Influence of Topography and Soil Characteristics on *Acacia senegal* Distribution and Gum Arabic Production in Northern Kenya.

By

GODANA JILLO DOYO

Thesis submitted in Partial fulfillment of the Requirement for the Degree of Master of Science in Range Management (Resource Ecology Management Option), Department of Range Management, Faculty of Agriculture, University of Nairobi

1994

DECLARATION

This thesis is my original work and has not been presented for a degree in any other University.

Date 13th October, 1994

Godana Jillo Doyo

This thesis has been submitted for examination with my approval as the University supervisor.

Date 25-10-94

Dr. TADINGAR TOLOUMBAYE
Lecturer, Department of Range Management,
University Of Nairobi.

Date 27-10-94

Dr. B. M. Woie
Principal Research Officer, and Centre Director,
National Arid Land Research Centre, KARI, MARSABIT.

Dedication

- To my mother who, though she lacked formal education, still remains my tutor.

- To all men who, without vanity, vileness, or favouritism, uphold the sanctity of human endeavour and achievements.

Acknowledgements

I wish to thank the EEC Delegation in Kenya for the scholarship I was awarded through KARI and funded my MSc programme. I am greatly indebted to my first supervisor, the late Dr. Tandigar Toulombaye, of Department of Range Management, University of Nairobi, for his assistance, encouragement and guidance from the proposal stage, throughout the field work and the subsequent thesis completion. He took personal interest and initiative in my work and, as a truly great tutor he was, he patiently and tirelessly laboured through my ponderous manuscript and made it what it is now. I also wish to express my sincere thanks to Dr. Kinyamariio of Department of Botany, University Of Nairobi, who after the death of my first supervisor, through his invaluable comments, helped me to crystallize my thesis. I also wish to acknowledge the encouragement and advice of Dr. N.K.R. Musimba on many occasions after the defence of my thesis.

I am also grateful to all KARI employees based at Ngurunit Sub-station for the support and encouragement they gave me, especially Diba Guyo, Moses Ima Olengarite, Appollo Parnat, Ms. Rose, Mr. Timando, Gesille, and Esinyon. I should also not forget all the pastoralists who put aside their pressing chores and lent me their ears and freely volunteered their opinion and impacted me with their knowledge.

Special thanks to Dr. Kassim O. Farah, Chairman, Department of Range Management, for his overall guidance and support, and to Mr. Guyo Okola Haro and Mr. Florin Menzeel, both of GTZ-Marsabit Development Programme, for their moral and material support. And Big thanks to all relatives and friends who consistently offered me encouragements through out the long period of my M.Sc. especially (after the defence) during the 20-odd-months it took Dr. Ngugi R. Kinuthia to certify that I have done corrections as required by the Board of the Examiners.

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ABSTRACT

A study was conducted to investigate the effects of soil characteristics, topography, sites and seasons on the distribution of A. senegal and on gum arabic production. Relationship between the gum yield and shrub morphological parameters were also investigated.

Two sites, on the plain and on the hill slope, were selected for the study. One of the site on the plain and on the slope had no Acacia senegal. While one site with A. senegal were also selected both on the hill slope and on the plain. Soils were sampled from profile pits and analysed for texture, moisture retention, hydraulic conductivity, pH, and fertility. Gum yield was measured by tapping randomly selected shrubs of A. senegal. Factorial layout was used in analyses of data on gum yield variation with the seasons, and sites. Simple analysis of variance (ANOVA) was used in the analyses of soil parameters. Multiple regression analysis were used to select the parameters that best predicted gum yield.

In the study area A. senegal predominantly occurred on the sandy sedimentary plains and rocky hill slopes of the old Pre-cambrian gneissic Ndoto Mountain ranges. From the recorded data the factors responsible for the distribution of A. senegal on the hill slopes were inconclusive. At the plain sites a number of soil characteristics including texture, percentage of clay content, moisture retention and hydraulic capacities, and sodicity and salinity may have influenced distribution of A. senegal.

Gum yield by A. senegal shrubs varied significantly with site (P<0.05) and seasons (P<0.001). The plain sites consistently yielded more gum than the hill slope sites. Highest gum yield was recorded for the shrubs tapped on the onset of the dry season (in early June), followed by the mid-dry season and least in the wet season. The average yield per shrub on the plain site was 118.21g for eight week harvest. On the hill slope over the same period the mean yield per plant was 13.13g per shrub. The was no conclusive explanation to what factor(s) were responsible for the discrepancies in the gum yield between the two sites. The observed morphological dissimilarities may have played a role.

Multiple regression analyses indicated that height was the parameter which best predicted gum yield. Regarding phenological rhythms, optimum gum production was associated with average leaf cover of 50%, at least at the plain site. Potential commercial gum arabic exploitation in the study area is constrained by lack of infrastructure, low prices, and the low yield due to dependence on the natural exudation. Introduction of tapping practice may improve both the yield and quality of gum arabic and ensure sustainable utilization if other problems constraining gum arabic trade are addressed.

CHAPTER ONE

INTRODUCTION

A circular announcing the International Symposium on Wildland Shrubs - Their Biology and Utilization, Logan, Utah, USA, in July, 1971, stated that, ... "There is an increasing awareness that man has given but scant attention to the usefulness of shrubs for animal feed, soil conservation, low maintained landscaping and industrial products as he has attempted to increase the productivity of the world's dry lands. Shrubs have many excellent characters to offer that have either been ignored or considered a problem" (McKell et al. 1972). The above symposium marked the beginning of new era as far as trees and shrubs are concerned. Since then, woody species in semiarid and arid tropical ecosystems started generating new interest as scientists continued searching for low-cost and low-tech methods of increasing crop and grassland production, and for reversing the environmental deterioration that accompanies population growth in many parts of the region. Trees and shrubs in this region are presently viewed as having the potential to increase grass production (silvo-pastoralism), increase crop production (agro-forestry), improve soil fertility, and halt or reverse desertification (Nair 1984, Steppler and Nair 1987, Young 1987). In addition, trees can provide important cash incomes from sale of fruits, wood for building, and so on, and serve as assets that can be sold in times of need (Chambers and Leach 1987).

Except for very arid conditions, trees and shrubs are the dominant vegetation of the world's extensive arid and semi-arid regions. They possess a wide range of adaptation - from some of the highest mountains to the lowest and extending from wet foothills out into the drier desert areas where most grasses are not able to accompany them, except for a few ephemeral opportunistic annual grasses and forbs (McKell et al 1972).

Rural people throughout the world have managed and used many trees and shrubs in their environment from time immemorial. Many woody species have multiple uses and different parts of trees are used differently by different people according to their local needs and preferences. Most uses depend on local people's indigenous knowledge, based on long-term experience. Given time and opportunity, local people will continue finding new uses for these plants. Yet man's use and understanding of them falls far short of their potential (McKell 1975).

Their role as a source of potential change particularly in the African pastoral areas has tremendously increased. Today, a wide range of trees and shrubs are being developed and used for landscaping purposes. Some ranchers in southwestern United States have obtained substantial income from the sale of shrubs, particularly cactus (Opuntia sp.), agave (Agave sp.) and ocotillo (Fouqueria sp.), for use as ornamentals in landscaping (Steger and Beck 1973). The desert shrub jojoba (Simmondsia chinensis), endemic in the Sonora desert in the southern United states and northern Mexico, may be a suitable replacement for sperm whale oil as an industrial lubricant. Guayule (Parthenium argentatum), another desert shrub, contains rubber that can be used for tires, medical supplies and other items. Some of the desert forbs and shrubs contain substances that may inhibit cancer growth and have other medicinal properties. Many range plants have the potential to be developed into valuable domestic food and forage species using new genetic engineering techniques.

In Africa, Acacia trees/shrubs are highly valued. Their many uses include gum arabic production, soil erosion control, animal fodder, wood for poles and implements, fuelwood and seeds for human consumption. Acacia senegal and A. seyal are the most important species for gum production. Of the two, the former produces the best quality gum in the world.

Gum arabic has been, at least, for the last 4000 years, a commodity of international commerce. Ancient Egyptians used it extensively for ink production, as medicine, in crafts and textile industry (Christian 1991, Maydell 1986, Anon 1979, Booth and Wickens 1988). Today, gum arabic is widely sought after by industrialized countries for use in confectionery and beverages; pharmacy, photography and lithography/printing (Barbier 1990). According to FAO (1985), potential world demand for gum arabic was about 90,000 tons, but only half of that amount was produced. Low gum production can be attributed partly to declining world prices and partly to the fact that the industry is still largely a peasant (pastoral) occupation with most of the gum being collected from wild trees. Policies that offer farmers incentives to cultivate and improve tree species, are missing. Due to prevailing prices and government policies, the gum gardens of Sudan have substantially declined.

Although occurrence of A. senegal and its related affines has been recorded in various parts of Kenya (Dale and Greenway 1961, Brenan 1983), information on edapho-climatic factors influencing gum arabic production is lacking. The potential ability of A. senegal varieties to yield maximum quantities of industrially desirable gum, remains a myth to both the producers and researchers. Little is known about A. senegal seedling requirements for successful establishment and subsequent population dynamics. Distribution of A. senegal, even within edapho-topographical zone, is highly patchy. A preliminary survey of Ngurunit vegetation confirmed the high degree of discontinuity. Major stands of A. senegal were found to occur on two topographically different areas: the hillslopes and the plains.

In view of the importance attached to A. senegal trees and shrubs by the native pastoral peoples of sub-Saharan region in general and Kenya, in particular, this study addressed the basic biological questions of soil, climatic and topographic parameters that influence A. senegal distribution and gum arabic production. The specific objectives were:-

1. To determine differences in soil characteristics between A. senegal-inhabited and -uninhabited sites.
2. To determine differences in seasonal gum arabic production between lowland and upland sites.
3. To establish the relationship between gum yield, and A. senegal stem diameter, height, crown diameter and above-ground biomass.

CHAPTER TWO

LITERATURE REVIEW

Geographical Distribution, Taxonomy and Ecology of *Acacia senegal* (L.) Willd.

Geographical Distribution

Acacia senegal (L.) Willd. is a deciduous shrub or tree of the family Leguminosae and sub-family Mimosoideae. As a species with a wide ecological amplitude, *A. senegal* is widely distributed across tropical and sub-tropical Africa, from West Africa (Senegal, Gambia, Nigeria, Mali, Ghana, Niger), through the Sudano-Sahelian region to Eastern Africa down to Southern Africa (Booth and Wickens 1988, Brenan 1983, Maydell 1986, Ross 1979). It also occurs outside Africa in countries like Oman, Pakistan and India (Booth and Wickens 1988, Brenan 1983, Maydell 1986, Ross 1979).

In Kenya, the plant is widely distributed in various vegetation associations, mainly in the arid and semi-arid regions. It occurs in almost all the ASAL districts including Kitui, Machakos, Embu, Nakuru, Baringo, West Pokot, Turkana, Samburu, Marsabit, Isiolo, the whole of North Eastern Province and in the arid parts of Coast province (Dale and Greenway 1961, Pratt and Gwynne 1977).

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Taxonomy

Taxonomy of A. senegal is controversial and confused as is clear from the inconsistent taxonomic literature on the species and the many synonyms associated with it (Ross 1975, 1979, Brenan 1983). Brenan (1983) listed four main varieties of A. senegal, but stated that many related sub-species or varieties may be just phenotypic variants of the same. While there are other variations which are taxonomically important, they may, however, not be recognizable in the field hence making identification difficult. Brenan (1983) and Ross (1975, 1979) emphasized that delimitation of varieties of A. senegal and those of closely related species, is far from being satisfactory and that more information about them is badly needed.

Hybridization is thought to be the main cause of difficult in identification of A. senegal varieties. The origin of hybridization is Somalia from where it spreads to other parts of Africa (Ross 1975). In northern Kenya which is close to Somalia, the problem of verification seems to be more acute and hence needs detailed study. Field experience, indicates severe constraints to verification particularly from Herbarium specimen. There are such extensive genetic differences, phenotypic similarities and ecological overlap that morphological features alone, are not sufficient for verification or delimitation of the various varieties. Use of cryptic (cytogenetic, physiological and biochemical) variations (Snaydon 1984) may probably be the solution to this problem, although this method has little practical field use. However, it is believed that all the four varieties of A. senegal described by Brenan (1983) occur in Kenya.

Ecology of A. senegal

A. senegal thrives well under tropical and sub-tropical arid and semi-arid conditions. The plant achieves optimal growth in areas where climatic and edaphic conditions provide adequate moisture required for survival (Gaye 1988). Depending on climatic and edaphic factors, A. senegal occurs in either continuous pure stands or patches of dispersed individuals. Specific plant communities associated with stands of A. senegal vary from region to region and site to site (Sene 1988, Cheema and Qadir 1973, Seif-el-Din and Obeid 1970a).

A. senegal, an important Sahelian plant, is very drought resistant. It can tolerate continuous dry periods of 8-11 months in a year. Depending on edaphic factors such as texture and clay content, the plant can survive in areas with as low as 150mm minimum mean annual rainfall. Optimal growth occurs under 200-500mm mean annual rainfall (Booth and Wickens 1988). In sandy soils, A. senegal requires higher mean rainfall - 200-800 mm. On clay soils, A. senegal does well if annual rainfall ranges between 800 and 2000 mm (Gaye 1988, Maydell 1986, Duke 1981, Anon. 1979).

Acacia senegal thrives well under coarse-textured soils such as fossil (stabilised sand) dunes, and skeletal soils such as lithosols. The plant tolerates a pH range of 5.0 - 8.0 with the most suitable range being between 7.4 and 8.2 in top soil (Cheema and Qadir 1973). Coarse sand, irrespective of topographic conditions, supports high densities of A. senegal. Little or no relationship has been observed between soil organic matter content and A. senegal plant density. Other soil characteristics listed by Cheema and Qadir (1973) as critical to the distribution of A. senegal are, moisture holding capacity and carbonate content. A dense stand of A. senegal has been reported to be closely associated with certain ranges of both moisture holding capacity and carbonate levels (Cheema and Qadir 1973). The plant occurs at a wide elevation range - between 100m in Senegal and 1950m in central Rift Valley of Kenya (Booth and Wickens 1988, Maydell 1986).

A. senegal can tolerate high diurnal temperature variations. The mean maximum temperature is 45°C and the mean minimum is 16-17°C (Duke 1981, Tahir 1987, Booth and Wickens 1988). In India, higher maximum and lower minimum temperatures - 48°C and -4°C, respectively, have been reported (Duke 1981). However, the sites must be frost free (Duke 1981).

Economic Importance of A. senegal

Acacia senegal serves extraordinarily diverse social, economic and ecological functions (Pearce 1988). The greatest economic importance of A. senegal is resin or gum arabic production which is a highly valued exudate, widely sought after by industrialized countries because of its many uses in confectionery, beverage, pharmaceutical, photography, lithography, printing and pesticide industries" (Pearce 1988).

Although it grows naturally in most parts of the world, it is cultivated as a multipurpose tree/shrub in a number of countries. In Sudan, cultivation of A. senegal is part of centuries-old shifting cultivation practice (Booth and Wickens 1988, Fagg and Barnes 1990, Seif-El-Din and Obeid 1970a). The system consisted of 15-20 years of bush-fallowing dominated by A. senegal with intervening 4-5 years period during which crops such as sesame, millet, sorghum and groundnut were cultivated. When soil fertility was exhausted, the area was left fallow during which time A. senegal regenerated. However, this traditional practice is disappearing fast. Increased human population has led to increased demand for land for crop cultivation which has in turn resulted in drastic reductions in lengths of fallow periods. The ecological significance of this is the disappearance of A. senegal stands due to inability of the plants to regenerate on permanently cultivated lands (Seif-el-din and Obeid 1970b, Tahir 1987, Pearce 1988).

A. senegal provides fodder for livestock, firewood, construction poles, and other minor products. Being a leguminous plant, A. senegal has been shown to enhance soil fertility through fixation of atmospheric nitrogen into the soil. It has been reported that A. senegal can naturally and artificially nodulate (Basak and Gayel 1975). Gerakis and Tsangarakis (1970) recorded significant increases in total nitrogen content of soils around individual A. senegal tree/shrub which they attributed to nitrogen fixation by the plants.

A. senegal protects the soil from wind or water erosion. Upto 40% of A. senegal's total biomass is underground with a deep, well spread lateral root system that renders it suitable to soil stabilization especially on sand dunes (Pearce 1988). This characteristic makes A. senegal an ideal tool against any form of soil erosion and hence acts as a buffer against the forces of desertification. In some countries A. senegal is the plant of choice for firewood and charcoal. Occasionally, plantation of A. senegal have been established for the sole purpose of providing fuelwood to settlements and urban centres since the plant coppices very well (Anon. 1987, Tahir 1987, Anon. 1979). A. senegal wood is also used in construction of livestock night enclosures. Root fibres and woody roots are used in basket and rope weaving and in lining of water well walls (Anon. 1979, Tahir 1987, Heine and Brenzinger 1988, ICRAF 1992).

Leaves and pods of A. senegal provide forage for livestock and wild game, especially goats, sheep, camels, giraffes and gazelles. The crude protein content of the pods is reported to be comparable to other high quality ruminant feeds (Booth and Wickens 1988, Tahir 1987, Maydell 1986).

Other uses of A. senegal include provision of feed for bees in form of pollen, shade, ornamentals and rehabilitation of degraded areas (Booth and Wickens 1988, Tahir 1987). In range areas, pastoral herders collect and eat gum arabic as a snack. Occasional it is used as medicine (Heine and Brenzinger 1988, Fagg and Barnes 1990).

Gum Arabic Production

Gum arabic is the dry exudate of A. senegal. It is produced when plants are under physiological stress and plants in optimum growing conditions have never been observed to produce gum (Glicksman and Sand 1973). It is believed that any environmental stress that reduces plant vigour such as low soil fertility, low moisture or high temperatures, increases gum production (Glicksman and Sand 1973).

Production of gum arabic is a normal metabolic process in the plant with quantity and quality of gum being a function of the prevailing environmental conditions (Malcolm 1936, Seif-el-Din 1981/82). Ghosh and Purkayastha (1962), Joseleau and Ulimann (1990) and Seif-el-Din (1981/82) reported highest gum synthesis to occur from the bark and outer stem and branch woods. Less gum is produced from the inner wood and very little from the roots. Gum synthesis therefore, is not necessarily restricted to injured sites.

Climatic factors that influence gum production include rainfall amounts, relative humidity and temperature. Sene (1988) reported that gum production increased with increase in environmental temperature, with optimum gum production being achieved at a mean daily temperature of 30°C and a maximum of 35°C, coupled with a relative humidity of between 12-30%. Similar finding have been reported in Sudan (Anon. 1979).

In areas, where there are distinct cold and warm seasons such as in western Sudan, northern Nigeria and Senegal, no gum production occurs during the cold or dry periods no matter how much leaf loss occurs (Oleghe and Akinnifesi 1992, Sene 1988, Booth and Wickens 1988). Also, virtually no gum is produced during the wet season (Sene 1988). The bulk of Sudan's gum arabic is from trees growing in areas with 300-400mm of annual rainfall and 8-10 months of dry spell (Fagg and Barnes 1990).

In some places, availability of soil moisture from the ground water has been linked to occurrence of A. senegal stands and subsequent gum production where otherwise, climatic conditions alone in terms of total annual precipitation would not have supported the plant survival (Gaye 1988).

Edaphic factors also influence gum production in terms of quantity and quality. In Sudan, economically viable gum production is achieved from stands of A. senegal growing in sandy soils; and rarely from clay soil sites (Fagg and Barnes 1990).

Tahir (1986) reported great inter-plant variations in gum production even within the same provence. In trees of the same age, gum production has been reported to be positively correlated to height and girth of the tree (Oleghe and Akinifesti 1992). Phenologically, maximum gum production is associated with a leaf fall of upto 80% (Sene 1988).

Gum Yields

In the high density A. senegal "gum gardens" of Sudan, annual average gum yields are about 250g per tree (Fagg and Barnes 1990). This figure drops to about 100g in western Sahel; namely, Senegal, Nigeria and Mali (Booth and Wickens 1988, Fagg and Barnes 1990).

Gum yields across individual trees is variable depending on age and physiological status. For instance, young trees of var. senegal yield 100g-2856g of gum annually, while older ones yield 379-6750g. Optimum production is realized between 5 and 7 years of age and tapping can go on for the next 15 years, after which yields will decline (Booth and Wickens 1988).

Until recently, the bulk of gum arabic on the market was as result of exudation from accidentally injured trees, rather than deliberate tapping. However, deliberate tapping is common these days. Tapping involves making of a shallow incision, about 4cm wide, into the bark, followed by peeling of the bark backwards, 60-100cm. The gum accumulates below the incision and is harvestable within the next 2-3 weeks. Subsequent gum collection from the same incision is possible for 8-10 weeks. Tapping can be done on either the stems or the main branches (Booth and Wickens 1988). Maximum gum yield is realized at beginning of the dry spell. In Sudan, tapping is normally once per year around October and gum collection spreads over 8-10 weeks (Booth and Wickens 1988).

Gum Quality

Commercially suitable of gum arabic is determined by quality standards listed in Pharmacopeial and Food Chemicals Codex specifications for substances used as pharmaceutical and food additives (Anderson et al 1983, Anderson 1986). Major quality parameters include viscosity, moisture content, bacterial counts, solubility, colour, ash content, contaminant level, acid equivalent, calcium and magnesium contents, acid-insoluble ash, sulphated ash, and optical activities (Glicksman and Sand 1973, Mhinzi et al. 1989, Anderson and Wang 1990). These properties vary with regions, sites and varieties of the plant (Conveney and Islip 1956, Sene 1988, Makwati Pers. Comm.). Gum properties are also affected by plant age, time of exudation and storage conditions (Faggs and Barnes 1990).

Uses of Gum Arabic.

Gum arabic has been in the manufacturing industry for the last 4,000 years. Today, it has many applications as food additive with no toxicity problems (Anderson 1986). Due to its desirable properties in terms of viscosity and solubility, gum arabic is widely used in beverage and other food industries. Glicksman and Sand (1973) listed a wide range of industrial applications of gum arabic - as stabilizers, fixatives, emulsifiers, clouding agent, anti-crystallizer in confectionery products and fixtures in baking industry. In pharmaceutical industries, gum arabic is used as suspending agent, demulcent in syrup, emulsifying agent and in binding and coating of tablets. In medicine, gum arabic has been used in treatment of low blood pressure and nephritic oedema; and in cosmetic industry, it is used in liquid soap and body lotion preparations. Gum arabic has also been used in preparation of adhesives for stamps, labels and permanent slides. Gum arabic is also an important component of special-purpose inks in lithography, while in textiles, it is used as finishing and sizing agent for print formulations (Anon.1979,Pearce 1990, Booth and Wickens 1988).

CHAPTER 3

MATERIALS AND METHODS.

Description of Study Area.

The study was conducted in Ngurunit area in Marsabit District of northern Kenya. Ngurunit lies on the eastern side of Ndoto Mountain ranges, about latitude 1° 4'N and longitude 37° 20'E, at 600-800m above sea level.

The study area is characterized by low rainfall with high degree of spatial and temporal distribution. Long rains come between March and May, and short rains between October and December. Ngurunit's mean annual rainfall is 500mm (Jaztold et al. 1992). Mean monthly temperatures at Ngurunit vary from 27 to 29°C, with a mean minimum of 20°C and a mean maximum of 35°C. On average, July/August months are relatively cool and January/March relatively warm.

Relative humidity at Ngurunit shows higher diurnal amplitudes than the annual, closely following the tropical temperature regime. Minimum and maximum relative humidity is estimated at 40% and 90%, respectively (Bake 1983). Highest relative humidity is experienced in April and October, corresponding to the wettest seasons. Peak diurnal relative humidity occurs during early morning hours, and the minimum during late afternoon hours (Bake 1983).

Ndoto Mountain ranges and the adjacent plains belong to the pre-cambrian basement system rocks, having been uplifted around the tertiary period when the Rift-Valley was also being formed. The plains are dominated by alluvial deposits derived from weathering of the hills' basement rock systems (Kekem 1986).

The hill slopes are extremely rocky, with 70% of the area consisting of bare rock and the rest being occupied by well-drained, shallow, dark/brown, stony to very stony, loamy sand to sandy loam soils. Soils are low in available potassium, low to moderate in calcium and magnesium, but high in phosphorus. Organic carbon content is estimated at 0.3%, and pH at about 7.8.

Soils on the plains are medium in texture, well drained and very deep. Soil structure is described as sandy loam to sandy clay loam. It is moderately supplied with phosphorus, low in available calcium, magnesium, potassium and organic carbon (0.1-0.2%), and pH of 7.7 (Kekem 1986).

Vegetation

The study area has two major vegetation types: an upland bushland and lowland woodland. The lowland woodland vegetation occurs along the major drainage lines and is dominated by Acacia tortilis. The bushlands, representing the principal transitional vegetation type between uplands and lowlands, are dominated by Acacia tortilis, A. nilotica, Balanites aegyptica, and Commiphora spp. Dominant shrub species include Acacia mellifera, A. senegal, A. reficiens, Commiphora spp., Duosperma eremophilum and Indigofera spinosa. Dominant grasses include Aristida spp., Cenchrus spp., and Enneapogon spp. The hillslope bushland woody vegetation is dominated by Commiphora spp, A. senegal and Boswellia spp, while the herb layer is dominated by perennial grass species like Chloris roxburghiana and annuals like Aristida spp (Herlocker 1979, Jaztold et al. 1992).

Site Selection

A preliminary survey of the vegetation of study area revealed that major stands of A. senegal occur on two topographically different areas - hillslopes and lowlands (plains). Therefore, two sites, inhabited and uninhabited by A. senegal on both the lowland and upland locations were randomly selected. The A. senegal-dominated lowland and hillslope sites were labelled IA and IIA, respectively, while the plain and hillslope sites without A. senegal were labelled IB and IIB, respectively. Each of the sites was characterised in terms of elevation, slope, soil characteristics, vegetation composition and A. senegal density.

Soil Characteristics

Soil samples were taken from the two plain sites at three randomly selected locations. At each location, a 1.5m profile pit was dug and soil core ring samples taken in triplicate at three different depths, ie. 10cm, 0.75m and 1.5m for determination of moisture retention capacities, hydraulic conductivity capacities, fertility, pH and texture analyses. The hillslope sites were too rocky for deep profile sampling. Therefore, only shallow pits (upto 30cm deep) were dug and soil samples taken.

All soil samples were analysed at the National Agricultural Laboratory (NAL). Soil texture was determined by the hydrometer method (Day 1956); soil reaction (pH) and electrical conductivity (Ec) by glass electrode method (Black 1965); phosphorus content by Watanabe and Oslen (1965) method; organic carbon by Wakley and Black (1965); saturated hydraulic conductivity by constant head method (Klute 1965); available nutrients by mass analysis method (Mehlich et al 1962); and saturated moisture retention capacity by van der Harst and Stakman (1965) method.

Acacia senegal Size-Class Structure

On sites 1A and IIA, three 10x100m belt transects were randomly mapped out. Within each belt, all A. senegal trees/shrubs were counted and their heights, stem and crown diameters determined and recorded. The average number of A. senegal shrubs per transect was calculated and then expressed on per hectare basis. Shrub height and crown diameter were determined by tape measure.

Basal stem diameter for young A. senegal shrubs was determined by means of a 15cm calliper at 30cm above the ground. For bigger A. senegal trees, stem diameter was determined at breast height using a tape measure to get the circumference from which the stem diameter was calculated using the standard formular. For crown diameter, two readings were taken and averaged out. Diameter was computed as follows: $C=\pi D$, where C = circumference and D = diameter. Crown or canopy cover (cc, (%) was calculated as follows: $CC=(D_1 + D_2)^2\pi/4$; where D_1 and D_2 are the two crown diameter readings (Mueller-Doumbois and Ellenberg 1984). Height measurements were used to establish height classes of A. senegal. Height of A. senegal shrubs recorded were tallied into various height classes of below 1m, 1.1 to 2.0m, 2.1 to 3.0m and so on. Relative frequency of each height class was computed as follows;

$$\% \text{ Height-class Frequency} = \frac{\text{No. of Shrubs/Ht. Class}}{\text{Total No. of Height-classes recorded}} \times 100$$

Height size-classes were computed in the following way:

$$\% \text{ Size-class Frequency} = \frac{\text{Size-class Freq.}}{\text{Total Frequency of all size-classes}} \times 100$$

Seasonal Gum Arabic Yields

A. senegal trees/shrub selected for tapping were grouped into 3 classes: small (0-4cm), medium (4.0-6.0cm) and large (above 6.0cm), based on stem diameter. Tapping was done during the wet (October/November) and dry (June/July) season. For each tapping, five shrubs from each stem diameter-class were randomly selected. Each of them was immediately fenced off using thorny bushes to minimize interference from people monkeys and baboons that relish the gum.

Tapping involved making a shallow incision (4cm wide) on each stem, 60cm above the ground and peeling off the bark backwards (30-60cm). A polytene sheet was then wrapped around the peeled-off area to keep out rain from the gum that would accumulate. Gum from each tree/shrub was harvested after 30 days, weighed and recorded separately.

The first set of incisions was made during the last week of October and the gum harvested in November while the second set was made during the third week of November and the gum was harvested in

December. The third set was made in June and gum was harvested in July. For the next four weeks gum was collected every 2 weeks. June-tapped shrubs were then cut at ground level to determine above-ground biomass.

Statistical Analyses

Simple analysis of variance (ANOVA) was used for the soil data. A 4x3x2 factorial layout was used to analyse the gum production in which the two sites represented Blocks (B), four periods of tapping were treatments (A) and the 3 stem class-size were factor C. Five (5) randomly selected shrubs were used as replicates in each diameter class.

Gum yield data from the June tapping and harvested over 8 week period were combined with data from recorded morphological parameters and used in calculation of correlation coefficients and stepwise multiple regression to develop relationships between plant measurable morphological parameters (basal stem diameter, crown diameter, height, weight, and number of stem) and gum yield and best gum predictor. This allowed selection of the best gum yield predictor from the recorded parameters and generate regression equation for gum yield prediction (Draper and Smith 1981). Duncan's Multiple Range Test (DMRT) was used to separate sample means when they were statistically significant (Steel and Torrie 1980).

CHAPTER FOUR

RESULTS

Site soil characteristics

Table 4.1 shows average percent sand, silt, Clay and textural grades of soils occurring in A. senegal-inhabited and A. senegal-uninhabited sites. Both of the inhabited sites had loamy-sand, while the corresponding two uninhabited sites had sandy-loam top soils. All four sites had sandy-clay-loam sub-soils. Percent clay content in both the inhabited and the uninhabited plain sites increased with increase in profile depth, although the differences were not statistically significant (P<0.05). Percent clay content was generally lower in the inhabited sites than the uninhabited sites. Comparisons between surface and subsurface soils in terms of average percent sand, silt and clay content between the two hillside sites was not carried out because the soils were too shallow.

Table 4.2 shows the hydraulic conductivity (Cm/hr) of surface and sub-surface soils of the plain sites. Soils occurring on plain sites dominated by A. senegal showed a generally higher hydraulic conductivity across the entire soil profile than those without A. senegal, although the differences were not significantly different (P<0.05). On the other hand, soil moisture retention capacity was higher in the plain sites uninhabited by A. senegal than those with A. senegal. (see Appendix 4.2-4.7).

Table 4.1 Average Percent Sand, Silt and Clay; and Textural Grades of Soils occurring in Acacia senegal-inhabited and Uninhabited sites.

Soil Layer	Site	Sand %	Silt %	Clay%	Texture Grade
Top soil(0-15cm)	IA*	73.0_a	14.6_a	12.4_a	ls
	IB*	60.7_b	14.3_a	23.8_b	sl
Subsoil (.75m)	IA	70.6_a	14.8_a	14.4_a	scl
	IB	59.8_a	10.0_a	30.2_a	scl
Subsoil (1.5m)	IA	65.8_a	13.9_a	20.3_a	scl
	IB	59.2_a	8.1_a	33.7_a	scl
Top soil (Composite sample)	IIA	74.8_a	11.7_a	13.5_a	ls
	IIB	71.2_a	14.2_a	14.6_a	sl

Means in the same column with the same letter subscript are not significantly different (P<0.05). A* denotes sites with A. senegal and B* denotes sites with no A. senegal.

Table 4.2 Saturated Hydraulic Conductivity (cm/hr) of Surface and Subsurface Soils of Plain sites.

Soil layer	Site	Mean Hydraulic Conductivity
Top soil	IA	2.33_a
	IB	1.88_a
Subsoil (0.75m)	IA	2.70_a
	IB	2.68_a
Subsoil (1.5m)	IA	1.86_a
	IB	1.26_a

Means with the same letter subscript are not significantly different (P>0.05).

Table 4.3 and appendix 4.11 shows average pH and mineral content (m.e. and %) of soils occurring in the plain and hillslope study sites. Soils from both sites fell within moderately alkaline pH range (pH 7.4-8.2), although only the hillslope sites without a prominent A. senegal stand had significantly different (P<0.05) pH from the other sites. For the same sites, mean calcium, potassium, magnesium and sodium content was generally higher than in sites dominated by A. senegal, although only sodium was statistically significantly (P<0.05). Calcium and magnesium content was significantly different (P<0.05) higher on plain than hillside sites. Electrical conductivity (Ec) values of below 1.2 indicated non-saline conditions (Table 4.3 and Appendix 4.9). These were significantly higher (P<0.001) in plain sites uninhabited by A. senegal than the inhabited ones.

Table 4.3 Average pH and Percent Mineral Content of Soils occurring in the plain and hillslope study sites.

Site	pH	Na m.e.%	K m.e.%	Ca m.e.%	Mg m.e.%	P ppm	C m.e.%	EC m.e.%
IA	8.2_A	0.63_A	1.02_A	14.1_A	3.9_A	29.0_A	0.47_B	0.29_B
IB	8.1_A	0.59_B	1.27_A	18.7_A	4.5_A	32.0_A	0.57_A	0.57_A
	7.9_A	0.54_A	0.92_A	4.5_B	2.0_B	17.2_A	0.35_C	0.23_B
IIA	7.4_B	0.47_A	0.76_A	3.3_B	2.1_A	25.3_A	0.51_A	0.17_B
IIB								

Means in the same column and with the same subscript letter are not significantly different P<0.05).

Vegetation Characteristics

A. senegal density was 160 and 523 shrubs per hectare on the plain and hillslope sites, respectively. On each of the A. senegal-inhabited sites, composition of the associated vegetation types varied considerably (Appendix 11-16). The plain site vegetation consisted of decidous Acacia bushland and a thick shrubby understorey. Associated species included A. reficiens, A. tortilis, Commiphora spp, Duosperma eremophilum and Indigofera cliffordiana. The hillslope site vegetation consisted of A. senegal-Boswellia spp. bushland with A. senegal, Boswellia hilderbrandtii, Commiphora spp. Boscia spp., Indigofera spinosa and Justicia odora as common associates (Appendix 4.11-16).

In terms of morphological characteristics, phenological rhythms and density, stands of A. senegal on the two sites showed marked variations (Table 4.1 and 4.8, and Figure 4.1 and 4.2). A. senegal stand on the plain site was dominated by the var. Kerensis schweinf.

Figure 4.1 and 4.2 show population height-class structure of A. senegal trees/shrubs as indicators of age-structure. On the plain sites, individuals of A. senegal shrubs under the 1.0m class were the majority with over 100 plants per hectare. Individuals in 2.1-3.0m and 3.1-4.0m category were few. There were no trees/shrubs in the >5m height-class. On the hillslope site, individuals in <1m and 1.0-2.0m classes constituted the largest group. This group had an estimated density of 290 plants ha[1] constituting over 55% of the total number of A. senegal trees. A few individuals were more than six metres high.

Table 4.4 Means, and S.E. of Height, Basal Diameter, Crown Diameter and Number of Stems of A. senegal occurring on the Two Sites.

Site	Plant Height	Basal Stem Diameter	Crown Diameter	No. of Stems
IA (Plain)	3.50 ± 0.07M $_A$	23.43 ± 1.12CM $_A$	5.62 ± 0.16M $_A$	$4.63 \pm 0.26_A$
IIA (Hill Slope)	3.52 ± 0.11M $_A$	6.82 ± 0.32CM$_B$	3.59 ± 0.12M $_B$	$1.01 \pm 9.43_B$

Site 1A (Plain Site) N = 109. Site IIA (Hillslope site) N = 108.
Means in the same column and with the same subscript letter are not statistically significantly different (P<0.05).

FIG. 4.1 POPULATION HEIGHT CLASS

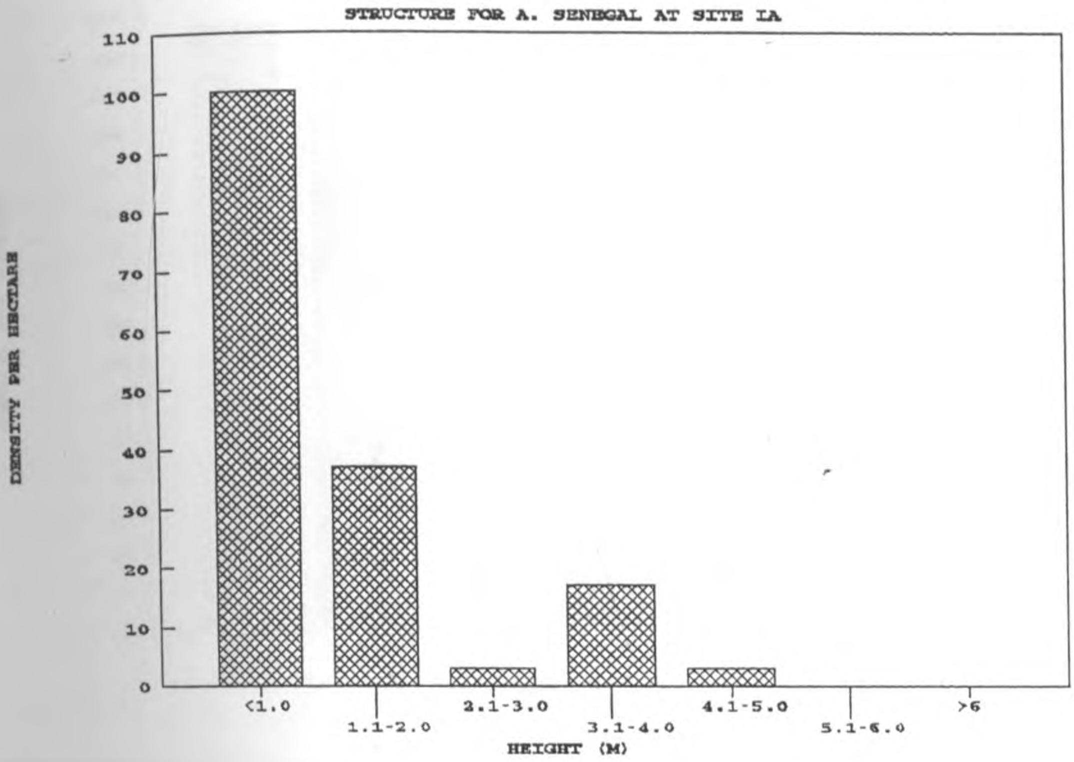
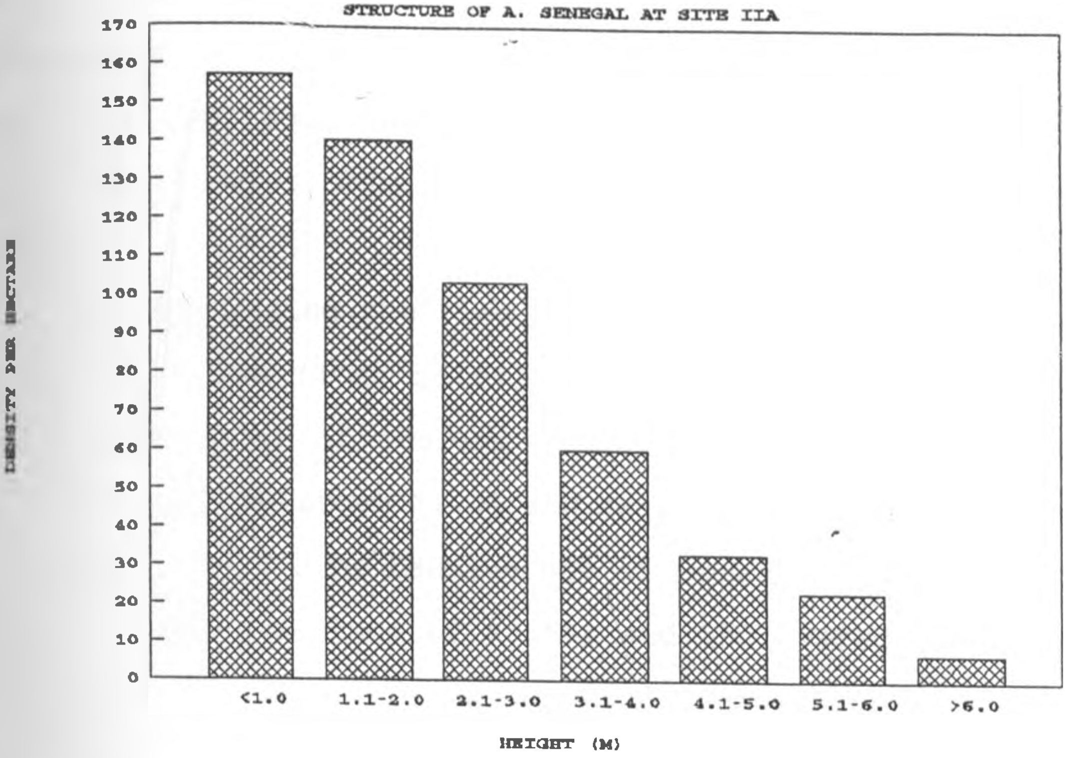


FIG. 4.2 POPULATION HEIGHT CLASS



Gum Production

Gum yield differed significantly (P<0.05) between seasons (wet and dry) and sites (Table 4.5 and 4.6). There were also significant differences (P<0.05) in tapping dates (Table 4.7). The highest gum yield was realized from shrubs tapped at the onset of the dry season and lowest from shrubs tapped at the beginning of wet season.

Rainfall during the time of field work averaged 592mm (short rains) and 194mm (long rains). For 30 days following tapping in November, a total of 158.8mm of rainfall was recorded; relative humidity averaged about 71.0% and mean daily temperature was 30°C.

The month of June had average minimum daily relative humidity of 32.06% and a maximum of 73.53% and the average daily relative humidity was 61.0%, while maximum daily temperature averaged 31.7°C and minimum daily temperature average was 19.0°C, with mean daily temperature of 27.2°C. The month of July had minimum daily relative Humidity of 41.4% average and maximum of 75.5%, and the month average was 58.4%. Average monthly mean temperature was 25.5°C, with mean minimum daily temperature of 19.2°C and maximum of 31.7°C. (Appendix 4.1). During the wet season, shrubs on both sites yielded negligible amounts of gum. However, during the dry season all tapped A. senegal shrubs yielded some gum. A. senegal shrubs on the plain sites consitently yielded more gum per tapping (Table 4.6 and 4.8). Gum yields from individual plants also showed considerable variation among all the four tapping dates.

Among the tapping dates, June and July tappings (tappings 3 and 4) were significantly different (P<0.001) from October and November tappings (Tappings 1 and 2), (Table 4.5 and 4.6). June tapping had the greatest gum yield, followed by July tapping. Highest total gum yield per site and per individual shrub and highest number of productive shrubs were recorded during June tapping. Least yields in all aspects were in October/November tapping (Table 4.7).

The A. senegal shrubs on the plain site consistently yielded more gum than that on the hillslope site, although the difference was not statistically significant (P>0.05), (Table 4.5, 4.6 and 4.7). Cummulative gum yield over 8-week period, was higher on the plain than the hillslope site. Average yield was 118.21g per shrub on plain site compared with 13.13g per shrub for the hillslope site. In terms of estimated yield per hectare, the plain site yielded 16 kg ha^{-1} compared to 7.43kg ha^{-1} of the hillside site. The highest gum yield from a single shrub on the plain site was 295.0g compared to 42.0g from the hillslope. Overall, 19.4% of the total shrubs tapped on the plain site yielded over 200g of gum.

Figures 4.3, 4.4 and 4.5 show height class distribution of productive shrubs within sites during the four tappings. On the plain site, tappable A. senegal shrubs were restricted to above 2.0m height (Fig 4.3). Shrubs in 3.1-5.0m height classes consistently yielded gum during all the four tappings. Productive shrubs within the hillslope site were evenly distrubuted along the height classes spectrum (Fig 4.4). Shrubs in the 1.0m or less height class did not yield any gum.

Gum yield across various stem-diameter classes was not statistically significant (P<0.05). Gum yield was also independent of seasons and site interactions (Table 4.8).

Table 4.5 Average Total Gum Yield During Dry and Wet Season.

Season (Tapping)	Mean (g)
Onset of Dry Season (3)	12.07_a
Middle of Dry Season (4)	7.79_a
Middle of Wet Season (2)	1.98_b
Onset of Wet Season (1)	0.74_b

Means with same subscript are not significantly different (P<0.05).

Table 4.6 Means and Standard Errors of Gum Yield by Season and sites

Site	Season	Mean Gum Yield (g)	SE
PLAIN (1A)	Onset of Wet Season 1st (October) Tapping	0.88_e	± 1.26
	Middle of Wet Season 2nd (November) Tapping	3.64_c	±1.79
	Onset of Dry Season 3rd (June) Tapping	16.02_a	±6.64
	Middle of Dry Season 4TH (July) Tapping	13.21_a	±3.74
Hillslope (IIA)	Onset of Dry Season 1st (Oct.) Tapping	0.60_e	±1.25
	Middle of Wet Season 2nd (November) Tapping	0.53_f	±1.59
	Onset of Dry Season 3rd (June) Tapping	0.88_e	± 1.26
	Middle of Dry Season 4th (July)	2.38_d	±1.07

Means with the same subscript letter are not statistically significantly different (P<0.05).

Table 4.7 Average Percentage Productive Shrubs and gum Yield per shrub (g)

Tapping Date	Site	% of Productive Shrubs	Mean Yield Per shrub(g)
October	IA	23.33	1.36_f
October	IIA	23.33	0.71_f
November	IA	30.0	2.66_d
November	IIA	23.33	1.21_d
June	IA	97.14	12.75_a
June	IIA	70.59	6.30_b
July	IA	81.25	9.04_c
July	IIA	50.0	2.28_e

Means with the same subscript letter are not statistically significantly different (P<0.05).

Table 4.8 ANOVA for Gum Production by Sites, Treatment, and Size-classes.

Source of variation	d.f.	Sum of Squares	Mean Square	F
Main Effects				
Site (B)	1	672.0387	672.0387	10.966**
Treatment(A)	3	1105.933	368.444	6.016***
Classes (C)	2	31.514	15.757	0.257ns
Interactions				
AB	11	447.984	149.328	0.424ns
BC	2	5.654	2.826	0.965ns
AC	6	371.280	61.880	0.42ns
ABC	6	51.656	0.843	0.540ns
Error	92	5637.825	61.281	
Total	119	8684.124		

C.V. = 59.98% for site II
C.V. = 19.49 for site I
*** significant at P< 0.001
** significant at P< 0.01
n.s. = not significant

Figure 4.3 Height Class Distribution of

Productive Acacia senegal Shrubs

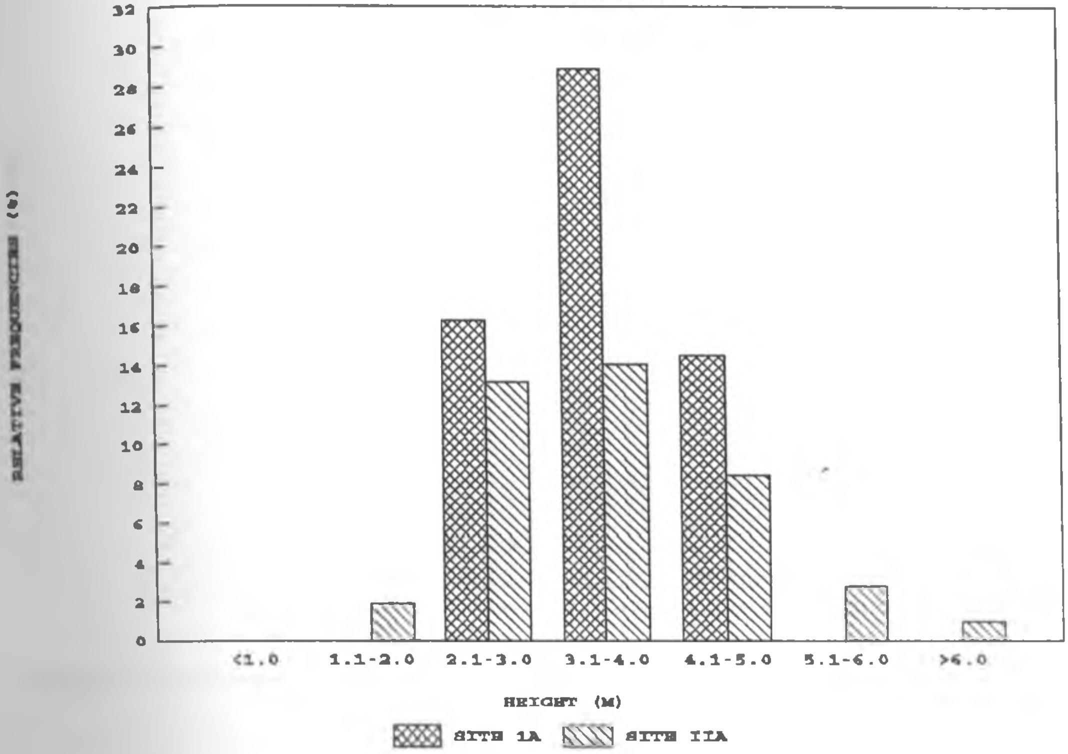


Figure 4.4 Height Class Distribution of

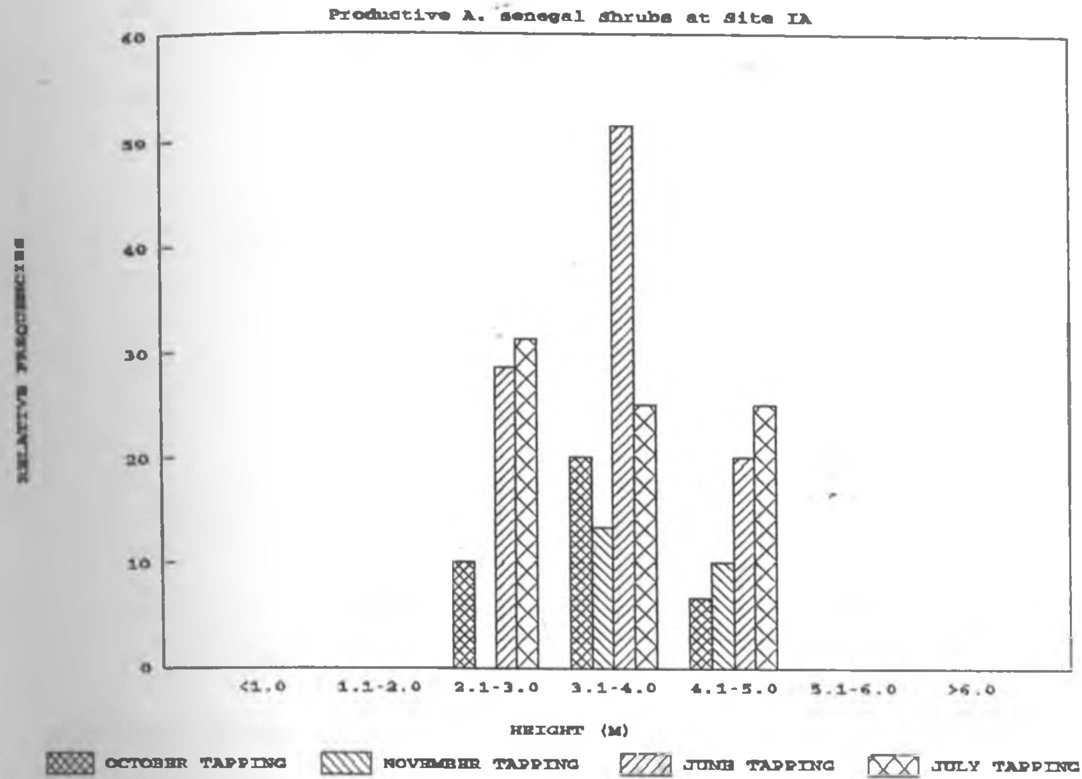


Figure 4.5 Height Class Distribution of

Productive A. senegal Shrubs (Site IIA)

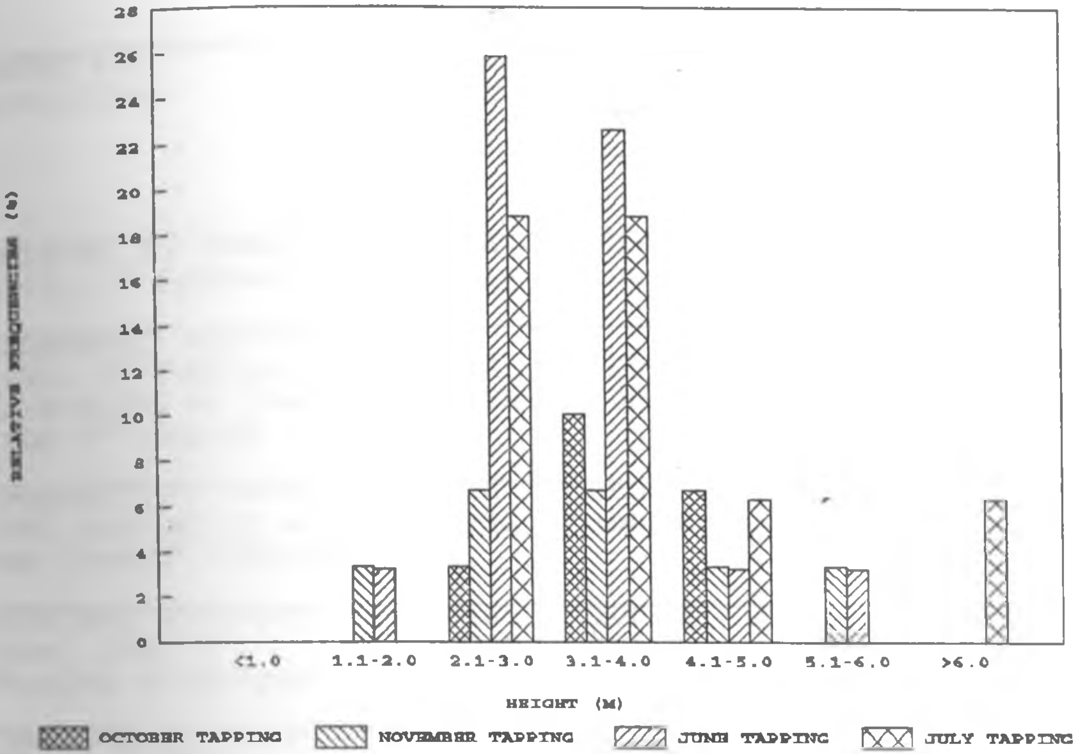


Table 4.9 Summary of Tapping Activities and Associated Phenological Rhythms.

Dates and Activities	Sites	Phenological Status (%)		
		leaf cover	Pod cover	Inflore -scence
October 3rd week, 1992, 1ST Tapping	IA IIA	100 100	0.0 0.0	0.0 0.0
November 3rd week, 1992. 2nd Tapping; Harvesting of Gum from 1st Tapping	IA IIA	100.0 100.0	0.0 2.5	0.0 0.0
December 3rd week, 1992 Harvesting of Gum from 2nd Tapping	IA IIA	100.0 100.0	1.0 0.0	0.0 0.0
Late May to early June, 1993 3rd Tapping of Shrubs	IA IIA	100.0 100.0	30.0 55.0	45.0 20.0
Early July, 1993, 4th Tapping, and Harvesting of Gum from 3rd Tapping	IA IIA	45.0 <5.0	40.0 10.0	0.0 <2.0
Early to mid August, 1993 Harvesting of Gum from 4th Tapping; Destructive Sampling	IA IIA	40.0 0.0	30.0 1-2.0	0.0 0.0

Gum Yield Prediction.

Correlation analyses (Table 4.10) revealed that the relationship between gum yield and morphological parameters of A. senegal were identical for both sites (r=0.77 and 0.69 for plain and hillslope site, respectively). Significant (P<0.05) and positive correlations were observed in plant weight (WT), plant height (HT), and basal stem diameter (BSD) for both sites. Plant height was the parameter with the highest correlation to gum yield. The number of stems (NOS) per plant and crown diameter (CD) were positively but poorly correlated to gum yield (Table 4.11).

Although none of the parameters entered in the final multiple regression model were significant ($P<0.05$), all the parameters could predict gum yield. Plant height was the best predictor of gum yield for both sites. The model ($R^2 = 0.67$) for plants on site 1A was given by the following equation: Log Gum Yield = 0.98 + 0.82 WT + 5.24 Ht + 1.09 NOS - 3.09 BSD. For site IIA, the hill slope, the model ($R^2 = 0.87$) is given by the equation: Log Gum Yield = 5.00 + 3.76 WT + 3.88 NOS - 5.88 BSD - 4.53 HT (Table 4.11).

Table 4.10 Correlation Coefficients of Morphological Parameters and Gum Yield for Third (June) tapping.

	NoS	HT	WT	BSD	CD	Gum Yield
Number of Stems (NOS)		0.57	0.58	0.75	0.64	0.39
Plant Height (HT)	0.28		0.95	0.85	0.80	0.69
Plant Weight (WT)	0.35	0.91		0.94	0.91	0.66
Basal Stem Diameter(BSD)	0.68	0.86	0.92		0.88	0.59
Crown Diameter (CD)	0.36	0.37	0.49	0.44		0.39
Gum Yield	0.31	0.77	0.68	0.54	0.31	

Gum Yield = dependent variable, Bottom = Site 1A (Plain), N=15 Top = Site I1A (Hillslope), N = 9

Table 4.11 Regression Equations Relating Gum Yield to Morphological Parameters

Site	Gum Yield (y)	Equation	r
IA	Log (y)	0.98+0.82logWT+5.42LogHT+1.09 LogNOS-3.09LogBSD	0.82
IIA	Log (y)	5.00+3.76LogWT+3.88LogNOS-5.88 BSD-4.53 logHT.	0.93

CHAPTER FIVE

DISCUSSION

The effect of Soil Characteristics on *A. senegal* Distribution

Results from available data suggest that no recorded soil physical or chemical characteristic could conclusively account for the occurrence or absence of *A. senegal* at all the four sites. The parameter which appeared most limiting on the plain sites turned out to be unimportant on the hill slope sites. The lack of consistency in variation of the soil characteristics between sites with *A. senegal* or those without, suggests that certain soil factors other than those studied could be responsible, alone or in concert with those recorded or not recorded, in influencing the distribution of the *A. senegal* in all the four study sites.

On the plain sites, however, both soil physical and chemical characteristics may have influenced *A. senegal* distribution. Given that the soil morphology (texture and particle sizes), water holding and retention capacities, and certain chemical characteristics, such as sodicity and salinity, differed considerably, and at times significantly ($P<0.05$), between the two plain sites suggests that these parameters may be the main causes of variability in vegetation types. Cheema and Qadir (1973) reported that soil texture and percentage sand content were most important in influencing *A. senegal* distribution. These characteristics also influence water holding properties and subsequent wilting level. Bunting and Lea (1962) reported that soils under a dense A. senegal stand have high phosphate and calcium contents. In the current study, phosphate levels were moderate for all the sites, while calcium levels were moderate in the site under A. senegal and very high in the plain sites devoid of A. senegal. Analysis of soil textural composition, moisture holding capacity, hydraulic conductivity, etc. reported in current study were similar to those reported by Cheema and Qadir (1973). It appeared most likely that these factors were responsible for the present distribution of A. senegal within the plain sites.

It appears that the differences in soil morphological parameters, particularly the high clay content recorded in the top and subsoils, in the plain sites uninhabited by A. senegal, may be responsible for the poor establishment of A. senegal. How exactly this happens is not clear, but it is most likely that the high percentage clay content which increased considerably with increase in depth may be physically hindering root growth, contributing to poor aeration or poor water movement from above (precipitation) and below (capillary movement) thus, preventing establishment of A. senegal.

On the hill slope sites, available data indicates that except for the textural class of the top soil and the level of available Mg^{2+}, none of the other soil parameters studied could explain the distribution of the A. senegal within the two hillslope sites. For instance, even the significantly high p<0.05) pH values recorded in the soils of the hillslope sites without A. senegal, were within the pH ranges reported by Cheema and Qadir (1973) as tolerable to A. senegal. Also, although the organic mater content of soils under the A. senegal differed significantly from those sites without A. senegal, Cheema and Qadir (1973) reported no relationship between soil organic matter content and A. senegal distribution.

Given that the available soil data in this study is not sufficient to explain the presence or absence of the A. senegal on the hillslope sites, attempts have been made to infer possible factors that could influence the distribution of A. senegal within the two sites. Various authors have suggested that the distribution of plant species in the tropical arid lands is primarily a function of soil moisture as influenced by soil physical characteristics and site microclimate (Jensen 1990, Kovda et al. 1979, Kelley and Walker 1976). In the current study, significant difference between the two hillslope sites in terms of microclimate may be assumed to be unimportant and thus, differences in vegetation types could most probably be due to soil moisture variation. It is likely that soils of the hillslope site with A. senegal had higher available moisture because of both higher permeability to downward movement of water and retention capacity than the corresponding hillslope site devoid of A. senegal. This may be possible due to different characteristics of the surface and sub-soils which may have given rise to higher rate of runoff and hence less infiltration rate on he hillslope site without A. senegal than on the corresponding illslope site with A. senegal. The cause of differences in nfiltration rate between the hillslope sites is not clear, but ould be attributed to varying degree of sloppiness, degree of urface rockiness (amount of rocks and boulders) and probably the legree of variation in both the chemical and physical characteristics of the underlying soils. The textural difference recorded between the top soils of the two sites may be a pointer to varying soils morphological characteristics.

The limited infiltration rate on the hillslope site without A. senegal may also be supported, at least indirectly, by certain soil chemical characteristics. Along the available moisture gradient, sodium and calcium tend to reach maximum levels under condition of limited leaching (Birkeland 1984), a pattern recorded on the two hillslope sites, but with highest level being attained in the soil from the site without A. senegal. It is most likely that the lower degree of leaching on the hillslope site without A. senegal is mainly due to higher rate of run-off resulting in limited infiltration rates.

Lack of uniformity among the soil characteristics under A. senegal indicates definite differences between the two stands. The significantly different level (P<0.05) of Ca^{2+} between the plain and hillslope sites may only influence the distribution of A. senegal if the A. senegal stands at the two sites belonged to different populations. Whether the observed differences in site characteristics and morphological parameters of the two stands is site-specific or genetically fixed can not be ascertained. According to the qualitative observations, however, it appears that a genetic factor is involved. The A. senegal stand on the plain site has been positively identified as A. senegal var. kerensis Schweinf while that on the hillslope is probably var. Leirchochis.

The Effect of Seasons and Sites on Gum Arabic Production

The significant decrease in gum yield during the wet season can be explained by the increase in plant vigour that accompanies increase in available soil moisture from the rains (Sene 1988, Oleghe and Akinifesti 1992). Plants also suffer less stress during wet season because of reduction in rate of evapo-transpiration due to increase in relative humidity (Appendix 4.1).

Conversely, higher gum yield during the dry season than during the wet season is mainly due to moisture stress that reduces plant vigour through reduced photosynthetic activity caused by leaf loss. The significant differences ($P<0.05$) in yield between the dry and wet season follows seasonal patterns in gum yield observed for other regions (Sene 1988, Gaye 1988, Oleghe and Akinifesti 1992). Sene (1988) and Oleghe and Akinifesti (1992) reported zero gum production during both the wet season and extreme drought.

During the dry season, the observed pattern of gum production as the season progressed suggests that gum production is a physiological response to stress and corresponding phenological rhythms (Glicksman and Sand 1973, Sene 1988, Gaye 1988, Oleghe and Akinnifesti 1992). In this study, lack of significant annual temperature variations implies that rainfall and relative humidity are the main driving factors (Kekem 1986, Kelley and Walker 1976, Kovda et al. 1979, Jensen 1990). The cumulative effect of these two climatic parameters relates directly to available soil moisture (Pratt and Gywnne 1977, Edwards et al. 1979). During the wet season, high R.H. and rainfall availability corresponds to optimal plant growth period as total available moisture increases from a deficiency to a level above plants' requirements. During the dry season, low R.H. and absence of any precipition, leads to moisture stress due to loss through increased rate of evaporation and enhanced evapotranspiration.

From the results of this study and other studies elsewhere (Sene 1988, and Oleghe and Akinnifesti 1992), it appears that the initial shortage of available moisture at the onset of the dry season is necessary for gum production, but as deficiency escalates, gum yield also declines. Oleghe and Akinifesti (1992) reported that moderately stressed trees yielded more gum than trees under severe moisture stress or those receiving surplus moisture. This suggests that during the early stage of a dry season, limited leaf loss leads to reduced photosynthetic activities and hence correspondingly diminished metabolic processes. However, this initial reduction in metabolic activities may curtail production of metabolites essential for sealing of injuries, but not production of other metabolites that constitute the gum. As drought advances, subsequent available soil moisture stress lead to complete loss of leaf cover and hence severe restriction on photosynthesis and metabolism resulting in limited or no gum production at all.

Significant variation in total gum production and mean per shrub between the two sites and during all the tappings could not be explained. Sene (1988) reported different yields for the stands of A. senegal on hilltops, hillslopes and footslopes with highest yields being realized from footslope stands which was attributed to higher available soil moisture. The higher yields from trees on the lower sites, correspond to the findings of this study. The study by Sene (1988), however, was based on stands of the same population of A.senegal distributed over topographically diverse sites. In this study, there were obvious differences in the phenotypic characteristics of the two stands of A. senegal. Whether the differences in gum yield observed between the two sites is as a result site-related environmental variables or is a genetic variations, is unclear.

That the observed differences in site characteristics between the two sites can be important in influencing the critical available soil moisture. There should be significant hydrological differences between steeply inclining gneissic slopes and the gently undulating sedimentary plains. Hillel and Tadmor (1962) reported that topography can play an important role in soil water balance in arid lands. Lowland depressions receive more water than the uplands because they receive more water from surface run-offs from higher areas. The existing hydrological difference between the study sites could, therefore, bring about significant spatial, vertical and temporal soil moisture differences that could create a more xeric conditions within the hillslope sites and more mesic conditions within the plain sites. This view is supported by the characteristics of the plant communities occurring within the two sites.

If the difference in gum yield between the two sites is related to the inferred available soil moisture variation, this argument can only be valid during the dry season when soil moisture stress is most critical to plant growth and productivity. During the wet season, sufficient rainfall eliminates variability in available soil moisture and, therefore, the inferred soil moisture difference between the two sites can not explain the observed gum yield differences. The significant differences in gum yield between the two sites during the wet season, therefore, suggest that, besides the environmental parameters included in this study, other factors influenced gum yield. The most likely factors are biological, implying that the two A. senegal stands are not necessarily from the same population, and that the described phenotypic variations (stem sizes, phenological rhythms, etc.) are indeed of two distinct varieties. Consequently the observed variability in morphological parameters and gum arabic yield may have only partial relationship to the discrepancy between the site characteristics.

The selection of height and stem diameter as best predictor of gum arabic production on both sites is in agreement with findings of Oleghe and Akinifesti (1992). However, the lack of significance of parameters included in the multiple regression model at the level of selection ($P<0.05$) and the relatively low regression coefficient values suggests that gum yield may be influenced by other factors besides those included in this study. Factors such as age, physiological and climatic conditions must play an important role in influencing gum yield.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

Acacia senegal is multi-purpose shrubs/trees which is source of forage for livestock, construction material for livestock night enclosures and houses, provide food for human beings, fuelwood, and shade. The ecological significance of Acacia senegal is mainly soil protection (Pearce 1987, and ICRAF 1992). Gum arabic production adds a major economic dimension to the multi-purpose nature of A. senegal tree/shrub.

The results of this study suggest that a number of factors govern the distribution of Acacia senegal. The critical factor is inferred to be available soil moisture as influenced by soil properties, particularly the morphology (texture and profile), and percentage of the sand, silt and clay content of both surface and subsurface soils. It appears that different topographic zones support different varieties of A. senegal stand. A. senegal plants on the plain sites have been identified as var. kerensis Schweinf, while that of the hillslope is thought to be var. leirchochis. The population size-class structure revealed similar pattern for the A. senegal stands.

The stand of A. senegal at the plain site consistently and significantly ($P<0.001$) yielded higher gum than the stand at the hill slope site. On effect of seasonality on the gum yield, highest gum yield is achieved from the shrubs tapped at the onset of dry season. The shrubs of the A. senegal stand at the hill slope site, had maximum gum yield of 15.15g per shrub, a figure which low and thus can be un-viable for commercial production. The mean yield of 118.21g of gum per shrub of A. senegal var. kerensis at the plain site, is a figure comparable to yield by var. senegal in West Africa countries which are commercial producer of gum arabic. Productive shrubs were limited to shrubs of over 2M height classes. Optimum gum production were associated with relative humidity daily average of 60.9%, daily average temperature of 23.4°C. The parameters selected as best gum yield predictor based on coefficient of correlations was height. What factors are more responsible for the significant gum yield variation between the two sites was inconclusive, but inferred to be available soil moisture variation.

Introduction of tapping of A. senegal may improve both quality and yield of the gum arabic in the area. However, a number of constraints exist and where possible have to be addressed to ensure sustained optimal utilization. Major constraints are lack of market for the gum arabic, and the general poor infrastructure of the area. Tapping should be carried out at the beginning of dry season when the shrubs have shown signs of leaves dropping and limited to shrubs over 2 metres height. Accumulated gum should be harvested every two weeks or so for 8-10 weeks or until the gum exudation have ceased. Although from the available data the var. kerensis will the suitable candidate for tapping, any other varieties, especially those with stands in the plains should be tapped.

Monkeys and baboons will be a problem so fencing of each tapped plant by thorny enclosure is necessary. This will also raise the issue of environmental impact of gum production. Another foreseeable problem will be the problem of tree/shrub ownership on the communal land.

This study, due to the duration of the field work may be inconclusive and therefore similar study should be carried out incorporating data from soil moisture regime, age of sample plants, tapping of large plant samples preferably over two week interval for a period of at least an year, and analyses data separately for plain and hill slopes sites. In the multiple regression model more variables including soil moisture regime, climatic variables and age to be incorporate for generation regression equation for gum yield prediction. More work is needed to asses the full potential of gum arabic production in the general ASAL areas of Kenya, in terms of total available acreage under A. senegal stand, capacity of the different varieties of A. senegal at different localities to yield commercial gum arabic. Further work should be done to investigate the potential of establishing man-made plantation of high yielding A. senegal varieties.

In conclusion exploitation of gum arabic, if wisely promoted, may offer a rare, non-pastoral means of utilizing an existing resource on sustainable basis in the ASAL area.

scope for future research priorities on the A. senegal in the study area.

Owing to wide scope of factors that govern gum production, many aspects remain un-investigated, and the following should constitute the research priorities on A. senegal in the study area:

1. Carry out extensive survey of the study area to establish the exact distribution of and map out the stand of the A. senegal in S.W. Marsabit district.
2. Investigate the quality of gum arabic in the study area and how it varies with varieties, sites and seasons
3. Carry out germination and vegetative propagation trials, especially of the varieties with optimum gum quality with view of carrying out experimental planting of man-made stand.
4. Assess the response of the A. senegal to human use and how the current environmental degradation in the general study area have affected the status of the Acacia senegal population in the study area.
5. Make detailed investigation on the ecophysiology of Acacia senegal and gum production especially in relation to soil moisture regime
6. Investigate the biological factors like the pests and diseases that may affect the A. senegal and it's gum production.

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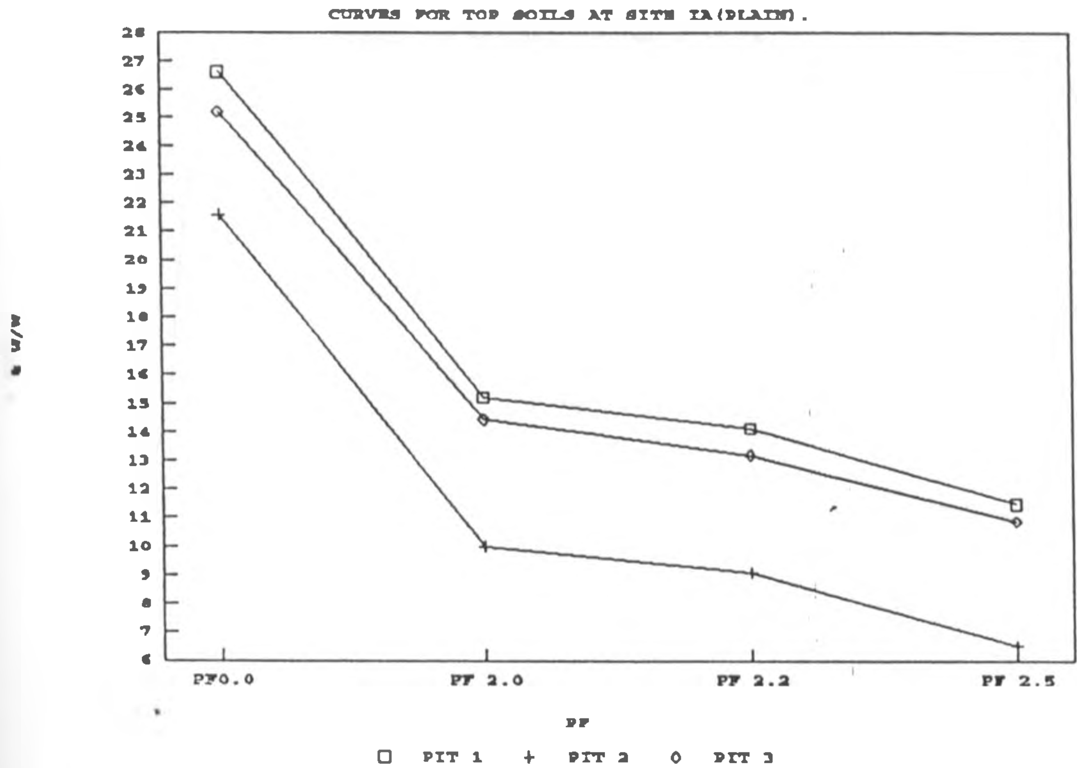
Appendix 4.1 Mean Monthly Rainfall, Relative humidity and Temperature for the Period of the Fieldwork.

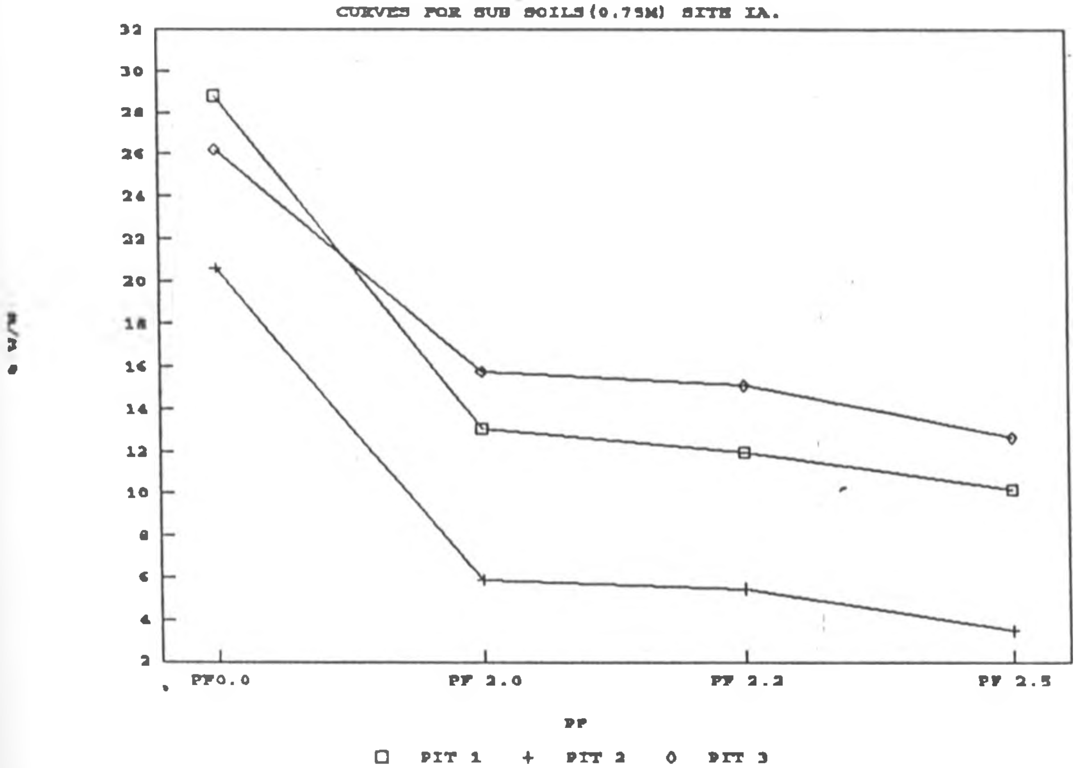
MONTH	RAINFALL (mm)	R.H.(%)	TEMPERATURE (°C)
OCTOBER	43.4	51.0	30.0
NOVEMBER	144.5	63.0	27.0
DECEMBER	181.5	79.0	25.0
JANUARY	150.4	81.0	23.0
FEBRUARY	72.2	-	-
MARCH	0	63.0	28.0
APRIL	11.2	73.0	25.0
MAY	82.44	76.0	26.0
JUNE	0	60.71	26.0
JULY	0	58.42	25.47

APPENDIX 4.3 MOISTURE RETENTION

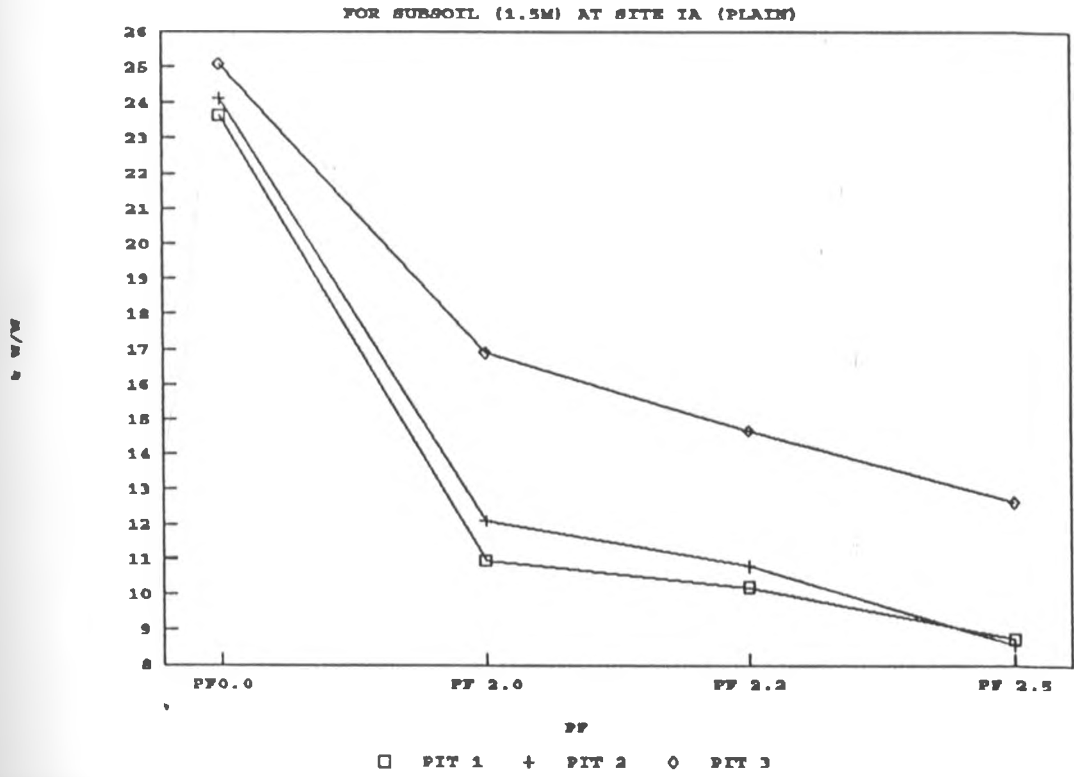


APPENDIX 4.4 MOISTURE RETENTION

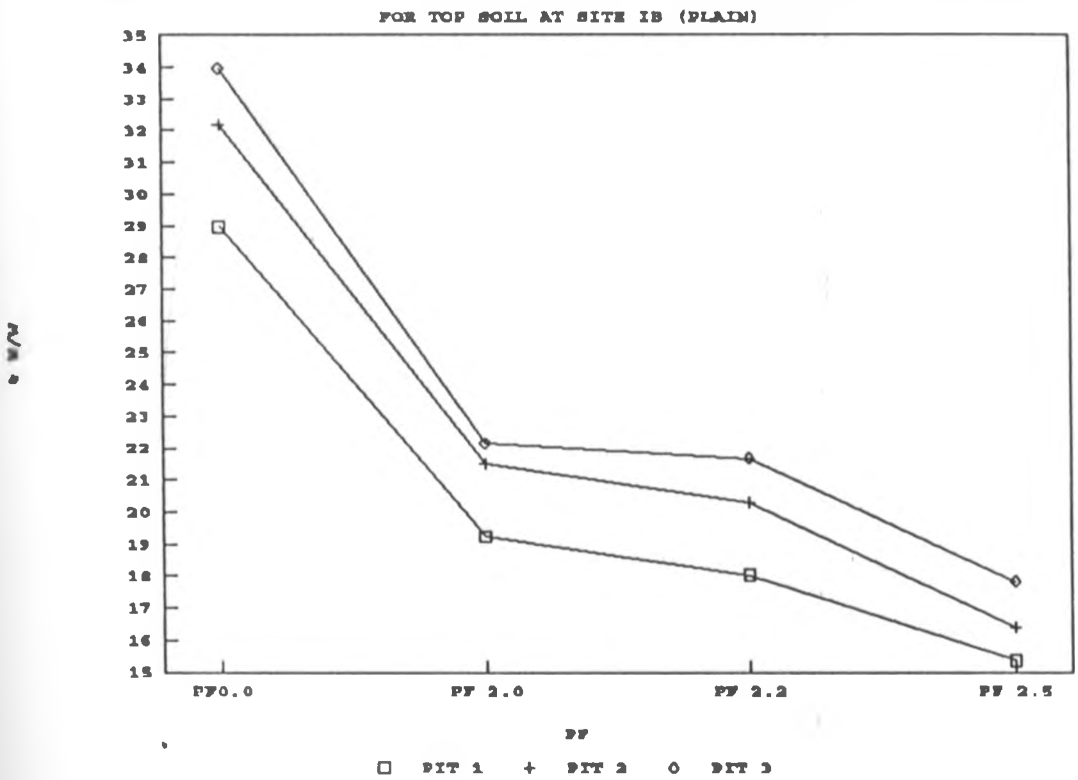
CURVES FOR SUB SOILS (0.75M) SITE IA.

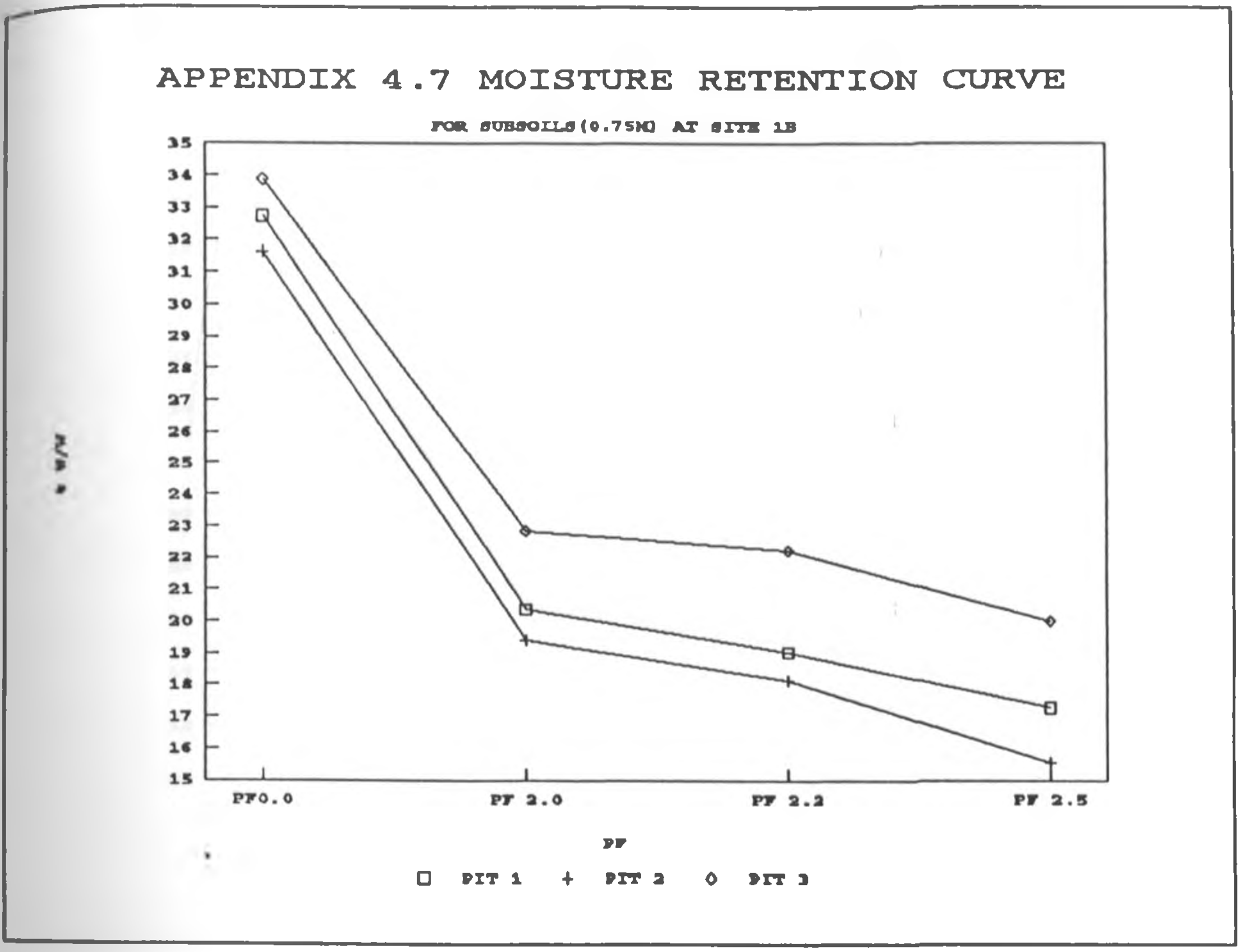


APPENDIX 4.5 MOISTURE RETENTION CURVE

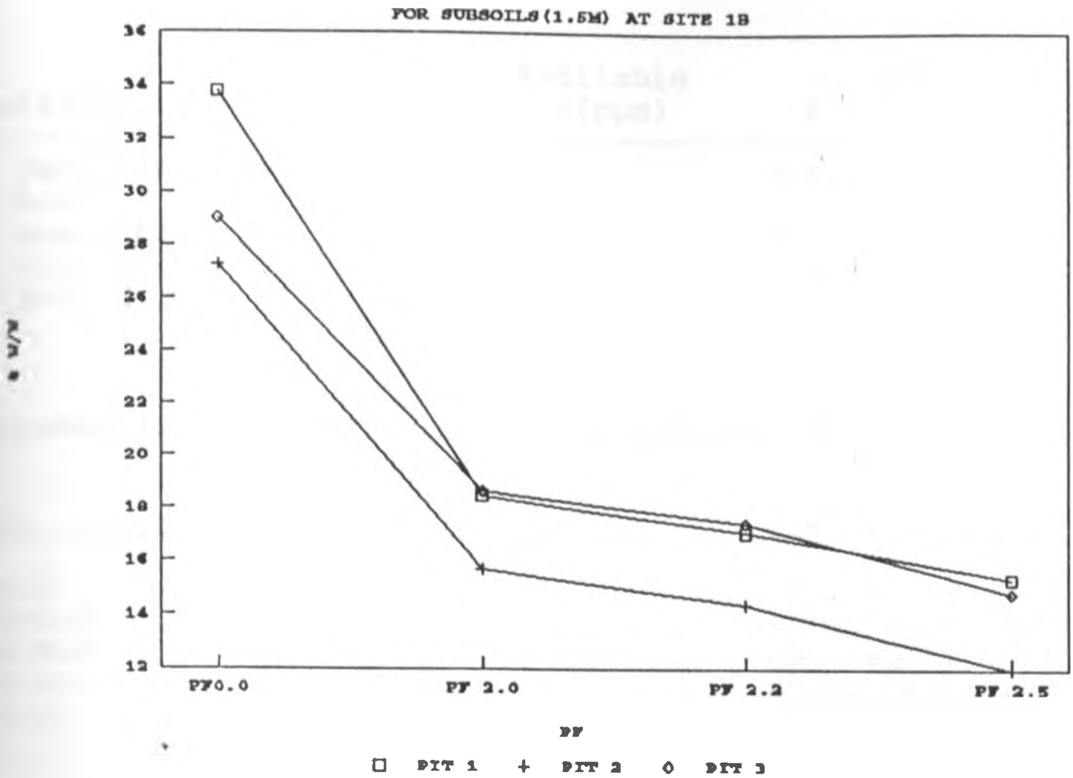


APPENDIX 4.6 MOISTURE RETENTION CURVE




APPENDIX 4.7 MOISTURE RETENTION CURVE
FOR SUBSOILS(0.75M) AT SITE 1B
35
34
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
% W/W
PF0.0
PF 2.0
PF 2.2
PF 2.5
PF
PIT 1
PIT 2
PIT 3

APPENDIX 4.8 MOISTURE RETENTION CURVE



Appendix 4.9 Four Classes defined for Available P and K, Ca, and Mg as used by National Agricultural Laboratories (NAL). (Touber 1983).

(me/100g)Class	Available P(ppm)	K	Available Ca	Mg
1. Very Low	0-20	0-0.2	0-2.	0-1
2. Low				
3. Moderate	20-80	0.2-1.5	2-9.0	1-3
4. High	80+	1.5+	10+	3+
5. Very High	-	-	-	-

Appendix 4.10 Classification of Electrical Conductivity (EC) Reading.

Ece	Classification
0-1.2	non-saline
1.2-2.5	slightly saline
2.5-5.0	moderately saline
5.0-10.0	strongly saline
>10.0	Excessively saline

Appendix 4.11 pH Classes.

>4.5	-	Extremely acid
4.5-5.0	-	v. strongly acid
5.1-6.0	-	strongly acid
6.1-6.5	-	medium acid
6.6-7.3	-	neutral
7.4-7.8	-	mildly alkaline
7.9-8.4	-	moderately alkaline
8.5-9.0	-	strongly alkaline
>9.0	-	excessively alkaline

Appendix 4.14 Herbaceous Species Botanical Composition and Percentage Ground Cover for Site IIA (Hill slope).

Major categories	Botanical Composition %	%Ground Cover
Dwarf shrubs and other herbs		
Indigofera spinosa	18.0	9.38
Justicia odora	11.0	5.63
Indigofera cliffordiana	9.0	5.0
Barleria eremoides	6.0	3.13
Purpelia sp.	6.0	3.13
Ocimum suave	5.0	2.5
Sericocomposis hilderbrandtii	1.0	0.63
Unidentified herb (Ngalayoi)	2.0	1.25
Unknown herb I	22.0	11.88
Unknown herb II	2.0	1.25
Lippia sp.	1.0	0.63
Kyllinga sp.	4.0	1.88
Tetrapogon sp.	13.0	6.88
Other categories		
Litter		1.88
Grass litter		6.25
Woody litter		10.0
Standing dead (woody)		0.63
Bare soil		1.88
Bare pavement and Rocks		7.5
Gravel		18.75

Appendix 4. 15 Herbaceous Species Botanical Composition and Percentage Ground cover at site IIB (Hill Slope).

Major categories	Botanical Composition %	% Ground Cover
Dwarf shrubs and herbs		
Barleria eremoides	8.0	2.9
Justicia odora	13.0	5.0
Indigofera cliffordiana	8.0	2.9
Indigofera species	5.0	2.6
Amaranthus species	3.0	1.2
Indigofera spinosa	9.0	3.3
Hibiscus sp	2.0	0.83
Ocimum suave	2.0	0.83
unknown herb I	5.0	2.07
Duosperma eremophilum	1.0	1.24
Sessemum ocimum	1.0	0.41
unidentified herb (Ngalayoi)	1.0	0.41
Unidentified grass I	2.0	0.83
Unidentified grass II	1.0	0.41
Oropetium sp.	7.0	2.4
Tetrapogon spathecous	25.0	10.4
Lycium sp.	3.0	1.24

Appendix 4.14 Herbaceous Species Botanical Composition and Percentage Ground Cover for Site IIA (Hill slope).

Major categories	Botanical Composition %	Ground cover
Dwarf shrubs and other herbs		
Indigofera spinosa	18.0	9.38
Justicia odora	11.0	5.63
Indigofera cliffordiana	9.0	5.0
Barleria eremoides	6.0	3.13
Purpelia sp.	6.0	3.13
Ocimum suave	5.0	2.5
Sericocomposis hilderbrandtii	1.0	0.63
Unidentified herb (Ngalayoi)	2.0	1.25
Unknown herb I	22.0	11.88
Unknown herb II	2.0	1.25
Lippia sp.	1.0	0.63
Kyllinga sp.	4.0	1.88
Tetrapogon sp.	13.0	6.88
Other categories		
Litter		1.88
Grass litter		6.25
Woody litter		10.0
Standing dead (woody)		0.63
Bare soil		1.88
Bare pavement and Rocks		7.5
Gravel		18.75

Appendix 4. 15 Herbaceous Species Botanical Composition and Percentage Ground cover at site IIB (Hill Slope).

Major categories	Botanical Composition %	GroundCover
Dwarf shrubs and herbs		
Barleria eremoides	8.0	2.9
Justicia odora	13.0	5.0
Indigofera cliffordiana	8.0	2.9
Indigofera species	5.0	2.6
Amaranthus species	3.0	1.2
Indigofera spinosa	9.0	3.3
Hibiscus sp	2.0	0.83
Ocimum suave	2.0	0.83
unknown herb I	5.0	2.07
Duosperma eremophilum	1.0	1.24
Sessemum ocimum	1.0	0.41
unidentified herb (Ngalayoi)	1.0	0.41
Unidentified grass I	2.0	0.83
Unidentified grass II	1.0	0.41
Oropetium sp.	7.0	2.4
Tetrapogon spathecous	25.0	10.4
Lycium sp.	3.0	1.24