegal* trees. In fact, Daaba had the highest number of respondents who obtained poles from *A. senegal* for construction purposes followed by Chumviare and Ngare Ndare respectively. Very few respondents in Nantudo got poles from *A. senegal* for constructing livestock sheds and traditional houses.

The use of *A. senegal* in fencing was confirmed by a comparable number of respondents in the four sites. However, Chumviare had the highest number of respondents of interviewees utilizing *A. senegal* for fencing followed closely by Nantudo. Daaba and Ngare Ndare had almost an equivalent number of respondents who used *A. senegal* for fencing.



Source: Field data (2009)

Figure 4.4: Evaluation of local uses of *A. senegal* in sites

4.7 Gum arabic production and collection

The production of gum arabic in Isiolo District was based entirely on wild *A. senegal* trees in natural stands owned communally either in reserved forests or parks. According to the local communities, the gum trees prefer well-aerated soils, especially sandy-loam or sandy soils. All the respondents (100%) collected natural exudates though in times of high demand it was supplemented through tapping using informal tools such as stones.

Gum arabic usually exudes naturally from mechanical injuries on the bark of the stems and branches of *A. senegal* trees. The collection season begins in January to March and June to September because these are dry months of the year and gum arabic production is regularly highest in the dry season. The gum trees begin to produce gum arabic when the leaves turn yellowish and start shedding off. The June to September season is the best in terms of yield since it comes after the long rains. More gum arabic is therefore collected during this particular season than January to March season.

Pastoralists and agro-pastoralists that include poor members of the community, men, women and children carry out the collection of gum arabic. The gum is removed by hand, if hard and difficult to remove, it is knocked off by a panga and if very high up the tree, a forked stick is used to pull down the branch. Generally, collection is done on individual level

and women are the mainstream collectors on full time basis. However, few people carry out gum arabic collection on part time basis particularly children as they fetch water/fuelwood or when herding livestock.

In average, three people per household were involved in collection of gum arabic. Additionally, in average, one person per household was involved in gum arabic collection on full time basis while two people per household collected gum arabic on part time basis. The quantity of gum arabic reportedly collected per day per collector varied from 1 kg to 10 kgs. The average quantity collected per individual was 4.3 kgs per day. Chikamai and Odera (2002) reported a figure of 5 kgs per collector per day meaning that the average quantity collected per collector per day has slightly decreased by 0.7 kgs. On average, the collectors spent four days in a week collecting gum which is in contrast with the results of previous studies by Chikamai and Odera (2002) which suggested that on average, collectors work 5 days in a week on gum arabic collection as an activity. This means that the economic value of gum arabic has declined forcing some people to abandon the collection.

4.7.1 Tools used for gum arabic collection

The following tools were found to be used for gum arabic collection from the trees; panga, forked stick, long straight stick and stones. Gum arabic collectors used pangas (58.0%) in their course of collection (Table 4.4). Another 41.0% of those interviewed used long forked stick to facilitate collection. Only a few collectors' used stones (1.0%) to injure the gum trees in order to induce gum production.

Table 4.4: Tools used for gum arabic collection

Tool	Response (%)
Panga	58.0
Forked Stick	41.0
Long straight Stick	9.0
Stone	1.0

Source: Field data (2009)

As shown above, the tools used during gum collection include; pangas, forked stick, long straight stick and stone and hence the present findings concurs with report by Chikamai and Odera (2002) but deviate slightly from the results of Luvanda *et al.* (2006) who found that special axe, knife and panga were the main tools used for collection. These tools are primarily used by the collectors to access *A. senegal* trees and to injure them to induce gum arabic production. Pangas are used to clear any thicket or vegetation surrounding gum arabic producing trees and to make cuts on the tree stems and branches to induce gum arabic production.

Occasionally, collectors use stones to injure the trees by hitting the bark to stimulate gum arabic exudation. The use of stones to induce gum arabic exudation by hitting the bark of the branch or stem of the gum trees result into low quality gum arabic because gum arabic harvested as a result of this kind of tapping is contaminated with impurities mainly small and tiny pieces of tree bark. Stone tapping also causes more injury to the trees' cambium cells and does not allow the tapper to reach the tree branches, which are high up the tree with ease and as a result, it should be discouraged at all cost. Forked stick and long straight stick are used in pulling down tree branches that have gum arabic exudates for easy collection. The mentioned tools used by local communities during collection of gum arabic are made locally by local communities' artisans and hence indigenous to the communities. It's important to note that all the collectors carry containers during the collection, which are used for carrying home and storing gum arabic collected before it is sold to the buyers.

4.7.2 Environmental factors influencing gum arabic production/yield

According to the local communities, rainfall is critical for gum arabic production and determined the quantity harvested in a given season. Unreliable rainfall pattern was cited by 51.0% of the respondents as the cause of poor yields while drought was cited by 7.0% of the respondents as another factor limiting gum arabic production/yield. These two factors are interrelated in influencing gum arabic yield in the District. A further 14.0% of the respondents agreed that both rainfall and drought influence the yield of gum arabic whereas 29.0% declined to give any response (Table 4.5).

Table 4.5: Factors affecting gum arabic production/yield

Factors	Rainfall	Drought	Rainfall and drought	N/R[a]
Response (%)	51.0	7.0	14.0	29.0

[a] *No response*

Source: Field data (2009)

The locals believed that yield depended primarily on the duration and amount of rainfall preceding the dry season. The eight-year trend in yields observed in the research plantation of Sudan demonstrated that the annual rainfall received in the season immediately preceding tapping strongly and positively affects gum arabic yield (Ballal *et al.*, 2005). When there is high amount of rainfall extending over a long period, the yield of gum arabic will also be high in the subsequent dry season. Prolonged drought period hindered gum arabic production and thus reduces yield drastically. Historically, years that have been characterized with long drought have led to a decline in the output of gum arabic sometimes even to the extent whereby the trees fail to produce gum arabic completely. This study confirms earlier reports by several authors including Jackson (1968), Anderson (1993), Ballal *et al.* (2005) and Luvanda *et al.* (2006) who established that long and severe droughts resulted into low gum arabic yields. For instance, the 1973/1975 and 1983/1985 droughts in Sudan created world shortage of gum arabic forcing some major users to seek alternative modified starches (Anderson, 1993).

The yield of gum arabic also depended on the frequency of harvesting, age and size of the tree and altitude. Other related studies by Luvanda *et al.* (2006) have shown that season, soil type, age and size of the tree, variety and rainfall are the most important factors determining the yield of gum arabic in that order. Thus, the yield per tree per season varied from tree to tree depending on the interplay of rainfall, drought, harvesting frequency, age and size of the tree and altitude. However, it is difficult to estimate the quantity produced per individual tree per season using local knowledge as the basis because the collectors lack records of collection. Collection is carried out randomly and the collectors do not mark the trees they collect gum arabic from for further reference and quantification throughout the production season. Gum arabic collected from different trees is pooled together in a container and sold to the agents in this form making it difficult to know the amount gathered from individual trees.

The high levels of illiteracy that has engulfed the local people living in these areas further compound this problem of yield estimation.

4.7.3 Rationale of selecting *A. senegal* trees for gum arabic collection

Age and size of the tree were the main factors that led the collectors to selecting the kind of trees they target for gum arabic collection. Small sized trees with a basal diameter approximately the size of the arms wrist are preferred because it is assumed that the small trees are young in age as confirmed by 91.0% of the respondents (Table 4.6). It was clear the tree branching system had the least impact on guiding the gum arabic collectors in picking the prospective candidate trees for gum arabic collection as it was represented by a mere 3.0%. Some gum arabic collectors took into consideration the colour of the bark when choosing potential gum trees for collection (6.0%).

Table 4.6: Selection criteria of *A. senegal* trees for gum arabic collection

Factor	Response (%)
Age and size of the tree	91.0
Colour of the bark	6.0
Number of branches	3.0

Source: Field data (2009)

Thus, preference was given to small sized trees, which are assumed younger in age because they are easily accessible and more productive as confirmed by previous reports (Luvanda *et al.*, 2006). Big trees produced less gum because they are old and senescent and that is why the locals rarely target them for collection. Moreover, big trees are difficult to access especially the branches, which are high up the tree. Local communities believe that tree branches produce more gum arabic than the stems, which is in sharp contrast with the scientific results that indicated tree stems produce more gum arabic than the branches (Section 4.8.2 of this study).

4.7.4 Traditional ecological knowledge on the habitats of *A. senegal* trees

Majority of the respondents (88.0%) reported that they collected large quantity of gum arabic from *A. senegal* trees located in hilly and rocky areas whereas 56.0% reported they got

high yields in plain and flat areas free of rocks. Some 9.0% of the respondents indicated that they gather high amounts of gum arabic from gum trees along riverbanks (Table 4.7).

According to the authors' observation, *A. senegal* trees found growing along riverbanks (luggas) do not experience acute soil water deficit during dry season as those in very rocky and hilly areas and have low levels of physiological stress that enhances gum arabic production. This is the reason why the respondents cited low yield among these riverine trees. On the other hand, soils in hilly and rocky sites tend to lose moisture very fast because they are sandy in nature. As a result, gum trees in hilly and rocky sites undergo desiccation at a more rapid rate once dry spell begins setting in, forcing the gum trees to counter the physiological stress by producing gum arabic in order to seal any wound present on the tree's bark either on the stem or branch to stop water loss. As such, *A. senegal* trees growing in the hilly and rocky sites yield high quantities of gum arabic.

Table 4.7: Habitats of *A. senegal* based on traditional ecological knowledge

Habitat	Response (%)
Hilly and rocky places	88.0
Plain areas	56.0
Sites along the river banks	9.0

Source: Field data (2009)

4.7.5 Knowledge of *A. senegal* based on gender

This study established that women had a deep understanding of *A. senegal* tree resources and gum arabic production as reported by 74.0% of the respondents than men (26.0%) who are believed to have a limited knowledge on *A. senegal*. This observation is attributed to the fact that women are the majority gum arabic collectors and therefore they understand the trees better due to their regular interaction with the gum trees during gum arabic collection sessions.

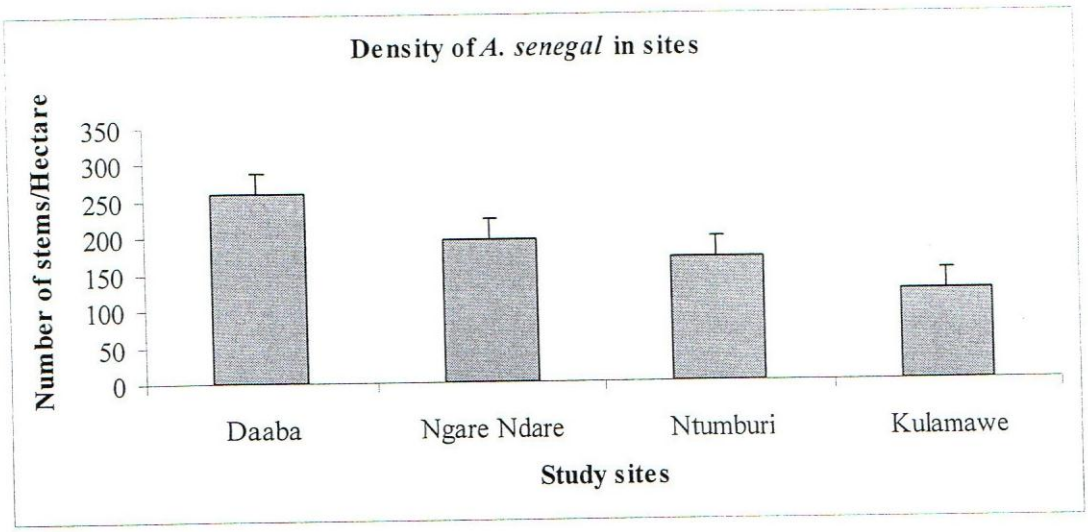
4.8 *Acacia senegal* resources assessment

The continued existence of *A. senegal* in a natural forest community largely depends on its age class distribution and regeneration under varied environmental conditions. Consequently,

age class distribution and regeneration of *A. senegal* is a critical phase of *A. senegal* management for gum arabic production because it maintains the desired age class composition and stocking density required for enhanced production of gum arabic even after disturbances. It is against this background that the density, age class distribution and regeneration status of *A. senegal* varieties were assessed from the population dynamics of young, middle-aged and mature trees as well as the saplings in the natural *A. senegal* forest community.

4.8.1 Density of *A. senegal* in sites

The density of *A. senegal* varied between the sites (Figure 4.5). The highest density was observed in Daaba plot, which had 259 stems per hectare (sph) and the lowest in Kulamawe plot, which had 123 stems per hectare (sph). Ngare Ndare and Ntumburi plots had 196 and 170 sph respectively; hence, the average number of trees per hectare in all the four sites was 187 sph. The present study results are in contrast with results of similar previous studies conducted in Karamoja region of Uganda by Obua *et al.* (2006) in which the density of *A. senegal* varied from 400 sph to 1100 sph and with an average of 741 sph. This study results on density of *A. senegal* also differs with earlier studies conducted by Chikamai *et al.* (1995), which established that the average density was 281 sph for *A. senegal* var. *kerensis*. Thus, results of this study indicate that there has been a decline in the population of naturally growing *A. senegal* in Kenya compared to the tree population fourteen years ago due to deforestation resulting from overgrazing and other human related activities.



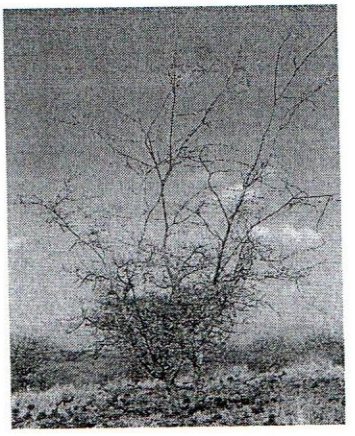
Source: Field data (2009)

Figure 4.5: Density of *A. senegal* in sites. Bars indicate S.E.D (± 0.5)

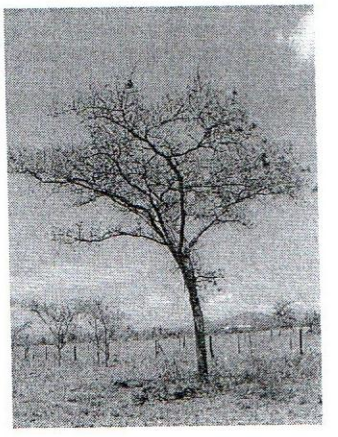
The difference in distribution of *A. senegal* trees per hectare in different sites studied is linked to the variety, soil type and land use patterns. The tree density was higher in Daaba and Ngare Ndare sites, which are inhabited by *A. senegal* var. *kerensis* and was low in Kulamawe where variety *leiorhachis* is the main species. The density of *A. senegal* var. *senegal* at Ntumburi fell in between the other two varieties (*leiorhachis* and *kerensis*) confirming that variety is a significant factor influencing the density of these trees. Disturbed sites with limited anthropogenic activities such as grazing and charcoal production had higher densities of *A. senegal*. Grazed areas had low densities of the species due to constant damage by livestock. This was observed at Kulamawe plot, which has been subjected to high grazing pressure resulting into reduced stocking density of *A. senegal* var. *leiorhachis*. Soil type seems to influence the density of *A. senegal* varieties with Ngare Ndare and Daaba, which have sand and sandy-loam soils respectively having high densities than Kulamawe and Ntumburi that exhibit rocky-sand and clay-loam soils respectively showing less densities. The results of the present study are in line with a previous report by Obua *et al.* (2006), which indicated that the density of *A. senegal* was linked to soil type and the intensity and type of land use pattern. Similarly, other studies by Chikamai *et al.* (1995) found that the density of *A. senegal* was affected by land use pattern with disturbed areas having low densities.

No previous studies that have been conducted to evaluate the population structure and density of different varieties of *A. senegal* in the wild but the present study demonstrate that *A. senegal* var. *kerensis* exhibit high densities than *A. senegal* varieties *leiorhachis* and *senegal* in Kenya.

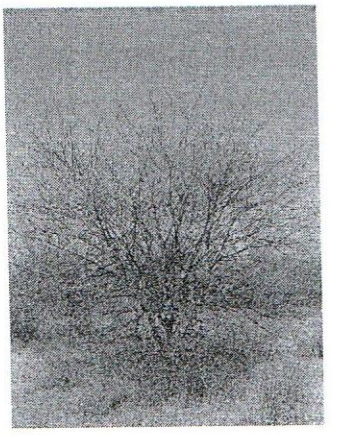
Ntumburi had big sized trees than the rest of the sites with a mean basal diameter (BD) of 11.245cm followed by Kulamawe (10.793cm) while Ngare Ndare had small sized trees with a mean basal diameter (BD) of 6.815cm and hence the variation in density. The presence of large *A. senegal* trees in Ntumburi and Kulamawe was due to low densities in the two study sites, which has reduced the competition for important resources required for tree growth such as water, soil nutrients and space and thus the tree growth is vigorous. There is a high competition for resources especially soil moisture in Daaba and Ngare Ndare plots due to high densities of the *A. senegal* trees leading to reduced growth rate of trees and this explains why the trees have small basal diameters (BD) and hence are small sized. Moreover, the size, the shape and form of *A. senegal* trees belonging to different varieties vary and hence are responsible for the differences in basal diameters of these varieties of *A. senegal* (Plate 2).



(a) *A. senegal* var. *leiorhachis*



(b) *A. senegal* var. *senegal*



(c) *A. senegal* var. *kerensis*

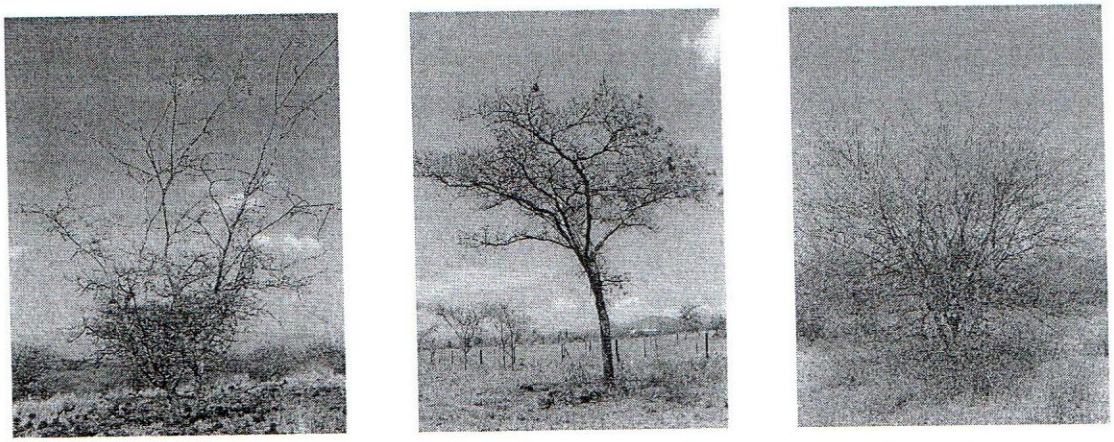
Plate 2: Morphological manifestation of *A. senegal* varieties

4.8.2 Distribution of *A. senegal* saplings in sites

Ntumburi had the highest number of saplings per hectare (133) followed by Ngare Ndare (90 saplings per hectare). Kulamawe and Daaba had the least numbers in this category with 15 and 8 saplings per hectare respectively (Figure 4.6). The rate of natural regeneration was therefore high in Ntumburi and Ngare Ndare but low at Daaba.

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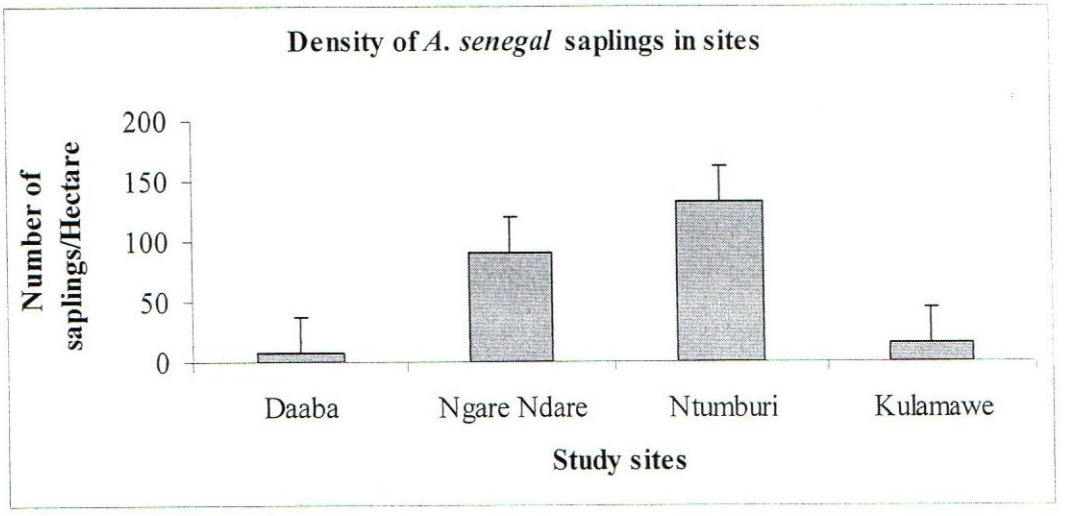


(a) *A. senegal* var. *leiorhachis* (b) *A. senegal* var. *senegal* (c) *A. senegal* var. *kerensis*

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Source: Field data (2009)

Figure 4.6: Density of *A. senegal* saplings in sites. Bars indicate S.E.D (± 0.5)

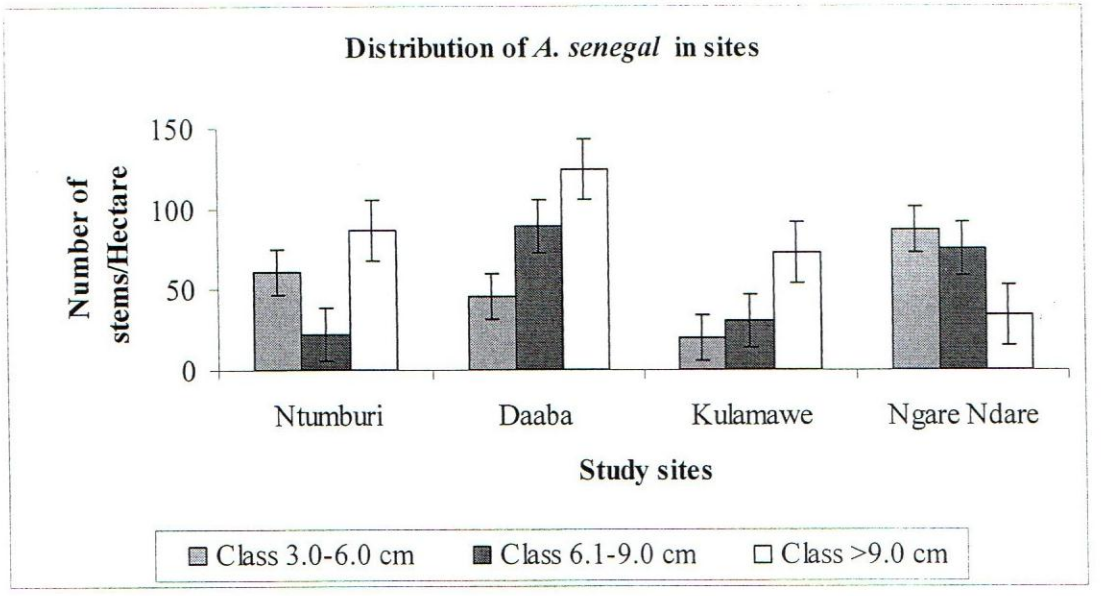
The high number of saplings in Ntumburi can be attributed to restricted access to the plot. The plot is fenced on two sides and agricultural farming is practiced in farms bordering the remaining two sides minimising human activities such as grazing. Secondly, Ntumburi receives a high amount of precipitation than the rest of the sites and has high altitude and thus is cool with low surface temperatures. Therefore, the soils have relatively high moisture content that facilitate successful germination of seeds once they fall down on the soil surface.

However, the state of affairs is different at Kulamawe whereby the plot is accessible to all (a common property resource) and therefore overgrazed. Besides, the soil is sandy and rocky and therefore has poor moisture retention ability; soil moisture is a critical factor in seed germination. Also, the absence of shade at Kulamawe due to *A. senegal* var. *leiorhachis* tree form encourage high surface temperatures attainment by bare soils resulting to adverse and possibly lethal effect on any dormant or germinating seeds lying on the soil surface, discouraging revegetation.

Overgrazing and wildlife browsing were identified as the main factors causing low density of saplings in Daaba and Ngare Ndare sites respectively and thereby hindering *A. senegal* var. *kerensis* recruitment. Wild animals and livestock trample and browse on the saplings killing them and hence reducing their population.

4.8.3 Distribution of *A. senegal* in sites

The distribution of *A. senegal* varieties in the different basal diameter (BD) size classes is shown below (Figure 4.7). The density increased with increase in diameter size classes at Daaba and Kulamawe. However, at Ngare Ndare, the density decreased with increase in diameter size classes. Ntumburi on the other hand showed a different pattern whereby trees with the largest basal diameter were the highest in number followed by those in the smallest basal diameter (BD) class whereas class 6.1-9.0 cm had the least number of trees. In diameter classes of 6.1-9.0 cm and >9.0cm, the density was highest in Daaba. There was a high density of trees within diameter class of 3.0-6.0 cm in Ngare Ndare, followed by Ntumburi, Daaba and then Kulamawe, which had the least sph.



Source: Field data (2009)

Figure 4.7: Distribution pattern of *A. senegal* in sites. Bars indicate S.E.D (± 0.5)

The distribution pattern of *A. senegal* in the four sites revealed that most of the trees were old in Ntumburi, Daaba and Kulamawe and this presents a problem in gum arabic production in these sites because as alluded to earlier in this study, younger trees tend to produce more gum than old trees. Furthermore, the high number of trees in the larger diameter size classes indicated poor regeneration in the three sites. However, at Ngare Ndare, most trees were young indicating that the site has a high gum arabic production potential and the regeneration rate is higher.

4.8.4 Tree species associated with *A. senegal* in sites

All the three varieties of *A. senegal* in their natural stands were found to be mixed with other dryland tree species (Table 4.8). Tree species associated with *A. senegal* var. *leiorhachis* at Kulamawe included *Acacia mellifera, Acacia tortilis, Boswelia neglecta, Cordia sinensis, Commiphora africana, Grewia tenax, Grewia villosa* and *Boscia coriacea*. At Ntumburi *A. senegal* var. *senegal* is associated with the following species: *Commiphora africana, Osyriss lanceolata, Acacia tortilis, Rhus natalensis, Balanites aegyptiaca* and *Euphorpia tirucalli*. In Ngare Ndare, tree species occurring with *A. senegal* var. *kerensis* at this site were; *Commiphora africana, Boscia coriacea, Grewia tenax, Grewia villosa, Delonix elata, Acacia tortilis* and *Cordia sinensis*. The *A. senegal* var. *kerensis* in Daaba was dominant in the plot with only few trees of *Acacia tortilis* and *Cordia sinensis*. Consequently, this study shows that in sites where *A. senegal* is found growing, certainly *Acacia tortilis* is found growing in the same place. This is because in all the four-sample plots representing different varieties of *A. senegal*, the presence of *A. tortilis* was noted as significant.

Table 4.8: Tree species associated with *A. senegal* varieties in sites

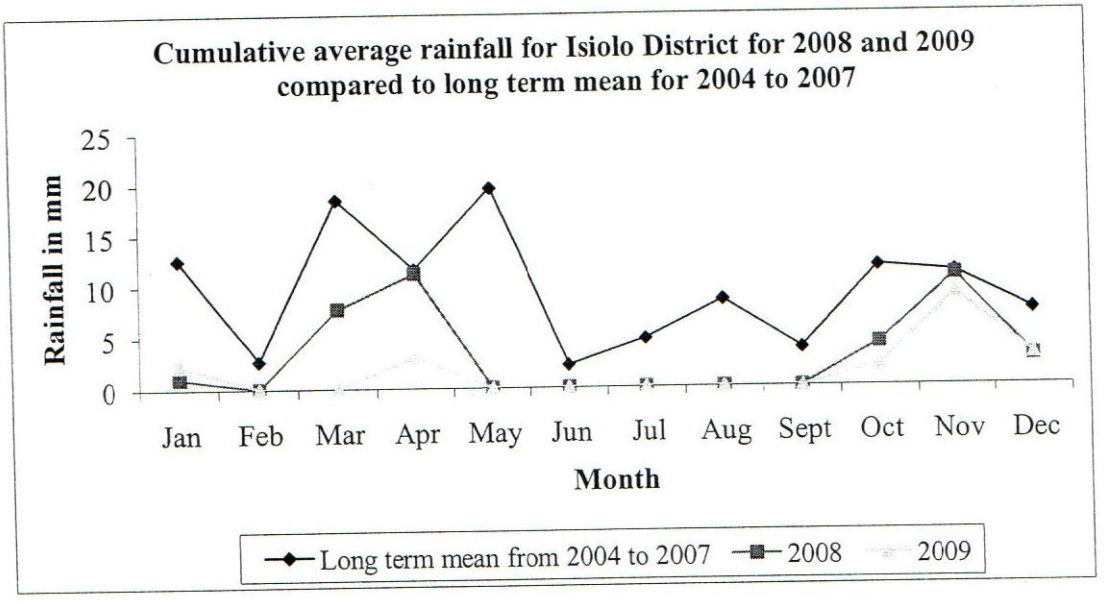
	Number of trees/one hectare plot in sites			
Tree species	**Ntumburi**	**Daaba**	**Kulamawe**	**Ngare Ndare**
Acacia tortilis	27	28	44	12
Acacia mellifera	0	0	11	0
Balanites aegyptiaca	14	0	0	0
Cordia sinensis	0	31	6	14
Boswelia neglecta	0	0	1	0
Boscia coriacea	0	2	7	3
Grewia tenax	0	0	5	7
Grewia villosa	0	0	2	11
Euphorpia tirucalli	1	0	0	0
Osyriss lanceolata	2	0	0	0
Commiphora africana	30	0	24	24
Rhus natalensis	3	0	0	0
Delonix elata	0	0	0	2

Source: Field data (2009)

4.9 Physical characteristics of the study sites

The following physical characteristics were studied, atmospheric temperature, soil temperature and soil moisture. Data on rainfall pattern for Isiolo district during the study period was also collected. These physical characteristics as well as the rainfall pattern were studied because they have a significant effect on the physiology of deciduous trees such as *A. senegal*. As earlier indicated in this study, gum arabic production by *A. senegal* trees is a physiological process and as such, these physical factors and rainfall amount affect its production in terms of yield and quality.

The rainfall pattern for the 2008 and 2009 compared to long-term mean 2004-2007 is given below (Figure 4.8).



Source: ALRMP (2009)

Figure 4.8: Cumulative average rainfall for Isiolo District for 2008 and 2009 compared to long-term mean for 2004 to 2007

The long rains performance was poor in both spatial and temporal distribution with most areas of the district receiving rainfall amounts below the long-term average (Figure 4.8). Besides, the rains started late by one month and were unevenly distributed and as such, they could not support high production of gum arabic by *A. senegal* trees during the succeeding dry season. Other related studies by several authors including Jackson (1968), Anderson

(1993), Ballal *et al.* (2005) and Luvanda *et al.* (2006) have shown that high amount of rainfall enhances increased gum arabic yield in the succeeding dry season. For example, the 1973/1975 and 1983/1985 droughts in Sudan created world shortage of gum arabic forcing some major users to seek alternative modified starches (Anderson, 1993).

The mean variation of physical characteristics of the study sites is presented below (Table 4.9). The mean atmospheric and soil temperatures were highest at Kulamawe, followed by Daaba, Ngare Ndare and then Ntumburi. Ntumburi had the highest mean soil moisture followed by Kulamawe, Daaba and then Ngare Ndare.

Table 4.9: ANOVA table for sites physical characteristics

Characteristic	Daaba	Ngare Ndare	Kulamawe	Ntumburi	S.E	CV (%)
Atmospheric temperature (°C)**	29.9a	28.3b	31.8c	25.7d	2.857	9.9
Soil temperature (°C)***	32.3a	31.3a	33.4a	29.9a	5.49	17.3
Soil moisture (%)**	5.3a	3.6b	5.6a	12.9c	1.435	20.7

Source: Field data (2009)

*Any means in the same row having a common letter are not significantly different

**Significant at $p<0.01$

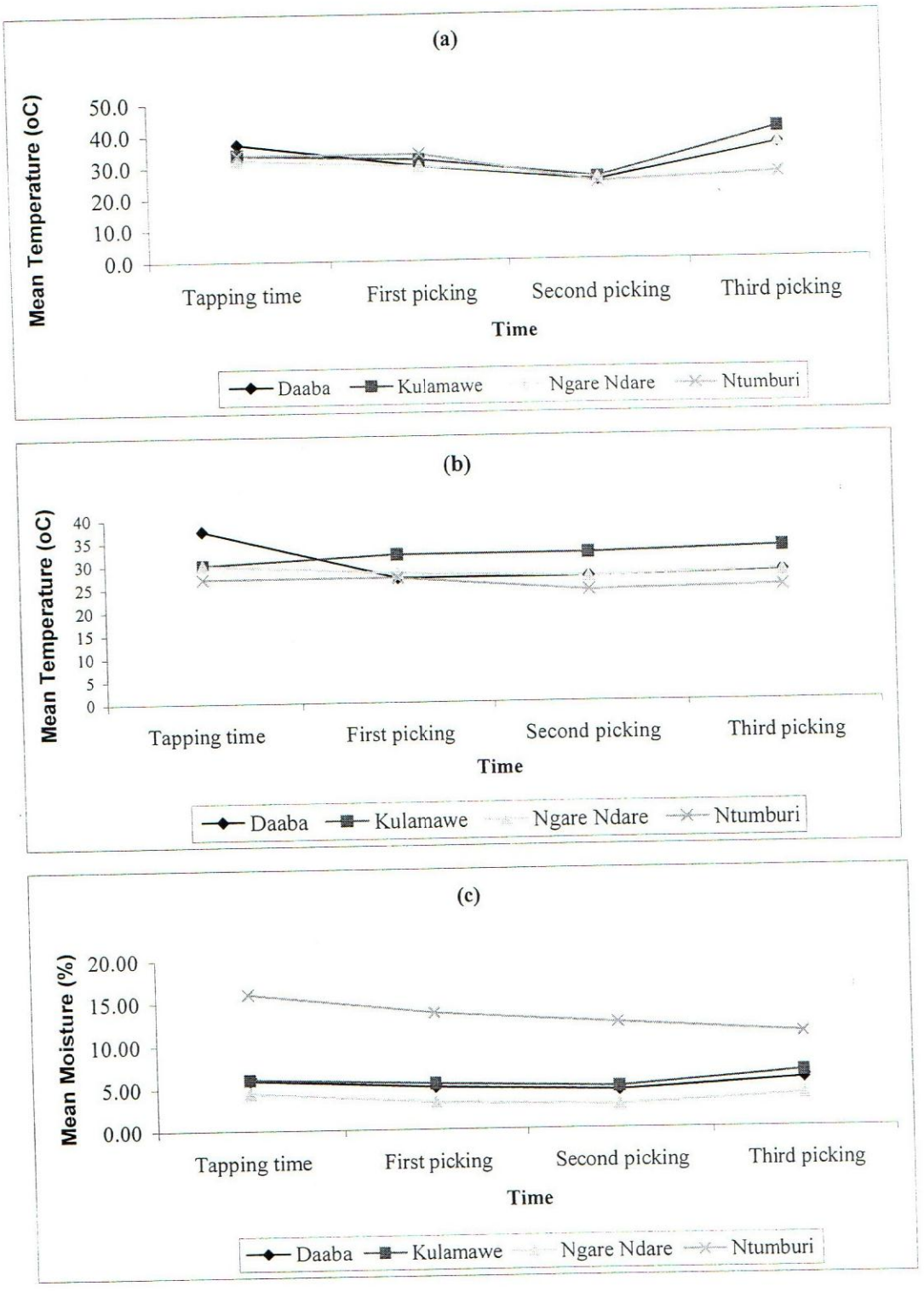
***Significant at $p<0.05$

A significant difference ($p<0.01$) in atmospheric temperature between sites existed with Kulamawe being the hottest followed by Daaba and Ngare Ndare respectively while Ntumburi had the lowest recorded atmospheric temperature (Table 4.9). Daaba experienced highest atmospheric temperature at tapping time than the rest of the sites, which decreased from tapping to first picking and then remained steady in subsequent pickings. In Kulamawe, atmospheric temperature increased steadily from tapping time to third picking. The atmospheric temperature at Ngare Ndare and Ntumburi decreased slightly from tapping time to first and second pickings before going up slightly at third picking (Figure 4.9b). The variation in atmospheric temperatures in the sites is due to differences in elevations. Kulamawe, Daaba and Ngare Ndare, which have low elevations (altitude), have high atmospheric temperatures compared to Ntumburi, a site with high altitude.

There was no significant difference ($p<0.05$) in soil temperature between the sites ($p>0.532$). Soil temperature was high during the tapping dates and at third picking in all the sites but low during the second picking (Figure 4.9a). Daaba had the highest soil temperature at tapping time compared to the other sites whereas Kulamawe exhibited this condition of high soil temperature at third picking.

General analysis of variance revealed a highly significant difference ($p<0.01$) in soil moisture content between the sites (Table 4.9). Ntumburi had the highest soil moisture content while Ngare Ndare had the lowest throughout the study period. When individual sites are compared for soil moisture content, there was no significant difference in soil moisture content between Kulamawe and Daaba ($p<0.05$). However, soil moisture content differed significantly ($p<0.05$) between Ngare Ndare, Daaba, Kulamawe and Ntumburi. Soil moisture content at Ntumburi decreased from tapping date to the third picking and was lowest during the third picking of gum arabic (Figure 4.9c). The trend was different for the rest of the three sites where soil moisture content decreased slightly from tapping date to first picking but remained steady at first and second pickings before slightly increasing at the third picking.

The different soil types explain the variations in soil moisture levels observed in the study sites. Ngare Ndare is dominated by sandy soils, which loses moisture fast due to their coarse texture. Ntumburi has clay-loam soils with good water retention ability and hence hold moisture for a long period. Soils at Kulamawe and Daaba are rocky-sand and sandy-loam respectively hence not able to hold and retain moisture for long. The results in the present study are in line with what was previously reported by Raddad and Luukkanen (2005) that the finer the soil particles, the larger the soil water capacity implying that clay, silt and loam soils have a high water holding capacity than sand soil. Consequently, *A. senegal* growing in sites with sandy soils experience rigorous water stress and therefore produce high quantities of gum arabic than their counterparts in sites exhibiting clay, silt or loam soils.

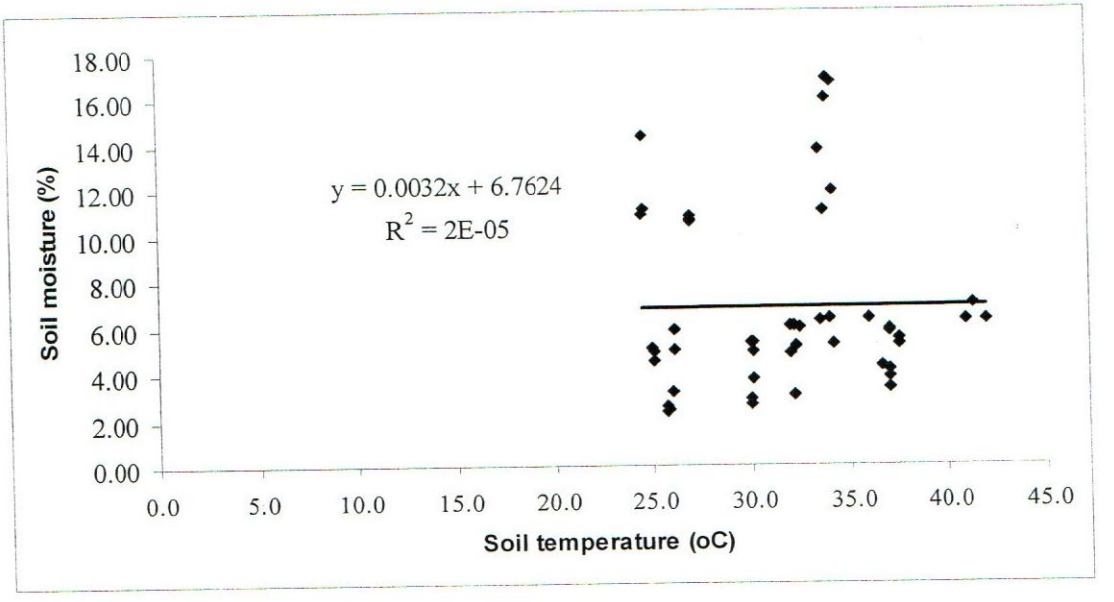


Source: Field data (2009)

Figure 4.9: Trend in sites physical characteristics (a) Soil temperature (b) Atmospheric temperature (c) Soil moisture

4.9.1 Effect of soil temperature on soil moisture content

Correlation analysis (Kendall's rank correlation) pointed out that there was no significant ($p<0.05$) positive correlation ($r=0.1339$, $p=0.0869$) between soil moisture and soil temperature (Figure 4.10). These data therefore suggests that soil temperature does not influence the level of soil moisture. Thus, other factors such as the amount of precipitation and soil type could have influenced soil moisture levels in the sites. According to Raddad and Luukkanen (2005) soil texture, largely govern the amount of water that infiltrates or can be held in a soil body and this seems to be the main factor influencing soil moisture in the study sites and not soil temperature.

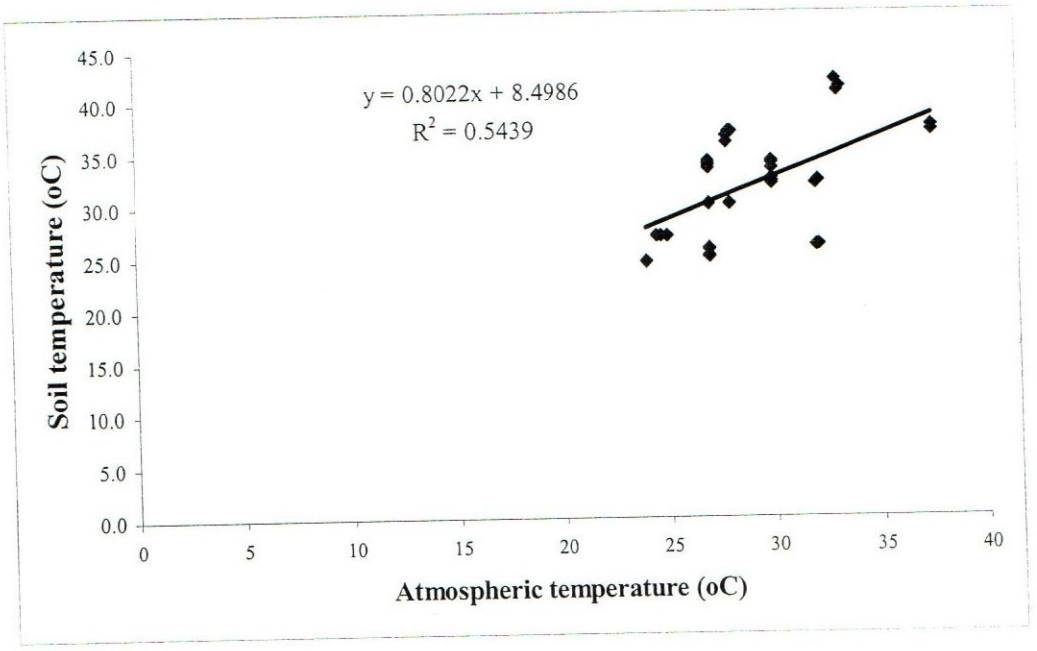


Source: Field data (2009)

Figure 4.10: Relationship between soil moisture (%) and soil temperature (°C)

4.9.2 Effect of atmospheric temperature on soil temperature

Results obtained in the present study shows that there was a significant positive correlation ($r^2=0.5439$, $p<0.01$) between the atmospheric temperature and soil temperature (Figure 4.11). This was expected because the prevailing atmospheric temperature influences the soil heat at a given period and therefore, the atmospheric temperature can be used to predict the soil temperature which is a critical factor that influences gum arabic production and hence the yield.

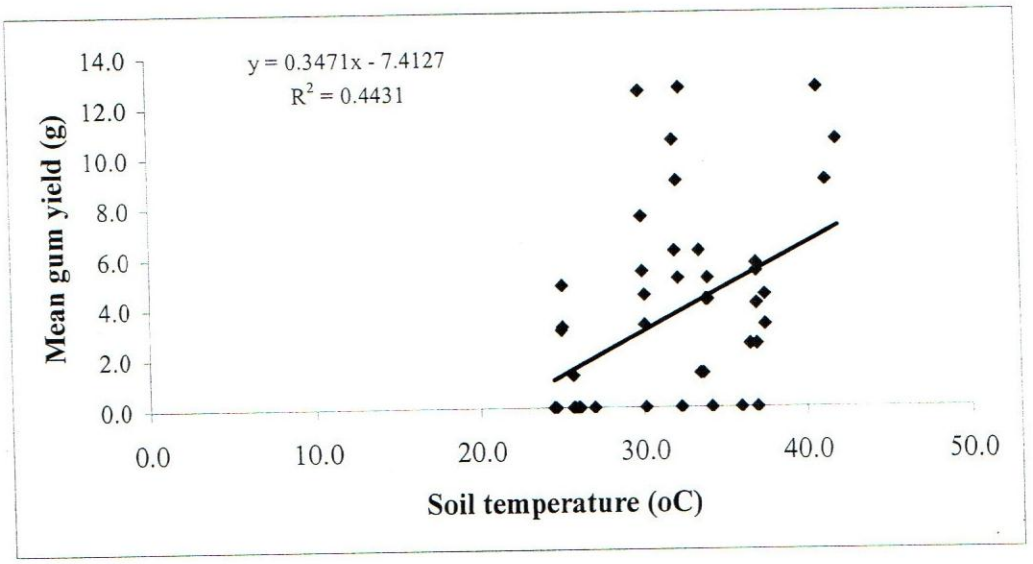


Source: Field data (2009)

Figure 4.11: Relationship between soil and atmospheric temperatures (°C)

4.9.3 Effect of soil temperature on gum arabic yield

There was a highly significant positive correlation ($p<0.05$) between soil temperature and gum arabic yield ($r^2=0.4431$, $p=0.0037$) as shown below (Figure 4.12). Consequently, gum arabic yield is positively influenced by the soil temperature. This obviously reflects the sensitivity of *A. senegal* trees to high soil temperature when adjusting to physiological stress and comply with earlier reports by (Jackson, 1968; Duke, 1981) that the higher the average soil and atmospheric temperatures, the higher the yield of gum arabic.

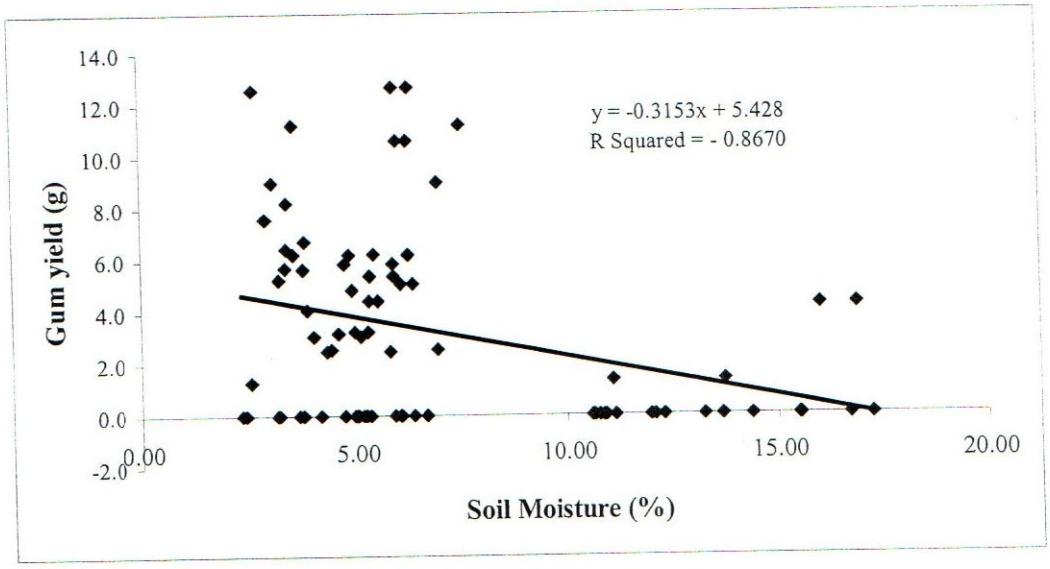


Source: Field data (2009)

Figure 4.12: Relationship between soil temperature (°C) and gum arabic yield (g)

4.9.4 Effect of soil moisture on gum arabic yield

Regression analysis ($p<0.01$) indicated that gum arabic yield by *A. senegal* is a function of the amount of water or moisture retained or available in the soil. Thus, as the moisture content in the soil increased, there was a decline in the yield of gum arabic (r^2=-0.8670, p=0.002) as shown below (Figure 4.13). According to Jackson (1968) and Gaafar *et al.* (2006), soil moisture has an effect on the yield of gum arabic with low soil moisture favoring increased gum arabic production. Similarly, information gathered on TEK indicated that rainfall affects gum arabic yield underscoring the fact that soil moisture is a critical factor in gum arabic production since soil moisture is directly dependent on rainfall. Other studies (Salmon, 1996; UNEP, 1998) have found that TEK has predictive power, intellectual traditions and observations, which are interpreted within a particular cultural context, and exists in parallel to western science and has been recognized as having equal status with scientific knowledge. Thus, it is important to note that there is an agreement between TEK and the field experiments that soil moisture affect gum arabic production particularly the yield.



Source: Field data (2009)

Figure 4.13: Relationship between soil moisture (%) and gum arabic yield (g)

4.10 Gum arabic yield assessment

A combined analysis of the yield data revealed highly significant interactive effects between site conditions, treatment and tree part on gum arabic yield for each of the three pickings of gum arabic ($p<0.001$).

4.10.1 Effect of site physical characteristics on gum arabic yield

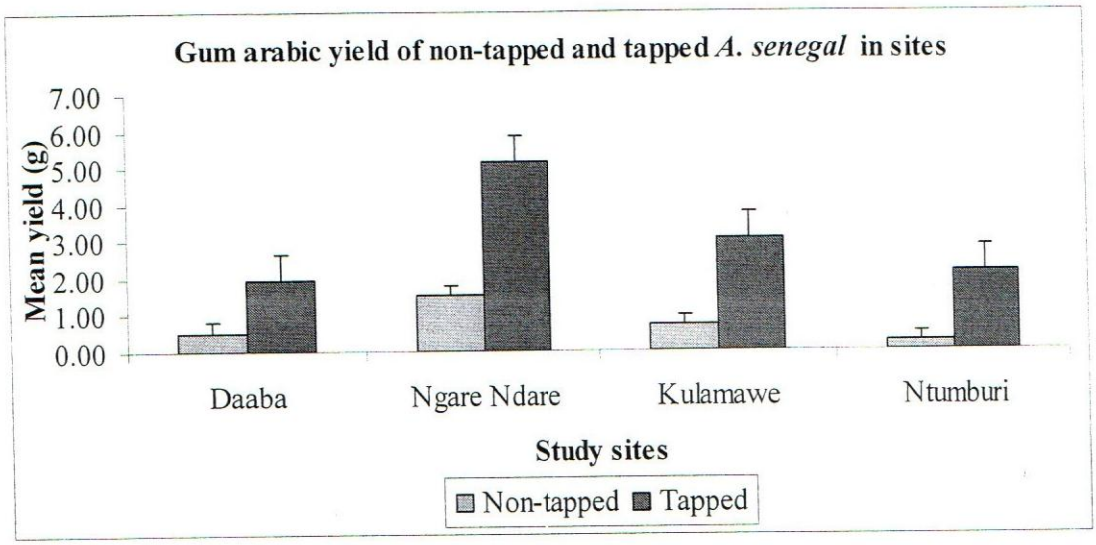
Generally, there was significant difference ($\chi^2=30.69$, $p<0.01$) in gum arabic yield between the sites with Ngare Ndare with a mean rank (768.06) having the highest yield followed by Kulamawe, which is inhabited by *A. senegal* var. *leiorhachis* with a mean rank (739.41). Comparatively, Ngare Ndare had significantly higher yield than Daaba although the two sites are occupied with *A. senegal* var. *kerensis*. Ntumburi, the study site for *A. senegal* var. *senegal* had the lowest production of gum arabic. Generally, different varieties of *A. senegal* yield different quantities of gum arabic with *A. senegal* var. *kerensis* being the main producer. The present findings therefore confirm that *A. senegal* var. *kerensis* is the main species that produces commercial gum arabic in Kenya and confirms the results of earlier studies by Chikamai and Banks (1993).

This study has assertively established that site physical characteristics influence gum arabic yield because though Daaba and Ngare Ndare have similar variety (*A. senegal* var. *kerensis*); Ngare Ndare produced high quantity of gum arabic than Daaba. The yield differs in these two sites due to differences in soil physical properties, altitude and both atmospheric and soil temperatures. Ngare Ndare has sand soil that loses moisture faster and the site exhibited low soil moisture throughout the study period than Daaba, which has sandy-loam soil, and therefore retains moisture longer. Given that low soil moisture favors high gum arabic production due to the trees being subjected to high physiological stress, *A. senegal* trees at Ngare Ndare yield more gum arabic than those at Daaba where the stress level of the trees resulting from water deficit is not very high. Other related studies by Raddad and Luukkanen (2005) have shown that soil texture; largely influences the yield of gum arabic with *A. senegal* growing in sandy soils producing high quantities than their counterparts in clay soils and this is mostly because of the amount of soil moisture a soil type can hold for a period of time.

Personal observation by the author established that the phenological behavior of *A. senegal* var. *kerensis* in Daaba and Ngare Ndare differed sharply with trees in Daaba having an extended leafing period than those in Ngare Ndare. Since gum arabic begins to ooze out when trees start shedding leaves, there is a delay in its production at Daaba compared to Ngare Ndare and this explains why the trees in Ngare Ndare yield more gum arabic than those at Daaba. The differences in genetic composition of the two populations of *A. senegal* var. *kerensis* at Ngare Ndare and Daaba also account for the differences in gum arabic yield because neighbor-joining topology grouped the two populations of *A. senegal* var. *kerensis* in two different main groups (Omondi, 2009).

4.10.2 Effect of tapping and tapping position on gum arabic yield

The experiments clearly show that tapping increases gum arabic production and consequently the yield in all the three varieties of *A. senegal*. There was a significant difference ($p<0.01$), ($U=206683$, $Z=10.24$) in gum arabic yield between tapped and untapped trees whereby tapped trees had higher average yield (3.1g) per tree per season than untapped trees (0.7g) per tree per season (Figure 4.14). Besides, the average gum arabic yield per picking per tree resulting from tapping *A. senegal* trees was higher than the average gum arabic yield per picking per tree for non-tapped trees in all the three diameter classes (Appendix iii).



Source: Field data (2009)

Figure 4.14: The overall mean gum arabic yield for non-tapped and tapped *A. senegal* in sites. Bars indicate S.E.M (± 0.5)

Analysis of variance using Mann-Whitney U (Wilcoxon rank-sum) test showed a significant difference in yield ($Z=7.24$, $p<0.01$) between stems and branches whereby the stems produced higher gum arabic yield than the branches (Table 4.10). The stem tapping caused the highest mean gum arabic exudation/yield per individual tree per season (2.6g) irrespective of the diameter classes whereas tapping the branches gave the lowest gum arabic yield per tree per season (1.1g). These results are in disagreement with TEK report, which suggests that *A. senegal* tree branches produce more gum than the stems (Section 4.5.3 of this study). Furthermore, other related studies by Fadl and Gebauer (2004) have shown that the middle stem tapping of A. *seyal* var. *seyal* causes the highest gum exudation while tapping the branches gives the lowest gum yield per tree per season.

Table 4.10: Mean gum arabic yield of tapped tree stems and branches

Tree part	Mean yield/tree/season (g)
Tree stem	2.6
Tree branch	1.1

Source: Field data (2009)

Results of this study demonstrates that in order to enhance gum arabic production, tapping has to be done which is consistent with common yield enhancement practices in other gum arabic producing countries like Sudan, Nigeria and Senegal where *A. senegal* trees are tapped to increase gum arabic production. Agriculture Research Corporation (ARC) of Sudan reported that tapping increases yield of gum arabic by 47%-60% and is supported by the results of present study, which have established that tapping of *A. senegal* trees increases gum arabic yield by more than 77.42%.

4.10.3 Gum arabic yield per tree in relation to tapping

The overall average gum arabic yield for tapped trees (1.95g/tree/season) at Daaba (*A. senegal* var. *kerensis*) constituted 37.86% of that (5.15g/tree/season) at Ngare Ndare (*A. senegal* var. *kerensis*) and was 36% and 9.5% less than 3.05g and 2.15g/tree/season at Kulamawe and Ntumburi respectively (Table 4.11). The overall average gum arabic yield/tree/season (3.05g) for *A. senegal* var. *leiorhachis* at Kulamawe was 29.5% more than (2.15g/tree/season) obtained in natural stand of *A. senegal* var. *senegal* at Ntumburi and 40.8% less than 5.15g/tree/season at Ngare Ndare (*A. senegal* var. *kerensis*). Accordingly, the overall average gum arabic yield by tapped trees (2.15 and 1.95g/tree/season) for Ntumburi and Daaba respectively was not significantly different ($p<0.05$) although the two sites were inhabited with different varieties of *A. senegal*.

In Kulamawe, diameter class of 3.0-6.0 cm produced more gum arabic (3.9g/tree/season) followed closely by diameter class of 6.1-9.0 cm which produced 3.4g/tree/season of gum arabic. Big sized trees with a basal diameter greater than 9 cm produced the least quantity (1.85g/tree/season). The scenario was different in Ntumburi whereby diameter class of 6.1-9.0 cm produced the highest quantity of gum arabic (4.35g/tree/season) while diameter classes 3.0-6.0 cm and >9.0 cm yielded 2g/tree/season and 0.1g/tree/season respectively.

Table 4.11: Overall average gum arabic yield/tree/season for tapped *A. senegal*

Site	Mean yield/tree/season for diameter classes (g)			Mean yield (g)
	3.0-6.0 cm	6.1-9.0 cm	>9.0 cm	
Daaba	1.45	1.6	2.8	1.95
Ngare Ndare	3.2	6.4	5.85	5.15
Kulamawe	3.9	3.4	1.85	3.05
Ntumburi	2.0	4.35	0.1	2.15

Source: Field data (2009)

In the view of present study, gum arabic yield for natural stands of *A. senegal* var. *senegal* in Kenya was not similar to that found in natural stands of *A. senegal* var. *senegal* in Sudan and generally was lower. Ballal *et al.* (2005) reported an overall average gum arabic yield of 99.2 g/tree for *A. senegal* var. *senegal* growing in natural stands in the Sudan's gum belt region for an assessment period of eight years that is equivalent to 16 gum arabic production seasons because each calendar year has two seasons. Taking the overall average gum arabic yield of 99.2g per individual tree and dividing it by 16 seasons, the overall average yield/tree/season is 6.2g. Therefore, the outcome of present study is lower than what Ballal *et al.* (2005) reported. In fact, the overall average gum arabic yield of *A. senegal* var. *senegal* per tree per season (2.15g) in Kenya represents only 34.7% of what was harvested from an individual tapped tree of *A. senegal* var. *senegal* found growing in the natural stands of *A. senegal* var. *senegal* in Sudan in a single season.

Conversely, overall average yield of gum arabic for tapped *A. senegal* var. *senegal* in scientifically well managed plantations of the Sudan according to the earlier results of Ballal *et al.* (2005) was 10.88g/tree/season which is five times more than 2.15g/tree/season for natural stand of *A. senegal* var. *senegal* in Kenya. Consequently, *A. senegal* var. *senegal* trees in well-managed plantations yield high quantities of gum arabic than those growing in natural and disturbed stands.

Further, present study findings on gum arabic yield of *A. senegal* var. *senegal* contradict previous reports by several authors such as NAS (1979), Duke (1981) and Dagnew (2006) who reported that *A. senegal* var. *senegal* gum arabic yield range from 200g-6700g per tree

per year a figure that translate to about 100g-3350g per tree per season. Additionally, the present findings on gum arabic yield of *A. senegal* var. *kerensis*, which range between 1.95g/tree/season and 5.15g/tree/season are in sharp contrast to the report of Chiveu *et al.* (2009) that the yield ranges from 0.66-0.81g/tree/season. No previous studies have been done to quantify gum arabic yield of *A. senegal* var. *leiorhachis* in Kenya; nevertheless, the results of present findings with authority assert that this variety yield 3.05g/tree/season.

The overall average gum arabic yield for *A. senegal* var. *kerensis* (5.15g/tree/season) at Ngare Ndare compares well with the figure (6.2g/tree/season) that was reported for *A. senegal* var. *senegal* found in natural stands in Sudan (Ballal *et al.*, 2005) although the two varieties are different. This emphasizes the fact that *A. senegal* var. *kerensis* is the main species for commercial gum arabic production in Kenyan ASALs as earlier reported by Chikamai and Banks (1993) and its yield can therefore be compared to the yield of *A. senegal* var. *senegal* in Sudan which is the main species producing commercial gum arabic. It is essential to note that *A. senegal* var. *leiorhachis*' overall average gum arabic yield (3.05g/tree/season) gives a strong signal that this variety has a great potential for gum arabic production to supplement *A. senegal* var. *kerensis*.

4.10.4 Gum arabic yield per tree in relation to non-tapping

The overall average gum arabic yield for non-tapped trees (0.52g/tree/season) at Daaba (*A. senegal* var. *kerensis*) was 34.07% less than (1.52g/tree/season) at Ngare Ndare for *A. senegal* var. *kerensis* and 30.7% less than 0.75g/tree/season at Kulamawe for *A. senegal* var. *leiorhachis* (Table 4.12). The overall average gum arabic yield (0.23g/tree/season) obtained in natural stand of *A. senegal* var. *senegal* at Ntumburi was 55.8% less than 0.52g/tree/season collected from non-tapped *A. senegal* var. *kerensis* at Daaba.

Table 4.12: Overall average gum arabic yield for non-tapped *A. senegal*

Site	Mean yield/tree/season for diameter classes (g)			Mean yield (g)
	3.0-6.0 cm	6.1-9.0 cm	>9.0 cm	
Daaba	0.5	0.7	0.35	0.52
Ngare Ndare	0.6	1.15	2.8	1.52
Kulamawe	0.6	1.25	0.4	0.75
Ntumburi	0.7	0	0	0.23

Source: Field data (2009)

A survey carried on TEK relating to gum arabic production indicated that though locals collect natural exudates of gum arabic, there are no records on individual tree yield per season because collectors do not keep such records, as the collection is randomly carried out (Section 4.5.2 of this study). However, field experiments in this study suggests that gum arabic yield resulting from natural exudation is very low ranging from 0.23-1.52g/tree/season depending on the variety of *A. senegal* and site physical characteristics such as soil type which has come out strongly in this study as a significant factor influencing gum arabic yield especially when similar variety is considered. As it was the case for tapped trees, Ngare Ndare yielded high quantity of gum arabic, followed by Kulamawe, Daaba and Ntumburi in that order.

4.10.5 Effect of tree size on gum arabic yield

Kruskal-Wallis One-Way Analysis of Variance showed no significant difference ($p<0.05$) in gum arabic yield between different diameter classes in the sites ($\chi^2=4.951$, $p=0.084$) implying that the diameter classes' assessment had no effect on the average yield of gum arabic per tree per season when all the four study sites are compared. However, gum arabic yield per tree per season varied significantly ($p<0.001$) between the basal diameter classes in Kulamawe and Ntumburi sites with small sized trees in diameter class (3.0-6.0 cm) producing higher yields than the other two diameter classes (6.1-9.0 cm and >9.0 cm). Big trees with a basal diameter greater than 9.0 cm for *A. senegal* varieties *leiorhachis* and *senegal* did not produce substantial amounts of gum arabic at all whether tapped or not tapped. On the other hand, the gum yield for *A. senegal* var. *kerensis* at Daaba and Ngare Ndare showed no

significant difference ($p<0.001$) among the three different basal diameter classes although Ngare Ndare had higher overall gum arabic yield than Daaba in all the diameter classes.

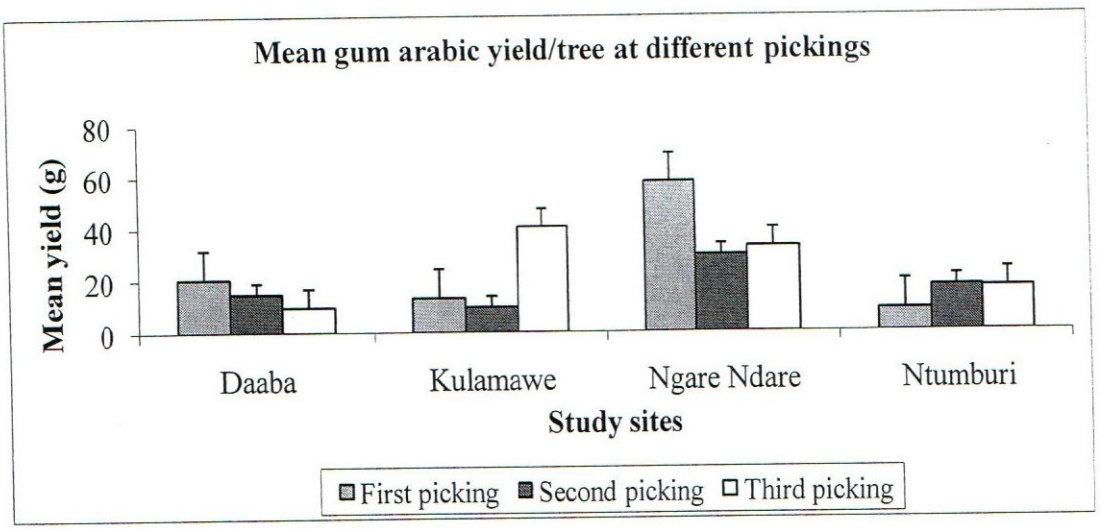
The interpretation of these results regarding prediction of gum arabic yield for *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* in view of basal diameter classes largely validates the idea that gum arabic yield is related to the size and/or age of the trees. In this connection, a series of linkages between factors affecting tree growth or gum arabic production and age of the tree might have caused trees of different sizes to yield different quantities of gum arabic. Other studies (ITC, 1983; Abdel Rahman, 2001) in contrast, have found that gum arabic yield is low in trees 5 to 10 years of age but increases to reach its peak at 15 years of age, and then decreases at the age of 20 years.

TEK based on experience of gum arabic collectors pointed out that small sized trees produce more gum arabic than bigger trees. Similarly, results of field experiments for the case of *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* revealed that trees in diameter class 3.0-6.0 cm yielded more gum arabic than those in diameter classes 6.1-9.0 and >9.0 cm hence validating the TEK report. However, for *A. senegal* var. *kerensis*, the diameter class did not affect the average gum arabic yield per tree per season and consequently deviates from TEK report that indicated that small sized *A. senegal* trees produced large amount of gum arabic than big sized trees.

The higher yield observed in small sized trees than big trees at Kulamawe (*A. senegal* var. *leiorhachis*) and Ntumburi (*A. senegal* var. *senegal*) can be attributed to the roots architecture of the trees. The number of fine root intersects in the surface soil layer depend on tree age and increases with tree age. Thus, tree root density of small sized trees decreases sharply with increasing soil depth, with most fine roots being found in the surface layers where they mainly utilize accumulated soil water content in the upper soil layer and hence not deep enough to reach deep water table as compared to big sized trees, which are deep rooted. As a result, small sized trees experience high water stress levels during the dry spell than big trees. Secondly, variation in gum arabic production in different diameter classes can be due to the differences in the rate of metabolic activities of the trees. Small sized trees are young and hence are still in active growth phase and are very sensitive to physiological changes especially due to change in soil water status.

4.10.6 Effect of pickings on gum arabic yield

A combined analysis for tapped and non-tapped trees shows that there was significant difference ($p<0.05$) in yield between different picking times in *A. senegal* varieties in the study sites ($\chi^2=7.119$, $p=0.028$). Generally, the mean gum arabic yield/tree irrespective of the treatment (tapping or non-tapping) and the tree part (stem or branch) at Daaba decreased from first picking to third picking while at Ngare Ndare, the yield decreased from first picking to second picking before slightly increasing in the third picking. Further, at Kulamawe, the yield decreased slightly from first picking to second picking and then increased sharply at third picking to reach the peak. The mean gum arabic yield at Ntumburi increased from first picking to second picking before remaining steady in the third picking (Figure 4.15).



Source: Field data (2009)

Figure 4.15: Mean gum yield/tree at different pickings. Bars indicate S.E.M (± 0.5)

The mean gum arabic yield trend per tree in the study sites was dependent on soil moisture. As the amount of moisture in the soil increased as observed earlier in Figure 4.9c of this study, the yield of gum arabic declined in all the study sites (Figure 4.15 above). The yield of gum arabic was also dependent on soil temperature whereby high soil temperature enhanced gum arabic yield. There is a directly proportional relationship between soil temperature and gum arabic yield, which is clearly revealed by soil temperature and gum arabic yield trends in Figures 4.9a and 4.15 of this study respectively. However, the atmospheric temperature

remained constant throughout the three pickings in all the study sites and therefore did have an impact on the yield of gum arabic at different pickings (See Figure 4.9b of this study).

4.10.6.1 Trends in gum arabic yield for tapped *A. senegal*

The trends on average gum arabic yield per tree for tapped trees collected from the stems and the branches of tapped trees and relating to the diameter class for the different varieties in the study sites are presented below (Table 4.13). The general average gum arabic yield trend of type of *A. senegal* variety or site for different basal diameter classes on trees' stems and branches at different pickings was quite different.

The findings in this study demonstrates that at Daaba (*A. senegal* var. *kerensis*), the average gum arabic yield/tree collected from tapped tree stems decreased from first picking to third picking for all the diameter classes. For diameter class (3.0-6.0 cm), the average yield was 3.0g, 1.6g and 1.3g for first, second and third pickings respectively while diameter classes 6.1-9.0 cm and >9.0 cm gave mean values of 4.3g, 2.9g and 0g and 4.8g, 3.8g and 1.5g for first, second and third pickings respectively. The branches, on the other hand showed a different trend for different diameter classes. In diameter class 3.0-6.0 cm, the second picking (2.0g) had the highest average yield followed by third picking (0.9g) whereas the first picking (0.2g) produced the least yield while for diameter class 6.1-9.0 cm, the average yield per tree increased with subsequent pickings with values of 0.2g, 0.7g and 1.7g for first, second and third pickings respectively. The average gum arabic yield from tapped branches of trees in class >9.0 cm at Daaba was highest in the first picking (4.2g), followed by third picking (1.7g) and then second picking (1.0g).

The average gum arabic yield at Ngare Ndare (*A. senegal* var. *kerensis*) from stems of tapped trees in diameter class 3.0-6.0 cm showed an increasing trend from first picking to third picking with values of 2.3g, 4.8g and 5.4g for first, second and third pickings respectively being recorded. However, a decreasing average yield per tree from first picking to third picking (9.0g, 7.0g and 6.9g respectively for first, second and third pickings) was observed on stems of tapped trees falling within 6.1-9.0 cm diameter class. The trend in diameter class >9.0 cm showed that first picking yielded more gum (10.5g) followed by third picking (5.0g), whereas second picking generated the least amount (2.8g) of gum arabic on tapped tree stems. In contrast, results of average gum arabic yield by the branches of tapped trees in diameter class 3.0-6.0 cm indicated that second picking (3.3g) yielded more gum than

first (1.5g) and second (1.8g) pickings. In the case of trees in diameter class 6.1-9.0 cm, the average branches' yield per tree was 12.9g, 0.6g and 1.9g for first, second and third pickings respectively. Gum arabic average yield on tree branches (diameter class >9.0 cm) decreased from first picking to third picking (11.2g, 2.9g and 2.7g) for first, second and third pickings respectively.

The average yield of gum arabic showed a clear trend in Kulamawe (*A. senegal* var. *leiorhachis*) for the tree stems in all the diameter classes. The average yield trend on tapped tree stems for diameter classes 3.0-6.0 cm, 6.1-9.0 cm and >9.0 cm decreased from the first picking (4.6g, 3.2g and 0.9g) to 3.9g, 2.1g and 0.7g in the second picking before it reached its peak in the third picking (7.2g, 7.5g and 7.9g) respectively. However, branches' average gum arabic yield showed inconsistent trend for different diameter classes. The branches' average gum arabic yield for diameter classes 3.0-6.0 cm and 6.1-9.0 cm decreased from the first picking (2.7g and 1.4g) to 1.2g and 1.2g in the second picking before it reached its peak in the third picking (4.1g and 5.0g) respectively. Tapped branches of trees in diameter class >9.0 cm did not produce any gum during first and second pickings but at third picking, an average yield of 1.4g/tree was collected from the tree branches.

The average yield of gum arabic showed no clear trend at Ntumburi (*A. senegal* var. *senegal*) for both tapped tree stems and branches in the entire diameter classes. The average yield trend in tapped tree stems for diameter class 3.0-6.0 cm decreased from the first picking (3.5g) to 2.1g in the second picking before slightly decreasing again in the third picking (3.3g). The trend was however, different for diameter class 6.1-9.0 cm whereby the average gum arabic yield per tree on tree stems increased from 2.4g in the first picking to 12.5g in the second picking before slightly falling to 9.0g at third picking. The tapped stems for trees in diameter class >9.0 cm yielded no gum in first and second pickings before producing an average amount of 0.7g at third picking. The branches' average yield showed different trends for different diameter classes. The branches' average gum arabic yields for diameter class 3.0-6.0 cm increased from 0.0g in first picking to 2.0g during the second picking before falling to 1.1g in the third picking. On the other hand, trees in diameter class 6.1-9.0 cm, showed that the yield increased from the first picking (0.0g) to 0.8g in the second picking before it reached its peak in the third picking (1.4g). Tapped branches of *A. senegal* var. *senegal* trees in diameter class >9.0 cm did not produce any gum during first, second third pickings.

Table 4.13: Trends of gum arabic yield for tapped *A. senegal*

		Mean gum yield/tree/season (g)								
		Basal Diameter (BD) Classes (cm)								
		3.0-6.0 cm			6.1-9.0 cm			>9.0 cm		
Site	**Tree part**	1st picking	2nd picking	3rd picking	1st picking	2nd picking	3rd picking	1st picking	2nd picking	3rd picking
	Stems	3	1.6	1.3	4.3	2.9	0	4.8	3.8	1.5
Daaba	Branches	0.2	2	0.9	0.2	0.7	1.7	4.2	1	1.7
	Stems	2.3	4.8	5.4	9	7	6.9	10.5	2.8	5
Ngare Ndare	Branches	1.5	3.3	1.8	12.9	0.6	1.9	11.2	2.9	2.7
	Stems	4.6	3.9	7.2	3.2	2.1	7.5	0.9	0.7	7.9
Kulamawe	Branches	2.7	1.2	4.1	1.4	1.2	5	0	0	1.4
	Stems	3.5	2.1	3.3	2.4	12.5	9	0	0	0.7
Ntumburi	Branches	0	2	1.1	0	0.8	1.4	0	0	0

Source: Field data (2009)

4.10.6.2 Trends in gum arabic yield for non-tapped *A. senegal*

The trends on average gum arabic yield per tree for non-tapped trees collected from the stems and the branches of untapped trees and relating to the diameter class for the different varieties of *A. senegal* in the study sites are presented in Table 4.14. The general average gum arabic yield trend of type of *A. senegal* variety or site for different basal diameter classes on the trees' stems and branches at different pickings was to a certain extent different.

The findings in this study showed that at Daaba (*A. senegal* var. *kerensis*), the average gum arabic yield/tree collected from untapped stems of trees in diameter class (3.0-6.0 cm) was 0.8g, 0.9g and 1.4g for first, second and third pickings respectively. Moreover, the diameter classes 6.1-9.0 cm and >9.0 cm gave average gum arabic yield values of 2.1g, 1.0g and 1.2g and 0.9g, 1.0g and 0.0g for first, second and third pickings respectively. The branches, on the other hand yielded no gum arabic in all the diameter classes for the three pickings.

The average gum arabic yield at Ngare Ndare (*A. senegal* var. *kerensis*) from stems of untapped trees in diameter classes 3.0-6.0 cm and 6.1-9.0 cm showed a decreasing trend from first picking (1.6g and 3.6g) to second picking (0.0g and 0.6g) before slightly increasing to 1.2g and 1.3g in the third picking respectively. The trend was different in diameter class >9.0 cm where the yield increased from first picking (2.2g) to 7.1g in second picking before slightly decreasing to 4.3g at third picking. Conversely, the branches of untapped trees in diameter class 3.0-6.0 cm yielded no gum arabic in the first and second pickings but third picking yielded little gum arabic (0.8g). In diameter classes (6.1-9.0 cm and >9.0 cm), the average branches' yield showed an increasing trend of 0.0g, 0.5g and 1.1g and 0.0g, 0.4g and 1.1g for first, second and third pickings respectively.

The average yield of gum arabic showed no clear trend in Kulamawe (*A. senegal* var. *leiorhachis*) for stems of untapped trees for the different diameter classes. The average yield trend on stems for diameter class 3.0-6.0 cm increased from first picking to third picking as represented by 0.0g, 0.3g and 2.7g for first, second and third pickings respectively. Untapped stems of trees in diameter class 6.1-9.0 cm did not yield gum arabic at all while the stems of untapped trees in class >9.0 cm produced gum arabic during third picking (2.5g). The tree branches' average gum arabic yield also showed no clear trend for the three diameter classes. The branches' average gum arabic yield for diameter class 3.0-6.0 cm decreased from the

first pick (0.4g) to 0.3g in the second picking before it reached 0.0g mark at third picking whereas class 6.1-9.0 cm had an increasing yield trend of 0.0g, 0.7g and 2.5g for first, second and third pickings respectively. Untapped branches of trees in diameter class >9.0 cm did not produce gum arabic in the entire three pickings.

The average yield of gum arabic at Ntumburi (*A. senegal* var. *senegal*) for untapped tree stems in diameter class 3.0-6.0 cm was highest in the first picking (2.7g) with third picking in this diameter class producing 1.4g which is almost half of the amount in the first picking. There were no gum arabic exudates in the second picking on tree stems in this particular diameter class. Untapped stems of trees in diameter classes (6.0-9.0 cm and >9.0 cm) failed to produce any gum arabic at all. In the case of untapped *A. senegal* tree branches; no gum arabic was produced in this study site in all the three diameter classes.

Table 4.14: Trends of gum arabic yield for non-tapped *A. senegal*

		Mean gum yield/tree/season (g)								
		Basal Diameter (BD) Classes (cm)								
		3.0-6.0 cm			6.1-9.0 cm			>9.0 cm		
Site	**Tree part**	1st picking	2nd picking	3rd picking	1st picking	2nd picking	3rd picking	1st picking	2nd picking	3rd picking
Daaba	Stems	0.8	0.9	1.4	2.1	1	1.2	0.9	1	0
	Branches	0	0	0	0	0	0	0	0	0
Ngare Ndare	Stems	1.6	0	1.2	3.6	0.6	1.3	2.2	7.1	4.3
	Branches	0	0	0.8	0	0.5	1.1	2.9	0	0.4
Kulamawe	Stems	0	0.3	2.7	0	0	0	0	0	2.5
	Branches	0.4	0.3	0	0	2.2	0.7	0	0	0
Ntumburi	Stems	2.7	0	1.4	0	0	0	0	0	0
	Branches	0	0	0	0	0	0	0	0	0

Source: Field data (2009)

4.10.7 Quantification of gum arabic yield per unit area

The density of *A. senegal* influenced the average yield of gum arabic per tree per season. The findings in this study have established that high density of *A. senegal* var. *kerensis*, the main species producing commercial gum arabic in Kenya caused low average gum arabic yield per tree per season while low density resulted into high gum arabic production per tree per season (Table 4.15). Thus, at Ngare Ndare where the density of *A. senegal* var. *kerensis* was low (196 sph), the average gum arabic yield per tree per season was high (5.15g). In contrast, at Daaba, the density of *A. senegal* var. *kerensis* was high (259 sph) but the average yield of gum arabic per tree per season was low (1.95g). Other related studies in Sudan (Ballal *et al.*, 2005) for *A. senegal* var. *senegal* grown in plantations and which is the main species for commercial gum arabic in the Sudan have found that the average gum arabic yield per tree per season was high at higher densities.

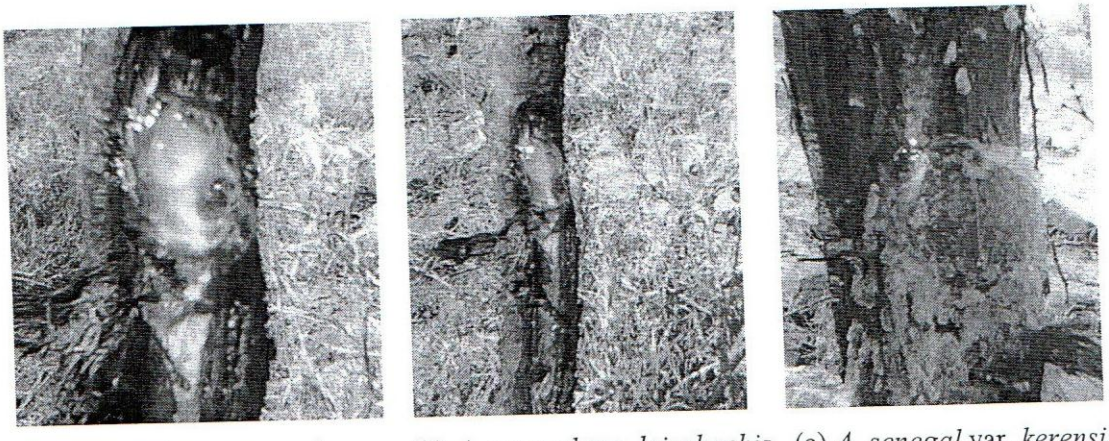
The high yield of gum arabic per tree per season at Ngare Ndare where the density of *A. senegal* var. *kerensis* was low can be attributed to less competition among the trees for important resources required for growth and especially the soil moisture, which is critical for gum arabic production. In contrast, at Daaba, the competition for soil moisture is high because of high density of *A. senegal* var. *kerensis* and hence, the trees do not get adequate moisture to facilitate the process of gum arabic formation and the subsequent production. Correspondingly, an earlier report in this study on TEK indicated that drought and unreliable rainfall reduced gum arabic yield considerably.

The mean gum arabic yield per ha per season of 1.009kg for *A. senegal* var. *kerensis* at Ngare Ndare was the highest followed by 0.505kg at Daaba for the similar variety (Table 4.15). Ntumburi (*A. senegal* var. *senegal*) yielded the least quantity (0.366kg). Assuming that the yield of gum arabic is even for each production season and with two seasons per year, the yield per ha per year for *A. senegal* var. *kerensis* for Ngare Ndare, Daaba and Ntumburi is 2.018kg, 1.11kg and 0.732kg respectively. Thus, present study results imply that the yield is very low and diverge from a report by ITC (1983) that gum arabic yield per ha per year ranges between 30 to 40 kg in case of open stands of *A. senegal* and as much as 100 kg in the case of dense stands.

Table 4.15: *A. senegal* density and gum arabic yield/season/hectare

	Tapped *A. senegal*			Non-tapped *A. senegal*		
Site	Average gum arabic yield/tree (g)	Number of sph	Gum arabic yield/ha (kg)	Average gum arabic yield/tree (g)	Number of sph	Gum arabic yield/ha (kg)
Daaba	1.95	259	0.505	0.52	259	0.135
Ngare Ndare	5.15	196	1.009	1.52	196	0.298
Kulamawe	3.05	123	0.375	0.75	123	0.092
Ntumburi	2.15	170	0.366	0.23	170	0.039

Source: Field data (2009)



(a) *A. senegal* var. *senegal* (b) *A. senegal* var. *leiorhachis* (c) *A. senegal* var. *kerensis*

Plate 3: Gum arabic exudates from tapped *A. senegal*

4.11 Gum arabic quality

The physicochemical properties of gum arabic studied included moisture content, absolute viscosity, specific/optical rotation, nitrogen content and pH. These properties are the main quality indices set to characterize the nature and quality of gum arabic. Since international trade in gum arabic requires rigorous quality control specifications to identify the quality of the product, it is essential that quality parameters be established for gum arabic derived from different varieties of *A. senegal*. This study evaluated analytical data of gum arabic samples from three varieties of *A. senegal* (var. *senegal*, var. *kerensis* and var. *leiorhachis*) from four different sites in order to set specifications to characterize this important commodity of trade internationally.

4.11.1 Quality of gum arabic of different varieties of *A. senegal*

Evaluation of gum arabic carried out in this study for the three varieties of *A. senegal* growing naturally in Isiolo District of Kenya against international specifications and gum arabic characteristics from known destinations such as Sudan and Tanzania and results of previous studies reported in Kenya by Chikamai and Banks (1993) and Lelon (2008) has shown differences in the physicochemical characteristics of gum arabic. The physicochemical properties for gum arabic samples are presented in Table 4.16.

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Table 4.16: Physicochemical properties of gum arabic of *A. senegal* varieties

Site	Gum arabic quality characteristics[a]				
	Optical rotation (degrees)**	Nitrogen content (%)**	Moisture content (%)**	Absolute viscosity (cP)***	pH****
Daaba	25.5a	0.30a	9.15a	383.7a	4.58a
Kulamawe	25.1a	0.17b	8.83a	114.9b	4.53a
Ngare Ndare	21.8b	0.23c	12.09b	666c	4.24b
Ntumburi	22.6b	0.17b	11.16b	376a	4.43a
S.E.D	0.96	1.67	1.037	4.5	0.0683
F- value	7.26	2.76	0.787	5008.12	9.89
P-value	0.011	0.034	<0.001	<0.001	0.005
%CV	5	2.8	24.9	1.4	1.9
S.E	1.18	0.96	2.54	5.51	0.08

Source: Field data (2009)

*Any means in the same column having a common letter are not significantly different

**Significantly different at $p<0.05$

***Significantly different at $p<0.001$

****Significantly different at $p<0.01$

[a] Means of three replicates

4.11.1.1 Moisture content in gum arabic

Moisture content analysis of gum arabic samples showed moisture content value of less than 15% for all the three varieties of *A. senegal*. However, a significant difference ($p<0.001$) in gum arabic moisture content between the varieties existed. Gum arabic from *A. senegal* var. *kerensis* at Daaba was characterized by low moisture content (9.15%) compared to the same variety at Ngare Ndare (12.09%). These values diverge considerably from 14.7% and 15.4% reported in other related studies by Chikamai and Banks (1993) and (Lelon, 2008) respectively for gum arabic from *A. senegal* var. *kerensis*.

Gum arabic from *A. senegal* var. *senegal* had moisture content value of 11.16%, which is different from values of 15% and 14.9%, assigned to gum arabic from *A. senegal* var. *senegal* in Sudan and Kenya respectively by several authors including Idris *et al.* (1998) and Karamalla *et al.* (1998) and Lelon (2008). However, the current results compares well with previous results reported by FAO (1996) for authentic (10.6%) and commercial (11.6%) gum arabic samples for *A. senegal* var. *senegal* in Sudan.

Gum arabic from *A. senegal* var. *leiorhachis* exhibited the least moisture content (8.83%) compared to gum arabic of *A. senegal* var. *senegal* (11.6%) and the overall mean value for gum arabic of *A. senegal* var. *kerensis* at Daaba and Ngare Ndare (10.62%). The moisture content value (8.83%) was lower than (13.8%) reported in similar studies undertaken in Tanzania for gum arabic from *A. senegal* var. *leiorhachis* by Mhinzi and Mrosso (1997).

4.11.1.2 Absolute viscosity of gum arabic

The absolute viscosity of gum arabic from *A. senegal* var. *kerensis* at Ngare Ndare (666 centipoises) was significantly higher ($p<0.001$) than that of gum arabic collected from *A. senegal* var. *kerensis* at Daaba (383.7 centipoises) at the same concentration of 25% or 250 grams per litre (g/l). Gum arabic samples collected from *A. senegal* var. *senegal* at Ntumburi had an absolute viscosity of 376 centipoises (cP), a value that was not significantly different ($p<0.01$) from that of gum arabic obtained at Daaba although the varieties are different. Gum arabic of *A. senegal* var. *leiorhachis* was the least viscous with an absolute viscosity of 114.9 centipoises (cP). This value compares well with 110 centipoises (cP) reported by Karamalla *et al.* (1998) for gum arabic from *A. senegal* var. *senegal* in Sudan though the varieties are different. Thus, the present findings approves earlier results reported by Chikamai and Banks (1993) that gum arabic from *A. senegal* var. *kerensis* is of high viscosity and further showed

that gum arabic from *A. senegal* var. *kerensis* is more viscous than gum arabic from *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis*. Consequently, absolute viscosity can be used to predict the origin of gum arabic in relation to *A. senegal* variety.

4.11.1.3 Specific/optical rotation of gum arabic

The specific/optical rotation values of gum arabic from *A. senegal* varieties are remarkably different. The specific/optical rotation values of gum arabic samples of the three varieties of *A. senegal* were significantly different ($p<0.05$). Specific/optical rotation of for gum arabic collected from *A. senegal* var. *senegal* at Ntumburi was -22.60°. Thus, the specific/optical rotation value of gum arabic from *A. senegal* var. *senegal* (-22.60°) in this study contrasts with what has been reported for Sudanese gum arabic from *A. senegal* var. *senegal* of -30° (Anderson *et al.*, 1983) and -35° (Karamalla *et al.*, 1998). Correspondingly, the specific/optical rotation value of -22.60° contrasts with the value of -25° that has been reported for Tanzanian gum arabic from *A. senegal* var. *senegal* (Mhinzi and Mrosso, 1997). The differences between specific/optical value obtained in this particular work and the value reported for Tanzania is however not large and hence comparable.

The least negative specific/optical rotation (-21.78°) was that of gum arabic collected from *A. senegal* var. *kerensis* at Ngare Ndare and the highest value (-25.52°) was found in *A. senegal* var. *kerensis'* gum arabic collected from Daaba (Table 4.16). In the present findings, gum arabic from *A. senegal* var. *kerensis* at Ngare Ndare has been found to have less negative specific/optical rotation (-21.78°) than gum arabic of *A. senegal* var. *kerensis* at Daaba (-25.52°). The specific/optical rotation values of gum arabic obtained from Ngare Ndare and Daaba for *A. senegal* var. *kerensis* were significantly lower than the value of -33° previously reported by Chikamai and Banks (1993) for gum arabic samples collected from *A. senegal* var. *kerensis* in different sites in Isiolo District, Kenya.

Gum arabic collected from *A. senegal* var. *leiorhachis* at Kulamawe had a specific/optical rotation value of -25.05°. This value is lower than (-50°) reported by Mhinzi and Mrosso (1997) for *A. senegal* var. *leiorhachis* in Tanzania. It is interesting to note that the specific/optical rotation value of gum arabic from *A. senegal* var. *leiorhachis* and *A. senegal* var. *kerensis* at Daaba was not significantly different ($p<0.05$) but significantly different ($p<0.05$) from the specific/optical rotation value of gum arabic from *A. senegal* var. *kerensis* at Ngare Ndare.

4.11.1.4 Nitrogen content in gum arabic

Nitrogen content is considered as one of the very useful parameters in distinguishing the quality of gum arabic from different *A. senegal* varieties (Anderson, 1976; 1977). In fact, (FAO, 1990) introduced the specification for nitrogen content (0.26%-0.39%) in the definition of gum arabic to ensure identity, quality and purity of gum arabic. The nitrogen content in gum arabic of the three varieties differed significantly ($p<0.05$). Besides, the nitrogen content in gum arabic from *A. senegal* var. *kerensis* at Daaba and Ngare Ndare was significantly different ($p<0.05$). The nitrogen content in gum arabic from *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* at Ntumburi and Kulamawe respectively was not significantly different ($p<0.05$). The nitrogen content of the gum arabic samples of *A. senegal* var. *kerensis* (0.30%) at Daaba was found to be significantly higher ($p<0.05$) than that of *A. senegal* var. *kerensis* gum arabic (0.23%) at Ngare Ndare (Table 4.16).

Nitrogen content in gum arabic of *A. senegal* var. *kerensis* at Daaba was in the range of 0.26%-0.39% as specified by FAO (1990) and comparable to the value reported in Sudan for *A. senegal* var. *senegal* by Karamalla *et al.* (1998) of 0.35% and FAO (1996) of 0.32%. However, this nitrogen content value was lower than 0.34% earlier reported for gum arabic from *A. senegal* var. *kerensis* (Lelon, 2008). Similarly, the value is in contrast with what was reported by Chikamai and Banks (1993) who found nitrogen content values of 0.40%, 0.43%, 0.50% and 0.42% for gum arabic samples collected from *A. senegal* var. *kerensis* in Isiolo, Ngurunit, Kargi and Turkana respectively. Thus, the present study results revealed that there was a decrease of nitrogen content (0.23%) in gum arabic from *A. senegal* var. *kerensis* at Ngare Ndare with a significant magnitude from earlier results of Chikamai and Banks (1993) of 0.40% for gum arabic collected from Isiolo District, Kenya.

Gum arabic from *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* has been found in this study to have a slightly lower level of nitrogen compared with gum arabic from *A. senegal* var. *kerensis* with a value of 0.17% being observed for both varieties (*A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis*) found in Ntumburi and Kulamawe respectively. Thus, the nitrogen content in gum arabic from *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* growing naturally in Kenya compares well.

The nitrogen content value of gum arabic from *A. senegal* var. *leiorhachis* (0.17%) found in this study differs with the value of gum arabic from *A. senegal* var. *leiorhachis* (0.44%) in

Tanzania as previously reported in related studies by Mhinzi and Mrosso (1997). This reflects a distant relationship between the identical variety of *A. senegal* inhabiting different geographical locations.

The nitrogen content of gum arabic from *A. senegal* var. *senegal* was 0.17%. This value differs from the results of other studies undertaken by Mhinzi and Mrosso (1997) in Tanzania of 0.33% for the same variety. The present study results are also in contrast with results by FAO (1996) and Karamalla *et al.* (1998) who reported nitrogen content values of 0.32% and 0.35% respectively for gum arabic from *A. senegal* var. *senegal* in Sudan. Furthermore, Lelon (2008) indicated that gum arabic of *A. senegal* var. *senegal* in Baringo District, Kenya had nitrogen content value of 0.28%, which again differs from 0.17%, reported in this study. The differences observed in gum arabic nitrogen content within *A. senegal* var. *kerensis* in Kenya and between *A. senegal* var. *senegal* in Kenya, Tanzania and Sudan can be attributed to geographical differences and environmental factors such as climate and soil conditions as earlier reported by Chikamai (1997).

4.11.1.5 Gum arabic pH

The pH of gum arabic samples from the three varieties of *A. senegal* was significantly different ($p<0.01$). The analyzed samples of gum arabic from all the study sites were slightly acidic. The measured pH values were 4.58, 4.53, 4.24 and 4.43 for gum arabic from Daaba, Kulamawe, Ngare Ndare and Ntumburi respectively. These values are in agreement with reported pH values of gum arabic in other related studies by several authors such as Mhinzi (2003), Chikamai (1997), Lelon (2008) and Karamalla *et al.* (1998).

The difference in the quality parameters of gum arabic of *A. senegal* var. *kerensis* in Daaba and Ngare Ndare could be due to individual tree differences as well as differences in the provenances and environmental factors such as climatic and soil conditions as suggested by Chikamai (1997) and FAO (1995). Another possible cause of the difference in quality might be the variation in the genetic composition of different populations of *A. senegal* var. *kerensis*. A recent study by Omondi (2009) on the genetic structure and diversity of Kenyan populations of *A. senegal* var. *kerensis* revealed that although the geographical distance between Ngare Ndare and Daaba is close, approximately 45 kilometers on a straight line, genetic distance between the two populations is far apart. In fact, the neighbor-joining

topology grouped the two populations of *A. senegal* var. *kerensis* in two different main groups.

4.11.2 Quality of Kenyan gum arabic against international specifications

The comparison between the quality of gum arabic collected from the three varieties of *Acacia senegal* growing in the ASALs of Kenya and more specifically Isiolo District and international standard requirements as set up by FAO (1990) is shown below (Table 4.17).

Table 4.17: Comparison between properties of gum arabic of *A. senegal* varieties and international specifications

	Sites/Quality standard				
Physicochemical properties	**Daaba[a]**	**Kulamawe[b]**	**Ngare Ndare[a]**	**Ntumburi[c]**	**International specifications[d]**
Specific/optical rotation (degrees)	-25.52	-25.06	-21.78	-22.60	-26 to -34
Absolute viscosity (cP)[e]	383.7	114.9	666	376	75-110
Nitrogen (%)	0.30	0.17	0.23	0.17	0.27-0.39
pH	4.58	4.53	4.24	4.43	4.2-4.8
Moisture (%)	9.15	8.83	12.09	11.16	<15

[a] *A. senegal* var. *kerensis* [b] *A. senegal* var. *leiorhachis* [c] *A. senegal* var. *senegal* [d] (FAO, 1990) [e] Concentration of 250g/l

Source: Field data (2009)

Tanzania as previously reported in related studies by Mhinzi and Mrosso (1997). This reflects a distant relationship between the identical variety of *A. senegal* inhabiting different geographical locations.

The nitrogen content of gum arabic from *A. senegal* var. *senegal* was 0.17%. This value differs from the results of other studies undertaken by Mhinzi and Mrosso (1997) in Tanzania of 0.33% for the same variety. The present study results are also in contrast with results by FAO (1996) and Karamalla *et al.* (1998) who reported nitrogen content values of 0.32% and 0.35% respectively for gum arabic from *A. senegal* var. *senegal* in Sudan. Furthermore, Lelon (2008) indicated that gum arabic of *A. senegal* var. *senegal* in Baringo District, Kenya had nitrogen content value of 0.28%, which again differs from 0.17%, reported in this study. The differences observed in gum arabic nitrogen content within *A. senegal* var. *kerensis* in Kenya and between *A. senegal* var. *senegal* in Kenya, Tanzania and Sudan can be attributed to geographical differences and environmental factors such as climate and soil conditions as earlier reported by Chikamai (1997).

4.11.1.5 Gum arabic pH

The pH of gum arabic samples from the three varieties of *A. senegal* was significantly different ($p<0.01$). The analyzed samples of gum arabic from all the study sites were slightly acidic. The measured pH values were 4.58, 4.53, 4.24 and 4.43 for gum arabic from Daaba, Kulamawe, Ngare Ndare and Ntumburi respectively. These values are in agreement with reported pH values of gum arabic in other related studies by several authors such as Mhinzi (2003), Chikamai (1997), Lelon (2008) and Karamalla *et al.* (1998).

The difference in the quality parameters of gum arabic of *A. senegal* var. *kerensis* in Daaba and Ngare Ndare could be due to individual tree differences as well as differences in the provenances and environmental factors such as climatic and soil conditions as suggested by Chikamai (1997) and FAO (1995). Another possible cause of the difference in quality might be the variation in the genetic composition of different populations of *A. senegal* var. *kerensis*. A recent study by Omondi (2009) on the genetic structure and diversity of Kenyan populations of *A. senegal* var. *kerensis* revealed that although the geographical distance between Ngare Ndare and Daaba is close, approximately 45 kilometers on a straight line, genetic distance between the two populations is far apart. In fact, the neighbor-joining

topology grouped the two populations of *A. senegal* var. *kerensis* in two different main groups.

4.11.2 Quality of Kenyan gum arabic against international specifications

The comparison between the quality of gum arabic collected from the three varieties of *Acacia senegal* growing in the ASALs of Kenya and more specifically Isiolo District and international standard requirements as set up by FAO (1990) is shown below (Table 4.17).

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Table 4.17: Comparison between properties of gum arabic of *A. senegal* varieties and international specifications

Physicochemical properties	Sites/Quality standard				
	Daaba[a]	Kulamawe[b]	Ngare Ndare[a]	Ntumburi[c]	International specifications[d]
Specific/optical rotation (degrees)	-25.52	-25.06	-21.78	-22.60	-26 to -34
Absolute viscosity (cP)[e]	383.7	114.9	666	376	75-110
Nitrogen (%)	0.30	0.17	0.23	0.17	0.27-0.39
pH	4.58	4.53	4.24	4.43	4.2-4.8
Moisture (%)	9.15	8.83	12.09	11.16	<15

[a] *A. senegal* var. *kerensis* [b] *A. senegal* var. *leiorhachis* [c] *A. senegal* var. *senegal* [d] (FAO, 1990) [e] Concentration of 250g/l

Source: Field data (2009)

The results of this study show that a number of quality characteristics of gum arabic for the three varieties of *A. senegal* in the four study sites complied with international standard quality requirements for the five specifications tested as set up by FAO (1990) while others did not as shown in Table 4.17 above. This is because out of the five quality indicators tested for gum arabic of *A. senegal* var. *kerensis* at Daaba, four of them (pH, moisture and nitrogen content and specific/optical rotation) fall within FAO (1990) requirements implying that its quality is reasonably good for industrial application in pharmaceutical and food industries. Gum arabic collected from *A. senegal* var. *kerensis* at Ngare Ndare is of very high absolute viscosity, has less negative optical/specific rotation and its nitrogen content falls short of the FAO (1990) specifications by 0.04% and thus, the grade of the gum can be classified as being of low quality.

Gum arabic from *A. senegal* var. *senegal* has less negative optical/specific rotation, high absolute viscosity and low nitrogen content compared to international specifications (FAO, 1990) and as such, the quality is also low. Gum arabic of *A. senegal* var. *leiorhachis* did not conform to FAO (1990) specifications due its high absolute viscosity, slightly less negative optical/specific rotation and low nitrogen content.

The present study suggests that the major problem subordinating the quality of gum arabic of the three varieties of *A. senegal* is high absolute viscosity. An earlier report by Chikamai and Banks (1993) concluded that gum arabic from *A. senegal* var. *kerensis* has higher viscosity. This study assertively confirms the results of the two authors and goes further to reveal that gum arabic of *A. senegal* var. *leiorhachis* too has high absolute viscosity. Low nitrogen content is another serious factor singled out during this study affecting gum arabic quality especially in *A. senegal* var. *leiorhachis*. The pH and moisture content values of gum arabic for the three varieties of *A. senegal* were within the stipulated range as per international specifications set up by FAO (1990).

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

This study showed that traditional ecological knowledge was widely employed by the local communities namely the Turkana, Samburu, Borana and Somali in the management and conservation of *A. senegal* tree resources on sustainable basis thereby promoting gum arabic production. Gum arabic is sold to generate income while at the same time, it is consumed in its raw form in times of hunger by the locals. *A. senegal* is also used for fuel wood, fodder, fencing materials, human medicine and conserves the environment.

The usefulness of traditional ecological knowledge in natural *A. senegal* resource management should be viewed from the aspect of realizing its limitations such as the local way of inducing gum arabic production by injuring the trees' stems and branches with stones and building on this limitation to improve *A. senegal* resource management by introducing proper tapping procedure using recommended tools like the sonke to enhance gum arabic productivity.

The density of *A. senegal* varied between and within *A. senegal* varieties. The present study demonstrates that *A. senegal* var. *kerensis* exhibit high densities than *A. senegal* varieties *leiorhachis* and *senegal*. Moreover, the density of *A. senegal* var. *kerensis* at Daaba was high than at Ngare Ndare.

These results reveal that different varieties of *A. senegal* yield varying amount of gum arabic. Further, there is a difference in the quantities of gum arabic produced by trees of a similar variety occupying different geographical locations or sites. Generally, *A. senegal* var. *kerensis* ranked higher compared to the *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* in average gum arabic yield per tree per season. As a result *A. senegal* var. *kerensis* remains the main source of commercial gum arabic in Kenya.

A key result in the present study was that tapping of *A. senegal* varieties stimulated gum arabic production and increased the yield by over 77.42% when compared with collection

through natural exudation. When tapped, *A. senegal* trees' stems produce more gum arabic than the tree branches in all the three varieties.

Gum arabic production process in *A. senegal* was highly influenced by soil temperature and the moisture content in the soil. A positive relationship existed between soil temperature and gum arabic yield with high soil temperatures enhancing high gum arabic yield. Conversely, a decrease in soil moisture caused *A. senegal* trees to produce more gum arabic whereas high soil moisture levels reduce gum arabic yield.

The size and age of *A. senegal* trees influenced gum arabic yield per tree per season for *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* with trees in basal diameter class 3.0-6.0 cm producing more gum arabic than their counterparts in diameter classes 6.0-9.0 cm and >9.0 cm. On the other hand, *A. senegal* var. *kerensis* produced almost the same average gum arabic yield per tree per season irrespective of the diameter class.

The density of *A. senegal* influenced the average yield of gum arabic per tree per season. The findings in this study have established that high density of *A. senegal* var. *kerensis*, the main species producing commercial gum arabic in Kenya resulted into low average gum arabic yield per tree per season while low density resulted into high gum arabic production per tree per season.

Results obtained in this study show that the first gum arabic picking appears to be an important factor in gum arabic production and could be used as an indicator for the prediction of the total mean gum arabic yield per tree per season for *A. senegal* var. *kerensis* at Ngare Ndare and Daaba. This is because the first picking yielded more gum arabic than the second and third pickings for *A. senegal* var. *kerensis* at Ngare Ndare and Daaba. Conversely, for *A. senegal* var. *leiorhachis*, third picking yielded high quantity of gum arabic than first and second pickings and can therefore be used in providing a good hint of gum arabic yield per tree per season for this variety. The quantity of gum arabic collected from *A. senegal* var. *senegal* during the three pickings was highest in the second picking and therefore, the second picking can be used to provide an estimate of average gum arabic yield per tree in a single season.

Thus, the findings of the present study, with respect to yield levels and trends, could be used to estimate gum arabic yield per picking, per tree, per season and per unit area in natural stands for the three different varieties of *A. senegal*. This could help in overcoming the instability and decline in gum arabic production that have been described as the main problems facing the gum arabic industry in Kenya. In addition, the present results bridges the gap on information related to the effects of soil moisture and soil temperature on gum arabic yield and yield trends.

Apart from the pH that indicated gum arabic from the three varieties of *A. senegal* was slightly acidic, results of this study reveals that the three varieties produce gum arabic with different physicochemical properties. The properties of the gum arabic exudate from *A. senegal* var. *leiorhachis* at Kulamawe differ from that obtained from *A. senegal* var. *kerensis* at Daaba and Ngare Ndare widely known as the source of commercial gum arabic in Kenya by being much less viscous and having lower proportions of moisture and nitrogen contents.

The properties of gum arabic exudates from *A. senegal* var. *kerensis* at Ngare Ndare and those of gum arabic of *A. senegal* var. *kerensis* at Daaba are quite different. At Ngare Ndare, gum arabic is much more viscous and has high proportion of moisture content than at Daaba. However, gum arabic collected from Daaba has more percentage of nitrogen.

Notable differences were also observed in this study between the properties of gum arabic from *A. senegal* var. *senegal* which is the main source of commercial gum arabic in the Sudan and *A. senegal* var. *leiorhachis* gum arabic. Gum arabic from *A. senegal* var. *senegal* has a high moisture content, a less negative optical/specific rotation and significantly more viscous than that of *A. senegal* var. *leiorhachis*; nonetheless, the nitrogen content was similar.

Gum arabic of *A. senegal* var. *senegal* has lower nitrogen content, higher moisture content and less negative optical/specific rotation compared with gum arabic from *A. senegal* var. *kerensis* from Daaba but there is no considerable difference in absolute viscosity. However, the gum is less viscous, has less moisture content and lower nitrogen content than that of *A. senegal* var. *kerensis* from Ngare Ndare.

5.2 Recommendations

i) There is need to integrate both TEK and scientific ecological principles for effective management and conservation of *A. senegal* resources for increased gum arabic production.

ii) There is need to facilitate the transfer and exchange of ideas, information, experiences and practices associated with TEK in the management of *A. senegal* resources and gum arabic production among relevant stakeholders in the sector.

iii) A special tapping tool known as the sonke should be used for tapping because it causes less injury to the trees' cambium cells and gum arabic produced as a result of tapping using this tool (the sonke) is free from impurities, clean and therefore of good quality. Besides, the sonke allows the tapper to reach the branches, which are high up the tree with ease as it is fitted with a long wooden handle.

iv) Further research should be done to assess the effect of tapping intensity on gum arabic yield *A. senegal* found growing in natural stands. The yield assessment should also be carried out for several seasons to ascertain the effect of seasonal factors such as variation in rainfall on gum arabic yield.

v) The influence of different tapping dates/time on gum arabic yield should be studied to determine the best tapping dates/time.

vi) Finally, further research should also be carried out to establish the optimum level of soil moisture and soil temperature at which gum arabic production by *A. senegal* varieties reaches the peak before starting to decline.

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APPENDICES

Appendix i

Households Questionnaire

DEMOGRAPHIC INFORMATION

1. Name of household head.....
2. Name of Respondent.....Age.....
3. Sub-location.....Location.....Division.....
4. Marital status.....Level of Education .....
5. Sex.....Family size.....
6. Occupation.....

MANAGEMENT OF *Acacia senegal* RESOURCES

7. Which organizations/Departments are involved in the management of *A. senegal* in this area? .....
8. What Management practices are performed on *A. senegal* trees?
   a) Natural/Wild [ ]
   b) Others (specify) [ ]
9. How do you conserve and encourage natural regeneration of *A. senegal* trees in this area?
   a) Temporary homesteads [ ]
   b) Movement of livestock [ ]
   c) Local by-laws [ ]
   d) Collecting dead wood materials [ ]
   e) Others (specify) [ ]

GUM COLLECTION, TAPPING AND QUALITY

10. How many family members are involved in gum arabic collection?
    Fulltime.....Part-time.....Total.....
11. Which specific areas/sites produce the high quality gum?
    a) Rocky/Hilly areas { }
    b) Plain areas { }
    c) Others (specify) { }

12. What criteria do you use to select trees for gum tapping?

a) Age { }

b) Size { }

c) Number of branches { }

d) Others (specify) { }

13. Do you collect? 1. Tapped gum [ ] 2. Natural exudates [ ] 3. Both [ ]

14. If you tap, please describe the process briefly.....

15. Which tools do you use in tapping and collection of the gum? And why?

Tool	Use/Reason
1.	
2.	
3.	

16. Which periods of the year do you tap and/or collect the gum? (Specify the month).....

17. Why this period? Explain .....

18. Does gum arabic yield fluctuate through the year and between years? If yes why?.....

19. How is the collection organized? 1. Groups [ ] / 2. Individual [ ]

20. What quantity of gum does a collector harvest per day in kg?.....

21. What is the price of gum in this area in Kshs?.....

22. Which other gums and resins are harvested in this area? .....

THE IMPORTANCE OF *Acacia senegal* TREE RESOURCES

23. Generally, are *Acacia senegal* trees important to you?

.....

24. Which other products do you get from *A. senegal* trees? How are these products used?

Product	Domestic use	Commercial use
a) Fodder		
b) Poles/posts		
c) Firewood/fuel wood		
d) Medicine		
e) Fibres		
f) Others (specify)		

25. How is gum arabic used in this area apart from selling it to earn income?.....

CULTURE, TRADITIONS AND GENDER ISSUES

26. Whose responsibility is to collect gum? And why?

Collector	**Tick**	**Reason**
1. Men		
2. Women		
3. Children		
4. Others (specify)		

27. Who is more knowledgeable about *A. senegal* trees in the community?

a) Men [ ]

b) Women [ ]

28. What roles do various members of the family play in promoting sustainable gum production?

Role	**Women**	**Men**	**Boys**	**Girls**
a) Management				
b) Collection				
c) Tapping				
d) Marketing				

29. What problems do women face when collecting gum arabic?.....

Interviewer.....**Date**.....

Appendix ii

Focus group discussions guide for Government agencies, NGOs and CBOs

MANAGEMENT OF *Acacia senegal* STANDS

1. Which organizations are involved in the management of *A. senegal*?
2. How *is A. senegal* trees managed in this area?
3. What management practices are performed on the trees?
4. What is the role of the local community in the management of *A. senegal*?
5. What problems are experienced in performing these management practices?
6. What are possible solutions to these problems?
7. How does the community perceive the *A. senegal* tree resources?
8. What are the main uses of *A. senegal* tree resources?

GUM ARABIC COLLECTION

9. How is gum collection and tapping organized?
10. What problems do the local people experience in collecting and tapping quality gum?
11. How are these problems being solved?
12. How do these resources contribute to the economic well-being of the communities?
13. Are there any traditional beliefs and customs attached to these resources?

Appendix iii

Table of means for gum arabic yield

Site	Diameter class	Tree part	Treatment	1st Picking	2nd Picking	3rd Picking	Mean yield
Daaba	3.0-6.0 cm	Branches	Tapped	0.2	2	0.9	1
			Untapped	0	0	0	0
		Stems	Tapped	3	1.6	1.3	1.9
			Untapped	0.8	0.9	1.4	1
	6.1-9.0 cm	Branches	Tapped	0.2	0.7	1.7	0.8
			Untapped	0	0	0	0
		Stems	Tapped	4.3	2.9	0	2.4
			Untapped	2.1	1	1.2	1.4
	>9.0cm	Branches	Tapped	4.2	1	1.7	2.3
			Untapped	0	0	0	0
		Stems	Tapped	4.8	3.8	1.5	3.3
			Untapped	0.9	1	0	0.7
Kulamawe	Diameter class	Tree part	Treatment	1st Picking	2nd Picking	3rd Picking	Mean yield
	3.0-6.0 cm	Branches	Tapped	2.7	1.2	4.1	2.6
			Untapped	0.4	0.3	0	0.2
		Stems	Tapped	4.6	3.9	7.2	5.2
			Untapped	0	0.3	2.7	1
	6.1-9.0 cm	Branches	Tapped	1.4	1.2	5	2.5
			Untapped	0	0	2.2	0.7
		Stems	Tapped	3.2	2.1	7.5	4.3
			Untapped	0	0	0	0
	>9.0cm	Branches	Tapped	0	0	1.4	0.5
			Untapped	0	0	0	0
		Stems	Tapped	0.9	0.7	7.9	3.2
			Untapped	0	0	2.5	0.8
Ngare Ndare	Diameter class	Tree part	Treatment	1st Picking	2nd Picking	3rd Picking	Mean yield
	3.0-6.0 cm	Branches	Tapped	1.5	3.3	1.8	2.2
			Untapped	0	0	0.8	0.3
		Stems	Tapped	2.3	4.8	5.4	4.2

		Untapped	1.6	0	1.2	0.9
6.1-9.0 cm	Branches	Tapped	12.9	0.6	1.9	5.2
		Untapped	0	0.5	1.1	0.5
	Stems	Tapped	9	7	6.9	7.6
		Untapped	3.6	0.6	1.3	1.8
>9.0cm	Branches	Tapped	11.2	2.9	2.7	5.6
		Untapped	2.9	0	0.4	1.1
	Stems	Tapped	10.5	2.8	5	6.1
		Untapped	2.2	7.1	4.3	4.5

Ntumburi	Diameter class	Tree part	Treatment	1st Picking	2nd Picking	3rd Picking	Mean yield
	3.0-6.0 cm	Branches	Tapped	0	2	1.1	1
			Untapped	0	0	0	0
		Stems	Tapped	3.5	2.1	3.3	3
			Untapped	2.7	0	1.4	1.4
	6.1-9.0 cm	Branches	Tapped	0	0.8	1.4	0.7
			Untapped	0	0	0	0
		Stems	Tapped	2.4	12.5	9	8
			Untapped	0	0	0	0
	>9.0cm	Branches	Tapped	0	0	0	0
			Untapped	0	0	0	0
		Stems	Tapped	0	0	0.7	0.2
			Untapped	0	0	0	0

Appendix iv

Kruskal-Wallis One-Way ANOVA

Variate: yield (g)

Group factor: site

Value of H = 12.97

Adjusted for ties = 30.69

Sample	Size	Mean rank
Group Daaba	360	713.74
Group Kulamawe	360	739.41
Group Ngare Ndare	360	768.06
Group Ntumburi	360	660.78

Degrees of freedom = 3

Chi-square probability < 0.001

Variate: yield (g)

Group factor: Diameter class

Value of H = 2.093

Adjusted for ties = 4.951

Sample	Size	Mean rank
Group 3-6 cm	480	730.15
Group 6.1-9 cm	480	733.20
Group >9cm	480	698.15

Degrees of freedom = 2

Chi-square probability = 0.084

Variate: yield (g)

Group factor: Assessment period

Value of H = 3.009

Adjusted for ties = 7.119

Sample	Size	Mean rank
Group 1st Picking	480	741.58
Group 2nd Picking	480	695.51
Group 3rd Picking	480	724.41

Degrees of freedom = 2

Chi-square probability = 0.028

Appendix v

ANOVA for gum arabic quality and physical characteristics in study sites

Analysis of variance for gum arabic optical/specific rotation

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	30.104	10.035	7.26	0.011
Residual	8	11.055	1.382		
Total	11	41.159			

Analysis of variance for gum arabic absolute viscosity

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	455939.08	151979.69	5008.12	<.001
Residual	8	242.77	30.35		
Total 11 456181.85					

Analysis of variance for gum arabic pH

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	0.207533	0.069178	9.89	0.005
Residual	8	0.055933	0.006992		
Total 11 0.263467					

Analysis of variance for gum arabic moisture content

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	141.153	47.051	7.29	<.001
Points	2	3.108	1.554	0.24	0.787
Site. Points	6	30.584	5.097	0.79	0.584
Residual	35 (1)	225.922	6.455		
Total 46 (1) 399.803					

Analysis of variance for atmospheric temperature

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	235.251	78.417	9.61	<.001
Points	2	0.132	0.066	0.01	0.992
Site. Points	6	0.225	0.037	0.00	1.000
Residual	35 (1)	285.718	8.163		
Total 46 (1)	512.600				

Analysis of variance for soil temperature

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	67.45	22.48	0.75	0.532
Points	2	1.94	0.97	0.03	0.968
Site. Points	6	2.60	0.43	0.01	1.000
Residual	35 (1)	1054.95	30.14		
Total 46 (1)	1126.35				

Analysis of variance for soil moisture

Source of variation	d.f. (m.v.)	s.s.	m.s.	v.r.	F pr.
Units' stratum					
Site	3	646.666	215.555	104.74	<.001
Points	2	3.516	1.758	0.85	0.434
Site. Points	6	19.079	3.180	1.55	0.193
Residual	35 (1)	72.031	2.058		
Total 46 (1)	699.948				