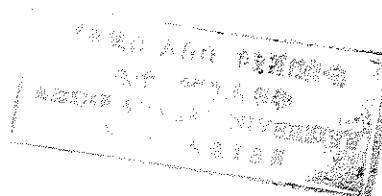


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ADDIS ABABA UNIVERSITY
SCHOOL OF GRADUATE STUDIES

**ROOT GROWTH PATTERNS AND PLANT
ADAPTABILITY IN THREE *ACACIA* SPECIES**



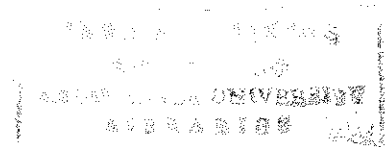
TEKLEHAIMANOT HAILESELASSIE

June, 1998

ROOT GROWTH PATTERNS AND PLANT ADAPTABILITY IN THREE *ACACIA* SPECIES

TEKLEHAIMANOT HAILESELASSIE

**A Thesis submitted in partial fulfillment for the degree of
Master of Science in Biology**



June, 1998

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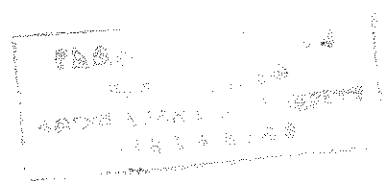
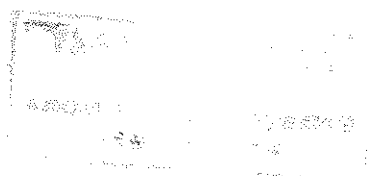


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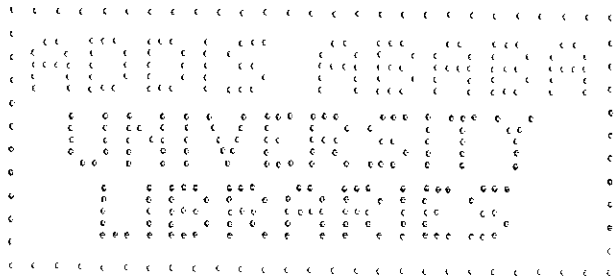
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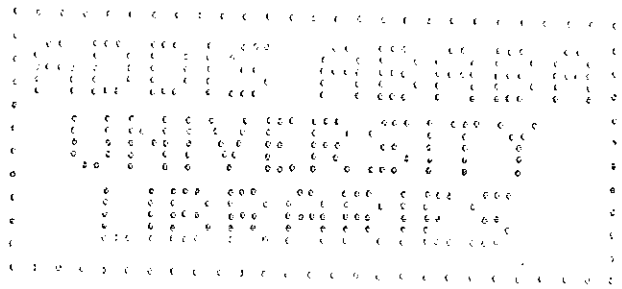
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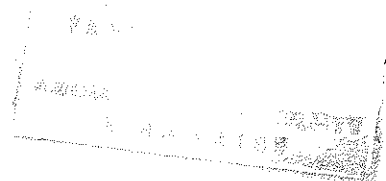
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ABSTRACT

Trees and shrubs screened for desirable properties can play an important role in the rehabilitation of degraded lands. Indigenous species adapted to harsh conditions of degraded sites can reverse degradation processes by stabilizing soils, increasing organic matter and improvements of nutrient status etc. Studies have shown that *Acacia* species have a potential for use in agroforestry systems and rehabilitation of degraded lands. For proper evaluation of the use of *Acacia* species in rehabilitation schemes and for agroforestry systems, studies in the root growth patterns and adaptability are essential. The main objective of this study was, therefore, to assess the root growth patterns of some *Acacia* species namely, *A.seyal* Del., *A.senegal* (L.) Willd. and *A.tortilis* (Forrsk) Hayne and see the relevance of the results in adaptation to aridity. The study was conducted in Abernosa Ranch and Abiyata Shalla National Park. To investigate rooting patterns of the selected *Acacia* species, young trees were carefully excavated exposing a representative portion of the root system and quantitative data taken on depth at which the first lateral root starts, radial spreading of lateral roots and the zone of most intense lateral roots. Saplings were completely uprooted and separated for shoot and root parts, and oven-dried for the determination of shoot-root ratio. To see the effect of the *Acacia* trees on their undergrowth, comparison of herbaceous root biomass was carried out with adjacent open grassland in Abernosa. There was some difference in root growth patterns between species, *A.seyal* characterized by few but very big lateral root in close proximity to the surface, *A.senegal* with very dense lateral roots near to the surface and *A.tortilis* with less prominent lateral roots as compared to the others. The length of the taproots and shoot-root ratio of the saplings uprooted indicated that *A.tortilis* has greater depth penetration. There was no significant difference within species between the two sites for depth of first lateral root, zone of most intense lateral roots and for radius of lateral spread. Depth penetration and ramification of lateral roots seem to be a function of soil and bedrock conditions. The herbaceous root biomass under *A.seyal* was significantly higher than the adjacent open grassland indicating the influence in increasing productivity.

1. INTRODUCTION

1.1 Scope of the problem

An estimated 34% of Ethiopia's land area was thought to be originally covered by high forests and with the inclusion of savanna woodlands, this can be extended to some 66% of the country's land area (FAO, 1981). However, Tewolde Berhan Gebre Egziabher (1986) argues that this estimate is wrong. The argument is that, this would make agriculture in Ethiopia about 100 years old, since the above claim for forests would cover all the present day agricultural highlands.

Regardless of the above arguments on percent forest cover, over the last 5000 years there has been progressive deforestation that has tremendously increased during the last century as the country's population has grown. High forests were estimated to cover about 2.7% land area in 1989 and are expected to be much less at present. This recent transformation of the environment is most advanced in the southwestern part of the country where extensive forest clearing is taking place. Degradation of the environment in the north might have taken its toll long ago (National Conservation Strategy (NCS), 1990).

The main forces behind this change in vegetation are population growth and economic pressures that have led to increased demands for crops, timber and pasture. Ecological factors might have also played a role by making the regeneration of trees more difficult (NCS, 1990).

Furthermore, FAO/UNDP (1980) identified the following factors as substantial causes for the depletion of forests in Ethiopia. These are:

- The traditional attitude of the Ethiopian peasants to a forest has been that it is either a potential cropland, and hence its presence interferes with cultivation, or it is a source of fuel. This attitude together with lack of clearly defined ownership, and lack of authority of control over the forest, have been the major causes for heavy encroachment (Tewolde Berhan Gebre Egziabher, 1986, 1990).
- Grazing fires, which destroy all undergrowth and prevent the trees from regenerating.
- Uncontrolled commercial exploitation, which is not followed by any silvicultural treatment so that logged areas can be rehabilitated.
- Success in forest protection basically lies in the growing economic wealth and social consciousness of the need for forests.

At present there is an urgent need to rehabilitate or restore the ecosystems that have been damaged by natural and human activities.

Tree and shrub species screened for desirable properties can play an important role in the rehabilitation of degraded lands. Numerous studies have shown that indigenous species adapted to harsh conditions of degraded sites can reverse degradation processes by stabilizing soils, increasing organic matter through enhancement of above-ground and below-ground litter production and turnover and decomposition rates, moderation of soil pH and improvement of nutrient status (Parrotta, 1992; 1993; Schroth, 1995). In addition,

plantations and wind breaks provide fuelwood and fodder that are often in short supply and protect both fields and villages from winds and dust storms. The local water cycle also becomes more stable (Grainger, 1986). A number of studies have shown that *Acacia* species could meet these standards (New, 1984; Parrotta, 1993; and Fagg and Stewart, 1994).

There are about 1250 species of *Acacia* of which 134 species (represented by 170 taxa) are native to Africa. Despite this richness of *Acacia* species, relatively few appear to have been investigated (FAO, 1995) for their potential in agroforestry and rehabilitation of degraded lands.

According to FAO (1995) approximately 55% of the land surface of Africa is arid and semi-arid characterized by annual rainfalls of less than 100 mm to ca. 600 mm in a short season of 2-4 months. The total precipitation in the arid and semi-arid regions varies widely from year to year and its distribution within a year is also variable. This low, irregular and poor distribution of rainfall, especially in areas with less than 400 mm, places greater value on multi-purpose trees such as *Acacia* species.

Most *Acacia* species are important commercial sources of gums and tannin. Many are utilized by rural populations in local medicines, for fiber, domestic utensils and handicrafts. According to Fagg and Stewart (1994) their value in arid zones lies in their extreme resistance to heat, drought, salinity and alkalinity, drifting sand, grazing and repeated cutting. Thus, most *Acacia* species have a potential for use in agroforestry systems and

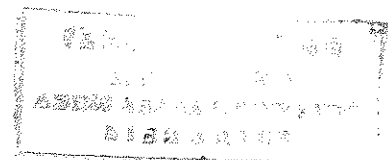
rehabilitation of degraded lands. Promising results were found from retaining *A. albida* (currently known as *Faidherbia albida*) trees by farmers to benefit crops underneath i.e., increase productivity (Vandenbeldt, 1991; Kamara and Hague, 1992).

Although Ethiopia has more than 58 *Acacia* species (Asfaw Hunde and Thulin, 1989), some endemic to the country, there have been few investigations on the potential of these species for agroforestry and rehabilitation purposes (Asferachew Abate, 1994). For proper evaluation of the use of *Acacia* species in rehabilitation schemes and for agroforestry systems, a study in the growth patterns and adaptability are essential (Lawton, 1996). The present work, therefore, aims to explore the root growth patterns of some *Acacia* species and see the relevance of this in their adaptation to aridity.

According to Schroth (1995), the following benefits are expected from the presence of root systems of trees used in agroforestry:

- Soil enrichment with organic matter, maintenance of soil biomass and enhanced nutrient cycling through root production and turnover.
- Uptake of water and mobile nutrients from the soil, thus reducing leaching losses.
- Pumping up nutrients from subsoil layers below the main rooting zone.
- Improvement of soil penetrability for crop roots and of other soil physical properties.
- Fixation of atmospheric nitrogen.

Plant root systems have been studied in their morphological and physiological aspects for



a long time, but little is known about characteristics such as the size of the root systems, root growth rates under field conditions, interrelations among root systems of different plant species (Dhyani *et al.*, 1990). This is at least partially due to the fact that roots, especially very fine roots and entire (deep) root systems, are difficult to observe (Kummerow, 1981; Caldwell and Virginia, 1989).

Recent methodological innovations present opportunities for improved understanding of the functional importance of root architecture in the efficient acquisition of soil resources and plant adaptation to suboptimal soil conditions (Lynch, 1995). According to Lynch (1995) root architecture refers to “the spatial configuration of the root system, i.e. the explicit deployment of root axes”. Usually studies of root architecture do not include fine structural details, such as root hairs, but are concerned with an entire root system or a large subset of the root system of individual plants.

Structure, growth, penetration and the characteristics of root spread are species specific (Baitulin, 1996) but they are influenced by the interaction of a number of factors, including the physical, chemical and geological properties of the soil, topography, aspect and climate (Lawton, 1996; Persson and Baitulin, 1996). For example, Baitulin (1996) has found that the deeply rooted desert tree *Haloxylon aphyllum* on alkali soils reaches 4.1 m, on half fixed hilly sands or brown sandy loam soil 7.3 m, and in soils with deep deposits of ground water up to 10 m depth, due to ground water conditions.

Baitulin (1996) also showed that root systems as organs clearly reflect the conditions of their habitats in arid climates. There they must exploit the poor soil and water resources

most effectively. Extreme environmental conditions cause functional changes in the root system and lead to reorganization of the system.

Plant growth in non-agricultural conditions is limited more by soil-derived resources than by carbon dioxide or solar radiation (Fitter, 1987). It seems evident, therefore, that an understanding of the functioning of plants within natural communities must require an equal understanding of the behavior of roots and root systems (Fitter, 1987; Gile *et al.*, 1994; Kummerow, 1981). The importance of root architecture in plant productivity stems from the fact that many soil resources are unevenly distributed or are subject to localized depletion. The spatial deployment of the root system, therefore, will in large measure determine the ability of a plant to exploit these resources (Lynch, 1995; Groot and Soumarè, 1995).

The selections of species for afforestation programs (especially for areas with unfavorable conditions) requires knowledge of the root behavior of plants. Therefore this study aims at looking into the difference in root growth patterns among three *Acacia* species and differences (if any) within species in different areas.

African savannas include a broad range of vegetation types characterized by grassland associated with a discontinuous woody overstorey (Georgiadis, 1989; Belsky, 1994). Trees growing at low densities in arid and semi-arid pastoral ecosystems have often been found to improve understorey environments (Belsky *et al.*, 1993). The exact conditions altering the productivity under tree canopies relative to the open grassland are unknown.

It is suspected that reductions in understorey productivity are due to rainfall interception by overhead canopies, reductions in total solar radiation reaching the ground and competition between trees and herbs for water and nutrients. Increases in understorey productivity on the other hand, are thought to be due to cooler temperatures and reduced evapotranspiration in the shade (Forst and McDaugald, 1989, Norman and Campbell, 1989). The relative effect of the above factors can result in either reduced or increased understorey vegetation in contrast to open grasslands.

It is clear that in savannas tree density increases available nutrients, water infiltration rate, and soil organic matter compared to open grasslands. The reasons given for this increase in soil fertility under trees are varied (Kellman, 1979; Kelly and Walker, 1976; Georgiadis, 1989; Weltzin and Coughenour, 1990; Vetaas, 1992; Belsky, 1994). For example:

- The extensive root systems of trees explore large soil volumes and extract nutrients that are concentrated under the crown through litter fall (Garcia-Moya and Mckell, 1970; Knoop and Walker, 1985),
- tree are used as perches by birds, the area under the crown might be enriched by bird droppings,
- large mammals that graze in the grassland and rest under the shade deposit nutrients in their dung,
- trees trap precipitation inputs more efficiently,
- canopy leaf fall from trees,
- dust accumulation on trees and branches.

In general, litter fall from trees, root hair decomposition, dust accumulation on trees and symbiotic nitrogen fixation (in nitrogen fixing species) might be the main factors that enrich under canopy soils with essential plant nutrients. This has got important implications for agroforestry and silvopastoralism. In light of the above, the root biomass of under-crown herbaceous plants under the *Acacia* trees and their adjacent grasslands were compared to see if there is difference in productivity.

1.2 Objectives of the study

The specific objectives of this study were the following.

- To compare the root growth pattern among different *Acacia* species and differences within species in different sites.
- To relate root growth patterns with major soil types/environmental conditions.
- To investigate adaptive significance of root patterns of three *Acacia* species.
- To relate root growth pattern and overall canopy features both with survival and growth features in different species.
- To compare root biomass between under-canopy and open-grassland herbs to evaluate the potential of *Acacia* trees for Agroforestry.

1.3 Description of the Study Areas

1.3.1 Location

The study was conducted at two different sites within the Ethiopian Rift valley, namely Adamitulu cattle ranch about 180 km south of Addis Ababa and Abiyata-Shalla National Park (7°33'N, 38°31'E), about 200 km south of Addis Ababa in Eastern Shoa Zone. The altitude of the area is about 1700 m above sea level.

3.2 1 Geology and Soils

Geology: A detailed account of the geology of the Rift Valley System of Ethiopia was given by Mohr (1962, 1967a and 1967b) and Perrott (1979). The main Ethiopian Rift Valley is a NNE - SSW trending trough bordered by the Ethiopian and Southeastern plateaus, which exceed 2500 m in elevation over wide areas. The two study sites are found within the main Rift Valley.

In the region of the Zeway-Shalla Basin, the Rift floor rises to 1500-1700 m above sea level. It is bounded by strongly faulted escarpments (Perrott, 1979). Both plateaus are largely underlain by 'Trap Series' flood basalts and intercalated ignimbrites of Oligocene to Miocene age (28 to 19 m.y. and upwards), which rest on an upwarped Mesozoic basement. However most of the basalts are now concealed by a cover of silicic stratoid volcanics, the Nazareth Series, which is dated from 9.5 to ca. 2 m.y. These also underlie the present Rift floor.

According to Perrott (1979) and Mohr (1962, 1967b) basaltic lavas and cinder-cones as well as silicic flows and domes of Quaternary age occur in two main fields which are both thought to originate from fissure eruptions. One is located near the main western boundary faults of the Rift and the other east and northeast of Lake Zeway. Recent sediments of Quaternary age which are composed of conglomerates, sands, silt, and clay represent non-volcanic rock units in the study sites (EMA, 1988).

Soils: The major soil types in the Rift Valley clearly show the influence of soil parent material and extent of weathering. The central belt of skeletal or weakly developed soils has formed from lacustrine sediments, river alluvium and pumice (Perrott, 1979).

Murphy (1959, 1968) has made a detailed survey of the soils in the study area. The area that is fenced as pasture for the cattle ranch has soils that are usually sandy loams to loams. These soils are usually gray or gray brown in color when dry, and dark gray to very dark gray brown when moist. Most of these soils are neutral (pH 6.6 to 7.3) and some of them are more likely to be somewhat mildly to moderately alkaline. The subsurface and sub-soils are more basic than the surface soils. Surface soils of these pastures were found to contain more than 3% organic matter and more than 0.15% total nitrogen, which is an amount thought to be enough for native grass pasture. The total phosphorus content is on the low side the average being 145 ppm, and the bases (potassium, calcium and magnesium) are moderately available (Murphy, 1968).

Leaving the Adamitulu area and in the narrow valley between Lakes Langano and Abiyata and Shalla area, a pumice horizon is often encountered at about 15 to 30 cm. The surface soil is commonly a loose (low bulk density), light-weighted, friable loam, sandy loam or clay loam. It is usually dark brown to dark grayish brown in color when dry. The color of the pumice varies from gray to brown.

1.3.3 Climate

The present climate of the Rift floor is semi-arid, with pronounced wet and dry seasons, although altitude has a moderating influence on the temperatures experienced (Perrott, 1979). The rainfall pattern in Ethiopia is governed by two moist wind systems, one coming from the Atlantic Ocean and the other from the Indian Ocean (Griffiths, 1972; Daniel, 1977). The Rift Valley experiences a nearly bimodal rainfall distribution. From March to May, southeasterly winds from the Indian Ocean bring the unpredictable "small rains". After a short break in May and June, the main rains come in July and August. The months October to March are dry and windy.

Mean annual rainfall amounts recorded around the lakes range from ca. 465 mm at Langano (1600 m) to more than 800 mm on the Meki-Awash and Shalla-Awasa divides.

Air temperatures also show strong altitudinal trends, although available data from within the basin are scanty. At Zeway (1640 m), the main daily temperature record is 19.3°C, and at Langano, around 20-21°C (Makin *et al.*, 1976). Seasonal variations are small, the lowest temperatures occurring during the rainy seasons (Perrott, 1979)

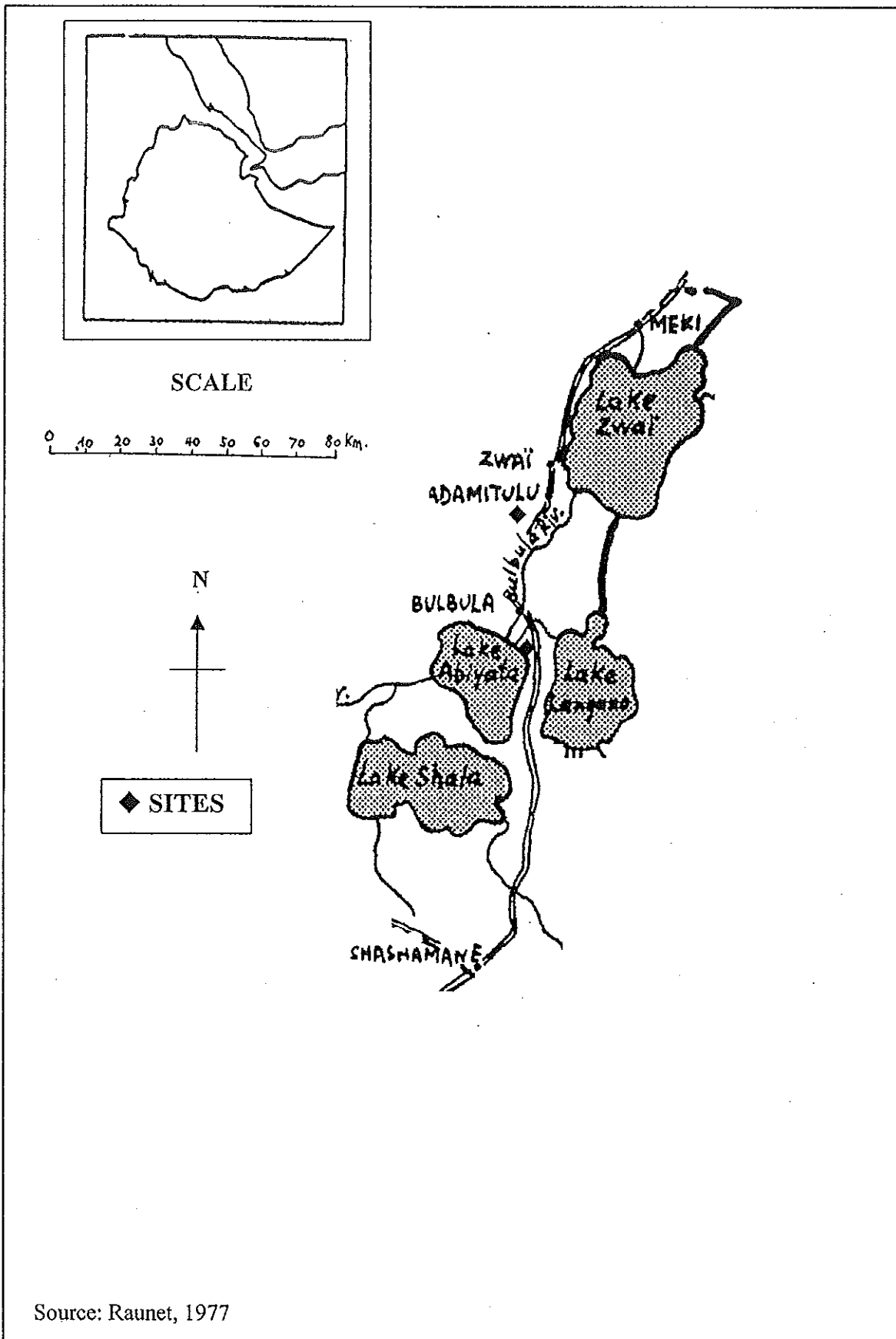
1.3.4 Flora and Fauna

The vegetation of Ethiopia has been grouped into nine major zones (Ensermu *et al.*, 1992). The vegetation of the study area belongs to *Acacia-Commiphora* woodland (Ensermu *et al.*, 1992). According to Zerihun Woldu and Mesfin Tadesse (1990) the vegetation type of Adami Tulu and Abiyata-Shalla National park area belong to a low altitude deciduous vegetation type dominated by *Acacia tortilis*, *A. seyal*, *A. senegal* and *Balanites aegyptiaca* on sandy soils. *A. tortilis* and its associated species cover a large portion of the Rift valley lake region. In the study site near Adamitulu a relatively intact form of this vegetation type is currently found as it is managed as a cattle ranch with controlled grazing.

According to records by IUCN (1987) and Hillman (1993) the Lakes around the study area are sites for some 300 bird species including pelicans, eagles, flamingoes, egrets, and herons, breeding colonies of white-necked cormorant, plovers and ducks. Mammals include Klipspringer, Grant's gazelle, oribi, greater kudu, mountain reedbuck and eastern black- and white colobus and baboon, Jackal and hyena in significant numbers. Because the Valley Lake areas are home for the above mentioned species and others they are recognized as one of the Ecologically Sensitive Sites in Africa (World Bank, 1993).

1.3.5 Land Use

There is considerable cultivation of agricultural crops and livestock raising in all areas. Corn, beans and tef are the major crops in the area. Grazing, tree felling, charcoal-production and fishing by the local population are also widely practiced. As cutting trees for wood and charcoal are wide spread and lucrative business in the Rift Valley, *A. seyal* and other tree species, which could be easily cut and burned have suffered the most. The Rift Valley is an important source of charcoal for the nearby towns and Addis Ababa (Zerihun Woldu and Mesfin Tadesse, 1990). Specially, the Abiyata-Shalla National Park is situated in one of the most populated areas of Ethiopia; recently the whole area has been overrun, and permanent settlements established. At the time of the changeover of government in Ethiopia in May 1991, major destruction on looting occurred in the park, virtually destroying all management infrastructures (Hillman, 1993; IUCN, 1987). In fact, during the time of this study it is witnessed that an effort has been started to rehabilitate the infrastructures and the office has moved from Arsi Neghelle to within the Park.



Source: Raunet, 1977

Fig. 1 Map of the study area

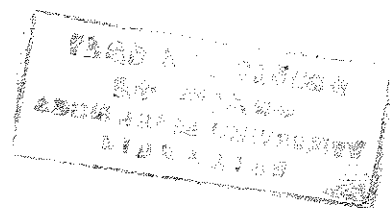
1.4 Description of the Study Trees

The nomenclature of the species follows Asfaw Hunde and Thulin, M. (1989) in the Flora of Ethiopia Volume III and descriptions were taken from Asfaw Hunde and Thulin, (1989), Maydell (1990), Azene Bekele *et al.* (1993) and IBPGR (1984).

1.4.1 *Acacia senegal* (L.) Willd. (1806)

Description: *A. senegal* is grouped under family Fabaceae and subfamily Mimosoidea. It grows as a tree (or shrub) of 2-6 m, occasionally up to 8 m in height, with umbrella-shaped crown. The stem is very branched with many upright twigs, wider spreading in the upper part. Bark is light gray to light brown, smooth on young, very scaly on older trees. It has characteristic prickles in triplets the central one hooked downwards and the other two laterals \pm curved upwards, or solitary and brown to black in color. Leaves are compound with pinnae in 3-8 pairs, mostly less than 0.5 mm apart and leaflets in 7-25 pairs. Flowers are creamy spikes usually developing before the rainy season. The fruits are in pods variable, thin and flat, oblong to 14 cm long, narrowing at both ends and splitting to release 3-6 flat, round light brown seeds.

There are two varieties in Ethiopia: var. *senegal* and var. *leiorhachis* and var. *senegal* is found in the study area.



Ecology: *A. senegal* is very drought resistant and grows with annual rainfalls that may range between 100 and 800 mm, but mainly between 300-400 mm, with a long dry period of 8-11 months. The tree tolerates very high daily temperatures, dry winds and sandstorms. It is particularly common in Dry and Moist Kolla agroclimatic zones in Ethiopia. These zones are characterized by annual rainfall of 300-900 mm and 900-1400 mm, respectively and average temperature above 25°C. The altitude is between 500-1500 m above sea level. Although generally soils should be well drained, there are exceptions where it grows also on heavy clay soils with approximately 800 mm of annual precipitation.

Distribution: It is wide-spread in tropical Africa; a typical tree of the Sahel from Senegal to the Red Sea with varieties occurring in East and South Africa, essentially limited to areas between 11° and 16° northern latitude. In Ethiopia it is widespread in wooded grassland, deciduous bushland, dry scrub areas found in Afar, Wollo, Shoa, Arsi, Bale, Hararege, Gojam and Sidamo between altitudes of 600-1700 m above sea level.

Uses: *A. senegal* produces nearly 90% of the GUM ARABIC of international trade and is extensively exploited for this. Bark, leaves, and gum of *A. senegal* are used to treat diseases such as gastric disorders and hemorrhage. Further uses of *A. senegal* include nectar for bees and forage for livestock, in particular the pods, but also leaves and young shoots. The wood is in demand as fuelwood and for charcoal production. Through its extended lateral roots it is important in soil stabilization, besides soil improvement by nitrogen fixation and litter fall. *A. senegal* is also an important tree for agroforestry systems in arid and semi-arid areas of Sudan and western Ethiopia.

1.4.2 *Acacia seyal* Del. (1813)

Description: *A. seyal* is grouped under Family Fabaceae and Subfamily Mimosoidea. It is a tree up to 9 m high with usually flattened crown. The bark on the trunk is powdery, white to greenish yellow or orange red, often peeling to reveal greenish underbark. It has wide-angled pairs of strong white spines up to 8 cm long. The leaves are compound with 3-7 pairs pinnae and with 11-20 leaflets. Flowers are several, bright yellow in color and in heads besides the thorn. Fruits are in bunches of narrow, curved pods 7-20 cm long, splitting open on the tree.

There are two varieties: *Var. seyal* and *Var. fistula*.

Ecology: This species is found on seasonally flooded black-cotton soil, in river valleys and wooded grassland of Dry- and Moist-Woina Dega agroclimatic zones. These zones are found in altitudes between 1500-2300, get 300-900 mm and 900-1400 mm annual rainfall, respectively and the average temperature is 18-25°C.

Distribution: found in woodland, wooded grassland areas in Gojam, Arsi, Shewa, Hararge, Ilubabor, Kefa, Sidamo, Western Tigray, western Wollo regions. It is widespread in western Eritrea, northern tropical Africa, extending to Egypt, and southwards to Malawi and Mozambique. The altitude ranges between 500 - 2100 m above sea level.

Use: The bark and exudate have medicinal uses. Red dye can also be extracted from the bark. In western Ethiopia, the tree is widely used to shade coffee. It has also other uses as given for *Acacia* as a whole including firewood, charcoal, fodder, nitrogen fixation etc.

1.4.3 *Acacia tortilis* (Forrsk) Hayne (1827)

Description: A tree to 20 m tall but usually smaller, with a flat or very broadly spreading crown. The bark is gray to black, rough and fissured. The spines are of two types, some short, hooked and up to 5 mm long, others straight and whitish up to 10 cm long. Leaves are compound with 2-10 pairs of pinnae and with leaflets 6-22 pairs. Inflorescence is a spherical head of many tiny and cream or white flowers, about 1 cm in diameter. It has characteristic pods that are thin textured, narrow and twisted often into a spiral that dry out and break open on the ground to set free hard flat seed about 4-7 x 3-6 mm in size.

Two subspecies are recorded for Ethiopia, Subsp. *tortilis* and Subsp. *spirocarpa* and Subsp. *spirocarpa* is found in the study area.

Ecology: It is a wide-ranging species of the arid and semi-arid regions of Africa. It is found widespread in dry land and moist Kolla and Weyna Dega agroclimatic zones of the country. It favors alkaline soils and can grow on shallow soils. It produces enormous deep roots penetrating a wide area to collect water.

Distribution: woodland, wooded grassland, dry scrub; c. 600-1900 m of the Afar plain, Bale, Hararge, Shewa, western Wollo, and western Tigray. Elsewhere it is found in western Eritrea, Sudan, Somalia, and southwards to southern tropical Africa, also in Arabia and Israel.

Use: An important shade and browse tree whose seeds are said to be edible and used as famine food. The wood has many uses including firewood, charcoal, timber (local construction), fodder (leaves, fruit), tool handles, fences (cut branches), and gum.

2. MATERIALS AND METHODS

The following species were selected for investigation during the reconnaissance survey.

These are:

1. *Acacia senegal* (L.) Willd. (1806) Var. *senegal*.
2. *Acacia seyal* Del. (1813) Var. *seyal*.
3. *Acacia tortilis* (Forssk) Hayne (1827) Subsp. *spirocarpa*.

The study area was in Adami Tulu Woreda. The two sites selected were Abernosa Cattle Ranch and Abiyata-Shalla National Park. The sites were selected for the following reasons:

- availability of the *Acacia* species of interest required for the investigation,
- relatively well protected and little human influence as compared to other sites in the area,
- the sites are thought to have different soil types (Asferachew Abate, 1994), and
- easily accessible from the main road

Fieldwork was carried out between 12-28/03/97 and 7-31/05/97. During these two periods, investigations were carried out on the root growth patterns of the *Acacia* species as given below.

2.1 Root growth pattern

To investigate rooting patterns of *A. senegal*, *A. seyal*, and *A. tortilis*, young trees of average height 4.2 m, 6.7 cm dbh, and 5.3 m crown (canopy) diameter and 8.1 cm diameter at ground level were carefully excavated. The plants were excavated from relatively undisturbed areas within the sites by unearthing the roots with various digging tools from a trench of 1.50m length and 1.00m width, to observe horizontal and vertical planes of root architecture. The taproots were not excavated to the end of the root, as the method employed was excavation of part of the root system- termed the sector method- exposing a representative portion of the root system (Böhm, 1979). The depth of the trench was determined by the depth of the zone of lateral roots branching from the taproot and the rockiness of the soil. Four individual trees were excavated from each species at both study sites except for *A. seyal* in Abiyata-Shalla.

Young trees were excavated because of the difficulty of digging up root system of large trees manually. There is the general understanding that the root architecture of mature trees would be similar to that of young trees except that the roots of the old ones extend further (Belsky, 1994). Photographs of old trees at the edge of big gullies whose roots had been exposed by erosion were taken for *A. tortilis* and *A. seyal* (*A. senegal* was not available for this purpose).

After excavation, the soil, which adhered to the roots, was gently removed using simple hand tools to expose the root system for observation and photography. Photographs of roots were taken against the soil profile wall in most cases. As roots are frequently dark in color, they do not contrast very well with the surrounding soil and are hard to distinguish in a photograph. To improve the contrast, a 1 m x 0.7 m mounting paper sectioned into 10cm x 10cm grids, was inserted behind the roots which made better contrast between the roots and vertical trench wall. However, this had its own limitation as the roots get detached from their natural position and was practiced only on a few occasions.

The excavated root systems were converted into quantitative data and records taken on depth of penetration of the taproot, radial spreading of lateral roots, depth at which the first lateral root starts to grow, and the zone of most intense lateral roots following methods of Kummerow (1981). *In situ* observations were also made on morphological changes occurring in the roots and abnormal features of root parts.

Saplings of average 1.03 m in height and 1.21 cm in diameter at ground level (base) were completely uprooted. The uprooted plants were separated for root and aboveground portions and put in plastic bags and were brought to the laboratory for the determination of shoot-root ratios for oven-dried weights. The shoot-root ratios were calculated by dividing shoot weight over root weight. Values greater than one indicate that above ground parts have more development than roots. Total length of the taproot of the saplings was measured after being uprooted. Observations on how the taproot grew to make its way through the soil were also made.

2.2 Soil

Soil samples (forty) were taken from the soil profile under each tree excavated. The soil colors of the soil were taken indicative of the soil horizons and samples were collected at 30 cm interval throughout the depth of the trench. Soil samples were also taken using metal cores for the determination of bulk density. Soil moisture content was measured in the field and soil analysis for some physical and chemical properties were carried out in the Soil and Ecophysiology Laboratory of the Department of Biology.

2.2.1 Soil moisture content

Measurement of bulk soil water content was carried out using Time Domain Reflectometry (TDR) (Model 6050 x 1 Trase System) following Dalton *et al.*, (1984) and Topp and Davis (1985). The metal waveguide used for depth measurements were 15 cm long stainless steel rods. As the measurements were taken long after excavation was made, and as this could affect the result because of evaporation, measurements were taken through digging a new trench nearby. Four measurements were taken for each trench, i.e. 0-120 cm at an interval of 30 cm along depth gradient. The data stored (saved) in the TDR was downloaded to a personal computer using RS-232 compatible serial port.

2.2.2 Soil texture

The texture of the soil samples was determined following the Hydrometer Method of Mechanical analysis (Juo, 1978). Fifty ml of 5% sodium hexametaphosphate along with

100 ml of distilled water was added to 51 g of two mm sieved soil samples. After stirring, the suspension was allowed to stand for 30 minutes. The soil suspension was stirred for 15 minutes with a multi-mix machine and then transferred to a one liter measuring cylinder. Then the cylinder was filled with distilled water up to the liter mark and mixed by covering the top of the cylinder with the palm of the hand and inverting several times until all soil was in suspension. The first hydrometer and temperature readings were taken in 40 seconds after the cylinder was put on a table. The second hydrometer and temperature readings were taken three hours later. The percentage of different soil particles were calculated following (Juo, 1978) as follows:

$$\% \text{ Sand} = 100 - [H_1 + 0.2 (T_1 - 68) - 2.0]^2$$

$$\% \text{ Clay} = H_2 + [0.2 (T_2 - 68 - 2)]^2$$

$$\% \text{ Silt} = 100 - (\% \text{ sand} + \% \text{ clay})$$

where; H_1 - the first hydrometer reading

H_2 - the second hydrometer reading

T_1 - the first temperature reading

T_2 - the second temperature reading

2.2.3 Bulk density

Bulk density was determined following Wilde *et al.* (1979). Soil samples were taken using a cylindrical metal corer. The corer was pressed into the soil and then removed by a spade with its content and the surplus soil was removed using a knife. Samples were

taken from different depths (i.e. 0-30 cm, 30-60 cm, 60-90 cm and >90 cm). The samples were then dried to constant weight in an oven for 48 hours at 75°C and weighed. Bulk density was recorded as the weight of the sample divided by its volume.

2.2.4 Soil pH

The pH of the soil was determined using a 1:1 soil water ratio (Jackson, 1973; Juo, 1978). Twenty grams of soil, passed through 2 mm sieve was mixed with 20 ml of distilled water in 50 ml beaker. The suspension was stirred occasionally and after 30 minutes the pH was determined using a Beckman pH meter after standardizing with buffer solutions of pH 4 and 7.

2.2.5 Total Nitrogen

Total Nitrogen was determined following the Macro-Kjeldhal method as described below. The Kjeldhal method for nitrogen determination involves three processes: digestion, distillation and titration. To one gram of soil samples, passed through a 0.5 mm sieve, seven g of potassium sulfate and 0.8 g of cupric sulfate was added to macrokjeldhal tubes. The mixture was digested at 420°C for about three hours until a clear solution developed. After cooling, 75 ml of distilled water was added and let to stand overnight. After dispensing 50 ml of 40% sodium hydroxide, the digest was distilled. The distillate was received in 25 ml of 4% boric acid mixed with indicators and titrated with 0.1 N

hydrochloric acid until the green color of the distillate changed to neutral gray. Similarly the blank was passed through all the processes as for the samples to compensate for any contribution from the reagents used. Then the percentage of nitrogen present was calculated as follows:

$$\% N = \frac{(T - B) \times N \times 14.007 \times 100}{\text{Weight of sample in mg}}$$

Where; T- titration volume for the sample

B- titration volume for the blank

N- normality of the acid

2.2.6 Available Phosphorus

Available phosphorus for acidic soils was determined following Bray No. 2 and for basic soils using Olsen and Sommers (1982), as recommended by Tamirie Hawando *et al.* (1986). In Bray No.2, to 2.85 gram of soil sample, passed through 2 mm sieve, 20 ml of the extracting solution (0.03 M NH_4F and 0.1 M HCl) was added. This was shaken for 40 seconds on a mechanical shaker and the suspension was centrifuged at 2,000 rpm for 15 minutes. Then 2 ml of the clear supernatant was pipetted into 20ml test tubes. Five ml of distilled water and 2ml of ammonium molybdate solution was added into the 20ml supernatant and the content mixed. Then one ml of diluted stannous chloride ($\text{SnCl}_2 \cdot 2\text{H}_2\text{O}$) was added and after 5 minutes the transmittance of the resulting complex was determined using a spectrophotometer (Spectronic 1001) at 660 nm. The

concentration of available phosphorus in the soil was calculated from the standard curve obtained with known concentrations of phosphorus.

The concentration of dilute fluoride-dilute acid extractable phosphorus in the soil was calculated as follows:

$$\begin{aligned}\text{ppm of P in soil} &= \text{ppm of P in solution} \times 10/2 \times 20/2.85 \\ &= \text{ppm of P in solution} \times 35\end{aligned}$$

In Olsen method, 5 gm of soil, 1 teaspoon of carbon black, and 100 ml of extracting solution (NaHCO_3) were added to a 250 ml Erlenmeyer flask. After shaking the flask for 30 minutes the suspension was filtered through a Whatman No. 40 paper. To a 5 ml aliquot of the extract kept in a 25 ml volumetric flask 5 ml of the ammonium molybdate solution was slowly added. Then, the content was diluted to about 22 ml with distilled water and 1.0ml of the dilute SnCl_2 solution was added to the flask. Finally, the solution was diluted to volume and contents mixed. The transmittance of the resulting complex was determined at 660 nm and available phosphorus in the soil was calculated from the standard curve obtained with known concentrations of phosphorus.

$$P (\text{ppm}) = \text{ppm of P in sample extract} \times 100/s$$

Where, 100 = ml of extracting solution, s =soil sample weight in grams (5g).

2.2.7 Organic carbon

Organic carbon of the soil was determined following the Walkley and Black wet oxidation method under standardized conditions with potassium dichromate in sulfuric acid medium (Chopra and Kanwar, 1976). The values obtained by this method are only approximate, since only 60-90% of all the carbon is oxidized with a mean value between 75-80%. For this reason, the value obtained was corrected by a factor of 1.33 according to Juo (1978). The method was as follows. Ten ml of 1 N potassium dichromate and 20 ml of sulfuric acid were added to one gram of soil sample passed through 0.5 mm sieve in a 250 ml Erlenmeyer flask. The mixture was shaken for two minutes and allowed to stand for 30 minutes. Then 150 ml of distilled water, 10 ml of 85% phosphoric acid and 1 ml of diphenylamine indicator solution was added and titrated with 0.5 N ferrous ammonium sulfate solution. Similarly blank determination was also carried out to standardize the dichromate solution. Then the % organic carbon was calculated using the following formula:

$$\% \text{ organic carbon (air-dry basis)} = \frac{(\text{me } \text{K}_2\text{C}_2\text{O}_7 - \text{me FeSO}_4) \times 0.003 \times 100 \times (f)}{\text{g of air-dry soil}}$$

Where, correction factor, $f = 1.33$, $\text{me} = \text{Normality of solution} \times \text{ml of solution used}$.

2.3 Canopy characteristics

Canopy data were taken for the young trees before being excavated for investigation and for 20 old trees from each species at both study sites. A meter tape was used to measure

diameter at breast height (dbh), approximately 1.5 m above the ground, diameter at ground level, canopy diameter, canopy depth, and tree height. Canopy diameter was measured by stretching the meter tape from one edge of the canopy to another. Tree height was recorded by measuring the distance from the base of the tree to its top. Canopy depth was measured from the pole where bifurcation of branches began to the top of the tree.

2.4 Root biomass under canopy of *Acacia* trees and in open grassland

To compare the productivity of under canopy growth of isolated *Acacia* trees and nearby open grassland soil cores were taken using 15 cm long and 4.5 cm diameter corers made from plastic water pipe for the determination of root biomass following the method of Belsky *et al.* (1993). Twenty cores were taken randomly from under three trees for each *Acacia* species in Abernosa ranch and twenty cores from the corresponding grassland zone at least 20 meters distant from the canopy of the isolated tree. Roots were cleaned from the soil by dry sieving through 0.5 mm sieve and then allowed to float in water to pick the bigger roots with forceps and then wet sieved thorough 0.3 mm sieve to recover fine roots. As sandy particles and organic materials were floating with the roots and adhering to them, separation was made by hand as much as possible. The roots were then oven-dried at 75°C for 48 hours and weighed. The results were expressed as weight in grams per volume of soil taken.

2.5 Statistical Analysis

The data collected were analyzed using the MINITAB for Windows (Release 10) statistical package. One-way Analysis of Variance (ANOVA) was run using Fisher's individual error rate to test for significance in root growth patterns and canopy features among the three *Acacia* species within the same site and between sites and root biomass of herbs undercanopy and open grassland in Abernosa. Two way ANOVA was also run for soil moisture, bulk density and soil physical and chemical properties to see the interaction between depth and site.

3. RESULTS

3.1 Root growth patterns (root architecture)

Mean (and standard error) for the three *Acacia* species on some characteristics in the root growth patterns (root architecture) of the excavates are given in Table 1, averages of root length of saplings uprooted in Table 2, and shoot dry weight, root dry weight and shoot-root ratio for the saplings uprooted in Fig. 2.

A. seyal

The excavation of *A. seyal* trees has shown that the species had more or less the same root growth patterns in both Abernosa and Abiyata-Shalla. The greatest horizontal spread recorded in this study was 7.70 m at Abernosa and 8.20 m at Abiyata-Shalla. The radial spread mean value for the species was greater than for *A. senegal* and *A. tortilis* (Table 1.) in both study sites. However, the difference was not statistically significant at $p < 0.05$. The depth of zone of intense lateral roots was also the highest among the species studied in Abernosa (71.00 ± 8.813 cm). Besides, *A. seyal* had very prominent lateral roots as could be observed from Plates 1 and 4.

A unique observation on this species was that the lateral roots make a circular growth around the crown shade that projects on the ground by neighboring trees (Plate 1g shows the direction of root growth in relation to the neighboring tree).

The mean root length (421.5 ± 49.0 cm) for *A. seyal* saplings uprooted was higher than for the other species (Table 2). Observation on individual saplings uprooted has shown that root length was a function of the compactness or rockiness of the soil. For example, one sapling of *A.seyal* had a 420.0 cm long tap root while another growing on rocky soil had only 46 cm long taproot. In the later, however, the lateral root was the longest of all recorded during this study. This bigger lateral root bifurcated lower down at 42.0 cm depth, the point where the soil started to become compact and rocky. But the root grew up and the root tips of the branches were recovered at 15-20 cm depth from the surface.

Table 1. Mean (and Standard Error, SE) of some characteristics in the root growth patterns (root architecture) of three *Acacia* species excavated in Abernosa ranch and Abiyata-Shalla National park (n=4 for Abernosa and n=3 for Abiyata-Shalla).

Site	Species	Depth of first lateral root (cm)	Zone of most intense lateral roots (cm)	Radius of lateral spread (cm)
Abernosa	<i>A.seyal</i>	15.00 ± 2.47^a	71.00 ± 8.81^a	570.0 ± 117.0^a
	<i>A.senegal</i>	12.75 ± 0.75^a	64.00 ± 7.91^a	509.0 ± 61.0^a
	<i>A.tortilis</i>	12.00 ± 1.58^a	60.00 ± 10.40^a	298.0 ± 73.0^a
Abiyata-Shalla	<i>A.seyal</i>	14.33 ± 1.67^a	62.33 ± 7.88^a	733.0 ± 49.0^a
	<i>A.senegal</i>	10.00 ± 0.58^{ab}	53.67 ± 2.33^a	518.0 ± 33.0^b
	<i>A.tortilis</i>	7.67 ± 1.45^b	58.33 ± 9.28^a	4.33 ± 85^b

a b: mean values with different superscripts within the same column are significantly different at $p < 0.05$

using Fisher's individual error rate.

A. senegal

Abernosa area was found to be less rocky and the trees had their roots growing to relatively greater depths. Among the four *A. senegal* trees excavated, three had taproots branching into two or more after a depth of 1 m. All had powerful lateral roots and all were concentrated in the upper 64.00 ± 7.906 and 53.67 ± 2.333 cm of the soil in Abernosa and Abiyata-Shalla respectively (Table 1). The species stands next to *A. seyal* in the depth of the zone of intense lateral roots along depth gradient. The density of the roots of *A. senegal* were found to be higher as compared to the other species from visual observations (see plates 2a and b). As a peculiar characteristic of the species, part of the taproot was found to be swollen after about 30-40 cm depth in most of the cases and most of the powerful lateral roots were branching from this part (Plates 2 and 5).

A. senegal had its first lateral roots growing near to the surface in both study sites and it was significantly different from *A. tortilis* at $p < 0.05$. The roots were very powerful and had greater radial extension especially when the soil was rocky after a depth of 0.50 m as was the case in Abiyata-Shalla area (Plate 5a and d). The pattern of radial spread of the roots was similar in both sites, but the length was higher in Abiyata-Shalla though it was not highly significantly (Table 1).

Most of the roots of the excavated trees of this species grew towards the direction of the shade of neighboring trees. As can be seen from Plate 2f the workers are carrying the largest three lateral roots unearthed, growing to the direction of a neighboring *A. tortilis*

tree. In the afternoon, the excavated tree was completely under the shade of this tree. In fact, there were also other lateral roots that were growing to other directions as well but they were shorter ones

As can be observed from plates 2 and 5, there was not much difference in root growth pattern between the trees in Abernosa and Abiyata-Shalla. The difference observed was only that those in Abernosa grew to greater depth where as those in Abiyata-Shalla were very shallow because of the rockiness of the area.

A.tortilis

Qualitative information on restraints to root penetration was obtained by visual observations of the resultant modification in the root systems of *A.tortilis*. In all cases, the roots grow vertically straight for 1.2-1.4 m only. After this depth the soil was compact in all the trenches. The taproots then start to grow horizontally but making twists (loops) along their way. The main root of *A. tortilis* (Plate 3d), for example, started to grow horizontally after 1.4 m depth for 0.85 m. The length of the portion of the root that grew horizontally was 1.65 m, almost double the length of the area it occupied. This was due to the loops and bends it was forming along the way.

Table 2. Averages (and standard error) for taproot length of the three *Acacia* species saplings fully uprooted in Abernosa and Abiyata-Shalla (n=2).

Site	Species	Taproot length (cm)
Abernosa	A.seyal	421.5±48.5
	A.senegal	365.0±113.0
	A.tortilis	386.0±76.0
Abiyata-Shalla	A.seyal	80.5±34.5
	A.senegal	170.0±166.0
	A.tortilis	302.5±42.5

N.B. Samples were only two, too small for statistical analysis.

Different from the *A. tortilis* trees excavated in Abernosa, those in Abiyata-Shalla had their taproots branching after a depth within a range of 0.70-0.85 m. Some of the branches continued to grow vertically side by side but in some excavates the branches of the taproots started to grow horizontally.

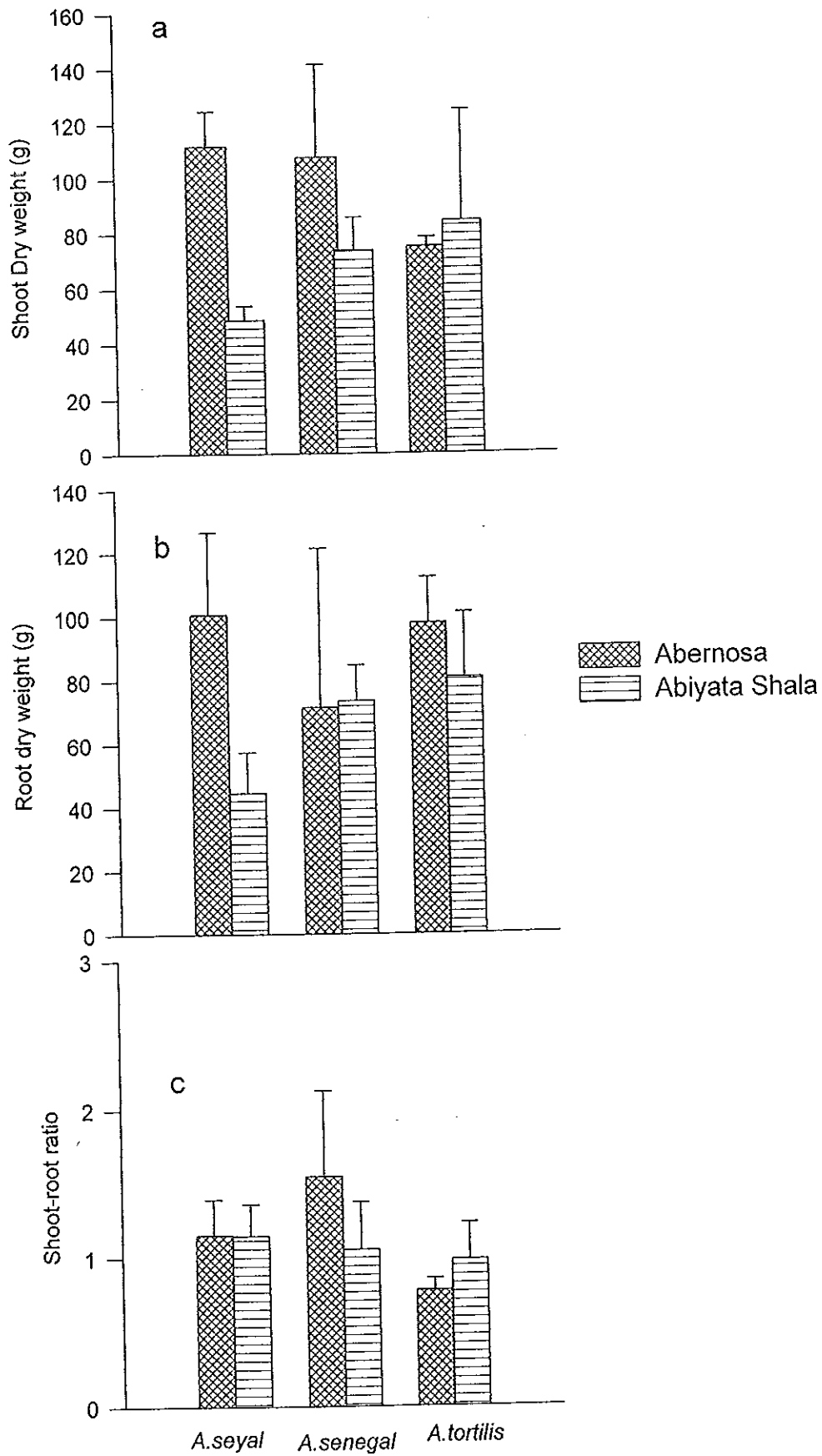


Fig. 2. Shoot dry weight (a), root dry weight (b) and Shoot-root ratio (c) for *Acacia* spp. saplings uprooted in Abernosa and Abiyata Shala

When compared to the other *Acacia* species excavated, the range of diameter of the lateral roots and second order branches for *A. tortilis* were the least i.e. the lateral roots were not as powerful as those of the other species. The length of the zone of intense lateral roots along depth gradient was comparable to the others but the horizontal spread was very low. It was recorded that the *A. tortilis* saplings completely uprooted in both study sites had the long taproots (365.0 ± 48.5 and 302.0 ± 42.5 cm for Abernosa and Abiyata-Shalla, respectively).

In general, One way ANOVA showed no significant difference between sites for depth of first lateral root, zone of most intense lateral roots and for radius of lateral spread. However, there was a significant difference for depth of the first lateral root and radius of spread between *A.seyal* on one hand and *A.senegal* and *A.tortilis* on the other (Table 1).

The difference between sites in the root length uprooted for the *Acacia* saplings was highly significant with mean values 440.8 ± 185.7 and 184.3 ± 149.0 cm in Abernosa and Abiyata-Shalla respectively. As uprooting of saplings was labor intensive, time taking and destructive, only two samples per species were taken which may be too small for statistical analysis. As a result the mean could be biased in cases where one sapling is uprooted from rocky areas. The same holds true for shoot weight, root weight and shoot-root ratio as well.

3.2 Soil moisture under excavated trees

The percent moisture content of the soil under the excavated *Acacia* trees was measured using Time Domain Reflectometry (TDR) from four different depths. One way ANOVA shows no significant difference along depth gradient taking all sites together. However, a significant difference in moisture content was found between species where it was higher under *A.tortilis* than *A.seyal* and *A.senegal*. There was also highly significant difference in soil moisture between Abernosa and Abiyata-Shalla, with mean values 3.665 ± 1.856 and 6.997 ± 1.416 respectively (Table 3). Comparison between depths and species within the same site was also carried out. In Abernosa, there was no difference between depths except for *A.tortilis* where the moisture content was significantly higher especially at the depth between 60-120cm. There was no difference in moisture along depth in Abiyata-Shalla but for the depth 90-120 cm it was higher for soil under *A.senegal* and *A.tortilis*.

Table 3. Mean (and standard error) percent soil moisture under the three *Acacia* species excavated in Abernosa and Abiyata-Shalla.

Percent moisture in soil						
Depth (cm)	Abernosa			Abiyata-Shalla		
	A.seyal	A.senegal	A.tortilis	A.seyal	A.senegal	A.tortilis
30	3.18±0.67 ^{2A}	3.15±0.32 ^{2A}	4.30±0.28 ^{2A}	6.67±0.43 ^{2A}	7.17±0.77 ^{2A}	5.37±0.20 ^{2A}
30-60	3.33±0.45 ^{2A}	2.93±0.38 ^{2A}	3.70±0.23 ^{2A}	6.93±0.32 ^{2A}	6.67±0.23 ^{2A}	6.40±0.25 ^{2A}
60-90	2.08±0.25 ^{2A}	2.35±0.41 ^{2A}	6.15±0.76 ^{2B}	7.00±0.42 ^{2A}	6.90±0.90 ^{2A}	5.67±0.83 ^{2A}
90-120	2.43±1.05 ^{2A}	2.73±0.60 ^{2A}	7.68±0.17 ^{2BC}	7.40±0.55 ^{2A}	9.40±0.90 ^{2B}	9.17±1.20 ^{2B}

Means followed by the same lower case letter in rows and means followed by the same upper case letter in columns are not significantly different at $p < 0.05$ using Fisher's individual error rate.

3.3 Bulk density of soil under excavated trees

This feature showed the same pattern as for soil moisture; cores for determination of bulk density were taken from four depths. Oven-dry soil bulk density shows no significant difference between species from where soil cores were obtained. There was also not much variation in bulk density of the soil along depth gradient. Nevertheless, the bulk density in Abiyata-Shalla was significantly different (with mean values 1.279 ± 0.15 and 1.466 ± 0.13 for Abernosa and Abiyata-Shalla, respectively) at $P < 0.05$ (Table 4).

Table 4. Mean (and standard error) bulk density for the soil under the three *Acacia* species excavated in Abernosa and Abiyata-Shalla.

Bulk density (g/cc)						
Abernosa			Abiyata-Shalla			
Depth (cm)	<i>A.seyal</i>	<i>A.senegal</i>	<i>A.tortilis</i>	<i>A.seyal</i>	<i>A.senegal</i>	<i>A.tortilis</i>
0-30	1.27±0.16	1.26±0.02	1.31±0.02	1.50±0.28	1.54±0.08	1.39±0.02
30-60	1.25±0.40	1.31±0.15	1.13±0.09	1.58±0.05	1.42±0.04	1.34±0.14
60-90	1.46±0.01	1.16±0.01	1.25±0.12	1.52±0.06	1.41±0.08	1.55±0.04
90-120	1.30±0.04	1.39±0.08	1.35±0.16	1.54±0.03	1.39±0.02	1.36±0.10

Comparison of means using Fisher's individual error rate shows no significant difference in bulk density of the soil under the three species in both sites, but there was significant difference between sites.

3.4 Selected physical and chemical properties of the soil in the study area

The soil physical and chemical characteristics of Abernosa and Abiyata-Shalla are given in Table 5. Textural classification of the 40 soil samples collected from both sites indicate that the soils were 67.5% sandy loam, 25% loamy sand, 2.5% sandy clay loam and 5% loam. There was no significant difference in the proportion of sand, clay and silt along depth gradient in both sites but the difference was significant between Abernosa and Abiyata-Shalla in clay with mean values 5.106 ± 2.52 and 9.214 ± 5.00 . The pH values of aqueous extracts of soils from 1:1 soil water ratio ranged from slightly acid (pH=5.90) to

alkaline (pH=9.15). There was a tendency for an increase in pH along depth gradient.

The percent organic carbon (OC) and nitrogen were significantly higher in surface soils and mean values along depth gradient ranged from 2.84-1.14 and 0.21-0.08, respectively.

The percent OC was significantly higher in Abernosa (mean=1.726±0.80) than in Abiyata-Shalla (mean=1.203±0.66). Similarly, there was a trend for available Phosphorus to be higher in surface soils with a little variation in the lower depths.

3.5 Canopy features of mature *Acacia* tree species

There was significant difference in tree height among *A.tortilis*, *A.senegal* and *A.seyal*. On individual tree records, *A.tortilis* stands first in tree height, dbh, diameter at the base of the tree and canopy diameter (Table 6). There was no significant difference for dbh and diameter at the base between *A.seyal* and *A.senegal* but both markedly differed from *A.tortilis* at $p<0.05$. There was no significant difference in canopy depth and canopy diameter between species from comparison of means taking all species in both sites. When sites are compared differences were significant for dbh and diameter at the base with *A.tortilis* exceeding the other two in both sites. There was no difference in canopy diameter and canopy depth between species in Abernosa but there is in Abiyata-Shalla. The interaction between site and species in Two-way ANOVA showed significant difference (at $p<0.05$) for DBH, diameter at the base and canopy diameter.

3.6 Root biomass of herbs under *Acacia* tree canopies and open grassland

Dry root biomass data was obtained from herbaceous plants under the canopy of the study trees and adjacent open grassland in Abernosa. There were significant differences in root biomass between the three species (Table 8; Fig. 7). The mean root biomass of the three *Acacia* species investigated showed that it was lower than the open grassland except for *A.seyal*. However, taking the total amount of root biomass obtained, under canopy root biomass was found to be higher than the open grassland.

Table 5. Mean (and standard error) for selected physical and chemical properties of the soil in Abernosa and Abiyata-Shalla.

Site	Texture (%)							
	Depth (cm)	pH	Sand	Clay	Silt	%OC	%N	P (ppm)
Abernosa	0-30	6.85±0.24 ^{ab}	61.74±2.75 ^a	5.2±136 ^a	33.06±1.99 ^a	2.84±0.32 ^a	0.21±0.02 ^a	65.82±7.69 ^a
	30-60	6.30±0.26 ^a	72.85±3.47 ^a	4.18±0.5 ^a	22.97±3.10 ^a	1.55±0.12 ^b	0.14±0.02 ^b	52.24±7.32 ^b
	60-90	7.30±0.30 ^b	68.62±6.31 ^a	5.89±1.14 ^a	25.50±5.37 ^a	1.35±0.13 ^b	0.09±0.03 ^b	44.66±8.26 ^b
	90-120	7.66±0.41 ^b	64.74±6.25 ^a	5.16±1.45 ^a	30.10±4.86 ^a	1.14±0.19 ^b	0.08±0.02 ^b	47.30±10.73 ^b
Abiyata	0-30	6.54±0.29 ^a	63.88±5.02 ^a	6.65±1.22 ^a	29.48±3.97 ^a	1.79±0.23 ^a	0.15±0.02 ^a	47.36±7.51 ^a
	30-60	6.92±0.23 ^{ab}	61.26±3.78 ^a	8.29±1.68 ^a	30.46±3.24 ^a	1.19±0.20 ^{ab}	0.11±0.03 ^a	53.36±7.79 ^a
	60-90	7.42±0.24 ^b	64.45±4.11 ^a	9.63±1.11 ^a	25.92±3.21 ^a	1.19±0.37 ^{ab}	0.03±0.02 ^a	46.16±7.88 ^a
	90-120	7.86±0.12 ^{bc}	64.62±3.04 ^a	12.29±3.73 ^a	23.10±4.12 ^a	0.64±0.14 ^b	0.08±0.03 ^a	31.28±6.92 ^a

a b: mean values with different superscripts within the same column are significantly different at p<0.05 using Fisher's individual error rate.

Table 6. Mean (and standard error) for some canopy characteristics of three *Acacia* species in Abernosa and Abiyata-Shalla.
(n=20)

Site →	Abernosa			Abiyata-Shalla		
	A.seyal	A.senegal	A.tortilis	A.seyal	A.senegal	A.tortilis
Height (m)	8.28±0.55a	7.33±0.29a	8.47±0.91a	7.45±0.27a	6.15±0.25b	7.98±0.36a
DBH (cm)	22.96±1.41a	29.43±1.73b	34.54±3.21b	26.50±1.91a	22.25±1.04a	32.62±1.67b
D-base (cm)	25.96±1.40a	31.41±0.81a	37.77±2.96b	28.62±1.68a	24.50±1.12b	36.29±1.52c
C-diam.(m)	14.95±0.71a	16.00±0.81a	15.45±1.53a	15.50±0.78a	12.55±0.55b	16.10±0.70a
C-depth (m)	6.09±0.55a	5.38±0.30a	6.03±0.93a	5.74±0.23a	4.273±0.22b	5.39±0.41a

a b: mean values with different subscripts within the same row are significantly different at $p < 0.05$

using Fisher's, individual error rate.

Key: DBH= diameter at breast height; D-base =Diameter at the base; C-dam. = canopy diameter;

C-depth = canopy depth

Table 7. Mean (and Standard error) root biomass of herbs below *Acacia* tree canopies and adjacent open grassland in Abernosa Ranch (n=20 each tree taken as replicate).

Tree no.	Root Biomass (g m^{-2})					
	canopy Zone			Grassland Zone		
	<i>A.seyal</i>	<i>A.senegal</i>	<i>A.tortilis</i>	<i>A.seyal</i>	<i>A.senegal</i>	<i>A.tortilis</i>
1.	310.90±31.29	1170.86±151.78	207.556±18.03	279.73±39.02	1341.81±238.70	305.03±31.16
2.	732.52±80.98	903.93±131.15	354.76±34.70	400.38±43.26	904.371±125.57	354.96±46.93
3.	798.19±93.25	234.63±23.84	391.46±29.81	254.46±25.93	299.49±35.71	1231.76±189.41
Av.	613.87±152.67	769.81±278.46	317.93±56.19	311.52±77.98	848.56±302.18	630.58±300.93

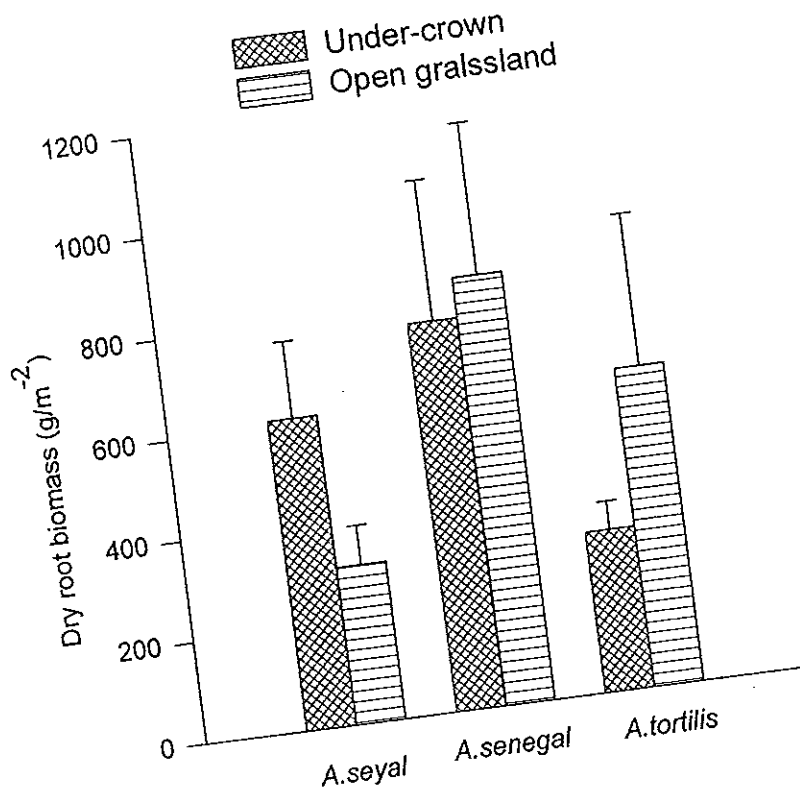
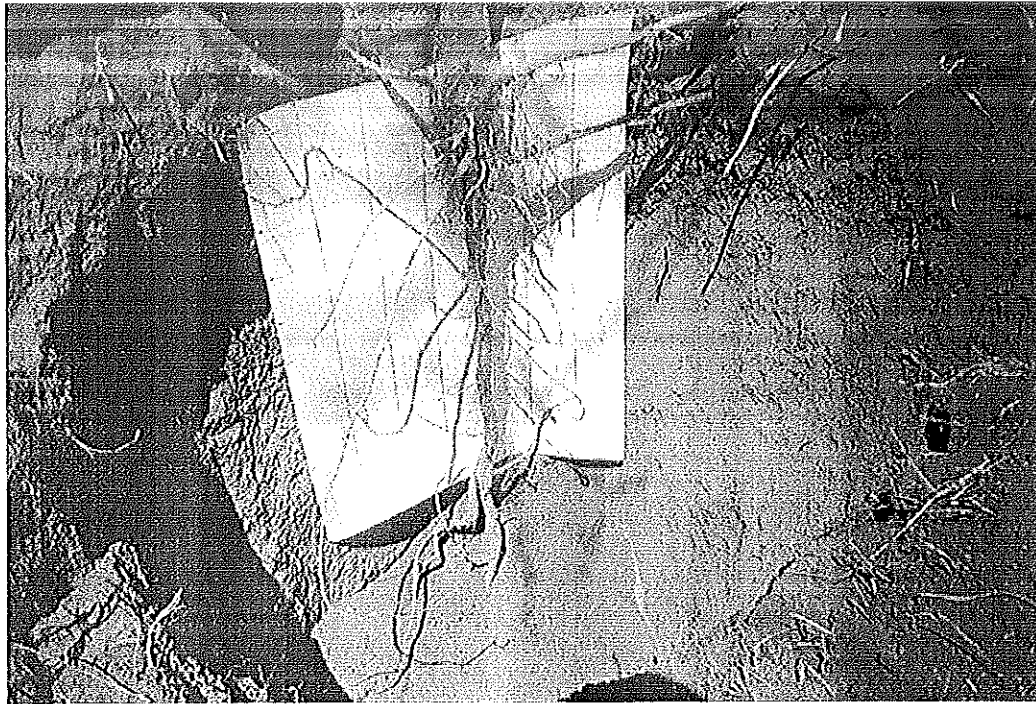


Fig. 3. Dry root biomass of herbs below *Acacia* tree crowns (a) and adjacent open grassland in Abernosa

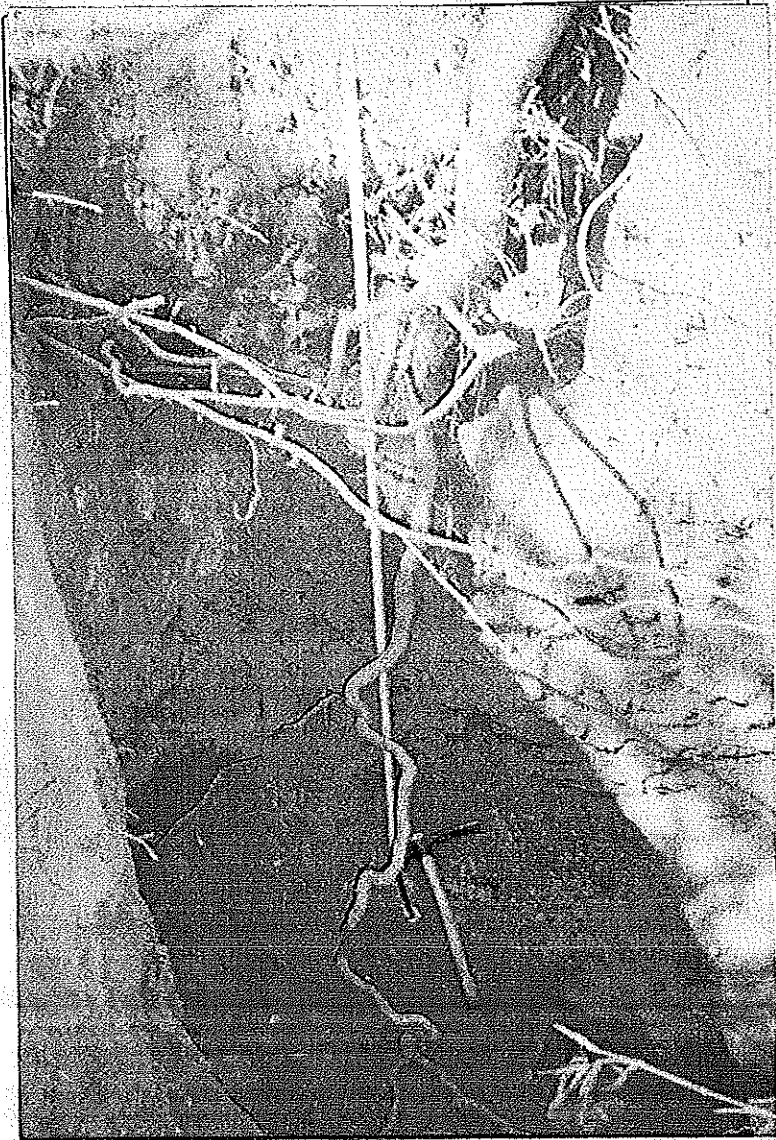


1a

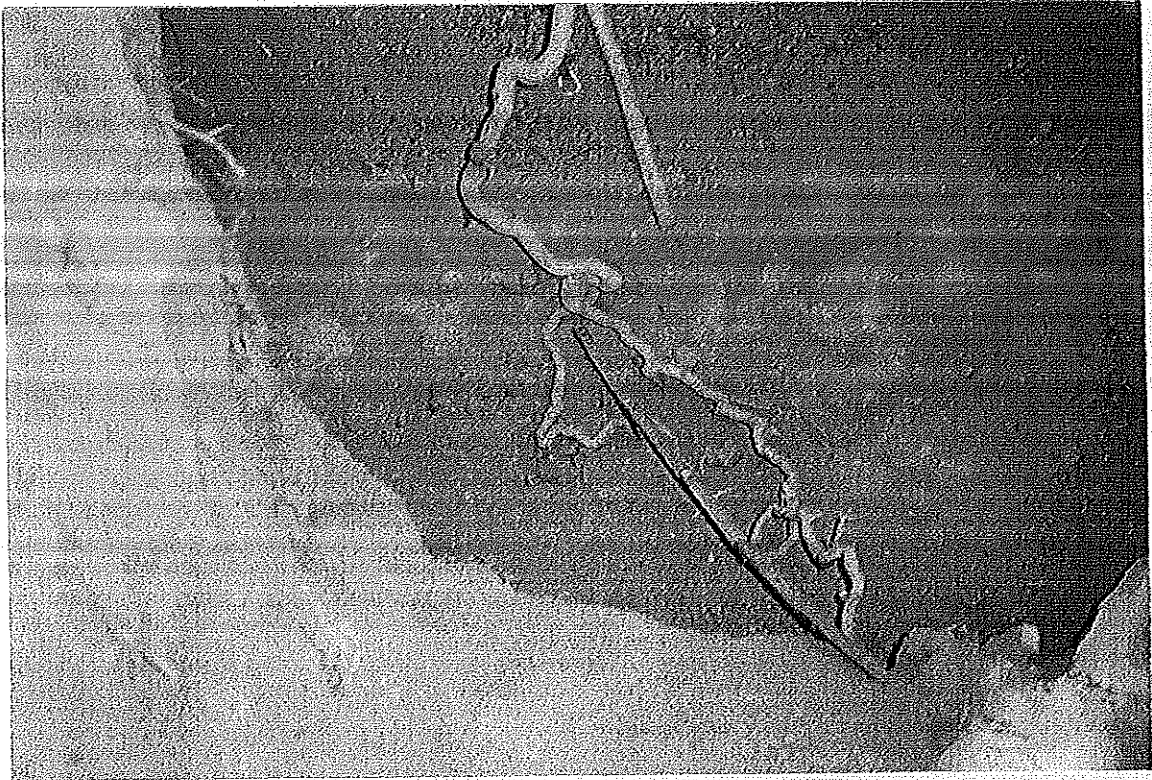
Plate 1 (a-g). *A.seyal* trees excavated at Abernosa Ranch. Notice the powerful lateral roots in closer proximity to the surface in all cases. The taproot branches into two or more after 1.0-1.5 m depth in a, c, e and f. Lateral root of (b) made circle around the shade from the crown of an *A.tortilis* tree, the excavators carry the unearthed root to show this in (g). Part of the taproot of (c) is shown in (d) to see the modification of the root part due to impediment by the soil, notice also the upper lateral roots making a U-turn to wards the shade of neighbouring trees in (c).



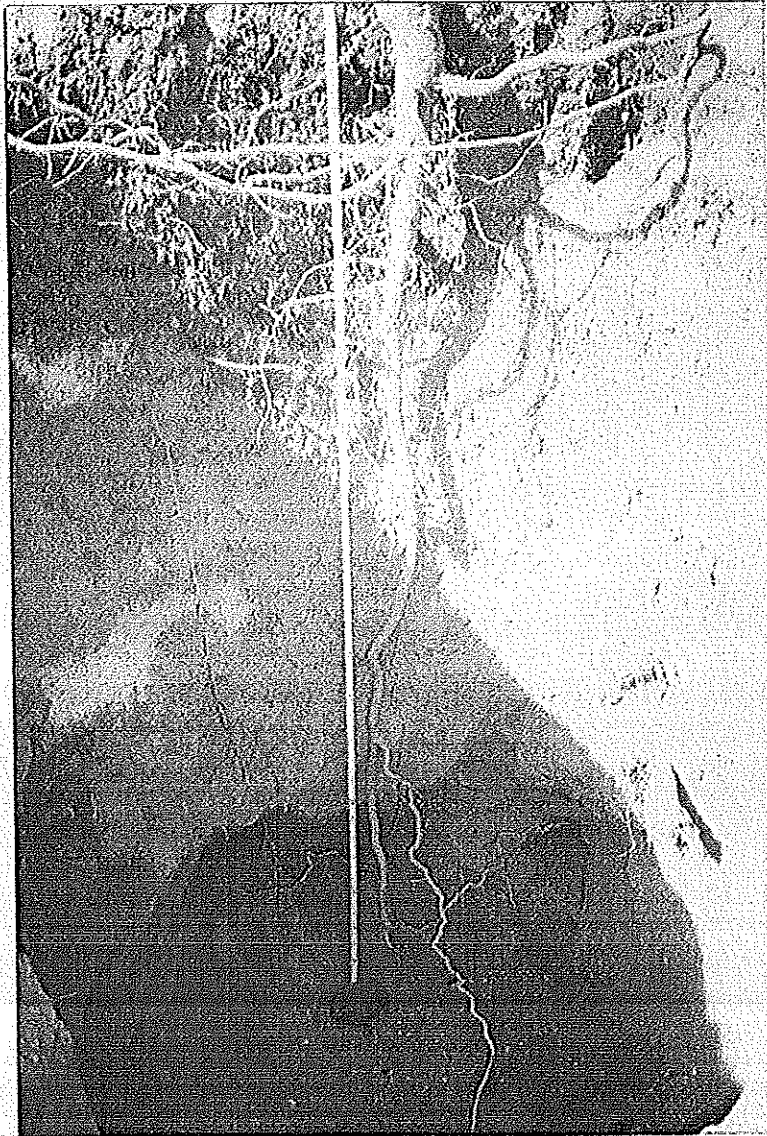
1b



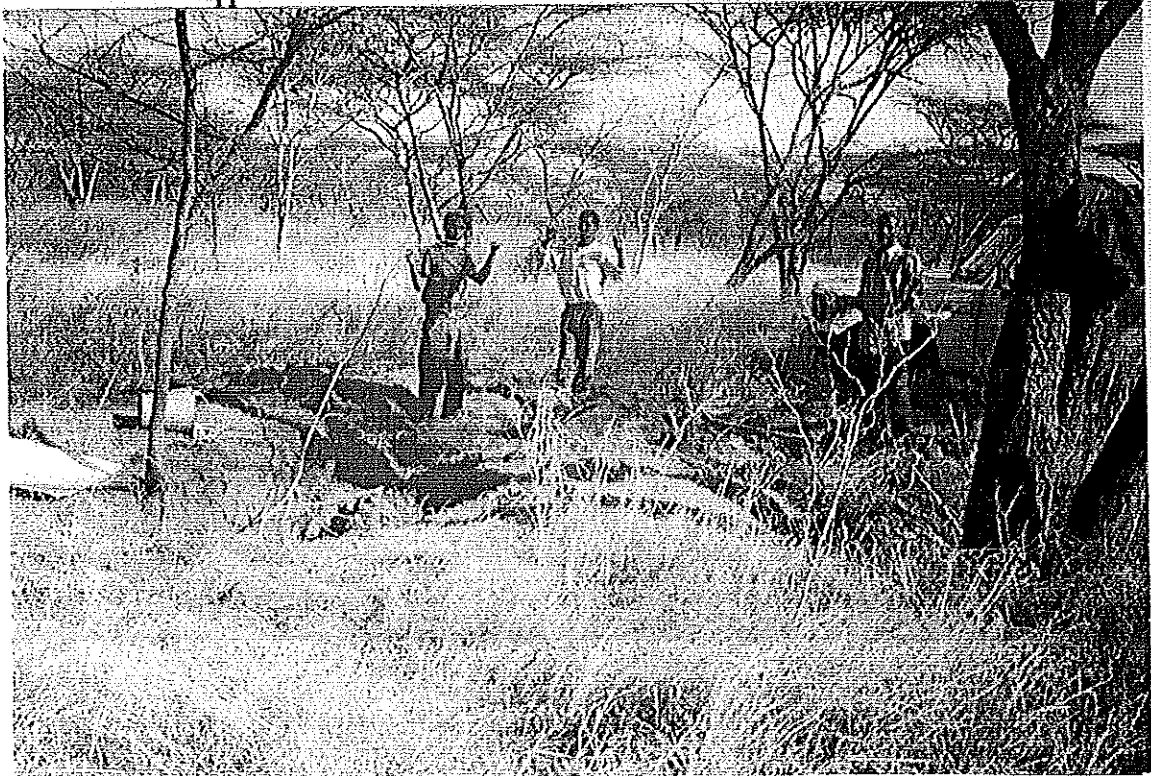
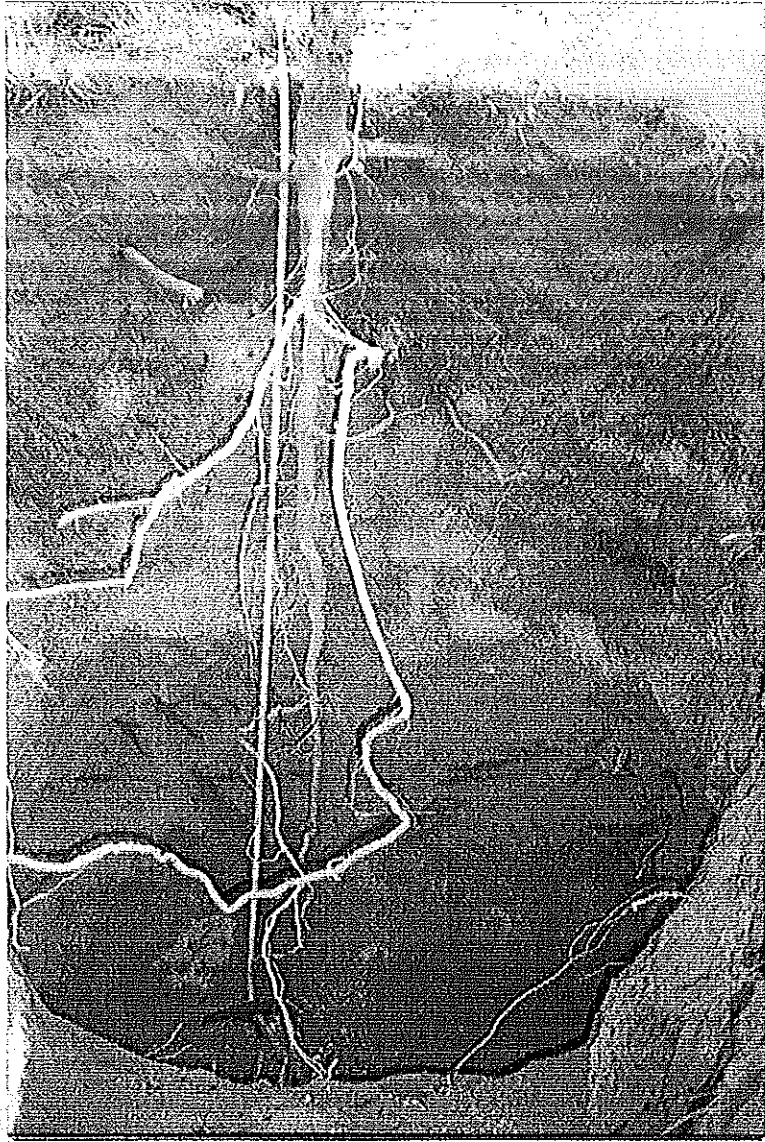
1c

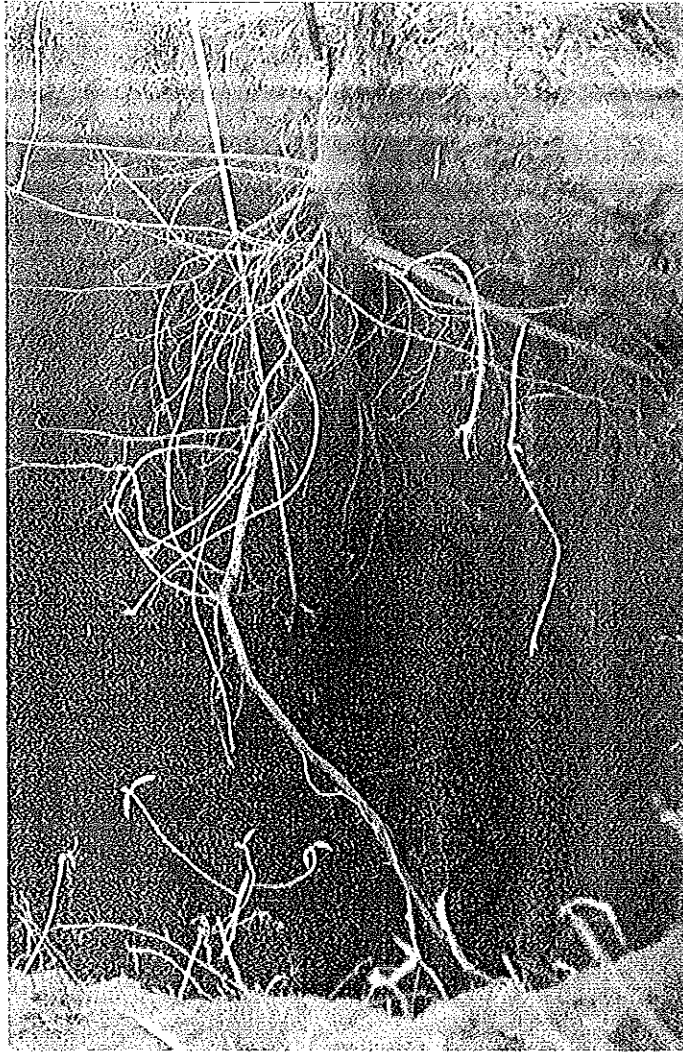


1d



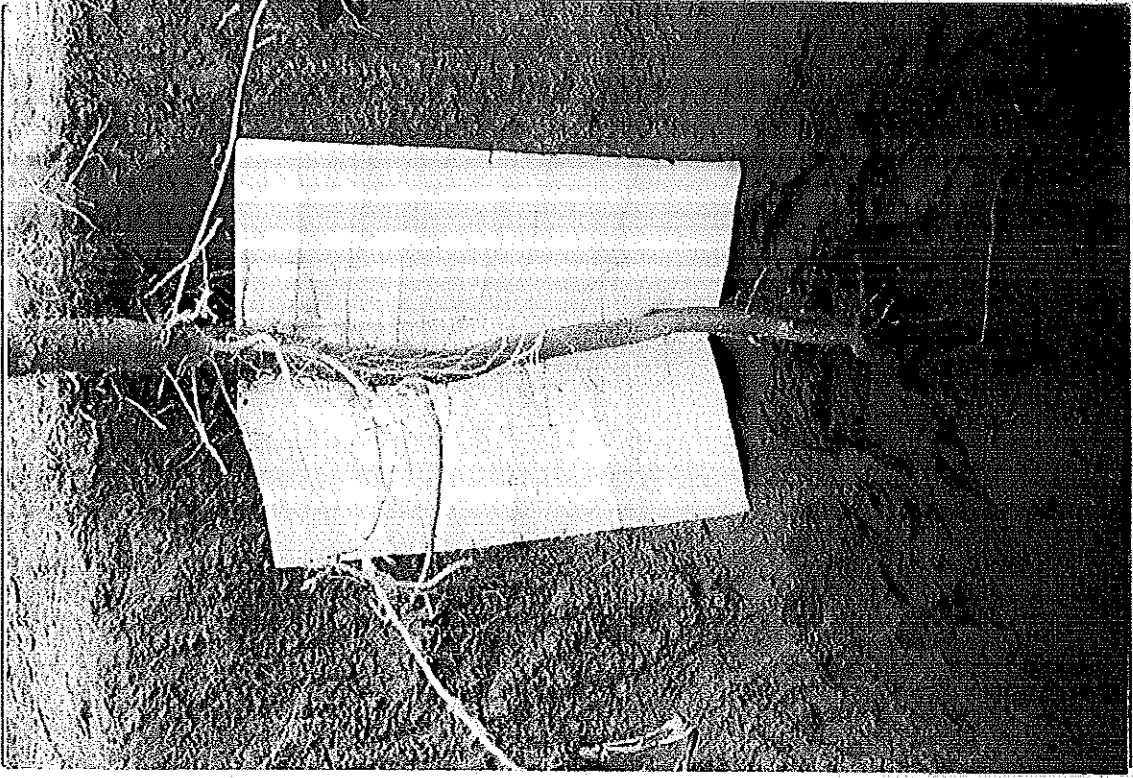
1e



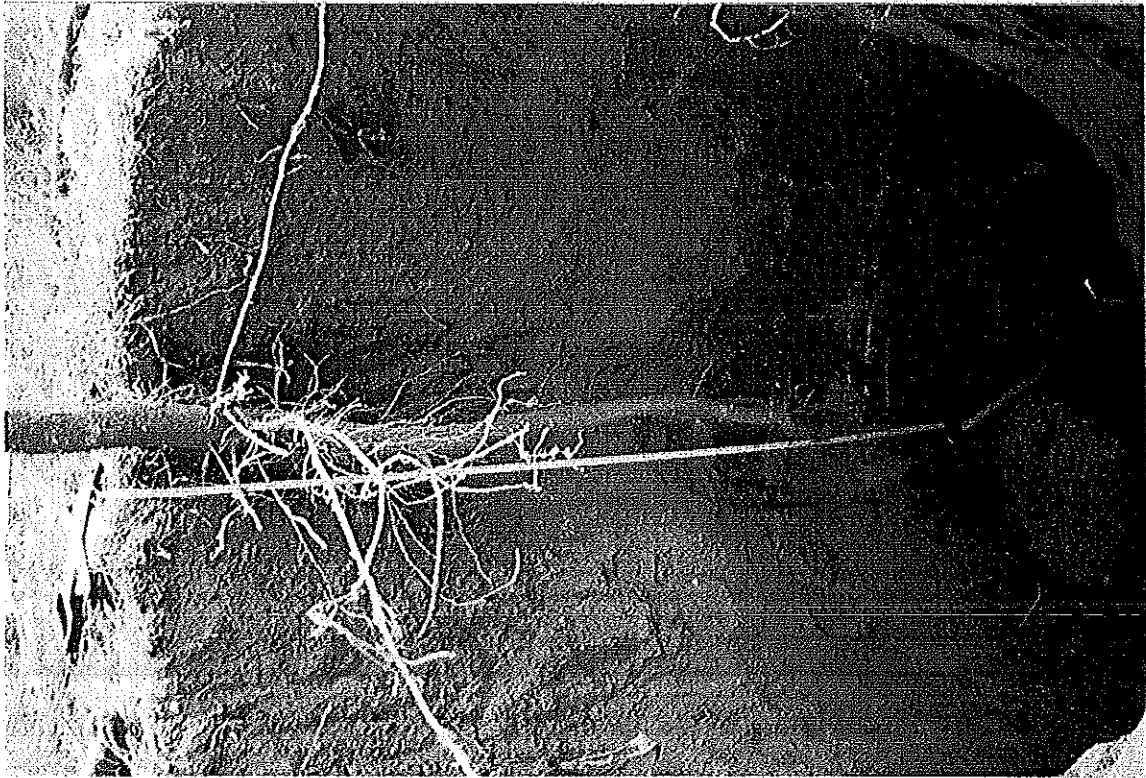


2a

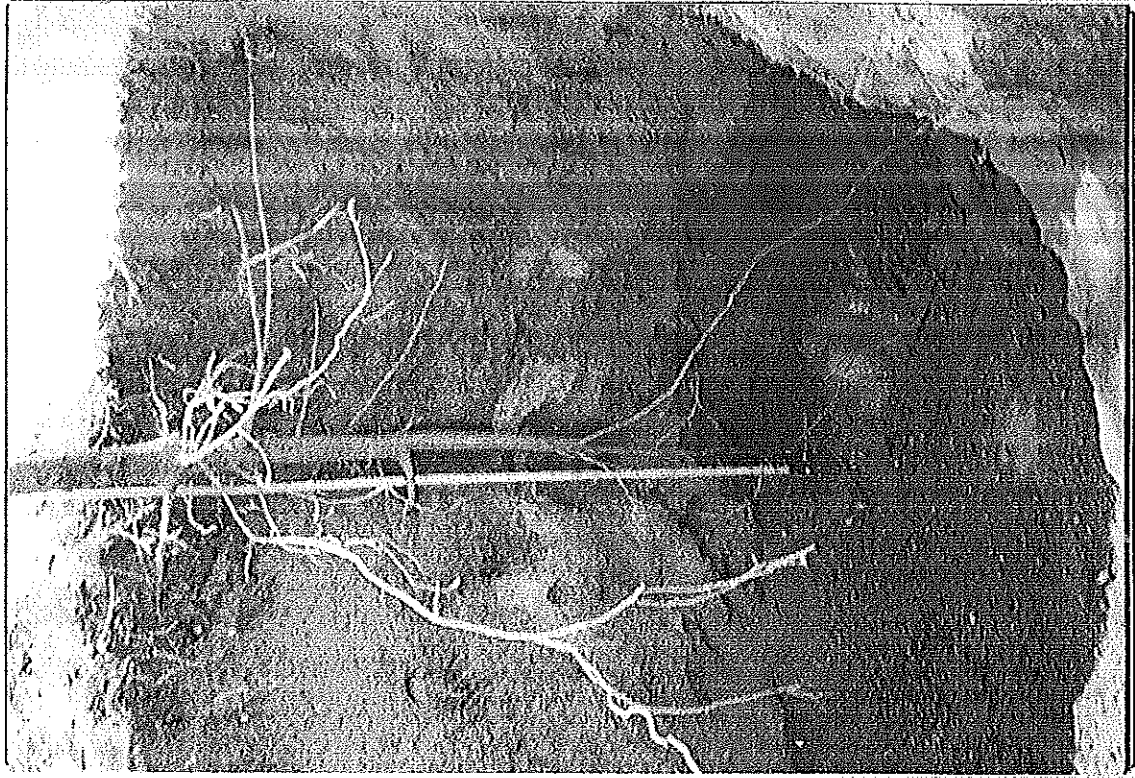
Plate 2 (a-f): *A. senegal* trees excavated in Abernosa Ranch. Look at the dense laterals that were mainly in the upper 76 cm in (a). (b) and (c) are the same but the paper with grid was used to see the contrast between the trench wall and the roots and notice the taproot branching into many after 1 m depth. The taproot of (d) bifurcated as well at 1.32 m and branches grew vertically parallel to each other. In (e) the taproots branched into five all of which grew horizontally at a depth of 1.58 m. In (f) the most prominent lateral roots grow to the direction of a nearby big tree.



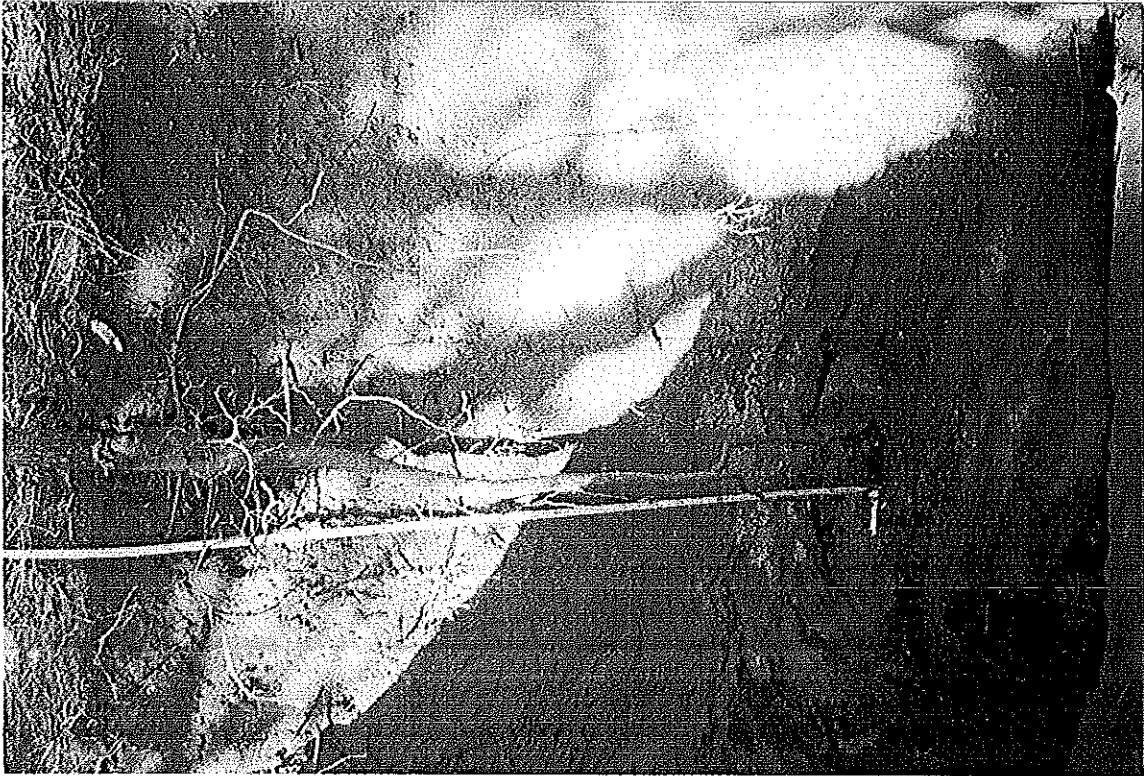
2c



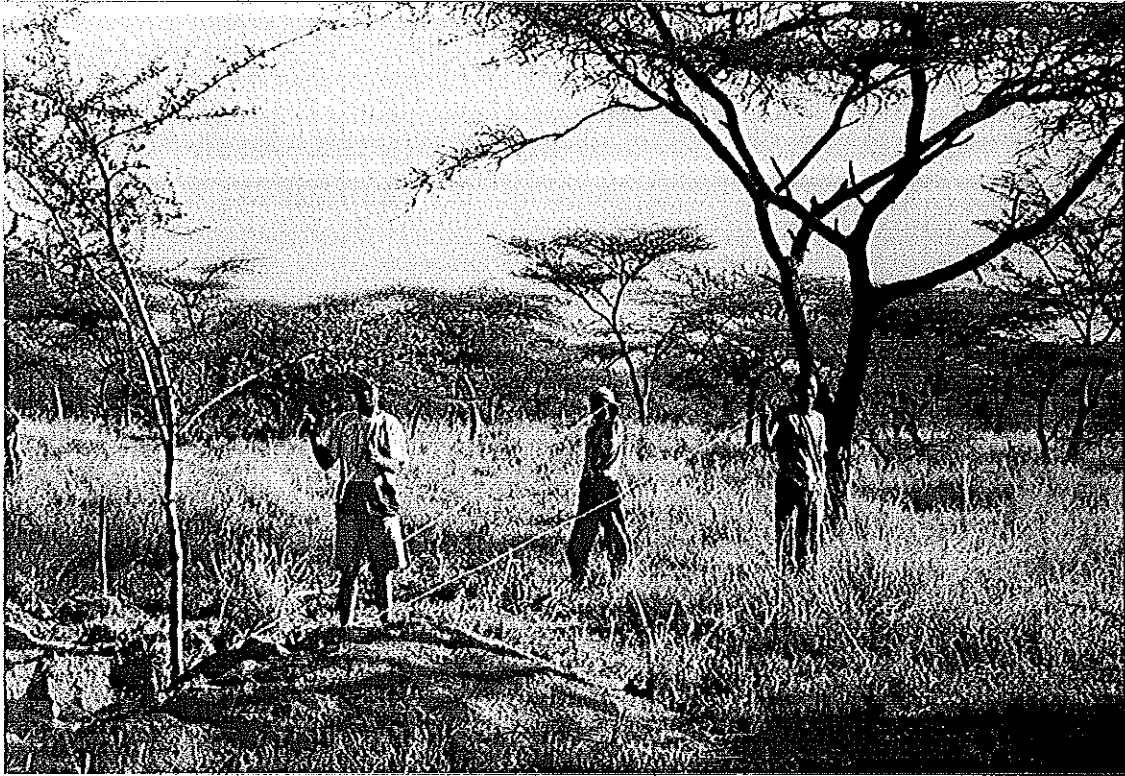
2b



2e



2d

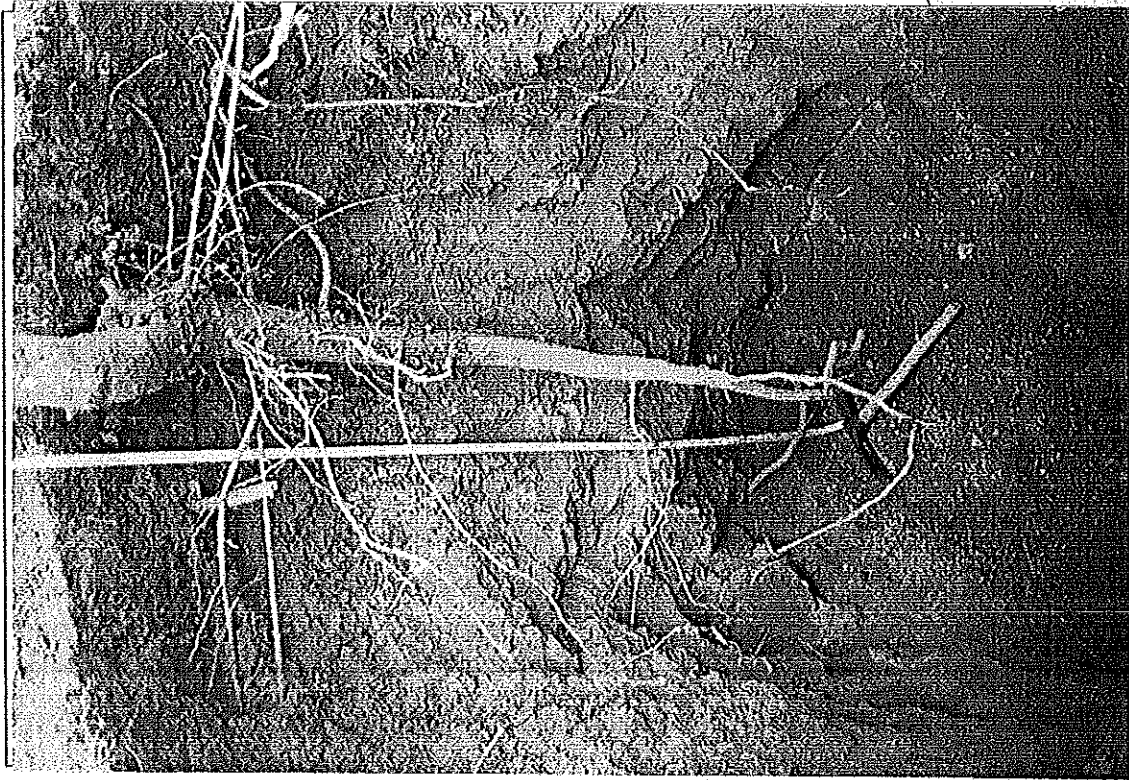


11

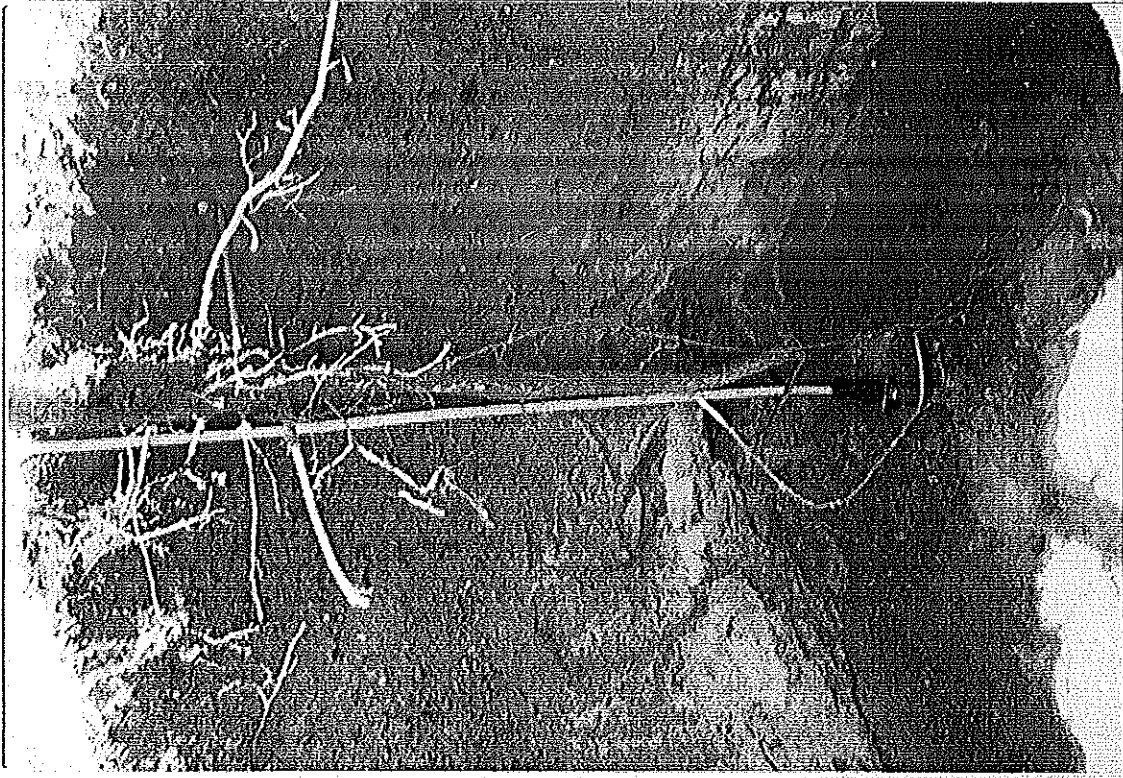


3a 3^a

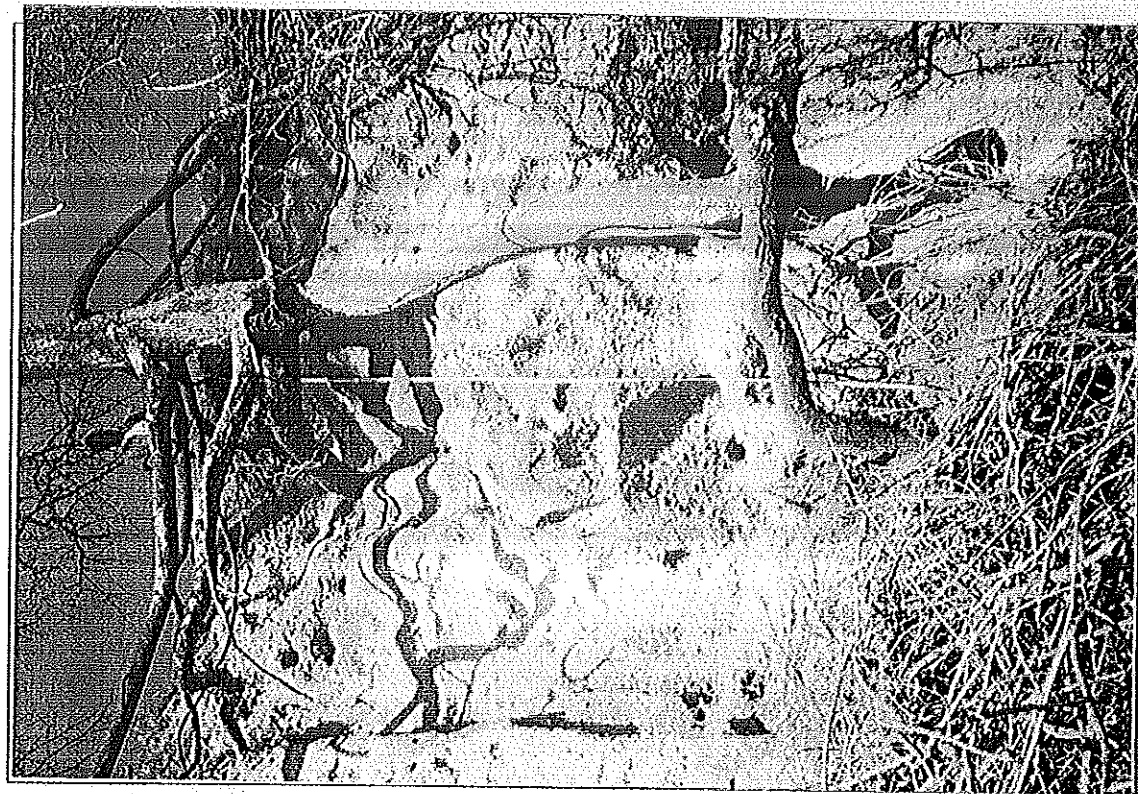
Plate 3 (a-e): *A. tortilis* trees excavated in Abernosa Ranch. Notice the change in direction of growth in all the excavated trees and this is highly elaborated in (d). After a depth of about 1.4 m there was no more vertical growth in b, c and d. The part of the lateral root of (d) below the paper that was growing horizontally measured 1.65 m over a 0.85 m distance due to formation of loops (bends) to make its way along the compact soil. The picture in (e) shows the roots of an old *A. tortilis* tree in a deep gorge whose half part is exposed by erosion. Notice at the lateral roots near the surface and the thickness of the taproot even at a depth of 5.2 m from the surface.



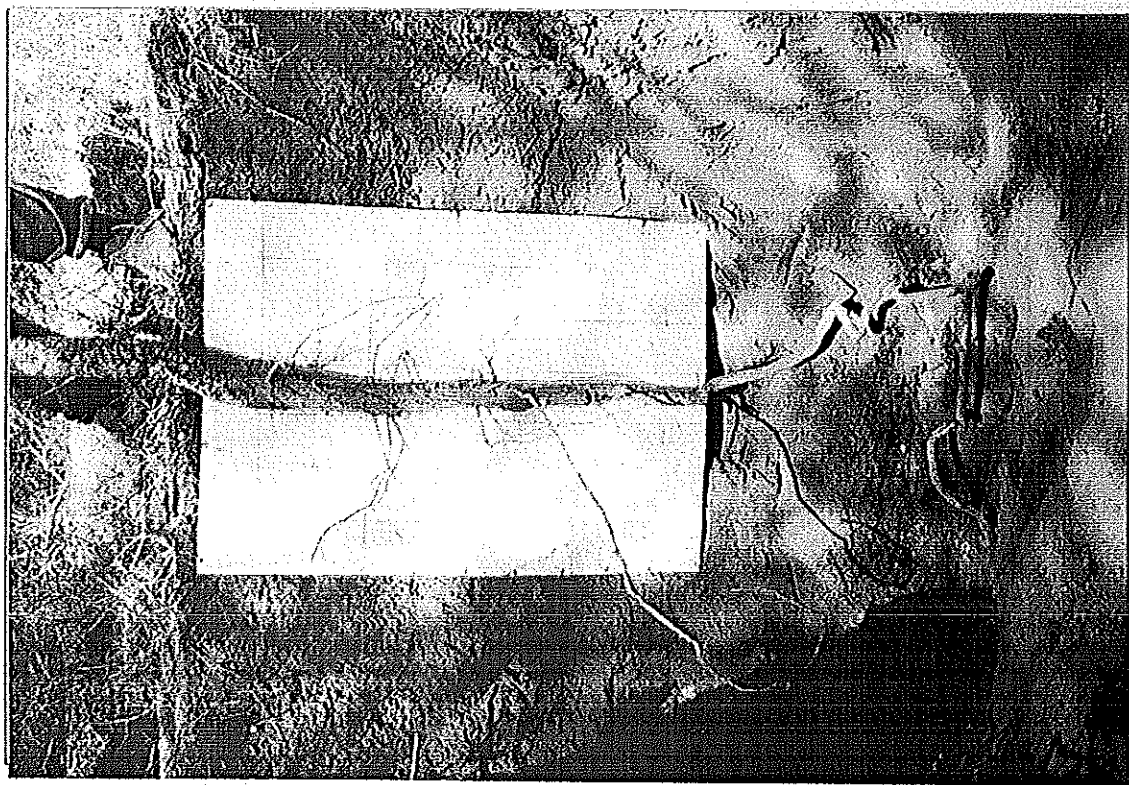
3b



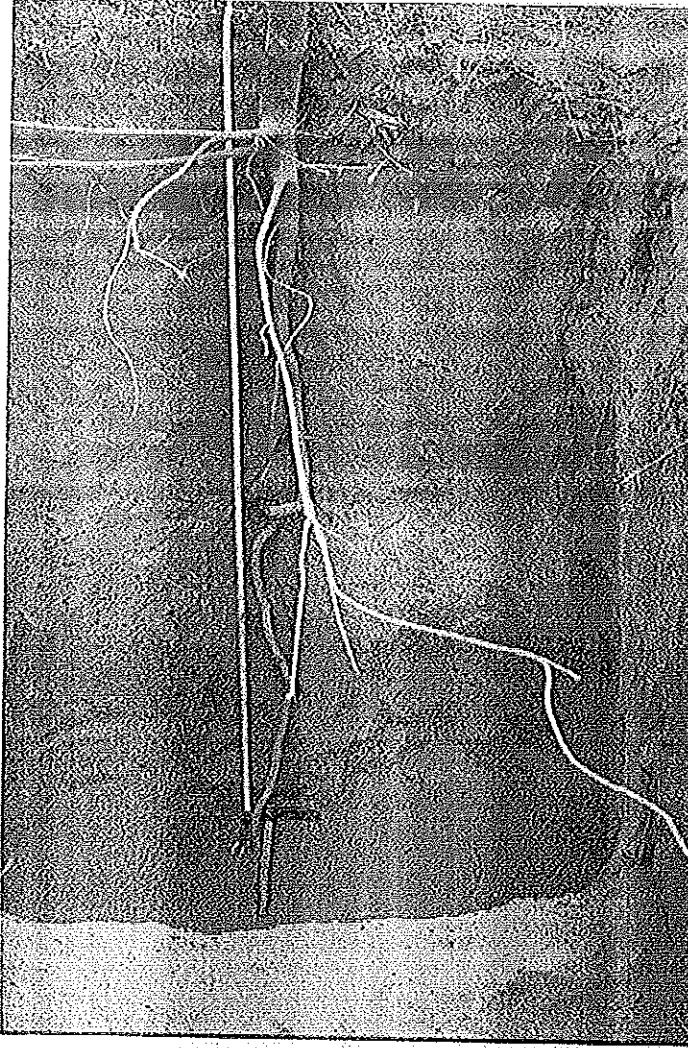
3c



3e

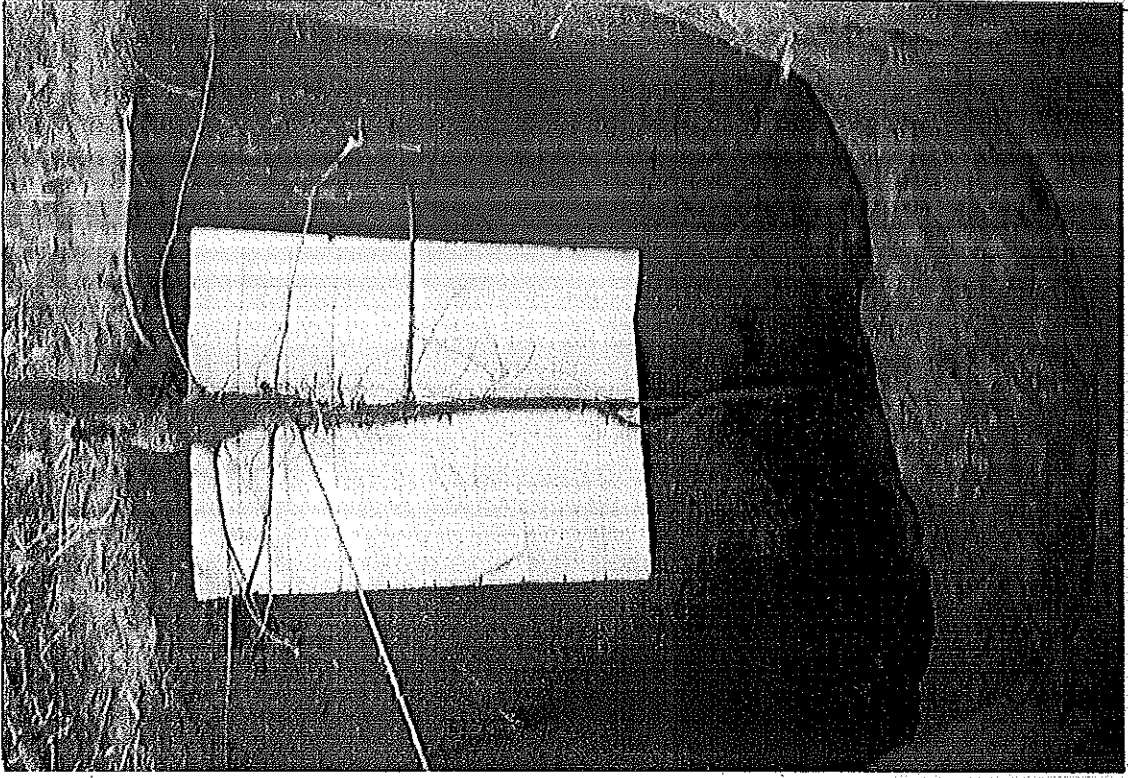


3d



4a

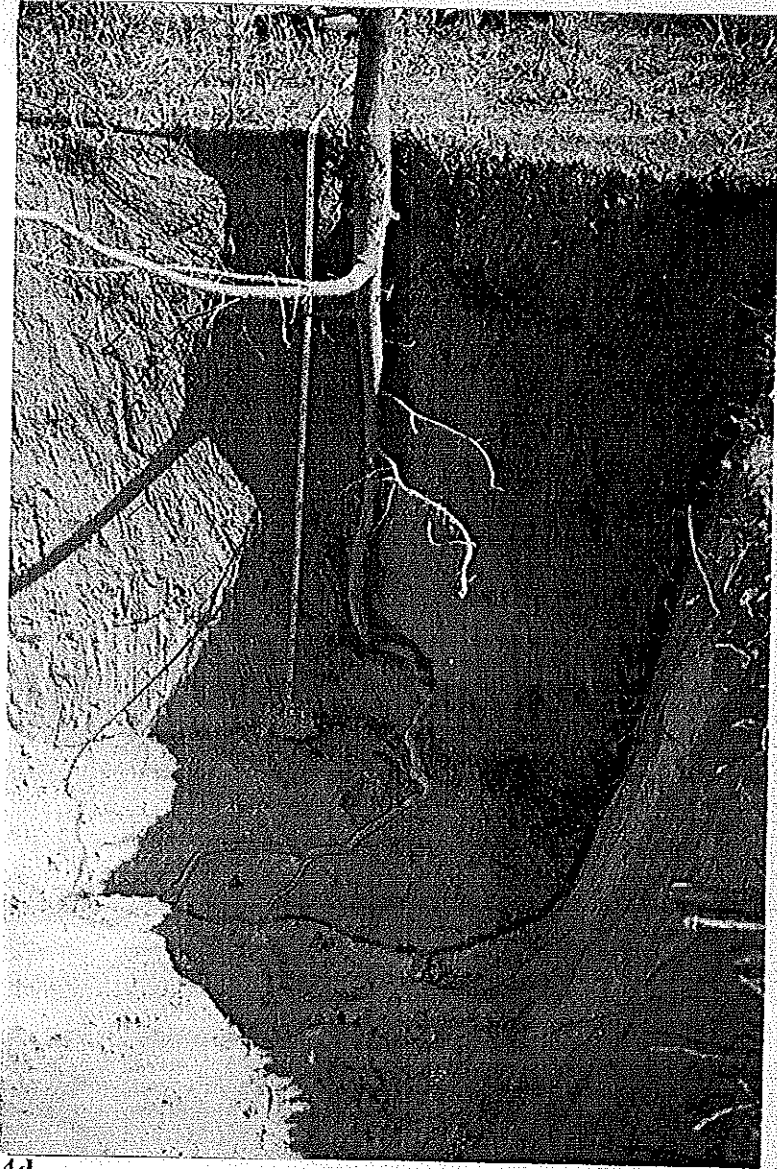
Plate 4 (a-f). *A.seyal* trees excavated in Abiyata Shala National Park. (a) had the longest lateral root (8.20) which was 5.30m out of its canopy in the direction of a gully crossing the area. Notice the few but powerful lateral roots typical of the species. In (e) lateral roots excavated are shown and the tip of the longest was recovered under the shade of dense young *A.tortilis* (held by the young man on the extreme left). Prominent lateral roots growing in different directions and dense small laterals are shown from *A.seyal* tree on the edge of a gully (f) showing similar growth pattern to the others.



4c



4b



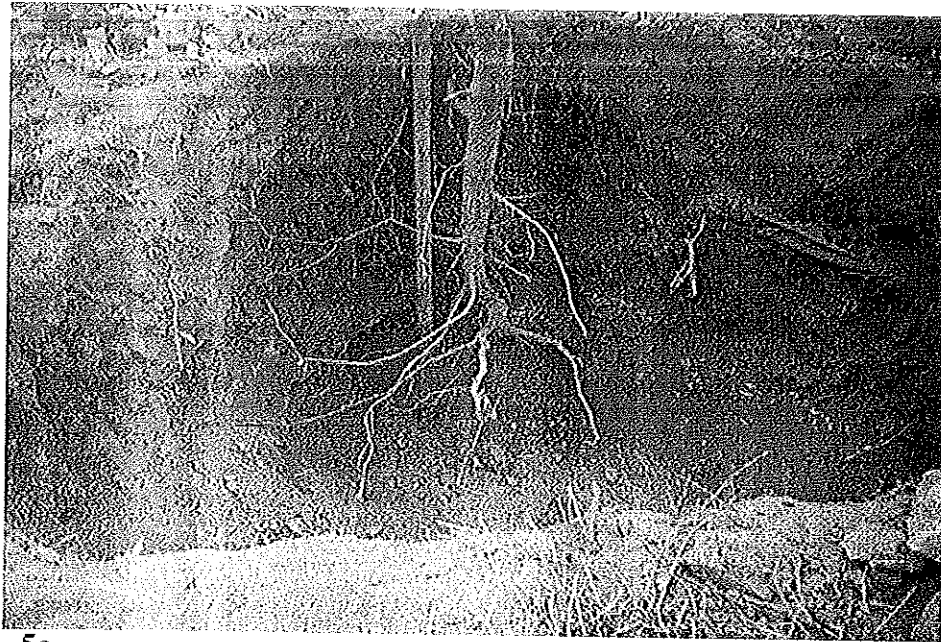
4d



4c

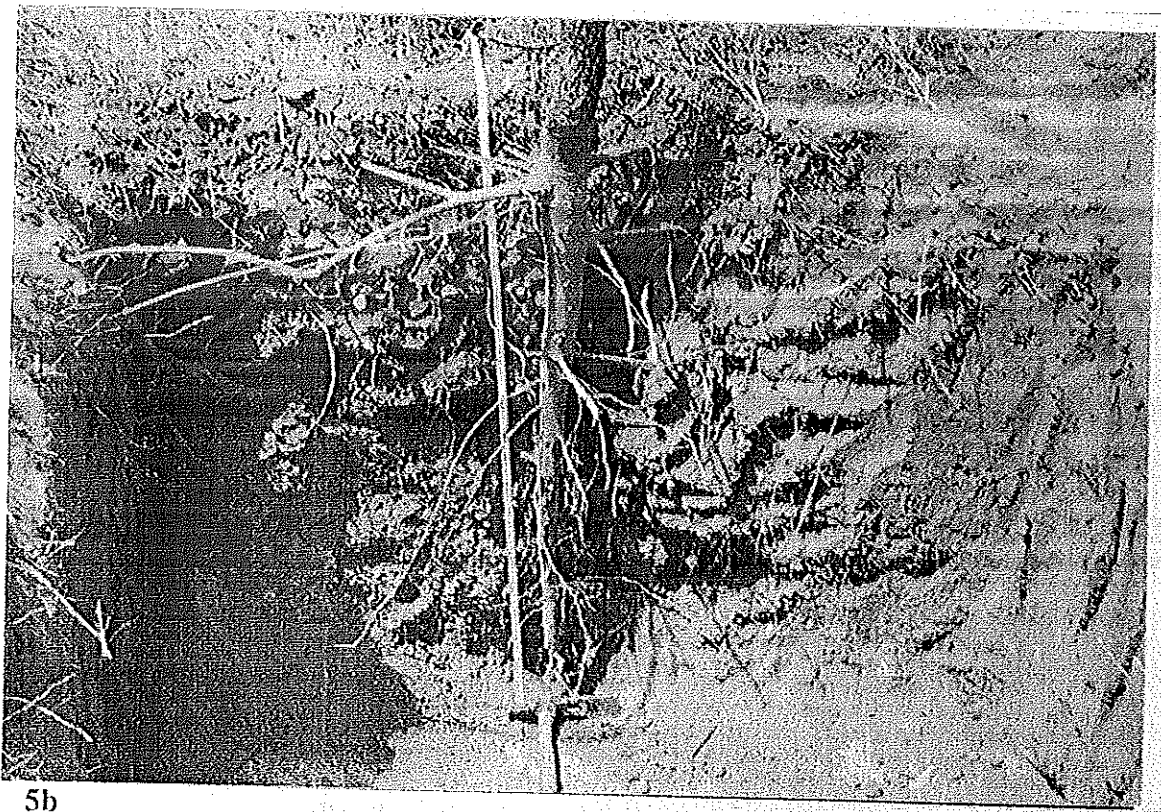


4f

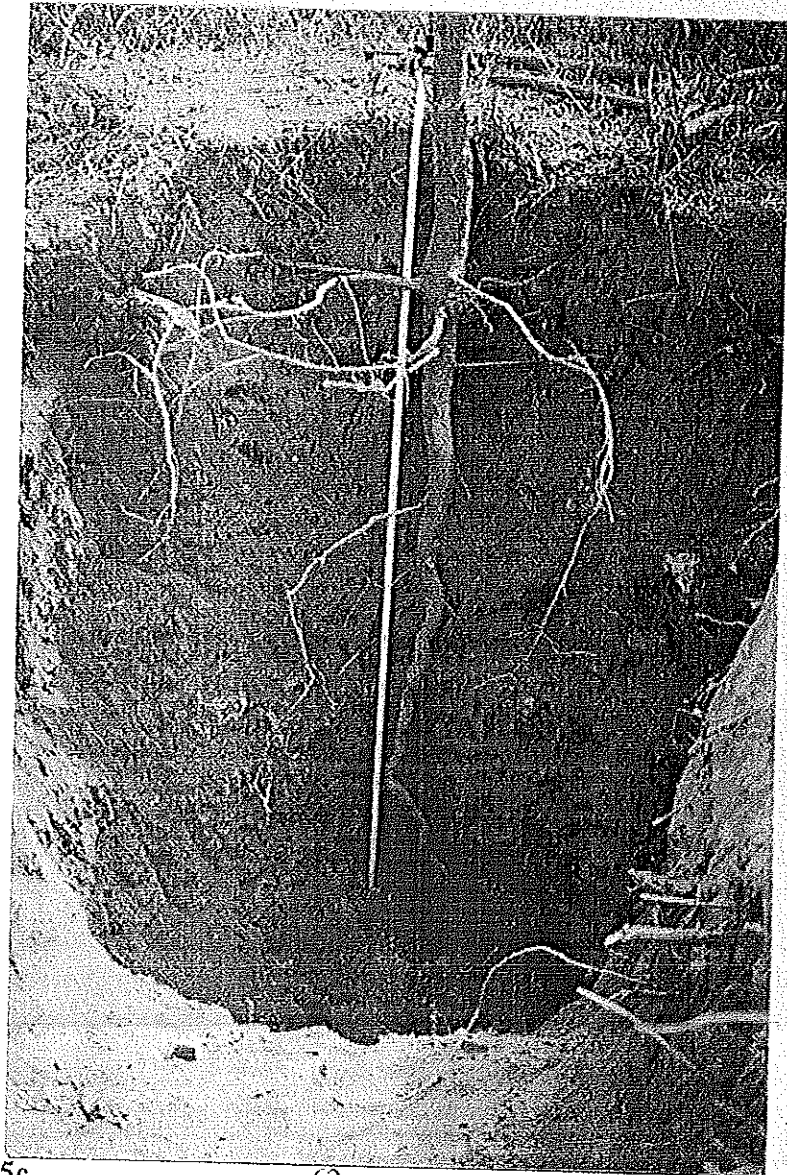


5a

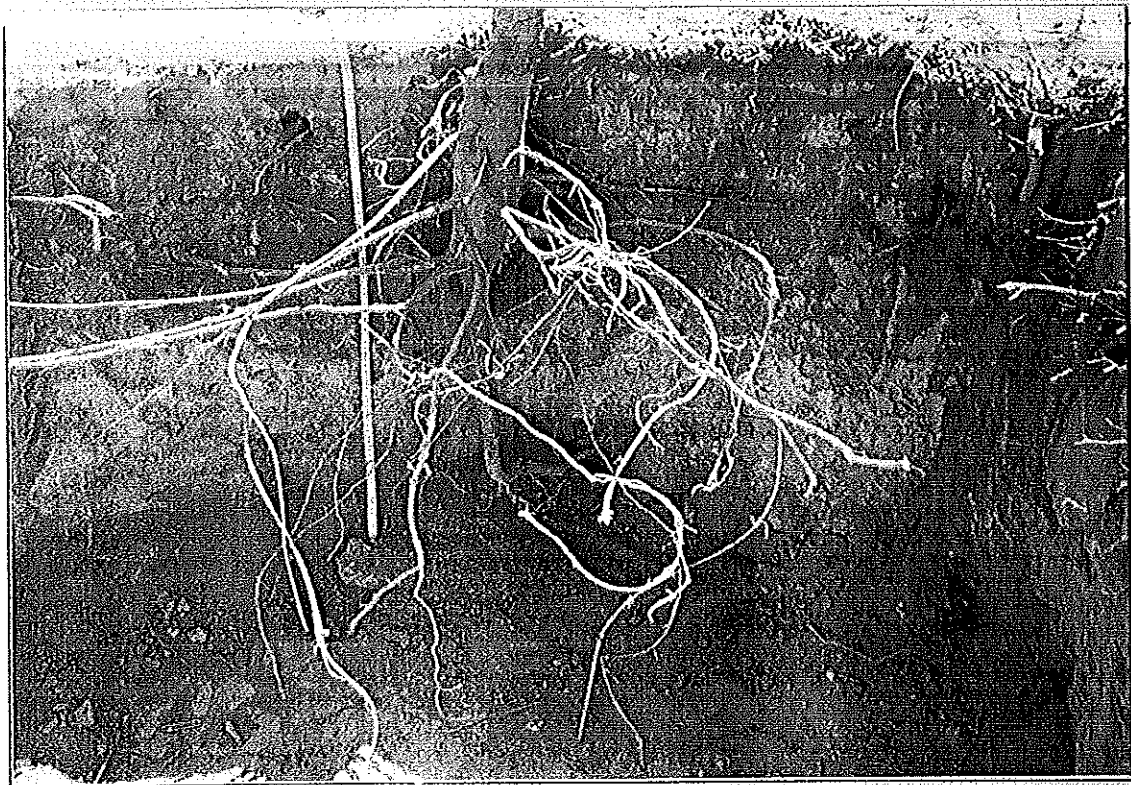
Plate 5 (a-d). *A. senegal* tree excavated in Abiyata Shala National Park. The soil was rocky after a depth of about 60-70 cm in (a) and (d). Most lateral roots were formed at the part of the taproot near the rocky layer. Notice the swelling, and tapering of the taproot and emergence of elaborate lateral roots in (d), part of the lateral root that managed to pass through the crevice had flattened parts.



5b



5c



5d

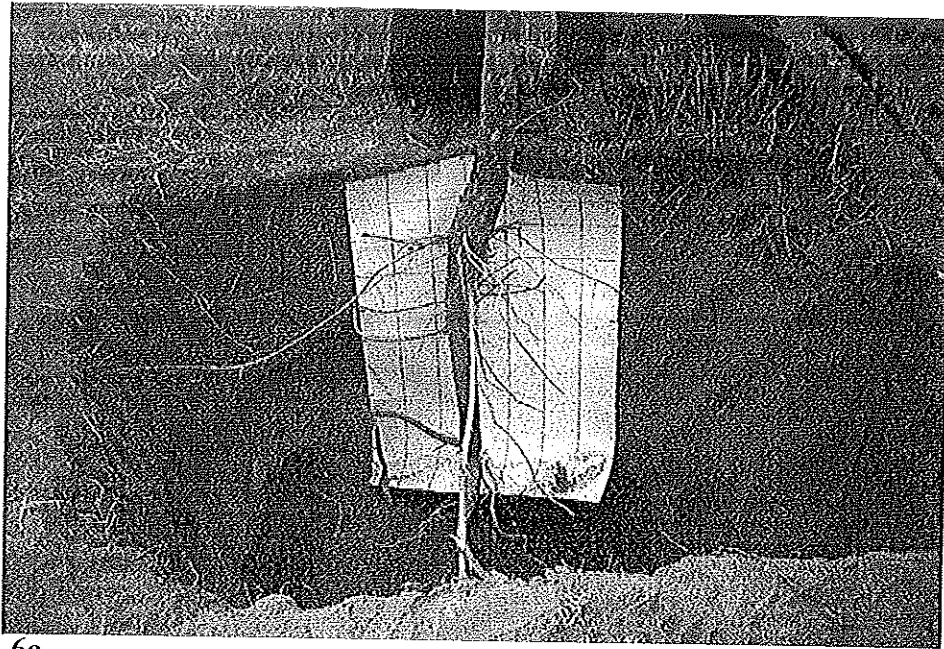
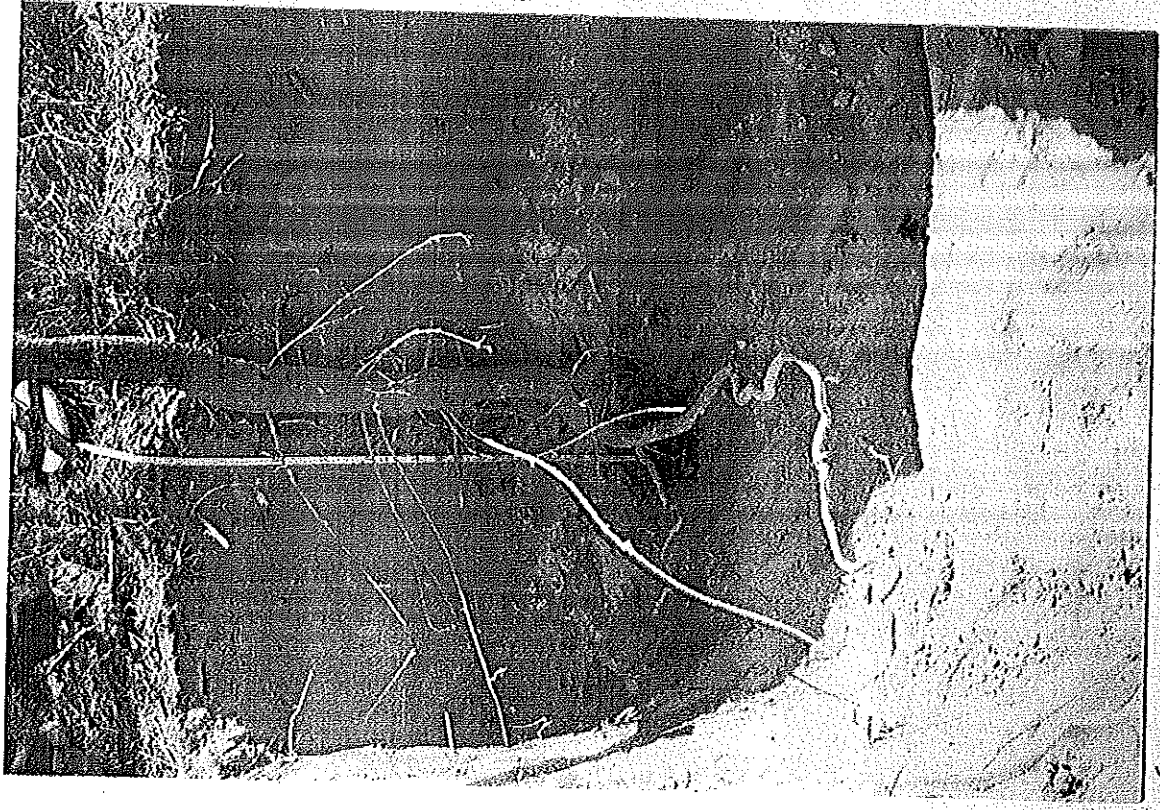
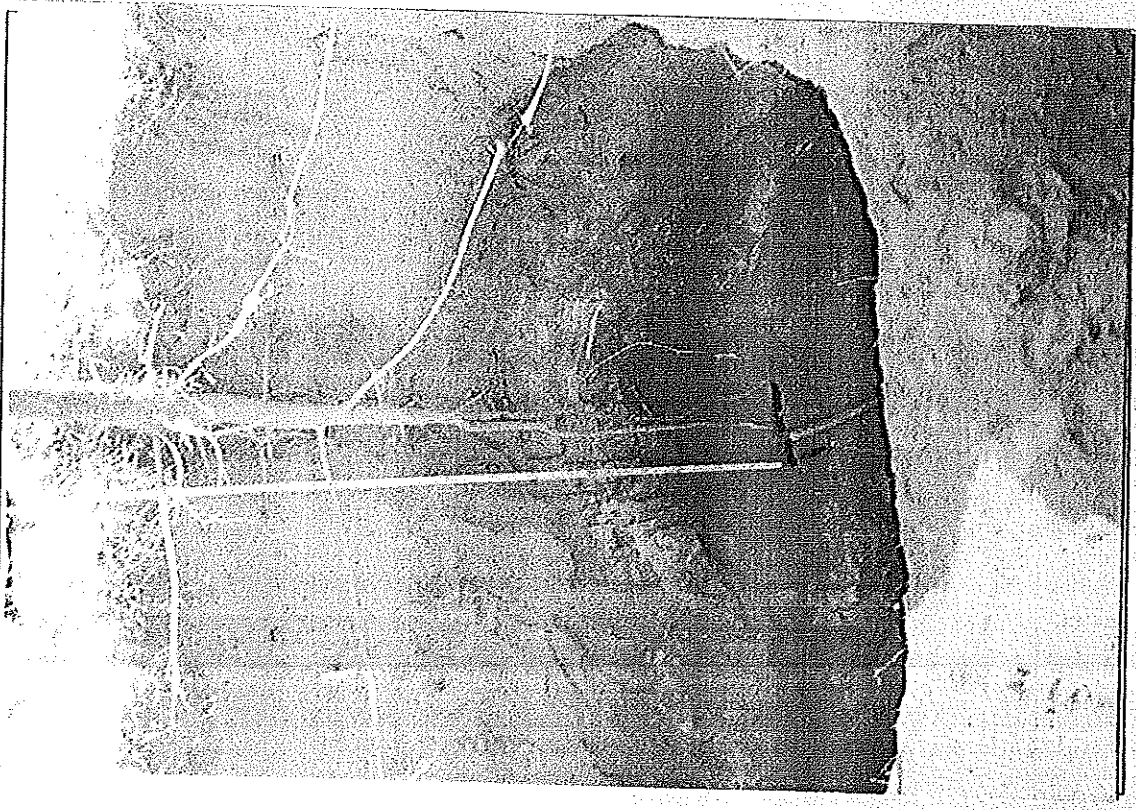


Plate 6 (a-c). *A. tortilis* trees excavated in Abiyata Shala. At a depth of 0.71 m (a) the taproot branched into four and the largest continued to grow vertically downwards while the others grew horizontally. The taproot of (b) also branched at about 0.70 m depth where both grew parallel vertically. In (c) the taproot grew vertically down up to a depth of 0.85 m but branched into two both of which grew horizontally in opposite directions. One of these grew horizontally 1.55 m long over a small area making bends (compare with Plate 3d



6c

65



6b

4. Discussion

Root systems show considerable architectural variation among species, among genotypes of a given species, and even within different parts of a single root system (Lynch, 1995; Lichtengger, 1996). They are very plastic in their potential for adaptation to a wide range of soil depths (Kummerow, 1981; Sydes and Grime, 1984). Recently, much attention has been given to understanding the functional importance root architecture has in the efficient acquisition of soil resources and plant adaptation to sub-optimal conditions (Lynch, 1995).

The main objective of this study was to investigate the root systems of three *Acacia* species that are dominant in the Rift Valley, particularly in Abernosa Ranch and Abiyata-Shalla National Park.

There were differences (though not very elaborated) in root growth patterns among species and even within species according to the substrate whether in Abernosa or Abiyata-Shalla. However, a significant difference in root architecture was not found within species in the two study sites (Table 1).

As compared to the other species investigated, *A.seyal* had the widest horizontal spread, 8.20 m at Abiyata-Shalla and 7.70 m at Abernosa (Table 1). The length of zone of intensive lateral roots was also slightly higher for this species. This shows that the roots of these species could take minerals and water from lower horizons to the topsoil layers. Besides, the lateral roots near the surface were very powerful (thick) and had greater

radial expansion.

Kramer (1983) noted that the amount of water and minerals available to plants depends very much on the volume of soil with which their roots are in contact. For this reason, the development of large root systems by vertical and horizontal extension and branching are important to the success of plants. Mambani and Lal (1996) concluded that drought avoidance is better achieved through a deep root system rather than through the mechanism of Stomatal closure in their study on response of upland rice varieties to drought stress.

Plates 1e and f and 4a-d show that *A. seyal* has the typical "T-root system" (two part root system). According to Veste and Breckle (1996) such a feature in arid areas gives plants an ecological advantage for water uptake. During and after the rainy season water uptake is effective from both wet layers i.e. the surface layers and the water table. During the dry season of the year, shrubs and trees use water from deep layers.

The extension of the lateral roots towards the shade of neighboring tree was common for most trees excavated. However, that of *A.seyal* was unique in that the lateral roots made a circular growth under the crown shade of neighboring trees (see plate 1g). The reason could be attributed to the moisture status of the soil under the shade of the neighboring trees. Many workers argue that, the preferential growth of roots in wetter zones of the soil profile is of considerable importance to survival of plants in arid zones. Highly branched roots occur in moist pockets of soil water, in cracks in bed-rock and isolated pockets of

clay or organic matter which retains water (Drew, 1979). Roots are often said to grow in search of water. However, Drew (1979) comments that there is no clear evidence of any hydrotrophic responses and that most observations can be explained by roots extending preferentially into media of lower mechanical resistance (and therefore higher water content).

A. seyal was found localized in flat plains with alluvial deposits and the trenches dug were the deepest as it was less compact. It had higher depth penetration that was evidenced from the taproots of the saplings uprooted (420.0 cm long). However, the fact that depth penetration is a function of the degree of rockiness of the soil was also shown from the other sapling uprooted. One of the longest lateral roots was about 166.0 cm long while the taproot was only 46.0 cm long. This indicates that more resource allocation by the plant might have been made to the lateral spread than for depth penetration. In agreement with the above it has been reported that plants have the ability to compensate, by increasing root growth in a favorable part of the soil for the lack of growth in unfavorable regions, when a part of the root system of a plant is subjected to high soil strength, compaction or high mechanical stress (Russell, 1983; Ennos and Fitter, 1992). Misera and Gibbons (1996) have also reported a concomitant increase in length of lateral roots and initiation of new lateral roots, with increasing soil strength, in support of the existence of such compensatory mechanism.

Abernosa area is less rocky than Abiyata-Shalla and the trees had their roots growing relatively to greater depths. However, most *A. senegal* trees excavated had their taproot

branching either into two or more after a depth of only 1 m. For this reason the species had well ramified and powerful lateral roots which were concentrated in the upper 60-75 cm of the soil. The higher density of the roots of *A. senegal* in both study sites can be observed from Plates 1a and b, 2a, b, and d. As a peculiar feature of the species, the part of the taproot just below the ground was swollen and most of the biggest lateral roots were branching from this part, especially in rocky soil such as those found in Abiyata-Shalla (plate 5d).

Root penetration in depth is limited in some areas by rocks. Because of the shallowness of the soil in such areas, the vegetation is more subject to injury from drought than on deeper soils (Kramer, 1983). The success of the *A. senegal* trees on rocky soils as in Abiyata-Shalla (Plate 5a and d), therefore, might depend on resource allocation to the development of dense branches than to depth penetration. This might help the plant to exploit resources (water and nutrients) on the upper region of the soil horizon very efficiently. According to Russell (1983) next to root depth, extensive root branching is often the most important characteristics of root systems that favor the uptake of water.

Similar to the *A. seyal*, most lateral roots of *Acacia senegal* were also growing towards the direction of the canopy shade of a neighboring tree. As can be seen from Plate 2f the largest three lateral roots unearthed could be observed growing to the direction of a neighboring *A. tortilis* tree. As mentioned above it is believed that roots are very sensitive to changes in soil moisture status (Russell, 1983; Mambani and Lal, 1996). In this regard, the shade of the neighboring tree could reduce soil surface temperature thereby reducing

evaporation of water and providing a better moist condition to the roots.

Three out of the four samples of *A. senegal* trees excavated were growing on rocky ground. From this observation it could be inferred that *A. senegal* could cope with rocky conditions by modifying its root growth patterns as is evidenced from Plates 5a and b in which the roots penetrate through rock crevices. The roots that were passing through the rocky layer of the soil did not have the normal round (cylindrical) structure but were deformed (contorted). It may safely be assumed that the crack in the rocky layer were formed by the roots themselves in an effort to make their ways through for greater depth. Gratani (1996) has pointed out that an individual may increase its fitness through the extension of environmental range in which it can survive; i.e. by increasing its adaptability. In many environments, fitness will be maximized not by a character which is best suited to a particular environmental state, but by one that allows the organism to track environmental fluctuations (Fitter and Hay (1993) quoted in Gratani, 1996).

A. tortilis of optimally desired size in Abernosa were excavated from the same area where the species is localized and dominant over the other species. Although the species is known to be deep growing, restraints on root penetration were observed from the modified roots. In all cases of those excavated in Abernosa, the roots of the trees did not proceed to grow vertically more than 1.2-1.4 m (see Plates 3 and 6). After certain depths the taproots change the direction of growth and make twists or loops.

Studies have shown that excessive soil strength, whether caused by an increase in soil density or by a decrease in soil water content is considered as key factor in determining the effect of compacted soil on plant rooting habits (Yapa *et al.*, 1988; Nicoullaud *et al.*, 1994; Materechera *et al.*, 1994). This can cause greater mechanical resistance or impedance to root extension, gas exchange between the soil and the atmosphere (Russell, 1983).

The range of diameter of the lateral roots and second order branches for *A. tortilis* were the least i.e. the lateral roots were not as powerful as those of the other species. The length of the zone of intense lateral roots along depth gradient was more or less equal to the others but the horizontal spread was very low.

It was observed that the saplings of *A. tortilis* completely uprooted in both study sites had the longest taproots next to *A. senegal*. This shows that the roots of this species could grow to greater depths depending on the nature of the substrate. That *A. tortilis* trees are deep growing was observed from old trees that grew on the edges of deep gullies exposed by years of erosion (Plate 3e). Thus, the absence of very dense and extensive lateral roots can then be compensated by a deep taproot, that could draw water from deep layers or from the water table.

The fact that roots are dependent on shoot for carbohydrates, growth regulators and organic substances; and that shoots are dependent on roots for water, minerals and growth regulators has been well established. Successful growth of plants therefore depends on maintenance of the balance in growth and function between roots and shoots (Kramer,

1983). Thus, considerable emphasis is given to the shoot-root ratio as an indicator of satisfactory balance between the two (Kramer, 1983; Shetron and Spindler, 1983) and the assessment of carbon allocation to the root system (Veste and Breckle, 1996). Furthermore, Ennos and Fitter (1992) show that the cost of the root system is determined by the allocation of resources within the plant. Preferential allocation of resources results in a higher root:shoot quotient, which may be found where either water or nutrients limit growth.

In this study, there was no significant difference among the three species in different sites in shoot-root ratio from statistical test (samples were only two per species). But a difference was seen from the averages between species where *A.tortilis* had shoot-root ratio less than one (Fig. 2), indicating that the underground parts were more developed than the aboveground parts. The higher development of the roots also was shown in the depth penetration of the taproots. For example, *A.seyal* had more than 4 m long taproot (Table 2) whereas the average height of the shoot was only about a meter. It was reported that the seedling of *A.tortilis* with 3 cm tall shoot had a root of 45 cm long (Lawton, 1996). According to Mansfield and Atkinson (1990) one of the most important responses a plant makes when it is confronted by drought is a shift in the distribution of new assimilates to support the growth of the roots at the expense of the shoots. This increases both the capacity of the roots to explore for further supplies of soil water, and restricts leaf expansion so that the area from which transpiration occurs is reduced. According to Begon *et al.* (1986) most roots have features that insure they are explorers. They elongate before they produce laterals (shoots initiate leaves before they elongate) and this ensures

that exploration precedes exploitation.

Other studies have also indicated that plant species differ in shoot-root ratio and the morphology of roots and root systems, because of inherent variations and differences in environmental conditions, such as availability of water and nutrients (Boot and Mensink, 1990; Shetron and Spinder, 1983). Results of this study also indicate the slight variation between and within species could have been environmentally induced.

Soil moisture is the main factor limiting root growth in arid climate conditions (Kutschera-Mitter, 1996) and plant productivity and growth rates have been found to be proportional to water availability (Punaire *et al.*, 1994). Sarmiento (1996) also notes that plant available moisture is one of the crucial ecological limitations for the growth of savanna plants.

The moisture content of the soil in the study area was low since the measurements were taken during May, which is a dry period. The moisture content of Abiyata-Shalla could be expected to be lower than Abernosa as a result of the rockiness of the former. However, results indicate that the reverse is true. The percent moisture was relatively lower in Abernosa with mean values ranging from 2.08 ± 0.25 to 7.68 ± 0.17 than in Abiyata-Shalla with mean moisture ranging from 5.37 ± 0.20 to 9.40 ± 0.90 . This could be attributed to the unexpected rain that might have fallen earlier because of the Elnino phenomenon of 1997.

A direct relationship between the moisture content along the depth gradient and root growth pattern was not observed in this study but the facts that gave indications were that:

1. there were restraints to root growth both in the excavated ones and in the uprooted saplings even in non-rocky soil which could be due to shortage of moisture, and
2. most lateral roots were growing to the direction of shade of other trees probably in search of moist ground.

Belsky (1994) reported lateral roots of *A. tortilis* in low rainfall site in Kenya extended into the grassland and terminated at least 9 meters beyond their crowns. In contrast, at the high rainfall site many of the roots of the excavated saplings terminated near or directly below the tree crown. The differences in lateral root extension by trees in the low-and high-rainfall sites were attributable to differences in soil moisture conditions. At the drier site, roots had to extend farther into the grassland and explore large volumes of soil for the acquisition of adequate moisture. At the lower sites, where water was less limiting, more tree roots terminated within or near tree crown zone, where they could take advantage of the more nutrient rich soils (Belsky *et al.*, 1989, 1993a; Asferachew Abate, 1994).

In this study there was no significant difference in bulk density along depth gradient. The bulk density of the soil under the three species within the same site was also not significantly different. There was, however, marked difference between sites where bulk density on the Average was higher for Abiyata-Shalla than for Abernosa. The lowest record is from Abernosa (mean = 1.13 ± 0.09) and highest record is from Abiyata-Shalla (mean= 1.58 ± 0.28). In general it is known that roots are severely impeded if bulk densities exceed 1.55, 1.65, 1.80 and 1.85 g cm⁻³ on clay loams, silt loams, fine sandy loams and

loamy fine sands, respectively (Gregory, 1988). In the study area the results were within the range (1.5-1.6 g cm⁻³) where root growth and water penetration could be significantly slowed (Thompson and Troeh, 1978; Marschener, 1986; Wilde, 1993) especially for those in Abiyata-Shalla. This was evidenced by the growth patterns in the excavated trees as well as saplings uprooted.

The effect of compact and drying soils is not only impediment of root penetration and slowing water infiltration (Russell, 1983) but also nutrients are rendered less mobile because the pores between soil particles are replaced by air and the pathway from the soil to the root surface becomes less direct (Pugnaire, 1994).

Soil texture has very considerable effect on the available water holding capacity because the water is held as films on the surfaces of soil particles and in the small pore spaces between the particles (Thompson and Troeh, 1978). Textural classification of the soil in the study area shows that the soil is by in large sandy loam with small proportion of loamy sand. According to Kramer (1983) sandy soils have volume of non-capillary pore space that ensures good drainage and aeration. They are relatively inert chemically, are loose and non-cohesive, and have a low water holding capacity.

Observations during the study have shown that in most cases roots were penetrating deep and impedance was minimal indicating that the sandy loam soils offered less resistance to the roots. However, as in the case of areas where *A. tortilis* were excavated in Abernosa and others in Abiyata-Shalla, due to low availability of moisture in the soil (dryness) there



was impedance to the roots though the soil was sandy loam. Drew (1979) indicated that sands and gravel often include a range of particle sizes in which the finer particles pack tightly in voids between the large ones. Even favorable soils may then become resistant as their water content decreases.

The amount, form and distribution of nutrients in soils influence the amount of root growth and distribution (Gregory, 1988). The size of root system therefore has great importance for the uptake of mineral nutrients with low mobility in the soil, such as phosphorus and potassium (Sattelmacher *et al.*, 1990). The pH of the soil is one of the most indicative chemical property of a soil as it influences the rate of plant nutrient release by weathering, solubility of all materials in the soil and amount of nutrient ions stored on the cation exchange site (Thompson and Troeh, 1978). The mean soil pH of Abernosa and Abiyata-Shalla was 6.30 ± 0.26 - 7.86 ± 0.12 and this is within the maximum availability range (6.0 and 7.5) for most nutrients such as N, P, Ca, and Mg (Thmpson and Troeh, 1978; Moore and Chapman, 1986; Killham, 1994; Mengel and Kirkby, 1982).

The results of this study show that the percentage of organic carbon (2.84 ± 0.32 for Abernosa and 1.79 ± 0.23 Abiyata-Shalla) in the soil was in the high range and nitrogen (0.21 ± 0.02 for Abernosa and 0.15 ± 0.02 Abiyata-Shalla) in the medium range according to the rating by Murphy 1959, 1968) in his survey of Ethiopian soils. The amount of both nutrients was significantly higher in the surface soils in the two study sites as expected the higher value being for Abernosa which could be due to the density of the *Acacia* trees and cow dung from the cattle in the Ranch.

According to Drew (1979) pronounced localized concentrations of inorganic nutrients, particularly nitrogen, can occur near the surface in some arid soils, due to the localized accumulation and mineralization of organic matter. As a result, there is proliferation of roots in these more fertile pockets of the soil. Results in this study show that the amount of nitrogen in the soils of the study area (0.21 ± 0.02 and 0.15 ± 0.02 percent for Abernosa and Abiyata-Shalla, respectively) is adequate for the plants since exacting (demanding) species require soils containing in their surface layer about 0.2% of nitrogen. The amount of organic matter (2.84 ± 0.32 and 1.79 ± 0.23 for Abernosa and Abiyata-Shalla, respectively) is also above the requirement (1%) by exacting species (Wilde *et al.*, 1979).

Medina (1996) suggested that availability of phosphorus seem to regulate the frequency and productivity of legumes in tropical savannas. The available phosphorus in the study area is above the required concentration (>20 ppm) for plant growth (Murphy 1959, 1968; Tamrie Hawando *et al.*, 1986). The reason for this high availability of phosphorus could be due to pH between 6.5 and 7.5 which is usually optimal for availability of phosphorus (Thompson and Troeh, 1978).

In view of the chemical properties of the study area we may conclude that availability of nutrient was not a limiting factor for root development and a cause for modifications in growth pattern.

The study on the effect of isolated trees on their understorey environments is getting greater attention recently (Jackson *et al.*, 1990; Belsky *et al.*, 1989, 1993). The woody

species in savanna areas increase species diversity by creating low-light-micro-habitats suitable for colonization by shade-tolerant species. Woody plants also increase spatial heterogeneity in the community by focusing nutrients to sub-crown tree environments (Belsky, 1994) thereby affecting the productivity of the herbaceous understorey (Kellman, 1979; Jackson *et al.*, 1990; Belsky *et al.*, 1993).

Belsky *et al.* (1989) showed that organic matter and nitrogen content, availability of phosphorus, and exchangeable potassium and calcium were higher under the crowns of the deciduous trees *A.tortilis* and *Adansonia digitata* compared to open grassland in Tsavo National Park in Kenya. This difference in nutrients occurs both in high and low-rainfall areas and influences the nutritional values and the productivity of the grasses growing underneath the crowns (Belsky *et al.*, 1993).

In this study, assessment of the root biomass of under canopy vegetation and open grassland was made to infer the effect the trees have on the productivity of the undergrowth. Results obtained (Table 8; Fig. 7)) show that root biomass was different within species and between species. This may be due to difference in microhabitat conditions. Only the root biomass obtained from under-crown of *A.seyal* was greater than that in the open grassland, the difference on the average being negligible for *A.senegal*. Root biomass of the adjacent grassland was significantly higher than undercanopy of *A.tortilis*. On the average there is the indication that the total root mass from undercanopy is greater than the open grassland.

Belsky *et al.* (1993) reported that the herbaceous-root biomass in the under canopy was similar to the open grassland in Tsavo National Park. Whereas at a low-rainfall site root biomass was approximately the same as in the canopy and grassland zones, at a high rainfall site it was 11% higher in the grassland zone. Thus, root biomass alone is not enough to indicate the productivity of undercanopy vegetation and aboveground biomass should also be considered.

Asferachew Abate (1994) compared the nutrient status of the soil under canopy of *A.tortilis*, *A.senegal*, and *Balanaites aegyptiaca* in the study area. The results reported show that the organic carbon, total nitrogen, and available phosphorus were higher in the surface soils of undercanopy of the trees than the adjacent open grassland. Besides, there was also high percentage cover and diversity of species in undercanopy vegetation than vegetation outside canopies.

Observations in this study have also shown that, the cover of aboveground vegetation was very high under *A.tortilis* and *A.senegal*. This could be attributed to the canopy diameter and density of the branches that make the canopy under the two species. However, the herbaceous species under these two tree species and mainly under *A.tortilis* were dominated by annual dicots particularly *Tagetes minuta*, *Bidens pilosa*, *Achyranthus aspera*, etc. with less grass composition. Under the crown of *A.seyal*, grass composition was more dominant than other dicot herbs and the high root biomass underneath could be attributed to the tufted roots of the perennial grasses.

From these observations, in general, it can be concluded that the tree species in the study area contribute to the productivity of the under-growth. Belsky *et al.* (1993) has pointed out that this increase in productivity is localized under or near tree crown and is found most often in the tropics and subtropics and in communities with low tree diversity, low rainfall and moderate soil fertility.

5. CONCLUSION

The *Acacia* species investigated showed some variation in root architecture as can be observed from the plates of the representative species we studied. However, the rooting depth for each *Acacia* species excavated seems to be more a function of soil and bedrock conditions. In areas where the soil was deeper, the young trees excavated as well as the uprooted saplings grew deeper. But in cases where the soil was compact and rocky (e.g. Abiyata-Shalla) modification in the root structure and growth direction was observed. Other reports have also shown that the same species could be described as shallow-rooted when bedrock impeded deep root growth and deep-rooted when such restraints are absent (see Kummerow, 1981). Thus, there was not much difference in root growth pattern within species in different sites except that depth penetration and ramification of lateral roots varied according to the particular nature of the substrate where the trees were excavated.

Investigation of the saplings uprooted showed that roots of the three *Acacia* species studied allocate most of their resources for depth penetration during the early stages of their growth in order to establish themselves. By doing so absorption of water from deep layers during the dry season could be secured.

The chemical properties of the soil show that nutrient availability was not the main constraints to root development in the *Acacia* species of the study area. The main factors that could be attributed to the differences in root growth patterns and modification of root

parts seem to be the relative dryness of the soil (low moisture content) and rockiness of the soil. However, the fact that these species were able to grow in soils with low moisture and with mechanical impedance to root development indicates that they are good candidates for the rehabilitation of degraded lands.

Although shoot-root ratio is known to be a better index to evaluate the effect of trees on productivity of under-growth as compared to open grassland, the results obtained on root biomass alone have also shown that trees improve productivity of the undergrowth. As mentioned elsewhere, this is through addition of organic matter and nutrients through leaf-fall, by reducing soil temperatures and evapotranspiration.

6. Recommendations

1. Methods based on excavation of trenches or excavation of all or part of the root system show the gross morphology at a given site in time. This is important when knowledge of depth and extent of roots of individual plants is required. However, studies on the temporal patterns of root development are needed to get a complete picture (Hughes and Gandar, 1993). Further study on temporal root development should therefore be carried out by employing underground root laboratory (rhizotrons) methods.
2. The influence of trees on productivity of savanna was estimated from the root biomass of the herbaceous undergrowth by comparing the results to those in open grassland. According to Noordwijk *et al.* (1995), root distribution tends to be patchy and there is much variability between samples. A large number of replicate samples are therefore needed. The study of the influence of trees on undergrowth, could be supplemented by estimating aboveground biomass in different growing seasons.
3. It has been observed that in both sites there were some localities where only one species dominates to the extent that it could be hard to find the others. This might partly be explained by microhabitat preferences. However, Zerihun Woldu and Mesfin Tadesse (1990) suggested as well that there is selective felling (e.g. *A.seyal*) for charcoal production. The awareness of concerned authorities and the public at large should therefore be raised before complete destruction of the *Acacia* trees takes place.

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