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The Effect of Spacing of Hashab (*Acacia senegal*, (L.) Willd) Plantation on Yield of some Traditional Field Crops in Southern Darfur.

BY

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A Thesis

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Dedication

**To the soul of my father. To my mother and to my family.
With deep love and respect, for their patience and
encouragement.**

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Abstract

An experiment was conducted during the rainy seasons, 2001 to 2004, in Nyala locality in southern Darfur to investigate the effect of *Acacia senegal* on crops yield and to recommend the most appropriate tree spacings for cultivating agricultural crops within *Acacia senegal* plantations in “Gardud” soils. In addition, to assess gum arabic yield productivity within this system. The tree spacings used were 4x4 m, 4x8 m and 8x8 m. Meanwhile crop species used were millet (*Pennisetum glaucum*), sorghum (*Sorghum bicolor*) and sesame (*Sesamum indicum*). The trial was laid out in a completely randomized block design with three replications for each crop as well as control plots for trees and crops.

Tree parameters measured include tree height in (m), tree diameter (cm), tree canopy diameter (m) and tree crown projection (m) as well as tree root profile was excavated to determine lateral tree root zone. The crop variables were; plant population density in ha, number of leaf/plant, plant height (cm), days to 50% flowering, days to harvesting time, crops yield (kg/ha), 1000-seeds weight (g), straw weight (kg/ha) and land equivalent ratio (LER). Soil parameters namely, soil fertility (nitrogen, organic carbon and phosphorus) as well as soil moisture content were measured. Therefore, soil samples were augured under trees and in the open areas in

each plot at varied depths, namely 0-20 cm, 20-40 cm and 40-60 cm and 0-25 cm, 25-50 cm and 50-75 cm in the first two seasons and third season respectively. Besides, composite soil samples were also augured at 30 cm depth under tree canopy and in the open areas as well as control areas to determine soil nitrogen, organic carbon and phosphorus contents. Gum arabic yield was tapped within the tree spacings concerned to determine gum yield production per tree in (g).

The results indicated that plant population density, number of leaf/plant and plant height were affected by tree spacings. Therefore, significant differences were obtained within crop species and tree spacings in the different studied seasons. In addition, crop days to 50% flowering and crops days to harvesting time were affected by tree/crop interface as well as soil moisture content in the third season. While, crops yield, 1000-seeds weight and straw weight were affected by both tree spacings and rainfall amounts between the studied seasons. Land equivalent ratio was found higher in the 8x8 m tree spacing for millet and sesame crops. Whereas tree height, tree diameter, tree canopy diameter and tree crown projection were affected by tree/crop interaction particularly in the intercropped plots. Furthermore, tree root zone was superficial and fine roots were spread in the surface soil layer. However, total soil moisture content was found to be higher under this agroforestry system than in open areas, namely in the 4x4 m and the 8x8 m tree spacings. In addition,

tree canopy has substantial effect in rainfall interception. Moreover, tree/crop interface was found higher under surface soil layer for sesame crop, namely the 0-25 cm soil depth whereas under millet and sorghum crops this interaction was extended to the 25-50 cm soil depth. In contrast, soil fertility, namely nitrogen and organic carbon and phosphorus contents were not affected whether under tree canopy or in open areas. Whereas gum arabic yield was higher in the 4x8 m tree spacing than in the 4x4 m and the 8x8 m. Therefore, rainfall amounts and tree/crop interface particularly in narrow tree spacing were found to have substantial effect in this agroforestry system. Thereby, for modeling any agoforestry system for dry land however, these matters should be taken in consideration.

بسم ا   الر   ن الرحيم

خلاصة البحث

أجريت هذه التجربة   الفترة ب   2001 إ   2004 خلال فترة ا ريف   لية نيالا بولاية جنوب دارفور من اجل معرفة اثر شجرة ا شاب على إنتاجية ا اصيل . و كذلك من اجل التوصية با سافة البينية ا ناسبة للتحميـل ين ا شاب و ا اصيل   أراضي القردود. كذلك من اجل تقييم إنتاجية الصمغ العر   ت ضوء هـذا النظـام الزراعـ ـ ـ ـ ـ ـ ـى الغـ ـ ـ ـ ـ ـا . اسـ ـ ـ ـ ـ ـتخدمت ا ـ ـ ـ ـ ـ ـسافات بـ ـ ـ ـ ـ الاشجار التالية (4 4 متر و 4 8 متر و 8 8 متر) بينما ا اصيل ا   استخدمت فهى الـ دخن و الـ ذرة و السمسم .   استخدام تصميم القطاعات الكاملة العشوائية   تنفيذ التجربة بعدد 3 مكررات بالإضافة إ   الشواهد .   قياس متغ ات الأشجار طول الأشجار با تر و قطر الأشجار بالسم و تاج الأشجار با تر و   ريط التاج با تر بالإضافة إ   ا   فر لتحديد عمق ا ذور السطحية للشجرة و انتشارها. بينما ا تغ ات ا اصة با اصـيل فهـي : كثافة النباتات با كتار و عدد الأوراق   النبات الواحد و طول النباتات و عدد الأيام ل 50 % أزهار و عـدد الأيام للحصاد و إنتاجية ا صول با كتار بالكجم و وزن 1000 حبة با رام و الوزن للمادة ا افـة با كتـار بالكجم و الوزن ا كا   للأرض بالإضافة إ   ا علومات ا اصة صوبة التربة مثل النتروج   و الكربون العضوي و الفوسفور قد أخذت و كذلك رطوبة التربة.   اخذ هذه العينات من التربة بواسطة الاوجر من   ت الأشـجار و الأماكن ا الية من الأشجار على أعماق 0-20 سم و 20 - 40 سم و 40-60 سـم   الـسنة   الأوائـل للتجربة بينما أخذت على أعماق 0-25 سم و 25-50 سم و 50-75 سم   السنة الثالثة علـى التـوا . بالإضافة إ   عينات التربة ا ختلطة على عمق 30 سم من الأشجار و الأماكن ا الية من الأشجار و الـشواهد لتحديد عناصر النتروج   و الكربون العضوي و الفوسفور. بينما   طق الصمغ العر   نفس ا ـسافات البينيـة

للأشجار لتحديد إنتاجية الشجرة با رام. أعطت النتائج أن كثافة النباتات با كتار و عـدد الأوراق النبـات الواحد و طول النباتات تأثرت با سافات البينية للأشجار و كذلك وجدت أن هنالك فروق معنوية ب ا اصـيل ا ختلفة سنوات البحث باللاضافة إ إن عدد الأيام ل 50% أزهار و عدد الأيام للحصاد قد تأثرت بعمليـة التنافس ا ذري ب الأشجار و ا اصيل و كمية الرطوبة التربة السنة الثالثة. كذلك إنتاجية ا صول و وزن 1000 حبة و وزن ا ادة ا افة قد تأثرت با سافات البينية للأشجار و كمية الأمطار ا واسم ا ختلفة . ا عدل ا كا للأرض وجدت أ ا عالية ا سافة البينية 8 8 م للدخن و السمسم. بينما قطر الأشجار و قطر الساق و قطر تاج الأشجار و التخريط للأشجار قد تأثرت بعملية التنافس ا ذري ب الأشجار و ا اصيل خاصة مواقع التحميل . بالإضافة إ إن جذور الأشجار قد وجدت سطحية بالإضافة إ وجود جذور دقيقة بكثافة عالية على نفس العمق السطحي. ا دير بالذكر أن ا توى الكلى للرطوبة التربة أعلي منها الزراعة الغابية عن ا نـاطق ا الية من الأشجار خاصة عند ا سافات البينية للأشجار 4 4 م و 8 8 م . بالإضافة إ ذلك إن قطـر التـاج للشجرة له تأث مادي على كمية الأمطار ا تساقطة . كذلك وجد أن التنافس ا ذري ب الأشجار و ا اصـيل تكون عالية الطبقة السطحية للتربة عند صول السمسم بينما تصل هذه العملية إ عمق 25-50 سم عنـد صو الدخن و الذرة. بينما عناصر التربة من النتروج و الكربون العضوي و الفوسفور تتأثر ت الأشجار و الأماكن ا الية من الأشجار. بينما إنتاجية الصمغ العر وجدت أ ا عالية ا سافة البينية 4 8 متر عنـها 4 4 متر و 8 8 متر. لذلك فان كميات الأمطار و عملية التنافس ا ذري ب الأشـجار خاصـة حالـة ا سافات البينية الضيقة للأشجار ا اثر مادي على هذا النظام الزراعى الغا و لابد من وضعها الاعتبار عند تـ ـ ـ ـصميم نظـ ـ ـ ـ ـم زراعيـ ـ ـ ـ ـة غابيـ ـ ـ ـ ـة للمنـ ـ ـ ـ ـاطق ا افـ ـ ـ ـ ـة.

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CHAPTER I

INTRODUCTION

Agriculture is the backbone of Sudan economy. Traditionally the practice was a form of shifting cultivation where a small piece of forest or bush land is basically cleared by the peasents for growing their food crops. With increasing population, farmers got more sedentary and permanent fields were cultivated. Large schemes were established since the twenties of last century. The Gezira agricultural scheme was developed in 1925 when Sennar Dam was built. Other schemes followed after independence *e.g.* New Halfa, Elsuki, Elrahad, Western Sennar and Kenana, Assalaya sugar schemes. Moreover, individual private irrigated schemes were established along the Blue Nile, the White Nile and the main Nile. In addition, rainfed agricultural schemes were allotted to big farmers mainly in Gadarif area and the Blue Nile and to a small extent in the Nuba Mountains. The main agricultural crops were cotton, groundnuts, sorghum and horticultural crops in irrigated schemes (latter wheat was introduced in Gezira, New Halfa and Elrahad schemes for food security).

In the rainfed schemes, the major crops were *Sorghum bicolor*, Sesame (*Sesamum indicum*) and latter Sunflower (*Helianthus annuus*). In River Nile and Northern States, horticultural crops, wheat, and pulses were the major crops together with date palm.

In Southern Sudan agriculture was not so intensive –smallholdings were cultivated for food crops such as cassava, sorghum, pineapple and Mango. It is more or less subsistence agriculture. Along with these, traditional agriculture concentrated in western Sudan.The main agriculture practice was peasant farming associated mainly with *Acacia albida* and *Acacia Senegal*. The major agricultural crops are groundnuts, sesame, millet, karkadi, lubia, and watermelon in Qoz soils. In volcanic soils of Jebel Marra, there is room for Mediterranean crops because of the cool weather. Thus crops cultivated there are citrus, apples, grapes, wheat, potato, pulses, faba beans etc. The area is potentially highly productive. On clay soils, the main crops are sorghum, okra, sesame and fodder crops, horticultural crops are confined to watercourses and special soils. The general practice is household farming in small plots near the dwellings inside the natural forests or bush lands.

In some parts of western Sudan mechanized farming was introduced during the seventies but was abandoned due to the negative effects on soil and the prevalence of drought. In 1979, Western Savanna project covering an area of 137000 km2 funded by ODA-IDA and IFAD was initiated. The objectives were to establish a sustainable farming system for Southern Darfur utilizing *Acacia senegal* trees to restore soil fertility in field rotation, thereby, helping nomadic settlements and maintaining safe agricultural practices in the area, *e.g*. using animal drawn ploughs instead of tractor ploughs particularly in the Qoz sands. Also, introduction of chisel plough in the Nagaa soils (Gardud), which proved usefull. Seed propagation centers were also developed within the project area to provide improved seeds. Fodder legumes were also propagated *e.g. Clitoria ternata, Stylosanthus hamata, Stylosanthus scabra, Stylosanthus guianensis and s*irato *(Macroptilium atropurpurum)*. Altogether six settlements were established throughout the project area in Eldaein, Buram, Tulus, Rahaid Elbirdi and Idd Elfirsan. These settlements helped in establishing communal settlements where grazing rights are preserved for every body and services provided in localized centers. This minimized tribal conflicts and ensured pasture and dwellings for the people and their animals. These settlements, however, led to some negative impacts on the soils due to concentration of crop cultivation and grazing in limited areas where un-organized agriculture is practiced. It is, therefore necessary to up-grade the agricultural practice by developing a model that would incorporate trees and crops in a sustainable agroforestry practice. The main objectives of this study were:

1/ to investigate the effect of *Acacia senegal* on crop yields.

2/ to study the effect of spacing on performance of three crops within *Acacia senegal* plantations in Gardud soils of Southern Darfur.

CHAPTER 11

LITERATURE REVIEW

2.1. Agroforestry definition:

There are many definitions for agroforestry (AF). Lundgren (1983) defined agroforestry as a collective name for land use systems and technologies where woody perennials (trees, shrubs, palms, bamboos etc) are deliberately used in the same land management unit as agricultural crops and/or animals either in some form of spatial arrangement or temporal sequence. According to Raintree (1984) agroforestry was defined as a sustainable land use system, which combines crop production with trees and/or animals simultaneously or sequentially on the same unit of land applying management practices that are compatible with the cultural practices of the local population. It is thus, a socially and economically acceptable integrated form of land use, involving trees that improves or does not degrade the soil and permits or increases land productivity for plant, animal and wood.

Baumer (1990) defined agroforestry as a collective term for system and technology of land use where perennial woody plants are deliberately cultivated on ground otherwise used for crop and/or livestock rearing in spatial or temporal arrangement and where there are interactions at once (ecological and economic) between the woody plants and other components of the system as stated by Lundgren and Raintree (1982).

2.2. Agroforestry background:

Agroforestry was practiced in different parts of the world under various forms and names. The term agroforestry became firmly established since the late sixties and early of seventies of last century in international development and rural science terminology. Raising trees together with agricultural crops on the same piece of land has been practiced for many years in the tropics. The traditional agroforestry systems which based on *Acacia albida* and other multi-purpose trees is practiced by Fur people in Jebel Marra area. According to King (1968), agroforestry has been the practise throughout the world as planting trees species and agricultural crops in combination. It was the general custom in Europe until the middle ages to clear fell derelict forests, burn the slash, cultivate food crops for varied periods on the cleared areas and plant or sow tree species before along with or after the sowing of agricultural crops. This farming system is no longer practiced in Europe. It was practiced in Finland to the end of the last century and in Germany to 1920's.

Farmers in central America planted a variety of crops with different growth habits e.g. coconut or papaya with a lower layer of bananas or citrus; a shrub layer of coffee or cacao with tall or low annuals such as maize and a spreading ground cover of plants such as squash (Wilken, 1977).

In Philippine, the Hanunoo farming system planted or conserved trees from the original forests for provision of food, medicine, cosmetics, wood and protection for food crops (Conklin, 1957).

In southern Nigeria, yamo, maize, pumpkins and beans were typically grown together under cover of scattered trees (Forde, 1937). The Yoruba of western Nigeria practiced an intensive system of mixed herbaceous shrub and trees cropping as an-inexpensive way of controlling erosion and leaching and maintaining soil fertility (Ojo, 1966). In Zambia, numerous subsistence crops were grown in mixture with tree species (British Government, 1938). The system is spread in southern Africa by 1887 (Hailey, 1957), to India by 1890 and to Bengal in 1896 (Raghavan, 1960). The system was abondoned for few decades in Benegal and resumed in. In the second decade of the 20^{th}, the system became more popular as a relatively in-expensive method of establishing forests (Shebbeare, 1932).

In Kenya, the Shamba system was practiced as an agroforestry system (Mburu, 1981). Up to 10% of maize production came from forest areas in Kenya (Wannyeki, 1981).

In India, agroforestry practices indicated that ‘askali’ land could be improved by growing *Prosopis juliflora* trees and Kernal grass. Introduction of Kernal grass and fuel wood increases while soil pH decreased (Singh *et al*.1969). In Sudan, there are some agroforestry pracitces such as**:**

1/*Acacia senegal* bush fallow cultivation cycle (Hussein, 1983). Viz.

A/ Clearance of the trees.

B/ Cultivation for field crops for period of 4-6 years.

C/ Bush fallow in which *A.sengal* is the most vigorous tree colonizer.

D/ Tapping of gum at 4-6 years.

E/ Bush clearance in 12-15 years.

Hussein and Eltohami (1998) reported that *A.senegal* plantation proved to be beneficial in retaining the depleted soil nutrients particularly organic carbon and nitrogen.

2/ In Jebel Marra, semi-permanent terraced fields are cultivated with millet and other subsistence crops under multi-purpose trees dominated by *A.albida.* Others species are included such as *Cordia abyssinica* and *Zizyphus spina Christi* (Miehe, 1986). The system has supported a densely settled population for centuries. The present subsistence farming in the region is more exploitive resulting in a decreased tree cover, increased danger of soil erosion and declining soil fertility.

3/ In the Gezira irrigated Eucalyptus (*Eucalypus microthica)* plantations were grown with sorghum, lubia and short grass as a trial.

4/ In Khartoum North, at the University of Khartoum Top Farm, 5 studies were conducted in alley cropping with *Leucaena leucocephala*. The prunings ameliorated the soil and improved crop yield of Dura (S*orghum bicolor)*.

2.3 Examples of agroforestry practices by farmers in Sudan:

A/ Vegetables – alfalfa (Berseem), Henna – fruit trees grown between citrus and date palms in the Nile and Northern provinces. These were practised under irrigation.

B/ Bulbrush millet and sorghum were grown under *A.albida* for grain production as well as pods, fodders, grain and fuel wood in western Sudan, where annual rainfall is about 300-650mm.

C/ Lubia, sorghum and maize between *E.microthicato produce* grains, fodder and fuel wood in Gezira scheme under irrigation.

D/ *A.senegal* and millet cycle to produce fuel wood, gum arabic and fodder in Kordafan region where rainfall 300-650 mm (Bayoumi, 1984).

It worthmentioning that other works such as trials with sorghum on Qoz sands of Kordafan have shown that five year yields on soil cultivated after 12 years of fallow under *A.senegal* were much better with spots of the land where *A.senegal* trees were naturally uprooted than at distances away (Daxiades Associates, 1964). Composite soils samples taken around up-rooted 12 years old *A.senegal* trees at various distances from the trees for the horizons A, B and C showed that nitrogen and carbon contents were higher near the trees. The highest nitrogen content was about 1.75 m away from the tree. Clay content was also slightly higher around the tree base, but soil pH, P, and K were unaffected. The higher fertility around trees was due to accumulation of nitrogen due to litter mineralization and root decay.

On the other hand Ferguson (1949), reported that continuous cultivation of sorghum for 30 years under *Acacia albida* indicated that soil fertility is adequately maintained under the tree. Similarly, irrigated wheat gave higher yields under trees.

2.4. Agroforestry classification:

1/ Agro- silvicultural (Agriculture+ forestry):

Here crops and trees including shrub/vines are incorporated in different ways viz:Intercropping, alley cropping, or (avenue cropping), on farm planting etc.

2/ Silvopastoral (wood + domestic animals):

Use of trees for browsing and wood plus animal production.

3/ Agro-silvo-pastoral ((Agriculture +forestry + livestock):

Crop, animal and woody perennials mix around dwelling. Multi-purpose woody hedges and integrated crop –shrub animal production are incorporated.

In Sudan agroforestry has been mainly practiced with *Acacia senegal* and *A.albida* in the form of Taungya and intercropping or on-farm planting. The system has helped establishing large areas of *Acacia senegal* in the central clay plains by sowing *Acacia senegal* seeds with S*orghum vulgare*. In sand dunes of western Sudan, agricultural crops of as groundnuts, sesame and millet have been cultivated in the gum garden especially in kordafan state. In Darfur state, millet has been cultivated with *Acacia albida* giving higher yields for the agricultural crops and maintaining the soil fertility (Hussein and Fadl, 2001; Nasreldin, 1996; Miehe, 1986).

2.5. Agroforestry forms:

2.5.1. Dune fixing:

Woody perennials are used to stop sand movement and to create a favourable environment for the production of wood, forage, food, recreation, wild game etc.

2.5.2. Home gardens:

These are made of numerous plants both woody and herbaceous carefully mixed and forming several vegetation storey of multi-purposes species. They are particularly attractive in high rainfall areas (Nair, 1985b). Commercial crops: include woody perennials grown for commercial purposes (coffee, cacao, tea, gum arabic), the other components should be selected carefully e.g. grass cover, over storey of shade trees, mixed intercropping. Animals can benefit from tree shelter and forage production. Judicious selection is necessary.

2.5.3. Green hedges:

These consist of lines of woody plants, one or more rows deep, forming a continuous barrier and cut regularly so that the barrier formed by the mass of stems and branches remains dense. The woody perennials may be affected by repeated cutting and competition, which may hinder the practice. Trees can be utilized for drying out swamps e.g. *Sesbania sesban* planted on ridges in marshy depression in Rwanda.

2.5.4. Green fence:

Trees are planted at close spacing and wires may be stretched between wider spaced trees. The tree can be pruned to provide fodder or fuel.

2.5.5. Fringe planting:

Trees are planted around agricultural fields. The trees managed by pruning, trimming or pollarding depending on the site conditions.

2.5.6. Alley cropping:

This is practiced in humid zones or where irrigation is possible. The woody perennials can provide wood, forage for animals as well as shelter to the crops and it improves the soil.

2.5.7. Bush fallowing:

In this system land is abondoned for considerable peroids of time after continuous cultivation in order to improve nutrient status of the soil. Thus in humid areas species like *Leucaena leucocephala* are excellent since their leaves decompose easily due to ample soil moisture. However, This process resulted in adding organic carbon, nitrogen and other nutrient elements to the soil. But care should be taken so that it does not get out of hand and become a weed.

2.5.8. Intercropping:

In this practice perennials are intercropped with herbaceous plants and/or animals in different arrangements. It is an alternative to shifting cultivation that causes plant cover denudation and rapid degradation of ecosystem under human pressure on land. Thus, in order to achieve compatibility in agroforestry with respect to intercropping, phonological characteristics of woody components should be considered. This helps in managing the capabilities of competition as well as the potential of micro-site enrichment (Huxley, 1984).

2.5.9. Agroforestry practices identified by ICRAF:

2.5.9.1. Shifting cultivation:

The term shifting cultivation has been applied to a wide range of cropping systems. Here, it refers to "a system in which relatively short periods of continuous cultivation are followed by relatively long periods of fallow" (FAO/UNIVERSITY OF IBADAN, 1982). Hereby, it has been distinguished from short fallow and permanent cultivation. Shifting cultivation originated in Africa and pparticularly redominated in the humid areas of the middle belt of West Africa. It is found in sparsely populated areas of Tanzania, Zambia, northern Mozambique and Zaire (FAO, 1984).

In areas where population density is high and land is in short supply, shifting cultivation in its traditional form is neither appropriate nor possible because it requires surplus land that can be held in long-term fallow. In effect, it involves the practice of clearing by fire and cultivating the cleared plots. Farmers prefer cleaning forest regrowth rather than high forest, which they protect (Lassilly-Jacob, 1982).

The main purpose of fallow period in shifting cultivation is to improve soil fertility and soil’s capacity to resist erosion. In this respect, other methods to decrease the length of fallow period can be introduced to some extent without “seriously compromising these functions” (Jean, 1975).

Nevertheless, the actual length of time depends on various factors, such as soil and vegetation types as well as the intensity of previous cultivation of the area. In wetter climates, sophisticated means of weed management techniques were used to prolong the period of cultivation or to spend more time on this work (FAO, 1983). In realizing shifting cultivation in the tropics, a crisis in man–land relations is developing; pressure on land has already led to far reaching changes in agricultural economy. Four probable directions are in use:

1/ Evolution towards permanent cultivation of annual crops *e.g.* Eastern Nigeria.

2/ Increasing tree planting in the acreage lands as oil palm, which provides assured cash income.

3/ Farmers are engaged partially in other works such as trade and manufacturing and in plantation during the wet season.

4/ Migration of labour force to cities, leaving the rural areas as in Nigeria, Zambia (FAO, 1983, Grossman, 1974, Richards, 1939).

2.5.9.1.1Crops grown in the shifting cultivation:

2.5.9.1.2. Sorghum (*Sorghum bicolor*):

Sorghunm (Sorghum bicolor) is divided into sub-species *bicolor* which include all the domesticated grain sorghum and the two wild sub-species *drummondii* and *arundinaceum* (Dwet, 1978). The cultivated sorghum is divided into five basic races: Bicolor, Guinea, Caudatum, Kafir and Dura (Harlan and DeWet, 1972). Sorghum is believed to have been originated in Africa: its diversity center may be Kordafan in Sudan as stated by Evelin (1951).

The major ecological zone for sorghum cultivation lies between humid forests and near the equator and the deserts of arid and semi-arid tropics (Sheetharama *et al*. 1984).

Worldwide Sorghum is grown both under irrigation and rainfed. It can be grown under a wide range of rainfall ranging from 250 mm up to 1500 mm or more. The yield production under good condition ranges between

3000 to 4000 kg/ha. Under limited soil moisture the yield is reduced to 300 kg/ha (House, 1985).

In Sudan, sorghum is grown both in irrigation and rainfed sectors. The average yield is about 750 kg/ha (Year book of Agriculture, 1984).

Sorghum considered as the major staple food and as export crop besides it's uses as fodder for animals and as building material. It is worthwhile to mention that most of sorghum is photosensitive as they flower at the end of the rainy season (October –November) and grain ripens after the rain have finished. Therefore, the optimum temperature for grain sorghum germination is around 25° C. Soil moisture and temperature are the most important factors affecting sorghum seed germination as stated by Amin (1988).

2.5.9.1.3. Millet (*Pennisetum glaucum)*:

Pearl millet (*Pennisetum glaucum)* is a diploid species (2n: 14); it was believed to be originated in West Africa (Stoskopf, 1985; Jauhar, 1981). It is now widely cultivated in different parts of the world. Pearl millet is of great importance in the semi-arids zones and the tropics, where it is the stable food for millions of the people. The crop commonly is grown under the most difficult farming conditions including those in drought –stricken areas where soil fertility is low and food supplies are dependent on rainfall. It is also grown in erratic rainfall areas (Vanderlip, 1991). Solar radiation is high in these areas as a result of infrequent cloudness conditions and low humidity thus leading to high evaporation. In Sudan pearl millet comes after sorghum in terms of area-wise and production. The productivity of pearl millet in Sudan is low when compared with the world average. This low productivity is attributed to the low rainfall where pearl millet is traditionally cultivated (Abul Elgasim, 1989). It is worthwhile mentioning that temperatures ranged between 10-12° C as base temperature and 33-34° C as the optimum for germination. Germination rate increases linearly within this range and declines to zero at about 45- 47° C. Temperature range of 2-3° C were reported to damage the seedling (Stoskopf, 1985). Other developmental processes as leaf and spikelet initiation and tillering respond similarly to temperature. Furthermore, yield is influenced by both temperature and light.

Pearl millet was reported to flower and set seed at temperature between 25-45° C. Thus pearl millet is a short day plant and adversely affected by the long day duration (Burton, 1980).

2.5.9.1.4. Sesame (*Sesamum indicum, L.*).

It is a very ancient crop with a wide distribution in tropical and sub-tropical region. The main producing countries are: India and China. The crop has various uses of which oil is most important. Seed yield is governed by many factors of which genetics and environmental interaction are the most influential. Therefore, good seed yield may be achieved through proper agronomic techniques as well as by adequate use of irrigation. Sesame is an important cash crop in Sudan. It is grown under the rainfed conditions in both the mechanized sector and the traditional farming system. Dry spells during flowering or capsules filling limit the yield. Growth can be greatly reduced by drought particularly 30-40 days after sowing at the commence of flowering. This coincides with the period when maximum leaf production occurs.

Sesame normally requires relatively warm conditions during growth to produce maximum yield. A temperature range of 25-27°C encourages rapid germination and initial growth and flower formation (Weiss, 1971). Sesame is basically a short day plant. It requires 10 hours/day. It normally flower in 40-50 days (Tomar and Bhargava, 1980; Naryanan and Reddy, 1982). In Sudan days to maturity for sesame ranges between 67 and 158 days (Khidir and Osman, 1970; Osman, 1973; Ahemed, 1985). DAOAD (1988) reported a yield of 102 kg/ha for sesame

2.5.10. Taungya:

Agricultural crops are planted between tree seedlings during the early establishment phase and up to 3-5 years in Kenya (*Cuppressus*, *Eucalyptus spp +maize*, potato, beans etc). Forage plants can also be used (*Acacia senegal* and *Andropogen gayanus*). There should be a suitable planting programme for long rotation trees. The practce is effective in providing food for forest workers and forage for cutting by cattle rearers.

The farmers should participate voluntarily: Foresters accept the system if farmers, driven by need, request it.

2.5.11. Apiculture:

In this form of agroforestry system trees and shrubs are utilized for honey production: They should have nectar that attracts bees.

2.6. Agroforestry in the Semi-arid Tropics:

The semi-arid tropics (SAT) cover an area of about 20 million km². It covers most of west, east and the southern part of central Africa; most of India, northern Myanmar, north eastern Thailand and northern Australia; most of Mexico; and large parts of eastern and central South America. The SAT environment is characterized by: high atmospheric water demands, a high mean annual temperature (>18° c), and low, variable annual rainfall (400 to 1900 mm) as indicated by Swindale (1982). The climate of most of the SAT is monosoonal with over 90% of the rainfall occurring in the period April –October in the Northern Hemi-sphere and October-April in the Southern Hemi-sphere.

2.6.1. Parkland System:

This agroforestry system is largely extended in Sub- Saharan Africa in which mature of multi-purpose trees (mainly *Faidherbia albida)* are dispersed in cropped fields (Vandenbeldt, 1990; Miehe, 1986). This agroforestry (AF) system extended across the entire Sudano-Sahelian zone of west Africa comprising associated crops under varying densities of mature trees. In India, much efforts were focused on *Prosopis cineraria* /millet mixture; *Faidherbia albida* grain system spread throughout the Sahelian zones. Many studies have shown the enhanced effect of these species, particularly *Faidherbia albida* on grain crops underneath (CIRAT, 1996; Nasreldin, 1996). The increase in crop yield was attributed to the improvement of soil characteristics under trees as a result of litter fall or animal dungs (Miehe, 1986; Nasreldin, 1996).

Negative effects may exist due to root competition and over shading e.g. *Prosopis juliflora* reduced sorghum yield as reported by Prajapati *etal*. (1971). Similarly *Vitellaria paradoxa* and *Parkia biolobosa* reduced crop yields in parkland agroforestry system due to competition. Therefore, the choice of tree and crop species should be considered and the optimum combination carefully adopted. Recently several parklands were converted to mono cropping for cash in Africa (Kessler and Breman, 1991).

2.6.2. Silvopastoral systems:

These systems combine fodder trees and animals. Intensive silvopastoral systems exist worldwide (Nair, 1985b). In SAT countries two examples may be cited: (A) The animals are the permanent feature of the farm as in India where animals are fed with supplementary pasturing; (B) Nomads move from one site to another according to the changing pasture condition or herded to distant pastures during the rainy season (Vandenbeldt, 1990). In both examples, livestock plays an important role in sustaining soil fertility through the animal manure. In India, the manure is collected and spread in the farmyard while in the Sahel; herds are hired to graze animals on arable fields.

In Africa up to one-third animal feed comes from rangelands.

NAS (1984) reported that trees and shrubs provide animals with digestible protein, minerals and vitamins. As in Senegal research work showed that Bovine consumes about 1200 kg of grass and herbs and more than 500 kg of woody forage. However, this consumption was reported in the dry season (November to July). Therefore, about 5 ha of average bush lands are needed to feed one tropical livestock unit that corresponds to 250 kg. Whereas in highly productive sites "as seasonally flooded depression", one ha will suffice (NAS, 1984). In drier parts, 10-20 ha of bush land may be required to feed one livestock unit. Since most grazing land in SAT of Africa and India are public ownership, over use and irreversible decline are expected (Jodha, 1985; Jahnke, 1982). Acacias and other pod producing trees and shrubs offer high quality fodder in the dry season. Moreover, they can also be grown alone or in association with agricultural crops (Raintree, 1985a).

Development of silvopastoral system in SAT countries would be beneficial. Much effort must be exerted to incorporate research on increasing fodder production into farming systems and designing of cut and carry systems (Vandenbeldt, 1990).

2.7. The influence of tree on crops:

Interaction occurs at three levels within crops and trees. There are interactions among trees, crops and between trees and crops. These interactions may be positive or negative. In positive interactions, the performance of crops did not affect by trees. This occurs when, for example, there are differences in rooting patterns and growth rhythms of the trees and annual crops. However, negative interactions between trees and crops are brought about when there is competition for resources especially water, nutrients, and light. Similarly allelopathic effects may occur and at times, the tree may attract diseases and pests. Therefore, the degree of competition between trees and crops in agroforestry depends mostly on species characteristics, planting density, spatial arrangement and tree management as stated by Nair (1993). Thus competition is expected to be more severe in agroforestry systems compared to sole cropping. In semi-arid zones below ground competition for water seems to be more severe than for light (Singh *et al.* 1989). Thus for the success of agroforestry in semi-arid conditions incorporation of less competitive species for water is essential (Singh *et al.*1989). Competition for light, precipitation interception, microclimate changes through modification of temperature, wind speed and relative humidity were found (Ong *et al.* 1992). In this respect, competition for light seems to be more important than for other above ground factors. This is because light directly affects photosynthesis, transpiration and energy balance of the associated herbaceous crops (Resonberg *et al.* 1993). However, shade is advantageous in reduction of soil temperature during crop germination and establishment in hot climates (Vandenbeldt *et al.* 1990); reduction of evapotranspiration of shaded crops, and prolongation of crop growth period (Singh *et al.* 1989). However, transpiration of trees under semi arid conditions may lead to water stress of associated crops as stated by Nair (1993). Shade suppresses weed under tree canopy and in other cases shade can suppress incidence of bacterial and fungal diseases due to increased humidity and decreased wind speed as stated by (Nair, 1993).

Shade can also control some pests and diseases. Balanced light used by trees is an important factor for successful agroforestry systems (Sato and Dalmacio, 1991). The amount of light intercepted in agroforestry system is the difference between the amount of the incident light and the fraction of light transmitted to the ground (Vandenbeldt, 1990). Trees reduce incident light by 10-80% according to the species and the distance between the trees (Corlett *et al.*1992). In agroforestry systems, competition for light may occur due to reduction in the amount of light recieved by the understorey crop. For example in Burkina Faso grain yield of sorghum was reduced by 50 % under Nere trees (*Parkia bilobosta)* compared to sole crops. The reduction in yield was explained by 20 % reduction in light intercepted by *Parkia bilobosta* canopy (Kessler and Breman, 1991).

2.8. Effects of trees on soils:

Agroforestry systems have the potential to make use of marginal and degraded land through the improving effects of trees. This can occurr through the capacity of trees to grow under difficult climatic and soil conditions coupled with their potential for soil conservation mainly in semi- arid, sloping lands and those with soil constraints. Therefore, tree litter and prunnings can substantially help to maintain soil organic matter and to improve physical properties and at the same time supply nutrients. Nevertheless, some problems between natural and agricultural ecosystem as water–use efficiency were found. However, other studies as in nutrient cycling showed positive effects as in windbreaks and contour hedges. Therefore, selection of trees to increase soil fertility should be characterized by:

1/ High rate of production of leafy biomass.

2/ Dense net work of fine roots, with a capacity for abundant mycorrhizal association.

3/ Existence of deep roots.

4/ High rate of nitrogen fixation.

5/ High and balanced nutrient content in the foliage (high in nitrogen, low in lignin and polyphenol).

6/ An appreciable nutrient content in root system.

7/ Either rapid litter decay, where nutrient release is desired, or a moderate rate of litter decay, where maintenance of a soil cover is required.

8/ Absence of toxic substances in litter or root residues.

9/ Capacity to grow on poor soils.

10/ Absence of severe competitive effects with crops, particularly for water.

11/ Low invasiveness.

12/ Productive functions or service functions other than soil improvement.

Thus, the capacity of trees to maintain or improve soils is shown by the high fertility status and closed nutrient cycling under natural forests, the restoration of fertility under forest fallow in shifting cultivation, and the experience of reclamation forestry and agroforestry.

Soil fertility can be measured or shown by the higher crop yields under trees canopy as in *Faidherbia albida*.

The trees improve soil fertility by processes which:

-Increase additions to the soil;

-Reduce losses from the soil;

-Improve soil physical, chemical and biological conditions.

Trees can attain these through: -

-Checking run off and soil erosion.

-Maintaining soil organic matter and physical properties.

-Increasing nitrogen fixation and uptake from the deep soil horizons (nutrient pumping).

-Promotion of more closed nutrient cycling.

About 100 species have been identified which are known to fulfill soil – improving functions, of which *Acacia species are* predominant (Young, 2001).

2.9. Effect of drought stress on plant growth and yields:

According to Kramer (1980) drought was defined as an environmental stress of sufficient duration to cause a plant water deficit or stress, which can affect plant growth and yield through its effect on the physiological processes. Therefore, adaptation of a plant to drought is classified in two major categories, these are: drought escape which is confined to those plants which can complete their life cycles before the dry season begins and seldom severely stressed. These include early maturing plants and ephemerals. This is often important when drought occurs late in the growing season. The second mechanism of adaptation to drought is drought tolerance, which refers to the ability of plant tissues to withstand water stress. This is further subdivided into dehydration postponement and dehydration tolerance. Dehydration postponement occurs by means of morphological or physiological modifications that reduce transpiration or increase adsorption. In this case, plants can withstand drought for a considerable period of time without becoming severely dehydrated. Dehydration tolerance e.g. dehydration without permanent injury, varies widely depending on the process under consideration, the stage of development, the duration of stress and the kind of plant. This mechanism is considered more important to crop plants because some plants can tolerate considerable water stress and recover when drought ends. However, crop plants rarely attain the genetic potential for yield because of the limitations imposed by the environment, especially unfavourable temperature and lack of water. Therefore, about one-third of the world potentially arable land suffers from inadequate supply of water and on the remainder; crop yields are periodically reduced by drought (Kramer, 1980). Turner and Begg (1981) reported that drought causes plant water deficit, which occurs in tissues of all transpiring plants as an inevitable consequence of flow of water along the plant. The degree of plant/ water deficit depends on the extent to which water potential and cell turgor are reduced below their optimum level (Kramer, 1980). However, plant water deficits are reported to result in the reduction in cell enlargement and consequently a reduction in leaf surface area. Field trials in millet showed significant differences between irrigation and rainfed regimes in grain yield, time to 50% flowering, time to maturing, number of heads per unit area, head mass and grain mass (Osmanzai, 1992). The mean yield of the irrigated millet was higher than the rainfed (3.04 t/ha and 0.97 t/ha respectively). However, time and intensity of stress may affect crop establishment, as in stress during the seedling stage or as in mid season stress that causes severe reduction on grain yield. Thus, if the stress terminated at or before flowering, the reduction in yield is small (up to 20 %) while the yield reduction approaches 70 % if the stress occurred during grain filling as reported by Sheethamara *et al* (1984). According to Hsiao *et al* (1976), some plants have the ability to adjust osmotically under water stress conditions as a drought resistance mechanism, which enable them to have a lower potential for stomatal closure and cell enlargement. Osmo-regulation has been observed in pearl millet (Henson *et al*. 1982) and sorghum (Wright *et al* .1983). Kanenmasu *et al*. (1984) showed that osmotic adjustment in pearl millet was lower than that for sorghum. Also, cell wall elasticity has been claimed as another mechanism for the maintenance of turgor under water deficit conditions. However, other factors may reduce grain yield *e.g.* in India dry land high temperatures before panicle initiation reduced the ultimate grain yield.

When sorghum crop is subjected to different moisture stress periods during the early growing period resulted in reduction in grain yield (from 1.4 to 23.8%). However, this reduction in grain yield increases if the stress periods extended from 59 to 71 days from sowing date as stated by Parashar (cited in Amin, 1988). According to Ahmed (1989) late season stress resulted in delaying of flowering, reduction in plant height, reduction in grain filling period, reduction in number of productive tillers, reduction in number of heads per meter square, reduction in grain size and reduction in grain yield in Sudan.

2.10. Contribution of Agroforestry to land tenure and forestry:

Agroforestry may be practiced either by integrating trees into farming systems or by integrating farmers into forests (Raintree, 1985). Appropriate selection of woody components may contribute to both productivity and sustainability of the farming systems as on marginal lands in several ways by; (1) enhancing the production of organic matter; (2) maintaining soil fertility; (3) reducing erosion; (4) conserving water and by creating a more favourable micro-climate for associated crops and livestock.

These “service roles” are above and beyond the direct “production role”. Trees can also play a role in supplying food, fodder, fuelwood, building materials and other raw materials for rural industries (Raintree, 1985). Furthermore, in traditional land use practices, agroforestry can play an important role in maximizing and diversifying the productivity even in highly fertile lands. In this context, intensive agroforestry systems exist in areas with a long history of population pressure reflecting its efficiency as a land use system (Raintree, 1985). On the other hand diversified agroforestry systems may be most appropriate form of land use where land tenure constraints, lack of marketing infrastructure or an unfavourable political economy make it imperative for small land-holders both in marginal or high potential lands in trying to reduce risks, or trying to satisfy most of their basic needs directly from the land resources under their control (Lundgren and Raintree, 1983). However, tropical land use systems were reflecting varying degrees of leakiness with response to the cycling of nutrients that are held in the soil vegetation complex (Nair, 1984) in spite of the fact that such systems like irrigated paddies, permanent trees crop and forests are predominately more sustainable than the others. Therefore, it is fundamental for trees in the tropics to have good prospects for plugging many of the holes in tropical farming systems. Thus the infilling of trees in agrofrestry systems can be extended from limited interstitial planting to virtually complete ones as in home garden mode. In this context, economic value of the tree can be identified either by deciding if it fits the existing pattern of land use or what useful niches for trees can be identified. Thus agroforestry niches have three components: -

(1) Functional role within the land use system; (2) Place within the land space; and (3) A time within the life cycle of a particular land use system (Raintree, 1985a).

2*.11. Acacia senegal (L.) Willd: -*

A.senegal is a short tree (around 7 m when mature). It is short living and sheds its leaves during the dry season (November to June). The tree develops a deep taproot in sandy soils but in clay, the root system is superficial. Seeds are easily germinating but they are susceptible to insect attack.

2.12. Gum arabic and it's yield:

Gum Arabic is tapped usally from hashab tree. It is a valuable export crop. The yield of gum arabic per tree however depends on numerous and un**-** related variables; such as age of the stand, density of the trees, soil types, rainfall (total and seasonal distribution), browsing effect, tapping techniques, alternative employment opportunites and so on. In this respect Blunt (1926) reported that 0.15 kg/tree as the mean annual production was measured in the government experimental plantation site in UmRuwaba in Kordofan province. Whereas Booth (1966) pointed out that 0.23 kg/tree was the mean annual production that observed in the Kordofan provice. In southern Darfur Hunting Technical Services (1976) reported that 0.1 to 0.2 kg/tree has been observed as well as two third of the tree are in production at any time. The remainder trees are otherwise too young or too little to produce gum. Therefore, a potential yield of roughly 60 kg/ha will be expected from 400 trees out of 600 trees in the hectare.

2.13. Land equivalent ratio (LER):

Land equivalent ratio (LER) is a way to assess the benefits of growing two or more crops togother, or intercropping. It is a method to measure productivity of different crops growing together. Thus it compares yields from two or more crops growing together with yields from the same crops in monoculture or pure stands.

The idea behind intercropping is to capitalize on the beneficial intercations between crops while avoiding negative interactions. In essence, The LER measures the effect of both the beneficial and negative interactions between crops. To calculate LER the following equation is used:

Intercrop1/pure1+ intercrop2/pure2+ etc. = LER

The resulting number is a ratio that indicates the amount of land needed to grow both crops together compared to the amount of land needed to grow pure stands of each. An LER greater than 1.0 usually shows that intercropping is advantageous and less than 1.0 shows a disadvantage (Sullivan, 1998).

CHAPTER III

MATERIALS AND METHODS

3.1. General features of the study area:

3.1.1. Locality:

This study was carried out in Nyala locality in South Darfur State (latitude 10° 00 N-12° 00 N and longitude 21° 00 E – 27° 00 E). The altitude of the area is 400 m.

3.1.2. Soils:

The soil type is "gardud" soil, which is deep, stratified and none-stratified; medium and heavy textured alluvial soil formed from reworked Qoz and Basement materials. The surface (loam-clay loam) suffers from hardness and sealing; subsoil (sandy clay loam – clay) is compact. Fertility is moderately high but mechanized cultivation is required to break the hard surface and allow water infiltration (Hunting.Technical Services, 1985).

3.1.3. Climate:

The climate of Southern Darfur is typically of the Savanna belt. Rainfall is of critical importance and variations within and between years result in widely fluctuating levels of crop and livestock production. Temperature is not a limiting factor to plant growth. But rainfall is of mono-modal character. Thus during the winter months, the intertropical convergence zone and associated fronts lie to the south. South Darfur is located in a zone of dry north-easterly Harmattan winds. In summer, this intertropical convergence zone and the associated fronts generally move to the north. Therefore moist south –westerly monsoon airstream was originating from the Atlantic Ocean that penetrates across the continent. Other easterlies moist came from the Indian Ocean overlies this airstream. Thus, conventional thunderstorms were initiated from these disturbed travelling winds. However, these winds resulted in short duration and high intensity rainfall. Besides, these thunders were commonly preceded by high winds that occur mainly in late afternoon and in the evenings (Hunting Technical Services, 1981).

Measurement of wind speed during the rainy season of 2001 was as fallows: 5.9 km/hr, 1.7 km/hr, 2.7 km/hr and 6 km /hr for July, August, September and October months, respectively.

The beginning of rainy season is uncertain: in some years spasmodic showers may occur in late April and May but generally effective rainfall (i.e. sufficient for farmers to begin preparations for planting) does not occur until mid- June. Peak monthly mean rainfall occurs in four months (June to September) forming 90 % of the precipitation; the remaining 10 % occur during May and October months. In the past, rainfall ranged between 450 mm around Nyala and 750 mm near Bahr Elarab (Hunting

Technical Services, 1981). In recent years rainfall dropped to 400 mm around Nyala.

Temperatures are relatively low in December –January (23.6° c) then increase steadily from February to May (30.5° C), then decline during July –August and rise slightly in September and October (Hunting Technical Services, 1981).

3.1.4. Vegetation:

The vegetation cover is a low rainfall Woodland Savanna where the dominant tree species are: *A.mellifera*, *A. nubica*, *A.senegal*, which form complex associations in areas to the north of Nyala province.

The herbaceous plant species include: *Cassia obtusifolia*, *Tribulus terrestris* and *Chloris gayana*. Formerly Savanna woodland species predominated the area. But, due to ecological changes as a result of shifting cultivation and droughtness in the recent years; the overall picture of the area has changed and environmental degradation was ensued (Hunting Technical Services, 1976). In the drier parts the majority of the trees are thorny–predominately Acacias while broad leaved deciduous trees are dominated in the abundant – rainfall pockets. The main *Acacia species* is *Acacia senegal* which forms a continuous belt in central Sudan (10° -15° N), but most successful in the stabilized sands of Kordofan and Darfur. Pure stands of *A.senegal* are found to west of the white Nile in the Acacia short grass formation (300-700 mm). However, these pure stands constitute about 50 trees per feddan in well stocked sites. In Darfur, *Acacia senegal* is found mainly in southern and eastern Darfur in mixture with *Acacia mellifra* and *Acacia nubica,* but pure stands were established around Nyala on Gardud and Goz soils as in the Savanna project area near Nyala (Huessein, 1983). The grass species are mainly annual than perennial but near the southern fringes around Bahr Elarab herbaceous species are also encountered (HuntingTechnical Services, 1976).

3.2. Materials:

The materials for this experiment include: (1) Hashab (*A.senegal*) plantations that were respaced to 4x4 m, 4x8 m and 8x8 m. However, this respacing was carried out in old plantations of Hashab trees of 4x4m spacing of more than ten years old. Thus one row of hashab trees was clear-felled and removed totally and brought to 4x8 m spacing. Whereas one row as well as one tree within each row were removed and substituted by 8x8 m spacing. In addition, undesired trees and bushes were also taken-off from all plots. This operation was done manually by using axes. The experimental site was well fenced and protected during the growing seasons against damage and animals during the seasons of the study.

(2) Field crops cultivated in between the trees viz. millet (*Pennisetum glaucum* var. Ashana), sorghum (*Sorghum bicolor* var. Tabat) and sesame

(*Sesamum indicum* var. Kenana 2) and other two plots, sole trees and sole crops were left as control (Plates, 1-13).

3.2.1. Methods:

3.2.1.1. Experimental design and establishment of agricultural crops:

A completely randomized block design with three replicates was conducted for each of the field crop used; millet (*Pennsitum glaucum),* sorghum (*Sorghum bicolor.L.)* and sesame (*Sesamum indicum).* Three tree spacings viz. 4x4m, 4x8m and 8x8m represented the treatments which were replicated three times for each crop (Plates 1-13). Certified seeds (obtained from Nyala Research Station) of test crops were sown at the recommended spacings of 75x75 cm for millet, 50 x 50 cm for sorghum and 50 x 10 cm for sesame. Planting was done at the on set of the rainy season. For millet and sorghum, three plants were left per hole whereas sesame was thinned where necessary.

The experinent block size was 16x20 m, whereas the plot size was 4x20 metre. Tree pruning was applied to make access for ploughing.

The proper cultural practices were carried out as recommended for the three seasons of the study.

3.3.2. Measurements and data collection:

3.3.2.1. Tree measurements:

The following measurements were taken:

1/ Tree height in meters using graduated poles.

2/ Tree diameter at breast height (cm) using graduated tape.

3/ Tree canopy diameter for each tree in meter, using measuring tape.

4/ Tree crown projection in meter, along four directions.

5/ Tree root profile has been made, through excavating the area of main roots of Hashab tree. An area of one meter, half sphere was exposed by spade, thus four trees of varied ages and locations were used. Four main tree roots and a number of fine roots were left intact and then photographed by digital camera.

3.3.2.2. Crop Measurement:

1/ Plant population density per ha.

2/ Number of leaves per plant at 50 % flowering.

3/ Plant height (cm); ten plants per plot were sampled for height measurement using a ruler.

4/ Days to 50 % flowering; the period at which 50 % flowering occurred

5/ Days to harvesting for each crop; the harvesting time was recorded at crop maturing.

6/ Crop yield (kg/ha) was determined for each crop by computing yield per plot into yield per hectare noting that the outer rows were not included. For sesame and sorghum, the net plot size would be 3x19 m and 2.5x18.5 m for millet. And by using quadrat ($0.25m^2$) in the third season, where crops yield were determined under tree canopy and outwards the tree canopies at 3 fixed distances according to tree spacings.

7/ Weight of 1000 seeds (grams): samples of grain for each crop were weighed using an electronic balance.

8/ Straw dry weight (kg/ha) for each crop was determined.

9/ Land equivalent ratio (LER) was calculated for the different crops

There are advantages for intercroppng if the calculated figure is more than one and vice versa according to (Sullivan, 1998).

3.3.4. Soil profile:

1/ One profile pit for the whole site was described according to the standard procedure then the gardud classification was identified as indicated in appendix (i).

2/ Soil moisture content was taken twice during the growing season, starting at the beginning of the first heavy rains before sowing and at harvesting in all plots under the different treatments in the first two seasons; and three times in the third season, as well as at crops flowering time. This parameter was determined gravimetrically. So, soil samples were augered from different locations under tree canopy and in the open areas, at depths of 0-10 cm, 10-20 cm, 20-40 cm and 40-60 cm in the first two seasons; and at depths of 0-25 cm, 25-50 cm and 50-75 cm in the third season (Figure 1). These soil samples were first weighed as fresh weight in (g) and then oven dried at 105° c for 24 hours and weighed to calculate moisture content on dry weight basis as fallows:

Moisture content % = wt of wet sample - wt of oven dry sample /wt of oven dry sample x100.

Where wt= the sample weight in grams.

3/ Composite soil samples were taken under trees and in open areas by auger at depth of 0-30 cm at distance of 1m and 2 m in the 4x4m spacing; and at distance of 1m and 4m from the trees in 4x8 m and 8x8 m spacings, to determine total nitrogen and organic carbon content as well as phosphorus element content in the third season, (Figure 2).

3.3.5. Climate data:

The following climatic data were recorded:

1/ Wind speed by Anenometer of 3 m height twice a day (morning and after noon for the whole rainy season).

2/ Rainfall quantity by using rain guage (Appendix ii).

.**3.3.6.Other data:**

1/ Tapping for gum arabic yield was carried out in the different hashab tree spacings, by using Sonki instrument. The tapping was carried out at the beginning of November after the end of the rainy season. The intensity of tapping was 3 for each tree in the all treatments namely, 4x4 m, 4x8 m and 8x8 m tree spacing. Collection of the two pickings was recorded after 6 and 8 weeks, respectively from the tapping date. The gum arabic yield was first dried and then weighed by using balance to determine gum Arabic yield per tree in (g).

2/ Pests and diseases were observed during the growing season and the major incidents were recorded.

Statistical analysis:

Analysis of variance (Anova) was used to analyse the data (SAS, 1995) and MSTAT-C software. Means separation was done by the least significant differences (LSD) method according to (Gomez and Gomez, 1984).

CHAPTER IV

RESULTS

4.1. Crop parameters:

4.1.1. Crop population density per hectare:

Crop population density was significantly affected by tree spacing in the first season; where millet and sorghum crops recorded significant differences in the wider spacing 8x8 when compared with 4x4 m spacing. Whereas in the second season, similar results were observed among the various crops except for sorghum; where 4x8 m and 8x8 m spacing were significantly different compared with 4x4 m (Table 1). In the third season, similar results were obtained for millet and sesame crops. Thus lower population densities were recorded for the tested crops (millet and sesame) in the three spacing treatments as compared to the control. Whereas sorghum crop recorded high population density in the 4x8 m spacing when compared with 4x4 m, 8x8 m spacing and control (Table 2).

4.1.2. Number of leaves per plant:

There were no significant differences among the three tree spacing in number of leaves per plant except for sesame in the first and second seasons (Table 3). Whereas in the third season, significant difference was obtained for millet and sesame crops; accordingly, higher leaf number was recorded in the 4x4 m spacing when compared with the other treatments. In the sesame crop, the leaf number was increased in 8x8 m spacing in contrast with 4x4 m and 4x8 m spacing and control (Table 4).

4.1.3. Crop days to 50 % flowering:

The period required for 50 % flowering was not influenced much by tree spacing in both seasons with respect to crop species (Table 5). However, in the third season, significant difference was observed in sesame crop. Thus 4x4 m and 4x8 m spacing recorded higher days to 50 % flowering in contrast to the 8x8 m spacing and the control. On the other hand, millet crop did not differ with respect to this spacing (Table 6).

Table 1: Effect of tree spacing on crops plant density in the first and second seasons (2001 and 2002):

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	21842b	70000b	8183a	24050b	82250a	100917b
4x8m	36269a	105000a	14233a	38220a	97650a	156917a
8x8m	38480a	105000a	148167a	377830a	983000a	163917a
LSD	5125.4	10496	78055	9676	21039	15365
CV%	7.02	4.96	27.8	12.79	10.00	4.82

-Means followed by the same letters are not significantly different at 5 % level.

Table 2: Effect of tree spacing on crops plant density in season 2004:

Tree spacing (m)	Crop species		
	Millet	Sorghum	Sesame
4x4m	38150.0c	35250.0b	50600.0b
4x8m	55600.0b	79475.0a	46200.0b

8x8m	44625.0b	55795.0b	28500.0c
Control	144704.9a	41361.5c	83790.0a
L.S.D C.V%	17920 40.08%	16420 49.07%	15730 55.64%

-Means followed by the same letters are not significantly different at 5 % level.

Table 3: Effect of tree spacing on crops number of leaves per plant in the first and second seasons (2001 and 2002):

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	5.67a	6.67a	25.33a	7.00a	6.33a	30.6b
4x8m	6.00a	7.33a	48.33a	7.00a	8.00a	40.6ab
8x8m	5.67a	7.33a	51.67a	6.33a	7.00a	56.00a
LSD	2.00	2.00	31.44	1.19	3.66	16.42
CV%	15.26	12.4	33.19	7.78	22.72	17.10

-Means followed by the same letters are not significantly different at 5 % level.

Table 4: Effect of tree spacing on crops number of leaves per plant in season 2004:

Tree spacing (m)	**Crop species**		
	Millet	**Sorghum***	**Sesame**
4x4m	10.40a	-	34.00b
4x8m	6.00b	-	27.40b
8x8m	6.40b	-	85.80a
Control	7.00b	-	59.40ab
L.S.D	1.328	-	40.07
C.V%	9.45%	-	36.68%

-Means followed by the same letters are not significantly different at 5 % level.

*No available data.

Table 5: Effect of tree spacing on crops days to 50 % flowering time in first and second seasons (2001 and 2002):

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	52.7a	63.33a	75.0a	55.0a	56.33a	48.0a
4x8m	61.7a	65.0a	56.3a	62.3a	58.0a	48.7a
8x8m	66.0a	57.7a	55.7a	62.3a	56.0a	48.67a
LSD	19.18	11.03	28.65	8.41	18.98	1.51
CV%	14.08	7.85	20.27	6.20	14.75	1.38

-Means followed by the same letters are not significantly different at 5 % level.

Table 6: Effect of tree spacing on crops days to 50 % flowering time in the third season 2004:

Tree spacing (m)	Crop species		
	Millet	**Sorghum***	**Sesame**
4x4m	70.0a	-	52.0ab
4x8m	64.0a	-	53.00a
8x8m	62.0a	-	47.0bc
Control	62.0a	-	42.0b
L.S.D	9.15	-	5.46
C.V%	6.79	-	5.59%

-Means followed by the same letters are not significantly different at 5 % level.

*No available data.

4.1.4. Crop Days to harvesting time:

Tree spacing did not affect days to harvesting time for the studied crops in both seasons (Table 7). Whereas in the third season, days to harvesting time differed with respect to crop species and tree spacing. Thus millet crop recorded higher days to harvesting time in 8x8 m spacing than in other spacing, namely 4x4 m, 4x8 m and control as shown in table 8. However, similar results were obtained for sesame crop in the same spacing (Table 8).

4.1.5. Plant height (cm):

The results of the experiment indicated that there was no significant difference in the plant height for the three tested crops as far as the tree spacing under study were concerned in the first season. In the second season, similar results were obtained except for sesame crop, where significant differences were observed (Table 9). However, marked variations were observed in the third season for sesame crop only. In this respect, higher plant height was recorded in the 8x8 m spacing when compared with the 4x4 m and the control. Whereas millet crop did not differed the tree spacing (Table 10).

Table 7: Effect of tree spacing on crops days to harvesting time in seasons 2001 and 2002:

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	74.7a	108.0a	68.67a	80.3a	105.67a	81.7a
4x8m	80.0a	82.3a	78.3a	86.7a	104.0a	82.3a
8x8m	86.3a	84.0a	75.0a	82.0a	103.3a	81.7a
LSD	12.07	25.86	9.92	9.71	2.45	5.75
CV%	6.63	12.47	5.92	5.16	1.04	3.1

-Means followed by the same letters are not significantly different at 5 % level.

Table 8: Effect of tree spacing on crops days to harvesting time in harvest, season 2004:

Tree spacing (m)	**Crop species**

	Millet	**Sorghum***	**Sesame**
4x4m	86.0b	-	80.0b
4x8m	86.0b	-	82.0ab
8x8m	90.0a	-	84.0a
Control	84.0b	-	82.0ab
L.S.D C.V%	3.59 2.07%	- -	2.77 1.68%

-Means fallowed by the same letters are not significantly different at 5 % level.

*No available data.

Table 9: Effect of tree spacing on crops height in (cm) in seasons 2001 and 2002:

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	74.6a	64.00a	40.2a	77.8a	49.46a	49.33b
4x8m	55.6a	74.40a	56.2a	80.2a	70.83a	55.07b
8x8m	89.2a	77.67a	77.83a	84.9a	69.37a	70.47a
LSD	51.48	32.76	54.74	48.00	41.81	17.79
CV%	31.06	20.07	41.58	26.17	29.18	13.46

-Means fallowed by the same letters are not significantly different at 5 % level.

Table 10: Effect of tree spacing on crops height in (cm) in season 2004:

Tree spacing (m)	Crop species		
	Millet	Sorghum*	Sesame
4x4m	7.00a	-	52.80ab
4x8m	6.80a	-	38.20b
8x8m	10.4a	-	76.20a
Control	6.40a	-	59.40ab
L.S.D	32.17	-	25.86
C.V%	12.1	-	22.59

-Means fallowed by the same letters are not significantly different at 5 % level.

* No available data.

4.1.6. Crop yield (kg/ha):

With regard to the effect of tree spacing, the results revealed significant differences in sorghum and sesame crops, in the 4x8 m and the 8x8 m spacing, whereas millet crop did not differ in the first season (Table 11). In the second season, similar results were observed for millet and sorghum crops. Higher yields were recorded in 4x8 m and 8x8 m spacing, respectively than in 4x4 m Table 12). However, sesame crop did not differ with tree spacing (Table 12). In the third season, millet crop was significantly affected by tree spacing. Higher yields were recorded in the 8x8 m spacing as compared to the other spacing and control. The sesame crop was not affected (Table 13).

4.1.7. Crop 1000- seeds weight (g):

No significant differences were found in the two seasons for the studied crops in 1000-seeds weight with tree spacing (Table 13). However, significant difference was recorded for millet crop in the third season. Where higher seed weight was observed in the 8x8 m spacing when compared to other spacing and control. Sesame crop recorded lower seed weight under tree spacing, namely (4x4m, 4x8m and 8x8m) when compared with control (Table 14).

Table 11: The effect of tree spacing on crops yield (kg/ha) in seasons 2001 and 2002:

Tree spacing (m)	Crop			Crop		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	33.2a	30.35b	8.75b	13.67c	45.8b	25.33a
4x8m	42.0a	292.45a	26.6ab	50.04b	139.97a	48.99a
8x8m	42.9a	440.64a	43.41a	101.0a	112.3ab	114.8a
LSD	26.76	202.21	29.04	27.48	83.89	93.85
CV%	30.0	35.05	48.8	22.9	37.25	65.67

-Means followed by the same letters are not significantly different at 5 % level.

Table 12: Effect of tree spacing on crops yield (kg/ha) in season 2004:

Tree spacing (m)	Crop		
	Millet	Sorghum*	Sesame
4x4m	161.6b	-	161.0a
4x8m	553.6b	-	73.67a
8x8m	5582.a	-	181.7
Control	1600.b	-	214.0a
L.S.D	2703	-	165.6
C.V%	95.81	-	48.07

-Means followed by the same letters are not significantly different at 5 % level.

* No available data.

Table 13: Effect of tree spacing on crops 1000-seeds weight in seasons 2001 and 2002

Tree spacing (m)	Crop species in season 2001			Crop species in season 2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	4.33a	13.33a	2.83a	3.33a	22.50a	1.83a
4x8m	5.17a	13.00a	3.00a	2.67a	22.33a	2.13a
8x8m	5.33a	12.83a	3.17a	3.17a	23.00a	2.27a
LSD	2.72	2.20	1.46	1.10	2.72	0.83
CV%	24.31	7.44	21.52	15.9	5.32	17.65

-Means followed by the same letters are not significantly different at 5 % level.

Table 14: Effect of tree spacing on crops 1000-seeds weight in season 2004:

Tree spacing (m)	Crop		
	Millet	Sorghum*	Sesame
4x4m	4.00c	-	2.4b
4x8m	4.8bc	-	2.4b
8x8m	8.8a	-	2.4b
Control	6.8ab	-	6.8a
L.S.D	2.49	-	4.12
C.V%	20.42	-	61.94

-Means followed by the same letters are not significantly different at 5 % level.

*No available data.

4.1.8. Straw weight (kg/ha):

Significant differences were caused by tree spacing in the two growing seasons (Table 15) on crop straw weight. Higher straw weight was recorded in the 8x8m spacing. Similar results were obtained in the third season for millet and sorghum crops, whereas sesame crop was not affected (Table 16).

4.1.9. Land equivalent ratio (LER):

The land equivalent ratio (LER) was calculated for millet and sesame crops in the third season, because sorghum crop failed in the third season due to bad rainfall distribution (appendix 2). The calculations indicated that LER was higher in the 8x8m spacing than in the other spacing namely, 4x4 m and 4x8m spacing i.e. Table 17).

Table 15: Effect of tree spacing on crops straw weight (kg/ha) in seasons 2001 and 2002:

Tree spacing (m)	2001			2002		
	Millet	Sorghum	Sesame	Millet	Sorghum	Sesame
4x4m	202.0c	202.46c	58.20c	837.33c	227.3b	791.29c
4x8m	742.1b	1090.5b	119.8b	1754.1b	342.2ab	824.74b
8x8m	982.0a	2142.3a	149.0a	2601.7a	646.5a	1001.9a
LSD	6.38	19.78	3.66	35.86	38.06	2.26
CV%	0.44	0.76	1.48	0.91	41.42	0.11

-Means followed by the same letters are not significantly different at 5 % level.

Table 16: The effect of tree spacing on crops straw weight (kg/ha) in season 2004:

Tree spacing (m)	Crop		
	Millet	Sorghum	Sesame
4x4m	675.0c	393.3b	407.3a
4x8m	1667.c	1333.3b	367.3a
8x8m	6500.a	2333.3a	784.7a
Control	466.7b	1333.3b	442.0a
L.S.D C.V%	1590 25.53	973.3 48.99	583.2 54.79

-Means followed by the same letters are not significantly different at 5 % level.

Table 17: Land equivalent ratio (LER) for millet and sesame crops yield (kg/ha) in the third season 2004:

Treatment	Inter-crropped to millet	Inter-cropped to sesame	Sole millet	Sole sesame	LER
4x4m	161.6	161.3	1600	214	0.85
4x8m	553.6	73.67	1600	214	0.69
8x8m	5582.0	184.7	1600	214	4.35

4.2. Tree parameters:

4.2.1. Tree height (m):

With respect to tree spacing the result revealed significant differences in favor of tree height in the control plots only. No differences were observed in the intercrops in the first two seasons (Tables 18 & 19). However, in the third season, no significant differences were observed under intercropped or control plots (Tables 20 & 21).

4.2.2. Tree diameter at breast height (cm):

No marked variations were observed in terms of tree diameter at breast height (dbh) with the different tree spacing, namely 4x4 m, 4x8 m and 8x8 m in the first two seasons (Tables 18 &19). Whereas marked variations were recorded in the intercropped plots in the third season. Thus, higher values were found with the 4x8 m spacing than with the 4x4 m and the 8x8 m spacing (Table 20). However, in the control plots the tree dbh did not differed (Table 21).

4.2.3. Tree canopy diameter (m):

Tree canopy diameter was significantly affected in the intercropped plots compared to the control plot due to tree spacing, in the first two seasons (Tables 18 &19). In third season, however, significant difference was recorded in the control plots only. Accordingly, higher canopy diameter was obtained in the 8x8 m spacing (Tables 20 and 21).

4.2.4. Tree crown projection (m):

There was substantial effect caused by tree spacing in the intercropped plots on tree crown projection in the first two seasons, compared to control plots (Tables 18 & 19). However, in the third season, the effect was recorded in the control plots when compared with the intercropped plots. In this respect, tree crown projection increased in the 8x8 m spacing compared to the other spacing (Tables 20&21).

4.2.5. Tree root profile:

Soil excavations indicated that the hashab tree (*A.senegal*) roots were superficial under this soil type and the tree roots extended to more than 1.5m only as was (Plates 15&15). In addition, tree fine roots were laterally spread to a depth not exceeding 50 cm (Plate 16).

Table 18: Tree height (m), tree diameter at breast height (cm), tree canopy diameter (m) and tree crown projection in the intercropped plots:

Tree spacing (m)	Tree height (m)	Tree diameter (cm)	Tree canopy diameter (m)	Tree crown Projection (m)
4x4	3.35a	8.24a	7.48a	14.13a
4x8	3.58a	6.59a	5.28b	8.52b
8x8	4.25a	6.19a	5.23b	8.03b
LSD	1.85	2.56	2.17	4.20
C.V%	24.15	16.75	16.87	20.15

-Means fallowed by the same letters in the same row are not significantly difference at 5 % level.

Table 19: Tree height (m), tree diameter at breast height (cm), tree canopy diameter (m) and tree crown projection in the control plots:

Tree spacing (m)	Tree height (m)	Tree diameter (cm)	Tree canopy diameter (m)	Tree crown Projection (m)
4x4	2.67b	6.44a	6.27a	11.12a
4x8	3.07ab	6.32a	6.17a	10.00a
8x8	5.50a	8.22a	5.75a	9.80a
LSD	2.68	3.61	1.96	3.09
C.V%	34.82	24.91	16.2	15.39

-Means fallowed by the same letters in the same row are not significantly difference at 5 % level.

Table 20: Tree height (m), tree diameter at breast height (cm), tree canopy diameter (m) and tree crown projection in the intercropped plots in the third season 2004:

Tree spacing (m)	Tree height (m)	Tree diameter (cm)	Tree canopy diameter (m)	Tree crown Projection (m)
4x4	3.11a	6.26ab	5.76a	11.86a
4x8	3.51a	7.38a	6.58a	12.53a
8x8	2.42a	5.99b	6.62a	10.96a
LSD C.V%	1.49 17.74	1.14 6.17	1.25 9.42	2.13 8.31

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 21: Tree height (m), tree diameter at breast height (cm), tree canopy diameter (m) and tree crown projection in the control plots:

Tree spacing (m)	Tree height (m)	Tree diameter (cm)	Tree canopy diameter (m)	Tree crown Projection (m)
4x4	5.00a	9.05a	5.10b	9.81ab
4x8	3.50a	8.40a	4.25b	8.50b
8x8	2.26a	6.65a	6.75a	11.74a
LSD C.V%	3.20 36.14	2.71 15.27	1.17 9.93	2.01 8.93

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

4.3. Soil moisture content:

4.3.1. Soil moisture content under tree canopy before sowing:

Soil moisture content did not show any significant difference under tree canopy with regard to tree spacing and in the control plots in the first season (Table 22). Whereas marked variations were observed in the second season. Higher moisture content was recorded in the 4x4 m and the 8x8 m spacing when compared with the 4x8 m and control treatments (Table 22). However, in the third season, significant difference was obtained in the 8x8 m spacing at the 25-50 cm depth only in the intercropped plots (Table 24). In the control plots, the higher moisture content was recorded in the wide tree spacing, namely the 8x8 m as (Table 25).

4.3.2. Soil moisture content in open areas before sowing:

Soil moisture content was substantially different in depths of 0-10 cm and 40-60 cm only for the second season. Accordingly, the 4x4 m spacing gave higher moisture content in the two depths when compared with other spacing and the control (Table 23). In the third season, marked variation in soil moisture content was recorded in the 8x8 m and the 4x8 m spacing in the intercropped plots under trees canopy and in open areas respectively, Table 25).

Table 22: Soil moisture content under tree canopy under the different tree spacing before sowing in the first and second seasons (2001&2002):

Treatment	Season 1					Season 2				
	Soil depths (cm)					Soil depths (cm)				
	0-10	10-20	20-40	40-60	Total	0-10	10-20	20-40	40-60	Total
4x4m	12.94a	13.29a	16.12a	12.81a	55.16	5.6a	4.60a	5.08a	5.55a	20.83
4x8m	14.01a	13.64a	25.01a	8.24a	60.9	2.7b	5.22a	4.21a	4.63a	16.75
8x8m	15.95a	16.91a	15.02a	10.61a	58.49	4.4ab	6.21a	6.03a	7.84a	24.44
Control	14.86a	17.32a	10.29a	10.82a	53.29	1.9b	0.94a	2.53a	2.92a	8.31
LSD	26.64	15.88	15.71	12.88	-	2.43	6.71	3.88	5.2	-
C.V%	70.03	40.81	41.0	42.17		25.4	55.31	33.57	38.15	

-Means fallowed by the same letters in the same row are not significantly difference at 5 % level.

Table 23: Soil moisture content in open areas under the different tree spacing before sowing and after harvesting in the second season 2002:

Treatment	Before sowing					After harvesting				
	Soil depths (cm)					Soil depths (cm)				
	0-10	10-20	20-40	40-60	Total	0-10	10-20	20-40	40-60	Total
4x4m	9.38b	3.67a	5.18a	10.25a	28.48	3.8a	4.33a	4.17a	5.53a	17.8
4x8m	2.21a	2.54a	4.63a	3.93b	13.31	4.2a	5.00a	5.30a	6.87a	21.34
8x8m	4.67ab	5.01a	5.76a	9.70a	25.14	3.2b	3.83b	5.00a	7.03a	19.06
Control	1.92a	0.94a	2.53a	2.92b	8.31	1.1b	1.46b	2.30b	2.95b	7.79
LSD	7.16	4.41	3.19	5.75	-	2.21	2.64	1.75	1.37	
C.V%	58.28	51.98	27.13	31.86		26.1	26.53	15.97	9.2	

-Means fallowed by the same letters in the same row are not significantly difference at 5 % level.

Table 24: Soil moisture content under tree canopy and open areas in the different tree spacing before sowing in the third season 2004 in the intercropped plots:

Trees spacing (m)	Under tree canopy Soil depths (cm)				Open areas Soil depths (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4m	8.46a	6.19b	9.51a	24.16	7.93ab	6.92b	7.48ab	22.33
4xm m	8.11a	6.97b	7.58a	22.66	5.24b	22.92a	5.45b	33.61
8x8 m	10.79a	11.51a	9.74a	32.04	9.63a	8.12b	8.83a	26.58
Control	8.2a	7.83b	5.83a	21.86	8.2ab	7.83b	5.83b	21.86
LSD	2.69	3.43	11.43	-	3.44	10.44	3.0	-
C.V	10.97%	15.9%	44.7%	-	14.7%	41.1%	15.26%	-

-Means fallowed by the same letters in the same row are not significantly difference at 5 % level.

The higher soil moisture content was observed in 8x8 m irrespective of soil depths and sampling locations (Table 25).

4.3.3. Soil moisture content during flowering time in the third season:

Results revealed significant difference with respect to soil moisture for millet crop under tree canopy in 0-25 cm and 25-50 cm soil depths. Soil moisture content decreased in the 8x8 m spacing and the control plots in the 0-25 cm depth. On the other hand, higher moisture content was obtained under tree canopies compared to the control plots at depths of 20-50 cm depth (Table 26). However, similar results were recorded in the open areas. Higher moisture content was recorded in the 0-25 cm and the 25-50 cm soil depth, respectively under tree spacing than in the control (Table 26). In the sesame crop, significant differences were observed in soil moisture content in the 0-25 cm depth under tree canopy. Accordingly, higher moisture content was recorded in the control plots than under tree spacing. However, in the open areas, the soil moisture was not different with respect to depths (Table 27).

4.3.4. Soil moisture content after harvest under tree canopy:

Marked variations were recorded for soil moisture content after harvesting for 40-60 cm depth in the first season. In which 4x4 m and 4x8 m spacings recorded the higher percentage in contrast to 8x8 m and control plots as was indicated in table 28. In the second season, higher percentages for soil moisture were obtained in the all tree spacings when compared with control. However, these magnitude percentages were recorded in 0-10 cm depth for 4x8 m and 8x8 m spacing respectively when compared with 4x4 m and control ones. Moreover, in 4x4 m and 4x8 m spacing higher moisture percentage were recorded in 10-20 cm depth when compared with control. Whereas in 20-40 cm and 40-60 cm depths the soil moisture content was significantly different under tree spacings than in control plots as was shown in table 28. However, significant difference was recorded for moisture content under millet crop experiment in 0-25 cm depth when compared with 25-50 cm and 50-75 cm depths. Thus higher moisture content was obtained in 4x8 m spacing (Table 29). Whereas in sorghum crop experiment higher moisture content recorded under 8x8 m spacing at 0-25 cm depth and in 4x4 m spacing and control in 50-75 cm depth (Table 30). In sesame crop experiment, significant difference in soil moisture content recorded in 0-25 cm only. Where soil moisture was lower under the tree spacings when compared with the control (Table 31). In the control trees, soil moisture content did not differ under tree canopy (Table 32).

4.3.5. Soil moisture content after harvesting in the open areas:

Substantial differences were observed for soil moisture content in the all depths with respect to tree spacings in the second season. However higher moisture percentages were obtained in the 4x4m and the 4x8m spacings in the first and second depths, namely 0-10 cm and 10-20 cm respectively when compared with 8x8m and control plots. Whereas soil moisture content percentages were significantly different in the all tree spacings in the remain depths; namely 20-40 cm and 40-60 cm than in the control one as indicated in table 23. However, significant differences were obtained for soil moisture content under millet crop experiment in the open areas. Soil moisture content was higher under 4x8 m spacing when compared with other tree spacing and control in 0-25 cm depth. Whereas in 50-75 cm depth, soil moisture content increased in 8x8 m spacing when compared with other spacing and control (Table 29). In sorghum crop, soil moisture content was increased in the 4x4 m and the 8x8 m spacing when compared with the 4x8 m spacing and control in the 0-25 cm depth. Whereas in 25-50 cm depth, soil moisture content was found to be higher under tree spacing when compared to control (Table 30). In the sesame crop, however, soil moisture content increased in control plots (Sole crop) when compared to tree spacing in the 0-25 cm depth; Whereas in the 25-50 cm depth soil moisture was increased in 4x4 m spacing and in control (Sole crop) in contrast with the 4x8 m and the 8x8 m spacing. Similar results were obtained in the 50-75 cm depth as in the 25-50 cm depth (Table 31). In the control plots (Tree sole plots) however, soil moisture content differed significantly in the 25-50 cm and the 50-75 cm depths, respectively. Therefore, higher moisture content was recorded in the 4x4 m and the 8x8 m spacing, respectively (Table 32).

Table 25: Soil moisture content under tree canopy and the open areas in the different tree spacing before sowing in the third season in the control plots:

Trees spacing (m)	Under tree canopy Soil depth (cm)				Open areas Soil depth (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4m	7.75b	7.33a	4.83b	19.91	8.76ab	7.7ab	4.95b	21.38
4x8m	5.37b	5.47a	2.76b	13.6	4.86b	4.47b	3.41b	12.74
8x8m	14.99a	15.40a	13.66a	44.05	13.95a	14.2a	14.46a	42.59
Control	8.2b	7.83a	5.83b	21.86	8.2ab	7.8ab	5.83b	21.86
LSD	6.92	14.11	7.35	-	7.03	8.28	6.58	-
C.V	40.98%	69.2%	60.7%	-	38.2%	43.1%	46.9%	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 26: Soil Moisture content at flowering time for millet crop experiment in season 2004 under trees and open areas:

Trees spacing (m)	Under tree canopy Soil depth (cm)				Open areas Soil depth (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4m	9.67a	9.94a	9.23a	28.84	11.97a	10.4a	9.13a	31.52
4x8m	9.55a	11.48a	11.30a	32.33	9.70a	10.6a	10.93a	31.22
8x8m	4.52ab	9.18a	10.04a	23.74	6.48ab	10.1a	12.05a	28.64
Control	2.92b	4.88b	11.32a	19.12	2.72b	4.88b	11.32a	18.92
LSD	5.99	3.22	5.95	-	6.82	5.05	3.79	-
C.V	57.5%	21.2%	33.8%	-	53.4%	31.7%	20.5%	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 27: Soil moisture content at flowering time for sesame crop under tree canopy and open areas in season 2004:

Trees spacing (m)	Under tree canopy Soil depth (cm)				Open areas Soil depth (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4m	4.55ab	9.26a	8.66a	22.47	4.46a	7.04a	8.25a	19.93
4x8m	3.27b	6.57a	6.84a	16.68	5.60a	8.52a	10.59a	24.71
8x8m	4.87ab	6.37a	6.96a	18.2	4.77a	7.62a	10.00a	22.39
Control	5.79a	8.33a	8.97a	23.09	5.79a	8.33a	8.97a	23.09
LSD	2.07	3.77	3.33	-	2.64	3.24	3.34	-
C.V	20.8%	24.8%	20.5%	-	24.2%	20.7%	18.2%	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 28: Soil moisture content under tree canopy in the different tree spacing after harvesting in the first and second seasons:

Treatment	Season 1					Season 2				
	Soil depth in cm					Soil depth in cm				
	0-10a	10-20	20-40	40-60	Total	0-10	10-20	20-40	40-60	Total
4x4m	1.70a	3.20a	4.80a	6.30a	15.28	2.4b	4.60a	5.57a	6.40a	19.0
4x8m	2.29a	2.91a	4.01a	6.84a	16.06	3.9a	4.73a	4.83a	5.77a	19.23
8x8m	1.34a	2.51a	2.14a	2.46b	8.41	3.2a	2.20b	5.23a	7.27a	17.87
Control	1.03a	1.89a	1.87a	2.33b	7.12	1.1b	1.46b	2.3b	2.95b	7.79
LSD	1.14	3.62	3.153	4.03	-	1.71	0.81	1.26	1.94	-
C.V%	18.25	43.99	8.76	44.89	-	23.8	7.82	10.7	13.2	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 29: Soil moisture content after harvesting time for millet crop under tree canopy and open areas in the third season 2004.

Trees spacing (m)	Under tree canopy Soil depth (cm)				Open areas Soil depth (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4	2.44b	3.14a	3.79a	9.37	1.98b	3.83a	2.86b	8.67
4x8	6.1a	5.57a	5.51a	17.18	6.81a	4.22a	6.59ab	17.62
8x8	4.5ab	7.96a	8.35a	20.81	3.53b	6.45a	7.11a	17.09
Control	1.81b	4.32a	5.31a	11.44	1.81b	4.32a	5.31ab	11.44
LSD	3.48	6.19	8.11	-	3.25	3.28	4.12	-
C.V%	42.45	47.5	54.21	-	40.02	27.67	33.98	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 30: Soil moisture content after harvesting time for sorghum crop under tree canopy and open areas in the third season 2004:

Trees spacing (m)	**Under tree canopy Soil depth (cm)**				**Open areas Soil depth (cm)**			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4	4.45b	7.02a	7.98a	19.45	4.44a	6.23a	7.3a	17.97
4x8	4.87b	5.16a	5.57b	15.59	3.41b	5.68a	6.17a	15.26
8x8	11.27a	5.08a	6.81ab	23.16	4.53a	7.14a	8.59a	20.26
Control	2.55b	1.39b	7.56a	11.5	2.55c	1.39b	7.56a	11.5
LSD	4.23	2.13	1.46	-	0.82	2.93	3.25	-
C.V	41.71	19.08	10.86	-	9.34	27.05	22.21	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 31: Soil moisture content after harvesting time for sesame crop under tree canopy and open areas in the third season 2004:

Trees spacing (m)	Under tree canopy Soil depth (cm)				Open areas Soil depth (cm)			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4	6.4ab	7.54a	8.05a	21.99	4.89c	7.79a	8.76a	21.44
4x8	4.81b	7.11a	7.61a	19.53	6.56b	4.68b	6.47b	17.71
8x8	5.35b	6.3a	7.54a	19.19	5.01c	6.9ab	7.8ab	19.68
Control	8.31a	8.53a	9.8a	26.64	8.1a	8.53a	9.8a	26.43
LSD	2.96	2.55	2.65	-	1.2	2.26	2.26	-
C.V	27.24	19.5	17.79	-	10.51	18.01	15.06	-

Means followed by the same letters in the same row are not significantly difference at 5 % level.

Table 32: Soil moisture content after harvesting time for the control plots under tree canopy and open areas in the third season 2004.

Trees spacing (m)	**Under tree canopy Soil depth (cm)**				**Open areas Soil depth (cm)**			
	0-25	25-50	50-75	Total	0-25	25-50	50-75	Total
4x4	3.21a	5.13a	5.47a	13.81	5.76a	9.59a	4.83b	20.18
4x8	5.22a	5.12a	6.73a	17.07	2.94a	6.5b	6.12b	15.56
8x8	4.19a	6.6a	6.32a	17.11	5.87a	7.4ab	8.12a	21.41
LSD	4.39	3.36	2.9	-	3.07	2.79	1.79	-
C.V	43.21	23.22	20.85	-	32.41	19.48	12.6	-

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

4.4. Soil chemical analysis:

4.4.1. Nitrogen content as percentage:

With regard to tree spacing, nitrogen content as percentage did not differ in the two locations namely under tree canopy and in the open areas (Tables 33 &34).

4.4.2. Organic Carbon:

Organic carbon was not affected substantially in terms of tree spacing and its locations under trees and in the open areas (Tables 33 &34).

4.4.3. Phosphorus:

Phosphorus content as percentage did not differ in the different locations whether under trees or in the open areas (Table 34).

4.4.4. Gum arabic yield (g)/tree:

Substantial effect was observed for Gum arabic yield with respect to tree spacing and pickings in the first season. Accordingly, higher yield was obtained in the first pick in the intercropped plots in the 4x8 m spacing when compared with other spacings. Similar results were obtained in the control plots. So that, higher yield was also obtained in the 4x8 m spacing when compared to the 4x4m and the 8x8 m spacing in the both pickings (Table 35). In the second season, significant difference was recorded in the first picking only in the intercropped plots. Table 35 indicated that the

4x8 m spacing recorded relatively higher yield in contrast with the 4x4 m and the 8x8 m spacing.

Table 33: Nitrogen and Organic Carbon contents as percentage under different tree spacing in early season 2004:

Tree spacing (m)	Under tree		Open areas	
	Nitrogen %	Organic Carbon%	Nitrogen%	Organic Carbon %
4x4m	0.011	2.16	0.014	2.46
4x8m	0.014	3.00	0.016	2.82
8x8m	0.011	1.80	0.011	1.74
Control	0.014	2.22	0.014	2.46

Table 34: Nitrogen, Organic Carbon and phosphorus contents as under different tree spacing in late season 2004:

Treatment	Under tree canopy			Open areas		
	Nitrogen %	Organic carbon %	Phosphorus pp/mg	Nitrogen %	Organic carbon %	Phosphorus pp/mg
4x4m	0.0180	4.0	4.0	0.0176	3.0	3.0
4x8m	0.0167	2.0	3.0	0.0161	2.0	3.0
8x8m	0.0163	2.0	3.0	0.0150	2.0	3.0
Control	0.0118	2.0	2.0	0.0105	2.0	2.0

Table 35: Gum arabic yield (g/tree) in the control trees and under intercropping in seasons 2001/2002 and 2002/2003.

Treatment (m)	Season 1				Season 2			
	Intercropped		Control		Intercropped		Control	
	Pick1	Pick2	Pick1	Pick2	Pick1	Pick2	Pick1	Pick2
4x4m	7.5b	7.30a	5.30b	5.90b	4.93b	5.40a	4.70a	5.00a
4x8m	11.20a	6.70a	13.50a	12.20a	7.85a	4.10a	5.20a	3.50a
8x8m	8.50ab	8.15a	6.20b	5.60b	6.00ab	4.10a	4.10a	7.00a
LSD	3.22	3.54	3.94	2.77	2.63	4.59	2.00	4.99
C.V%	16.04	21.11	20.54	16.24	22.04	42.65	20.99	43.03

-Means followed by the same letters in the same row are not significantly difference at 5 % level.

CHAPTER VI

DISCUSSIONS

This study was carried out in old plantations of hashab tree (*Acacia senegal*) that respaced to 4x4 m, 4x8 m and 8x8 m spacing in gardud soils in Nyala province, south Darfur. The primary objective was to incorporate these trees spacing with field crops viz. millet (*Pennisetum glaucum var. Ashana*), sorghum (*Sorghum bicolor var. Tabat*) and sesame (*Sesamum indicum var. Kennena 2*). Moreover, the core of the study was to evaluate the performance and productivity of the field crops within the tree spacing. Accordingly, a model for agroforestry production system for dry land farming in southern Darfur would be developed. Estimation of gum arabic yield within this system is necessary. Therefore, crop parameters viz. crop growth as well as yield components was measured. In addition, soil moisture content and soil fertility were also determined. Moreover, hashab tree growth and gum arabic yield were also measured. However, the results of crop parameters revealed that higher population density in the wide tree spacing were obtained compared to the closely ones for millet and sorghum crops in the first and second seasons (Table 1) as well as to all crops in the third season (Table 2). Furthermore, number of leaves in the sesame crop was significantly different in the second season as well as millet and sesame crops in the third season (Table 3&4). This might be probably due to tree canopy covering which revealed significantly higher tree canopy under close tree spacing as well as moisture stress particularly in the third season (Appendix 2). Late drought stress may lead to crop poor development and performance. Whereas the variation in days to 50% flowering for both millet and sesame crops in the third season may be due to water stress that resulted late in the season (Appendix 2). However, late season water stress affects plant performance and development as stated by Ahmed (1989). In this respect, the varied days to harvesting time in the third season, especially for millet and sesame crops might have been due to water stress as well as tree/crop interaction (Table 29&31). However, tree/crop interaction was found to be severe particularly in the surface soil layers where tree roots were found (Plates 13&14). So, crops have reduced days to harvesting due to tree/crop interaction where this action is more severe as in the 4x4 m and the 4x8 m spacing than in the 8x8 m where tree/crop interaction may be due to low competition for resources. Meanwhile, the marked variation in sesame height either in the second or the third seasons (Tables 9&10) might be due to low canopy effect in the 8x8 m spacing. So, adequate light was available than under narrow tree spacing. On the other hand, the variation in crops yield either for sorghum and sesame crops in the first and second seasons (Table 11&12), or for millet crop in the third season (Table 13) might be due to canopy coverage as mentioned above or more or less due to rainfall amounts, site topographic conditions and adequate moisture content (Table 29) more than be attributed to soil fertility. In this respect, soil fertility did not differ since this study was conducted in respaced tree spacings of the same site conditions and ages (Table 33 and 34). Nonetheless, other studies indicated that soil fertility was increased under hashab trees (Saif, 1990; Mohammed, 1996), besides hashab trees ameliorate soil underneath (Hussein, 1983) as well as agroforestry systems increased crops yield that associated with (Hussein and Fadl, 2001; Hussein and Eltohami, 1998: Nasreldin, 1996). The significant differences that obtained for millet and sesame 1000-seed weight in the third season (Table 14) might be attributed either to abundant moisture as in millet crop (Table 29) or due to tree/crop interface for sesame crop. Whereas the high straw weight that obtained in the varied crops as shown in tables (15&16) might have been due to competition as well as canopy coverage. Thus dense tree canopies as indicated in 4x4m spacing seemed to affect plant growth and development. This agreed with (Resonberg *et al.*, 1993; Sato and Dalmacio, 1991). Therefore, generally one tree spacing has bad substantial effect on crop growth and development.

Land equivalent ratio (LER) was found higher under 8x8 m spacing that probably due to low tree/crop interface under this spacing.

The significant difference for tree height in control plots (Table 19) might be due to low tree/crop interaction. Whereas the variation in tree dbh particularly in the 4x4 m spacing in the intercropped plots (Table 20) may be attributed to tree/crop interaction, since tree root zone is superficial (Plate 14&15). On the other hand, the variation in tree canopy diameter either in the intercropped plots (Table 18) or the control plot (Table 21) might be due to closely and dense tree crown in case of the 4x4 m spacing (Plate 2&6) or due to low competition in the third season for the 8x8 m spacing. Whereas the variation in tree crown projection particularly in the intercropped plots (Table 18) or the control plots (Table 21) might be also due to both dense crown or low competition for light in case of the 8x8 m spacing in the third season.

Furthermore, the significant soil moisture content that obtained before sowing under tree canopy might be due to effect of tree canopy interception. In this respect, Wadsworth (1997) reported that forest canopies affected rainfall interception. However, this interception varies widely according to rainfall density, intensity and duration. Meanwhile, the variation in soil moisture content in the open areas may be probably due to rainfall fluctuation as well as less evaporation in the 4x4 m spacing when compared with the 4x8 m and the 8x8 m spacings. In this respect, under forest areas soil moisture content can increase than in the agricultural areas due to less evaporation as reported by (Vandenbeldt *et al*., 1990; Singh *et al*., 1989). The variation in soil moisture content at flowering time, particularly for millet may be due to tree/crop interaction (Tables 26&27). Though, tree/crop interaction was higher under the two soil layers, namely the 0-25 cm and the 25-50 cm depths, since millet crop is of tap root characteristics whereas sesame is shallow root crop, its competition is confined to the 0-25 cm soil layer (Table 27) particularly under tree canopy. On the other hand, the significant moisture content at harvesting time was probably due to tree/crop interaction, less evaporation and water stress. In this respect, under tree canopy moisture content was higher namely in the dense tree canopies (Table 28) than in the wide tree spacing due to less evaporation under these conditions. Thus forest sites seem to conserve more water than in the open sites (agricultural areas). Whereas under millet crop experiment due to tree/crop interaction however, marked the variation was confined in the tree open areas (Table 29). Meanwhile, in sorghum crop experiment due to crop failure moisture content was found more under narrow and wide tree spacings compared to the 4x8 m spacing in the surface soil layer only. Whereas in sesame crop experiment, due to shallow root system however, the water stress was found to be more under tree spacing than under the control plots. That probably due to severe tree/crop interaction especially the interaction for them was confined in the surface layer since, tree root system was superficial and fine roots were existed in the surface layer (Plate 14-16). However, due to low competition, water stress as was confined in the deep soil layers in the control plots (Table 32). In this respect, due to rainfall, soil moisture content could differ in agroforestry since; competition for moisture content was severe in semi arid zones as reported (Nair, 1993; Ong. *et al.,* 1992). So, trees in the semi arid zones can lead to water stress particularly for the associated crops as reported by Nair (1993).

Meanwhile the change in gum arabic yield whether under pickings or tree spacings (Table 35) might have been due both to effect of tree/crop interaction and rainfall fluctuation. Thus competition for moisture content could make stress for trees in the agroforestry. This is in agreement with Ballal (1998) who stated that yield of gum arabic was governed by season and time of tapping. So that, gum arabic yield could decrease in low rainfall areas. Others workers such as Hunting Technical Services (1976) reported that yield of gum arabic could decrease due to pruning, grazing, soil and rainfall amounts. So, pruning and soil characteristics as well as rainfall amounts may be the main reasons for decreasing gum arabic yield per tree in this study when compared with the other gum arabic gardens productivity as reported by (Booth, 1966; HTS, 1976; Ballal, 1998).

In spite of the fact that, this study is going to investigate effect of tree spacing on field crops yield as well as to model an agroforestry production system for dry land farming. The results revealed that rainfall quantity was fluctuated in terms of amounts and distribution and tree/crop interaction was found to be higher for moisture content as well as tree canopy effect was severe in the narrow spacing. So, to provide adequate productivity especially for farmers; crop early maturing varieties could be essential as well as further work is necessary to investigate the low gum arabic productivity which could be attributed to tapping intensity or picking numbers and subsequently which may be related to rainfall fluctuations or pruning practice.

So that, the 8x8 m tree spacing was found to be the good for this intercropping under these conditions.

CHAPTER VI

Summary

The important findings and observations in the Thesis can be summarized in the following**:**

-The rainfall fluctuated in terms of distribution and amount during the study period.

-Crop population density was reduced by close tree spacing namely, the 4x4 m. Sorghum and millet crops were more affected than sesame crop.

-Millet and sesame leaf numbers were affected by narrow tree spacing whereas sorghum crop did not respond to tree spacing in favor of leaf number.

- Days to 50% flowering in the third season were increased in millet and sesame crops in the 4x4 m and the 4x8 m tree spacings than in the 8x8 m and the control due to canopy coverage.

- Days to harvesting time were increased in the 8x8 m tree spacing and in the control for millet crop and in the 8x8 m for sesame in the third season respectively.

-Sesame crop was influenced by tree spacing in terms of plant height whereas sorghum crop was not affected.

-Crops yield responded to tree spacing. So, crops yield were reduced in the narrow tree spacing when compared to wide tree spacing.

-Crop straw weight was higher under wide tree spacing (4x8 m and 8x8 m) than narrow (4x4 m) and the control.

-Crops 1000-seed weight was affected by tree/crop interaction and water stress particularly for sesame and millet crop respectively in the third season.

-Land equivalent ratio was higher under the 8x8 m tree spacing than in the 4x4 m and the 4x8 m spacing in the third season that may be due to tree/crop interaction.

-Soil fertility (nitrogen,Organic Carbon and Phosphrus) did not differ under hashab tree agroforestry system whether under tree canopy or open areas and control sites in this study.

-Tree height was not affected by tree/crop interaction in the control plots.

-Tree dbh was affected by tree/crop interface particularly by narrow tree spacing (4x4 m).

-Tree canopy diameter and tree crown projection were found higher under the 4x4 m and the 8x8 m spacing than in the 4x8 m.

-Tree root zone found to be superficial and laterally spread under this site conditions.

-Variation of soil moisture content whether before sowing, at flowering or at harvesting time was related to tree/crop interface as well as to tree canopy interception, rainfall fluctuations and low evaporation under forest areas sites. Therefore, total moisture content was higher under this agroforestry production system than open agricultural areas.

- Narrow tree spacing (4x4m) seems to conserve more water than in the 4x8 m and the 8x8 m spacing due to less evaporation.

- In millet and sorghum crops experiments; soil moisture was influenced by tree spacing at soil depth layers of the 0-25 cm and the25-50 cm due to its tap root characteristics. While in sesame crop, tree /crop interaction was confined to the 0-25 cm soil layer only due to its shallow root system.

-Under control tree plots moisture content was influenced much in the deep soil layer namely (50-75) cm only.

-Gum arabic yield higher under the 4x8 m spacing than in the 4x4 m and the 8x8 m spacing.

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APPENDICES

Appendix I. Soil profile in the experimental site.

1: Information on the site

a: Profile number 1
b. Soil name: Gardud.
c. Higher category classification.
d. Date of examination: 5.3.2002.
Author: Mustafa Abdalla Nasreldin.
e. Location: Nyala, Savannah, Kilo, Nyala locality, south Darfur.
Grid Reference: 12° 00 ‘ 58.8 E

24° 54 ' 02.6 N

Photo Reference: No photo
f. Elevation: 680 m. a.m.s.l.

Geomorphology:

Land system: Basement
a. Subsystem: basement.
b. Macro topography: level to gently undulating 0-2 percen slops;
c. Micro topography: Level.
h.slope on which profile is suited: level.
i. Land use: cultivated area + open grazing.
j. Vegetation: Moderately open *Albizia amara*, *Acacia sengal*, *Adansonia digitata*, *Balanites aegyptica*,
K.rainfall: 300-400 mm.

11. General Information on the soil:

a. Parent material: non-micaceous alluvium.
b. B. Drainage:
   Surface: somewhat excessive.
   Subsurface: Moderately well.
c. Moisture conditions in the profile: Dry throughout profile
d. Depth to ground water: > 140 m.
e. Nature of surface and presence of stones, rocks outcrops:
Dry, firm "scaled" surface with thin algal crust.
f. Evidence of erosion: Noderate rain splash and sheet erosion.
g. Presence of salt or alkali: Slightly calcareous sub-soil.
h. Human influence: cultivated area + overgazed.

111. Profile:

Profile: stratified micaceous alluvium with three distinct phases of pegdogensis; 1. 0-42 cm, 11.42-53 cm 111.53-100 cm.

iv. Profile Description:

Horizon Depth (cm) description

A1 0-42 cm Dark brown to brown, dry slightly hard; hard yellowish brown, moist, very friable sand to loamy sand; wet, slightly sticky, non plastic; weak, coarse angular blocky structure; few, medium, vertical tubular pores; many fine roots, abrupt, smooth boundary,

42-53 cm: Dark grayish brown to olive brown, dry, very hard; dark grayish brown, moist, firm clay loam; wet, slightly sticky, slightly plastic; moderate, medium angular blocky structure; few, fine and medium vertical tubular pores; few, fine roots; clear, smooth boundary.

53-100 cm: Grayish brown to light olive brown, dry, very hard, moist, firm, clay loam; wet sticky, slightly plastic; moderate to strong; medium angular blocky; common, fine vertical tubular pores; common thin clay skins on ped faces and as bridges between mineral grains; abundant, fine and medium, soft, disseminated carbonate filaments; clear, smooth boundary.

Appendix II: rainfall during the trial execution period in mm in Nyala:

Seasons	May	June	July	August	September	October	No. of rainy days	Total
2001	16.3	51.9	79.7	52.2	86.1	-	23	286.2
2002	-	30.1	28.5	79.2	106.6	67	23	311.4
2003	69.9	103	158.9	154.4	63.0		36	547.2
2004	-	63.4	85.5	172	51.2	12.1	21	384.2

Source : Nyala Research Station, ARC.