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IMPROVING THE MANAGEMENT AND PRODUCTIVITY OF *TAMARINDUS INDICA* AND *ZIZIPHUS MAURITIANA* IN AGROFORESTRY PARKLANDS SYSTEMS IN MALI, WEST AFRICA

By

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ABSTRACT

Three experiments were conducted on *Tamarindus indica* (Tamarind) and *Ziziphus mauritiana* (Ber) in parkland systems in Mali between 2006 and 2009: 1) the effect of Tamarind on yield and nutritional quality of African eggplant (*Solanum aethiopicum* L) in comparison with sorghum (*Sorghum bicolour* (L.) Moench) was performed in Siramana village; 2) methods of domesticating an improved cultivar of Ber on farms through intercropping with African eggplant and sorghum were performed in Sanankoroba and 3) methods of enhancing the growth of Tamarind and Ber seedlings through mycorrhizal inoculation were performed in the nursery of Sotuba research Centre. All the three sites are situated in South Sudanian zone with annual rainfall ranging from 900 to 1200 mm. The soils in Siramana and Sanankoroba have sandy clay loan and sandy loan texture respectively. For the third experiment, nursery soil was used which consisted of local soil (1/3), sand (1/3) and compost (1/3). Concerning the first experiment, six adult trees of Tamarind were randomly selected in the collaborating farmers' fields. The area around each sample tree was subdivided into three concentric zones: Zone A; Zone B and Zone C. A control plot (Zone D) was installed in an open area. Crop production (eggplant and sorghum) in these zones was assessed over two cropping seasons. Regarding the second experiment, an experimental plantation was established with seedlings of the local variety of Ber half of which were grafted *in-situ* with an improved cultivar of Ber called SEB. Crop production as well as the performance of Ber was assessed in each experimental plot over two cropping seasons. Concerning the experiment on mycorrhizas, three inocula were used: *Glomus aggregatum*, *Glomus fiscia* and unselected nursery soil inoculum as a control. The results of the study on the intercropping trial of Tamarind showed that Tamarind may have a positive effect on yield of eggplant but a negative effect on yield of sorghum. Tamarind had, however, no effect on nutritional composition of both crops. The results of farmer's feedback survey showed that growing eggplants under Tamarind has a great potential for adoption by farmers in Mali because majority of respondents mentioned that the tree-crop association tested was a good idea and should be promoted for making more productive use of land under trees, improving crop yields and increasing farmers' incomes. The results of the study on Ber domestication showed that SEB, the improved variety as well as the local variety of Ber had no detrimental effect on either eggplant or sorghum, both in terms of yield and nutritional quality, two years after establishment. In fact a beneficial effect of trees was found on the performance of both crops (yield, dry matter production) which suggest a complementarity of resource use. The high level of fruit production of the improved variety of Ber observed on farms under rain-fed conditions may be a source of additional income and diversification of diet for rural communities in Africa. Therefore, the adoption by farmers of the agroforestry practice of domesticating improved Ber varieties in association with food crops may help considerably in alleviating poverty in the region. The results of the mycorrhizal studies showed that VAM species differed in their ability to enhance plant growth. The growth of Ber was significantly improved by *G. aggregatum* inoculum while the growth of Tamarind was enhanced with nursery soil inoculum. The results on Tamarind suggest the need for isolating the local soil mycorrhizal fungi in future screening experiments.

DEDICATION

- To my father Kalifa Sidibé who died when I was in primary school.

  May your Soul rest in Peace, Amen!

- To my mother Djeneba Sidibé for her invaluable contribution towards my success.

- To my wife Mariam Touré, my sons Abdoulaye Sidibé, Mohamed Sidibé and my daughter Djina Sidibé who shared the feelings of loneliness while I was away for studies.

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LIST OF SYMBOLS AND ABBREVIATIONS

AMF: Arbuscular Mycorrhizal Fungi

AM: Arbuscular Mycorrhizas

ANOVA: Analysis of Variance

AVRDC: Asian Vegetable Research and Development Centre

BNF: Biological nitrogen fixation

CBO: Convention on Biological Diversity

CEC: Cation Exchange Capacity

DANIDA: Royal Danish Ministry of Foreign Affairs

ENDA: Environmental Development Action

FAO : Food and Agriculture Organisation of the United Nations

GLM: General Linear Model

IAASTD: International Assessment of Agricultural Science and Technology for Development

ICRAF: International Centre for Research in Agroforestry

ICRISAT: International Crops Research Institute for the Semi- Arid Tropics

ICUC: International Centre for Underutilised Crops

IER: Institut d'Economie Rurale

INCO-DC: Inter Cooperation with Developing Countries

INERA: Institut National de l'Environnement et de la Recherche Agricole

MEA: Millennium Ecosystem Assessment

MIP: Mycorrhizal Inoculum Potential

NGO: Non Governmental Organisation

NTFPs: Non Timber Forest Products

OHVN: Office des Hautes Vallees du Niger

PAR: Photosynthetic Active Radiation

PRA:	Participatory rural appraisal
RMD:	Relative Mycorrhizal Dependency
RLD:	Root Length Density
RWD:	Root Weight Density
SOC:	Soil Organic carbon
SOM:	Soil Organic Matter
UNESCO:	United Nations Educational, Scientific and Cultural Organization
UK:	United Kingdoms
US:	United States of America
USDA:	United States Department of Agriculture

CHAPTER I:

INTRODUCTION

1.1. Background and summary of the present research project

In most of the countries of West Africa, the majority of the population is rural, depending heavily on natural resources for nutrition and income. Living in drought-prone areas, they have adopted livelihood strategies based on diversification and risk avoidance, since relying on one crop type alone may be fatal. Indigenous fruit trees of agroforestry parkland systems, in particular, play an important role in the livelihood of local people in the region, because they provide food, important nutrients and vitamins to diets that are dominated by cereals and a source of income through commercialisation of a diversity of products (Teklehaimanot, 2004; Gausset *et al.* 2003; Boffa *et al.*, 2000; FAO, 2001; Warner, 2007). They are also used in traditional and modern medicine, provide a source of fire and construction wood and modify the microclimate suitable for crop production (Vandenbeldt and Williams, 1992; Jonsson *et al.*, 1999; Rao *et al.*, 1998; Ong *et al.*, 1992; Buresh and Tian, 1998; Ong *et al.*, 2002; Jose, 2009). Traditionally, farmers in the region retain the indigenous trees that they value most and those they know can modify microclimates on their farms when converting original woodland to cropland (Teklehaimanot, 2008). The importance of the two major native fruit species of agroforestry parkland systems in the region, *Vitellaria paradoxa* and *Parkia biglobosa*, in the local diet and for the generation of income is well-documented (Teklehaimanot 2004, Mertz 2000, Gausset *et al.* 2003). Although many species of indigenous fruit trees of agroforestry parkland systems are protected and consumed by rural people, their contribution to local livelihoods and economy has not been properly quantified and this may be one of the reasons for their under-prioritisation when development policies are made in the region. Good examples are *Ziziphus mauritiana* Lam., commonly called Ber and *Tamarindus indica* L., commonly called Tamarind, which are subjects of the present research project. According to socio-economic surveys conducted by ICRAF, Ber and Tamarind ranked among the top 12 most important species in Mali, Burkina Faso, Senegal and Niger (Bonkoungou et al. 2002).

Ber also known as Jujube (*Ziziphus mauritiana* Lam.) belongs to the family of Rhamnaceae. It is a multipurpose fruit tree widespread throughout the arid and semiarid regions of sub-Saharan Africa (Depommier 1988, Ouedraogo *et al.*, 2006). Ber has been reported to originate from Central Asia (ENDA, 2001) but it grows wild in West Africa. It is a thorny tree or shrub reaching up to 4 m in height. Ber in West Africa is an economically important species. It is highly valued for its fruits which are edible and sold in local markets. Yet, it has never been domesticated in the region and the fruits which are very small (1cm in diameter, 1-2 g in weight) are collected from the wild. The leaves are highly preferred by animals and have been highly used by farmers as browse species according to a survey conducted in Burkina Faso by Sanon *et al.* (2007). The leaves, the bark and the roots are widely used in traditional medicines. The anti-inflammatory and sedative properties of these plant parts have been proven experimentally (Fortin and Maynart, 1990). The role of this tree in improving soil fertility and microclimate has not yet been investigated but its persistence in crop fields could help to control erosion and its extensive and deep root system could recycle nutrients to the soil surface. Furthermore, Bâ *et al* (2000) have reported that Ber depends heavily on mycorrhiza and its high response to inoculation motivated researchers to choose the tree as control for several mycorrhizal investigations on other tree species in West Africa.

Recently, the Sahel Regional Program of the World Agroforestry Centre (ICRAF) has introduced three Indian cultivars of Ber to West Africa because of their precocity in fruiting (6 months), the larger size of their fruits and good taste (Ouédraogo *et al.*, 2006). Grafting the local Ber with these cultivars has now become a priority research of local research institutes in the West African region. The high performance of grafted Ber makes it suitable for intensive production through plantations or agroforestry systems and therefore a promising tree for the future. However, no studies have been carried out so far to find out how the improved cultivars of Ber can be introduced on farm as a component of agroforestry parkland system.

Tamarind (*Tamarindus indica*) belongs to the family of Ceasalpiniaceae (Fabaceae). It is a large evergreen tree which is found in many parts of the tropics. The tree can reach an average height of 20-25 m and trunk diameter (dbh) of 1 m. It has a wide spreading crown, a short trunk and a deep and extensive root system (DANIDA, 2000). The fruits are usually between 5 and 14 cm in length and approximately 2 cm wide. The ripe fruit contains a pulp which is sticky and used both in industry and domestically. Tamarind has been reported to grow in most tropical/subtropical regions of the world (ICUC, 1999; DANIDA, 2000). Its origin is Africa, where it grows wild (von Maydell, 1986; DANIDA, 2000; Jama *et al.,* 2008). Tamarind can produce an annual fruit yield in the range of 150-500 kg/tree (ICUC, 1999; Jama *et al.*, 2008). The fruits have low water content and the highest levels of protein and carbohydrate of any fruit. The pulp is high in potassium, phosphorus and calcium; it also contains iron and is a good source of the vitamins thiamine and niacin. Tamarind could therefore contribute significantly to the nutrition of rural households (Jama *et al.*, 2008). The pulp of Tamarind has many culinary traditional uses, for example, in porridges, drinks and juice. The fruit can also be eaten fresh. Animals reportedly feed on Tamarind leaves (ICUC, 1999; Jama *et al.*, 2008). American pharmaceutical industries processes 100 tons of Tamarind pulp annually and it is a common ingredient in cardiac and blood sugar reducing medicines (ICUC, 1999; Maiti *et al.* 2004). Some African societies venerate the Tamarind tree as sacred and many parts of the tree (bark, leaves, roots, fruits) are widely used in traditional medicine (Morton, 1987).

Many trading routes of Tamarind have been reported including from Thailand into Europe and from Mexico to North America and Europe (ICUC, 1999; Jama *et al.*, 2008). Although such exportations are common between West African countries (for example from Mali to Senegal), there is no reliable statistical data. However, Tamarind has never been cultivated in West Africa. So, fruits that are consumed by local households and traded in local markets and exported to neighbouring countries are collected from trees that grow in the wild (Jama *et al.,* 2008).

There are two main varieties of Tamarind, sweet and sour. The Tamarind present in West Africa is the sour variety but attempts are being done by ICRAF and National Research Institutes to introduce the sweet variety from Thailand by grafting it onto the local variety. Grafted trees are reported to fruit within 3 to 4 years (ICUC, 1999), while the tamarind seedlings take 10-14 years before fruiting (Jama *et al.*, 2008).

Due to over-cutting of trees for fuel and construction and expansion of mechanised agriculture in the region both Tamarind and Ber as well as several other tree species of agroforestry parkland systems are disappearing. Due to loss of tree cover, the productivity of agroforestry parkland systems in West Africa is also declining (Teklehaimanot, 2004). As the population of West Africa continues to rise, the need for food will grow, and the availability of unutilised arable land will decrease. Therefore, it is important to increase the productivity of land currently in use, using sustainable methods. One such method that can help maintain favourable and stable conditions needed for sustained food production on parklands is preserving and managing existing indigenous trees and domesticating them on farms (Sanchez, 1995; Rao *et al.* 1998, Young, 2000; Teklehaimanot, 2004).

The general aim of the present study is to contribute to knowledge in relation to the enhancement of the productivity of agroforestry parkland systems based on *Ziziphus mauritiana* (Ber) and *Tamarindus indica* (Tamarind). These tree species were chosen because they are underutilised, they are local fruit tree species of high economic value and they have not been objects of scientific study in West Africa until very recently.

The productivity of *Ziziphus mauritiana* will be assessed here through the introduction of improved variety of Ziziphus (SEB); the measurement of Ziziphus growth parameters; the evaluation of fruit production of both varieties of Ziziphus (improved and local) and the evaluation of the performance of associated crop (sorhum and eggplant) in terms of yield and above ground dry biomass. Nutritional quality of associated crops will be assessed. Concerning *Tamarindus indica* the productivity will be assessed through the performance of associated crops (sorghum and eggplant) in term of yield and dry biomass, the nutritional quality of these crops. Correlation analyses will be performed between the root length densities of Tamarind and the associated crops as well as roots length densities and crops nutritional composition and some soil chemical composition (N, P, K and C). It is important to mention that Tamarind fruit production could not be assessed in the present study.

Considerable progress has been made lately in our understanding of biophysical interactions between trees and crops in agroforestry parkland systems (Rao *et al.* 1998). In agroforestry parkland systems, reductions in crop yield under tree canopies compared to open areas due to competition between trees and crops for light, water and nutrients have been reported widely (Kessler, 1992; Kater *et al.*, 1992; Bayala, 2002).

In Burkina Faso, Kessler, (1992) found that sorghum yields under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees were reduced on average by 50% and 70% respectively while in southern Mali, Kater *et al.* (1992) reported a yield reduction of 60% under canopies of both species. Such a reduction in crop yield could, however, be avoided by growing shade-tolerant crops immediately beneath the crowns of trees and growing cereals which are shade-intolerant outside the shaded area if yield limiting interactions are found to be above gound. All previous studies on tree-crop interactions in agroforestry parkland systems were based on cereal crop production under tree crowns (Rao *et al.*, 1998; Bayala *et al.*, 2002; Jonsson *et al.* 1999; Kessler, 1992). Thus, information in literature on the performance of shade-tolerant crops under parkland trees is scanty. The major aim of the present study was, therefore, to investigate the effect of Ber and Tamarind on the performance of both shade-tolerant and shade-intolerant food crops.

There are several food crops that perform very well under the shade of tree crowns in parklands. Root crops such as yam, sweet potato, cocoyam and cassava have been reported to associate well with trees (Teklehaimanot, 1997). There are also several indigenous shade tolerant vegetable crops such as African eggplants (*Solanum aethiopicum* L.) that are used widely in West Africa, although predominantly grown on a small scale in compound gardens, but could be grown successfully under crowns of parkland trees.

African eggplant (*Solanum aethiopicum* L.) is a member of the family of *Solanaceae.* It is found throughout the Savannah belt of West and East Africa. According to Horna and Gruère (2006), the African eggplant (also called Garden egg) is one of the most important vegetable crops in West Africa. It is not only consumed daily by rural and urban families, but it also represents the main source of income for many rural households in West Africa (Grubben and Denton, 2004, Owusu Ansah *et al.* 2001). It can be grown on a wide range of well-drained soils with pH between 5.5 and 6.8. The optimum temperature for the crop is 23-35°C. The solanaceous vegetable crops (tomato, eggplants, and peppers) generally take up large amounts of nutrients. However, the eggplant is very effective in making use of plant nutrients already present in the soil, whereas tomato and peppers are not (Fawzy *et al.*, 2007). Small scale growers account for at least 80% of the total production of eggplants in many countries of Africa (AVRDC, 2003). Farmers traditionally harvest the fruit before it becomes ripe. The immature fruits are used as a vegetable and consumed in various sauces. Fruits are sold in markets and can be sometimes eaten raw. Ripened fruits have a reddish colour and are usually kept for producing seeds. If fruits are left on the plants, seeds will develop and few new fruits will be formed (AVRDC, 2003). The leaves of eggplants are also used for cooking and it is very popular in many African cities. The fruit of eggplant has been reported to be rich in vitamin A (Sanaransy, 1995; Norman, 1974), calcium, iron, phosphorus, fibre and carbohydrate (Grubben *et al.* 2004; Norman, 1992, Horna *et al.,* 2006; Shei, 2008). Despite its importance, there are limited investigations in to the production of African eggplants. The potential of such a food crop to contribute to food security and poverty alleviation has not yet been fully exploited. Research and development in Africa still focus on cereal crops such as sorghum, millet, maize and rice. As a result, little is known about the nutritional value of most of shade tolerant crops including African eggplants. Studies were carried out in the present research to assess the performance of eggplant both in terms of yield and nutritional quality in comparison with the common non-shade tolerant sorghum when grown in association with Tamarind and Ber.

It is well known that the two targeted tree species *Ziziphus mauritiana* and *Tamarindus indica* form mutualistic symbioses with soil borne arbuscular mycorrhizal fungi (AMF) that have been proven to influence plant production and nutrient cycling, especially in stressed environments (Michelsen and Rosendahl, 1990; Carrenho et al., 2002, Guissou *et al.*, 1996). Consideration of the relative mycorrhizal dependency (RMD) of plants (the degree to which a plant responds to inoculation) is one of the most important factors determining the magnitude of benefits from improved management of abuscular mycorrhizal fungi (Azcon and Barea, 1997; Planchette et al., 1983, Bâ e*t al.*, 2000). Although many investigations have shown a great potential of these plant-fungal associations in the domestication of wild fruit trees in semi-arid environments (Antunes and Cardoso, 1991; Bâ *et al.*, 2000), there is a need to understand the impact of the diversity and management of AMF on the performance of the trees at farm level. Therefore, a study was conducted in the present research on *Ziziphus mauritiana* and *Tamarindus indica* by comparing different AMF-based treatments. An indigenous AMF strain and two strains of inoculants (*Glomus aggregatum* and *Glomus fiscia*) from commercial sources were tested to assess their effects on seedling growth of *Ziziphus mauritiana* and *Tamarindus indica.*

Soils under trees of agroforestry parkland systems have been reported to have superior fertility compared to soils in the open areas (Belsky *et al.*, 1989; Tomlinson *et al.*, 1995; Boffa, 1999). For example, Kater *et al.* (1992) and Bayala *et al.* (2002) found higher C, total P and K under *V. paradoxa* crowns than in the open. Higher N, P, K and Ca under crowns of *A. digitata* than in the open were also reported by Belsky *et al.* (1989). Several factors contribute to the higher fertility status of soils under tree crowns than in the open, the major one being litterfall from the trees (Belsky *et al.*, 1989; Tomlinson *et al.*, 1995; Boffa, 1999). Bayala *et al.* (2004) demonstrated that by pruning trees, which was done to reduce light interception by trees in order to enhance crop yield, and applying the pruned materials as mulch could enhance further the fertility of soils both under trees and in the open areas in parkland systems.

New approaches in elaborating strategies for improved agricultural productivity and sustainability are based on closer interactions with farmers. These approaches have been labelled the new 'integrated natural resource management paradigm' (Izac and Sanchez, 1999). It is based on the assumption that future increases in productivity will occur and be sustainable only if the research community is able to involve stakeholders in the research process. This research project was, therefore, entirely participatory involving local farmers.

1.2. Aims of the project and objectives

The specific objectives of present research project were:

1. To ellicit from local farmers their knowledge and practices on the use and management of agroforestry parkland systems.

2. A. To investigate the effect of *Tamarindus indica* (Tamarind) on yield and quality of intercropped African eggplant (*Solanum aethiopicum*) in comparison with sorghum (*Sorghum bicolour*);

B. To clarify and test the efficiency of using "tree tolerant" understorey crops in the semi arid areas of the study with respect to mature Tamarind;

3. To test methods of domesticating an improved cultivar of *Ziziphus mauritiana* (Ber) on farms through intercropping with African eggplant and sorghum;

4. To enhance the growth of *Ziziphus mauritiana* and *Tamarindus indica* seedlings through mycorrhizal inoculation;

Definitions:

- **Shade tolerance:** Wong (1991) defined shade tolerance agronomically as the relative growth performance of plants in shade compared to that in full sunlight as influenced by regular defoliation. It embodies the attributes of both dry matter (DM) productivity and persistence. Stür (1991) stated that shade tolerance is normally used to describe those species which grow relatively better than other species in shaded habitats, such as plantations. A common characteristic is that they are better able to maintain their yield with decreasing light than less shade-tolerant species.

- **Yield advantage:** The commonest measure of yield advantage was that there was an advantage in mixed cropping if the tree crop yield was unaffected and the yield from the understorey was comparable to an average for an area (Newman, 1985). The most appropriate index to evaluate yield advantage is the land equivalent ratio (LER).

- **Relative yield:** The relative yield in an intercropping system is expressed as a percentage and is equal to the intercrop yield divided by the sole crop yield (e.g. an intercrop currently yielding 2 t/ha with a sole crop yield of 4 t/ha would have a relative yield of 50%).

- **Land Equivalent Ratio:** The most appropriate index of yield advantage appears to be the land equivalence ration (LER).
  LER= yi/ys*a +yi/ys*b

Where:

yi = yield per unit area for intercrop

ys = yield per unit area for sole crop

a = crop a

b = crop b

According to Newman (1985), a value of 1.3 would indicate that 30% more land is needed to obtain the same yield in monoculture. One of the advantages of this index is that systems containing more than two crops can be analysed (Newman, 1985).

- **Tree effect or crop yield reduction:** Tree effect is expressed in percentage as ((subcanopy yield - open field control yield)/ open field control yield **X** 100

- **Harvest index of crops:** the harvest index is the ratio of grain weight to the total plant weight

1.3. Study areas

The study was conducted in two villages: Siramana and Sanankoroba (Figure 1.4). Both villages are located in the South Sudanian zone of Mali.

The Sudanian zone of Mali is characterized by an annual mean rainfall varying from 700 mm to 1200 mm. The vegetation is woody savannah with few scattered trees. The dominant trees are karité (Vitellaria *paradoxa*), néré (*Parkia biglobosa*), baobab (*Adansonia digitata*), tamarind (*Tamarindus indica*), Ber (*Ziziphus mauritiana*), oil palm (*Eleais guineensis*), sebe (*Borassus aethiopum)*, sanan (*Daniella oliverii*), sô (*Isoberlinia doka*), kolokolo (*Prosopis Africana)*, diala (*Khaya senegalensis)* and nguenou (*Pterocarpus erinaceus)*.

According to Young (1976) and Hoefsloot et al. (1993), soils that are the most characteristic of West African Sudanian zone are Ferric luvisols (FAO soil classification) or Alfisols (US soil taxonomy). Pieri (1989) and Young (1976) reported that soils in this zone have low CEC and pH is normally >5.5. The structural properties of these soils are poor which explains their sensitivity to degradation. Soil organic matter content is very low and varies from 1% to 3% under natural vegetation and drops rapidly to 0.5- 1% after putting the land into cultivation (Jones, 1973).

In the South Sudanian zone, the farming system is a combination of traditional practices and modern farming techniques which have not been well adopted. Thus, crop production level is very low and a subsistence economy still persists. Maize and sorghum are the main food crops cultivated. Millet is cultivated to a lesser extent. Rice is cultivated in river plains and in valleys. Minor crops cultivated include peanuts, beans, eggplants, hot peppers, okra, sweet potatoes, yam and cassava. Most of these crops are cultivated manually. There is a very small fraction of land under cotton cultivation as oxen traction has not yet been fully adopted (Hoefsloot et al., 1993).

Compared to the North, the ecosystem stability of the South Sudanian zone is not threatened (Hoefsloot *et al.* (1993). Many villages have large areas in fallow and shifting cultivation can still be found. But this trend is changing due to the overexploitation of trees for charcoal production for town consumption. This overexploitation of trees has expanded over the past years and will continue to do so.

The study on intercropping of Tamarind was conducted in Siramana village while the domestication of the improved cultivar of Ber was carried out in Sanankoroba village. Sanankoroba was chosen for the domestication study because of its proximity to Bamako, because the domestication study required intensive follow-up of fieldwork activities.

1.3.1. Siramana

Siramana is a village situated 140 km from Bamako, located at an altitude of 354 m above sea level, at 11°77' N latitude and 8°12' W longitude. It is situated in the south Sudanian zone where the annual rainfall lies between 1100 and 1200 mm. It belongs to the commune of Tiakadougou Dialakoro which is situated in the Koulikoro region.

Four (4) types of soils were identified in Siramana according to the FAO-UNESCO system of classification (PIRT, 1987):

1) Cuirustults: This extensive unit of soil occupies eroded, laterite slopes, almost flat to moderately steep in the sub-humid moist zone of the study area. Parent material is essentially laterite colluviums. Soils are often reddish in color, gravely, and moderately deep to cuirasses; gravels and laterite blocks frequently litter the surface. The soils support a dense vegetation of medium trees, large shrubs and perennial grasses. Even on steep slopes the unit is cultivated for millet, sorghum and peanuts; otherwise, the unit is used for pasture.

2) Mollic Cuirorthents: This very extensive unit occupies eroded, laterized surfaces, flat to gently sloping, in the sub-humid and humid zones of the study area. The soil is very gravely and very shallow to cuirasses, generally well drained and often high in organic matter. Gravels and laterite blocks frequently litter the surface. Moderately dense patches of small trees and large shrubs are scattered throughout the unit. Burning grasses after the rainy season leave a large to extremely large bare gravelly surface. Though the unit primarily is used for pasture, some flatter portions in the south are infrequently used for rice production.

3) Petroferric Haplustults: This unit occupies flat to gently sloping laterized surfaces covered with a sandy alluvium and colluviums. In the humid zone of the high Bani-Niger (granites region), soils are medium to moderately fine textured and are moderately deep to shallow over hard laterite. They are generally cultivated, with a long fallow period, mainly for millet, sorghum, maize and peanuts but sometimes for tubers and other minor crops. Where not cultivated, the units support a moderately open vegetation of medium trees, large shrubs and perennial grasses.

4) Oxic Haplustults: On moderately well drained plains and valley bottoms throughout the sub-humid zone of the country, this unit is widespread and extensive. The unit is usually gently sloping and often occupies the outer areas of alluvial plains in association with units. Elsewhere it may be the main constituent of a valley floor or plain where drainage is adequate, as in the case of a narrow valley with a well-developed stream. The soils are normally deep and moderately fine textured, well drained and yellowish red in colour in at least the upper part of the profile to 75 cm. The lower part of the profile is often imperfectly drained with hydromorphic mottling. In general, the soils of this unit have the highest potential for rainfed agriculture. They are normally under continuous or short rotation cultivation for a wide range of crops. The general aspect of this landscape is gently sloping cultivated plains with scattered

trees (especially *Vitellaria paradoxa, Parkia biglobosa, Tamarindus indica*). Fallow areas support a wide variety of large shrubs.

Figure 1.1 shows the maximum and minimum temperatures at Bougouni weather station between 1991 and 2000. Bougouni is a town situated in the south Sudanian zone and the weather station is representative of the two study sites. The temperature is characteristic of south Sudanian climate where the minimum are observed in December and January (15- 16 °C) and the maximum in April and May (37- 38°C).

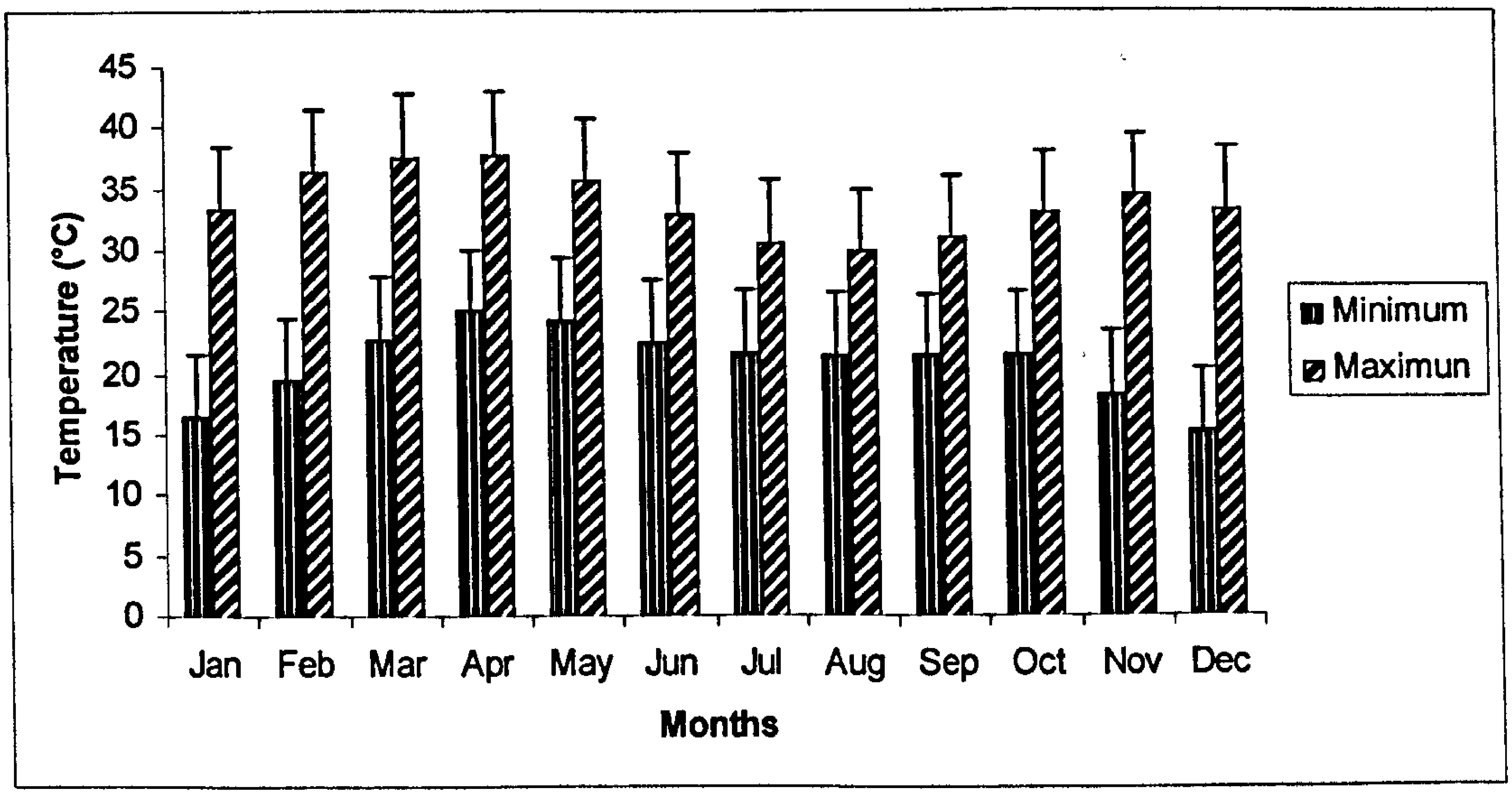


Figure 1.1: Maximum and minimum temperatures in Bougouni from 1991 to 2000

In Figure 1.2, the monthly rainfall in Siramana in 2007 and 2008 is shown. The rainfall is uni-modal with the mean annual rainfall of about 1197 mm.

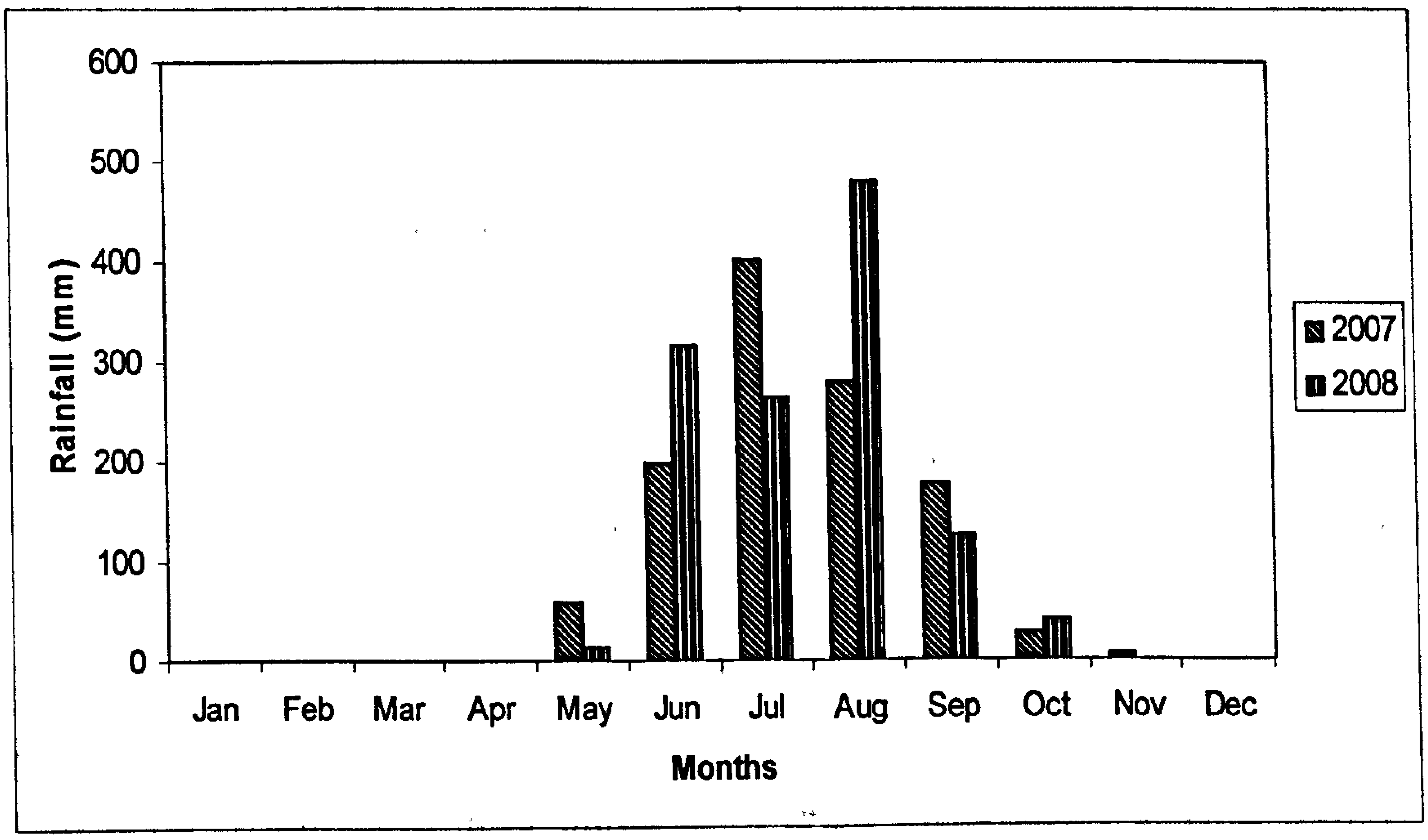


Figure 1.2: Monthly rainfall in Bougouni (Siramana) in 2007 and 2008

Majority of the population of Siramana is the Bambara ethnic group but some other ethnic groups including Malinké, Peulh and Dogon are also found. Agriculture is by far the main activity, but hunting, gathering, vegetable gardening, sedentary animal husbandry and apiculture are also practiced. In this village and surrounding areas, cutting of trees for charcoal production is a lucrative activity; the environmental degradation it causes is overlooked by the immediate financial return. The most cultivated food crops are maize, sorghum and millet. The cash crop cultivated in the village is mainly cotton. But this practice is declining due to the cotton crisis in Mali (privatisation of the sector). The minor crops cultivated in the area are: peanut, beans, okra, African eggplants and pepper. Livestock is composed of cattle, sheep, goats and donkey. Women collect seasonally shea, néré, tamarind and Ber fruits for home consumption and for sale in local markets. All these fruits are either eaten raw or processed into other products such as butter from shea fruit and soumbala from néré fruit.

1.3.2. Sanankoroba

Sanankoroba is a village situated in the south Sudanian zone at 35 km from Bamako, capital of Mali. It is located at an altitude of 364 m above sea level, at 12°38' N latitude and 7°92' W longitude. The annual rainfall lies between 1000 and 1100 mm. Sanankoroba is a commune situated in Koulikoro region.

Among the four (4) soil types identified in Siramana, three (3) are present in Sanankoroba. The only difference is that the Petroferric Haplustults is replaced by the Plinthic Haplustalfs in Sanankoroba. Plinthic Haplustalfs is mostly found on flat alluvial plains, and forms a total of 2.2 % of the study area. The soils of this unit are developed in moderately fine textured alluvium and are characterized by imperfect drainage and the presence of plinthite concretions, usually along with hydromorphic mottles in the lower horizons. The unit is often under fairly continuous cultivation, with a flat visual appearance. Cultivated areas have a light gray surface and scattered large trees (mainly *Vitellaria paradoxa, Parkia biglobosa, Daniellia oliveri* and *Tamarindus indica*).

In Figure 1.3, the monthly rainfall in Sanankoroba in 2007 and 2008 is shown. The rainfall is uni-modal with the mean annual rainfall of about 988 mm.

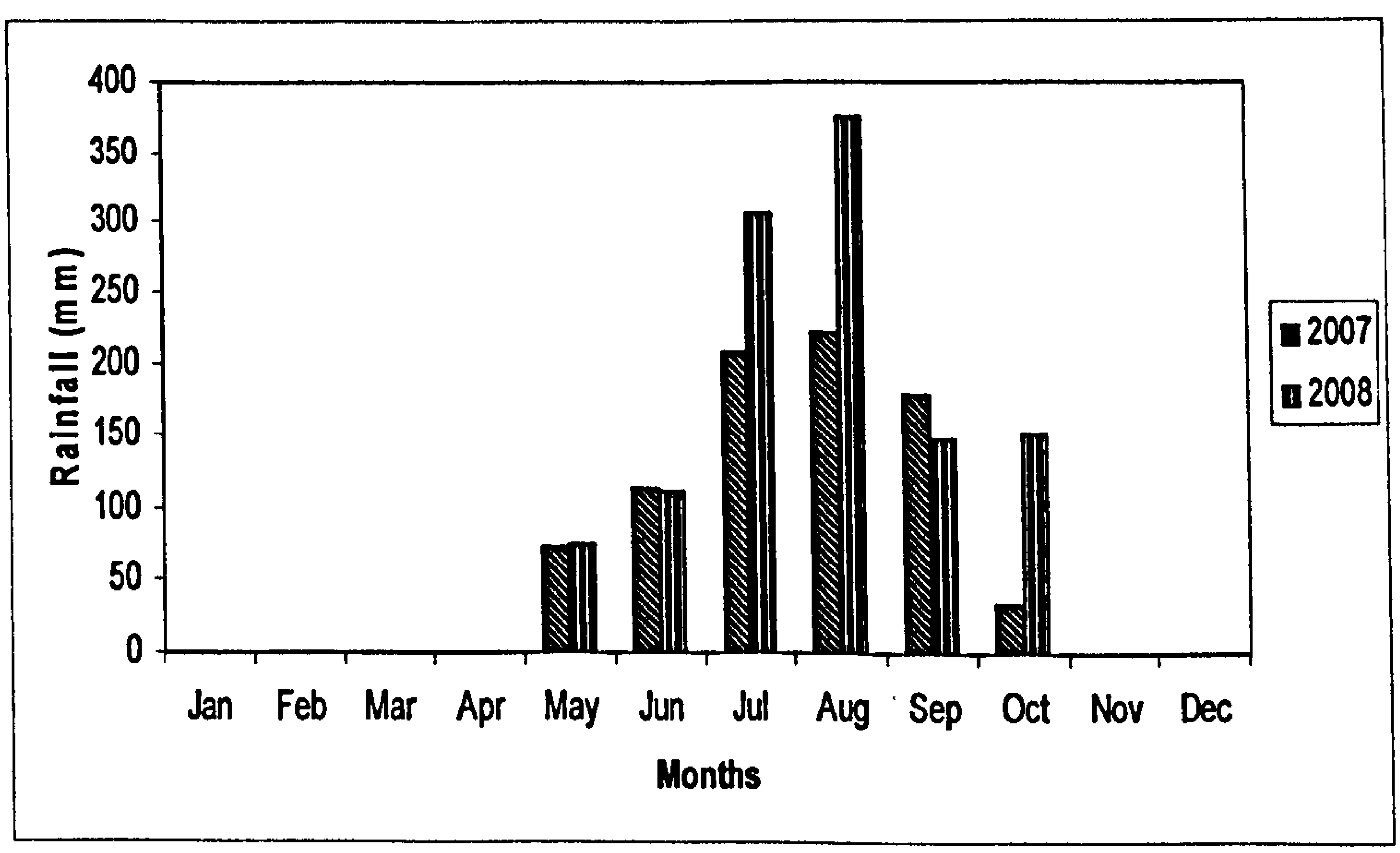


Figure 1.3: Monthly rainfall in Bamako-Senou (Sanankoroba) in 2007 and 2008

The population of Sanankoroba village is also predominantly of Bamanan ethnic group but some other ethnic groups such as Peulh, Malinke, Soninke, Sonrhai and Dogon are also found. The population is estimated at 33,060 inhabitants. Agriculture is the main activity, but gathering, vegetable gardening, sedentary animal husbandry and apiculture are also practiced. A few traders, handcrafters and government employees are present in the village. Due to its proximity to Bamako, the village is expanding; therefore many economic activities are being developed. The most cultivated food crops are maize, sorghum, millet. The minor crops are peanut, beans, okra, African eggplants and pepper. Livestock in this village is composed of cattle, sheep, goats and donkey. Women seasonally collect shea, néré, tamarind and Ber fruits for home consumption and for sale in local markets. In recent years, a decrease in soil fertility has reduced agricultural production and increased food insecurity (OHVN, 1996).

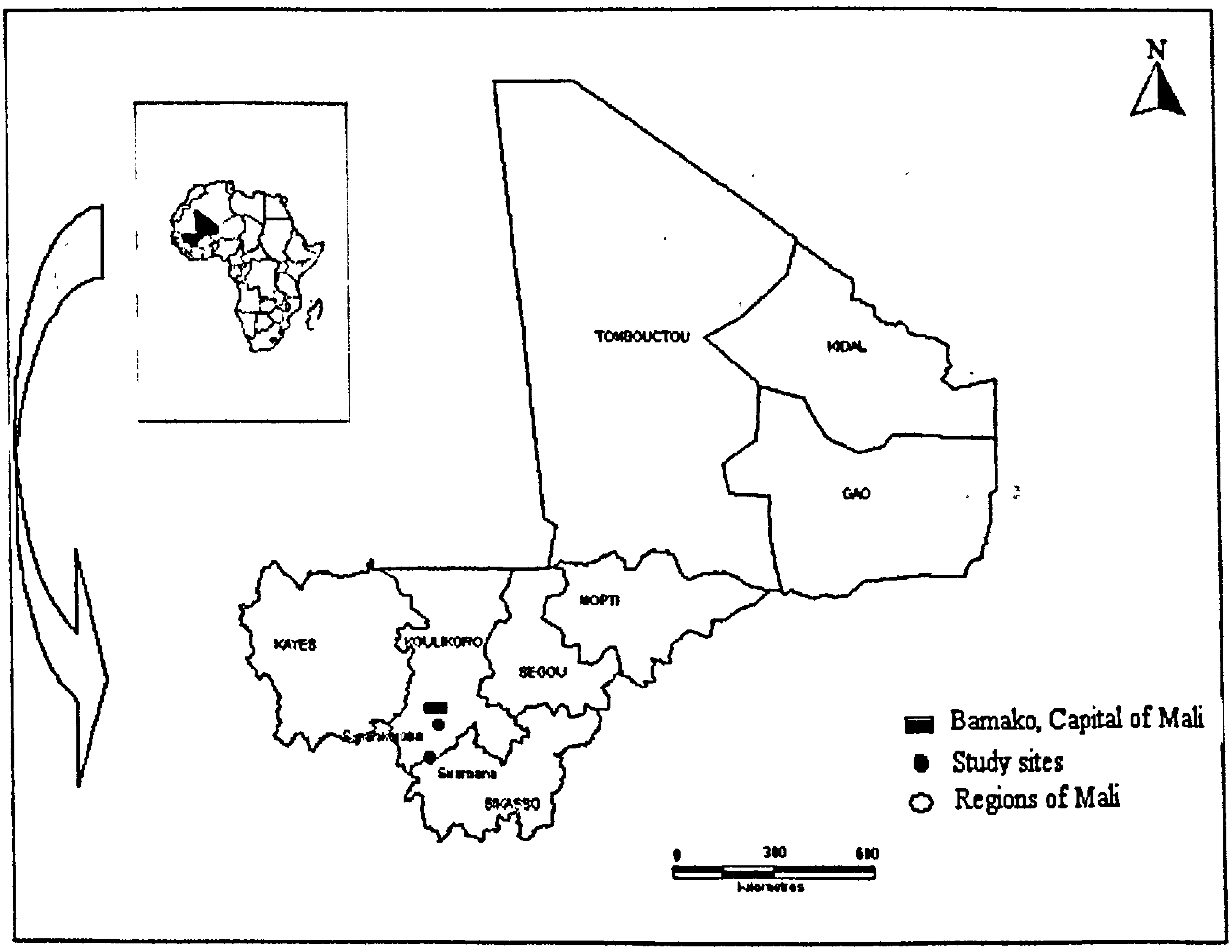


Figure 1.4: Location of the study sites (Sanankoroba is situated near Bamako and Siramana is situated south of Bamako).

1.3. Thesis structure

This thesis has seven (7) chapters. Chapter 1 presents this introduction and description of the study sites. Chapter 2 concerns the review of literature on parklands systems and consists of 4 subchapters. Subchapter 2.1 presents the contradiction between modern agriculture and agroforestry parkland systems. In subchapter 2.2, a description of agroforestry parkland systems is given. Subchapter 2.3 describes the different types of agroforestry parkland systems and subchapter 2.4 presents tree-crop interactions in agroforestry parkland systems. In this last subchapter (2.4), the following aspects have been reviewed: 1) effect of trees on light, 2) effect of trees on soil fertility, 3) effect of trees on water balance, 4) the effect of tree-crop interactions on crop yield, 5) the effect of trees on the nutritive quality of crops, 6 the trade-offs between crop productivity, tree products, and environmental functions and 7) the management options to minimise tree-crop competition for resources. Chapter 3 reports the base line survey carried out to illicit farmer's knowledge on use and management of agroforestry parkland systems. Chapter 4 presents the study of the Tamarind intercropping experiment carried out in Siramana village and consists of four subchapters. Subchapter 4.1 is an introduction to the intercropping of tamarind with shade-tolerant and shade-intolerant crops. In subchapter 4.2, the materials and methods are presented. Subchapters 4.3 and 4.4 concern the results and discussion. Chapter 5, which deals with the trial on domesticating of Ber in Sanankoroba village through grafting and intercropping, is divided into four subchapters. Subchapters 5.1, 5.2, 5.3 and 5.4 present the introduction, the material and methods, the results and the discussion, respectively. Chapter 6, which is concerned with enhancing the productivity of Ber and tamarind through mycorrhizal inoculation, is also divided in four subchapters. Chapter 6.1 is an introduction whilst subchapter 6.2, 6.3, 6.4 are the material and methods, the results from these studies, and the discussion, respectively. Chapter 7 is a general discussion on all the results of the different chapters and presents general conclusions and recommendations of the present research.

CHAPTER II:

LITERATURE REVIEW

2.1. Agroforestry parkland systems vs. modern agriculture

The first agricultural scientific bodies were based on mono-crop cultivation which is called modern agriculture. Farmers were encouraged to cut down trees on their farmlands when they had to practice modern agriculture, where trees did not have any place (Boffa, 1999, Gumbo *et al.*, 1990). This has been the basis of Western agriculture for a long time and was also considered appropriate for the less developed countries, which did not have any choice but to accept what was considered more productive than many traditional agricultural practices (Agraval, 2004). Despite the spread of modern agriculture, many traditional practices still exist in different parts of the world. One good example is the traditional agroforestry parkland systems of West Africa. When farmers were persuaded by extension agents to adopt modern mono-crop agriculture, they always used to say 'we have been practicing this for a long time, our fathers and grandfathers used to do so, and we inherited this from them; we know how literate you are but you cannot make us abandon our traditional practice' (Personal Experience). This explains why farmers continue practicing agroforestry parkland systems in West Africa. Farmers, for a long time, knew the role of trees on their farmlands. They knew the ecological, social and economic role of each tree species on their land and that is why they kept them (Ong *et al.*, 1999; Jama *et al.*, 2008; Louise, 1990). For this reason, the role of agroforestry researchers is nowadays focused on describing the multipurpose functions of trees and exploring options for their sustainable management in agroforestry parkland systems (Nair, 1987).

2.2. Description of agroforestry parkland systems

The agroforestry parkland system is an old and traditional cropland management system where scattered trees are left permanently in the field after clearing the original savannah woodland to cropland (Bayala, 2002; Nair, 1993). This agroforestry system has been functioning throughout sub-Saharan Africa for centuries (Ong and Leaky, 1999; Nair, 1987; Baumer, 1994; Boffa, 1999; Samba *et al.*, 2001). According to Nair (1993), agroforestry parkland systems are one of the most widespread traditional land use systems in Africa.

Wild multipurpose trees are retained on farmlands because they provide valuable products and services for farmers. Most of the trees in parkland systems yield marketable non-wood products both for local and international markets (Teklehaimanot, 2004; Boffa, 1999; Leaky and Simons, 1998; Jama *et al.*, 2008). Parkland trees are important sources of food and nutritional security, producing fruits, oils, leaves, nuts and spices that are main components of local people's diets (Bonkoungou *et al.* 1998, Bayala *et al.* 2002, Teklehaimanot, 2004). Trees are providers of wood for domestic use and also feed for livestock (Teklehaimanot, 2004; Bonkoungou *et al.*, 1998). Trees can reduce wind erosion during periods of drought and control water erosion during the rainy season (Bonkoungou *et al.* 1998). Ecological functions, such as microclimate and soil fertility ameliorations of parkland trees, are well recognized (Bayala *et al.* 2002; Boffa, 1999; Leaky and Simons, 1998; Teklehaimanot, 2004; Jose, 2009).

The coexistence of woody plants, pastures and crops in parklands is currently of great scientific interest due to the rate at which relative tree abundance is declining by human interference especially through the use of fire, grazing and bush clearing to create more crop fields (Bayala *et al.* 2007). Knowledge about the diversity of the plant species that occur in the different types of parkland systems and their respective functions is indispensable for scientifically documenting this threatened traditional system and also for enrichment and rehabilitation purposes.

2.3. Types of agroforestry parkland systems

There are many types of agroforestry parkland system in West Africa. The use or management of parklands depends upon their type, which is related to the type of soil, the climate, the farming systems adopted by farmers and the dominant tree species retained.

Table 2.1.Types of parklands found in the Dori region in Burkina Faso with an annual rainfall of 300-400 mm

Parkland type	% of total area
Faidherbia albida	30
Faidherbia albida- Hyphaene thebaica	25
Balanites aegyptiaca	15
Hyphaene thebaica- Balanites aegyptiaca	10
Hyphaene thebaica	8
Others	12

Source: Bonkoungou et al. (1998)

Table 2.2. Types of parklands in the middle Bani-Niger River basin with an annual rainfall of 700-800 mm

Parkland type	% of total area
Vitellaria paradoxa	27.04
Sclerocarya birrea- Vitellaria paradoxa	26.39
Borassus aethiopum	9.43
Sclerocarya birrea-Prosopis africana	7.67
Vitellaria paradoxa-Adansonia digitata	7.14
Faidherbia albida	6.4
Vitellaria paradoxa-Prosopis africana	4.07
Vitellaria paradoxa- Faidherbia albida	3.06
Prosopis africana	2.48
Faidherbia albida- Adansonia digitata	1.56
Adansonia digitata	1.4
Adansonia digitata- Prosopis africana	1.01
Combretum micranthum/ghazalense-Prosopis africana	0.79
Parkia biglobosa- Terminalia avicenioides	0.62
Adansonia digitata- Sclerocarya birrea	0.55
Borassus aethiopum-Hyphaene thebaica	0.22
Pterocarpus erinaceus- Faidherbia albida	0.1
Faidherbia albida- Hyphaene thebaica	0.07

Source: Bonkoungou *et al.* (1998)

The dominant tree species and the climate have, however, been used as the main basis for classification. According to ICRAF scientists (Bonkoungou *et al.* 1998), five types of parklands have been identified in places where mean annual rainfall is between 300 and 400 mm, and 18 types in places where mean rainfall is between 700 and 800 mm. The parklands are named after the dominant tree species as shown in Tables 2.1 & 2.2.
The dominant tree species and the climate have, however, been used as the main basis for classification. According to ICRAF scientists (Bonkoungou *et al.* 1998), five types of parklands have been identified in places where mean annual rainfall is between 300 and 400 mm, and 18 types in places where mean rainfall is between 700 and 800 mm. The parklands are named after the dominant tree species as shown in Tables 2.1 & 2.2.

Baumer (1998) used another approach for classifying agroforestry parkland systems. He suggested that parkland may be residual, selected or constructed based on the number of species present in the parkland and the degree of human selection. Residual parks resulted from the elimination by farmers of non-desired species and enrichment of useful species already present on the land. In constructed parklands, the selection is very high, well thought-out and elaborated; the number of species could be limited even to one species. Selected parklands are intermediate between residual and constructed and have less number of species compared to residual parklands. Baumer argued that the concept of parkland should be applied only to a stand of trees or by extension to shrubs based on a strong selective influence of farmers in the choice of few species having the following characteristics:

- Dominant trees having discontinued strata;
- Trees having open canopies;
- Trees having a positive ecological function on soil fertility,
- Trees having an important economical function for human nutrition or fodder for animals;
- Soil cultivated under trees;
- Soil used as pasture after crop harvesting.

The parkland systems found in the Sahelo- Sudanian zone according to Baumer are:

- Parklands of *Vitellaria paradoxa*;
- Parklands of *Faidherbia albida*;
- Parklands of *Parkia biglobosa;*

- Parklands of *Borassus aethiopum*; and
- Parklands of *Elaeis guineensis.*

Agroforestry parklands are generally dominated by few species, but they also contain a wide range of other species depending on the pre-existing vegetation, the needs of farmers, and local ethnic groups' knowledge of the uses of these species (Boffa, 1995; Bayala, 2002; Samba *et al.*, 2001). For example, Samba *et al.*, (2001) conducted studies on *Cordyla pinnata* parkland in Senegal. He found that the parkland contained 687 trees of 38 different species where four species accounted for over 80% of the total. *C. pinnata* [(A. Rich.) Milne-Redh] was the dominant tree species (60%), followed by *Lannea acida* (A. Rich.) (12%), *Anogeissus leiocarpus* [(DC.) Guill. Perrot.] (6%) and *Tamarindus indica* (L.) (2.5%).

Identification of parkland types according to soil is also of great importance but research in this field is scarce. Currently agroforestry researchers are just analysing soils at the field or station level but large-scale soil studies are very expensive and therefore are not yet well-documented in parkland systems.

Although the advantages of parkland systems are numerous, strong competition has been observed between trees and annual crops, which reduce crop yields significantly (Sanchez, 1995; Kater *et al.* 1992; Bayala, 2002; Lehmann *et al.*, 1998; Kessler and Breman, 1991). The competition for light, nutrients and water and the positive microclimate improvement and the buffering ability of trees have been well elucidated by previous workers (Kater *et al.* 1992; Bayala, 2002; Lehmann *et al.*, 1998; Kessler and Breman, 1991)

2.4. Tree-crop interactions in agroforestry parkland systems

Interaction is defined as the effect of one component of a system on the performance of another component and/or the overall system (Nair, 1993; Rao *et al.*, 1998).

One of the objectives of tree-crop interaction studies is to find out how agroforestry can improve the efficiency with which existing land and water are used and how to reach sustainable production and resource use. Exploitation of interactions between woody and non-woody components is the key to the success of all agroforestry systems (Rao *et al.* (1998). Quantifying the magnitude of interactions over a range of species, soil, management and climatic conditions will help determine the biophysical limits of the system (Rao *et al.* (1998). Rao *et al.* (1998) have stated that the interaction effect (I) on crop yields in the two major groups of AF systems can be expressed as follows:

Simultaneous systems: I = F+C+M+P+L+A and

Sequential systems: I = F+M+P+L+A

Where soil fertility (F) includes soil chemical , soil physical and soil biological interactions; competition (C) includes competitive interactions for soil water , soil nutrient and radiation ; microclimate (M), pest and diseases (P) includes interactions related to weeds , insects and diseases , soil conservation (L) and allelopathy (A).

The absence of (C) in sequential systems constitutes an important difference between the two groups of Agroforestry systems.

This literature review focuses on the parkland system which is a simultaneous agroforestry system with scattered or dispersed trees in croplands. Farmers' objectives for maintaining trees in these systems are to provide products such as fodder, fruits, and leaves as vegetables, poles and fuel wood and to reduce famine risks.

In parkland systems, according to Louppe *et al.*, (1996); Rao *et al.* (1998) and Bayala (2002) three interaction zones can be found:

1. A zone under tree crown where light and root competition occur;
2. A zone beyond the tree crown where root competition predominates;
3. Open cropped areas that are relatively free from the competition of trees.

An understanding of the functioning of these zones could help to determine the maximum tree density, to develop appropriate pruning regimes in order to maximise resource use and productivity of the systems.

Trees improve soil fertility and modify the microclimate under their canopies. These effects depend on tree species, root characteristics, age and size of trees which in turn depend on soil and climatic conditions. The overall productivity of parkland systems according to Rao *et al.*, (1998) depends on: (1) the complementarity of resource use by trees exploiting zones which cannot be reached by crops, (2) the efficiency of nutrient cycling and (3) the net value of tree products compared to the net value of crop loss. It is also important to bear in mind that most of the trees left in parklands have products that reduce farmers' risks in drought periods when crops fail. The flour of néré (*Parkia biglobosa*) and baobab (*Adansonia digitata*) fruit and leaves of baobab constitute substantial meals during famine in semiarid zones of Africa (Teklehaimanot, 2004).

The main tree-soil-crop interactions that affect crop yield in parkland systems are related to soil fertility (chemical, biological and physical), water balance and microclimate, especially light.

2.4.1. Effect of trees on light

It is assumed that competition for light is a main limiting factor for crops under tree canopies and that competition for water and nutrients could be the major factor beyond the crown (Rao *et al.*, 1998). Competition for light is likely to be a problem under large trees such as néré and Karité (*Vitellaria paradoxa*). Kessler (1992) reported that photosynthetic active radiation (PAR) transmission increased from 43% near the base of trees to 90% outside their crown. This light reduction under the canopy of big trees could cause a crop reduction up to 50%. The light reduction under tree crowns is species-specific and it is very much important for tree species with large and deep canopies with many leaves. Light competition is moderate for tree species with a small crown diameter or open canopies with less leaves.

The results of a study conducted by Bayala *et al.* (2002) on crown pruning showed that total pruned trees gave the highest millet production due to the reduction of the effects of large tree crowns on PAR transmission below crowns. They observed a reduction of 47% and 38% of the incident PAR under karité and néré, respectively. The study also shows that PAR under total-pruned karité and néré was reduced by up to 70% and 62% of the incident PAR, respectively. The PAR also increases from the base of trees to the outside and was 29%, 52% and 70% of the incident PAR respectively under Zone A (from the base to middle of the tree crown, B (from middle to the edge of the crown) and C (from the edge to 3 m away). The findings of Bayala *et al.* (2002) are in accordance with other workers like Jonsson *et al.* (1999) who reported a reduction of PAR to 24% of incident PAR under unpruned crowns of both karité and néré. These findings support the hypothesis that the reduction of crop production under trees crowns is correlated with reduced light intensity.

Competition for light is unlikely to be a major problem under the following tree species in agroforestry parkland systems:

- *Faidherbia albida* because of its reverse leaf phenology (The tree is in leaf during the dry season and defoliated during the rainy season, then competition with associated crops growing during the wet season is minimized);
- *Prosopis africana, Pterocarpus erinaceus, Pterocarpus lucens* because of heavy lopping of these species for feeding animals;
- *Tamarindus indica* because of lopping branches for harvesting fruits in some parts of Mali.

2.4.2. Effect of trees on water balance

Under certain conditions, trees improve microclimate under their canopies through the reduction of air temperature, irradiation, soil erosion and wind speed. These changes will positively affect soil water evaporation and humidity, which in turn could influence crop growth. Vandenbeldt and Williams (1992) reported that Faidherbia trees in the Sahel lowered soil temperature at 2 cm depth by 5° to 10°C depending on the movement of the tree shade. A reduction of 10°C in soil temperature can highly reduce the detrimental effect of high temperature on crop establishment, mostly in arid and semiarid areas where soil temperature can reach up to 50- 60°C at the beginning of rainy season. In the dry season in the arid regions, trees shade is the best, or the only shelter for humans and animals in daytime because the air temperature can reach up to 45°C in open areas and 35- 40°C in the shade. The reduction of temperature under the tree crown area depends on the size of trees. A study in Burkina Faso showed that top soil temperature under big trees (néré and karité) was lower than that of small trees (Jonsson *et al.*, 1997). Tree canopies lowered the wind speed, particularly in the later part of season, which is dominated by the desiccating Harmattan winds (Jonsson *et al.*, 1997; Rao *et al.*, 1998). The dryness of the atmosphere measured as vapour saturation deficit is closely related to temperature, since it increases when temperature is increased and /or when relative humidity is decreased. According to Sharkey (1984) and Sands and Mulligan (1990), plants are known to be less productive when vapour saturation is increased, because of its effect on assimilation rate via stomatal conductance. Soil water deficit is also a parameter which controls plant growth (Sands and Mulligan, 1990). Rook *et al.*, (1977) found that stem diameter and root growth of radiata pine were reduced by soil water deficit before transpiration and photosynthesis were affected. At greater soil water deficits, photosynthesis and other processes are directly inhibited and assimilation is also reduced due to stomatal closure (Sands and Mulligan, 1990). Sands and Mulligan (1990) reported that many studies show that fertilization is most effective when trees are not water-stressed, and that irrigation is most effective when nutrients are not scarce. In other words, roots in nutrient-deficient soil will be less efficient at water uptake because of reduced root hydraulic conductivity, and roots in dry soil will have reduced rate of nutrient uptake. This shows the strong relationship between nutrients and water.

Lal (1991) and Breman (1997) have reported that degraded lands in sub-Saharan Africa are often unproductive because of nutrient imbalance and inadequate water supply. The soil water-holding capacity is closely linked to its structure, texture and organic matter content (Hillel, 1980; Zougmoré *et al.*, 2004). Ouédrago *et al.*, (2001), stated that soil organic matter (SOM) improves the soil structure and then affect its water reserve. Trees are the main source of SOM in parkland agroforestry systems in West Africa since crop residues are removed from the fields. Therefore, maintaining trees means maintaining SOM which affects water reserves and this is a key component of sustainable land use management in arid and semi-arid zones of West Africa.

Some researchers (Cannell *et al.* (1996) argue that agroforestry may increase productivity provided that the tree captures resources which are not utilized by annual crops. In annual, unimodal rainfall systems like in the Sahel region, the remaining water in the soil after harvest and off-season rainfall are often unused, particularly in bare lands. The hypothesis that agroforestry may increase productivity by capturing a larger proportion of the rainfall was supported in a study by Ong *et al.*, (1992) which demonstrates that a maximum of 40% of the annual rainfall is utilised by the most effective cropping systems and the remaining water is lost as run-off (26%) or deep drainage (33%).

Water use by plants is determined by measuring their transpiration rates. Transpiration has been measured on a wide number of species in parklands. The results showed that when rainfall is below average, maize yields were negatively correlated with the amount of water transpired by the trees. Crop failures were observed when tree transpiration exceeded 100 mm (Anon, 1997).

It has also been reported that where groundwater is accessible, tree roots can take up water from moist zones of soil, transport it through the root system and release it into drier soil (Dawson, 1993, Ong *et al.*, 1992; Kizito *et al.*, 2007). Therefore, the temporal and spatial complementarity of agroforestry in areas where significant rainfall occurs outside the normal cropping seasons is important because they compensate for competition for other resources. Studies done by Kizito *et al.*, (2007) on soil water balance of annual crop-native shrub systems in Senegal, revealed higher soil moisture storage in crop-shrub treatments than in sole crop plots in the upper portion of the soil profile. The shrub species studied were *Guiera senegalensis* and *Piliostigma reticulatum* and the associated crop was Pearl millet (*Pennissetum glaucum*). They also found lower soil moisture storage in crop-shrub plots than in sole crops in deeper soil profiles. These two findings according to Kizito *et al.*, (2007) underline the high level of complementarity of water use in crop-shrub associations. .

In semi-arid and sub-humid climates, competition for water is considered to be far more than that of nutrients (Rao *et al.* 1998). However, Samba (1997) found that light appeared to be a more important environmental limitation for crop growth in *C. pinnata* parklands than water. Studies conducted for three years under eight karité trees in two different sites (four trees each site) in a sub-humid climate in Mali showed that in high rainfall years (rainfall above 1100 mm), sorghum yield under tree canopies was higher than that of the open areas. But the reverse is observed in low rainfall years i.e. sorghum yield is higher in open areas and very low under the tree canopy (INCO-competition, unpublished data). These results highlight the importance of the competition for water as stated by Rao *et al.* (1998). Therefore, studies that separate competition between trees for water from that for nutrients are needed for better understanding of the competition systems.

The benefit of deep-rooted vegetation for maintaining ecosystem functioning is a major attraction for using agroforestry for sustainable land and water management in areas where high energy input, large-scale agriculture is impractical (Kidd and Pimental, 1992). Deans *et al.* (1995) have reported that in the Sahel, removal of vegetation with deep roots has led to increased drainage from 10-20 to 200-300 mm per year and the leaching of nitrate to the water table. Rockstrom (1997) also reported that in the sandy soil of Niger, unfertilized millet fields utilise only 6-16% of the total rainfall in a watershed and the remainder is lost as run-off, drainage or through soil evaporation.

The hydrological impact of fast-growing exotic trees has caused concern to local peoples in many tropical countries in semi-arid regions (Ong and Leaky, 1999). One good example which illustrates this statement is the controversy around Eucalyptus trees. This species have been reported not only to extract all the rain that enters in the soil, but to uptake an additional 100 mm of water from each metre that the roots penetrate. Deans *et al.* (1995) reported that roots of mature scattered trees in the Sahel can even reach the water table at 30 m. This is why Ong and Leaky (1999) have suggested that it is important to consider the implication of increased water use on medium and long term water budget, when planting trees in association with crops in dryland agroforestry systems.

Studies done by Bayala et al., (2008) on five year old shea butter tree plantations gave an idea of tree water use, where transpiration rates of 2. 70 l day $^{-1}$ tree $^{-1}$ in 2004 and 2.85 l day $^{-1}$ tree $^{-1}$ in 2005 were reported. Further research is required on transpiration rates for larger more mature trees.

Tree canopies can intercept rainfall. Some of the intercepted water is lost through evaporation and the remainder is distributed to the soil under the canopy through stemflow and throughfall. According to Breman and Kessler (1995), on an annual basis, individual trees may account for 10% to 15% loss of rainfall in the tropics. However, it is also important to notice the positive effect of tree canopies in soil water evaporation reduction and moreover, Wallace *et al.* (1997) stated that the reduction in soil evaporation under tree canopies could be sufficient to offset the increased losses due to canopy interception.

Rainfall interception studies in West African parkland systems are scarce and this is why Samba *et al.*, (2001) stated that in their knowledge, there have been no published studies on rainfall interception in the semi-arid agroforestry parklands of West Africa. Climatic factors (evaporative capacity of the air) and the structural characteristics of the vegetation (stand age, density and developmental stage) influence the amount of rainfall intercepted by an ecosystem (Samba *et al.*, 2001; Plamondon *et al.*, 1984; Viville *et al.*, 1993; Aussenac *et al.*, 1982). Canopy storage capacity has been found by many authors to be a key factor controlling rainfall interception and different methods have been developed to estimate it (Aussenac, 1968, Jackson, 1975; Negi *et al.*, 1993). Samba *et al.* (2001) found that the rainfall interception of *Cordyla pinnata* is 22%. According to them, their findings are consistent with those of Ghunan and Lal (1987) in Nigeria who reported 22 and 23% during 1984 and 1985 respectively. In Malaysia, Manokoran (1980) found rainfall interception of 22% for a broad-leaved tropical tree species. Stemflow which is the proportion of rainfall intercepted by the canopy that flows along branches and the trunks before reaching the ground, is a very important parameter that have been rarely estimated in interception studies in West Africa (an example is Samba's work in Senegal, 2001).

2.4.3. Effect of trees on soil fertility

In parkland systems, soil fertility (Physical, biological and chemical) gradients around trees have been attributed by some authors to *a priori* differences in fertility, implying for better tree establishment on richer sites (Geiger *et al.*, 1994). In contrast, other researchers believe that these gradients are due to the contribution of trees to the formation of soil organic matter (SOM) content through litter and root decay (Bayala *et al.*, 2007). These two hypotheses are not mutually exclusive in parkland systems in Africa, since even if it is difficult for trees to grow on infertile soils, it is more difficult to restore soil fertility in a sustainable manner without trees.

According to Ingram (1990), soil fertility can be defined as the capacity of the soil to support plant growth. Thus, soil physical, chemical and biological properties all contribute to soil fertility and should be equally considered in fertility assessment.

Much research has been done on soil fertility in parkland systems. Most have reported improved soil fertility in terms of SOM, extractable P, and exchangeable cations under trees compared with treeless areas. Among these studies, we can notice that *Faidherbia albida* have drawn attentions of many researchers because of its reserve phenology (Kamara and Haque, 1992; Charreau and Vidal, 1965; Dancette and Poulain, 1969). Depommier *et al.*, 1992 have done studies on four *Faidherbia albida* parklands and found that soil under trees had higher nutrient status than soil in open areas: 14% to 100% more organic C and 13% to 117% more organic N. A significant increase was observed for P, Ca, and K. But they added that the fertility improvement was mostly noted in top soil (0-20 cm). Other tree species such as karité and néré showed the same trend for fertility improvement under their crown (Bayala et al. 2002). Generally, there was a fertility gradient with fertility decreasing from the tree base to the edge of the crown or beyond (Rao *et al.* 1998; Kessler, 1992; Kater *et al.*, 1992; Tomlinson *et al.*, 1995, Bayala *et al.*, 2002). Rhoades, 1995 suggested that higher SOM and organic forms of nutrient nearer the tree means that there could be increased mineralization and greater availability of plant available nutrients under trees than in open areas during the cropping season. Bayala *et al.* (2002) found a strong correlation between C and N in soil collected under Karité and Néré trees in Burkina Faso. Then, they suggested that this correlation demonstrates that the main source of C and N may be the trees because crop residues are always removed from farmer's fields. Moreover, the fact that soil was more fertile closer to the tree trunks than outside the tree crowns, could explain why millet production is higher under Zone B than the other zones. It is also worthwhile to note that soil improvement under trees is species-specific and depends on the size of trees and site conditions. In a previous study in western Kenya, Mekonnen *et al.* (1997) reported that *Sesbania sesban* utilises nitrogen below the rooting zone of maize and make it available to crops through its leaf litter. Buresh and Tian (1998) also indicate that the tree root systems in agroforestry practices are able to reduce the leakiness of the nutrient cycle through reducing the leaching of nutrients from the surface soil layers.

Measurement of the variation in ^{13}C isotopic composition allowed for a distinction between tree (C3) derived C and crop and grass (C4) in the total soil organic C content (Bayala *et al.* 2007). The organic carbon content of soil under Karité (6.43 ±0.45 g Kg^{-1}) and Néré (5.65 ± 0.27 g $Kg^{-1)}$ were significantly higher than in the open area (4.09 ± 0.26).The results of this research show that the C4 derived soil C was approximately constant and the difference in total C was fully explained by the C3 (tree) contribution to soil carbon of 4.01 ± 0.71, 3.2`± 0.53, 1.53 ± 0.10. This indicates that trees in parklands have a direct positive contribution to soil carbon content. This justifies the need to encourage the maintenance of trees in these systems where the carbon content of soil appears to be the primary limiting factor for crop growth. The soil carbon content constitutes one of the factors essential for assessing the sustainability of cropping systems (Bationo and Buerkert, 2001, Bayala *et al.*, 2007).

In natural forests, nutrients are efficiently cycled with very small inputs and outputs from the system (Sanchez *et al.* 1997, Bayala *et al.*, 2007). In most agricultural systems, the opposite happens.

According to Bayala *et al.*, 2007, there is a strong need to develop research activities on soil C sequestration as this is a truly win-win situation (Lal, 2002). However, above and below ground carbon sequestration values need to be generated locally, taking into account the duration of each agroforestry system and extrapolated geographically in a realistic fashion, based on the actual rate of agroforestry adoption (Sanchez *et al.* 1997, Bayala *et al.*, 2007).

Mmolotsi and Teklehaimanot (2008) have conducted a study in a silvopastoral farm in Wales. The results showed that large quantities of dead fine roots and root nodules were found in soils within the agroforestry and forestry treatments which could contribute significantly to build up soil organic matter and nitrogen content of the soil.

The following mechanism (Rao, 1998) could help for increased fertility under trees:

- Leguminous trees contribute nitrogen to the system through biological nitrogen fixation (BNF);
- Deep root system trees can take up nutrients from subsoil and recycle them to the surface through litter and twig fall;

- Lateral roots of some big trees such as néré, baobab, *Sclerocarya birrea* can take up nutrients from a large surrounding area and concentrate them under their crown (Groot and Soumaré, 1995);
- The excreta of livestock resting under trees during the dry season can also contribute to soil fertility improvement (Tomlinson *et al.* 1995);
- Tree canopies can intercept the fine particles of fertile soil carried by wind that reach the soil under trees through stemflow and throughfall in the rainy season;
- Symbiotic association with endomycorrhizae will help some tree species to accumulate phosphorus under their canopy (Mason and Wilson, 1994).

It has also been proven that trees can improve soil physical conditions under tree crowns compared with open areas. Belsky et al., (1994) reported that improvements are reflected through lower bulk density, while Campbell *et al.*, (1988) argued for lower resistance to water and root penetration, increased porosity and greater aggregate stability. All these improvements result in high rain water infiltration into the soil and the availability of water to crops. Soil physical condition improvement is closely associated with increased SOM. Soil organic carbon (SOC) plays an important role in supplying plant nutrients, improving cation exchange capacity, improving water retention through soil aggregation and enhances soil biological activity (Dudal and Deckers, 1993, Bationo *et al.*, 2007).

According to Bationo *et al.*, (2007), the low soil organic carbon level is due to the low shoot and root growth of crops and natural vegetation, the rapid turnover of organic materials resulting from high temperatures coupled with high activities of fauna (termites) and the low soil clay content.

Animals sheltering under trees in the dry season in most of the dry areas can cause soil compaction. At the same time these animals' dung and urine can be of great importance to soil enrichment under trees and could maybe balance soil compaction effects.

Atmospheric deposition of nutrients contained in dust as a result of wind erosion is very common in arid and semi-arid zones of West Africa and is captured by the rain, representing another mechanism whereby trees can capture nutrients.

Studies have been undertaken on the physical and chemical fertility improvement by trees in cropping systems in West Africa, but studies on biological aspects of soil fertility are scarce. West African soils have low to moderate fertility, and phosphorus (P) is often fixed and unavailable to plants (Gnankambary *et al.*, 2008, Bationo and Buerkert, 2001; Sanchez, 2002). Gnankambary *et al.*, (2008) have done studies in agroforestry parklands in Burkina Faso on nitrogen and phosphorus limitation to soil microbial respiration. They found that parkland canopies influence the availability of N and P for microbes. The increase in respiration rate was also faster in soils under *Vitellaria paradoxa* than in soil from outside the canopy. They conclude that under tree canopies in agroforestry parklands there is more P in forms that are immediately accessible to microorganisms than outside the canopy cover.

Plants roots provide an ecological niche for many soil microorganisms (Munyanziza *et al.*, 1997). The two very well-known symbiotic associations between plant roots and microorganisms are nitrogen fixation in tree nodules through the bacteria (rhizobium) and the mycorrhization (fungus-root).

The role and potential of woody legumes in nitrogen fixation is well known (Ingram, 1990). Many researchers have estimated the amounts of nitrogen fixed by agroforestry trees (Dommergues, 1987; Nair, 1984 and young, 1987). Felker (1978) estimated the nitrogen fixed by *Leucaena* species to be 500 $kg^{-1}ha^{-1}$ $year^{-1}$ and that of *Faidherbia albida* at 21 $kg^{-1}ha^{-1}$ $year^{-1}$. Nodulation is greater in conditions of low soil nutrient status and nitrogen fertilisers are known to inhibit nodulation (Ingram, 1990). For many legume trees, field evidence for nitrogen fixation is not yet explored and the results available are sometimes confusing.

Arbuscular mycorrhizal (AM) associations are widespread in the tropics with a wide range of annual and perennial plant species (Le tacon *et al.*, 1987; Sieverding, 1991; Munro *et al.*, 1999; Bâ *et al.*, 2000) and many plant species are dependant on them for growth under normal conditions (Munro *et al.*, 1999). It is well-documented now that mycorrhizal fungi improve growth of plants that are important in agriculture, horticulture and forestry (Munyanziza *et al.*, 1997; Wilson *et al.*, 1991; Diagne *et al.*, 2001). Mycorrhizal fungi provide a greater absorptive surface than root hairs through external hyphae and thus help in the absorption of relatively immobile ions such as phosphate, copper and zinc (Munyanziza *et al.*, 1997; Sailo and Bagyaraj, 2005). Furthermore, mycorrhizal plants were reported to have a greater tolerance to toxic metals, drought, high soil temperature, root pathogens and transplant shock than non-mycorrhizal plants (Bagyaraj, 1990; Bagyaraj and Varma, 1995; (Munyanziza *et al.*, 1997). The increased growth of AM plants is mainly attributed to increased phosphorus uptake (Munyanziza *et al.*, 1997; Sailo and Bagyaraj, 2005). Munro *et al.*, (1999), reported that the role of AM in nutrient uptake (especially phosphorus) and water uptake, enhancement of N2 fixation and improvement of soil structure make them particularly important in the tropics where these factors limit growth on many sites. Mason and Wilson (1994), stated that soil disturbance can lead to loss of mycorrhizal propagules (spores, mycelium and infected roots), inhibiting the renewal of vegetation cover.

The importance of extra radical hyphae of AM fungi in creating soil aggregates is now documented and recognized (Jacobsen *et al.*, 1992; Miller and Jastrow, 1990). Soil aggregation by extra radical hyphae plays an important role in soil conservation, especially in sandy soils (Bagyaraj and Varma, 1995).

Responses of plants to inoculation differs with respect to functional compatibility, measured as mycorrhizal formation, root colonization, external hyphal length, relative mycorrhizal dependency (RMD), hyphal P transport and P concentrations in shoots (Ravnskov and Jacobsen, 1995, Bâ *et al.*, 2000). Plenchette *et al.*, 1995 stated that the determination of RMD of plants is one of the most important factors determining the magnitude of benefits from improved management of AMF and they defined RMD as the degree to which a plant responds to inoculation. It is of great importance to determine whether or not a plant derives benefits from AM symbiosis and to know how to manage it accordingly (Bâ *et al.*, 2000). Studies by Diagne *et al.*, (2001) on mycorrhizal inoculum potential (MIP) of soils indicate the potential benefit to crop yield of maintaining a high level of mycorrhizal propagules in agroforestry soils and a possible role of trees in maintaining this source of inoculum. According to Munro *et al.*, 1999, nursery inoculation can produce benefits through: 1) growth promotion before outplanting; 2) enhanced mycorrhizal development (enabling the plant to withstand transplanting stress) and 3) compensating for mycorrhizal deficiencies at disturbed outplanting sites. Munro *et al.*, (1999) show that inoculation was highly effective in promoting mycorrhizal formation in non-sterile soils and found an improvement in tree growth with all three unselected inoculum mixtures. Many researchers have used non-sterile soil inoculum mixtures and reported growth improvement (Munro *et al.*, 1999; Varma *et al.*, 1993; Michelson, 1993; Sidibé, 1993; Sidibé and Dhillion, 2001; Ahmad and Maziah, 1988). Sidibé and Dhillion (2001) also used unselected soil inoculum mixtures of host plants on its cuttings and found that the growth of cuttings was highly improved. However, the degree of improvement was related to tree species and correlated with the percentage of infection of cutting roots. The advantages of using an unselected soil inoculum is due to the fact that these techniques require no sterilisation, no long term maintenance and no sophisticated laboratory equipment and methodology (Munro *et al.,* 1999) as used in temperate mycorrhizal research. Moreover, these low techniques could be easily taught through extension programmes (Munro *et al.*, 1999). The adaptation of tropical mycorrhizal research to a tropical condition (low input and low technique) has been pointed out for the first time by Janos (1988). Given the ecological importance of AM and their role in nutrient and water uptake, mostly P in nutrient deficient soils, more attention should be given to further exploration of this symbiosis in African parkland systems.

2.4.4. The effect of tree-crop interactions on crop yield

The effect of trees on crop yields depends on the site, the size of trees which also depends in most cases on age. Crop yield increases have been noticed under open and well-managed canopies of fully grown trees. Many researchers have reported yield increases under *Faidherbia albida* (Saka *et al.*, 1994; Poschen, 1986; Depommier *et al.*, 1992; Charreau and Vidal, 1965). The yield increases under *Faidherbia* are attributed to the effect of improved soil fertility, soil water and microclimate which in turn depend on soil and climatic conditions (Rao *et al.* 1998). According to ICRAF (1997), 60% of the 'albida effect' was estimated to be due to increased nitrogen availability and 40% due to increased phosphorus availability in the Sahel regions. Others factors such as microclimate (temperature, improved soil humidity) can contribute to increased crop yield under *Fairdherbia* trees. The root competition index of *Faidherbia albida* is very low in some drier zones in Mali, meaning that the tree develops only few lateral roots;

the competition for water and nutrients is therefore minimized (INCO Competition, unpublished data).

The decline of crop yields under tree canopies compared to open areas has been widely reported (Kessler, 1992; Kater *et al.*, 1992. Bayala, 2002). In Burkina Faso, Kessler, (1992) found that sorghum yields under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees were reduced on average by 50% and 70% respectively while in southern Mali, Kater (1992) reported a yield reduction of 60% under canopies of both species. When there is sufficient rainfall in Sahel zone, yield reductions under tree canopies are mainly due to reduced light. A significant negative correlation between yield and light under néré and karité canopies indicated that shade was the major factor in reduction of sorghum yields under those trees (Kessler, 1992).

In a pruning experiment performed in Burkina Faso, Bayala (2002) found a significant effect of pruning on both millet grain yield and dry matter production. Total-pruned trees had a higher grain yield at 507 kg ha^{-1} $year^{-1}$ than dry matter at 2033 ha^{-1} $year^{-1}$.
In pruning studies performed on parkland tree species in West Africa, the agreed conclusion is that light interception by trees appears to be the major factor responsible for the reduction of crop yields (Kater *et al.*, 1992; Kessler, 1992; Samba; 1997; Bayala, 2002; 2005). Based on past studies, Bayala reported that the main effects of pruning are: 1) more light can reach crops underneath and the temperature is increased; 2) more light leads to a beneficial effect in increasing crop yield; 3) Cereals (C_4 species) are very sensitive to shade.

The ecological ability of trees to combine with given crops is species-specific, and is a characteristic related to branching pattern and root architecture (Boffa, 1999). Sorghum yield is generally reduced under *Parkia biglobosa* than *Vitellaria paradoxa* (Kessler, 1992; Kater *et al.*, 1992). This reduction is less pronounced for millet (Maiga in Kessler, 1992). According to Boffa (1999) this difference is due partly to the larger size of *P. biglobosa* and different rooting patterns. *Parkia biglobosa* have low branches which extend laterally while *Vitellaria* trees have an ascending architecture. Kater *et al.* (1992) explain the difference in yield under these species by suggesting that superficial rooting is more extensive in *Parkia biglobosa* which resulted in more competition with crops. Although the negative effect of trees on crop yield is widely reported, Moussa (1997) reported that *Hyphaene thebaica* had a significant positive effect on grain and straw yields of sub-canopy millet in Niger. *Borassus aethiopum* is also believed to associate with crops without intense competition (Cassou cited by Boffa, 1999).

The studies of Ong *et al.* (2000) show that the nature and extent of the interactions between trees and crops change greatly as agroforestry systems mature and that the intensity of the interactions depends on the prevailing conditions, particularly seasonal rainfall. This implies the need to conduct long term studies in agroforestry which are dampened by the substantial financial, labour and time investment involved.

2.4.5. The effect of trees on nutritive quality of crops

Although much research has been done on the effect of trees on growth and yield of associated crops, little information exists on the effect of trees on the nutritional content of associated crops. Moreover, recent data on the nutritional content of associated crops are scarce.

Boffa (1999) stated that the high fertility status of soil under tree cover is reflected in the mineral content of associated herbaceous plants. He found that in Senegal, nitrogen content of aerial parts of herb plants was higher under *Acacia Senegal* and *Balanites aegyptiaca* than in the open.
Chareau and Vidal (1965) reported that the concentrations of all mineral elements except insoluble ash and sulphur were 25 to 40 percent higher in millet leaves under *F. albida* than in the open. The protein content of millet grain according to Chareau and Vidal, (1965) and reported by Boffa (1999) increased by 32 percent under *F. albida* and by 242 percent on kg/ha basis, due to the grain yield increase related to the presence of trees. Nutrient concentrations were also higher in millet grown under *F. albida* than in the open in Niger (ICRAF, 1996; Boffa, 1999). However Muoghalu and Isichei, (1991) found no significant difference in mean crude protein, fibre and lignin content between forage species grown under tree canopy.

More effort is needed in this field because knowledge of the nutritional content of associated crops could help extension workers to further convince farmers to maintain trees in their fields.

2.4.6. Trade-offs between crop productivity, tree products, and environmental functions

The statement of Ong and Leaky (1999) which said that it would be more worthwhile to focus attention on selection of trees to provide direct and immediate benefit to farmers with minimum loss of crop productivity, instead of focussing primarily on soil amelioration, should be one of the backbones of agroforestry research in arid and semi-arid regions of Africa. The rationale of the above statement is that it is widely recognised that the positive influence of deep-rooted tree species on crops and/or the positive '*Faidherbia albida* effect' would require 20-40 years in Ethiopia (Poschen, 1986; Ong and Leaky, 1999) and elsewhere. However, such a long gestation period may not be attractive for many farmers, since the benefit in crop productivity is relatively small taking into account the time scale. This may be the main reason for farmers' lack of interest (motivation) in tree planting. Farmers used to say for fruit trees with a long juvenile phase: 'if you plant this tree, you will never eat its fruits'.

Nelson *et al.* (1997) showed that the slow return from investment in contour hedgerows may explain why farmers are reluctant to adopt the technology. Farmers accept erosion control when they can combine it with a clear return on their investment. The importance of tree products in agroforestry was also described by Stewart and Blomley (1994) in a semiarid region in Kenya where farmers are keen to grow a fast-growing indigenous species *Melia volkensii* (Meliaceae). This species is reputed to be compatible with crops and can provide high value timber in 5-10 years. But recent studies in farmers' fields showed that this tree is highly competitive with crops. In order to find out if growing *M. volkensii* is cost-effective or not, Ong *et al.*, (2002) compared the value of timber products gained with that of the crop value lost due to competition over 11-year-rotation in Kenya. The estimate shows that at the end of the rotation, the accumulated income from tree products exceeds the accumulated value of crop yield lost through competition by 42% during average years. According to Ong *et al.*, 2002, the reasons for farmers to plant this tree include good financial return in a short time, high quality timber in 10 years and the ability to produce a different number of useful products continuously (firewood, fodder, poles) at each pruning, lopping or thinning event.

In the parkland systems of West Africa, shade of *Vittelaria paradoxa* and *Parkia biglobosa* can reduce millet yield by 50 to 80 percent (Kater *et al.*, 1992), but the tree is highly appreciated by farmers because tree products are commonly use in traditional diets and can also be sold in the local, regional and even international markets (Ong *et al.*, 2002; Teklehaimanot, 2004). Many farmers estimate that the benefit derived from tree products could compensate the lost of crop yield under the trees.

It become obvious from many studies in arid and semi-arid zones of Africa that in order to reduce the trade-offs between crop productivity and environmental functions in the semi-arid tropics, it is crucial to select appropriate trees with high and immediate useful products and to design tree spacing to minimise competition (Ong *et al.*, 2002) and/or to mimic the traditional parkland spacing pattern.

According to Ong and Leaky (1999), the capture of growth resources by trees and crops can be grouped in three categories: neutral, complementary and competitive interactions. In the trade-off or neutral category, tree and crop can exploit the same pool of resources; this implies that an increase in capture by one species results in a proportional decrease in capture by the associated crop. The ideal situation is the complementarity use of resources in which trees are able to capture the resources unavailable to crops and this will result in an increase of the overall uptake of resources. The competitive interaction between associated species may result in a drastic reduction in the ability of one or both species to uptake growth resources.

Jose (2009) stated that agroforestry is increasingly viewed as providing ecosystem services, environmental benefits and economic commodities, and these roles have been emphasized by both the Millennium Ecosystem Assessment (2005) and the International Assessment of Agricultural Science and Technology for Development (2008). In addition to poverty alleviation, agroforestry also provides proven strategies for carbon sequestration, biodiversity conservation, soil enrichment and air and water quality for not only the landowners or farmers, but for society at large (Jose, 2009). There is also a growing concern to provide financial incentives to farmers or landowners for land-use practices that maintain environmental services of value to the wider society (FAO, 2007; Jose, 2009). If such incentives are given to farmers, it will surely be a great motivation for planting trees in arid and semi-arid zones in Africa, because the lack of means to purchase seeds, labour, logistics and mainly water are among the known constraints to tree planting by farmers.

2.4.7. Management options to minimise tree-crop competition for resources

Farmers have managed trees in their farms for a long time with the aim of diversifying production and maintaining site stability in terms of soil fertility and microclimate amelioration (Teklehaimanot, 2004). The case studies undertaken by ICRAF (1998) in the Dori area revealed how intensively farmers are already managing Agroforestry trees in parkland systems. The management practices includeed debranching, pruning and pollarding to: 1) accelerate growth, 2) increase production of biomass and fruits, 3) reduce shade for associated crops, 4) obtain organic matter to fertilize soils, and 5) produce firewood. But actually, evidence of parkland degradation has been reported by many researchers (Boffa, 1999; Teklehaimanot, 2004; Gijsbers *et al.*, 1994). Degradation is perceived in the reduction of tree density in farms and by the ageing of trees due the low regeneration of useful tree species (Teklehaimanot, 2004; Gijsbers *et al.*, 1994; Nikiema *et al.*, 2003, Okullo *et al.*, 2003). In Burkina Faso, the average tree density declined from 10.7 tree ha^{-1} in 1965 to 8.3 tree ha^{-1} in 1985 (Gijsbers *et al.*, 1994). The findings of Kelly *et al.*, (2004) in Mali, where distinct differences have been found between the population structures of Karité in farmer's fields and forests may be due to greater competition in the forest and also trees may benefit from cultivation in the field. In crop fields, trees have a greater girth than in the forest. Some of the causes cited for degradation are: climatic changes, such as the persistence of drought in sub-Saharan Africa; the high human and animal pressure on the land; the conflict between traditional and state land tenure systems and the conflicting land use systems such as uncontrolled bush burning and deforestation. Some of the practices which lead to gradual deforestation are cutting trees and destumping to give way to monoculture and abusive charcoal production for consumption in towns. As big trees are disappearing in forests, some charcoal producers are even cutting down karité trees in farmlands. The case of *Pterocarpus erinaceus* overexploitation for fodder is another alarming situation. Bonkoungou *et al.*, (1998) reported that the *Pterocarpus* story begins outside large urban areas such as in Bamako (Mali) where trees are so heavily lopped that it is all but impossible to find healthy *Pterocarpus* trees. The regeneration of this tree is threatened because *Pterocarpus* can rarely fruit. Vendors have to travel from 30 to 50 km to fetch fodder. As cited by Oni (1997), the gene pools of many parkland trees (including Karité and Néré) are under threat. So there is a crucial need to develop sustainable management practices for parklands before the disappearance of the existing gene pools. Furthermore, there is an almost total agreement that for many reasons, farmers do not plant parkland tree species (Boffa, 1999; Teklehaimanot, 2004; Bayala, 2002; Hall *et al.*, 1996; Bonkoungou et, 1998; Ong and Leaky, 1992).

Many management options of agroforestry parklands systems that have recently been the concern of scientific research include 1) the aboveground and belowground pruning, 2) the improvement of intercropping systems, 3) the domestication of useful parkland tree species mainly for non-timber forest products (NTFPs) through vegetative propagation, mycorrhizal research, and genetic improvement. According to Leaky and Simons (1998), tree management strategies should be *farmer- driven* and *market-led* processes, and environmentally sustainable. This is scientifically-based, involving the identification, production, management and adoption of high quality germplasm. The greatest opportunity for simultaneous agroforestry practices in the drylands of the tropics seems to be the exploitation of the complementary interactions between crops and mature trees grown for their marketable products (Ong and Leaky, 1992).

Above ground competition for light can be reduced by crown pruning and below ground competition for nutrient and water can be reduced by root pruning, deep ploughing or root barriers. Crown and root pruning are management practices which are used to minimise competition. If competition is to be minimised, tree planting must be combined with appropriate management practices such as crown and root pruning (Ong *et al.*, 2002). The relative importance of above and below ground competition is crucial in determining the best management strategy, as is the timing of pruning (Ong *et al.*, 2002).

The purposes of crown pruning are manyfold and include wood, fodder, mulch production, improved fruit production, reduction of shade on associated crops, rejuvenation of trees and sometimes the control of plant parasites like *Tapinanthus spp.* Crown pruning is an old tree management practice which is done through out the arid and semi-arid zones of West Africa (Boffa, 1999; Bayala, 2002, Bayala *et al,* 2005; 2007). The results of studies by Bayala *et al.*, 2002 show that millet would benefit from crown pruning at least in the short term, but long term effects will depend on the ability of a tree to maintain fertility and how fast a tree will recover from pruning. This indicates that long term studies are necessary to determine the long-term effect of pruning on fruit production and crop production. Jones *et al.* (1998) found that crown pruning not only reduces transpiration and then competition, it also leads to tree root dieback. Crown pruning may also lead to the development of more superficial root systems than normal, which would be an undesirable outcome (Hairiah *et al.*, 1992; Ong *et al.*, 2002). Ong *et al.*, (2002) reported that where fruits are the target output from trees, there is a limited scope for crown-pruning without jeopardising fruit production, but for other species where firewood is the target, crown pruning is part of the management strategy. But as suggested by Bayala *et al.*, (2007, crown pruning is a management strategy to rejuvenate fruit trees.

Much research has been done recently on below ground interactions and many techniques have been developed for root studies (Cannell *et al.*, 1996. Van Noordwijk *et al.*, 1996, Schroth, 1999). Ong *et al.* (2002) have reviewed tree-crop interactions for below ground resources in rain-fed systems and found the following conclusions:

- Traditional methods of root excavation have highlighted the overlapping distribution of tree and crop roots within the crop rooting zone and the lack of spatial complementarity even for species which farmers regard as highly compatible for simultaneous agroforestry systems (Ong *et al.*, 1999; Schroth, 1999).
- Root length density of trees and crops within the crop rooting zone may be important in determining the intensity of competition between trees and crops (Odhiambo *et al.*, 1999);

- Less labour intensive approaches, such as competition indexes are poor indicators of competition (Ong *et al.*, 1999).
- Root and crown functions are the driving forces determining the severity of tree-crop interactions;
- Isotopic studies show how the competitive ability of an individual tree species can vary between sites with different hydrological characteristics;
- Selection of suitable species for intercropping in dry land agroforestry is surprisingly slow despite the recent interest in root studies. Van Noordwijk *et al.* (1996) stated that the twin goals of fast-growing trees and low competitive ability are mutually exclusive when nutrients and water are confined to the topsoil, which may explain this slowness.

Studies on root barriers and root pruning show that competition between roots was responsible for most of the reductions in crop yield (Ong *et. al.*, 2000). Jose *et al.* (2000) found in a study in Indiana USA that root pruning is not only beneficial for maize growth in alley cropping with black walnut (*Juglan nigra*) and that agroforestry is much more attractive economically than traditional agriculture or forestry. However Rao *et al.*, (1998) have questioned the feasibility for managing root pruning on many tropical farms.

Long-term studies of the effects of root-pruning are needed because such information is crucial for the promotion of the technology to farmers. The pressing scientific questions which should be addressed in long-term studies are:

- Can the growth of the tree and its stability in the wind be influenced by root pruning?
- Does the loss of fine roots and mycorrhizas diminish the capacity of tree roots to intercept and recycle plant nutrients that leach from the soil surface?
- What are the implications of severing surface roots on N2 fixation and mycorrhizal activity?

So before advising root pruning to farmers, the following studies should be undertaken:

- Long term studies of water balance at sites where trees have been root- pruned;
- Studies on the effect of root pruning on nutrient leaching, nitrogen fixation and mycorrhizas.

Surprisingly, Guillermo *et al.* (2007), in pot studies in laboratory indicated that the below-ground competition response is not dependent on the presence or absence of the symbiont. Moreover they have shown that the lack of an interaction between nutrient levels and the presence of root neighbours indicates that the below-ground competition response is also not dependent on nutrient availability. These findings may not be repeated under field conditions.

Pruning, sequential thinning and maintaining appropriate density are management options which can reduce tree-crop competition. However, it is important to bear in mind that each of these management practices have some drawbacks and merit investigation: (1) crown pruning is relevant for old trees in the scope of rejuvenation (Bayala *et al.* 2007) but farmers will be reluctant to prune good fruiting trees, (2) root pruning for the management of below ground competition is limited to the choice of trees which have deep and compact root systems, (3) farmers are reluctant to have a high density of trees in their field when animals traction is needed.

One of the management options which is not fully exploited by researchers and could be of great interest to farmers is the cultivation of shade tolerant crops under tree canopies (Teklehaimanot *et al.*, 1997). Tobacco, cassava, yam, sweet potato and large-leaved vegetables are often cultivated by farmers under trees (Kessler, 1992; Kater *et al.*, 1992; Wiersum and Slingerland, 1997). In practicing such tree-crop associations, farmers diversify resources; reducing the risks of crop failure through making efficient use of the microclimate environment. This management strategy deserves more attention because it is more likely to be adopted by farmers in parkland agroforestry systems. More investigations are needed in order to determine which shade-tolerant crops can be grown successfully under which trees. The identification of shade tolerant crop species through field screening should be a priority for the following reasons: 1) it is not yet clear whether many species which qualify as shade tolerant are effectively shade tolerant; 2) species may have different degrees of tolerance; 3) species may have different water use efficiencies. Moreover, according to Boffa (1999), research aiming at identifying optimal crop-tree combinations and the technical and socio-economic conditions required for their adoption are needed.

Janos (1988) asked the question: Are the temperate approaches of mycorrhizal application appropriate in the tropics? This question implies the adaptation of mycorrhizal research to tropical conditions (low input and low technique). An example is the low-cost method of mycorrhizal inoculation developed by Munro *et al.*, (1999). Such methods should be highly considered in future parkland agroforestry research. Although many investigations have shown a great potential of these plant-fungal associations in the domestication of wild fruit trees in Africa (Antunes and Cardoso, 1991; Bâ *et al.*, 2000; Sidibé and Dhillion 2001; Ahmad and Maziah, 1988; Munro *et al.*, 1999; Munyanziza *et al.*, 1997; Sailo and Bagyaraj, 2005), there is a need to understand the impact of the diversity and management of AMF on the performance of the trees at farm level. Still, mycorrhizal research is confined to laboratories and nurseries, so data on the performance of mycorrhizal inoculation in farmers' fields are seriously lacking.

Sanchez and Leaky (1997) define domestication through three determinants: 1) balancing food security with natural resource utilisation; 2) enabling policy environment that favours the rural development of smallholders; 3) providing the means to reduce soil fertility depletion. They also add that domestication cannot be dissociated from commercialisation, since without new markets; the incentive to domesticate intensively for self-consumption is not sufficient. According to ICRAF (1997), domestication is not only selection. It should integrate the processes of identification, production, management and the adoption of tree genetic resources. Domestication of important tree species such as *Vitellaria paradoxa* and *Parkia biglobosa* in agroforestry systems should be a priority because they provide not only useful non-wood products but also continuous tree cover and contribute to both the productivity and sustainability of farming systems by maintaining soil fertility and creating a more favourable microclimate for associated crops and livestock (Teklehaimanot, 2004). According to ICRAF (1998), if trees could provide the desired products and services in shorter time, as they could after the process of domestication, farmers would be more likely to invest their energy and time in planting them and by doing so they will rehabilitate the traditional agroforestry system which is environmentally important in the region.

Sustainable in-situ conservation, improvement and management of useful parkland trees require information on their current state of population genetics (Teklehaimanot, 2004). For example, Teklehaimanot (1997) found high genetic diversity within and between populations of Néré *(Parkia biglobosa)* species in West Africa. Similar genetic diversity was also reported for *Faidherbia albida.* According to Teklahaimanot (2004), this diversity is very important with regard to species improvement and should be conserved *in-situ* and *ex-situ* for use in selection and breeding programs. Studies conducted in Mali by Kelly and Bouvet (2003) on Karité revealed that populations in crop fields have a higher mean number of alleles as well as heterozygosity when compared with populations in fallow and forests. It appears that most of the genetic variation in Karité is within rather than between populations. The reason for this within population genetic variation could be explained by the investigation of Hamrick et al., (1991) who stated that long-lived, out-crossed, insect pollinated and widely spread species tend to have high within population variability. Boffa (1999) also reported that widely spread species tend to have high within population variability. Then, within population variation should be taken into account while selecting quality germplasm of karité trees (Bouvet et al., 2004) and this holds true for other useful parkland trees. According to Boffa (1999), the impact of practices used in parkland management on processes which influence genetic diversity remains widely unknown and provides numerous opportunities for research.

According to Teklehaimanot (2004), an understanding of the reproductive biology of a tree species is needed for developing successful crossing techniques for genetic improvement in overall fruit yield. For example; bats were reported to be the main pollinators agents of Néré in Burkina (Ouedrago, 1995) and Nigeria (Oni, 1997), while Okullo *et al.*, (2003) indicate bees as the major pollinator of Karité. In depth studies are needed in the field of reproductive biology of parkland species because as Teklehaimanot (2004) stated the success of both in-situ and ex-situ conservation of species like karité and néré largely depends on the available information on the reproductive process.

Two of the key themes in domestication of fruit trees are the ability to propagate vegetatively and the selection of elite clones with desirable traits. Vegetative propagation is one means of meeting the demand for improved plant material (Leaky and Simon, 1998; Teklehaimanot, *et al.*, 2000). Vegetative propagation is a valuable means for tree species for which there are problems of seed collection, viability, and germination (Teklehaimanot *et al.*, 2000; Sanou *et al.*, 2004). Scientists such as Leakey *et al.*, (1982) believe that vegetative propagation offers the opportunity to rapidly overcome such constraints.

Many of the temperate, mediterranean and tropical fruits are based on vegetative propagation techniques. It has been shown that some of the apparently highly bred fruits (such as apple) are only a few generations away from their wild relatives. This indicates that there could be large gains if such techniques could be applied in a systematic manner to West African fruit species. Whereas grafting of mango is carried out by nurserymen in the region, techniques for other trees have so far not spread from experimental stations, and very few farmers are able to reproduce trees vegetatively.

Methods for propagating of *Parkia biglobosa*, *Vitellaria paradoxa* and *Faidherbia albida* have been developed from juvenile and adult stem cutting by some researchers (Lovett *et al.*, 1996; Teklehaimanot *et al.*, 2000; Lovett and Haq, 2000; Nikiéma and Tolkamp, 1992; Ouédrago, 1993). Teklehaimanot *et al.*, (2000) have shown that néré can be clonally multiplied and differentiated by tissue culture and that it is possible to root air layers of Néré. Stem cuttings of three important species from tropical rain forest (*Lovea trichiliodes*, *Triplochiton scleroxylon* and *Terminalia ivorensis*) rooted successfully under mist conditions and form mycorrhizal symbiosis (Sidibé, 1993; Sidibé and Dhillion, 2001). This is an example which shows that the growth of stem cuttings of West African parkland tree species can be enhanced through appropriate mycorrhizal inoculation. For vegetative propagation using stem cuttings, Leaky *et al.*, 2003 have developed simple, inexpensive and low technology propagators, which can be made at farm level from readily available materials (wood, sand and polythene).

A grafting experiment of karité performed in Mali and Burkina Faso was successful (Sanou *et al.*, 2004). Five types of grafting were used: side cleft, top cleft, tongue, chip budding and side veneer. Moreover, one of the grafting techniques (two side veneer grafts) produced fruits in two years.

The Sahel Regional Program of the World Agroforestry Centre (ICRAF) has introduced three Indian cultivars of Ziziphus because of their precocity in fruiting (6 months), the larger size of their fruits and their taste (Ouedraogo *et al.*, 2006). The fruit of grafted jujube is commonly called "Pomme de Sahel" (ICRISAT, 2004). Grafting (top cleft) the local jujube with these cultivars is among the first priorities of local research institutes in the West African regions. The high performance of grafting jujube trees makes it suitable for intensive production through plantations and therefore a promising tree for the future. Grafting and stem cutting are means of vegetative propagation which can help shorten the juvenile phase of the species and allow the multiplication of superior quality trees, in order to develop cultivars with a greater potential for fruit production (Teklehaimanot, 2004).

Farmers' participation in the early stages of plus-tree selection is widely recognised to increase the adoption and efficiency of tree propagation (Ceccarelli, *et al.*, 1996). One of objectives of the Convention on Biological Diversity (CBO) is to empower farmers and make them direct beneficiaries of their indigenous knowledge and tree resources. Women are present from the beginning until the end of the NTFPs exploitation systems in Africa (from collection in the forest, transformation and selling in the markets). Women are more knowledgeable than men concerning NTFPs products. Thus, the involvement of women in selection and propagation processes should be given high priority. For agricultural seed supply, a major constraint is that (improved) seed only reaches a limited number of farmers, and the impact of research is limited (Tripp, 2001). There is also a need to develop sustainable alternatives to the traditional centralised tree seed supply.

CHAPTER III:

LOCAL KNOWLEDGE AND PRACTICES ON UTILISATION AND MANAGEMENT OF AGROFORESTRY PARKLANDS SYSTEMS IN MALI: A BASE LINE SURVEY

3. 1. Introduction

The Sahel regions of West Africa are characterized by unique climatic and soil conditions. Rainfall is insufficient and irregular. Wind and water erosion affect the quality of land and its productivity. The agricultural production systems based on annual cereal crop production are vulnerable and production levels cannot adequately feed the growing population. Food security is, therefore, a critical issue in the Sahelian countries of West Africa. The percentage of the population suffering from malnutrition is estimated at 20%, 36% and 36% for Mali, Burkina Faso and Niger, respectively (FAO, 2003). Cereal production has increased in the last decades, but the per capita cereal production remains the same and the adaptation of new technologies is low (Coulibaly *et al.*, 2007). A significant part of farmers' income is obtained from resource depletion, mining soil and degrading vegetation (Breman *et al.*, 2001). Thus, the current global food crisis is predominantly affecting the Sahelian countries which are already in food deficit situation.

Agriculture and environment are inseparable in the Sahel. Farmers in these countries have been integrating trees and crops on their farmlands for a long time as a strategy to safeguard essential products and services that they derive from trees to meet their needs for food, medicine, income generation and soil fertilization. In particular, the use of the wild fruit trees constitutes an important source of food security in the region. Biodiversity conservation in general and indigenous fruit trees in particular is, therefore, a prerequisite for long term food security and to eradicate hunger and poverty in the Sahelian countries (Naestard, 2007).

In Mali, the contribution of the wild fruit trees in the improvement of the living conditions of the populations is significant. Despite the importance of indigenous and wild fruit trees in the life of regions' people, little information has been documented on their current use and management by local communities and their potential as a resource for food security in the region (Okorio *et al.*, 2004; Djimde and Hoekstra, 1988). Therefore, in the present study, a base line survey was conducted to ellicit farmers' knowledge and practices concerning the type of tree species retained on farms, the most preferred tree species and their desired products and their optimal density on farms, most common and preferred shade-tolerant and shade-intolerant crops grown under the trees and ecological interactions between the trees and adjacent crops in the agroforestry parkland systems. An indigenous knowledge survey was conducted in order to integrate the indigenous knowledge in to the tree–crop interaction studies carried out in the present research as reported in subsequent chapters of this thesis.

Tamarind parklands are ageing due to lack or low level of regeneration. Farmers do not encourage regeneration by protecting wild seedling because of the negative effect of Tamarind trees on crops. Loss of Tamarind income reduces livehood resilence and in particular affects income of women. If valuable understories could be developed, this may not happen.

Warren and Cashman, (1988) defined indigenous knowledge as the sum of experience and knowledge of a given ethnic group that form the basis for decision making in the face of familiar or unfamiliar problems and challenges. Research into indigenous knowledge is considered to be of primary importance for the success of development projects in less developed countries today (Chambers, 1989). It is therefore important to take into account local knowledge during the planning stage of research projects in order to involve local people at all stages of the project. According to Ranasinghe and Newman (1993), one of the most important resources within agroforestry and unfortunately one of the quickest to be lost is traditional knowledge.

3.2. Materials and methods

3.2.1. Data collection

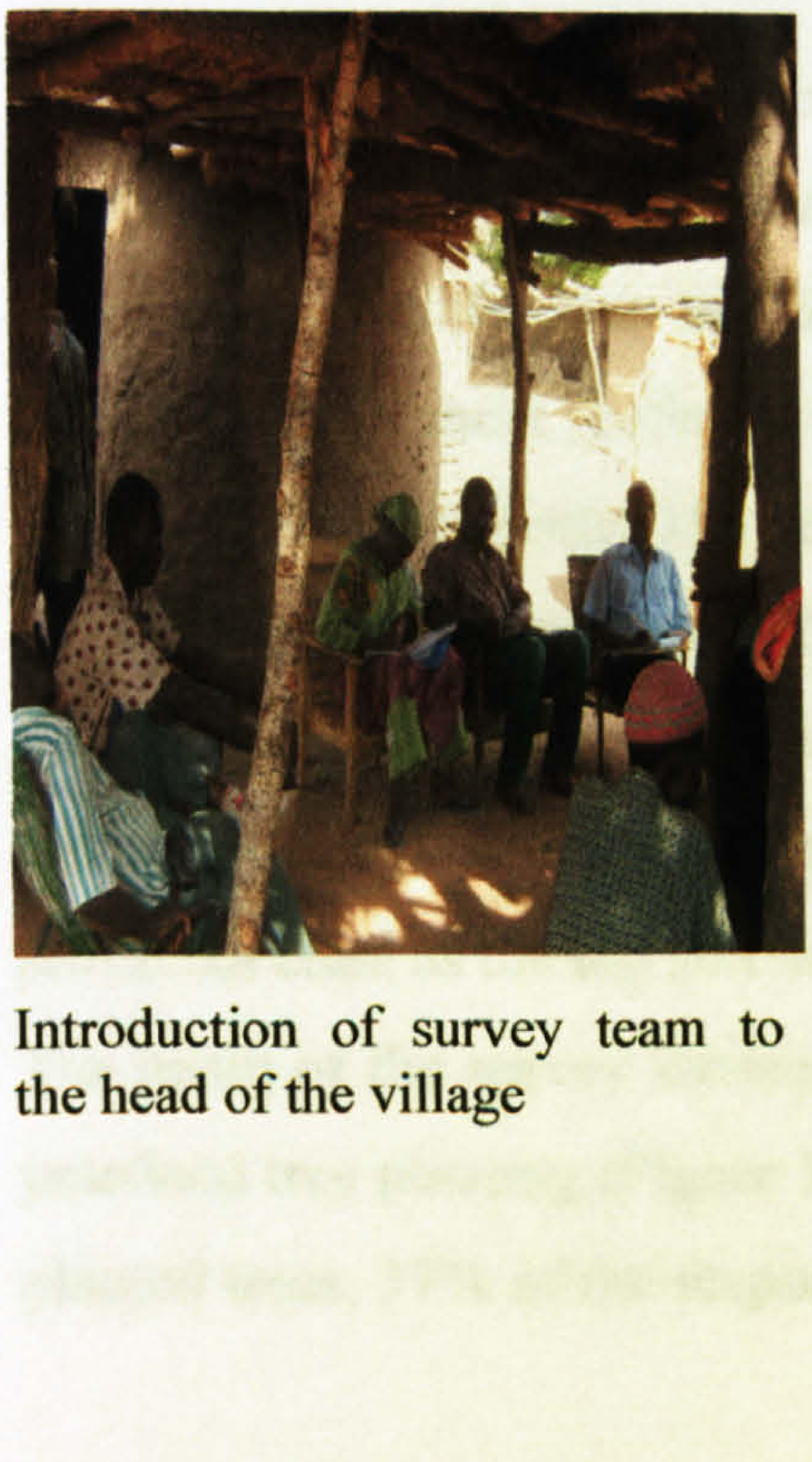
The study was conducted in Siramana village, in the south sudanian zone of Mali. A total of 108 farmers were randomly selected and interviewed, among which 69.3% were men and 30.7% women. An indigenous knowledge survey was used to establish the knowledge base. Tools including focus group discussions, structured and semi-structured interviews and mapping were used during the survey (Plate 3.1). The sample questionnaires used for structured and semi-structured interviews are given in Appendix 1.

Data related to the following aspects were collected:

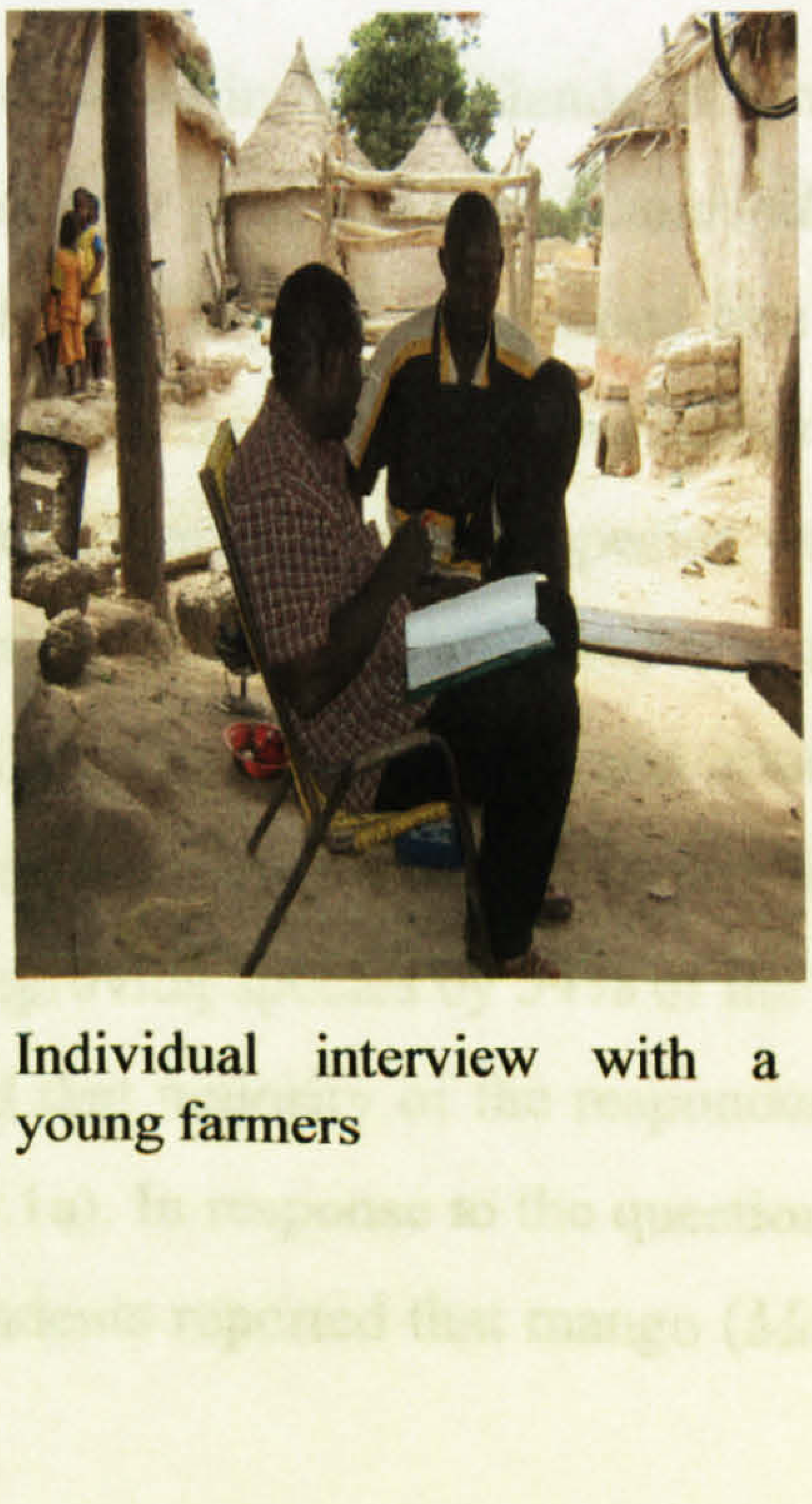
(1) Local knowledge on use and management of parkland tree species in particular *Tamarindus indica* and *Ziziphus mauritiana;* and

(2) Local knowledge on use and management of shade-intolerant and shade-tolerant crops with emphasis on Sorghum (*Sorghum bicolor*) and African eggplants (*Solanum aethiopicum*), respectively.

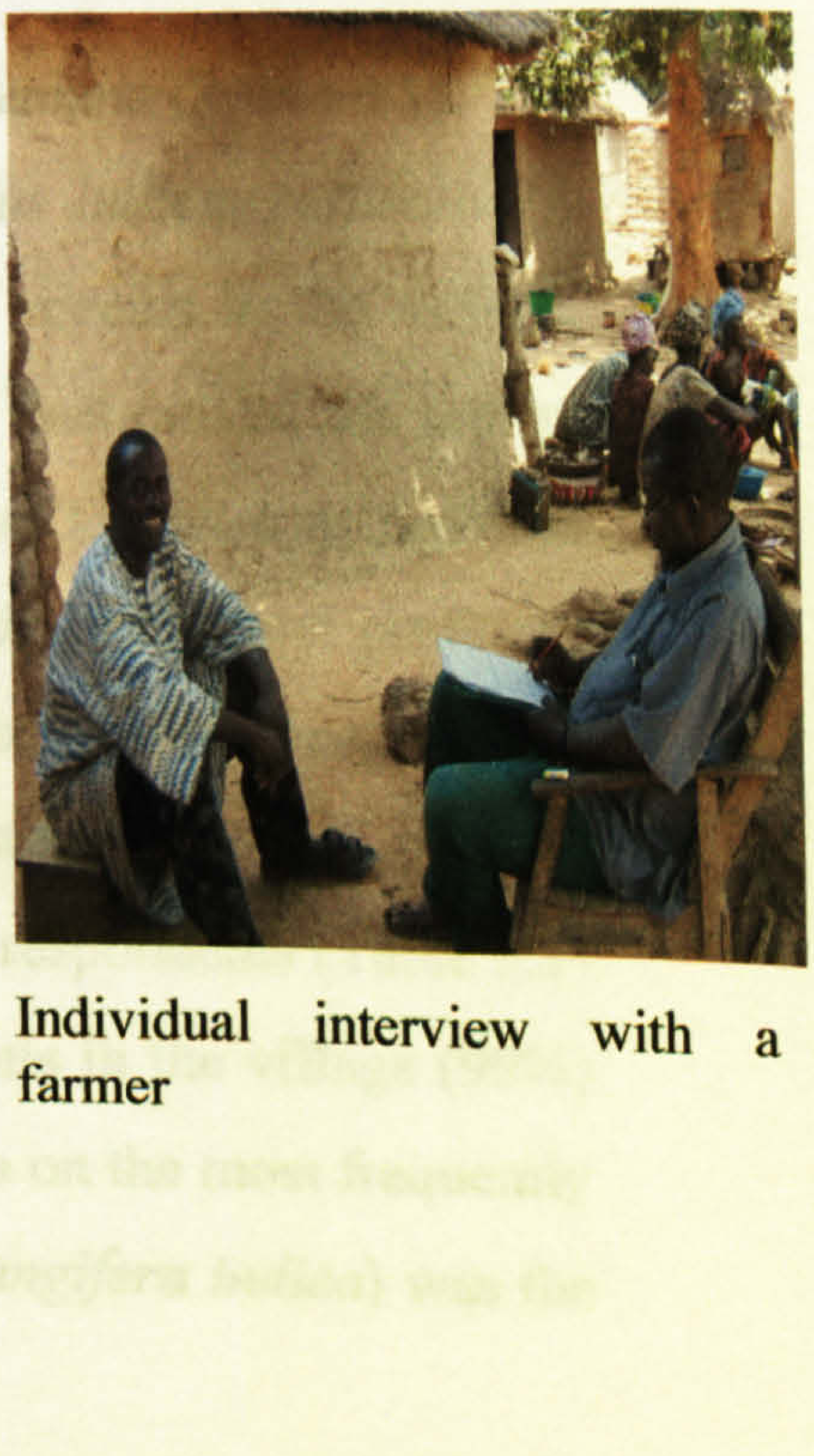
Plate 3.1 Indigenous knowledge survey tools used for baseline survey



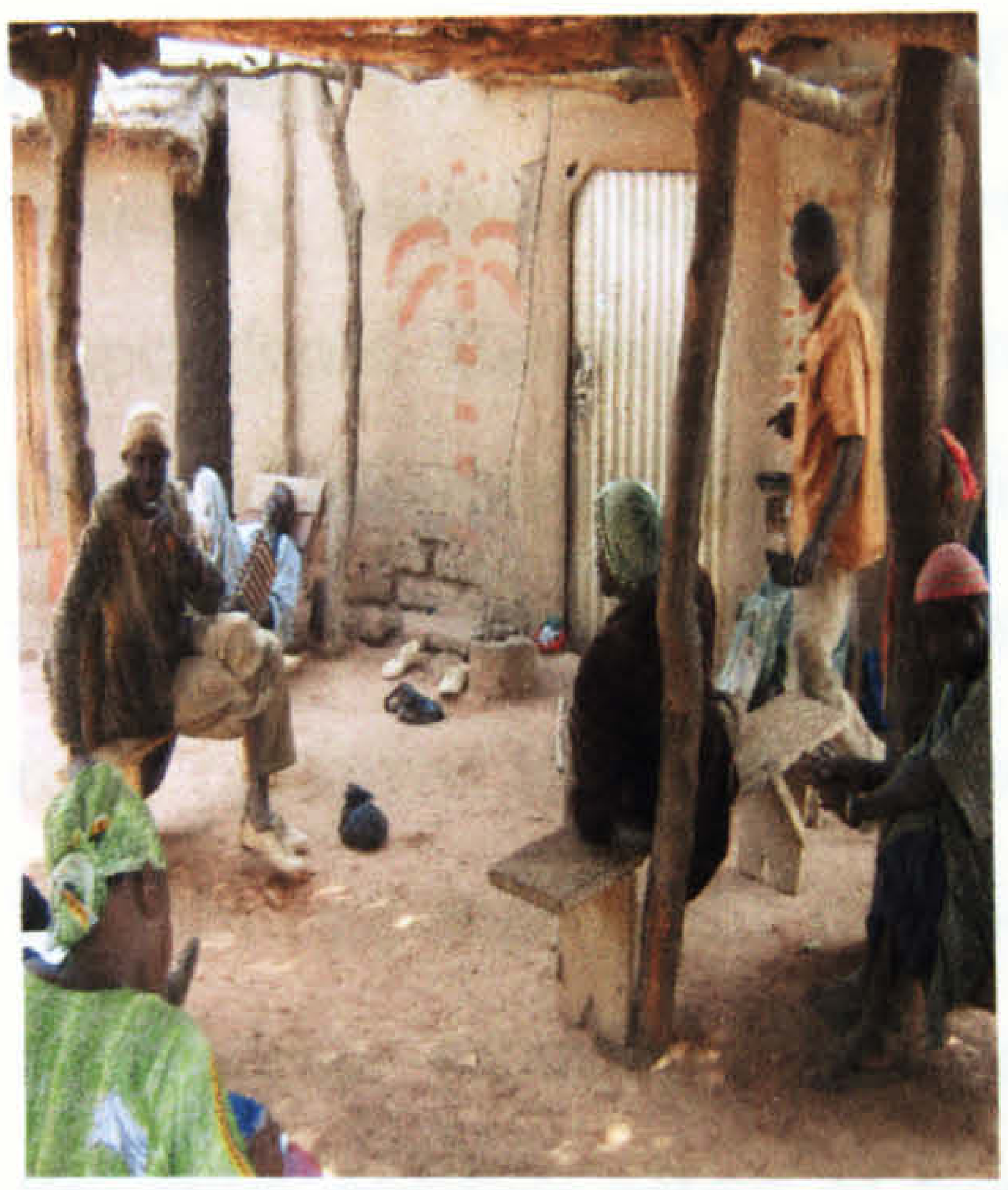
Introduction of survey team to the head of the village



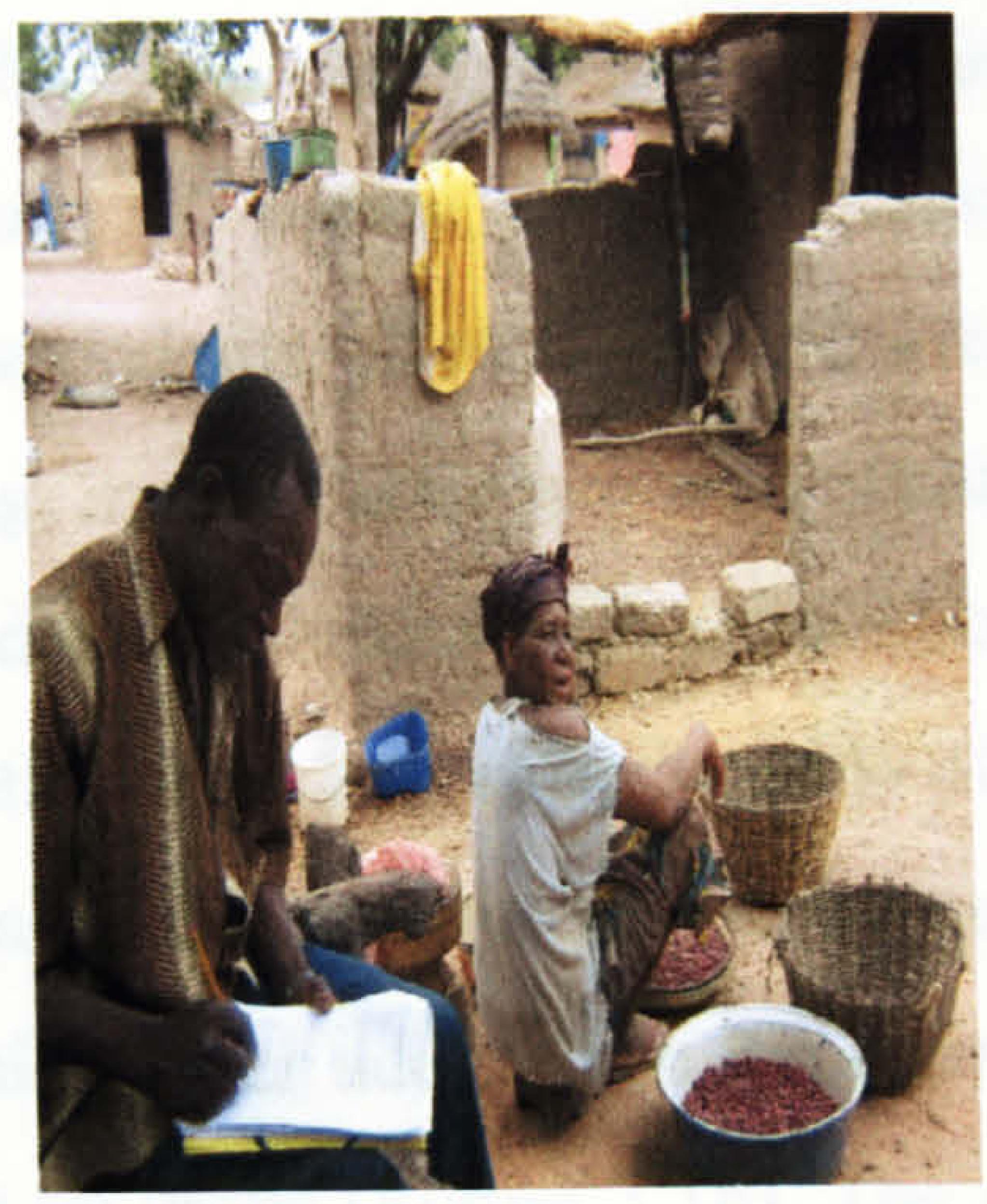
Individual interview with a young farmers



Individual interview with a farmer



Woman researcher in group discussion with farmers



Local surveyor doing individual interview with a woman

Siramana village map produced based on farmers participation

3.2.2. Data analysis

Statistical Package for Social Science (SPSS version 16 for Window) software was used to analyse the data. Frequencies of responses were analysed through descriptive statistics.

3.3. Results

3.3.1. Local knowledge on use and management of parkland tree species

A total of 17 tree species were recorded in the parklands of Siramana (Table 3.1). The dominant tree species were *Vittelaria pradoxa and Tamarindus indica, respectively. Ziziphus mauritiana* was the fifth among the indigenous tree species in the village. Concerning the most prefered species by farmers *V. paradoxa* was ranked the top by 23% of the respondents. The second most preferred species was *T. indica* as reported by 17% of the respondents (Table 3.1). *Z. mauritiana* was the fifth most preferred among the indigenous tree species. Respondents claimed almost all the trees species including *T. indica* and *Z. mauritiana* have a role in improving soil fertility, with *V. paradoxa* cited as the top soil improving species by 34% of the respondents (Table 3.1). The result of the survey showed that majority of the respondents in the village (90%) practiced tree planting (Figure 3.1a). In response to the question on the most frequently planted trees, 37% of the respondents reported that mango (*Mangifera indica*) was the most frequently planted tree (Table 3.1). Among the indigenous tree species, the most freqently planted was *A. digitata*. *T. indica* was also planted by only 2% of the respondents. But non of the respondents planted *V. paradoxa* and *Z. mauritiana*. In terms of location of tree planting, most of the trees were planted on parkland fields as reported by 50% of the respondents. Homesteads were also reported as the second most preferred location for planting trees according to 35% of the respondents (Figure 3.2). In response to the question on the positive effects of trees on crops, 61% of the respondents reported that organic matter addition in the form of litter to the soil was the most positive effect of trees on crops (Figure 3.1b). The effect of maintainance of high soil moisture beneth trees was also cited by 13% of the respondents, while 8% said that trees served as wind breaks. Only 8% of respondents reported that trees did not have any effect on crops. In response to the question on the negative effects of trees on crops, tree shade was mentioned as the major negative effect of trees on crops according to 75% of the respondents (Figure 3.1c). 7% of the respondents mentioned that trees attracted bird pests which fed on crops (7%), while 7% reported that increased soil moisture under trees and tree roots having a negative effect on crops. Concerning the positive effects of crops on trees (Figure 3.1d), 43% of the respondents mentioned that trees could benefit from the soil management practices such as tillage by farmers. 36% of the respondents also reported that trees are protected from bush fires when crop fields are cultivated. In response to the question whether crops have a negative effect on trees, 61% of the respondents mentioned that there was no negative effect. However 13% believed that the presence of crop residues could create a favorable condition for bush fires which could harm trees (Figure 3.1e). In response to the question whether there was a need to conserve existing trees on farms, a large mojority of the respondents (97%) reported that it was necessary to conserve existing trees as well as planting new ones (Figure 3.1f).

Table 3.1: Tree species present on farms, the preferred tree species, soil improving trees and the frequently planted trees in Siramana village

Rank	Tree species present on farms	Response (%)	Preferred trees species	Response (%)	Soil improving trees	Response (%)	Frequently planted trees	Response (%)
1	*Vitellaria paradoxa*	34	*Vitellaria paradoxa*	23	*Vitellaria paradoxa*	33	*Manguifera indica*	38
2	*Tamarindus indica*	14	*Tamarindus indica*	18	*Faidherbia albida*	12	*Citrus sp*	15
3	*Parkia biglobosa*	13	*Parkia biglobosa*	18	*Parkia biglobosa*	9	*Anacardium occidentale*	10
4	*Manguifera indica*	8	*Adansonia digitata*	12	*Manguifera indica*	8	*Psidium guayava*	8
5	*Adansonia digitata*	8	*Manguifera indica*	12	*Detarium microcarpum*	5	*Eucalyptus sp*	5
6	*Ziziphus mauritiana*	5	*Ziziphus mauritiana*	8	*Tamarindus indica*	4	*Azadirachta indica*	3

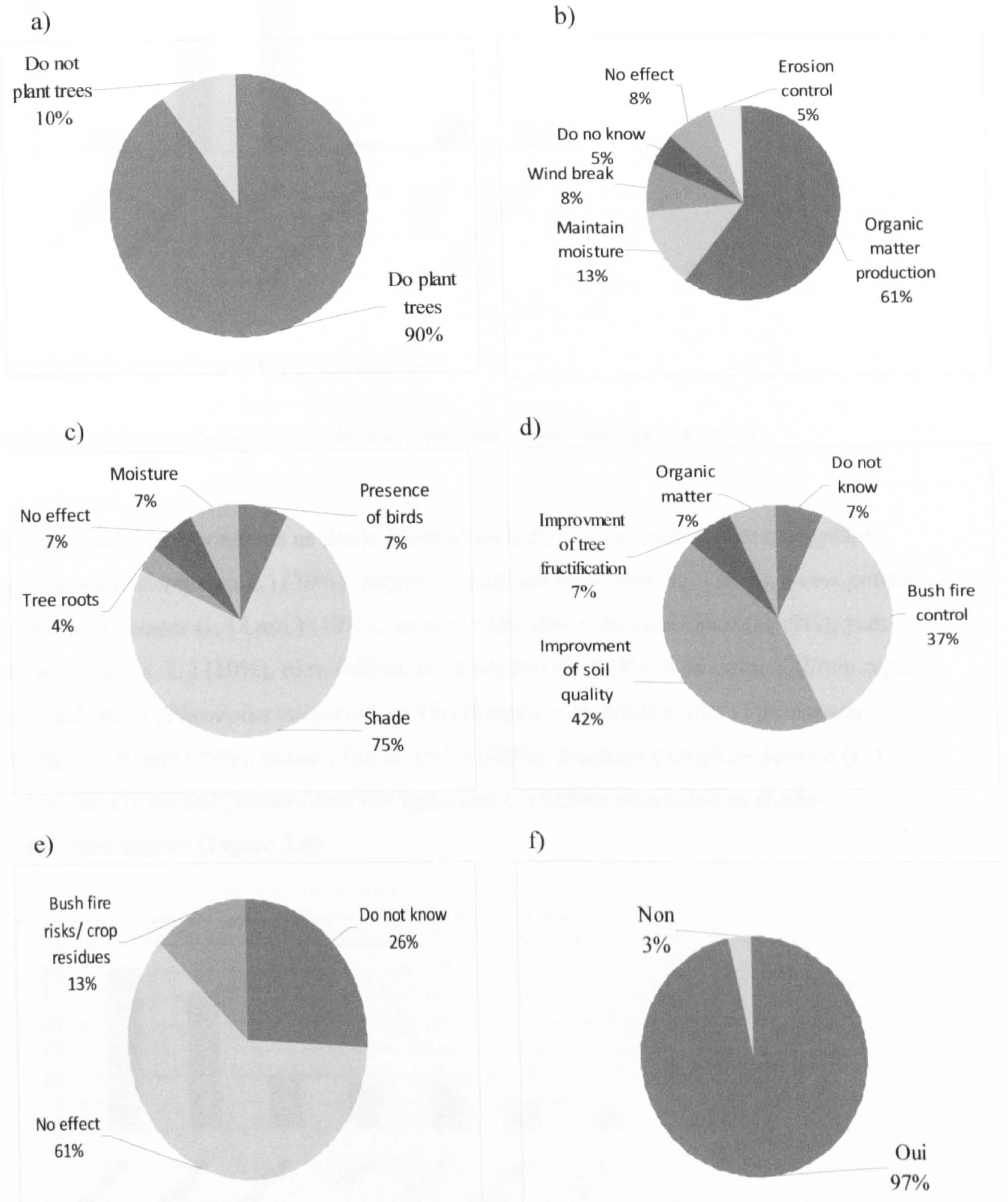


Figure 3.1: Farmers' tree planting activities (a), positive effects of parklands trees on crops (b), negative effect of trees on crops (c), positive effects of crops on parkland trees (d), negative effects of crops on trees (e), need for conseving or planting trees on farm (f).

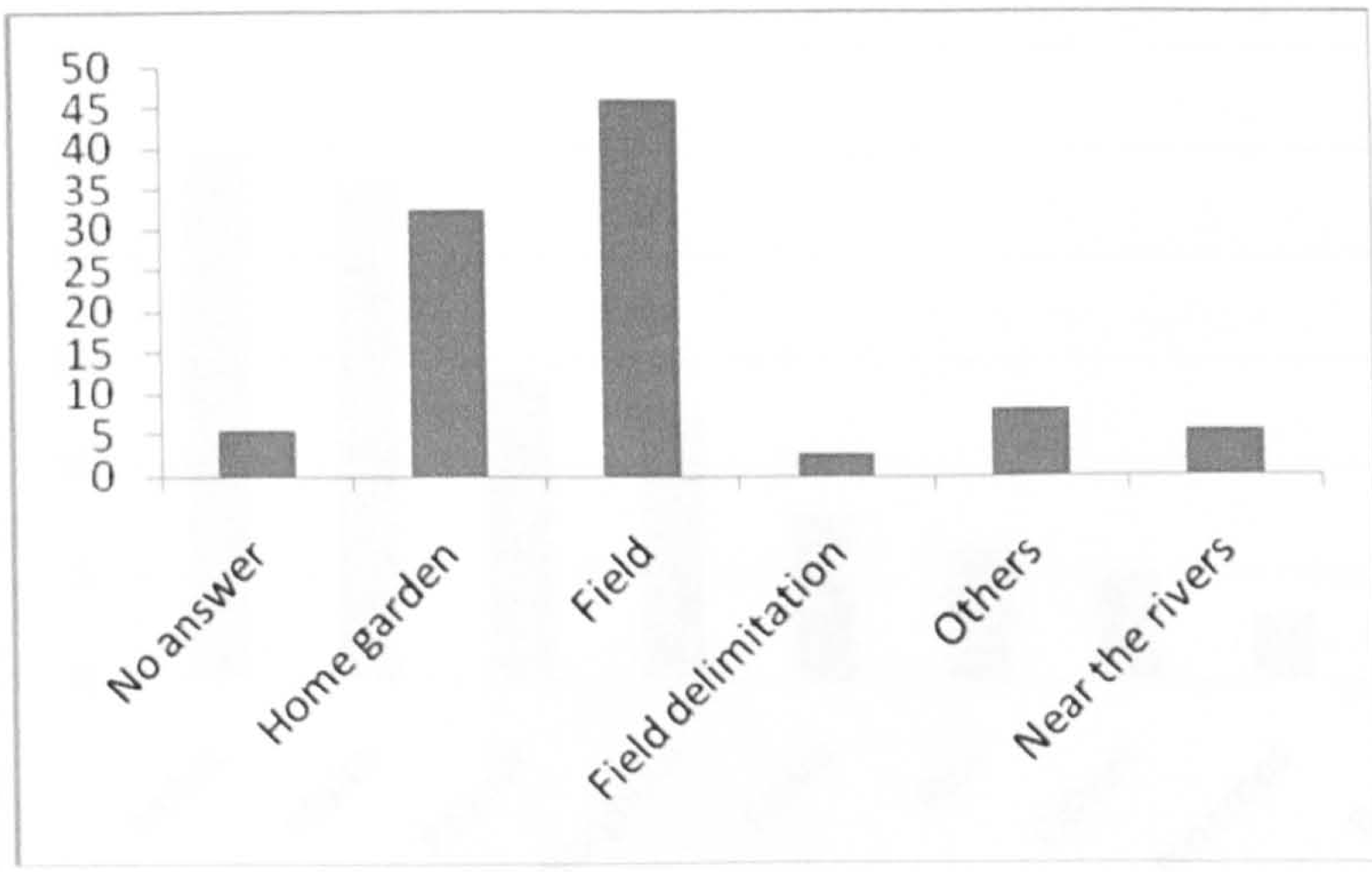


Figure 3.2: Locations of tree plantation

3.3.2. Local knowledge on shade-tolerant and shade-intolerant crops

Crops cited by respondents as shade-tolerant included, in desending order, eggplant (*Solanum aethiopicum L.*) (30%), pepper (*Capsicum frutescens L.*) (26%), sweet potato (*Ipomoea batatas* (L.) Lam.) (10%), cassava *(Manihot esculenta* Crantz) (10%), yam *(Dioscorea* sp. L.) (10%), okra *(Hibiscus esculentus* (L.)) (8%) and onion (*Allium cepa* L.) and beans *(Phaseolus vulgaris* L.) (7%) (Figure 3.3), while millet (*Pennisetum typhoides* Pearl) (25%), maize *(Zea mays* L.) (23%), sorghum *(Sorghum bicofor* (L.) Moench) (14%) and peanut *(Arachis hypogaea* L.) (12%) were cited as shade-intolerant species (Figure 3.4) .

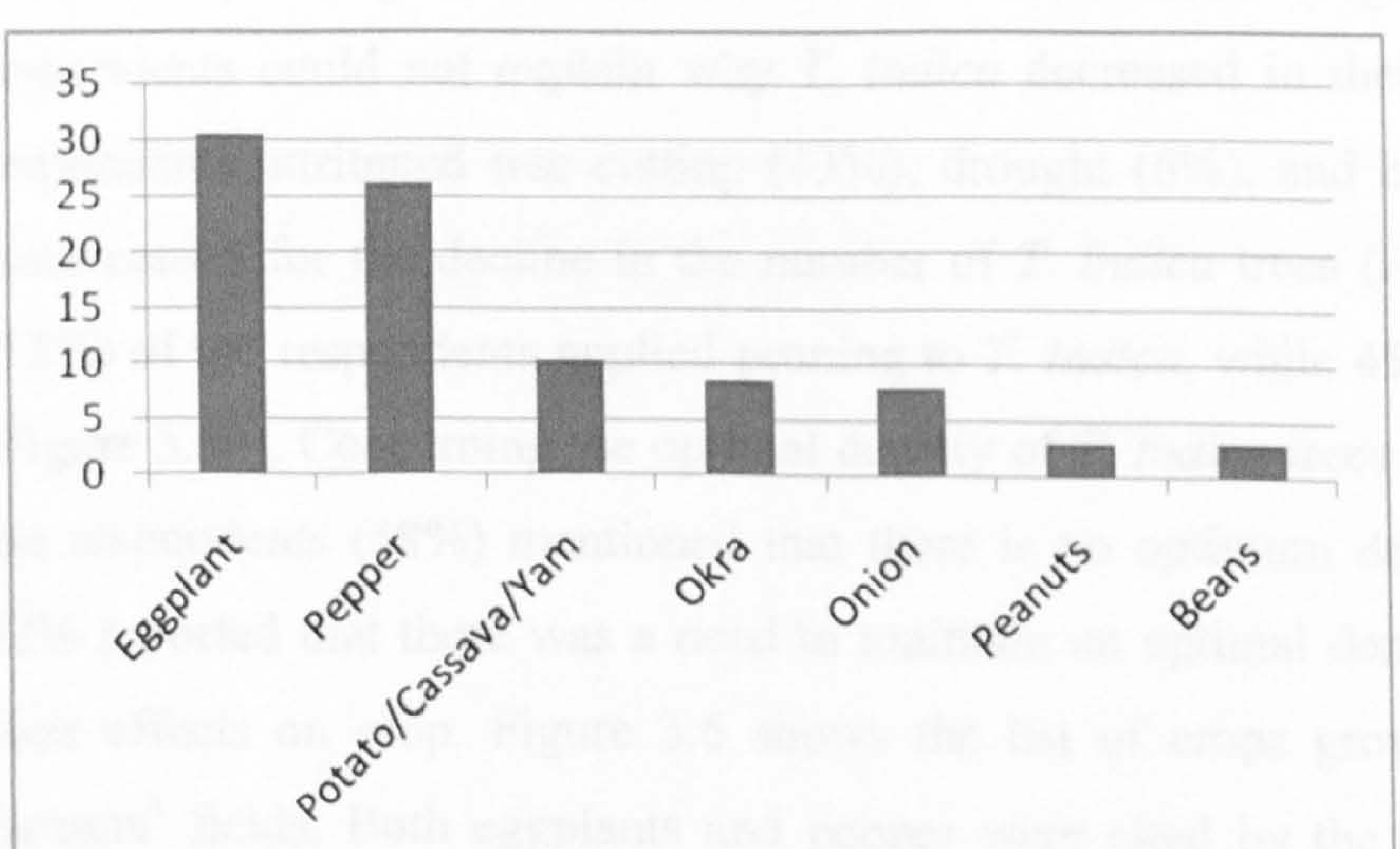


Figure 3.3: Shade-tolerant crops according to farmers

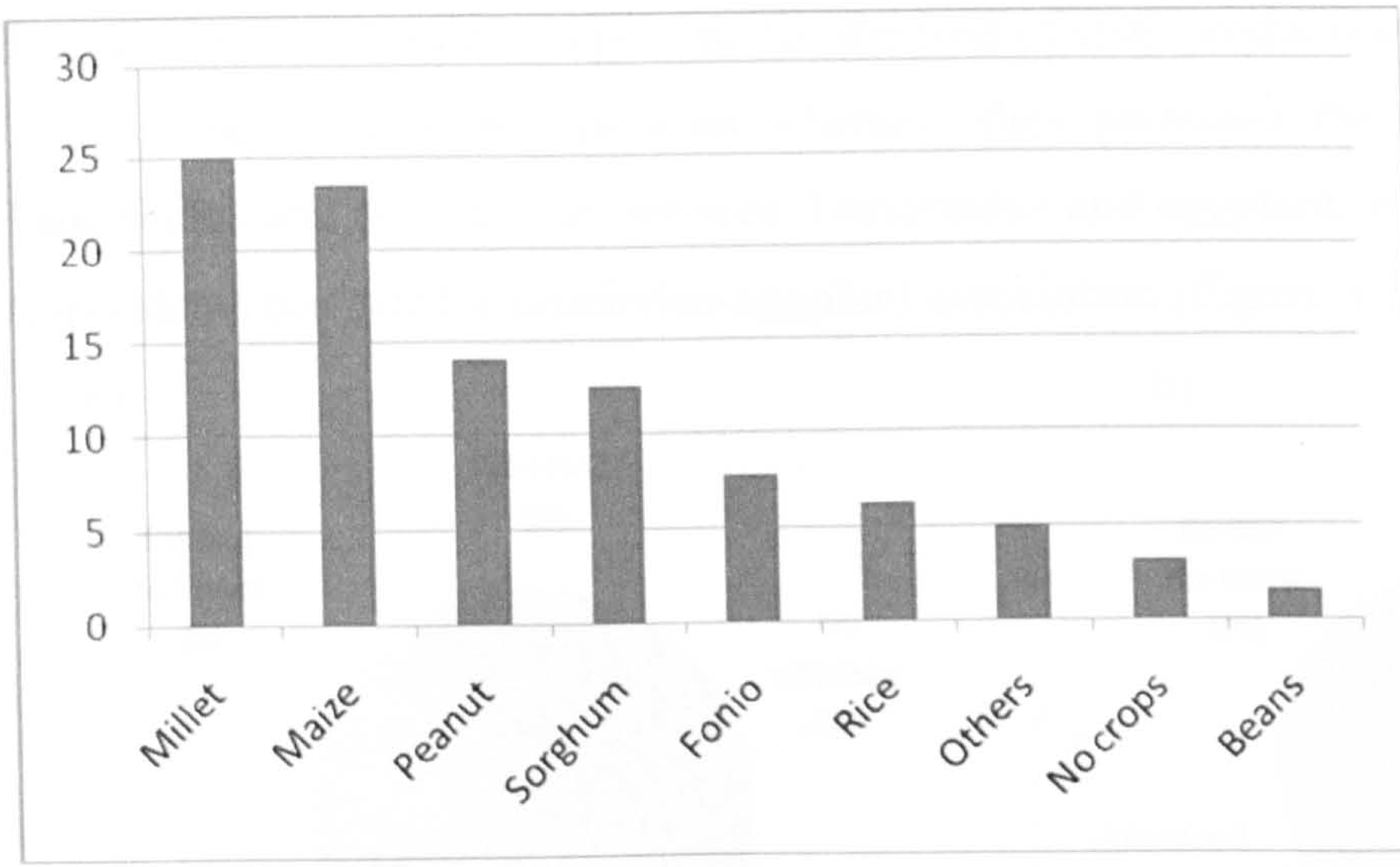


Figure 3.4.Shade-intolerant crops species

3.3.3. Local knowledge on use and management of *Tamarindus indica*

58% of the respondents mentioned that the protection of *T. indica* seedlings was the major management practice they applied to the species, while 33% never applied any management to the species (Figure 3.5a). Weeding was also reported to be practised by 7% of the respondents. Only 3% mentioned that cutting of *T. indica* was forbiden by National Forestry Law. In response to the question whether the number of *T. indica* trees had increased or decreased on farms, 46% of the respondents believed that the number had decreased while 37% thought that the number had increased. 17% did not observe any change in the number of *T.indica* on farms (Figure 3.5b). 65% of the respondents could not explain why *T. indica* decreased in their fields. Some of the respondents attributed tree cutting (13%), drought (6%), and bush fire (10%) as the main causes for the decline in the number of *T. indica* trees (Figure 3.5c). Majority (52%) of the respondents applied pruning to *T. indica*, while 45% said they never did (Figure 3.5d). Concerning the optimal density of *T. indica* trees on farm, a majority of the respondents (58%) mentioned that there is no optimum density of tree, whereas 42% reported that there was a need to maintain an optimal density of trees to reduce their effects on crop. Figure 3.6 shows the list of crops grown under *T. indica* in farmers' fields. Both eggplants and pepper were cited by the majority (17%) of the respondents as the most commonly cultivated crops under Tamarindus trees. The majority of the respondents (36%) mentioned that the products derrived from

Tamarindus trees could compensate for the loss of crop production under trees (Figure 3.7a). In response to the question whether they preferred the association between Tamarindus and sorghum or between Tamarindus and eggplant, majority (67%) of the respondents preferred Tamarindus-eggplant association (Figure 3.7b).

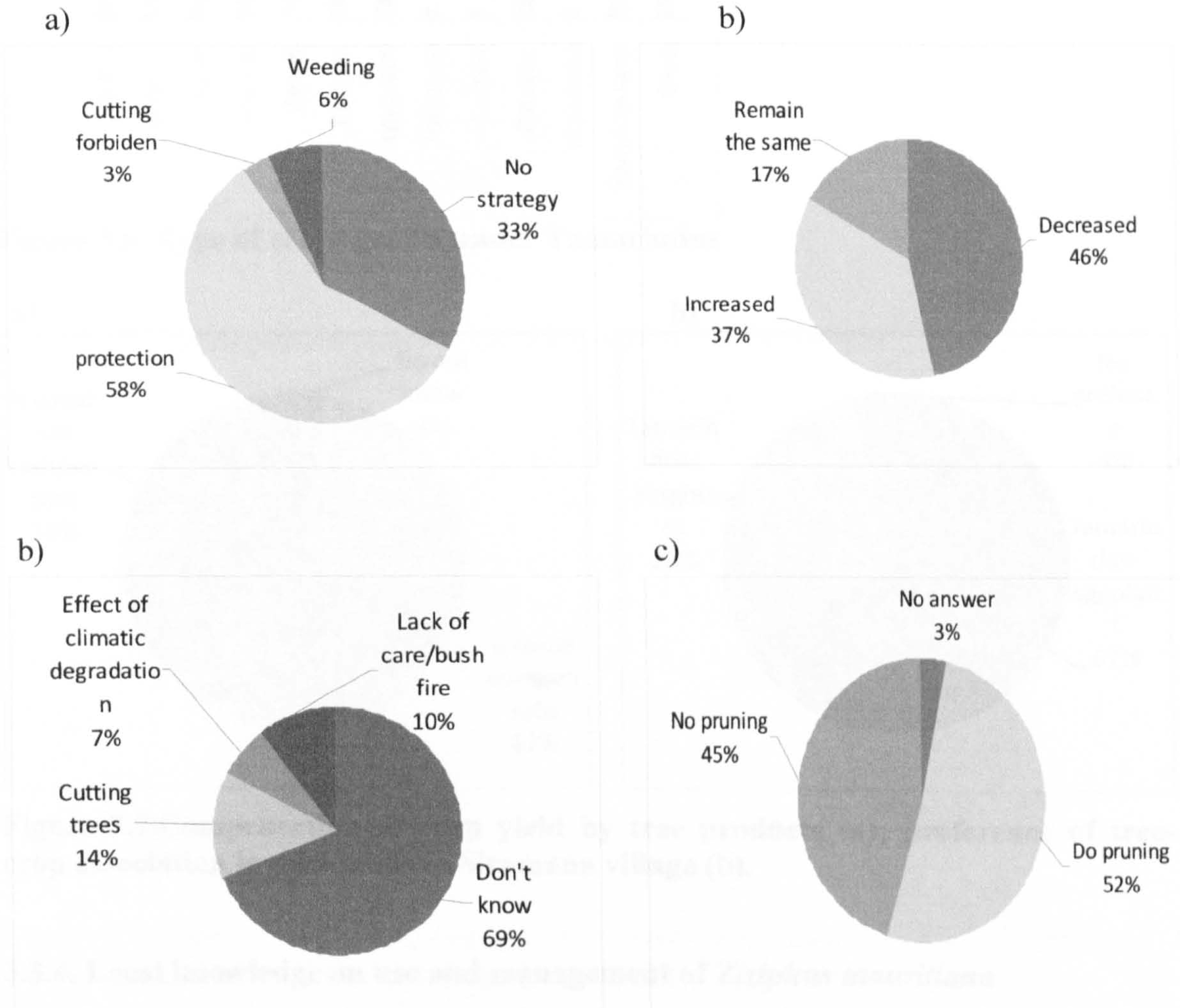


Figure 3.5.Traditional management practices (a), status of *T. indica* in parklands (b), reasons for the decline in the number of trees (c) and the pruning practices of *T. indica* in parklands in Siramana (d).

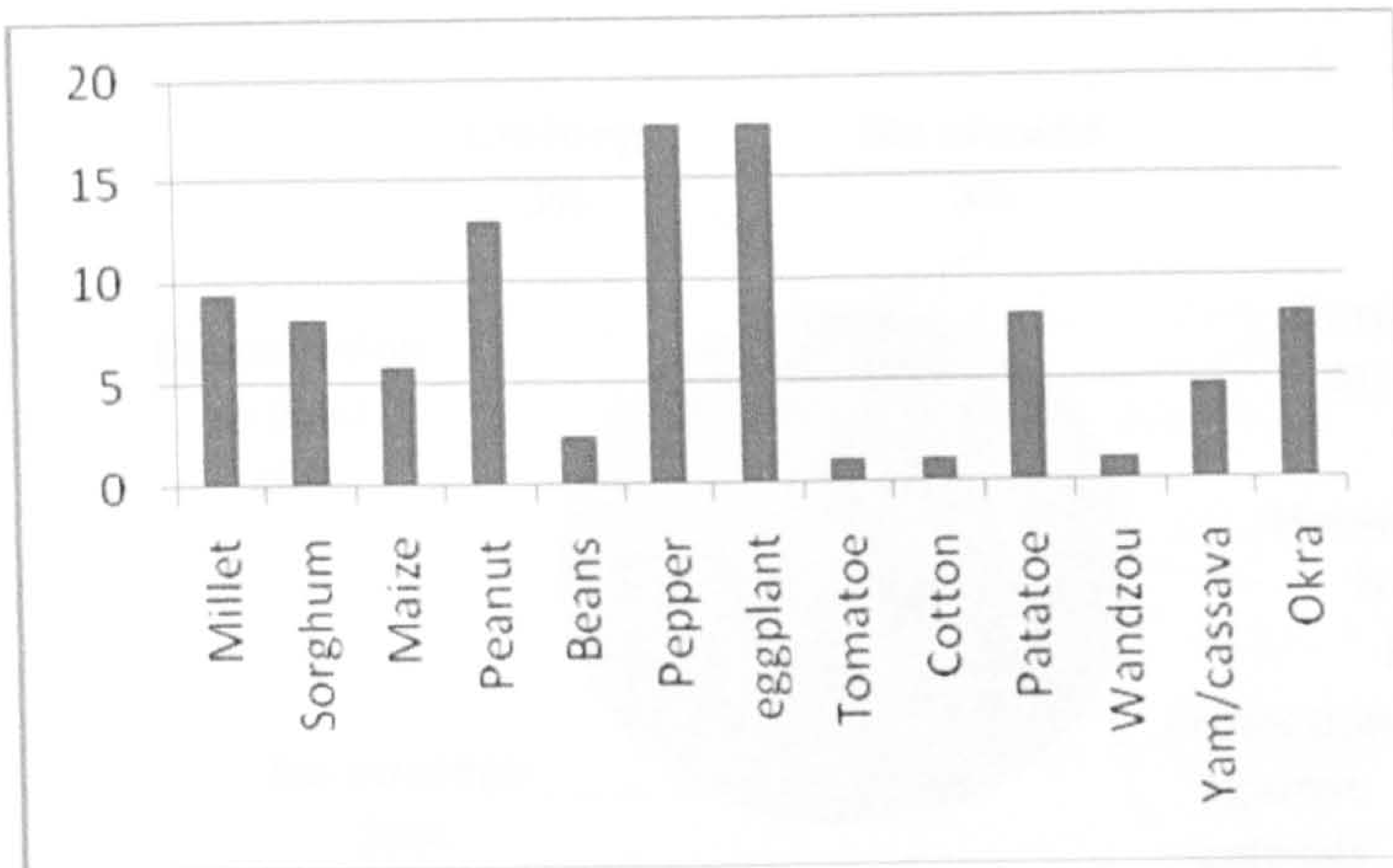
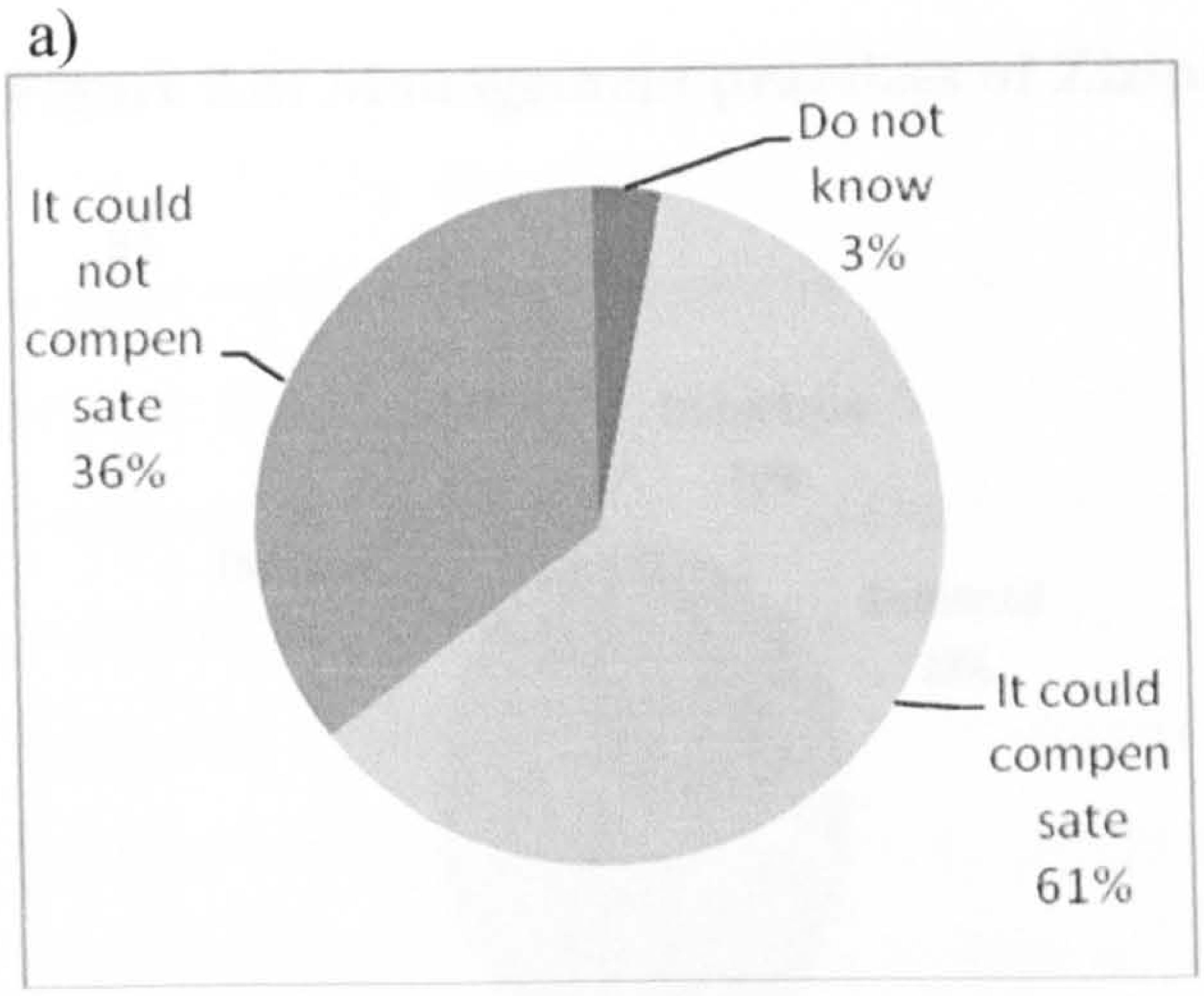


Figure 3.6. Type of crops grown under Tamarindus

a)



b)

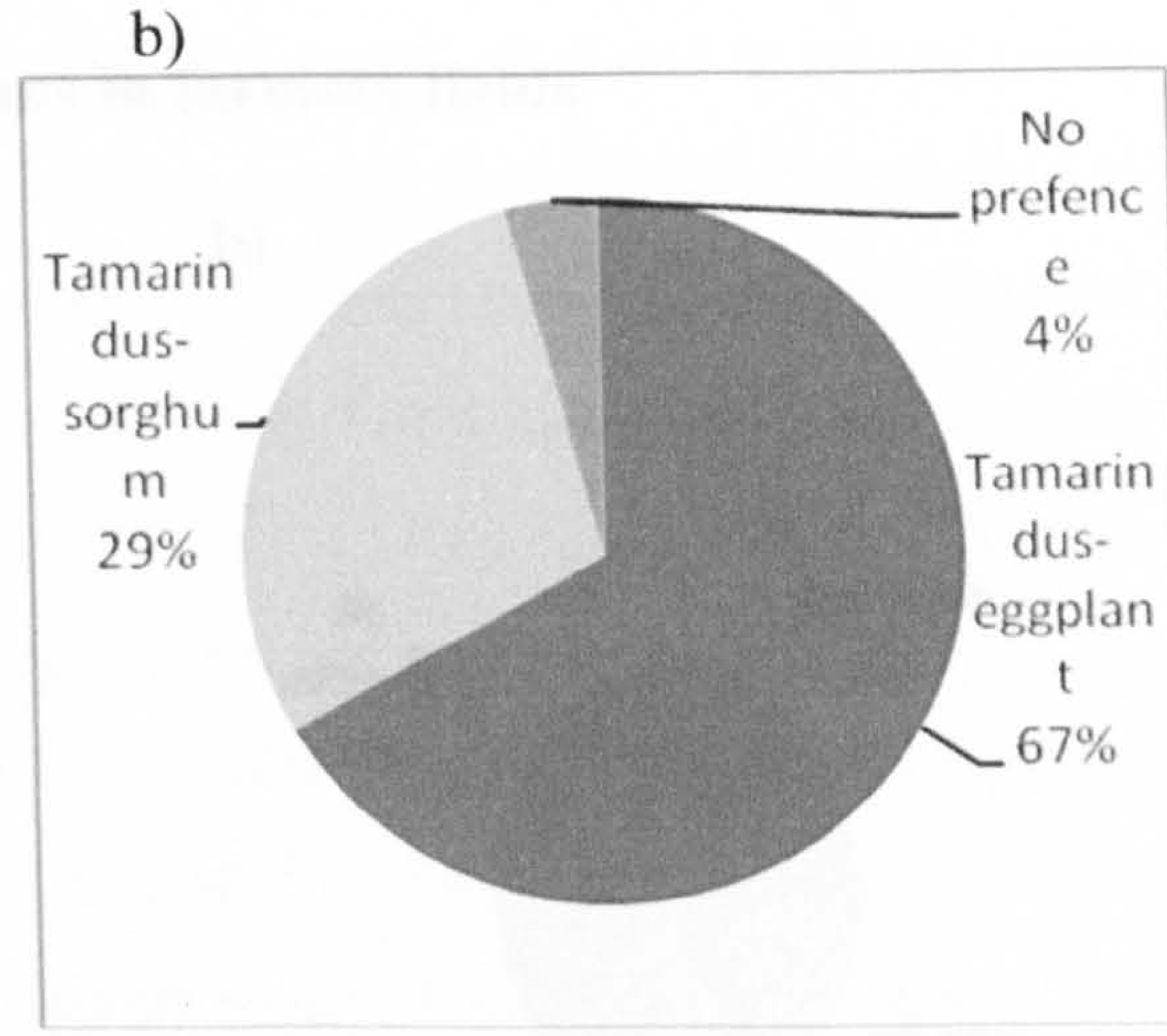


Figure 3.7.Compensation of crop yield by tree products (a); preference of tree-crop association in parklands in Siramana village (b).

3.3.4. Local knowledge on use and management of *Ziziphus mauritiana*

Majority of the respondents (37%) never applied any management practice to *Z. mauritiana* trees. Some (20%) of the respondents reported that they removed *Z. mauritiana* trees from crop fields to prepare the land for crop cultivation, while another 20% reported that they left them in their fields. Some (20%) also mentioned that they cut the trees during crop harvest time to use them as a fence to protect harvested crops against animals (Figure 3.8). Most of the respondents (60%) thought that the number of Ziziphus trees has increased in their fields (Figure 3.9a). Half of the respondents (50%) mentioned that Ziziphus could imropve soil fertility (Figure 3.9b). The type of crops that were grown under Ziziphus are presented in Figure 3.10. According to 16% of the respondents, millet was the most commonly grown crop under Ziziphus trees.

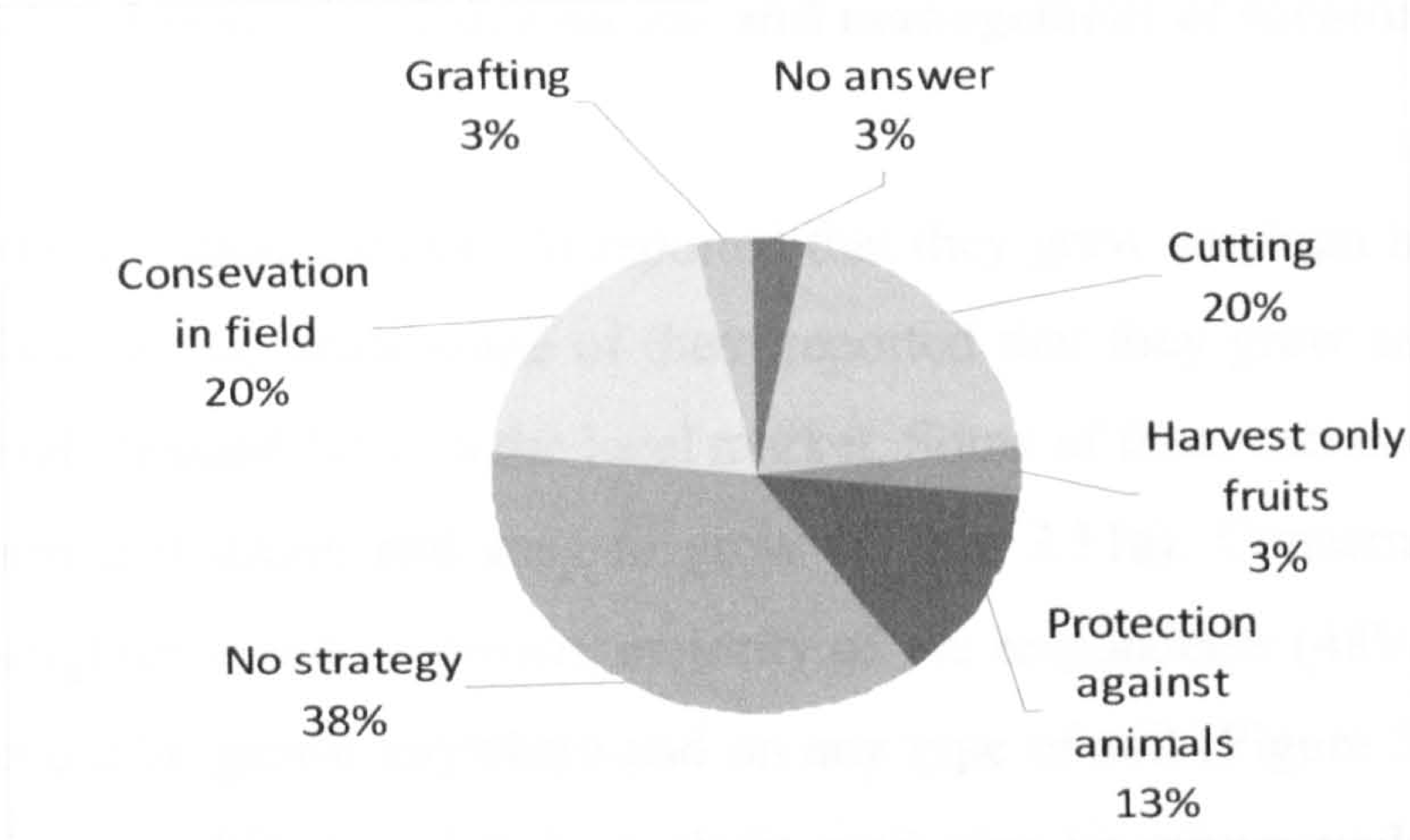


Figure 3.8: Management practices of Ziziphus in farmers fields

a) b)

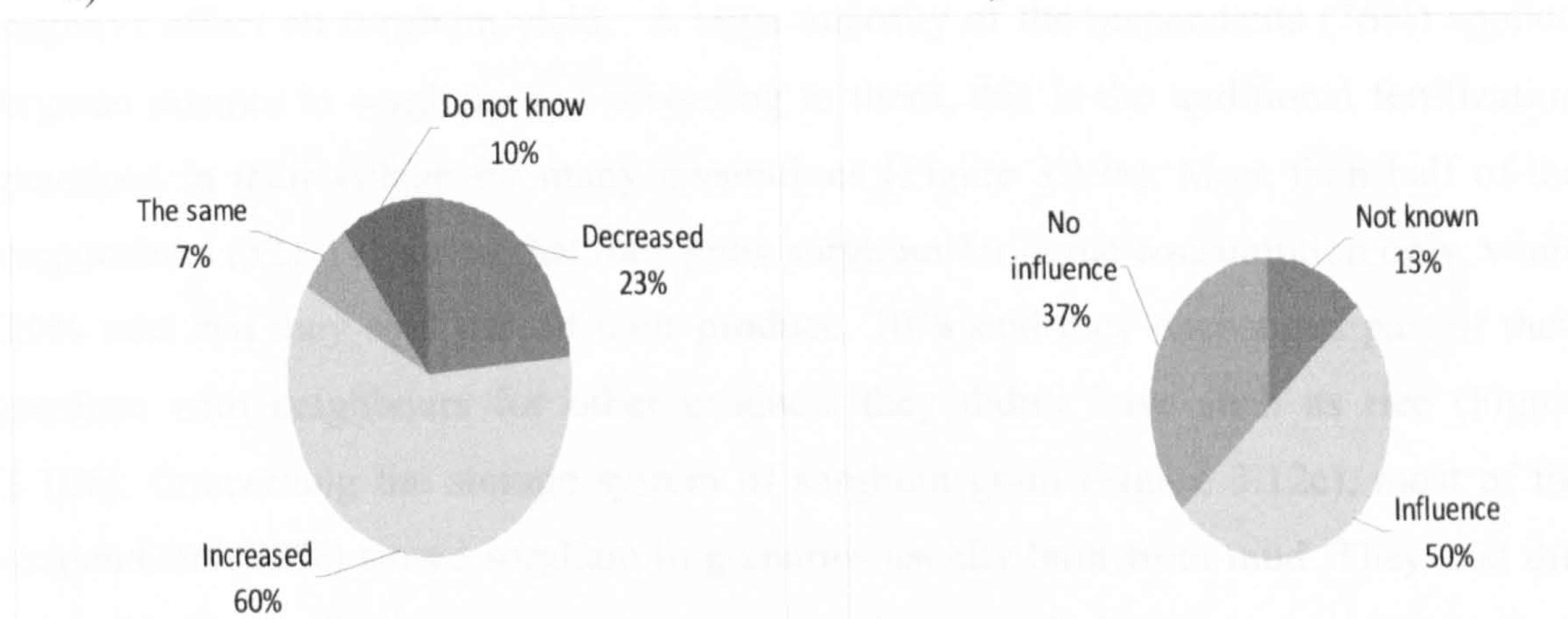


Figure 3.9: Density of *Z. mauritiana* in parklands (a); influence of *Z. mauritiana* on soil fertility in parklands in Siramana (b)

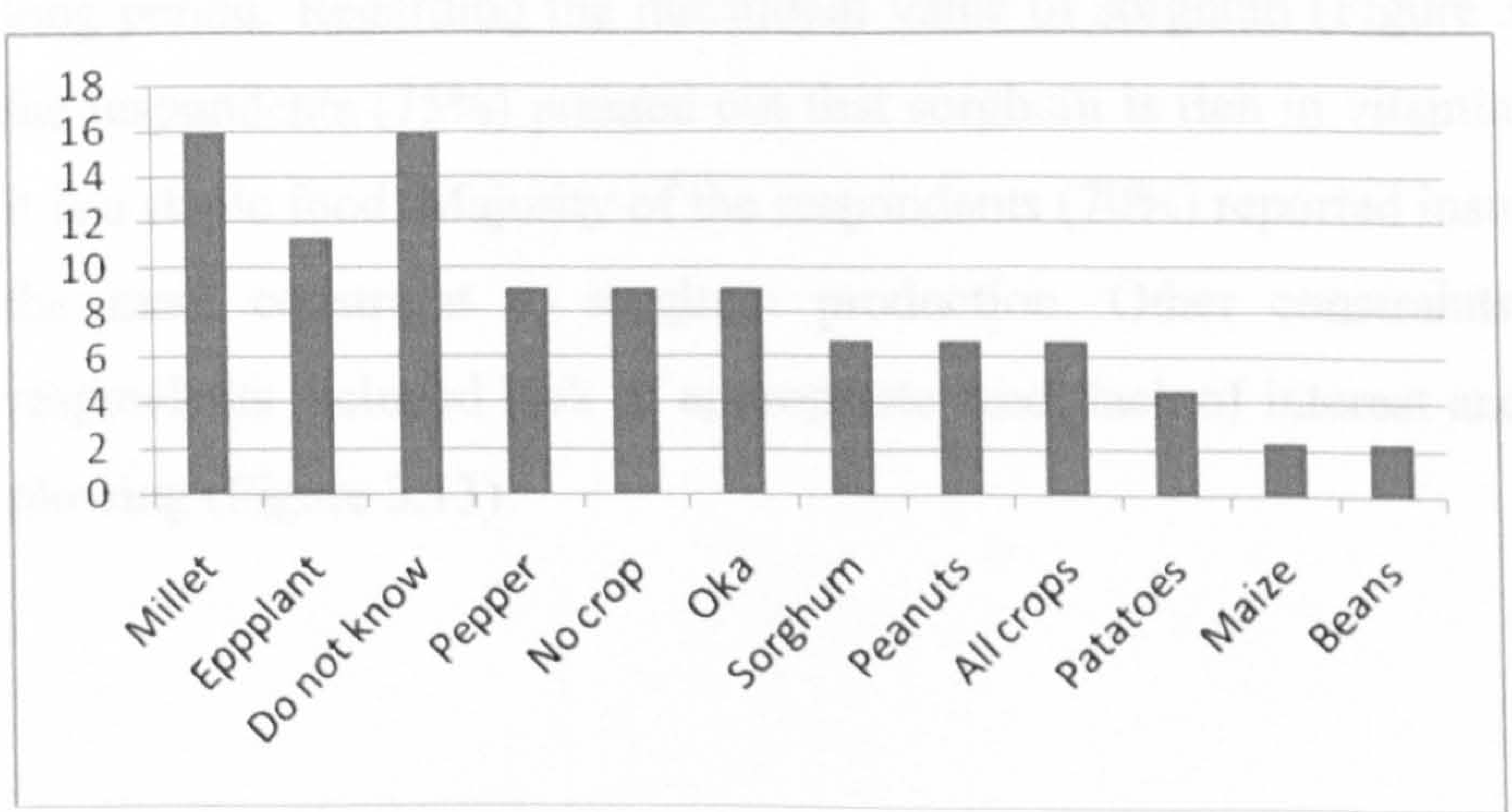


Figure 3.10: Crops grown under Ziziphus trees in parklands according to farmers in Siramana

3.3.5. Local knowledge on use and management of sorghum

Many respondents (42%) reported that they grew sorghum in order to meet household food needs, while some of them reported that they grew sorghum because there was high demand for it in the local market. Some of them mentioned that growing sorghum was a tradition and easy to grow (Figure 3.11a). Concerning suitable places where sorghum could be grown, majority of the respondents (48%) mentioned that sorghum could be grown anywhere and on any type of soil (Figure 3.11b). A large majority of farmers (88%) said that sorghum coul also be grown under trees (Figure 3.11c). In response to the question whether trees had an influence on associated sorghum yield (Figure 3.11d), the majority of respondents (85%) said that the shade of trees had a negative effect on sorghum yield. A large majority of the respondents (76%) applied organic manure to sorghum and according to them, this is the traditional fertilization practiced in their village for many generations (Figure 3.12a). More than half of the respondents (52%) reported that they grew sorghum for home consumption only, while 29% said that they sold part of their produce. 10% said they exchanged part of their produce with neighbours for other products they didn't have such as rice (Figure 3.12b). Concerning the storage system of sorghum grain (Figure 3.12c), most of the respondents (70%) stored sorghum in granaries usually built from mud. They said this was the most efficient means to store sorghum as it has been used for many generations. 9% used bags to store sorghum grain. Some of them (21%) reported using chemical insecticides in order to protect the grain against pests when they stored it for long period. Regarding the nutritional value of sorghum (Figure 3.12d), a majority of the respondents (75%) pointed out that sorghum is rich in vitamins. 22% reported that it is a staple food. Majority of the respondents (70%) reported insufficient rainfall to be the main constraint to sorghum production. Other constraints mentioned by the respondents included lack of appropriate seed, lack of interest and lack of animals for plowing (Figure 3.13).

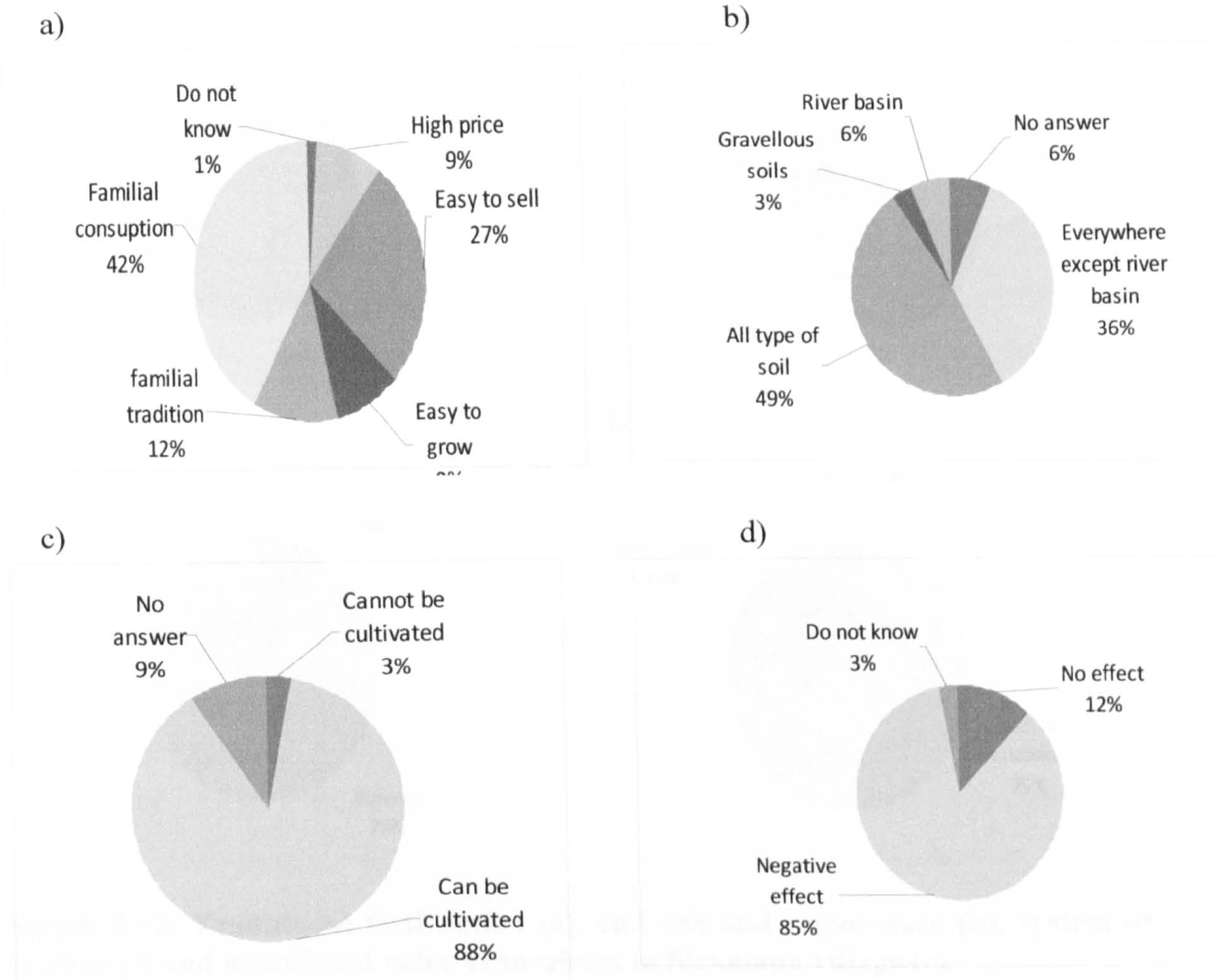


Figure 3.11: Objectives for growing sorghum (a), places where sorghum could be grown (b), cultivation of sorghum under trees (c) and the effect of tree shade on sorghum yield (d).

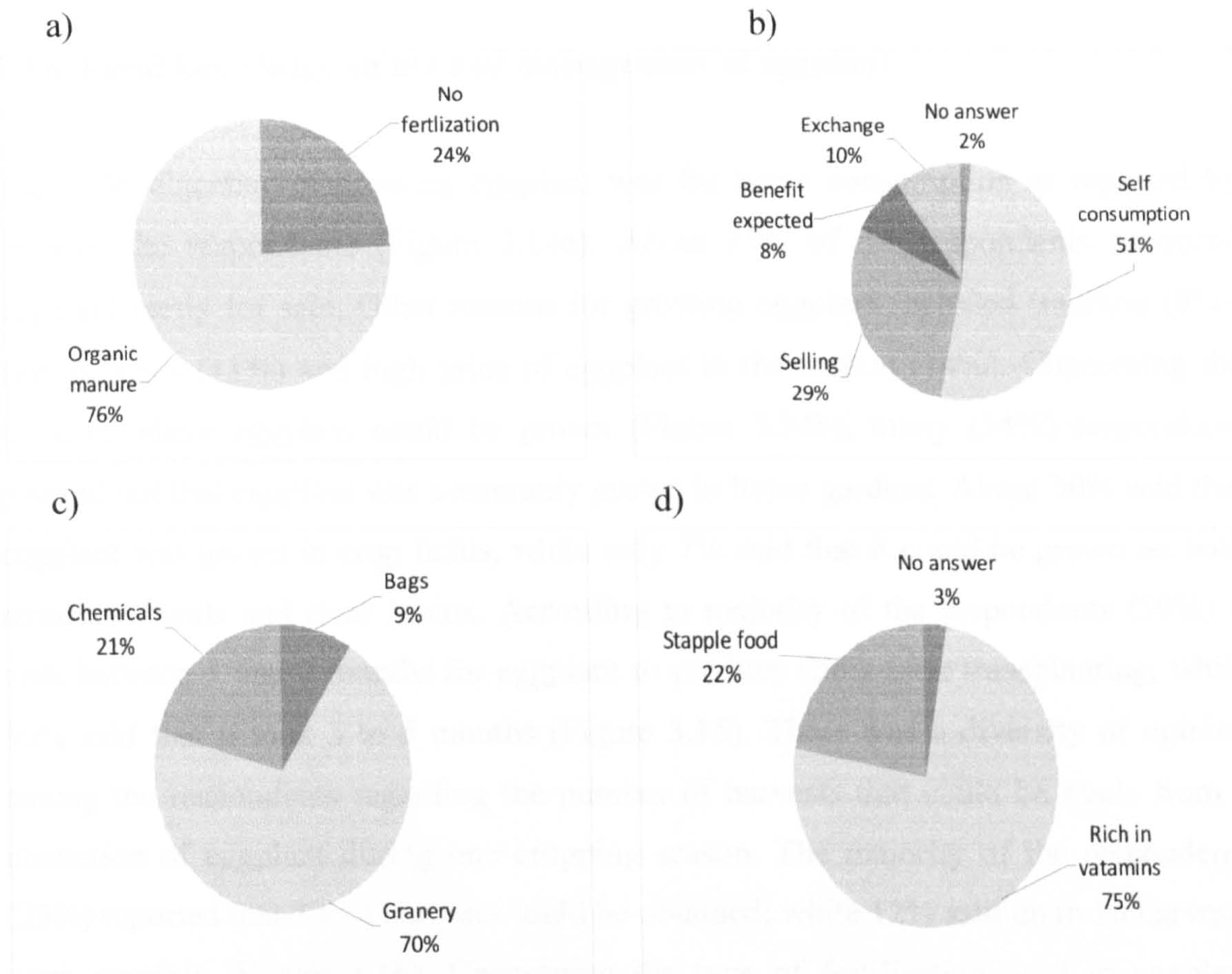


Figure 3.12: Traditional fertilisation (a), end use and importance (b), system of storage (c) and nutritional value of sorghum in Siramana village (c).

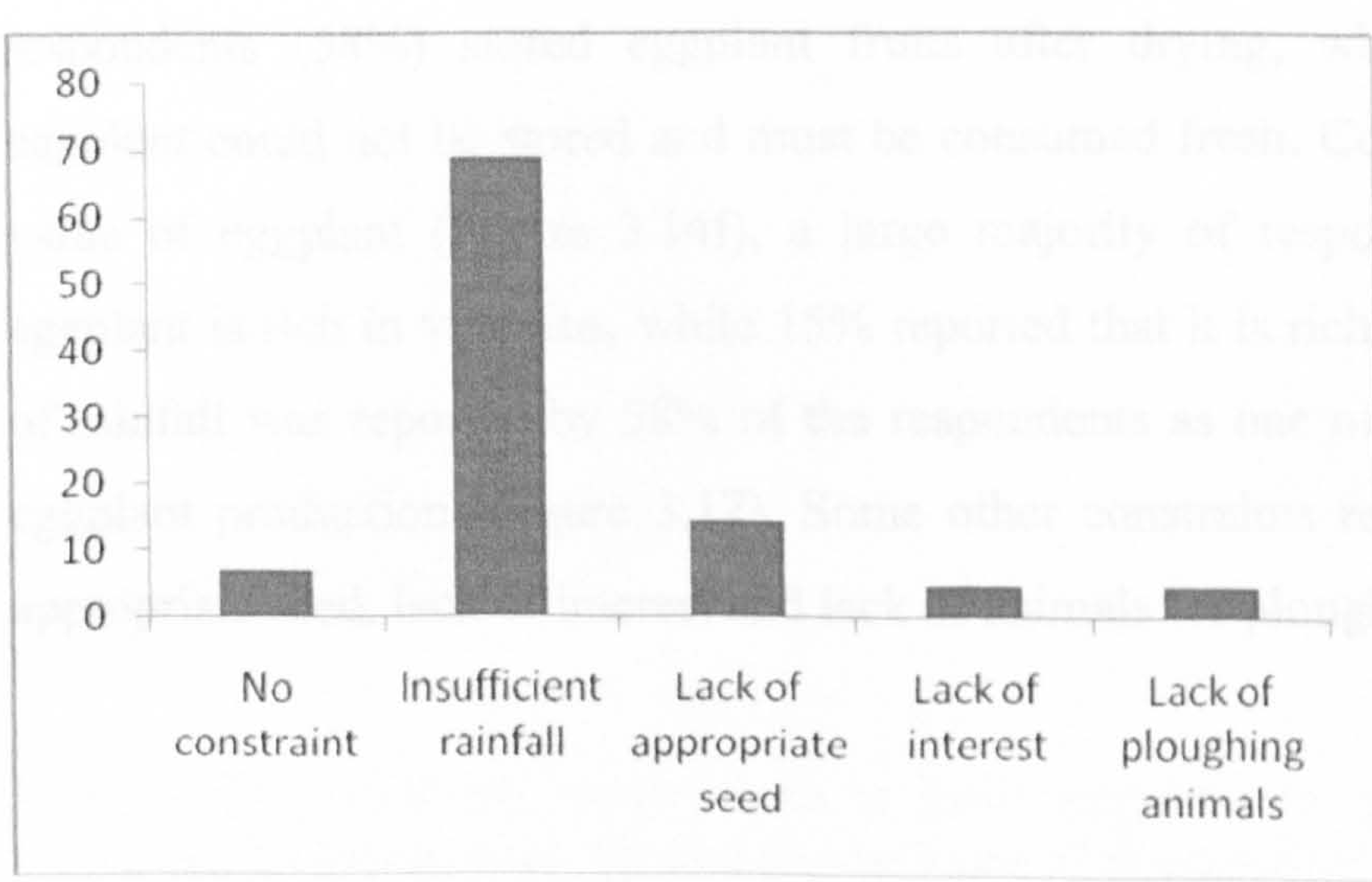


Figure 3.13: constraints to sorghum production

3.3.6. Local knowledge on use and management of eggplant

The main objective of growing eggplant was for home consumption as reported by 36% of the respondents (Figure 3.14a). About 31% of the respondents produced eggplant partly for sale. Other reasons for growing eggplant included tradition (8%), easy to grow (11%) and high price of eggplant in the market (14%). Concerning the location where eggplant could be grown (Figure 3.14b), many (54%) respondents pointed out that eggplant was commonly grown in home gardens. About 30% said that eggplant was grown in crop fields, while only 7% said that it could be grown on both termite mounds and river basins. According to majority of the respondents (50%) it took between 1 and 2 months for eggplant to produce fruits after transplanting, while 30% said that it took 3 to 5 months (Figure 3.15). There was a diversity of opinion among the respondents regarding the number of harvests that could be made from a plantation of eggplant during one cropping season. The majority of the respondents (23%) reported that 3 to 4 harvests could be obtained; while 12% said up to 10 harvests were possible (Figure 3.16). Concerning the type of fertilisation used in eggplant production (Figure 3.14c), the majority of the respondents (57%) used organic manure, while 37% used chemical fertilizers. According to the respondents, eggplant was produced mainly for sale (51%) and for household consumption (41%; Figure 3.14d). Concerning the storage of eggplant fruits (Figure 3.14e), the majority of the respondents (58%) stored eggplant fruits after drying, while 27% reported that eggplant could not be stored and must be consumed fresh. Concerning the nutritional value of eggplant (Figure 3.14f), a large majority of respondents (77%) said that eggplant is rich in vitamins, while 15% reported that it is rich in other nutrients. Lack of rainfall was reported by 58% of the respondents as one of the main constraints to eggplant production (Figure 3.17). Some other constraints reported included lack of appropriate seed, lack of interest and lack of animals for ploughing.

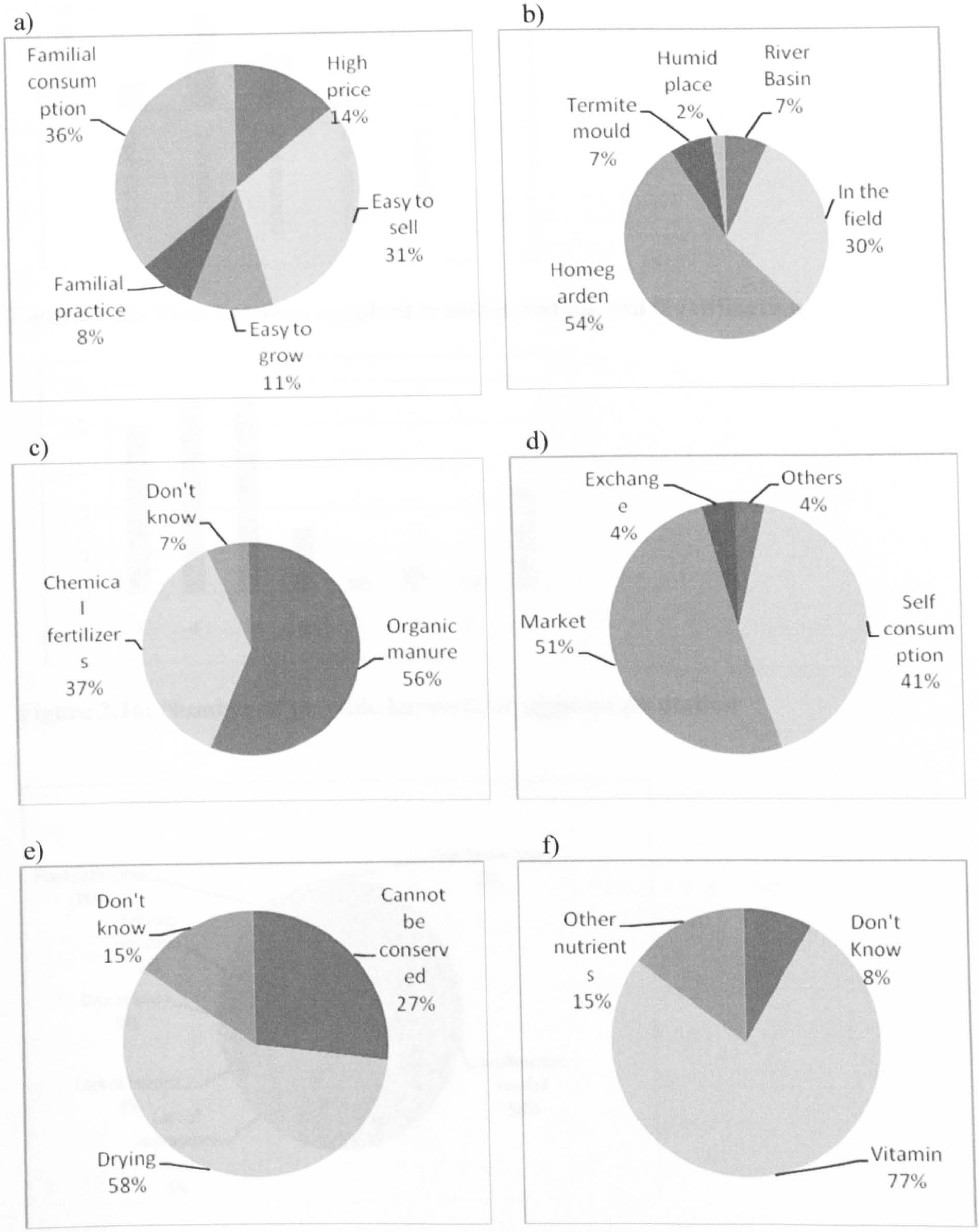


Figure 3.14: Farmers' motivations to grow eggplant (a) places of growing eggplant (b); type of fertilization used (c) and the end use of the products (d), storage techniques (e) and nutritional value of eggplant fruit in Siramana (f).

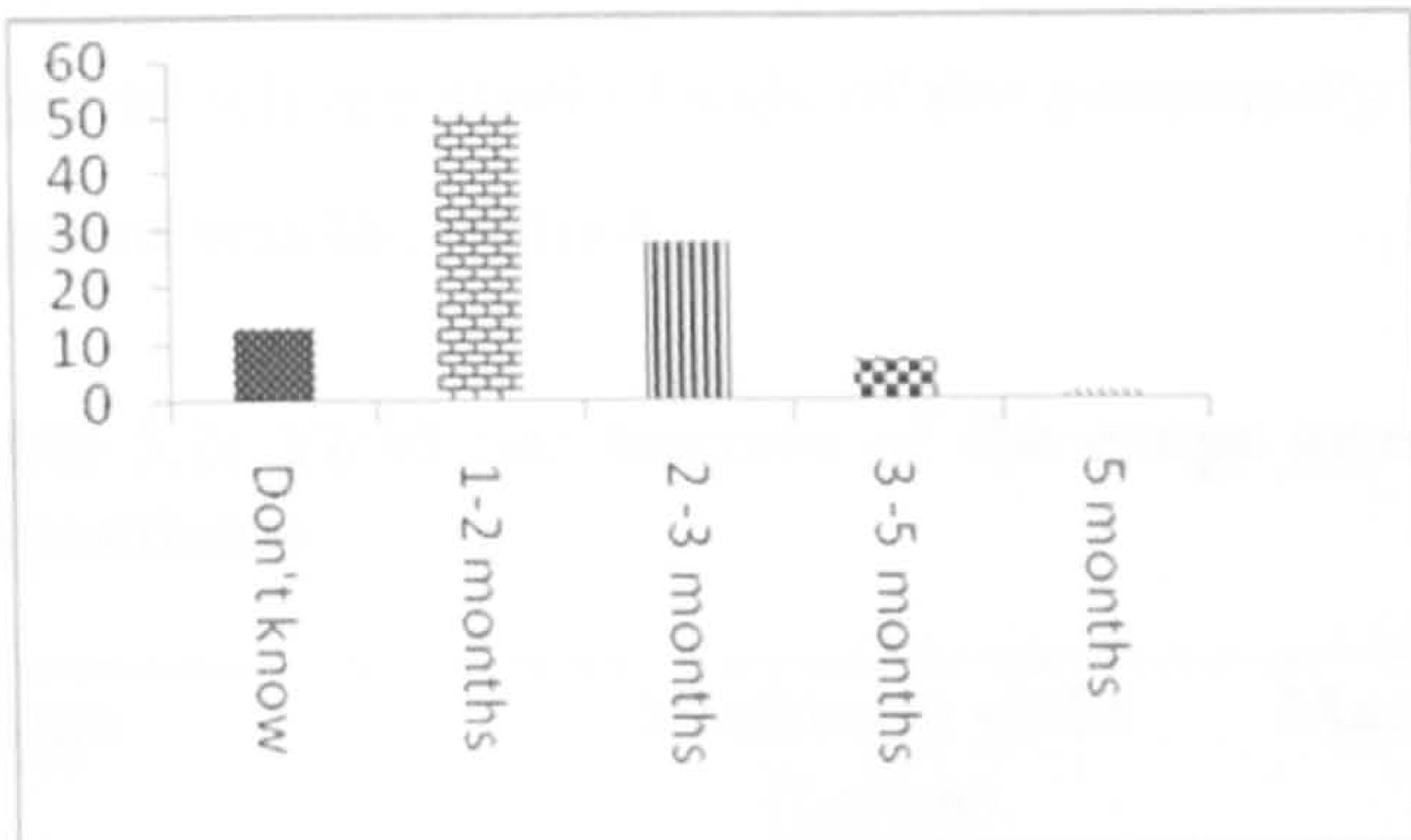


Figure 3.15: Time between eggplant transplantation and fructification

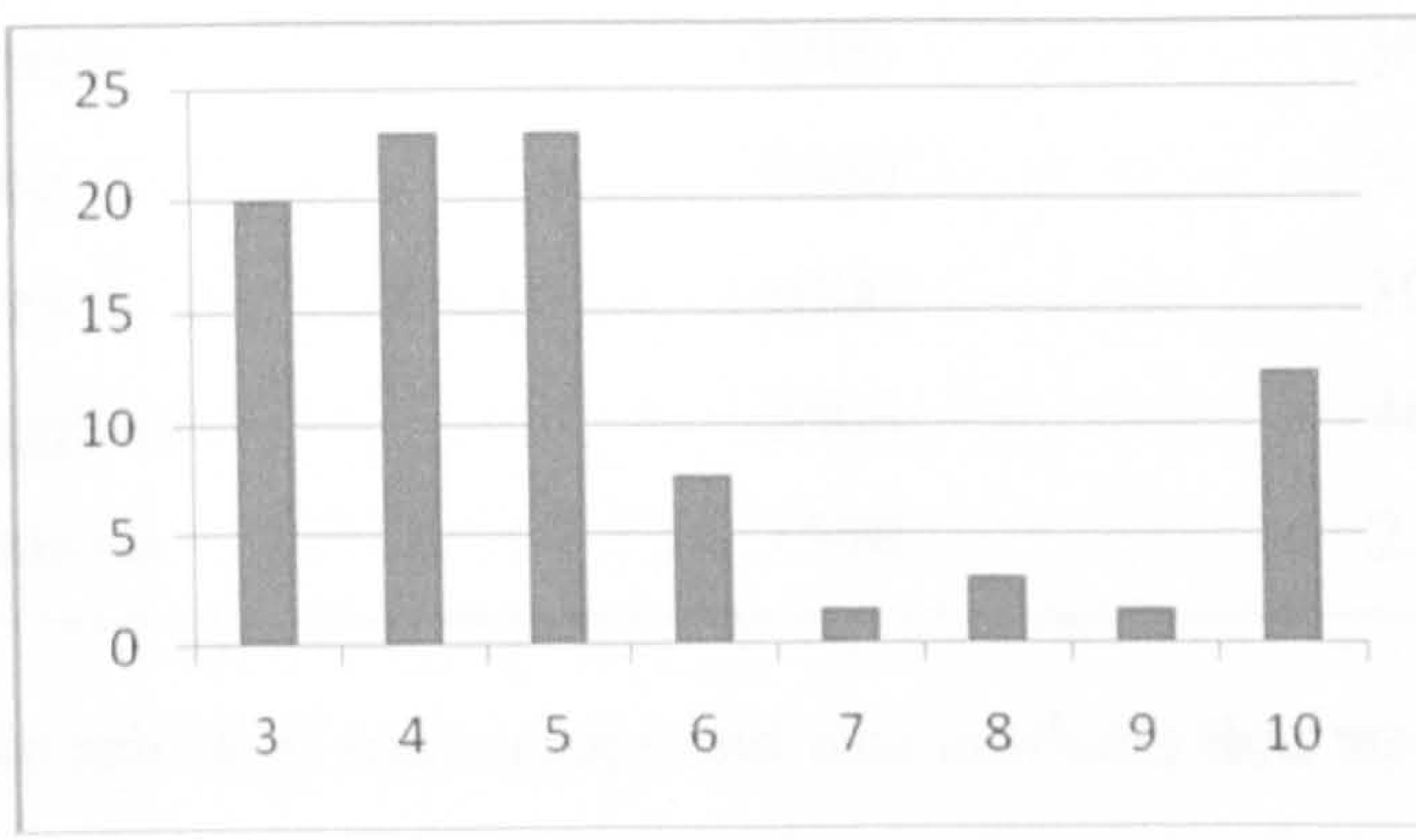


Figure 3.16: Number of possible harvests in eggplant plantation

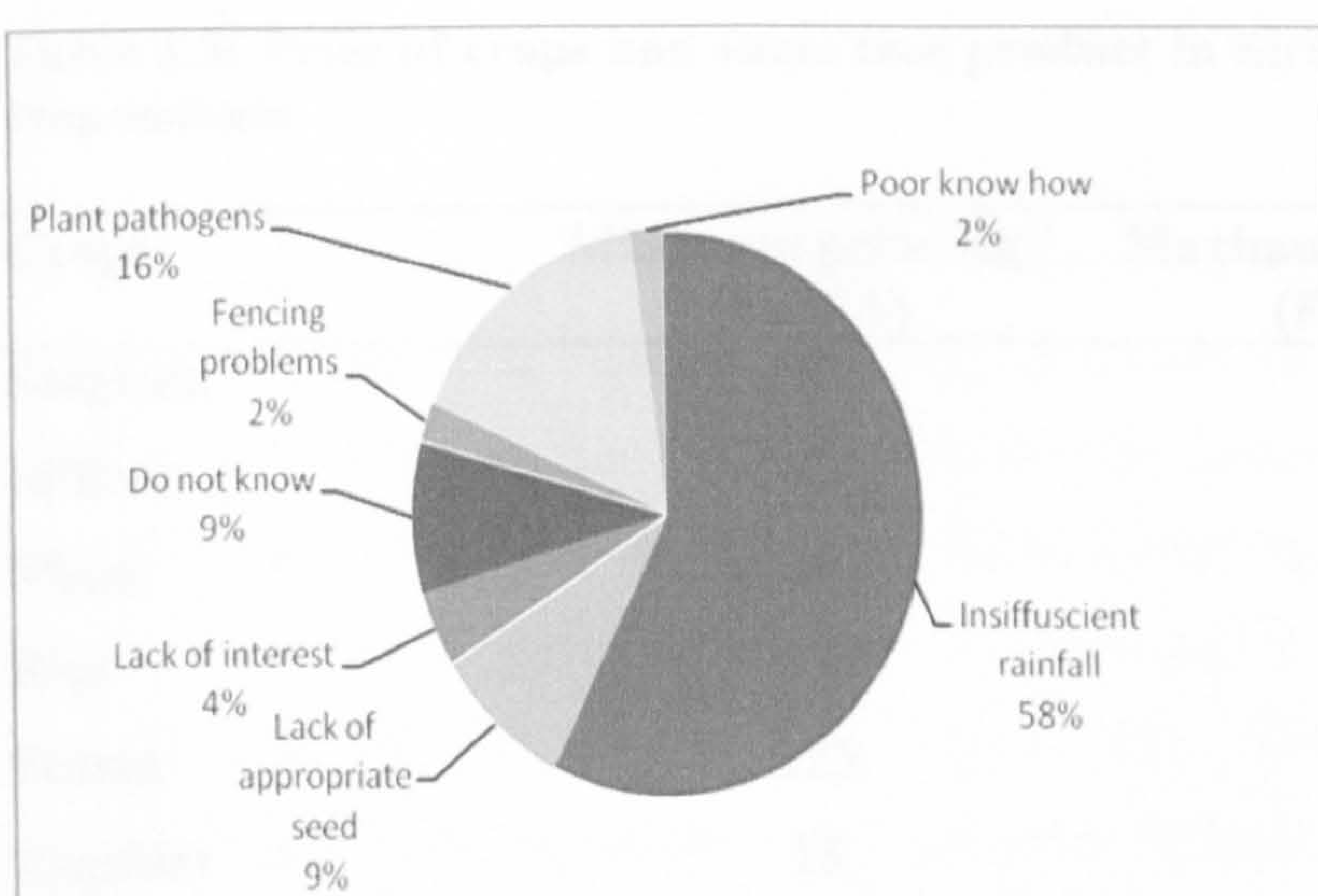


Figure 3.17: Constraints to eggplant production according to farmers in Siramana

3.3.7. Yield and marketing of crops and tree products

As shown in Table 3.2 the yields of maize and rice were higher than sorghum and millet which are staple foods of the community. Among vegetable crops the yield of eggplant was the highest.

Table 3.2: Yield per hectare of the crops grown in Siamana village according to respondents

Crops	Minimum yield (kg/ha)	MaximumYield (Kg/ha)
Sorghum	500	1500
Millet	400	1500
Maize	1500	5000
Rice	1000	5000
Peanut	1000	3000
Eggplant	2000	4000
Tomato	1500	2500

The prices of some crops and tree products that are shown in Table 3.3 were obtained from the respondents. According to the respondents the minimum price was for periods after crop harvest, while the maximum was for periods of food scarcity.

Table 3.3: Price of crops and some tree product in Siramana village according to respondents

Crops	Minimum price Kg^{-1} (F CFA)	Maximum price Kg^{-1} (F CFA)
Sorghum	90	125
Millet	75	150
Maize	50	110
Rice	200	275
Peanut	225	400
Eggplant	15	60
Tomato	15	60
Pepper (dry)	500	1500
Tamarindus fruit	100	250
Ziziphus fruit (dry)	100	150

3.4. Discussion

3.4.1. Local knowledge on use and management of parkland tree species

The result of the survey showed that 17 tree species were cited by respondents to be present in the parklands in Siramana. However, this list is not exhaustive because many other species are also found in the village such as *Ficus gnafalocarpa*, *Ficus toninghi, Sterculia setigera* and *Saba senegalensis* (Personal observation). It appears that the most cited trees were *Vittelaria pradoxa*, *Tamarindus indica* and *Parkia biglobosa*. Similar high diversity of tree species has been reported for parklands by previous workers. For example, Samba *et al.* (2001) reported 38 tree species in the parkland they studied in Senegal. Agea *et al.* (2007) also conducted a study in parkland in Uganda and found 16 indigenous fruit trees. It is worthwhile mentioning that *Mangifera indica* and *Eucalyptus spp* are exotic species but are well adapted to the conditions in the region. It is also worthwhile mentioning that not all the trees species cited by farmers in the present study are fruit trees but they are retained on farms for other useful purposes. For instance *Khaya senegalensis* is not a fruit tree but has high medicinal and cultural values. Eucalyptus is highly valued for its timber and poles and grows very fast. *Isoberlina doka* and *Daniella oliveri* have high medicinal value and they are used as timber, poles and fuelwood.

Concerning the most preferred species, *V. paradoxa* was ranked the top followed by *T. indica* and *P. biglobosa*. This finding is in agreement with the results of Bonkoungou *et al.* (1998) who found that the three species were among the top preferred species in four Sahelian countries (Mali, Senegal, Burkina Faso and Niger). Maghembe *et al.* (1998) found that *A. digitata, S. birrea, T. indica* and *Z. mauritiana* were among the top preferred species in Southern Africa. The results of a field survey by Teklehaimanot (2008) conducted in 5 countries in Eastern Africa showed that local people's tree species preferences varied from country to country. The top ranking species were as follows according to countries: *Sclerocarya birrea*, *Balanites aegyptiaca*, *Cordeauxia edulis*, *Vitellaria paradoxa* and *Vitex payos* in Tanzania, Sudan, Ethiopia, Uganda and Kenya respectively. With the exception of the last three species (F. *albida, A. leocarpus and E. camaldulensis*), all the other cited trees are indigenous fruit trees. This preference reflects the importance of indigenous fruit trees for the local communities. All the respondents reported that their families consumed the indigenous fruits daily throughout the year and that they constituted a regular source of income. This result is in agreement with the findings of Dhillion and Gustard (2004) who reported that baobab (*A. digitata*) leaves are consumed in Cinzana village in Mali throughout the year. The importance of local fruit trees in rural people's diet and income has been widely documented by many previous workers (Hall *et al.*, 1997; Teklehaimanot, 2004; Boffa, 1999; Dhillion and Gustard, 2004). The income generated by parkland tree products can reach from 20 to 50% of the household income in some West African countries (Boffa, 2000).

Looking at tree species that can improve soil fertility, the majority of the respondents believed that *V. paradoxa* (Karité) has a high soil improving property, followed by *Faiderbia albida* and *Parkia biglobosa*. The high soil improvement property of leaves of Karité has been reported by Traoré (2002). The soil improving property of *Faiderbia albida* is widely reported in the literature (Charreau and Vidal, (1965); Boffa, (1999); Poshen (1986). ICRAF (1996) reported that the improved nitrogen availability was the major parameter which contributes to crop productivity under *F. albida* tree.

Majority of the respondents in Siramana village did tree planting. But the most frequently planted trees were *Mangifera indica* and *Citrus sp* which are exotic trees. This result in agreement with the findings of Gerhardt and Nemarundwe (2006) who found in Zimbabwe, that the most planted trees were exotic species. People tend to protect and manage the indigenous trees growing around their homesteads rather than deliberately planting new ones (Campbell *et al.*, 1998; Gerhardt and Nemarundwe, 2006). Local fruit trees such as *A. digitata*, *T. indica* and *P. biglobosa* were also cited to be planted by few of the respondents. The finding of the present study is in accordance with the reports of previous workers who found that farmers do not plant indigenous parkland tree species (Boffa, 1999; Teklehaimanot, 2004; Bayala, 2002; Hall *et al.*, 1997; Bonkoungou et, 1998; Ong and Leaky, 1992; Jama *et al.*, 2008). One of the disincentives for planting indigenous trees is the long juvenile period of the species as cited by large majority of the respondents. Similar findings have been reported in the literature (Poschen, 1986; Ong and Leaky, 1999; Boffa, 1999; Gijsbers *et al.*, 1994).

Most of the respondents reported that addition of organic matter to the soil through litter fall was one of the positive effects of trees on crops. Trees in agroforestry parkland systems have been reported by several previous workers to significantly influence the fertility of soils by maintaining soil organic matter (Young, 1997; Kater *et al.*, 1992; Bayala *et al.* 2002; Belsky *et al.*, 1989; Tomlinson *et al.*, 1995; Boffa, 1999; Cissé, 1995). Maintenance of high soil moisture beneath trees and protecting crops against desiccating winds were also mentioned by some respondents as the benefits of trees to crops. This may be because of the reduction of air temperature, solar radiation and wind velocity, which decrease potential evapotranspiration (PET) under their crowns resulting in higher soil moisture under trees than in the open (Teklehaimanot, 2008; Belsky *et al.*; 1989; Boffa, 1999).

According to majority of respondents, tree shade constituted the major negative effect of trees on crops. This is in agreement with reports in the literature that tree shade is the major factor that reduces crop yield. Kessler (1992), Kater *et al.* (1992), Boffa (1999) and Bayala *et al.* (2002) reported that common cereal crops such as millet and sorghum were substantially reduced (30-60%) under mature parkland trees when compared with the open field. The reduction in crop yield has been attributed to tree shade. But fine root studies performed by Bayala *et al.*, (2004) showed that there is also strong competition between tree and crop roots for nutrients and water.

Crops cited by farmers as shade tolerant crops included eggplant, pepper, potato, cassava, yam, okra and onion, while millet, maize, sorghum and peanut were cited as shade intolerant species. The use of shade tolerant crops by farmers in parklands has been reported by many workers (Kessler, 1992; Kater *et al.*, 1992, Teklehaimanot, 1997; Boffa, 1999). Boffa (1999) stated that farmers use more efficiently the microenvironmental conditions under trees and also reduce crop failure risks through selective tree-crop associations.

3.4.2. Local knowledge on use and management of *Tamarindus indica*

Concerning the traditional management practices of *T. indica,* more than half of the farmers reported that protection was the main strategy. This result is in agreement with Dhillion and Gustard (2004) who found that people protect Baobab trees in farmlands in Ségou region in Mali. Boffa (1999) stated that the continued maintenance of parklands justifies their value to the local people and constitutes a proof that they were protected. Teklehaimanot (2008) stated that in Eastern Africa, maintaining trees on farm is traditional rule rather than the exception. According to Okorio *et al.* (2004) the major forms of tree management found in their study zones in Uganda were weeding of tree seedlings and pruning of mature trees.

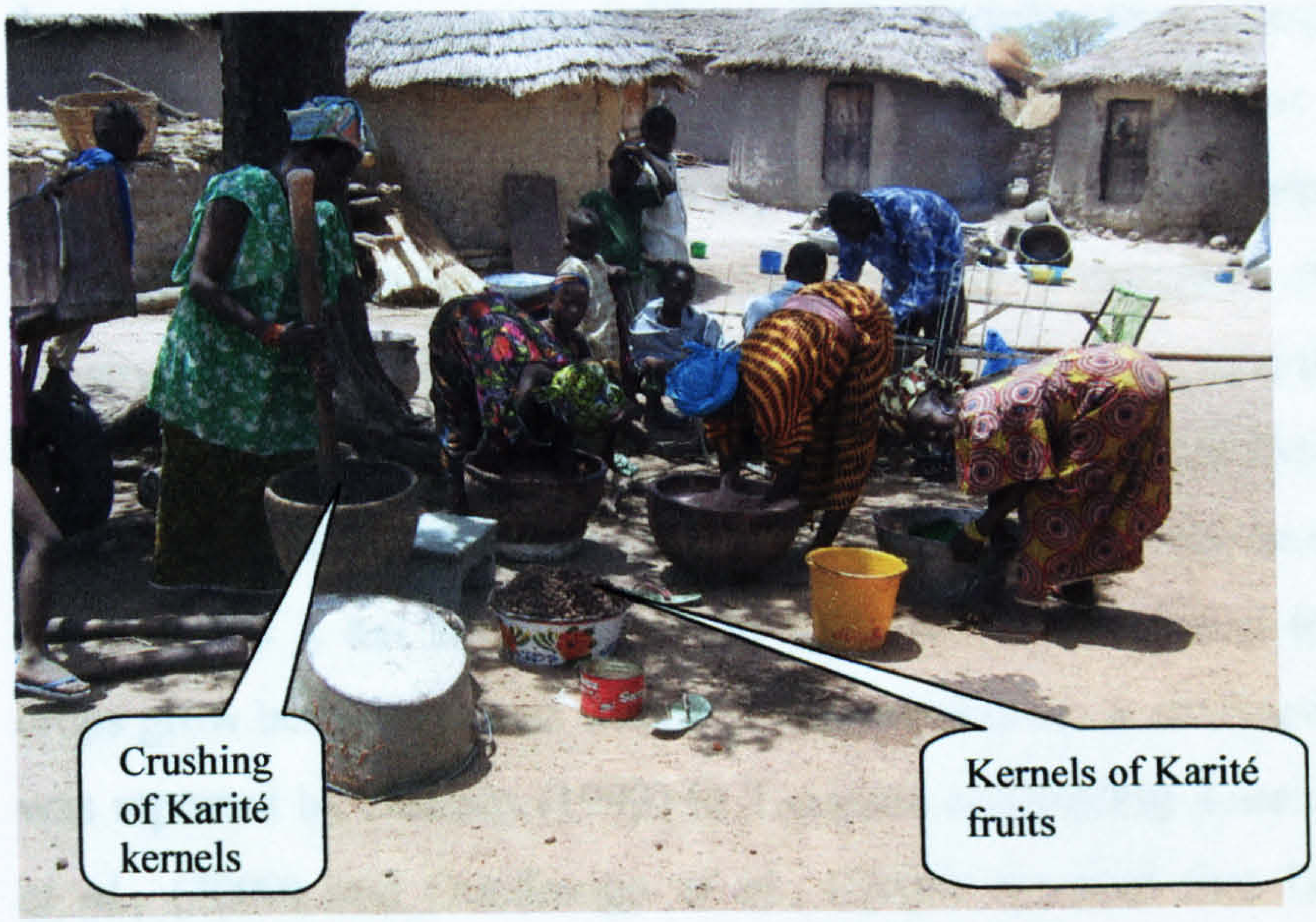
Some of the respondents reported that there was no management strategy for *T. indica.* A few reported that cutting the tree is forbidden by National Forestry code. In fact Tamarindus is one of the species highly protected by the Forestry Law of Mali (Personal experience). The opinions of farmers were diverse concerning the density of *T. indica* trees on farms. 46% of the respondents believed that the number had decreased while 37% thought that the number had increased. Some of the farmers did not perceive any change in the number of *T.indica* on farms. But the decline of useful trees densities in parklands is now widely reported. For instance, Bayala *et al.* (2007) stated that due to over-cutting of trees for fuel and construction and expansion of mechanised agriculture in the region, the density of parkland trees is decreasing. Due to loss of tree cover, the productivity of agroforestry parkland systems in East and West Africa is declining (Teklehaimanot, 2004; 2008).

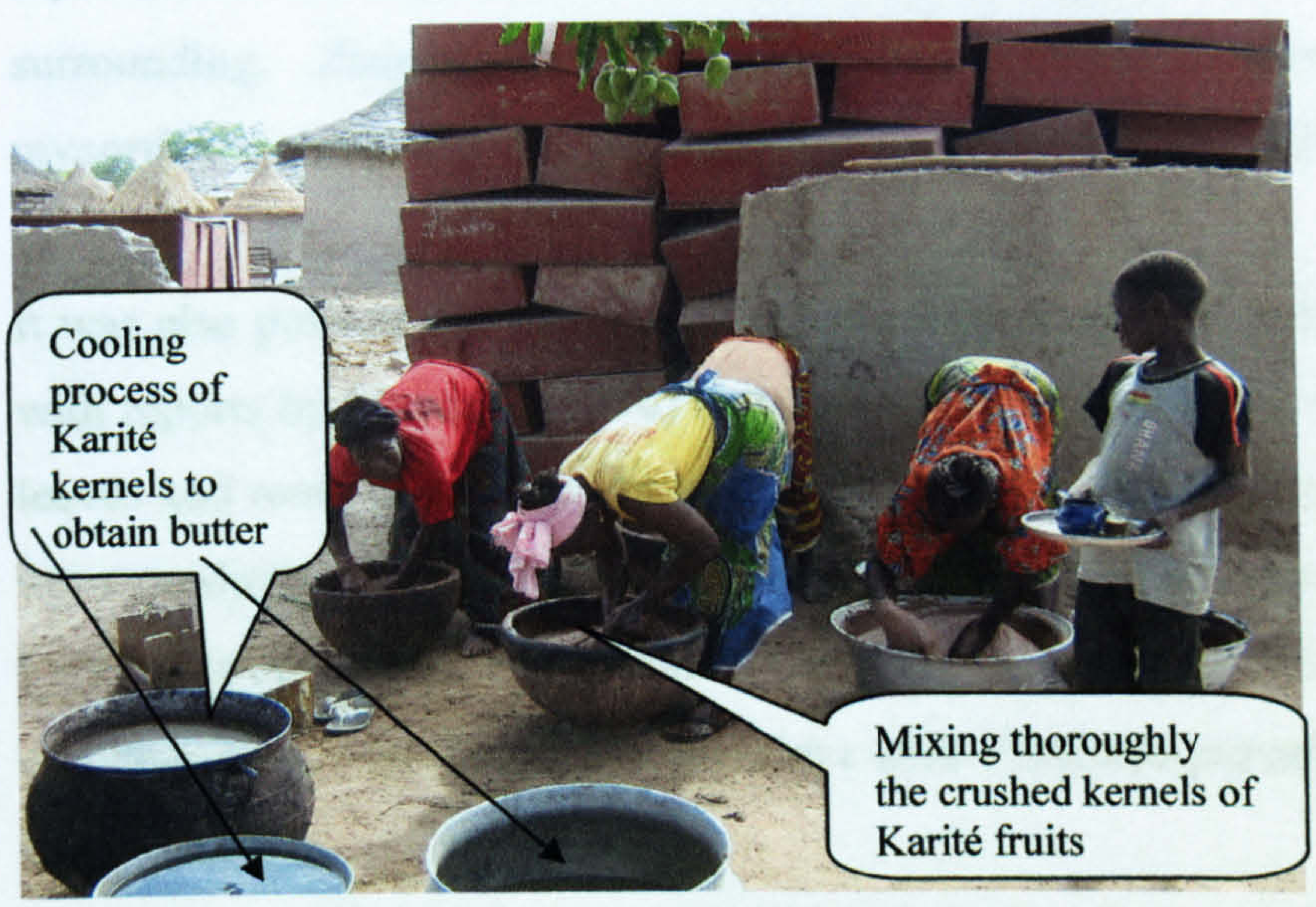
It appears that most of the respondents were not aware of the reasons for the decrease in *T. indica* tree numbers in their fields. Some farmers reported tree cutting as the reason while few cited climatic degradation such as insufficient rainfall. In general, it is very rare to find farmers cutting Tamarindus in parklands in Siramana village. Tamarindus has high medicinal, cultural and spiritual values. von Maydell, (1990) reported many medicinal values of *T. indica.* The bark, fruits, leaves and roots are all used in traditional medicine. During group discussions, farmers noted that many traditional spiritual practices can be done only under Tamarindus trees. As such many farmers protect the tree. Even farmer's opinion was diverse about Tamarindus pruning: 52% said that they carried out pruning while 45% said that they did not prune the tree. As suggested by Boffa (1999) and Pearce *et al.*, (1989) non-marketable values, such as, environmental functions, cultural or religious value of parkland trees are difficult to evaluate economically.

A majority of respondents noted that the use of spaces under trees in farmer's fields could increase crop yield. The opinion of farmers was diverse concerning the compensation of crop yield reduction by tree products. Based on three studies conducted in Mali and Burkina Faso (Bagnoud *et al.*, 1995; Boffa *et al.*, 1999; Kessler, 1992) and Boffa (1999) demonstrated the economic profitability of maintaining some parklands trees such as *V. paradoxa* and *P. biglobosa* in crop fields. He concluded that tree products compensated by far their negative effect on associated crops. Women seemed to agree that *T. indica* fruit can compensate the crop loss under the tree. The explanation was that women were reported to be the main actors involved in the exploitation of *T. indica* fruit (from the collection in parklands to home consumption and selling in the market). This finding is in agreement with Schreckenberg *et al.*, (2006) who reported that many indigenous fruit trees are particularly beneficial for women (Plate 3.2). While men are seen as the owners of trees, women are responsible for collecting, processing and marketing of fruit and are also responsible for the use of the generated income (Schreckenberg *et al.*, 2006). Boffa (1999) reported that marketing of Non Timber Forest Products (NTFPs) is dominated by women in West Africa. Jama *et al.* (2008) and Swai, (2005) also stated that children and women are the main users of indigenous fruit trees mostly available in dry seasons.

Both eggplants and pepper have been cited by many of the respondents among the most cultivated crops under Tamarindus tree. The fact that a majority of respondents (67%) reported that they preferred Tamarindus- eggplant association than Tamarindus-sorghum association highlights the use of shade tolerant crops by farmers in parklands (Kessler, 1992; Kater *et al.*, 1992, Teklehaimanot, 1997) and their extensive knowledge on tree-crop competition. In a survey conducted by Holmes (1993) in Tanzania, farmers (women) mentioned that the shade covering a crop is an important factor which affects yield. This indicates that farmers are aware of the shade tolerance level of the important crops, which is in close agreement with the present findings.

Plate 3.2: Traditional transformation process of Karité (*Vitellaria paradoxa*°) butter by women in the study area (another important NTFP)





3.4.3. Local knowledge on use and management of *Ziziphus mauritiana*

It is clear that many farmers do not have any management practice for Ziziphus except cutting. However, a few of them reported protecting Ziziphus against animals, especially when they needed the tree for use as fence. In fact at harvest time, Ziziphus is cut and used to protect the harvested crops against animals browsing in the field. It is extensively used in the region as a fence. Ziziphus is a drought-resistant species (Teklehaimanot, 2008). It can grow in sand, gravel, banks of rivers and waterholes (von Maydell, 1990). Farmers do not like the tree in farms because of its thorns which can wound both humans and animals during field activities. Before the beginning of the rainy season farmers cut and burn all the Ziziphus trees present in the field but after the rainy season the tree will regenerate profusely and grow before the next rainy season. The tree has an enormous capacity of regeneration probably due to its strongly developed root system (Maydell, 1990). Many respondents (60%) thought that the density of Ziziphus has increased in the field while some said that the number of trees has decreased. Most of respondents (70%) said that they cut Ziziphus.

Half of respondents reported that Ziziphus has an influence on soil fertility while 37% reported that it has no influence on soil. It was mentioned in group discussion that crops grow better in places where Ziziphus is found. A similar micro-site improvement was reported by Holmes (1993) in Tanzania concerning *Acacia tortilis*. Moreover, Bâ *et al.*, (2000) and Ouédraogo *et al.*, (2006) reported that Ber depends heavily on mycorrhizas and this could be a possible reason for fertility improvement in its surrounding. *Ziziphus mauritiana* has been reported to show high dependency on mycorrhizas under water stress conditions (Mathur and Vyas, 2000).

It was also pointed out that Ziziphus has a high medicinal value. This is in agreement with reports by Maydell, (1990) and Kalinganire, (2008) who stated that the barks, the leaves and roots of the tree are used in local medicine. The traditional use of parkland trees products in Mali for insect pest control was investigated by Cissé (2004) and Lehman *et al.* (2007). For instance, Cissé (2004) reported that one practitioner used to combine powdered *Ziziphus mauritiana* with *Vitellaria paradoxa* to produce effective insecticide.

According to 16% of farmers, millet is the most common crop grown under Ziziphus crown. Millet is followed by eggplant, pepper and okra.

3.4.4. Local knowledge on sorghum

The main motivations for growing sorghum are family consumption and selling. But sorghum is a staple food and this is why only 27% reported selling it. Sorghum was reported to be easy to sell. It is a tradition for many farmers to grow sorghum since it has been cultivated in the region for generations. A few farmers pointed out that they exchange part of the production when they needed other products. For instance, sorghum was exchanged with peanut, rice, or millet. It is assumed by many farmers that only when there is an overproduction, the excess can be sold. It emerged from the group discussions that sorghum plays a significant role not only in food security but also contributes to socio-cultural and socio-economic aspects of the lives of farmers. Similar findings were reported by Kudadjie *et al.*, (2004). The traditional alcoholic drink is made mainly from sorghum. Many varieties of sorghum were said to exist in the village. The local names of the two most frequent varieties found in the study village were 'Bimbiri' and 'kendé'. In other places in Mali, the same varieties have other local names. Chakanda (2000) found that in Mali the origin and the function are important in naming sorghum varieties. While all the varieties are used for food, farmers have preferences between the varieties concerning their use for preparation of specific type of food.

Seed collection for the following cropping season was done by selecting few vigorous panicles with well filled grains during the harvest period and generally conserved in kitchens. According to farmers, the permanent smokes in the kitchen prevent the grains against insect attacks. The same seed selection system was reported by Alvarez *et al.* (2005) in Cameroon.

Almost half of the farmers (48%) noted that sorghum can be grown on all type of soils. The adaptation of sorghum to poor soils is well known among farmers. Hulse *et al.*, (1980) reported in Holmes (1993) stated that sorghum become dormant during periods of stress, saving itself from struggling to survive in soil with very low available water. Most farmers (88%) reported that sorghum can be grown under trees while a few (3%) reported that it was not possible to grow sorghum under trees. Many of the respondents declared that men were first involved in sorghum cultivation, followed by youth and women.

All the respondents pointed out that sorghum yield was reduced under trees. They reported that the shade of trees has a negative effect on sorghum yield. Kessler, (1992); Kater, (1992); Bayala *et al.* (2002); Boffa, (1999) reported similar findings. Over 50% of the respondents reported that the spacing usually used between sorghum plants is from 50 cm to 100 cm.

A majority of the farmers do organic manuring in order to cultivate sorghum and according to them, this is the traditional fertilization practiced in their village. Some of them reported that they do not practice any fertilization for sorghum cultivation. Organic manure is applied in the fields surrounding each compound. They explained that sorghum was generally cultivated in bush fields which are far from the village (1-3 km). These sorghum fields can only benefit from the dung of cattle which are resting under parklands trees during the dry season. The same feature of local farming system was reported in Cameroon by Alvarez *et al.*, (2005).

Concerning the system of storage, many farmers (70%) stored sorghum in granaries usually built with wall made of clay and straw. According to farmers, granaries are traditional efficient means to store sorghum since it has been used for many generations.

Farmer's opinion on the nutritional value of sorghum was positive. Most of them reported that sorghum is rich in vitamins but they could not give the names of these vitamins. Sorghum and millets are rich in minerals, particularly iron, zinc and B vitamins (except B12) (Hulse *et al.*, 1980). However, these nutrients are concentrated in the pericarp, which is removed by decortications resulting in deficiency in the flour (Hulse *et al.*, 1980, Pederson and Eggum, 1983).

The main constraint to sorghum production according to farmers was insufficient and unreliable rainfall. Day *et al.*, (1992) reported that the rainfall situation causes many problems for the Malian farmer. Rainfall is generally low, always unpredictable and varies strongly between years (Sultan *et al.*, 2005; Sultan *et al.*, 2003). Farmers never know when rains will occur or when there will be sufficient moisture in the soil for crop cultivation. They cannot also be sure of the amount of rain they will receive for the season nor its distribution throughout the season. Breman *et al.*, (2001) argued that lot of semiarid zones experience variable rainfall which constraints farming. Erratic rainfall was identified as one of the constraints to sorghum production in Ghana (Kudadjie *et al.*, 2004). But meteorological studies performed in their study area showed an increase in annual rainfall over the latter period. So, Kudadjie *et al.*, (2004) suggested that farmer's perception about diminishing rainfall could be due to loss of organic matter of their soils which reduced the water-holding capacity of soil.

Some other constraints cited like lack of appropriate seed, lack or interest and lack of animal for ploughing are also important but can be overcame when appropriate measures and policies are adopted. Lack of bullocks and seed were also reported by Kudadjie *et al.*, (2004), as constraints to sorghum production in Ghana.

3.4.5. Local knowledge and management practices of eggplant

The main motivations for growing eggplant are familial consumption and selling in the village or in the market of neighbouring village (Dalabala).

A majority (54%) of the respondents reported that eggplant is grown in home garden. This result is in agreement with findings of Midmore *et al.*, 1991 and Rubaihayo, (2002). Some grow it in fields. A minority of respondents reported that they grow eggplant on termite moulds. Those who are growing it in dry season preferred the river basin because it is easy to overcome the water problem.

Seeds are left in the fruits, air dried and kept suspended in the smoke of the kitchen. This is the traditional form of seed storage by farmers. This technique of air drying eggplant fruit containing seeds was also reported by Lester and Seck, (2004) as a traditional mean of seed storage.

As with much traditional knowledge, techniques of growing eggplant were transmitted from father to son. This transmission of local knowledge from elders to youth was pointed out by Somnasang *et al.*, (1998). Boys often accompanied their fathers when they went fishing and hunting, so they learned these skills (Somnasang *et al.*, (1998). Friendships or social relations were also reported to be very important in the transmission of local knowledge. This transmission route was pointed out also by (Somnasang *et al.*, (1998). Extension workers were also reported to play an important role in the transmission of techniques.

The opinions of farmers were diverse on the possible number of harvests in eggplant plantations. Some of the respondents mentioned that 3, 4 and even 10 harvests could be made. Lester and Seck, (2004) reported that it is important to continue harvesting fruits even when there is no market because fruits change colour when left in the plant and became less eatable. AVRDC (2003) and Lester and Seck, (2004) advised regular harvestings since it will encourage future fruit development.

The use of organic manure to fertilise eggplant is for many of the farmers a tradition. Similar findings were reported by Rubaihayo, (2002) and Lester and Seck, (2004). Chemical fertilizers are being used currently by many farmers. They reported to use chemical fertilizers when the end use of the product is the market. They mentioned that when eggplants are produced using chemical fertilizers the taste deteriorates and the fruits decay easily.

Concerning the space between plants the majority of respondent mentioned spacing from 50 cm to 1m. This result is in agreement with some reports in the literature. According to AVRDC (2003), the spacing is 75 x 75 cm or 60 x 90 cm. Farm Africa (2006) advised 50 x 75 cm, whereas Lester and Seck, (2004) indicated that the Kumba Group grown in dry savannah regions are often spaced at 1 m x 1 m.

Drying appears to be the most traditional storage technique used by farmers. Many of them reported that eggplant cannot be stored. It is well known that the storage of eggplant fruit is difficult because it produces many fruits at the same time. These results are in agreement with findings of Lester and Seck, (2004) who stated that eggplant fruits and leaves are not normally processed or preserved for long periods. Lester and Seck, (2004) reported that fruits free of rot or damage can be stored for several days or even weeks but a good ventilation is required.

As reported in the section on sorghum, the only nutritional value cited by farmers was vitamins. FARM-Africa (2006) reported that eggplant is an excellent source of Vitamins A and C, as well as iron, protein, minerals and fibre. African eggplant is one of the most commonly consumed fruit vegetables in tropical Africa, in quantity and value probably the third, after tomato and onion, and before okra (FARM-Africa, 2006). According to Lester and Seck, (2004) the nutritional compositions of African eggplant fruit and leaves per 100g of edible portion is different (Table 3.4). They found that leaves are richer than fruits in all the nutrients analysed.

Table 3.4: The nutritional content of eggplant fruits and leaves (per 100 g of edible portion) according to Lester and Seck (2004).

Nutritional composition	Fruit	Leave
Water (g)	90.6	82.1
Energy (kcal)	32	51
Protein (g)	1.5	4.8
Fat (g)	0.1	0.3
Carbohydrate (g)	7.2	10.3
Fibre (g)	2.0	2.4
Ca (mg)	28	523
P (mg)	47	94
Fe (mg)	1.5	6.0
β-carotene (mg)	0.35	6.40
Thiamin (mg)	0.07	0.23
Riboflavin (mg)	0.06	0.44
Niacin (mg)	0.8	1.8
Ascorbic acid (mg)	8	67

Insufficient rainfall has been reported by more than half of the respondents as the main constraints to eggplant production. As reported in sorghum section, rainfall is unpredictable and erratic and constitutes a big problem in West Africa (Sultan *et al.*, 2005; Sultan *et al.*, 2003; Day *et al.*, 1992).

The division of tasks in households between men and women (gender issues) was perceived during the group discussion of this survey. Men are more interested in staple food (sorghum and millet) production while women are more concerned with the production of crops that are used in sauce (eggplant, pepper). The production system is gendered in such a way that if a man produces for instance eggplant it is first for its own need (selling) and second for the household and vice versa. Such gendered production systems have been reported by many workers (Boserup, (1970; Carr, 2008). Alvarez *et al.*, (2005) reported that in Wanté (Cameroon) yam was exclusively cultivated by men, whereas groundnut was cultivated by women. FARM-Africa (2006) suggested involving women in eggplant production because they are the main vendors of African indigenous vegetables in local markets.

Yields of eggplant reported by farmers from 2 to 4 tons ha^{-1} were lower than that mentioned by Leister and Seck (2004) who stated that without irrigation, yields are 5–8 tons ha^{-1}. However, sorghum yields reported by farmers form 500 to 1500 kg ha^{-1} were in close agreement with data found in the literature. Mendesil *et al.*, (2007) reported that the average sorghum yield in south-western Ethiopia was 810 Kg ha^{-1}. FAO, (1997) and Kouressy (2008) reported that from 1979 to 2001, sorghum production in West Africa increased from 5.1 to 13 million tones. However the regional mean yields did not increase significantly (890 kg ha^{-1} in 1979-81, 780 kg ha^{-1} in 1992-94, and 830 kg ha^{-1} in 2001). According to Breman *et al.*, (2001) the yield of sorghum in Mali was fluctuating between 500 and 800 kg ha^{-1}.

3.5. Conclusion

Many species were reported by farmers to be present in parklands in Siramana village. Farmers have traditional knowledge on their environment which include: the names, the uses, the role and the importance of each tree species; the harvest and transformation methods of their products; the management techniques of each tree species; the interactions between trees and associated crops; the growing technique of crops; the techniques of storage of tree products and crops, the prices of tree products and crops at village and market level. Concerning farmers' preference on tree species, *V. paradoxa* was the most preferred species followed by *T. indica*, *P. biglobosa* and *Z. mauritiana*. Eggplant was the shade tolerant crop preferred by farmers.

Based on the results of this baseline survey, it was decided to choose *Tamarindus indica* and *Ziziphus mauritiana* as tree species used for tree- crop interactions studies. The choice of these two species was also based on the fact they have not yet been subjects of scientific studies in the region. Much of the research on local fruit trees is still concentrated on *Vitellaria parodoxa* and *Parkia biglobosa.* The choice of sorghum was based on the fact that this crop constitutes one of the main staple foods in the village and it is highly appreciated by farmers. Eggplant was also chosen due to fact that this crop was identified by farmers as one of the best shade tolerant species which can be grown under both trees.

CHAPTER IV:

THE EFFECT OF *TAMARINDUS INDICA* ON THE PERFORMANCE OF ASSOCIATED SHADE-TOLERANT AND SHADE-INTOLERANT CROPS

4.1. Introduction

Traditional agroforestry parkland systems have existed in the semi-arid regions of West Africa for many generations (Baumer, 1994; Boffa, 1999, Samba *et al.*, 2001). Farmers grow annual crops in agroforestry parkland systems where scattered indigenous trees form an open permanent upperstorey (Nair, 1993, Bayala *et al.*, 2002). Indigenous fruit trees in particular constitute the dominant tree species of parklands. One such example is *Tamarindus indica* L., commonly called Tamarind, which is the subject of the present research. *T. indica* was chosen for the present study because of its socio-economic importance locally as well as worldwide, but it is one of the tree species which has not been subject of research investigation until very recently in West Africa.

At present, degradation is taking place in parklands because of the reduction of tree density as a result of population increase and the ageing of trees due lack of their regeneration (Teklehaimanot, 2004; Gijsbers *et al.*, 1994; Nikiema *et al.*, 2003, Okullo *et al.*, 2003). Due to loss of tree cover, the productivity of many types of parkland in West Africa is declining (Teklehaimanot, 2004). It is, therefore, necessary to increase the productivity of land currently in use, using sustainable methods. One such method that can help create favourable and stable conditions needed for sustained food production on parklands is preserving and managing existing indigenous trees because of the ecosystem services that they provide (Sanchez, 1995; Rao *et al.*, 1998, Young, 2000; Teklehaimanot, 2004).

Maintaining or increasing density of trees in rain-fed agroforestry parkland systems requires paying a price for reduction in annual crop production because of the competition for light, water and nutrients between trees and crops. Reduced yields of associated food crops under tree canopies in parklands compared to open fields have been reported widely in West Africa due to such competition (Kessler, 1992; Kater *et al.*, 1992; Bayala *et al.*, 2002). In Burkina Faso, Kessler, (1992) found that sorghum yields under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees were reduced on average by 50% and 70% respectively while in southern Mali, Kater *et al.* (1992) reported a yield reduction of 60% under canopies of both species. Such a reduction in crop yield could be avoided by growing shade-tolerant crops immediately beneath the crowns of trees and growing cereals which are shade-intolerant outside the shaded area. While many previous studies reported the reduction of cereal crop production under tree crowns (Rao *et al.*, 1998; Bayala *et al.*, 2002; Jonsson *et al.* 1999; Kessler, 1992), surprisingly there is no information in literature on the performance of shade-tolerant crops such as African eggplants (*Solanum aethiopicum* L.) in association with parkland trees. In fact, the tradition in West Africa is to grow vegetable crops in home gardens by women and cereal crops in parklands by men. Thus, many farmers are unfamiliar or are not aware that vegetables could be grown in parklands under trees.

The major aim of the present study was, therefore, to assess the effect of *Tamarindus indica* on yield and quality of African eggplant (*Solanum aethiopicum* L) (shade-tolerant crop) in comparison with sorghum (*Sorghum bicolour*) (shade-intolerant crop) based on agronomic measurements and chemical analysis of the nutritional composition of both crops.

Light reduction under parkland trees has been reported to be the major cause of decline of associated cereal crop yield by previous workers (Bayala *et al.*, 2002; Kater, 1992; Kessler, 1992). The competition for water and nutrients by roots of trees and associated crops could also contribute to the reduction in crop yield (Rao *et al.* 1998; Bayala *et al.*, 2002). Therefore, in the present study, root length density distribution of both Tamarindus and the associated crops was also investigated along with the study of the physical and chemical properties of the soil.

The hypotheses tested were:

1) The yield of associated crops (African eggplant and sorghum) are not affected by *Tamarindus indica*
2) The nutritive quality of associated crops (African eggplant and sorghum) is not affected by *Tamarindus indica*
3) There is no competition for nutrients and water between the root length densities (RLD) of the tree and the associated crops
4) There is no correlation between roots length densities (RLD) and crop yield and nutritional composition
5) There is no correlation between soil properties (N, P, K and C) and crop yield and nutritional composition

4.2. Material and methods

4.2.1. Tamarindus tree selection

It was a participatory research involving five farmers in Siramana village in Tiakadougou commune, Koulikoro region, Mali. Six isolated adult trees of Tamarindus were randomly selected in the five collaborating farmers' fields within an area of 100 ha (Plate 4.1).

The area around each sample tree was subdivided into three concentric zones as shown in Figure 4.1:

Zone A - from the trunk of each tree up to half of the radius of the tree crown;
Zone B - from half of the radius of the tree crown up to the edge of the crown;
Zone C – from the edge of the tree crown up to 3 m away;
A control plot (Zone D) for crop only treatment for each sample tree was delimited. This control treatment was an area of 8 x 8 m situated at least 40 m away from the edge of the crown of the sample tree but unshaded by any of the surrounding trees at any time of the day throughout the cropping season.

The experimental design used for Tamarind intercropping has some shortomings. The choice of 3m could be a limitation because the crown diameters of trees differ according to tree sizes and in this case big trees and small trees are affected the same 3m. It is obvious that small trees and big trees will not have the same influence zone in term of soil fertility and microclimate from the edge of the canopy. For example the influence zone of a small tree may not excced 1m while that of big trees could reach more than 5m from the edge of tree crown. So a more realistic approach could be to take for instance one time the diameter of tree crown. This method will allow better statistical comparisons and a better estimation of the influence of tree outside the tree crown. The main advantage is that the different zones will be expressed as a function of tree crown diameter.

It is important to mention that there is no scientific published data concerning Tamarind tree density or fruit yield in the study area. The lack of scientific work on Tamarindus in the region was one of the reasons for the choice of this species in the present study.

In this study, OM values were not adjusted for bulk density.

Sorghum was grown under three trees (tree number 1, 2 and 3), and egg plant was grown under the remaining three trees (tree number 4, 5 and 6), in the three concentric zones and in the control plot.

The spacing used between plants was 0.5 m X 0.5 m for sorghum and 0.6 m X 0.6 m for eggplants which are standard spacing used by farmers in the area.

At the end of the research, feedback on the potential of intercropping of eggplant under Tamarind for adoption was assessed through questionnaire survey conducted with participating and other farmers in the neighbourhood.

Figure 4.2 shows Siramana village and the geographical positions of the selected Tamarind trees for the intercropping trials and Table 4.1 shows the biophysical parameters of the six *Tamarindus indica* trees selected, the associated crops grown and the names of collaborating farmers.

Plate 4.1: Tamarindus parkland and its fruits in Siramana village

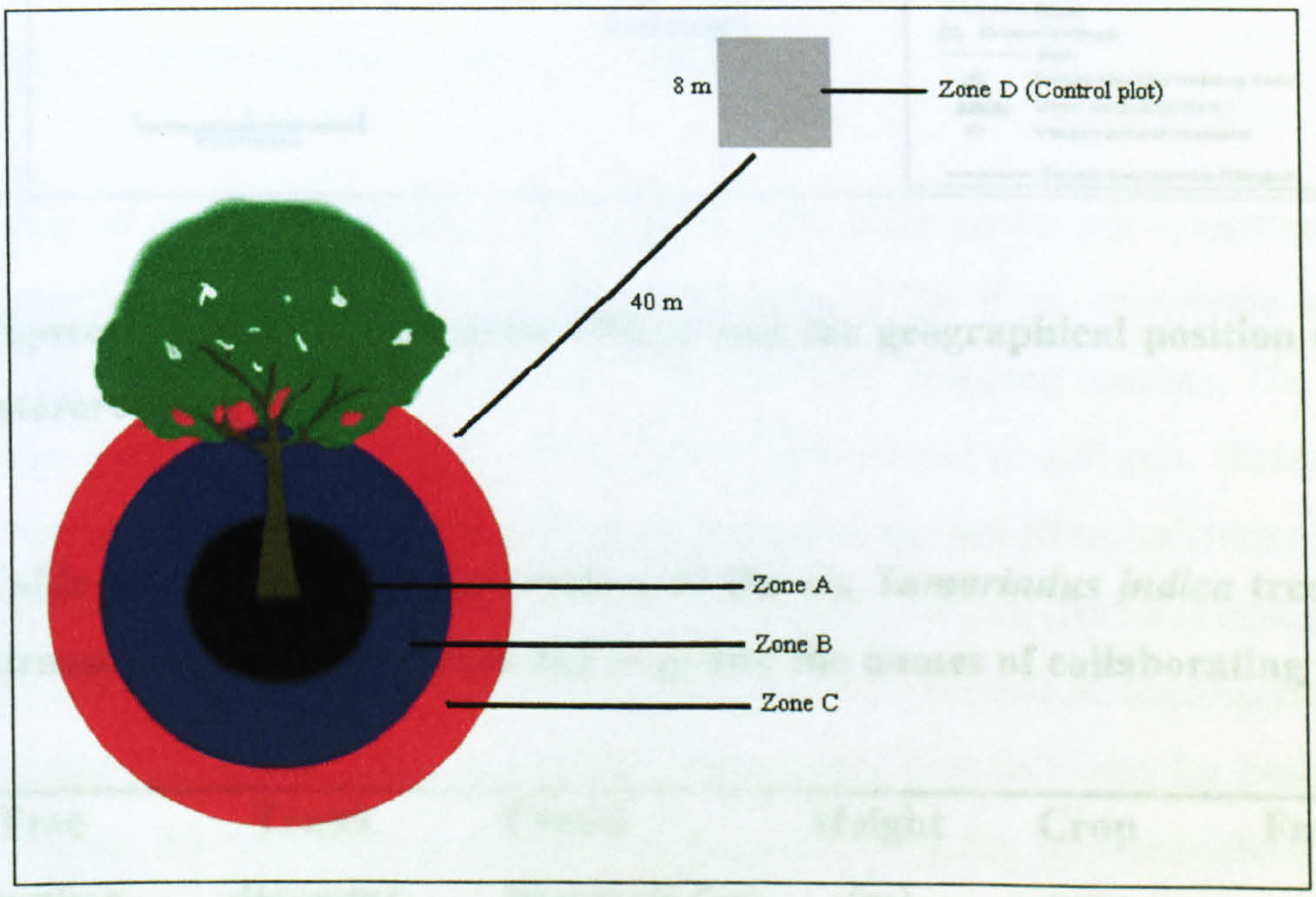


Figure 4.1: Areas around sample trees (three concentric zones)

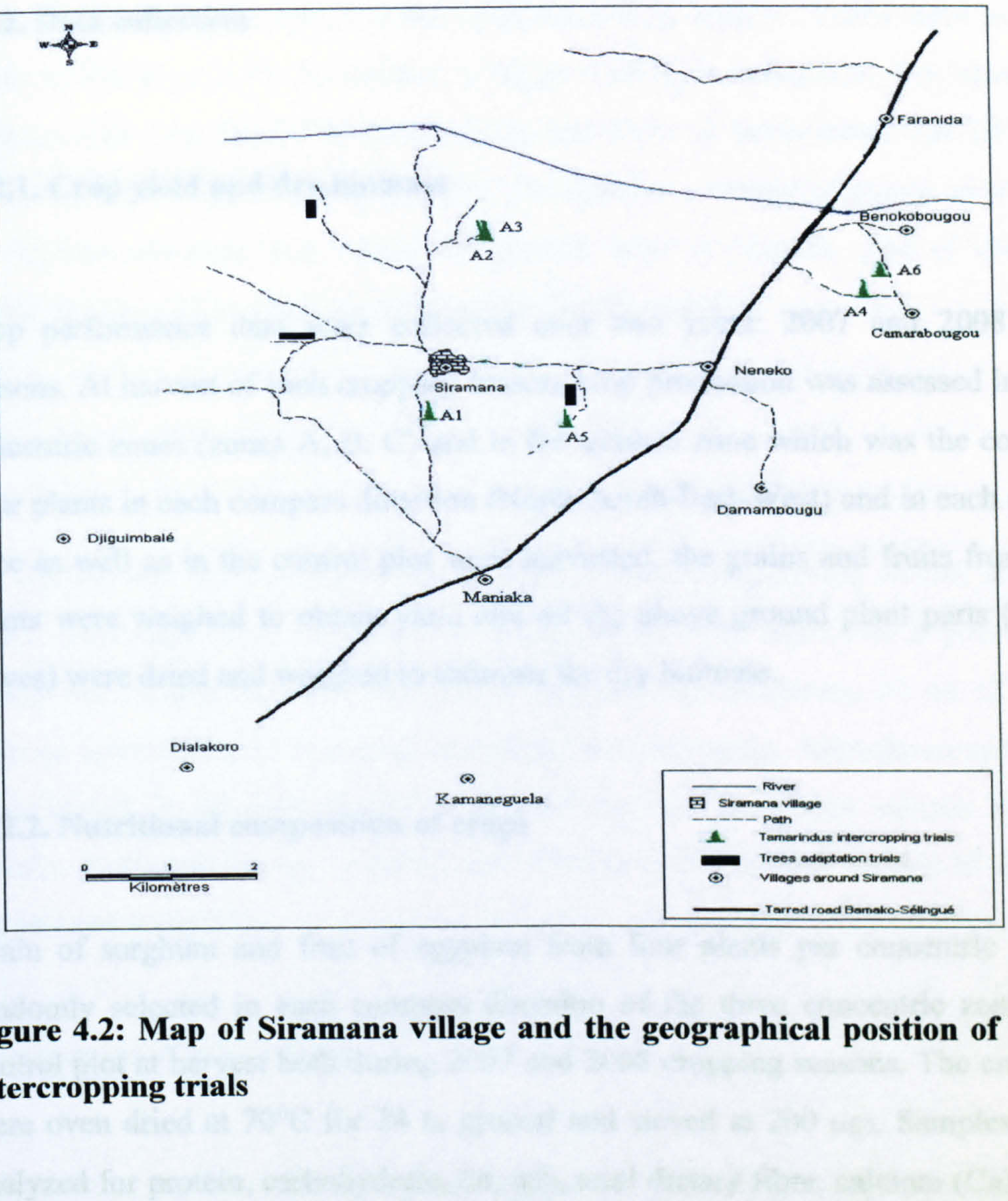


Figure 4.2: Map of Siramana village and the geographical position of Tamarind intercropping trials

Table 4.1: Biophysical parameters of the six *Tamarindus indica* trees selected in Siramana village, the associated crop and the names of collaborating farmers

Tree Number	Trunk diameter (DBH) (cm)	Crown Diameter (m)	Height (m)	Crop type	Farmer's name
1	24.52	5.30	7	Sorghum	Daouda Doumbia
2	34.07	5.75	12	Sorghum	Modibo Doumbia
3	26.11	4.20	8	Sorghum	Modibo Doumbia
4	41.72	6.76	15.5	Egg plant	Adama Doumbia
5	31.21	4.60	9.5	Egg plant	Ladji Bagayoko
6	32.16	6.04	14	Egg plant	Satigui Bagayoko

4.2.2. Data collection

4.2.2.1. Crop yield and dry biomass

Crop performance data were collected over two years: 2007 and 2008 cropping seasons. At harvest of each cropping season, crop production was assessed in the three concentric zones (zones A, B, C) and in the treeless zone which was the control plot. Four plants in each compass direction (North-South-East-West) and in each concentric zone as well as in the control plot were harvested, the grains and fruits from the four plants were weighed to obtain yield and all the above ground plant parts (stems and leaves) were dried and weighed to estimate the dry biomass.

4.2.2.2. Nutritional composition of crops

Grain of sorghum and fruit of eggplant from four plants per concentric zone were randomly selected in each compass direction of the three concentric zones and per control plot at harvest both during 2007 and 2008 cropping seasons. The crop samples were oven dried at 70°C for 24 h, ground and sieved at 200 µm. Samples were then analyzed for protein, carbohydrate, fat, ash, total dietary fibre, calcium (Ca), iron (Fe), magnesium (Mg), phosphorus (P), potassium (K), sodium (Na) and manganese (Mn) in the laboratory of the School of the Environment, Natural Resources and Geography, Bangor University, UK. Manufacturer's protocol was followed for both fat and fibre analysis. All the other elements were analysed using the standard laboratory protocols from Environment Centre of Wales (ECW). The laboratory analytical methods used are described below.

Assessment of protein content

The protein content of crop samples was obtained by measuring N content of the samples by Kjeldahl method using a Kjeltec 2300 analyser unit (FOSS, 2006). 200 mg of each sample were digested by adding 5 ml of sulphuric acid (98%) and 2 tablets of titanium catalyst were added to the tube containing sample. Tubes were put on heat block at 420 degrees for 30 minutes to digest. During the digestion, the nitrogen in the samples was converted into ammonia in the form of ammonium ion $NH4^+$ which binded to $SO4^{2-}$ ions of the acid. After the digestion, sample solutions were placed in the Kjeltec analyser unit which determined their N content. The N content was multiplied by 6.25 to obtain protein content in the samples.

Assessment of fat content

Fat content was determined by the Soxhlet method using Soxtec Avanti 2050 system (Foss, Denmark). Five (5) grams of each sample were placed in a porous thimble which was lodged into an extraction aluminium cup containing 80 ml of petroleum ether as solvent and fat was extracted by the Soxtec system. After the extraction, tubes were placed in an oven at 102°C to evaporate the remaining solvent and dry the sample. Extracted fat was weighed and divided by the sample weight (5 g) to obtain the fat content ($g\ g^{-1}$).

Assessment of ash content

Ash content was assessed by burning 2 grams of each crop sample in a furnace at 450 degrees for 18 hours. When samples are burnt, water and volatile substances are vaporized while organic substances are transformed into CO_2, H_2O and N_2 in the presence of oxygen. After samples were cooled, ash was weighed and the content ($g\ g^{-1}$) was calculated by dividing ash weight by the sample original weight.

Assessment of dietary fibre content

Dietary fibre includes some polysaccharides (cellulose, hemicellulose, pectin and hydrocolloids) and lignin which are not digestible. So, dietary fibre content determination consists of removing all digestible substances of the samples and weighing the rest. One (1) gram of each sample after fat extraction was used to assess dietary fibre content. Samples were dissolved in 50 ml of phosphate (pH 6), 0.1 ml of amylase was added and the solution was incubated at 95°C for 15 minutes. After the incubation, the solution was cooled to room temperature and its pH was adjusted to 7.5 by adding NaOH (0.275 N). Then 0.1 ml of protease was added to the solution and placed in a water bath at 60°C for 30 minutes. At the end of this second incubation, the solution was cooled at room temperature and the pH adjusted between 4 and 4.6 by adding HCl (0.325M). Then, 0.1 ml of Amyloglucosidase was added to the solution which was placed again in a water bath at 60°C during 30 minutes. By the end of this third incubation, 4 volumes of ethanol (95%) were added and the solution was let cool overnight at room temperature. After complete precipitation overnight, the solution was filtered and rinsed with ethanol (95%) and acetone to extract dietary fibre. Dietary fibre after filtration was dried in an oven at 70°C overnight and then weighed to obtain the content in the original sample (g g^{-1}).

Assessment of carbohydrates content

Digestible carbohydrate content was assessed based on the assumption that samples are constituted of ash, dietary fibre, fat, protein and digestible carbohydrate. So, when the contents of protein, fat, ash and dietary fibre are known for one (1) gram of sample, carbohydrate content could be calculated according to the formula below:
Carbohydrate content (g g^{-1}) = 1 – (Ash content + Dietary fibre content + Fat content + Protein content).

Assessment of Ca, Na and K contents

Flame photometry was used to determine Ca, Na and K contents in the crop samples (Plate 4.2). The flame photometer (model 410) measures the light of a specific wavelength emitted when a solution of a particular element is burnt. The light emitted is proportional to the element concentration in the solution. To prepare aqueous solutions of samples, 2 g of each sample were burnt at 450°C in a furnace overnight to remove the carbon which reacts with oxygen and is lost as carbon dioxide. 1ml of concentred HCL and 19ml dH2O was added to the ash of a 2 g dry weight sample, shaken briefly, and then filtered. The resulting solution is a 1 in 10 dilution of the sample. The solution obtained was diluted 10 times for K and Na and 80 times for Ca by adding distilled water. Standards used were 25, 50, 75 and 100 mg l^{-1} for K and Ca. For Na, standards were 5, 10, 15 and 20 mg l^{-1}. Blanks were also used. Then, the standards and the sample solutions were read by the flame photometer. A regression equation was derived between standard solutions and the readings of the flame photometer and the equation was used to obtain the concentration of elements in sample solutions (mg l^{-1}). Element content (g g^{-1}) in dry samples was then calculated using the dilution rates.

Assessment of P content

Phosphorus content was determined using the colorimetric method (Ames, 1966). This method is based on the principle that phosphate ion reacts with ammonium molybdate to give, when reduced by ascorbic acid, a blue complex which has an intense absorption band at 880 nm. The complex absorbance which is proportional to phosphate concentration in the original solution is measured by a spectrophotometer (BioTek, model PowerWave XS). Samples were diluted to 1/800 for the analysis. Standards were at 25, 50, 100 and 200 and 500 μM. A blank was included. 200 μl of samples/standard and 40 μl of AMES were pipetted into wells. After 48hours the absorbance was read in the plate reader spectrophotometer.

The regression equation between the concentration of standard solutions and the readings of the spectrophotometer was used to obtain the phosphate concentration (mg l^{-1}) in sample solutions and then the content (g g^{-1}) in dry samples was calculated using the dilution rate.

Assessment of Mg, Fe, Mn and Zn content

An atomic absorption photometer (VARIAN, model SpectrAA 220FS) was used to assess Fe, Mg, Mn and Zn content in crop samples. The principle is that each element when burnt emits a specific wavelength light which is proportional to the content of the element in the solution. Six concentrations of each element were used as standards to calibrate the photometer. Sample solutions were prepared as described above. Sample concentrations used were 1/100 for Mn, Fe and Zn and 1/10000 for Mg.

Assay tubes each containing 50 ml of sample solution was placed on a 60 well support where the first well was a tube of water and after each five (5) sample tubes, a drift solution was intercalated to control the photometer readings accuracy. The absorbance of solutions was read by the atomic absorption photometer and expressed as elements concentration (mg l^{-1}) according to the calibration done with standard solutions. The content in dry matter (g g^{-1}) was obtained by applying the dilution rates with regard to each element solution.

Plate 4.2: Flame photometry used to determine Ca, Na and K contents in the crop and soil samples

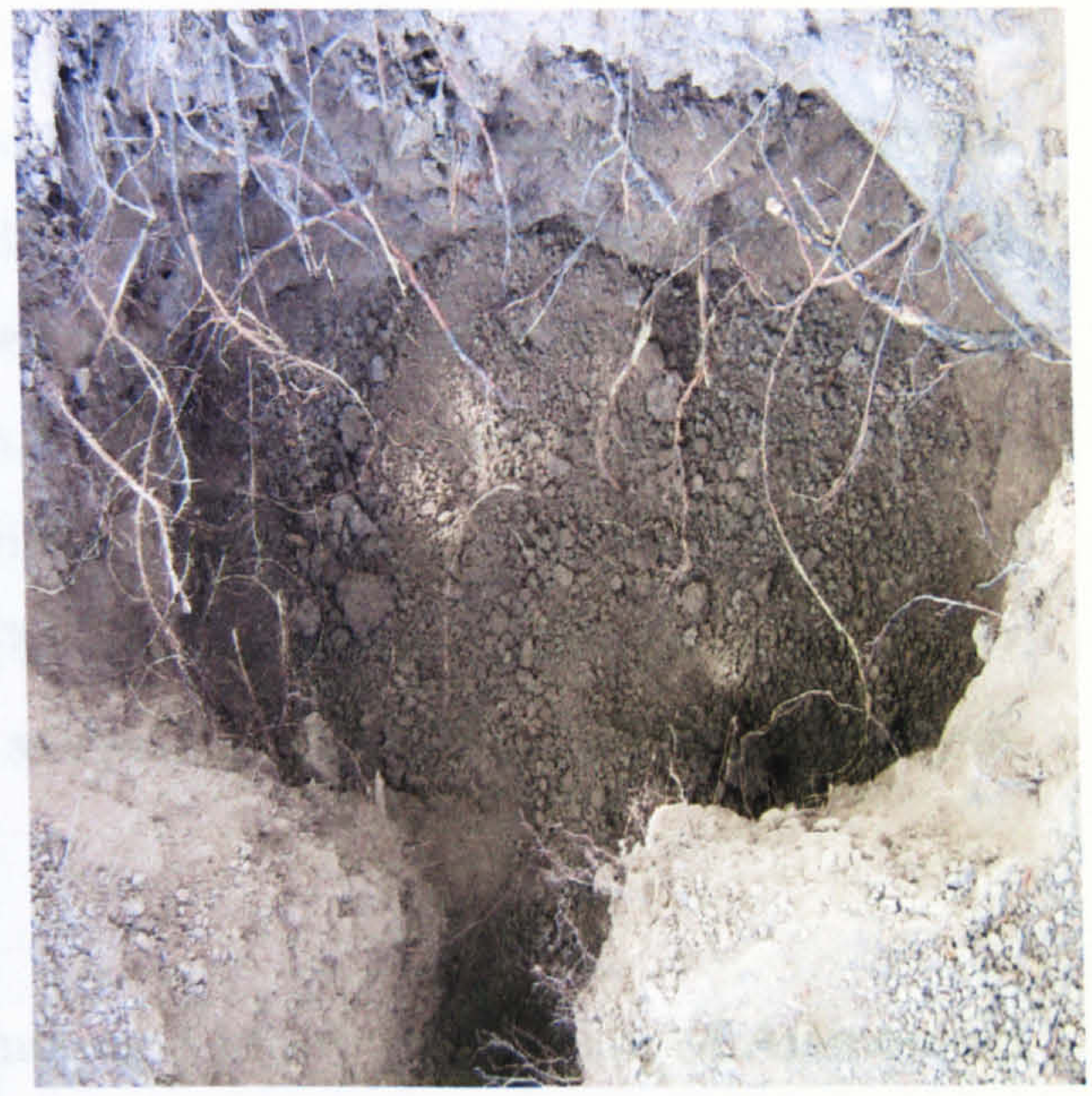
4.2.2.3. Root length density distribution

Root samples were taken in September 2007 when crops were well established. Two sampling positions were selected randomly in each concentric zone under trees (zones A, B and C) and in the control plot (zone D). Soil samples were taken at 10 cm intervals up to 30 cm soil depth. Roots below 30 cm depth in zone A could not be sampled because of the dense, big and superficial lateral roots of Tamarind which made it difficult to excavate roots from soil deeper than 30 cm. Then, under each tree, 24 samples of soil with roots were collected using metallic cube (Plate 4.3a) and washed manually using three sieves (plate 4.3b) of different sizes (2mm, 1mm and 0.25 mm). Roots were separated into three categories (tree roots, crop roots and other roots). Tamarind roots were easily recognisable by their brown colour (Plate 4.3d); sorghum roots were white and fine, while eggplant roots were white and bigger (Plate 4.3c). There were very few other roots because weeding was done frequently in the plots. Only fine roots (diameter <2 mm) were selected for this study. Roots > 2 mm diameter were discarded. Root length was determined using the grid line intercept method described by Tennant (1975). The root length density (RLD) was estimated by dividing the root length by the volume of soil excavated per 10 cm soil depth which was 10 x 10 x 10 cm (1000 cm^3). Roots were oven dried at 70°C for 48 hours in order to obtain root dry weight. Root weight density (RWD) was then determined by dividing the root dry weight of each sample by the volume of soil used for extraction (1000 cm^3).

a) Metallic cube of 10 cm long, 10cm large and 10cm deep

b) Sieves of different size used for washing roots

c) Roots of eggplant on the sieve after soil washing process



d) A pit showing the root system of Tamarindus

Plate 4.3: Instruments used for root sampling (a) and root washing (b); root of eggplant (c) and root of Tamarindus (d)

4.2.2.4. Soil physical and chemical properties

Soil analysis was carried out to characterise the site in terms of soil physical and chemical properties. Samples were collected in 2007 in the three concentric zones (A, B, C) under all the six selected trees and in the control plots (zone D) at two soil depths (0-15 and 15-30 cm). Analysis of soil physical properties included soil texture and density. These were carried out in the laboratory of Institut d'Economie Rurale (IER), Mali.

Particle size distribution was determined by Robinson's pipette method (Gee et al., 1986) using the pyrophosphate of sodium for dispersion and mechanical shaking.

Soil density was analysed using core method (Birkeland, 1984). Three undisturbed soil samples of 100 cm^3 were taken using cylindrical boxes (Plate 4.4) in each concentric zones of each tree and in the control plots. The soil samples were oven-dried at 105°C for 24 hours to obtain their dry weight, from which the density is calculated. Bulk density is a measure of weight of the soil per unit volume (g/cc), usually given on an oven-dry basis.

For chemical properties, soil organic matter, phosphorous, potassium and nitrogen contents were analysed in the laboratory of Bangor University, UK. For analysis of soil chemical properties, soil was first extracted using Ammonium Acetate Extraction Protocol. 18 ml Ammonium Acetate (NH4 Acetate) 1M pH7.0 was added to 2 g of soil using a small plastic scint tube. This was shaken for 1 hour at 250 rpm. The solution was filtered using filter paper and funnel. The filtrate was now ready to use on flame photometer for Phosphorous and Potassium analysis and Kjeldahl machine for analysis of Nitrogen.

P and K: stock solution was prepared by mixing 3 ml of 4% solution of Ammonium Molybdate (20g with 500ml epure water), 1 ml of Antimony (1.454g Antimony Potassium Tartrate in 500ml epure water), 10 ml of 2.5M sulphuric acid (34ml conc sulphuric acid in 250ml epure water), 1 ml of 5% ascorbic acid (2.64g ascorbic acid in 50ml epure water), 9 ml of AMES, and 6 ml of epure water. Seven standard solutions were then prepared according to the concentrations 0, 2.5, 5, 10, 15, 20 mg l^{-1}. Then, the standards and the sample solutions were read by the flame photometer by pippetting 20 μl of each sample solution (1/10), and 200 μl of each standard into wells. The sample solutions and standards were read at 882 nm and a calibration curve was obtained from the standards. The calibration equation was then used to obtain the concentration of P and K in sample solutions.

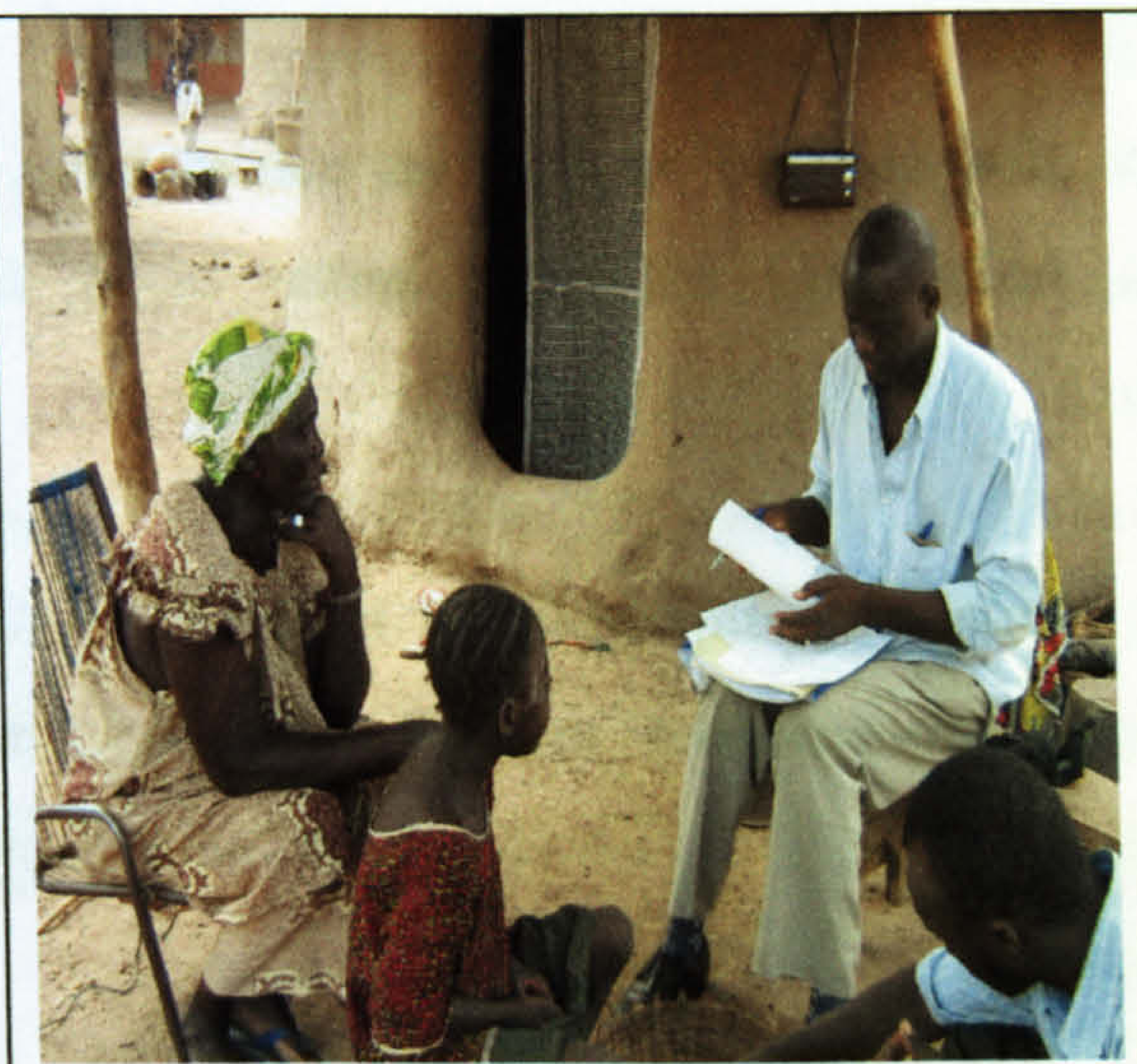
Nitrogen: Kjeldahl method was used for the analysis of N. 500 mg of oven dried sample was weighed into Kjeldahl specific tubes (100 ml). 5 ml of sulphurc acid and 2 tablets of titanium catalyst were added to the tubes. The tubes were put on heat block at 420 degrees for 30 minutes to digest. Tubes were cooled, and then run in the Kjeldahl machine to read the N content.

Plate 4.4: Bulk density works showing the pit for soil sampling

4.2.2.5. Farmers' feedback survey

A questionnaire survey was conducted in Siramana village at the end of the research in 2009 to get feedback from farmers on the potential of adoption of intercropping of eggplant with Tamarind. A total of 58 heads of households were randomly selected and interviewed. Out of these six (6) were participants in the present intercropping trial. A survey was used to establish the knowledge base (Plate 4.5). Tools including group discussions and semi-structured interviews were used. The questionnaire for the semi-structured interviews is given in Appendix 2.

Plate 4.5: Interviews during farmers' feedback survey

	
Field technician interviewing a participant (farmer) in intercropping trials	Field technician interviewing a woman about intercropping trials
	
A researcher in group discussion with farmers about the intercropping trials	Field technician interviewing a farmer about intercropping trials

4.2.3. Data analyses

Both One-Way and Two-Way analyses of variance (ANOVA) and General Linear Model (GLM) were performed on the data using Minitab 15 statistical software (Minitab Inc., USA) to determine statistical significance differences in crop performance, nutritive composition and roots between trees, crops and concentric zones. Fisher's Pair Wise comparisons test was also performed to determine possible statistically significant differences between means at 95% probability level.

Relationships between plant roots and crop performance as well as between soil properties and crop performance were established using Pearson's Correlation Analysis.

Data on feedback survey was analysed using SPSS Version 14. Descriptive statistics mainly using multiple responses were performed to capture farmers' feedback on the project and results were presented in a form of tables and graphs.

4.3. Results

4.3.1. Soil physical and chemical properties

The pH of the soil of the study site was almost neutral under tree crowns (zone A, B and C) and acidic in zone D (control plot). The soil was sandy clay loam in texture as shown in Table 4.2. There were no significant differences in soil densities between concentric zones under trees. However, a significant difference was found in soil density between soil depths ($P<0.001$). The upper soil layer 0-15 (1.56±0.02) had lower density than 15-30 depth (1.63±0.01).

The organic matter content of the surface soil was about 5%. There was a significant difference between concentric zones in organic matter content ($p<0.001$). The organic matter in zone A and zone C were significantly higher than that of zone D (Table 4.3). Zone B was not significantly different from zone A and C and also D. With regard to nitrogen content of soil under trees, significant differences were found between zones ($P<0.01$) and depth ($p<0.001$). The nitrogen levels in Zone A and C were significantly higher than zone D. Zone B was not significantly different from zone A and C and also D. Also the nitrogen content was significantly higher in surface soil (0-15 cm) than in the lower depth (15-30 cm). Phosphorous and potassium contents were very low and there was no significant difference between either concentric zones under trees or soil depth (Table 4.3).

Table 4.2: Soil density, pH and texture

Zones	Depth	Density	pH (H2O)	pH (KCl)	Sand (%)	Silt (%)	Clay (%)
A	0-15	1.52±0.02	6.67±0.12	6.13±0.08	54.00±3.00	23.50±3.00	22.50±0.00
	15-30	1.63±0.03	6.83±0.02	6.05±0.05	47.83±2.17	15.67±2.33	36.50±4.50
B	0-15	1.53±0.04	6.87±0.33	6.15±0.45	53.00±2.00	30.33±2.67	16.50±0.50
	15-30	1.64±0.02	6.83±0.37	6.05±0.45	55.33±7.67	18.67±5.67	25.67±2.17
C	0-15	1.57±0.03	6.35±0.20	5.82±0.28	48.50±7.00	27.50±9.00	23.33±2.33
	15-30	1.64±0.02	6.18±0.27	5.50±0.40	45.66±3.66	22.33±7.66	32.00±4.00
D	0-15	1.62±0.03	5.58±0.22	5.00±0.30	58.50±3.00	19.83±6.17	21.17±9.17
	15-30	1.60±0.04	4.68±0.17	4.15±0.20	52.67±5.83	16.33±3.17	30.83±8.83

Table 4.3: Soil chemical properties

Zone	**Depth**	**OM (%)**	**N (mg g^{-1})**	**P (mg g^{-1})**	**K (mg g^{-1})**
A	0-15	5.92±0.59	0.09±0.02	0.005±0.001	0.06±0.01
	15-30	5.07±0.85	0.05±0.01	0.002±0.001	0.07±0.02
B	0-15	4.45±0.22	0.08±0.00	0.004±0.001	0.05±0.01
	15-30	5.33±0.21	0.04±0.01	0.002±0.001	0.06±0.01
C	0-15	5.96±0.35	0.10±0.02	0.005±0.002	0.05±0.01
	15-30	5.93±0.14	0.05±0.00	0.002±0.002	0.06±0.01
D	0-15	3.82±0.00	0.04±0.00	0.001±0.000	0.06±0.00
	15-30	4.07±0.00	0.03±0.00	0.001±0.000	0.08±0.00

4.3.2. Sorghum performance

4.3.2.1. Sorghum yield

a) Sorghum yield in 2007

The mean yield of sorghum in 2007 was 531±35 kg ha^{-1} (Table 4.4). There was no significance difference in sorghum yield between the three trees, although the yield under tree number 2 was the highest (566.25±73.02 kg ha^{-1}).The yield under tree number 1 and 3 were respectively 475.62±47.08 kg ha^{-1} and 550.31±58.54 kg ha^{-1}.

Very high significant difference in yield was found between the zones under trees ($P<0.001$). Yield in zones B, C and the control plot were significantly higher than that of zone A, close to the trunk (64.16±21 kg ha^{-1}). The yield in zone B (548.33±57 kg ha^{-1}) was significantly lower than the yield in zone C (742±81 kg ha^{-1}) and zone D (768±52 kg ha^{-1}. The yield in zone C and zone D did not differ significantly from each other. There was an interactive effect of trees and zones ($P<0.01$). The relative yield of intercrop to sole crop using arithmetic average is 59% (Table 4.8). The relative yield of intercrop to sole crop using the average weighted by zone area is 86% (Table 4.10). Sorghum development stages under *T. indica* are presented in plate 4.6.

b) Sorghum yield in 2008

The average yield of sorghum in 2008 was 564.40±22.8 kg ha^{-1} (Table 4.4).There was no significant difference in sorghum yield between trees. The yield under tree number 1, 2 and 3 were respectively 526.61±33.40 kg ha^{-1}, 559.51±35.62 kg ha^{-1} and 607.19±47.71 kg ha^{-1}. Very high significant difference was found in yield between the different zones ($P<0.001$). Yield in zones B, C and the control plot were significantly higher than that of zone A (241.86±22 kg ha^{-1}). The yield in zone B (560.78±38 kg ha^{-1}) was significantly lower than the yield in zone C (745±52 kg ha^{-1}) and zone D (710±21 kg ha^{-1}. The yield in zone C is however higher than that of zone D, but they did not differ significantly from each other. There was interactive effect of trees and zones ($P<0.02$). The relative yield of intercrop to sole crop using arithmetic average is 73% (Table 4.9). The relative yield of intercrop to sole crop using the average weighted by zone area is 94% (Table 4.11).

The average yield of sorghum over the two years was 547.55 ±28.85 kg ha^{-1}. There was no significant difference in sorghum yield between the two years. There was also no significant difference in sorghum yield between the different directions. The only significance difference found in sorghum yield was between zones ($P<0.005$) (Table 4.6). The result of the General Linear Model (GLM) analysis showed that there were no interactive effects of year and direction, year and zone, direction and zone, as well as year and direction and zone on sorghum yield (Table 4.6). The relative yield over the two years of intercrop to sole crop using the arithmetic average is 67% while the relative yield of intercrop to sole crop using the average weighted by zone is 90%.

4.3.2.1. Sorghum dry biomass

a) Sorghum dry biomass in 2007

The average dry biomass of sorghum in 2007 was 2982±127 kg ha^{-1} (Table 4.4). There was significant difference in sorghum biomass between trees. The dry biomass under tree number 1 (2441.56±184.06 kg ha^{-1}) was significantly lower ($P<0.001$) than the dry biomass under tree 2 (3152.81±235.31 kg ha^{-1}) and number 3 (3352.81±225.35 kg ha^{-1}). Very high significant difference was found in dry biomass between the different zones ($P<0.001$). The dry biomass in zones B, C and the control plot were significantly higher than that of zone A (1180.83±123 kg ha^{-1}). The dry biomass in zone B (3260±242 kg ha^{-1}) although lower was not significantly different from the dry biomass in zone C (3820.42±271 kg ha^{-1}) and zone D (3668.33±142.02kg ha^{-1}). The dry biomass in zone C is higher than that of zone D. But they did not differ significantly from each other. There was a borderline interactive effect of trees and zones ($P<0.05$).

b) Sorghum dry biomass in 2008

The average dry biomass of sorghum in 2008 was 1923±109 kg ha^{-1} (Table 4.4).There were significant difference in sorghum biomass between trees ($P<0.001$). The dry biomass under tree number 3 (2608.7±232.85 kg ha^{-1}) was significantly higher ($P<0.001$) than the dry biomass under tree 2 (1938±166.20 kg ha^{-1}) which was also significantly higher than tree number 1 (1223.37±100.26 kg ha^{-1}). Very high significant difference was found in dry biomass between the different zones ($P<0.001$). The dry biomass in zones B, C and the control plot were significantly higher than that of zone A (804.51±78 kg ha^{-1}). The dry biomass in zone B (1773±171 kg ha^{-1}) was significantly lower than the dry biomass in zone C (2665±326 kg ha^{-1}) and zone D (2450±70 kg ha^{-1}). The dry biomass in zone C is higher than that of zone D. But those two dry biomasses did not differ significantly from each other. There was interactive effect of trees and zones ($P<0.001$).

The mean dry biomass of sorghum over the two years was 2452 ±118 kg ha^{-1}. There was significant difference in sorghum dry biomass between the two years (P<0.03). There was also significant difference in sorghum dry biomass between the different directions (P<0.001). Table 4.5 shows Sorghum yield and dry biomass during two cropping seasons (2007 and 2008) according to directions. The highest dry biomass was recorded in South (2946.74 kg ha^{-1}). A significance difference was found in sorghum dry biomass between zones (P<0.005) (Table 4.7). The result of the General Linear Model (GLM) analysis showed that there were no interactive effects of year and direction, year and zone, year and direction and zone on sorghum biomass (Table 4.7). However there was interactive effect of direction and zone on sorghum biomass (P<0.01).

Table 4.4. Sorghum yield and dry biomass during two cropping seasons (2007 and 2008) according to concentric zones in Siramana village in Mali.

Year	Tree Number	Zones	Mean Yield (kg ha^{-1})	Mean Dry Biomass (kg ha^{-1})
2007	1	A	122±39	1006±233
		B	660±111	2766±450
		C	535±101	2679±278
		D	585±37	3315±193
	2	A	9±0.8	1206±121
		B	445±86	2952±248
		C	951±185	4607±596
		D	860±101	3845±265
	3	A	61±44	1330±265
		B	540±96	4061±470
		C	740±106	4175±352
		D	860±101	3845±265
Mean			**531±35**	**2982±127**
2008	1	A	283±43	475±53
		B	485±65	966±93
		C	587±59	1013±77
		D	750±37	2440±90
	2	A	245±39	1142±169
		B	540±36	1629±123
		C	761±81	2525±559
		D	690±36	2455±136
	3	A	197±30	796±108
		B	656±83	2725±382
		C	886±110	4458±534
		D	690±37	2455±136
Mean			**564±23**	**1923±109**
Mean (2 years)			**548±29**	**2452±118**

Table 4.5: Sorghum yield and dry biomass during two cropping seasons (2007 and 2008) according to directions in Siramana village in Mali.

Year	Tree Number	Direction	Mean Yield (kg ha^{-1})	Mean Dry Biomass (kg ha^{-1})
2007	1	East	267±71	1676±352
		North	432±59	3240±354
		South	670±125	2640±399
		West	532±84	2210±270
	2	East	362±102	2760±325
		North	597±126	2490±284
		South	675±193	3950±702
		West	630±148	3411±405
	3	East	469±122	2812±471
		North	545±122	2940±420
		South	622±121	4058±481
		West	565±111	3600±394
2008	1	East	484±90	1112±219
		North	539±58	1396±188
		South	575±65	1205±199
		West	509±52	1179±206
	2	East	538±65	1613±175
		North	570±55	1624±200
		South	668±85	2757±546
		West	461±73	1758±186
	3	East	498±55	1676±201
		North	559±84	2459±362
		South	649±73	3069±469
		West	722±144	3231±649

Table 4.6: Result of General linear model analysis for sorghum yield (kg ha^{-1}) versus year, direction and zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	1	109111	109111	109111	0.44	0.570
Direction	3	2118837	2118837	706279	2.96	0.159
Zone	3	22162718	22162718	7387573	21.22	0.005
Year*Direction	3	405528	405528	135176	1.04	0.421
Year*Zone	3	734298	734298	244766	1.88	0.421
Direction*Zone	9	2099884	2099884	233320	1.80	0.203
Year*Direction*Zone	9	1169566	1169566	129952	1.31	0.229

Table 4.7: Result of General linear model analysis for sorghum dry biomass (kg ha^{-1}) versus year, direction and zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	1	107670771	107670771	107670771	23.06	0.035
Direction	3	50566366	50566366	16855455	3.48	0.086
Zone	3	300283762	300283762	100094587	9.98	0.006
Year*Direction	3	846642	846642	282214	0.26	0.851
Year*Zone	3	16400507	16400507	5466836	5.06	0.025
Direction*Zone	9	50761795	50761795	5640199	5.22	0.011
Year*Direction*Zone	9	9715497	9715497	1079500	0.64	0.766

Table 4.8: Sorghum relative yield of intercrop to sole crop using arithmetic average in 2007

Zone	Yield (Kg ha-1)	Relative yield (%)
A	64.16	8
B	548	71
C	742	97
D	768	100
Mean	530.7	59

NB: Zones A, B and C represent the intercrop; Zone D represents the sole crop

Table 4.9: Sorghum relative yield of intercrop to sole crop using arithmetic average in 2008

Zone	Yield (Kg ha-1)	Relative yield (%)
A	242	34
B	561	79
C	745	105
D	710	100
Mean	564.4	73

Table 4.10: Sorghum relative yield of intercrop to sole crop using the average weighted by zone area in 2007

Zone	Zone area	Relative yield (%) arithmetic average	Relative yield*Zone area	Relative yield average weighted (%)
A	7.21	8	57.68	
B	21.63	71	1535.73	
C	84.78	97	8232.66	
Sum	113.62		9817.07	9817/114=86

Table 4.11: Sorghum relative yield of intercrop to sole crop using the average weighted by zone area in 2008

Zone	Zone area	Relative yield (%) arithmetic average	Relative yield*Zone area	Relative yield average weighted (%)
A	9.26	59	314.84	
B	27.76	138	2193.04	
C	91.69	162	9627.33	
Sum	128.71		12135.33	**12135.33/128.71= 58.67**

Plate 4.6: Sorghum development under *T. indica* trees in a parkland system in Siramana village

Young sorghum plants (4 weeks after sowing)

Sorghum plants (10 weeks after sowing)

Sorghum field (3 months after sowing)

Sun drying of harvested sorghum

4.3.3. Eggplant performance

4.3.3.1. Eggplant yield

The results presented here are only for two trees (number 5 and 6). All eggplants under tree number 4 died before harvesting due to termite mounds that were created by termites under this tree in 2007. This tree was excluded from the study in 2008 also because of termite mounds (plate 4.7a).

a) Eggplant yield in 2007

The mean yield of eggplant in 2007 was 41701±216 kg ha^{-1} (Table 4.12). There was significance difference in eggplant yield between the two trees ($P<0.05$). The yield under tree number 6 (4530 ±284 kg ha^{-1}) was significantly higher than that under tree 5 (3810.94±322 kg ha^{-1}). Very high significant difference in eggplant yield was found between the zones under trees ($P<0.001$). Yield in zones B and C were significantly higher than that of zone A (2132.81±293.14 kg ha^{-1}) and the control plot (3631±260.28 kg ha^{-1}). The yield in zone D was also significantly higher than the yield in zone A. The yield in zone C (5898.44±443.27 kg ha^{-1}) and zone B (5018.75±390.55 kg ha^{-1}) did not differ significantly from each other. There was no interactive effect of trees and zones. The relative yield of eggplant intercrop to sole crop using arithmetic average is 120% (Table 4.16). The relative yield of intercrop to sole crop using the average weighted by zone area is 120% (Table 4.18).

b) Eggplant yield in 2008

The average yield of eggplant in 2008 was 2207±162 kg ha^{-1} (Table 4.12).There was significant difference in eggplant yield between trees. The yield under tree number 6 (2488.02±261 kg ha^{-1}) was significantly higher than that under tree number 5 (1927.90±188 kg ha^{-1}) with $P<0.005$. Very high significant differences were found in eggplant yield between the different zones ($P<0.001$). All the different zones differ significantly from each other. There was a decrease in yield from the control plot to zone A close to tree trunk. The yield in zones A, B, C and the control plot are respectively (459.88±51.04 kg ha^{-1}), (1700.17±185.55 kg ha^{-1}), (2467±266 kg ha^{-1}) and (4204.46±294.32 kg ha^{-1}). There was interactive effect of trees and zones ($P<0.005$). The relative yield of eggplant intercrop to sole crop using arithmetic average was 37% (Table 4.17). The relative yield of intercrop to sole crop using the average weighted by zone area was 51% (Table 4.19).

The average yield of eggplant over the two years under the two trees was 3189 ±148 kg ha^{-1}. There was significant difference in eggplant yield between the two years ($P<0.001$) (Table 4.12). There was no significant difference in eggplant yield between the different directions (Table 4.13). There was significance difference in eggplant yields between zones ($P<0.001$) (Table 4.12). The result of the General Linear Model (GLM) analysis showed that there were no interactive effects of year and direction, direction and zone, year and direction and zone on eggplant yield (Table 4.14). However, there was an interactive effect of year and zone on eggplant yield ($P<0.001$). The relative yield of eggplant over the two years of intercrop to sole crop using the arithmetic average was 78% while the relative yield of intercrop to sole crop using the average weighted by zone was 101%.

a) Eggplant above ground dry biomass in 2007

The mean dry biomass of eggplant in 2007 was 210±29 kg ha^{-1} (Table 4.12). There was no significant difference in eggplant dry biomass between the two trees. The dry biomass under tree number 6 (164 ±13 kg ha^{-1}) was lower than that under tree 5 (257±57 kg ha^{-1}). Very high significant difference in eggplant dry biomass was found between the zones under trees ($P<0.001$). The dry biomass in zones C (400.43±107.03 kg ha^{-1}) was significantly higher than that of the other zones. The dry biomass in zone D (219.27±14.75 kg ha^{-1}) was also significantly higher than the dry biomass in zone A (67.27±10.20 kg ha^{-1}). The dry biomass in zone B (156.81±27.01 kg ha^{-1}) did not differ significantly from those in zone A and D. There was interactive effect of trees and zones on eggplant dry biomass ($P<0.005$).

b) Eggplant dry biomass in 2008

The average dry biomass of eggplant in 2008 was 202±15 kg ha^{-1} (Table 4.12).There was no significant difference in eggplant biomass between trees. The dry biomass under tree number 5 (206.62±27.73 kg ha^{-1}) was higher than the dry biomass under tree 6 (198±15 kg ha^{-1}). Very high significant difference was found in dry biomass between the different zones ($P<0.001$). The dry biomass in zones B, C and the control plot were significantly higher than that of zone A (86.73±15 kg ha^{-1}). Eggplant dry biomass in zone B (197±24 kg ha^{-1}), zone C (273.5±46.7 kg ha^{-1}) and zone D (251.46±19 kg ha^{-1}) did not differ significantly from each other. There was a borderline interactive effect of trees and zones on eggplant dry biomass ($P<0.05$).

The mean dry biomass of eggplant over the two years was 206±16 kg ha^{-1}. There was no significant difference in eggplant dry biomass between the two years. There was significant difference in eggplant dry biomass between the different directions ($P<0.001$) (Table 4.13). The dry biomass in the North is significantly higher than that of the other directions which did not differ significantly from each other. Table 4.13 shows eggplant yield and dry biomass during two cropping seasons (2007 and 2008) according to directions. A significant difference was found in eggplant dry biomass between zones ($P<0.001$) (Table 4.12). The result of the General Linear Model (GLM) analysis showed that there were no interactive effects of year and direction as well as year and zone on eggplant biomass (Table 4.15). However there was interactive effect of direction and zone ($P<0.001$) as well as year and direction and zone on eggplant biomass ($P<0.005$).

Table 4.12: Eggplant yield and above ground dry biomass during two cropping seasons (2007 and 2008) according to concentric zones in Siramana village in Mali.

Year	Tree Number	Zones	Mean Yield ($kg\ ha^{-1}$)	Mean Dry Biomass ($kg\ ha^{-1}$)
2007	5	A	1676±345	61±13
		B	4812±453	176±52
		C	6051±704	621±199
		D	2704±369	172±16
	6	A	2589±456	74±16
		B	5225±648	138±15
		C	5745±559	179±30
		D	4558±171	267±18
Mean			**4170±216**	**210±29**
2008	5	A	491±86	57±11
		B	1724±276	211±45
		C	2215±461	341±88
		D	3282±174	217±19
	6	A	429±57	117±27
		B	1676±251	183±17
		C	2719±266	206±27
		D	5127±463	285±32
Mean			**2207±162**	**202±15**
Mean (2 years)			**3189±148**	**206±16**

Table 4.13. Eggplant yield and dry biomass during two cropping seasons (2007 and 2008) according to direction in Siramana village in Mali.

Year	Tree number	Direction	Mean yield (kg ha-1)	Mean dry biomass (kg ha-1)
2007	5	East	4178±634	183±41
		North	4653±834	626±21
		South	3636±576	132±25
		West	2776±431	89±19
	6	East	3911±472	129±24
		North	4417±658	173±33
		South	5002±702	152±23
		West	4788±397	203±24
2008	5	East	1881±305	169±25
		North	2269±523	390±90
		South	1666±306	118±20
		West	1896±348	149±26
	6	East	2479±515	192±33
		North	2242±520	208±27
		South	2127±539	158±27
		West	3105±529	234±30

Table 4.14: Result of general linear model analysis for eggplant yield (kg ha^{-1}) versus year, direction and zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	1	246453361	246453361	246453361	91.69	0.001
Direction	3	3669659	3669659	1223220	0.46	0.714
Zone	3	328335335	328335335	109445112	40.72	0.001
Year*Direction	3	12555141	12555141	4185047	1.56	0.201
Year*Zone	3	168150795	168150795	56050265	20.85	0.001
Direction*Zone	9	29096733	29096733	3232970	1.20	0.294
Year*Direction*Zone	9	43357724	43357724	4817525	1.79	0.071

Table 4.15: Result of general linear model analysis for eggplant dry biomass (kg ha^{-1}) versus year, direction and zone

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Year	1	4819	4819	4819	0.11	0.743
Direction	3	1774079	1774079	591360	13.24	0.001
Zone	3	2271271	2271271	757090	16.95	0.001
Year*Direction	3	200080	200080	66693	1.49	0.217
Year*Zone	3	301960	301960	100653	2.25	0.083
Direction*Zone	9	2551105	2551105	283456	6.34	0.001
Year*Direction*Zone	9	1202833	1202833	133648	2.99	0.005

Table 4.16. Eggplant relative yield of intercrop to sole crop using arithmetic average in 2007

Zone	Yield (Kg ha^{-1})	Relative yield (%)
A	2132.81	59
B	5018.75	138
C	5890.14	162
D	3631.25	100
Mean		120

NB: Zones A, B and C represent the intercrop; Zone D represents the sole crop

Table 4.17 Eggplant relative yield of intercrop to sole crop using arithmetic average in 2008

Zone	Yield (Kg ha^{-1})	Relative yield (%)
A	459.88	11
B	1700.17	40
C	2467.33	59
D	4204.46	100
Mean		37

Table 4.18. Eggplant relative yield of intercrop to sole crop using the average weighted by zone area in 2007

Zone	Zone area	Relative yield (%) arithmetic average	Relative yield*Zone area	Relative yield average weighted (%)
A	7.55	59	445.45	
B	22.66	138	3127.08	
C	86.67	162	14040.54	
Sum	116.88		17613.07	17613.07/116.88= **150.69**

Table 4.19. Eggplant relative yield of intercrop to sole crop using the average weighted by zone area in 2008

Zone	Zone area	Relative yield (%) arithmetic average	Relative yield*Zone area	Relative yield average weighted (%)
A	10.19	11	112.09	
B	30.54	40	1221.6	
C	96.08	59	5668.72	
Sum	136.81		7002.41	7002.41/136.81= **51.18**

Plate 4.7: Termite hills (a), young eggplant plant in zone C (b), mature fruits of eggplant under (c) and weighing eggplant above ground fresh biomass (d).

a) Termite hills under *T.indica* tree

b) Young eggplant plant in zone C under tree No 6

c) Mature fruits of eggplant under *T.indica* tree No 5

d) Weighing eggplant above ground fresh biomass

4.3.4. Nutritional composition of sorghum grain and eggplant fruit

Tamarind shade did not have any significant effect on the nutritional composition of either sorghum or eggplant with the exception of Mg and Mn (Table 4.20). However, nutrient contents significantly differed between 2007 and 2008 cropping seasons (table 4.20). As expected, there was also significant difference between the two crops in their nutrient contents with the exception of P, Mn and Zn. Protein, fibre, ash, nitrogen, potassium, sodium, calcium and iron were significantly higher ($P<0.001$, all) in eggplant than sorghum (Table 4.21, 4.22; 4.23 and 4.24). In contrast sorghum was richer than eggplant in fat ($p<0.05$) and carbohydrate ($p<0.001$).

Table 4.20: Significance level of nutrients according to year, crop type and concentric zones under trees.

Nutrients	Year	Crop type	Zones
Protein %	0.001	0.001	NS
Nitrogen%	0.001	0.001	NS
P mg/g	0.001	NS	NS
K mg/g	0.001	0.001	NS
Na mg/g	0.005	0.001	NS
Ca mg/g	0.001	0.001	NS
Mg µg/g	0.001	0.001	0.005
Mn µg/g	0.001	NS	0.001
Fe µg/g	0.05	0.001	NS
Zn µg/g	0.05	NS	NS
Fat g g-1	0.05	0.05	NS
Fibre g g-1	NS	0.001	NS
Ash g g-1	0.001	0.001	NS
Carbohydrate g g-1	0.001	0.001	NS

NS: Not significant

Table 4.21: Mineral contents of Sorghum grain

Year	Zone	N (%)	P (mg/g)	K (mg/g)	Na (mg/g)	Ca (mg/g)	Mg (µg/g)	Mn (µg/g)	Fe (µg/g)	Zn (µg/g)
	A	2.04±0.14	3.34±0.12	0.001±0.001	0.09±0.02	0.006±0.001	0.33±0.04	0.29±0.01	1.20±0.03	0.82±0.25
2007	B	1.76±0.06	4.15±0.40	0.002±0.000	0.12±0.03	0.007±0.001	0.39±0.00	0.34±0.03	1.20±0.09	1.08±0.07
	C	1.68±0.05	4.96±0.27	0.002±0.001	0.10±0.02	0.007±0.001	0.42±0.02	0.36±0.04	1.16±0.03	0.87±0.15
	D	1.74±0.08	3.52±0.31	0.001±0.000	0.09±0.01	0.006±0.000	0.33±0.02	0.39±0.01	1.49±0.29	0.79±0.13
	A	2.03±0.11	4.67±0.66	0.003±0.001	0.16±0.02	0.009±0.001	0.46±0.05	0.35±0.01	1.41±0.11	1.36±0.36
2008	B	1.94±0.05	5.46±1.04	0.004±0.001	0.17±0.00	0.008±0.000	0.60±0.05	0.45±0.01	1.59±0.09	1.27±0.36
	C	1.86±0.07	7.69±0.67	0.004±0.000	0.18±0.02	0.008±0.000	0.67±0.05	0.49±0.04	1.56±0.12	1.43±0.38
	D	2.12±0.09	6.66±0.99	0.004±0.000	0.21±0.02	0.008±0.001	0.79±0.09	0.70±0.08	1.69±0.21	1.78±0.36
Mean		1.90±0.05	5.06±0.53	0.002±0.000	0.14±0.01	0.008±0.00	0.49±0.06	0.42±0.04	1.4±0.07	1.18±0.12

Table 4.22: Mineral contents of eggplant fruit

Year	Zone	N%	P (mg/g)	K (mg/g)	Na (mg/g)	Ca (mg/g)	Mg (µg/g)	Mn (µg/g)	Fe (µg/g)	Zn (µg/g)
	A	2.75±0.17	4.83±0.39	0.03±0.01	0.31±0.03	0.01±0.00	0.58±0.02	0.42±0.02	3.26±0.36	0.86±0.11
2007	B	2.61±0.06	5.10±0.48	0.03±0.01	0.22±0.01	0.01±0.00	0.60±0.03	0.41±0.04	2.42±0.39	1.36±0.49
	C	2.46±0.08	5.10±0.22	0.03±0.00	0.27±0.03	0.01±0.00	0.58±0.03	0.44±0.04	2.74±0.89	1.00±0.05
	D	2.69±0.04	4.99±0.69	0.03±0.01	0.31±0.07	0.01±0.00	0.61±0.03	0.52±0.07	2.78±0.66	0.76±0.13
	A	2.73±0.11	5.47±0.55	0.04±0.00	0.31±0.05	0.01±0.00	0.57±0.04	0.39±0.03	1.77±0.14	0.93±0.08
2008	B	2.85±0.05	5.83±0.19	0.04±0.00	0.28±0.03	0.01±0.00	0.69±0.02	0.44±0.02	1.85±0.44	1.154±0.26
	C	2.79±0.09	5.61±0.37	0.04±0.00	0.30±0.03	0.01±0.00	0.62±0.03	0.44±0.01	1.57±0.13	1.27±0.29
	D	3.15±0.33	5.04±0.52	0.04±0.00	0.29±0.02	0.01±0.00	0.65±0.04	0.50±0.04	1.62±0.21	1.163±0.19
Mean		**2.76±0.07**	**5.25±0.12**	**0.03±0.00**	**0.29±0.01**	**0.01±0.00**	**0.61±0.01**	**0.45±0.01**	**2.25±0.22**	**1.06±0.07**

Table 4.23: Proximate composition of sorghum grain

Year	Zone	Protein (%)	Fat (g g-1)	Fibre (g g-1)	Ash (g g-1)	Carbohydrate (g g-1)
	A	12.80±0.87	0.04±0.01	0.19±0.02	0.02±0.00	0.62±0.02
2007	B	11.01±0.40	0.05±0.01	0.17±0.01	0.01±0.00	0.64±0.01
	C	10.55±0.33	0.05±0.00	0.23±0.05	0.02±0.00	0.59±0.05
	D	10.89±0.52	0.05±0.00	0.16±0.00	0.02±0.00	0.66±0.01
2008	A	12.73±0.67	0.05±0.01	0.29±0.03	0.02±0.00	0.52±0.04
	B	12.16±0.29	0.07±0.01	0.23±0.01	0.03±0.00	0.54±0.02
	C	11.63±0.42	0.07±0.01	0.27±0.01	0.04±0.00	0.50±0.01
	D	13.28±0.61	0.08±0.01	0.29±0.01	0.04±0.00	0.45±0.02
Mean		**11.88±0.36**	**0.06±0.00**	**0.23±0.02**	**0.03±0.00**	**0.57±0.02**

Table 4.24: Proximate composition of eggplant fruit

Year	Zone	Protein %)	Fat (g g-1)	Fibre (g g-1)	Ash (g g-1)	Carbohydrate (g g-1)
	A	17.24±1.09	0.05±0.03	0.57±0.02	0.018±0.02	0.12±0.02
2007	B	16.32±0.41	0.05±0.02	0.55±0.04	0.002±0.00	0.07±0.03
	C	15.38±0.49	0.05±0.02	0.55±0.02	0.005±0.01	0.15±0.04
	D	16.80±0.27	0.03±0.02	0.52±0.05	0.001±0.00	0.19±0.06
	A	17.08±0.69	0.05±0.00	0.68±0.02	0.021±0.02	0.06±0.04
2008	B	17.85±0.30	0.04±0.01	0.70±0.01	0.003±0.00	0.06±0.01
	C	17.42±0.57	0.05±0.00	0.69±0.04	0.024±0.02	0.04±0.06
	D	19.67±2.04	0.04±0.01	0.65±0.02	0.021±0.02	0.06±0.02
Mean		**17.22±0.44**	**0.05±0.00**	**0.61±0.03**	**0.012±0.003**	**0.09±0.01**

4.3.5. Root length and root weight density distribution

Mean root length density (RLD) of *T. indica* was 0.24±0.03 cm cm^{-3}. Significant difference was found between concentric zones in RLD of *T. indica* (Table 4.25) ($p<0.001$). RLD of *T. indica* in zone A (0.38±0.04 cm cm^{-3}) was significantly higher than that of zone B (0.20±0.04 cm cm^{-3}) and C (0.14±0.06 cm cm^{-3}). RLD did not differ between zone B and C. No *T. indica* roots were found in the control plot (zone D). RLD of Tamarind decreased significantly with increase in soil depth ($p<0.001$) (Equation 4.1). The RLD in upper layer (0-10 cm) (0.38 ± 0.04 cm cm^{-3}) was significantly higher than all the other layers.

Tamarindus RLD = -0.0670*(soil depth) + 0.4145 [r^2 = 46%; $P<0.01$] (4.1)

Mean root weight density (RWD) of *T indica* was 0.34±0.06 mg cm^{-3} (Table 4.26). A significant difference was found between concentric zones in RWD of *T indica* ($p<0.001$). RWD in zone A (0.54± 0.04 mg cm^{-3}) was significantly higher than that of zone B (0.29± 0.06) and C (0.19± 0.06 mg cm^{-3}). The RWD of these two zones did not differ significantly from each other. There was also significant difference in RWD according to soil depth ($p<0.001$). The upper layer 0-10 cm (0.54±0.05 mg cm^{-3}) had the highest mean root weight density.

RLD of sorghum was 0.17± 0.04 cm cm^{-3}. No significant difference was found between concentric zones in RLD of sorghum (Table 4.25) although the least RLD was found in the surface soil of zone A. However, RLD of sorghum decreased with an increase in soil depth ($p<0.05$) (Equation 4.2). The RLD in upper layers were significantly higher that of the deeper layers.

Sorghum RLD = -0.0396*(soil depth) + 0.2862 [r^2 = 44%; $P<0.001$] (4.2)

There was no significant difference in sorghum RWD between concentric zones (Table 4.26). Significant difference was found between soil depth in RWD ($p<0.05$). The RWD in upper layer was significantly higher than that of the deeper layers.

With regard to RLD of eggplant the mean value was 0.06±0.02 cm cm^{-3}. There was no significant difference between concentric zones (Table 4.25) although it was lower in the surface soil of zone A than zone B. However, significant difference was found between soil depths with the upper layer showing the highest RLD than the other layers (Equation 4.3).

$$\text{Eggplant RLD} = -0.0278*(\text{spoil depth}) + 0.1453 \qquad [r^2 = 46\%; P<0.001] \qquad (4.3)$$

There was no significant difference in eggplant RWD between concentric zones (Table 4.26). Significant difference was, however, found between soil depths in RWD ($p<0.001$). The RWD in upper layers 0-10 cm was significantly higher than that of the other layers.

Table 4.25: Root length densities of *Tamarindus indica*, sorghum and eggplant in an intercropping trial in a parkland in Siramana, Mali

Depth (cm)	0-10	10-20	20-30	Mean
Tamarindus				
Zone A	0.55±0.05	0.37±0.09	0.23±0.04	0.38±0.04
Zone B	0.42±0.03	0.27±0.07	0.18±0.03	0.20±0.04
Zone C	0.19±0.04	0.17±0.05	0.11±0.03	0.14±0.25
Mean	**0.38±0.04**	**0.27±0.04**	**0.17±0.02**	**0.24±0.03**
Eggplant				
Zone A	0.17±0.09	0.03±0.01	0.01±0.00	0.07±0.04
Zone B	0.23±0.14	0.03±0.01	0.02±0.01	0.06±0.03
Zone C	0.11±0.02	0.08±0.02	0.06±0.02	0.06±0.01
Zone D	0.11±0.00	0.08±0.06	0.06±0.04	0.06±0.01
Mean	**0.15±0.03**	**0.05±0.01**	**0.03±0.01**	**0.06±0.02**
Sorghum				
Zone A	0.19±0.06	0.18±0.05	0.16±0.05	0.17±0.03
Zone B	0.28±0.07	0.22±0.04	0.19±0.08	0.16±0.03
Zone C	0.35±0.05	0.17±0.09	0.21±0.12	0.19±0.04
Zone D	0.10±0.09	0.33±0.10	0.19±0.11	0.14±0.04
Mean	**0.23±0.04**	**0.23±0.05**	**0.18±0.04**	**0.17±0.04**

Table 4.26: Root weight density of *Tamarindus indica*, sorghum and eggplant in an intercropping trial in a parkland in Siramana, Mali

Depth (cm)	0-10	10-20	20-30	Mean
Tamarindus				
Zone A	0.78±0.06	0.51±0.01	0.32±0.05	0.54±0.08
Zone B	0.58±0.05	0.39±0.09	0.24±0.04	0.29±0.06
Zone C	0.26±0.05	0.24±0.07	0.15±0.03	0.19±0.06
Mean	**0.54±0.05**	**0.38±0.06**	**0.24±0.04**	**0.34±0.00**
Eggplant				
Zone A	0.18±0.10	0.03±0.01	0.02±0.00	0.08±0.04
Zone B	0.25±0.15	0.04±0.01	0.02±0.01	0.06±0.04
Zone C	0.12±0.02	0.08±0.02	0.07±0.00	0.07±0.02
Zone D	0.12±0.006	0.09±0.00	0.06±0.05	0.07±0.03
Mean	**0.17±0.07**	**0.06±0.03**	**0.04±0.02**	**0.07±0.03**
Sorghum				
Zone A	0.18±0.05	0.17±0.04	0.15±0.05	0.16±0.05
Zone B	0.27±0.08	0.21±0.04	0.18±0.08	0.16±0.06
Zone C	0.33±0.05	0.16±0.09	0.20±0.11	0.19±0.08
Zone D	0.10±0.08	0.32±0.10	0.18±0.11	0.15±0.09
Mean	**0.22±0.07**	**0.21±0.09**	**0.18±0.09**	**0.17±0.07**

4.3.6. Correlation between root length density and root weight density

Significant linear relationships were found between RLD and RWD (P<0.001) for *T. indica* and both crops (sorghum and eggplant) (equations 4.4 - 4.6).

Tamarindus RLD = 0.6596*RWD + 0.026 [r^2 = 95%; P<0.001] (4.4)

Sorghum RLD = 1.052* RWD + 0.000 [r^2 = 99%; P<0.001] (4.5)

Eggplant RLD = 0.8827*RDW + 0.006 [r^2 = 98%; P<0.001] (4.6)

4.3.7. Correlations between root length density and crop yield and nutritional composition

a) Correlation between crop and tree root length density (RLD) and crop yield and biomass

Pearson's correlation analysis showed that eggplant yield was negatively and strongly correlated with Tamarind RLD ($P<0.01$) (Table 4.27). There were also significant negative correlations between sorghum yield and Tamarind RLD ($P<0.05$) as well as between sorghum dry biomass and Tamarind RLD ($P<0.01$) in 2007 (Table 4.28).

Table 4.27. Correlations between plant root length density and eggplant yield and biomass according to concentric zones (Cell Contents: Pearson correlation; P-Value)

	Tamarind root	Eggplant root	Eggplant yield
Eggplant root	0.930		
	0.240		
Eggplant yield	-1.000	-0.927	
	0.005	0.244	
Eggplant biomass	-0.844	-0.587	0.848
	0.361	0.601	0.356

b) Correlation between root length density (RLD) and crop proximate composition

There was a significant positive relationship between roots of *T. indica* and sorghum grain protein content ($P<0.05$) (Table 4.29). The relationship between sorghum roots and fibre content was also significantly positive ($P<0.05$). There was also significant positive correlation between roots of *T. indica* and eggplant fibre content. The relationship between eggplant roots and ash content was also significantly positive ($P<0.01$) (Table 4.29). However, the relationship between eggplant roots and fat content was significant but negative ($P<0.05$).

Table 4.28: Correlations between plant root length density and sorghum yield and biomass according to concentric zones (Cell Contents: Pearson correlation; P-Value)

	Tamarind root	Sorghum root	Sorghum yield
Sorghum root	-0.600		
	0.590		
Sorghum yield	-0.998	0.650	
	0.040	0.550	
Sorghum biomass	-1.000	0.588	0.997
	0.009	0.599	0.050

Table 4.29: Correlations between plant root length density and crop proximate composition

Sorghum	Tamarind root	Sorghum root	Eggplant	Tamarind root	Eggplant root
Protein	1.000	-0.582	Protein	0.952	0.773
	0.015	0.605		0.198	0.438
Fat	-0.956	0.808	Fat	-0.950	-0.998
	0.189	0.401		0.202	**0.037**
Fibre	-0.574	0.999	Fibre	0.998	0.906
	0.611	**0.021**		**0.038**	0.278
Ash	-0.463	0.987	Ash	0.926	1.000
	0.694	0.104		0.247	**0.008**
Carbohydrate	0.349	-0.959	Carbohydrate	-0.016	0.353
	0.773	0.183		0.990	0.770

c) Correlation between crop and tree root length density (RLD) and crop mineral composition

A significant positive correlation was found between roots of *T. indica* and sorghum grain N content (P<0.05) (Table 4.30). There was also a significant but negative correlation between roots of *T. indica* and sorghum Mn content (P<0.01). There were, however, no correlations between RLD of Tamarind and mineral contents of eggplant (Table 4.30).

Table 4.30. Correlations between plant root length density and crop mineral composition

Sorghum	Tamarind root	Sorghum root	Eggplant	Tamarind root	Eggplant root
N	1.00	-0.58	N	0.952	0.773
	0.02	0.61		0.198	0.438
P	-0.95	0.81	P	-0.975	-0.988
	0.19	0.39		0.142	0.098
K	-0.97	0.37	K	-0.035	-0.400
	0.17	0.76		0.978	0.738
Na	-0.72	-0.12	Na	0.688	0.906
	0.49	0.93		0.517	0.278
Ca	-0.74	-0.09	Ca	-0.866	-0.621
	0.47	0.94		0.334	0.574
Mg	-0.99	0.72	Mg	-0.232	-0.574
	0.11	0.49		0.851	0.611
Mn	-1.00	0.61	Mn	-0.572	-0.230
	0.01	0.58		0.612	0.852
Fe	0.77	-0.97	Fe	0.821	0.974
	0.44	0.15		0.386	0.147
Zn	-0.45	-0.45	Zn	-0.550	-0.819
	0.70	0.71		0.629	0.389

4.3.8. Correlations between soil nutrients and crop yield and nutritional composition

a) Correlation between soil properties and crop yield and biomass

There were significant negative correlations between soil P and soil K and sorghum yield ($P<0.05$ and $P<0.01$, respectively) as well as sorghum biomass ($P<0.05$) (Table 4.31). There were, however, no correlations between soil nutrients and yield and biomass of eggplant (Table 4.31).

Table 4.31. Correlations between soil nutrients and sorghum yield and biomass

	C	P	K	N	Sorghum yield
Sorghum yield	-0.839	-0.953	-0.994	-0.909	
	0.161	**0.047**	**0.006**	0.091	
Sorghum biomass	-0.792	-0.912	-0.977	-0.873	0.990
	0.208	0.088	**0.023**	0.127	0.010
					Eggplant Yield
Eggplant Yield	0.566	0.250	-0.472	0.555	
	0.434	0.750	0.528	0.445	
Eggplant Biomass	0.623	0.209	-0.105	0.529	0.818
	0.377	0.791	0.895	0.471	0.182

b) Correlation between soil properties and crop proximate composition

There were significant negative correlations between soil nutrients (C, P, K and N) and fat content of sorghum (all $P<0.05$), whereas the correlation with the fat content of eggplant was only with soil K ($P<0.01$) (Table 4.32).

Table 4.32. Correlations between soil nutrients and crop proximate composition

	Sorghum				Eggplant			
	C	P	K	N	C	P	K	N
Protein	-0.367	-0.146	0.058	-0.230	-0.759	-0.438	0.490	-0.726
	0.633	0.854	0.942	0.770	0.241	0.562	0.510	0.274
Fat	-0.958	-0.984	-0.980	-0.989	0.749	0.861	-0.997	0.841
	0.042	**0.016**	**0.020**	**0.011**	0.251	0.139	**0.003**	0.159
Fibre	-0.098	-0.106	0.045	-0.034	0.414	0.776	-0.706	0.514
	0.902	0.894	0.955	0.966	0.586	0.224	0.294	0.486
Ash	-0.586	-0.796	-0.851	-0.679	0.190	0.528	-0.174	0.220
	0.414	0.204	0.149	0.321	0.810	0.472	0.826	0.780
Carbohydrate	0.646	0.674	0.547	0.613	-0.136	-0.412	0.802	-0.287
	0.354	0.326	0.453	0.387	0.864	0.588	0.198	0.713

c) Correlation between soil properties and crop mineral composition

There were significant negative correlations between Soil P, K and N and Sorghum Mg ($P<0.01$, 0.05 and 0.05, respectively) and between Soil C, K and N and Sorghum Fe ($P<0.01$, 0.05 and 0.01, respectively). There was a significant negative correlation between Soil P and eggplant Mg ($P<0.05$) (Table 4.33).

Table 4.33. Correlations between soil nutrients and crop mineral composition

	Sorghum				Eggplant			
	Soil C	Soil P	Soil K	Soil N	Soil C	Soil P	Soil K	Soil N
Crop N	-0.37	-0.15	0.058	-0.23	-0.76	-0.44	0.49	-0.73
	0.633	0.854	0.942	0.770	0.24	0.56	0.51	0.27
Crop P	-0.52	-0.75	-0.81	-0.62	0.32	0.02	-0.36	0.32
	0.480	0.254	0.186	0.379	0.68	0.99	0.64	0.68
Crop K	-0.69	-0.75	-0.85	-0.77	-0.19	0.04	-0.556	-0.048
	0.306	0.249	0.155	0.230	0.806	0.958	0.444	0.952
Crop Na	-0.93	-0.89	-0.79	-0.90	-0.255	-0.251	0.742	-0.359
	0.068	0.101	0.210	0.099	0.745	0.749	0.258	0.641
Crop Ca	0.424	0.655	0.784	0.552	0.618	0.205	-0.125	0.529
	0.576	0.345	0.216	0.448	0.382	0.795	0.875	0.471
Crop Mg	-0.95	-0.99	-0.96	-0.97	-0.842	-0.955	0.624	-0.853
	0.052	**0.006**	**0.042**	**0.031**	0.158	**0.045**	0.376	0.147
Crop Mn	-0.95	-0.93	-0.84	-0.93	-0.579	-0.846	0.928	-0.692
	0.053	0.070	0.165	0.073	0.421	0.154	0.072	0.308
Crop Fe	-0.99	-0.97	-0.94	-0.99	-0.003	0.203	0.294	-0.043
	0.009	**0.028**	0.063	**0.002**	0.997	0.797	0.706	0.957
Crop Zn	-0.74	-0.72	-0.58	-0.69	0.234	0.313	-0.795	0.356
	0.252	0.277	0.420	0.302	0.766	0.687	0.205	0.644

4.3.9. Results of the feedback survey

A total of 58 respondents were interviewed in the village of Siramana. Majority (98%) of the respondents were farmers. Some of the farmers also kept cattle (35%). About 25% of the respondents were involved in home gardening, while a few, 6% were also involved in trade and 4% were house wives.

4.3.9.1. Farmer's perception on the tested tree-crop association of the present study

A majority of respondents (90%) reported that the intercropping of eggplant with Tamarind developed by the project was good and should be promoted for making more productive use of land under trees, improving crop yields and increasing farmers' incomes (Figure 4.3). The farmers however, expressed a need for farm inputs such as fertilizers and insecticides for sustaining crop yields under tree canopies. On the other hand, a few farmers (4%) considered the method not worthwhile.

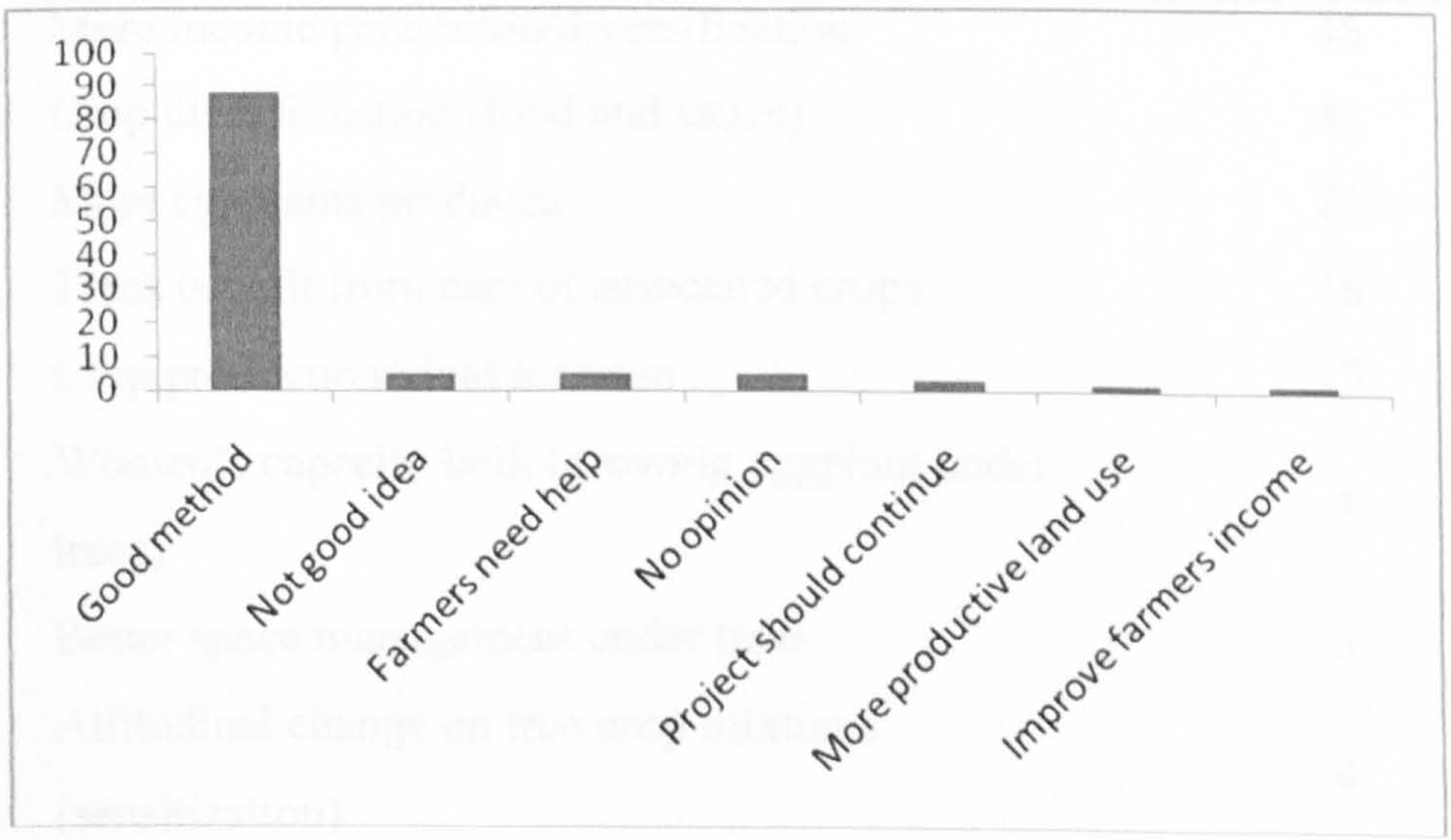


Figure 4.3: Farmers opinion on tree-crop association developed by the project

4.3.9.2. Advantages of the project tested tree-crop association compared to traditional practice

In response to the question on what are the advantages of the tested tree-crop association compared to the traditional tree-crop associations practiced in the study area, 46% of the respondents mentioned that increased income and income diversification were the main advantages of the new method (Table 4.34). Many of the respondents (41%) reported that crop diversification was the main advantage of the method. Increased production of eggplant was reported by 21% of the respondents. Some of the noteworthy advantages of the project reported by the respondents were: trees benefiting from management of associated crops (18%); crop production increase (13%); improvement of women's capacity (7%); better management of the spaces below trees (5%) and attitudinal change created by the project on tree crop mixtures (4%).

Table 4.34: Advantages of the tested method compared to traditional practices

Advantages of the method	(%) of cases
More income generation/diversification	46
Crop diversification (food and sauce)	41
More eggplants produced	21
Trees benefit from care of associated crops	18
Crop production/yield increase	13
Women's capacity built (growing eggplant under trees)	7
Better space management under trees	5
Attitudinal change on tree-crop mixtures (sensitization)	4

4.3.9.3. Disadvantages of the tested tree-crop association compared to the traditional practice

The majority of the respondents (61%) mentioned that the tested method had no disadvantages (Table 4.35). On the other hand, 24% of the respondents pointed out the need for intensive care as the major disadvantages of the method. The limited time available to farmers during the rainy season given other competing farming activities was mentioned by 12% of the respondents. Additional care needed was mentioned by 8% of respondents including weeding, manure application and in some cases of watering of crops below trees. 8% of the respondents reported that the method required fencing, while 3% of the respondents mentioned the lack of inputs, such as fertilizers, insecticides and farm equipment as disadvantage.

Table 4.35: Disadvantages of the tested method compared to the traditional practice

Disadvantages of the method	% of Cases	Rank
No disadvantage	61	1
Require more care	24	2
Lack of time (coincide with rainy season)	12	3
Require more manuring	8	4
Require fencing	8	4
Lack of input (insecticide, fertilizers equipment)	3	5
Require watering	3	5

4.3.9.4. Constraints for the adoption of the tested tree-crop association

The main constraints to the adoption of the system developed by the project according to the respondents were: the negative effect of tree shade on associated crops, intensity of care needed for the crops and the lack of inputs (such as fertilizers and insecticides). Some of the respondents reported insufficient rain (water scarcity) as a constraint while others observed that lack of fencing and difficulty in tree-crop matching were constraints to adoption of the system (Table 4.36).

Table 4.36: Constraints for the adoption of the tested tree-crop association

Constraints to adoption	% of cases
Tree shade reduces crop yield	48.2
Methods demands more care	22.2
Lack of equipment and input	11.1
Water problem during dry season	11.1
Need for fencing (protection)	9.3
Poor rain season	3.7
Difficulty in tree crop matching	5.6
Insect damage (especially by termites)	3.7
Lack of information on the technique/method	3.7
Lack of time in rainy season	3.7
Low adoption by young people	1.9

4.3.9.5. Management practices needed to minimize tree-crop competition

A majority of the respondents (84%) reported tree pruning or lopping as the most needed management practice to minimize tree-crop competition. Other mentioned management practices were: adding manure under trees; timely weeding; deep tillage and crop avoidance in the area close to the tree trunk. Better matching of tree-crop associations, watering during dry season and mulching were also reported as appropriately required management practices by a few respondents (Table 4.37).

Table 4.37: Management practices needed to minimize tree-crop competition

Management practices	% of cases
Lopping/pruning	84
Adding manure	19
Timely weeding	18
Deep ploughing/tillage	9
Avoid to sow crop near tree	7
Matching tree crop	7
Watering during dry season	7
Mulching	2

4.3.9.6. Suggested modifications to the tested tree-crop association

With regard to the modifications that should be done to the tested method, 27% of the respondents suggested that more sensitization on the method is needed for its adoption and scaling up (Table 4.38). About 19% of the respondents reported that farmers should be supported with inputs like fertilizers while 16% called for capacity building of farmers. More training on the tested method and more tree-crop association's trials were each cited by 14% of the respondents. Some additional suggestions were made by a minority of respondents and these included: fencing all tree-crop association plots, deep tillage under trees; more involvement of women; more demonstration plots of eggplant associated to other trees.

Table 4.38: Suggested modifications to tested method

Suggested method modification	% of Cases
More sensitization	27
Assist farmers with input	19
Capacity building/ training	16
More tree crop associations trials	14
Establishment of more demonstration plots	6
Deep tillage under trees	3
Involve more women	3

4.3.9.7. Main actors to be involved in the dissemination process of the tested method

A large majority (90%) of the respondents reported that women are the main actors who should be highly involved in the dissemination process of the method. Gardeners were ranked second by 80% of the respondents and men were ranked third in the dissemination process (70%). Actors such as public or NGO'S extension technicians, youth and school teachers were also reported by few respondents as important in the dissemination process (Figure 4.4).

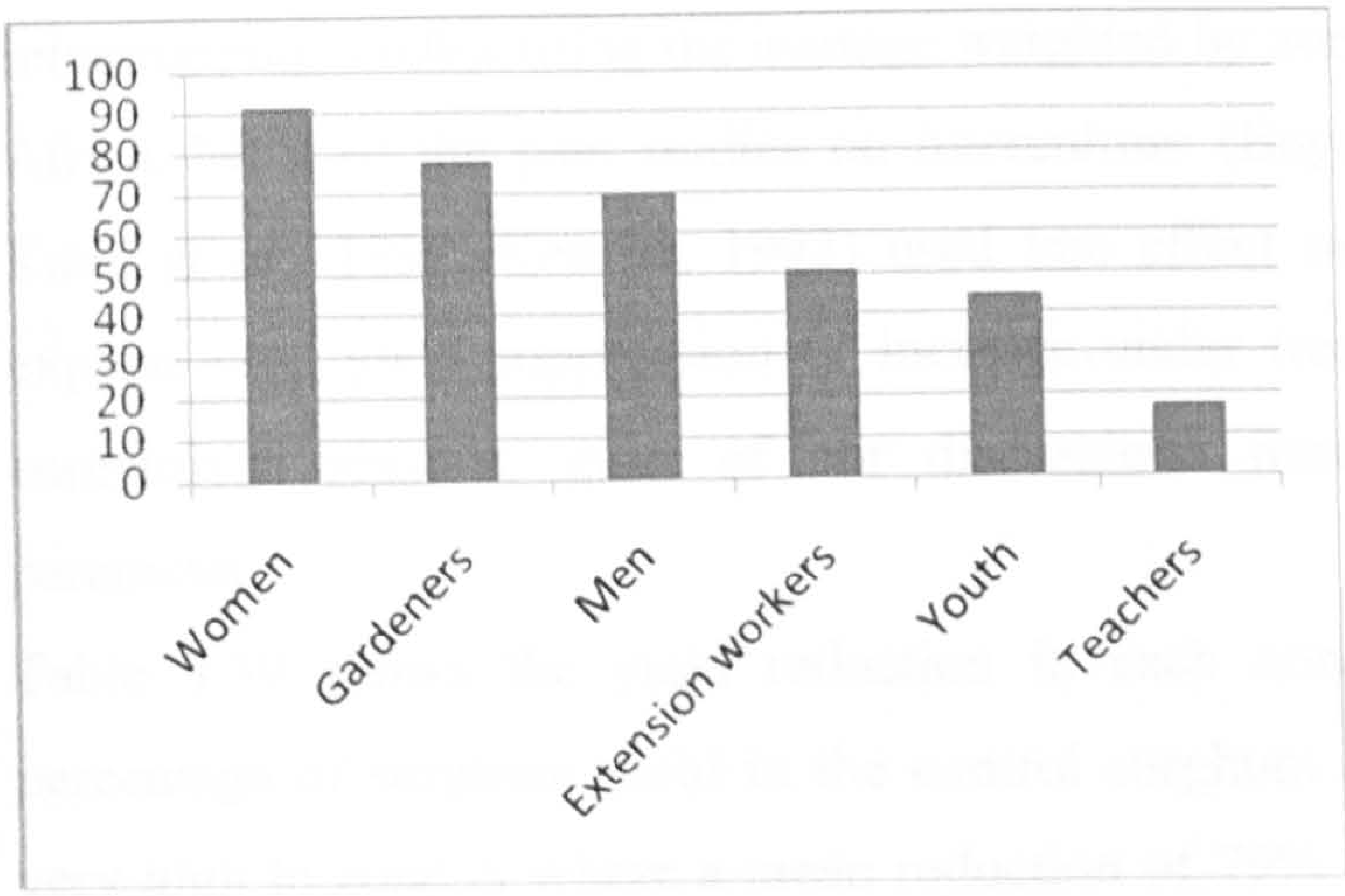


Figure 4.4: Main actors to be involved in the dissemination process of the tested method

4.4. Discussion

4.4.1. The performance of sorghum is not affected by *Tamarindus indica*

Tamarind had significant negative effect on sorghum grain yield because the yield in zone A, close to the tree trunk, and in zone B were significantly lower than the control. The relative yields of intercrop to sole crop using the arithmetic average were 57% in 2007 and 73% in 2008. The relative yields of intercrop to sole crop using the average weighted by zone area were 86% in 2007 and 94% in 2008. The relative yield of intercrop to sole crop using the average weighted by zone area over the two years was 90%. This shows that sorghum yield was suppressed by only 10% under Tamarindus over the two years. The relative yield of intercrop to sole crop using the average weighted by zone area gives more realistic estimate of yield advantage since it takes into account the area of each zone. If yield in zone C slightly overyields, the suppression observed in zone A will be quickly compensated because the area in zone C is sometimes 10 times larger than that of zone A. In this case with higher tree density per hectare and at large scale, the yield under zone A will not be agronomically significant. Our design could be improved by taking the crown diameter as zone C. As stated by Newman (1985), one of the constraints to research on intercropping is the lack of published information on the magnitude of any yield advantage arising from growing crops as mixture. This hold true because there is lack of literature of intercropping studies using the average weighted by zone area in the semi arid zones of Africa. Most of the past studies on interculture (Bayala, 2002; Bayala *et al.,* 2004; Kater *et al.,* 1992; Kessler, 1992) used tree effect or crop reduction as the tool to express crop yield suppression or increase under trees. It is not surprising that for comparison reasons, most of our discussions were done using yield reduction parameter.

Table 4.39 shows the yield reduction in each concentric zone expressed as the percentage of sorghum yield in the control sorghum plot. Grain yield reduction was very high in zone A where a mean reduction of 79% was observed. A similar drastic reduction (65%) was observed for the above ground dry biomass in zone A. Although there were reductions in yield and biomass in zone B they were not very much pronounced (26% and 20% for yield and biomass, respectively). In zone C, however, grain yield and biomass were higher than the control (1% and 7%, respectively). The mean yield reduction of 35%, taking into account all the three zones under Tamarind, was not as bad as the reduction of 50% and 70% in sorghum yield reported by Bayala *et al.* (2002) in Burkina Faso under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees, respectively. Kater *et al.* (1992) also reported a yield reduction of 60% under canopies of both species in southern Mali. The results of *Bayala et al.* (2002) and Kater (1992), however, corroborate the findings of the present study that Tamarind, compared to the above two common tree species of parklands, caused a moderate reduction in sorghum production due to perhaps a reduction in light availability under trees as also reported for the other trees of parklands by Bayala *et al.* (2002) and Kater *et al.* (1992).

The yields of sorghum in zone C (743.6±47.9 kg ha^{-1}) and the control plot (739±28.1 kg ha^{-1}) were in close agreement with the values reported in the literature. Ratnadass *et al.* (2007) reported that the average sorghum grain yield in Mali was 700 kg ha^{-1}. FA0 (2001) also estimated the average yield of sorghum in Africa to be 800 kg ha^{-1}. The values of dry matter of sorghum in zone C (3243±219 kg ha^{-1}) and the control plot (3059±100 kg ha^{-1}) of the present study were also very close to the value of 3659±657 kg ha^{-1} $year^{-1}$ reported by Bayala et al. (2002).

Table 4.39: Sorghum grain yield and aboveground dry biomass reduction in concentric zones under trees as a percentage of the yield of the control plot (Zone D)

Year	Zone A		Zone B		Zone C	
	Grain yield	Dry biomass	Grain yield	Dry biomass	Grain yield	Dry biomass
2007	92	62	30	11	3	+4
2008	66	67	21	28	+5	+9
Mean	79	65	26	20	+1	+7

+ indicates the increase in yield compared to the control

With regards to direction, no significant differences were found in sorghum yield and biomass between the South, North, East and West (Table 4.6 and 4.7).

When tree crown is asymmetric crop yield can be influenced by limiting factors such as light. Sun light is going from East to West. When there is more tree crown in the North, some areas in this side will receive less sun during the day, while all the areas in the South will receive light all day. Consequently, the growth and yield of the understory crop will be higher in South than in the North.

The ecological ability of trees to combine with a given crop is species-specific, and is a characteristic related to branching pattern and root architecture of the trees (Boffa, 1999). Sorghum yield is generally reduced more under *Parkia biglobosa* than *Vitellaria paradoxa* (Kessler, 1992; Kater *et al.,* 1992). This reduction is less pronounced for millet (Maiga in Kessler, 1992). According to Boffa (1999) this difference is due partly to the larger size of *P. biglobosa* and its different rooting patterns. *Parkia biglobosa* has low branches which extend laterally while *Vitellaria* has an ascending architecture. Kater *et al.* (1992) explained the difference in yield under these two tree species by suggesting that superficial rooting is more extensive in *Parkia biglobosa* which resulted in more competition with crops. Similarly the drastic reduction of crop yield in zone A under Tamarind (adjacent to tree trunk) in the present study could also be explained by the characteristics of *Tamarindus indica*. In fact, *Tamarindus indica* has a low branching pattern and a very dense fine root system in the vicinity of the tree as shown by the result of RLD of the present study and more extensive lateral rooting systems. The following description given by DANIDA (2000) characterises the tree: Tamarind has a wide spreading crown, a short trunk and extensive root system.

4.4.2. The performance of African eggplant is not affected by *Tamarindus indica* tree crown

The relative eggplant yields of intercrop to sole crop using the arithmetic average were 120% in 2007 and 37% in 2008. The relative yields of intercrop to sole crop using the average weighted by zone area were 151% in 2007 and 51% in 2008. The relative yield of intercrop to sole crop using the average weighted by zone area over the two years was 101%. In 2007, zone B and C overyield zone D, the results observed was an increase of production of 51%. In this case the suppression of crop yield under zone A is largely compensated. If this situation has to be extrapolated to 50-100 stems per hectare or at larger scale, zone A will not be agronomically significant. The result of the relative yield using the average weighted by zone area in 2007 and even over the two years showed that eggplant yield was not reduced by Tamarind tree. Rainfall total and rainfall distribution are critical for crop production in rainfed agriculture. If you have only two years data, it is becomes obvious that the yield will be higher in good rainfall year. Particularly in the present study we were obliged to harvest earlier eggplants because they were drying before the harvest period.

Table 4.40 shows the yield reduction in each concentric zone under Tamarind expressed as the percentage of eggplant yield in the sole eggplant plot (control plot). Fruit yield reduction was very high in zone A where a reduction of 65% was observed. A similar drastic reduction was observed for the above ground dry biomass (67%). However, an increase in eggplant fruit yield of 38 % and 62% in zone B and C respectively and an increase in eggplant aboveground dry biomass of 83% in zone C were recorded in 2007. The significant reduction of eggplant fruit yield in 2008 could be explained by the fact the rainy season lasted shorter in 2008 than in 2007 (see Table

1.1). This means eggplants had to be harvested about one month earlier in 2008 due to lack of rain. So, eggplant in 2008 did not have sufficient length of period for fructification to achieve maximum production. Overall, the reduction of eggplant yield under Tamarind was much less than the reduction of sorghum yield. The significant reduction of yield and biomass of eggplant in zone A could be attributed to competition for moisture and nutrients between Tamarind and eggplant roots and rooting systems explained above under sorghum. Based on these results, it may be concluded that, despite the reduction in zone A, Tamarind could potentially increase the yield of eggplant when grown under zone B and C when compared with the area outside tree crown. This proves that eggplant is a shade-tolerant plant which could benefit from the shade of Tamarind.

Eggplant production in the present study was not successful under tree number 5 essentially due to the termite mounds that were built under this tree after the experiment was set up. Termite mounds, also known as termitaria or anthills, are mainly built of clay which is brought to the surface by termites which ingest subsurface soil high in clay content. Because of the high clay content, termite mounds get hardened or compacted when there is no rain even for a short period of time. Thus, the eggplant under this tree could not survive.

Nkansah (2001) found higher plant height (246.6 cm), shoot dry weight (834 g) and lower number of fruits (6.26) of eggplants when grown at 40°C compared to those grown at 30°C in a greenhouse study. The plant height, shoot dry weight and the number of fruits of plant grown at 30°C were 225.1 cm, 689 g and 18.8, respectively. He concluded that high temperatures enhanced eggplant vegetative growth but suppressed reproductive activity such as flowering and fruiting, resulting in lower yield. This may explain why in the present study there was higher yield of eggplant under tree crown which could be due to the possible reduction in ambient temperature under trees.

Table 4.40: Eggplant fruit yield and aboveground dry biomass reduction in concentric zones under trees as a percentage of the yield of the control plot (Zone D)

Year	Zone A		Zone B		Zone C	
	Fruit yield	Dry biomass	Fruit yield	Dry biomass	Fruit yield	Dry biomass
2007	41	69	+38	28	+62	+83
2008	89	65	41	21	41	+9
Mean	65	67	2	25	+11	+46

+ indicates the increase in yield compared to the control

There was no significance difference in eggplant yield according to direction. However, significant difference has been found in eggplant yield according to direction. The fact that the dry biomass was significantly higher in the North could be explained for instance by the asymmetry of tree crowns mentionned above.

The fact that eggplants are produced by smallholder farmers (Plate 4.8) in home gardens makes it difficult to obtain reliable statistical data on production for comparison with the results of the present study. Furthermore research and development in Africa still focus on cereal grains such as sorghum, millet and maize. As a result, little is known about the performance of eggplant associated with parklands trees. As with many indigenous crops of African origin, the physiological activity of the African eggplant or garden egg has not been studied at all (Nkansah, 2001). However, the few available data indicate that the yield of the present study were much lower than the values reported in the literature. However if the yields in zone B and C under Tamarind under normal rainfall regime as in 2007 (5018±390, 5898±443 kg ha^{-1}, respectively) are considered, they are in close agreement with the values reported by Lester and Seck (2004) who found eggplant yields of 5–8 t ha^{-1} under rainfed condition in West Africa. However, higher values are reported elsewhere. For example, Rubaihayo (1994) reported a production of 7.5 t ha^{-1} in Uganda. This variation could be due to difference in cultivars. For example, according to Horna and

Gruère (2006), improved cultivar of 'jiló' in Brazil can yield 20–30 t ha^{-1} of marketable fruits.

Plate 4.8: Eggplant produced by smallholder in Feretoumou village, Mali

4.4.3. The nutritional composition of associated crops is not affected by *T. indica*

The results of the present study showed that *T. indica* shade did not have significant effect on most of the nutrient contents of sorghum and eggplant. In fact out of the fourteen (14) nutrients analysed over the two years, significance differences were only found for Mg and Mn.

As expected the nutritional composition of sorghum and eggplant differed significantly. The nutrient content of eggplant was significantly higher than sorghum for the following nutrients: protein, fibre, ash, nitrogen, potassium, sodium, calcium, manganese and Fe. Sorghum was richer than eggplant only in fat and carbohydrate content. Hulse *et al.*, (1980) did a large review of the chemical composition and nutritional quality of sorghum and millet from different regions (Africa, Central, West and South America, India, Australia, USA) of the world. The range of the mean proximate composition (%) of sorghum collected from 33 published data was: protein (7.8- 14.2), fat (2.7- 4), Carbohydrate (69.9- 90.2), fibre (1.2- 3.5), ash (1.5- 3). All the proximate components found in the present study for sorghum with the exception of carbohydrate are within the range reported by Hulse *et al.* (1980). The result on phosphorus content of the present study (5.06±0.53 mg g-1) was very close to that of Pedersen and Eggum (1983), who found 4 mg g^{-1}. The results of Pedersen and Eggum (1983) on proximate composition of sorghum, that is, ash (2%), protein (15.6%), fat (4.2%), carbohydrate (72.9%) and fibre (2.2%) are also in close agreement with the findings of the present study. The results reported on sorghum proximate composition of the present study were also in accordance with the findings of Khalil *et al.*, (1984): protein (15.3%), fat (4.7%), fibre (2.3%), ash (2.2%) and carbohydrate (75.5%). They stated that sorghum with 15% of protein content belongs to the high protein genotype. Boukari *et al.*, (2001) analysed 28 African foods for calcium and found that the calcium content of sorghum grain was 7.06 mg/100 g. The calcium content on sorghum reported by Boukari *et al.*, (2001) is higher than the result of the present study (0.008±0.00 mg g^{-1} = 0.8 mg/100g). The mean value of protein (11.88±0.36%) in sorghum of the present study was very close to the value reported by Barikmo *et al.* (2004) (10.4±0.7 g/100g). Their value of fibre content of 4.7 g/100 g was very low to the value of the present study (0.23±0.02 g g^{-1}= 23 g/100g). Their result of carbohydrate content of sorghum (73.5 g/100g) was, however, slightly higher than those found in the present study (0.57±0.02 g g^{-1}=57 g/100g). The values of iron and zinc (5.8 and 2.1 mg/100 g respectively) reported by Barikmo et al., (2007) were also higher than those found in the present study (1.4 ±0.07 μg/g and 1.18±0.12 μg/g, respectively). These may be due to differences in varieties or land races of sorghum. Barikmo *et al.* (2004, 2007) found considerable differences in nutrient content for sorghum between geographical regions in Mali. Kulp *et al.*, (2000) also concluded that the composition of sorghum varied significantly according to genetic and environmental conditions.

The proximate composition of eggplant found in the present study was higher than those reported in the literature (protein (17.22±0.44 %), fat (0.05±0.00 g g-1), carbohydrate (0.09±0.01 g g-1), fibre (0.61±0.03 g g-1)). For example, Grubben *et al.*, (2004) reported proximate composition of 100 g of eggplant as follows: protein (1.5 g), fat (0.1 g), carbohydrate (7.2 g) and fibre (2.0 g). AVRDC (2002) reported the following nutritional content for 100 g fresh weight of eggplant: fibre (1.14 g), protein (1.23 g). USDA (2005) also reported lower nutrient content than the present study for 100 g of edible portion of eggplant as follows: protein (1.0 g), fat (0.2 g) carbohydrate (5.7 g), fibre (3.4 g). The mineral contents of the present study were, however, lower than those reported by Grubben et al., (2004) and Norman (1992). For example, Grubben *et al.*, (2004) found higher calcium and iron contents (2.0 mg/100 g and 1.5 mg/100 g) than the present study. Norman (1992) reported the following results per 100 g of edible portion of eggplant: Calcium (7mg), Phosphorus (25 mg) and iron (0.4 mg). However, the results of mineral contents of the present study were higher than the values reported by Lawande and Chavan (1998) who found in 100 g of eggplant the following values: Ca (18 mg), Mg (16 mg), P (47 mg), Fe (0.9 mg), Na (3 mg) and K (2.0 mg). Again these variations could be due to different cultivars of eggplant analysed by previous workers.

4.4.4. There is no competition between the roots of Tamarind and the associated crops for nutrients and water

There was very high competition for resources between Tamarind and the two crops because Tamarind had significantly higher root length densities (RLDs) in all concentric zones and soil depths than sorghum and eggplant. This means Tamarind had a very high competitive advantage over the two crops. The mean RLD of *T. indica* was 0.24 ± 0.03 cm cm^{-3}. This result was higher than roots of some of the parklands trees studied so far. For example, Bayala *et al.*, (2004) reported RLD values of 0.163 ± 0.017 and 0.129 ± 0.017 cm cm^{-3} for Karité and Néré, respectively.

The highest RLD of Tamarind was in zone A (0.38 ± 0.04 cm cm^{-3}) and this may explain the high reduction of crop yield observed for both sorghum and eggplant in this zone. The reduction in yield in zone A indicates the existence of a high competition for nutrients and water. This result is in close agreement with the findings of Bayala *et al.*, (2004) who observed a high RLD under *P. biglobosa* and subsequent crop yield reduction of sorghum. The result of the present study also confirms the findings of Tomlisson *et al.*, (1998) and Odhiambo *et al.*, (2001) who reported higher RLD of trees close to tree trunks.

RLD of Tamarind in the present study decreased significantly with an increase in soil depth. The fact that highest RLD was also found in upper layer in zone A (0.55 ± 0.05 cm cm^{-3}) confirms the existence of superficial extensive root distribution in Tamarind and high competition between Tamarind and the two crops for nutrient and water. This result is also in accordance with the finding of Kater *et al.* (1992) who explained the difference in yield of sorghum under Karité and Néré by stating that the rooting system of Néré was superficial and more extensive which resulted in more competition with crops. The findings of the present study is also close agreement with those of Lehmann *et al.* (1998) who reported that the RLD in unpruned tree +crop treatment decreased with an increase in distance from tree trunk and that the highest RLD was found in the upper soil layer of 0-15 cm. Schroth *et al.*, (1995) also reported, in a humid zone of Côte d'Ivoire, that the maximum roots of nine leguminous trees were situated in the upper 10 cm of soil. Das and Chaturvedi (2008) did a study on root biomass distribution of five agroforestry tree species and found that the highest fine root biomass was contained in the upper soil layer of 0-20 cm and decreased with increasing soil depth.

There was no significant difference in RLD of eggplant between the concentric zones. There was, however, significant difference in RLD of sorghum according to concentric zones. In contrast to RLD of Tamarind, the highest RLD of sorghum was observed in zone C, away from the tree trunk (0.35 ±0.05 cm cm^{-3}). This result reinforces the finding of the present study where sorghum yield and biomass increased with an increase in distance from the tree trunk. This result also corroborates the finding of Odhiambo *et al.* (2001) who observed a decrease of tree RLD with increasing distance from tree and an increase of crop RLD with increasing distance from the tree trunk.

Significant difference was also found in RLD of sorghum between soil depths. The same pattern was observed in eggplant RLD. The results of RLD of both crops indicated that the maximum roots were found in the upper layer 0-10 cm of soil. The decrease in RLD of eggplant according to soil depth was more pronounced than that of sorghum. About 70% of eggplant RLD was situated in the upper 0-10 cm layer. This showed that there was an overlapping of niche between the roots of *T. indica* and the crops (eggplant and sorghum). The fact that RLD of *T. indica* and both crops decreased with increasing depth may be due to a better water recharge and relatively good amount of nutrients in the upper layer of soil as explained by several authors (Pandey *et al.* 2000; Bayala *et al.*, 2002; 2004). Gupta *et al.*, (2008) found that micronutrient concentrations were higher in the soil surface and decreased with soil depth.

4.4.5. There is no correlation between Tamarind roots and crop yield and nutritional composition

The results of Pearson's correlation analysis showed that crop production was directly related to tree RLD. The fact that the production of both crops (eggplant and sorghum) was negatively correlated with *T. indica* RLD reinforces the suggestion that bellow ground competition existed between crops and tree roots (Bayala *et al.*, 2004; Lehmann *et al.*, 1998; Ong *et al.*, 2002). This means when there was an increase in tree roots the production of crops was negatively affected. This may also explain why the yield of both crops was reduced severely in zone A where RLD of Tamarind was the highest.

There were a significant positive relationship between roots of *T. indica* and protein and N contents of sorghum and between RLD of Tamarind and eggplant fibre content. The positive correlation between eggplant fibre content and Tamarind RLD was expected because RLD of Tamarind and eggplant yield were higher under trees than outside the tree crown. Higher yield of eggplant means proportionally higher fibre content. The positive relationship between sorghum protein content and Tamarind RLD may just be an artefact. Protein and N are positively related because the value of protein is derived from the value of N.

4.4.6. There is no correlation between soil properties and crop yield and nutritional composition

There were significant correlations between soil properties and the performance of both crops. In the case of sorghum, there were significant negative correlations between soil P and soil K and sorghum yield as well as sorghum biomass. The correlation between soil nutrients and fat content of sorghum was also negative. There were also significant negative correlations between Soil P, K and N and Sorghum Mg and between Soil C, K and N and Sorghum Fe. The only correlations in the case of eggplant were the negative correlation between Soil P and eggplant Mg and between soil K and the fat content of eggplant. The negative correlations between soil properties and crop yield and nutrient contents may be due to the fact that as the soil nutrients decreased crop yield and biomass increased with an increase in distance from the base of tree. Higher yield and biomass of crop means proportionally higher crop nutrient contents. The reports in the literature are, however, contrary to the finding of the present study. For example, Asadu *et al.* (2002) found that N, K and Mn were among the soil variables that were found to correlate with harvest index of crops in humid zones of sub-Saharan Africa. Vrindts *et al.* (2003), in a study on winter wheat, found that wheat grain and straw were correlated with P. The results of correlation analysis conducted by Ha-Lin Zhao *et al.* (2007) on irrigated cropland showed that both plant height and aboveground biomass had a significant positive correlation with soil organic matter, total N and P, available N and K. Di Virgilio *et al.*, (2007) in a study on Switch grass (*Panicum virgatum* L.) found that biomass yield was significantly correlated to many soil parameters but particularly to nitrogen and phosphorous.

In conclusion, the present study showed that Tamarind had a positive effect on yield of eggplant but a negative effect on yield of sorghum. These results were expected because sorghum is a shade-intolerant crop while eggplant is a shade-tolerant crop. In addition to the effect of shade, competition for resources between Tamarind and the crops due to the difference in their rooting system was also shown to make a contribution to the performance of the crops. Tamarind was found to have higher RLD and superficial rooting system which gave it a competitive advantage over the two crops. Tamarind had no effect on crop nutritional composition. This means growing crops beneath trees as in agroforestry does not have detrimental effect on the quality of crops.

4.4.7. Feedback from farmers on the experiment

The fact that the majority of the respondents mentioned that increased income and income diversification were the main advantage of the method highlights farmers interest in the tested method. Some of the noteworthy advantages of the tested method reported by the respondents were: trees benefiting from management of associated crops; crops production increase; improvement of women's capacity; better management of the spaces below trees and attitudinal change created by the project on tree crop mixtures. All these positive ideas illustrated farmers' good perception of the tested method.

According to Hoefsloot *et al.*, (1993) the adoption of any innovation by farmers is not dependent only on its technical performance. Any good technical innovation, which is not economically feasible, does not give good financial return and has some constraints and limitations may not be adopted by farmers. The main constraints to the adoption of the tested method according to the respondents were: the negative effect of tree shade on associated crops; some respondents mentioned the need for intensive care as the major disadvantages of the method. The limited time available to farmers during the rainy season given other competing farming activities was mentioned by some of the respondents as one of the major constraints. The later problem was also reported by Hoefsloot *et al.*, (1993) who found that the introduction of new innovation different from farmer's normal and regular activities in rainy season as a major constraint to the adoption of fodder bank practice in Mali. Fencing and lack of inputs such as fertilizers, insecticides and farm equipment were also mentioned by some of the respondents as constraints. Fencing was also cited as another constraint to the adoption of fodder bank in Mali by Hoefsloot *et al.* (1993). Most of the constraints mentioned by respondents are due to the low income of farmers who cannot afford to invest in any of the required inputs to the tested systems. This was supported by World Bank (1989), Ronoh (2003) and Mwirigi (2009) who stated that the major constraint for adoption of agricultural innovations by farmers is generally due to their limited income. However, most of the inputs that respondents mentioned as constraints are not really needed. For example, fencing is not needed as the crops are grown in the open parklands like any other crops. Commercial fertilisers are also not needed because simple manuring, which is already a culture in the area, could suffice. As reported by Midmore *et al.*, (1991) and Rubaihayo, (2002) vegetables including eggplants can be produced cheaply using compost rather than commercial fertilizers.

The division of tasks in households between men and women was also described during the group discussion. Men were more interested in staple food (sorghum and millet) production while women were more concerned with the production of vegetables such as eggplant, pepper and okra. At present, vegetables are gown in the study area by women in home gardens. The role of gender in agricultural production systems have been reported by several previous workers (Boserup, 1970; Carr, 2008; Rubaihayo, 1994). Rubaihayo (2002) reported that in Uganda, even though rural women are responsible for feeding the family, they have limited access to resources. This also holds true in the context of the present study because all trees are situated in men's crop fields and they are owned by them. Since women who are the beneficiaries of the tested method do not own the trees, they have to negotiate with men to be able to cultivate eggplants under trees. This may lead to a dispute between men and women and this could be another constraint which was not identified during the feedback survey.

Although it was not ranked in the present study as a high priority, the role of extension services in promoting new innovations has been mentioned by several previous workers (Okorio *et al.*, 2004, Bayala, 2002). Therefore, the involvement of extension workers should be given a priority in the dissemination of the tested method.

CHAPTER V:

DOMESTICATION OF AN IMPROVED CULTIVAR OF *ZIZIPHUS MAURITIANA* ON A FARM IN ASSOCIATION WITH FOOD CROPS IN AGROFORESTRY PARKLAND SYSTEMS IN MALI

5.1. Introduction

In most of the countries in the Sahel zone of West Africa, the majority of the population is rural, depending heavily on natural resources for nutrition and income. In particular, indigenous fruit trees of agroforestry parkland systems play an important role in the life of people in the Sahel. They provide food and income. They are also used in traditional and modern medicine. Most of these necessary products are, however, derived from wild trees on the parklands. The density of indigenous trees on parklands is declining because of over-cutting to increase cropland and obtain wood for fuel and construction for an ever-increasing population in the region. The trees are also aging due to lack of regeneration. As a result, the overall productivity of current agroforestry parkland systems is also declining due to soil fertility depletion. There is an almost total agreement among previous workers that, for many reasons, farmers in West Africa do not plant parkland tree species although these trees are known to be an essential part of their livelihood and despite the decline of the population of these trees on parklands (Boffa, 1999; Teklehaimanot, 2004; Bayala, 2002; Hall *et al.,* 1999; Bonkoungou et *al.*, 1998; Ong and Leakey, 1992). Domestication of these valuable parkland trees is, therefore, the only means by which sustainability targets for the management of agroforestry parkland systems can be reached. Sanchez and Leakey (1997) stated that domestication of indigenous trees cannot be dissociated from commercialisation, since without new markets, the incentive to domesticate intensively for self-consumption is not sufficient. Domestication of important tree species in agroforestry parkland systems should be a priority because they provide not only useful non-wood products, but also provide continuous tree cover and contribute to both the productivity and sustainability of farming systems by maintaining soil fertility and creating a more favourable microclimate for associated crops and livestock

(Teklehaimanot, 2004). According to ICRAF (1998), if trees could provide the desired products and services in shorter term, as they could do after the process of domestication, farmers would be more likely to invest their energy and time in planting them and by doing so they will rehabilitate the traditional agroforestry system which is environmentally important in the region. The major aim of the present study was, therefore, to test methods of domesticating one of the most common and useful indigenous fruit tree species of the Sahel called Ber (*Ziziphus mauritiana*) in association with food crops on farms in parkland systems.

Ber, also known as Jujube, (*Ziziphus mauritiana* Lam.) is an underutilised, local fruit tree species of high economic value that has not been the object of scientific study in West Africa until very recently. It constitutes a major component in agroforestry parkland systems of West Africa and plays a significant role both in terms of ecological services (including soil-fertility and microclimate amelioration) and in securing the livelihoods and food security of the region's people. A survey in Mali, Niger, Burkina Faso and Senegal revealed that this species is among the farmers' 10 most preferred species (Bonkoungou *et al.*, 1998; Ouédraogo *et al.*, 2006). Ber can be grown from seed and by vegetative propagation. The Sahel Regional Program of the World Agroforestry Centre (ICRAF) has introduced three Indian cultivars of Ber (Umran, Gola and Seb) because of their precocity in fruiting (6 months), the larger size of their fruits and their taste (Ouédraogo *et al.*, 2006). The fruit of grafted Ber, highly appreciated in the Sahelian countries is commonly called "Pomme de Sahel" (ICRISAT, 2004; Jama *et al.*, 2008). Grafting the local Ber with these cultivars is among the first priorities of local research institutes in the West African region. The high performance of the grafted Ber tree i.e. its fast growth, precocity in fruiting and larger size of fruits make it suitable for intensive production through plantations. Ouédraogo *et al.*, (2006), in their study in Burkina Faso on some cultivars of Ber, reported the profit from selling fruits of Gola and Seb to be F CFA 966,974 and F CFA 899,198, respectively (€1 = FCFA 650). These values obtained from mono-crop plantations (without irrigation and fertilization) could be of a big incentive for farmers to plant Ber trees. Despite the high performance of this tree, no attempt has been made in the region to investigate the performance of Ber when integrated with food crops on farmers' fields in agroforestry parkland systems. The major aim of the present study was, therefore, to identify the best method of domesticating one of the best performing improved cultivars of Ber called SEB on farms in association with food crops in agroforestry parkland systems.

Tree shade in agroforestry parkland systems has been reported to cause reductions in yield of associated food crops such as sorghum. For example, Kessler, (1992) found that sorghum yields under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees were reduced on average by 50% and 70% respectively while in southern Mali, Kater *et al.* (1992) reported a yield reduction of 60% under canopies of both species. Such a reduction in crop yield could be avoided by growing shade-tolerant crops under trees. Therefore, in the present domestication trial of Ber, the associated plants tested were African eggplant (*Solanum aethiopicum* L), a shade-tolerant crop and sorghum (*Sorghum bicolour*), a shade-intolerant crop.

In addition to the reduction of yield of associated crops, tree shade has been reported to affect the nutritive composition of crops due to mainly reduced light under shade. For example, Ajithkumar and Jayachandran (2003) showed that crude fibre in ginger (*Zingiber offinale* R.) decreased with light reduction. Koukoura *et al.*, (2009) also observed an increase in K and P content in forage of *Dactylis glomerata* and *Festuca ovina*, *Medicago lupulina* and *Trifolium subterraneum* under shade. The nutritive quality of a crop grown under tree shade may depend on its ability to capture resources and photosynthesise efficiently under reduced light conditions. There is, however, dearth of information in literature on the effect of parkland trees on the nutritive quality of food crops. In the present study, therefore, the interactive effects of Ber and the two associated crops were investigated based on agronomic measurements and chemical analysis of the nutritive composition of the two associated food crops.

The hypotheses tested were:

1) There is no difference in performance between the local and improved varieties of *Z. mauritiana.*

2) The performance of improved *Z. mauritiana* is not affected by associated crops.

3) The growth and yield of associated crops are not affected by improved *Z. mauritiana.*

4) The nutritive composition of associated crops is not affected by improved *Z. mauritiana.*

5.2. Materials and methods

5.2.1. Experimental design

An experimental plantation was established with seedlings of the local variety of *Ziziphus mauritiana* half of which were grafted with an improved cultivar of *Z. mauritiana* called SEB that were introduced from India. The plantation site was in a village called Sanankoroba located at 35 km from Bamako, the capital of Mali. The seedlings were planted in August/September 2006. Grafting was done in early June (06 June 2007), ten months after planting the seedling rootstocks.

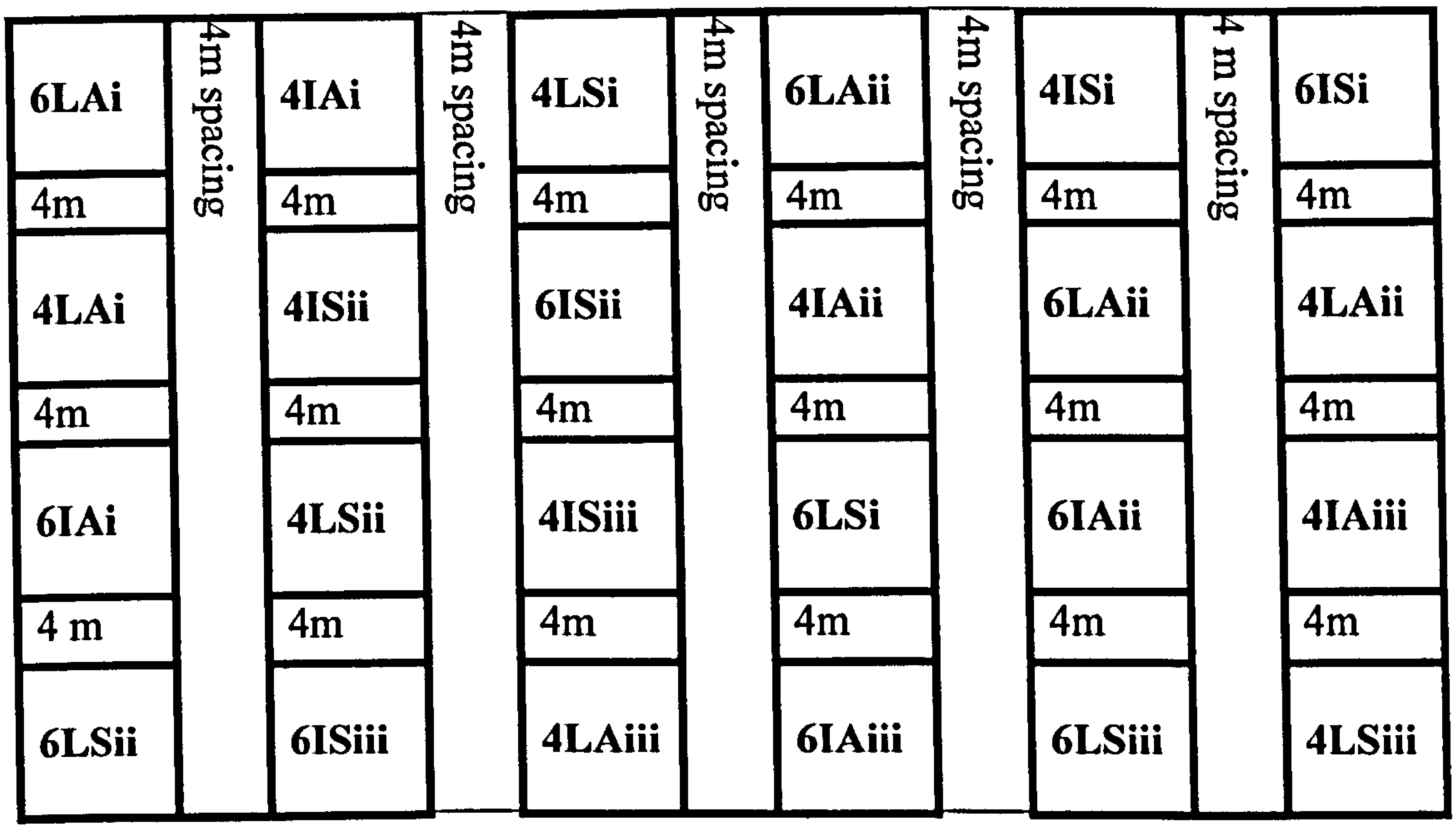
Three factors were studied. The first factor involved two varieties: local and improved varieties of *Z. mauritiana*. The second factor involved two spacings of Ziziphus: 4 m x 4 m and 6 m x 6 m. The third factor concerned food crops: African eggplant (shade-tolerant vegetable) and sorghum (shade-intolerant common cereal crop). The experimental design was a complete randomized block with varieties of Ziziphus as the main plot, spacing of trees as the subplot and crop type as the experimental unit. There were in total 8 treatments which were replicated three times which gave a total of 24 experimental plots. All experimental plots and blocks were separated from one another by 4 m spacing between them. An area of roughly 1.5 ha was used for the whole experiment. Each experimental plot consisted of 16 trees (4 x 4 trees). So a total of 384 trees of the local variety of *Z. mauritiana* were planted in the whole experiment in September 2006. 192 (half) of them that were planted to serve as rootstocks were grafted *in situ* with scions of the improved cultivar called SEB in June 2007 (Plate 5.1c), ten months after planting of the rootstocks, using the procedure of top cleft grafting (Plate 5.1d) described by Lee (1994). The average size of the scions used was 8 cm long and 1 cm diameter. After grafting, the scions were covered with a plastic bag to avoid desiccation. The plastic cover was removed three weeks after grafting.

Crop cultivation began immediately after grafting in July 2007. The spacing used for sorghum was 50 cm X 50 cm, while the spacing used for eggplant was 0.5 m within row and 1 m between rows. The experimental design is shown in Figure 5.1.

Figure 5.1: Design layout of the Ziziphus experiment

NB: 4 m spacing was used between blocks and experimental units

Block I Block II Block III



IS = improved variety of Ziziphus associated with sorghum

IA = mproved variety of Ziziphus associated with African eggplant

LS = local variety of Ziziphus associated with sorghum

LA = local variety of Ziziphus associated with African eggplant

The Arabic numeral before the Treatment Symbol indicates the spacing between trees

The Roman numeral after the Treatment Symbol indicates the replicate number

Plate 5.1: Plantation site and different stages of local Ziziphus seedlings

a) Site prepared for plantation

b) Seedlings of local variety of Ziziphus ready for planting

c) Rootstock of local Ziziphus (10 months after planting)

d) Top cleft grafting of local Ziziphus with SEB scion

5.2.2. Data collection

5.2.2.1. Ziziphus growth and fruit production

Measurement of tree growth parameters began five months after grafting in October 2007 (the baseline measurement) and at six month intervals thereafter. The last measurement was taken in March 2009. The measurement was taken on four central trees in each plot. The four central trees were chosen to avoid an edge effect on border trees. Total height, collar diameter and number of branches were measured. Annual increments of height and diameter were also calculated by subtracting the baseline measurement (October 2007) from the last measurement taken in March 2009. Fruit production was assessed 19 months after grafting or 26 months after planting in December 2008 (after almost two years). At the same time, samples of 50 fruits were used to estimate the average weight per fruit.

5.2.2.2. Associated crop production

Associated crop production was measured at harvest during two growing seasons (2007 and 2008). Four (4) individual plants were randomly selected in the middle of each experimental plot for crop production measurement each year.

- For sorghum, yield parameters measured were grain yield and above ground plant dry biomass (stems and leaves).
- For eggplant, parameters measured were fresh weight per fruit, the number of fruits, and above ground plant dry biomass (stems and leaves).

5.2.2.3. Nutritive composition of associated crops

Four plants were randomly selected in the middle of each plot at harvest. The samples were oven dried at 70°C for 24 h, ground and sieved at 200 µm. Sampled grain of sorghum and fruit of eggplant were analyzed for protein, carbohydrate, fat, ash, total dietary fibre, calcium (Ca), iron (Fe), magnesium (Mg), phosphorus (P), potassium

(K), sodium (Na) manganese (Mn) and vitamins were analysed after the harvest of 2007 and 2008 in the laboratory of the School of the Environment, Natural Resources and Geogrpahy, Bangor University, UK. The laboratory analytical methods used are described below.

Assessment of protein content

The protein content of crop samples was obtained by measuring N content of the samples by Kjeldahl method using a Kjeltec 2300 analyser unit (FOSS, Denmark). 200 mg of each sample were digested by adding 4 ml of sulphuric acid (98%) and 2 digestive tablets and warmed at 30°C for 4 hours. During the digestion, the nitrogen in the samples was converted into ammonia in the form of ammonium ion $NH4^+$ which binded to $SO4^{2-}$ ions of the acid. After the digestion, sample solutions were placed in the Kjeltec analyser unit which determined their N content. The N content was multiplied by 6.25 to obtain protein content in samples.

Assessment of fat content

Fat content was determined by the Soxhlet method using Soxtec Avanti 2050 system (Foss, Denmark). Five (5) grams of each sample were placed in a porous thimble which was lodged into an extraction aluminium cup containing 80 ml of petroleum ether as solvent and fat was extracted by the Soxtec system. After the extraction, tubes were placed in an oven at 102°C to evaporate the remaining solvent and dry the sample. Extracted fat was weighed and divided by the sample weight (5 g) to obtain the fat content (g g^{-1}).

Assessment of ash content

Ash content was assessed by burning 2 grams of each crop sample in a furnace at 600°C for 12 hours. When samples are burnt, water and volatile substances are vaporized while organic substances are transformed into CO_2, H_2O and N_2 in the presence of oxygen. After samples were cooled, ash was weighed and the content (g g^{-1}) was calculated by dividing ash weight by the sample original weight.

Assessment of dietary fibre content

Dietary fibre includes some polysaccharides (cellulose, hemicellulose, pectin and hydrocolloids) and lignin which are not digestible. So, dietary fibre content determination consists of removing all digestible substances of the samples and weighing the rest. One (1) gram of each sample after fat extraction was used to assess dietary fibre content. Samples were dissolved in 50 ml of phosphate (pH 6), 0.1 ml of amylase was added and the solution was incubated at 95°C for 15 minutes. After the incubation, the solution was cooled to room temperature and its pH was adjusted to 7.5 by adding NaOH (0.275 N). Then 0.1 ml of protease was added to the solution and placed in a water bath at 60°C for 30 minutes. At the end of this second incubation, the solution was cooled at room temperature and the pH adjusted between 4 and 4.6 by adding HCl (0.325M). Then, 0.1 ml of Amyloglucosidase was added to the solution which was placed again in a water bath at 60°C during 30 minutes. By the end of this third incubation, 4 volumes of ethanol (95%) were added and the solution was let cool overnight at room temperature. After complete precipitation overnight, the solution was filtered and rinsed with ethanol (95%) and acetone, to extract dietary fibre. Dietary fibre after filtration was dried in an oven at 70°C overnight and then weighed to obtain the content in the original sample ($g\ g^{-1}$).

Assessment of carbohydrates content

Digestible carbohydrate content was assessed based on the assumption that samples are constituted of ash, dietary fibre, fat, protein and digestible carbohydrate. So, when the contents of protein, fat, ash and dietary fibre are known for one (1) gram of sample, carbohydrate content could be calculated according to the formula below:

Carbohydrate content ($g\ g^{-1}$) = 1 – (Ash content + Dietary fibre content + Fat content + Protein content).

Assessment of Ca, Na and K contents

Flame photometry was used to determine Ca, Na and K contents in the crop samples. The flame photometer (model 410) measures the light of a specific wavelength emitted when a solution of a particular element is burnt. The light emitted is proportional to the element concentration in the solution. To prepare aqueous solutions of samples, 2 g of each sample were burnt at 450°C in a furnace overnight to remove the carbon which reacts with oxygen and is lost as carbon dioxide. The samples were then dissolved into 10 ml of hydrochloric acid (HCl) of 12M concentration. The solution obtained is diluted to 10 for K and Na and 80 times for Ca by adding distilled water. Seven (7) standard solutions were prepared for each element (Na, Ca and K) according to the concentrations 0, 5, 10, 30, 50, 70 and 100 mg l^{-1}. Then, the standards and the sample solutions were read by the flame photometer. A regression equation was derived between standard solutions and the readings of the flame photometer and the equation was used to obtain the concentration of elements in sample solutions (mg l^{-1}). Element content (g g^{-1}) in dry samples was then calculated using the dilution rates.

Assessment of P content

Phosphorus content was determined using the colorimetric method (Ames, 1966). This method is based on the principle that phosphate ion reacts with ammonium molybdate to give, when reduced by ascorbic acid, a blue complex which has an intense absorption band at 820 nm. The complex absorbance which is proportional to phosphate concentration in the original solution is measured by a spectrophotometer (BioTek, model PowerWave XS).

Six standard solutions (0, 10, 30, 50, 70 and 100 mg l^{-1}) of the PO_4 ion were used to determine the relationship between the spectrophotometer readings and phosphate concentrations. 80 µl of sample and standard solutions were placed in a 96 well plate, 180 µl of Ames reagent were added at 30 second intervals and finally 30 µl of ascorbic acid (10 %) were added in each well of the plate. The absorbance of the solutions was read by the spectrophotometer after 15 minutes at intervals of 30 seconds until the last well of the plate.

The regression equation between the concentration of standard solutions and the readings of the spectrophotometer was used to obtain the phosphate concentration (mg l^{-1}) in sample solutions and then the content (g g^{-1}) in dry samples was calculated using the dilution rate.

Assessment of Mg, Fe, Mn and Zn content

An atomic absorption photometer (VARIAN, model SpectrAA 220FS) was used to assess Fe, Mg, Mn and Zn content in crop samples. The principle is that each element when burnt emits a specific wavelength light which is proportional to the content of the element in the solution. Six concentrations of each element were used as standards to calibrate the photometer. Sample solutions were prepared as described above. Ten (10) times concentration solution was used for Fe, Mn and Zn while a ninety times (90) concentration was used for Mg. Assay tubes each containing 50 ml of sample solution was placed on a 60 well support where the first well was a tube of water and after each five (5) sample tubes, a drift solution was intercalated to control the photometer readings accuracy. The absorbance of solutions was read by the atomic absorption photometer and expressed as elements concentration (mg l^{-1}) according to the calibration done with standard solutions. The content in dry matter (g g^{-1}) was obtained by applying the dilution rates with regard to each element solution.

5.2.2.4. Soil analysis

Soil analysis was carried out to characterise the site in terms of soil physical and chemical properties. Analysis of soil physical properties included soil texture and density. These were done in the laboratory of IER, Mali. For chemical properties, soil organic matter, phosphorous, potassium and nitrogen contents were analysed in the laboratory of the Bangor University, UK.

Samples were collected at four random positions at two soil depths (0-20 and 20-40 cm). A total of eight samples were used for the analysis of both physical and chemical properties. Soil texture and density were analysed using Robenson's pipette method (Gee et al., 1986) and core method (Birkeland, 1984) respectively. The methods are described in chapter 4 of this thesis.

For analysis of soil chemical properties, soil was first extracted using Ammonium Acetate Extraction Protocol. 18 ml Ammonium Acetate (NH4 Acetate) 1M pH7.0 was added to 2 g of soil using a small plastic scint tube. This was shaken for 1 hour at 250 rpm. The solution was filtered using filter paper and funnel. The filtrate was now ready to use on flame photometer for Phosphorous and Potassium analysis and Kjeldahl machine for analysis of Nitrogen.

P and K: stock solution was prepared by mixing 3 ml of 4% solution of Ammonium Molybdate (20 g with 500 ml epure water), 1 ml of Antimony (1.454 g Antimony Potassium Tartrate in 500 ml epure water), 10 ml of 2.5M sulphuric acid (34 ml conc sulphuric acid in 250 ml epure water), 1 ml of 5% ascorbic acid (2.64 g ascorbic acid in 50 ml epure water), 9 ml of AMES, and 6 ml of epure water. Seven standard solutions were then prepared according to the concentrations 0, 2.5, 5, 10, 15, 20 mg l^{-1}. Then, the standards and the sample solutions were read by the flame photometer by pippetting 20 µl of each sample solution (1/10), and 200 µl of each standard into wells. The sample solutions and standards were read at 882 nm, and a calibration curve was obtained from the standards. The calibration equation was then used to obtain the concentration of P and K in sample solutions.

Nitrogen: Kjeldahl method was used for the analysis of N. 500 mg of oven dried sample was weighed into Kjeldahl specific tubes (100 ml). 5 ml of sulphurc acid and 2 tablets of titanium catalyst were added to the tubes. The tubes were put on heat block at 420 degrees for 30 minutes to digest. Tubes were cooled, then run in the Kjeldahl machine to read the N content.

5.2.3. Data analysis

Both One-way and Two-way analyses of variance (ANOVA) and a General Linear Model (GLM) were performed on the data using Minitab 15 statistical software (Minitab Inc., USA) to determine differences between agroforestry treatments in tree and crop performance. Fisher's pairwise comparison test was performed to determine the possible statistically significant difference between treatment means. The significance level applied was $P<0.05$.

5.3. Results

5.3.1. Physical and chemical properties of soil of the study site

The soil of the study site is acidic and sandy loam in texture as shown in Table 5.1. The organic matter content of the surface soil is 3% but very low in phosphorous, potassium and nitrogen contents (Table 5.2).

Table 5.1. Soil pH and texture

Soil Depth	pH (H_2O)	pH (KCl)	Sand (%)	Silt (%)	Clay (%)
0-10	4.78±0.11	3.9±0	44±3	45±7	11±4
10-20	4.05±0.15	3.35±0	41±3	24.5±3	34±4
20-30	4.2±0.04	3.3±0	33±2.	35±4	32±2

Table 5.2. Soil chemical properties

Soil depth	OM (%)	P (mg g^{-1})	K (mg g^{-1})	N (mg g^{-1})
0 - 20	3.02±0.18	0.001±0.0	0.05±0.01	0.03±0.01
20 -30	4.18±0.12	0.001±0.0	0.06±0.00	0.03±0.00

5.3.2. Tree performance

5.3.2.1. Tree survival

Table 5.3 shows the survival rates of *Z. mauritiana* (local and improved varieties) according to agroforestry treatments, 30 months after planting. There was significant difference ($P<0.01$) in survival rates between the two varieties. The mean survival rate of the local variety was significantly higher (95.31±1.36 %) than that of the improved variety (76.04±6.44%). Type of crop and spacing between trees had no significant effect on survival rates of both the improved and local varieties of Ziziphus.

Table 5.3: Survival rates of *Z. mauritiana* according to agroforestry treatments, 30 months after planting in Sanankoroba

Variety	Agroforestry Treatments	Survival rate (%)
	4IS	75.00±3.61a
	6IS	64.6±10.4a
Improved	4IA	89.58±5.51a
	6IA	75.00±6.25a
	Mean	**76.04±6.44**
	4LS	97.92±2.08b
	6LS	89.58±2.08b
Local	4LA	97.92±2.08b
	6LA	95.83±2.08b
	Mean	**95.31±1.36**

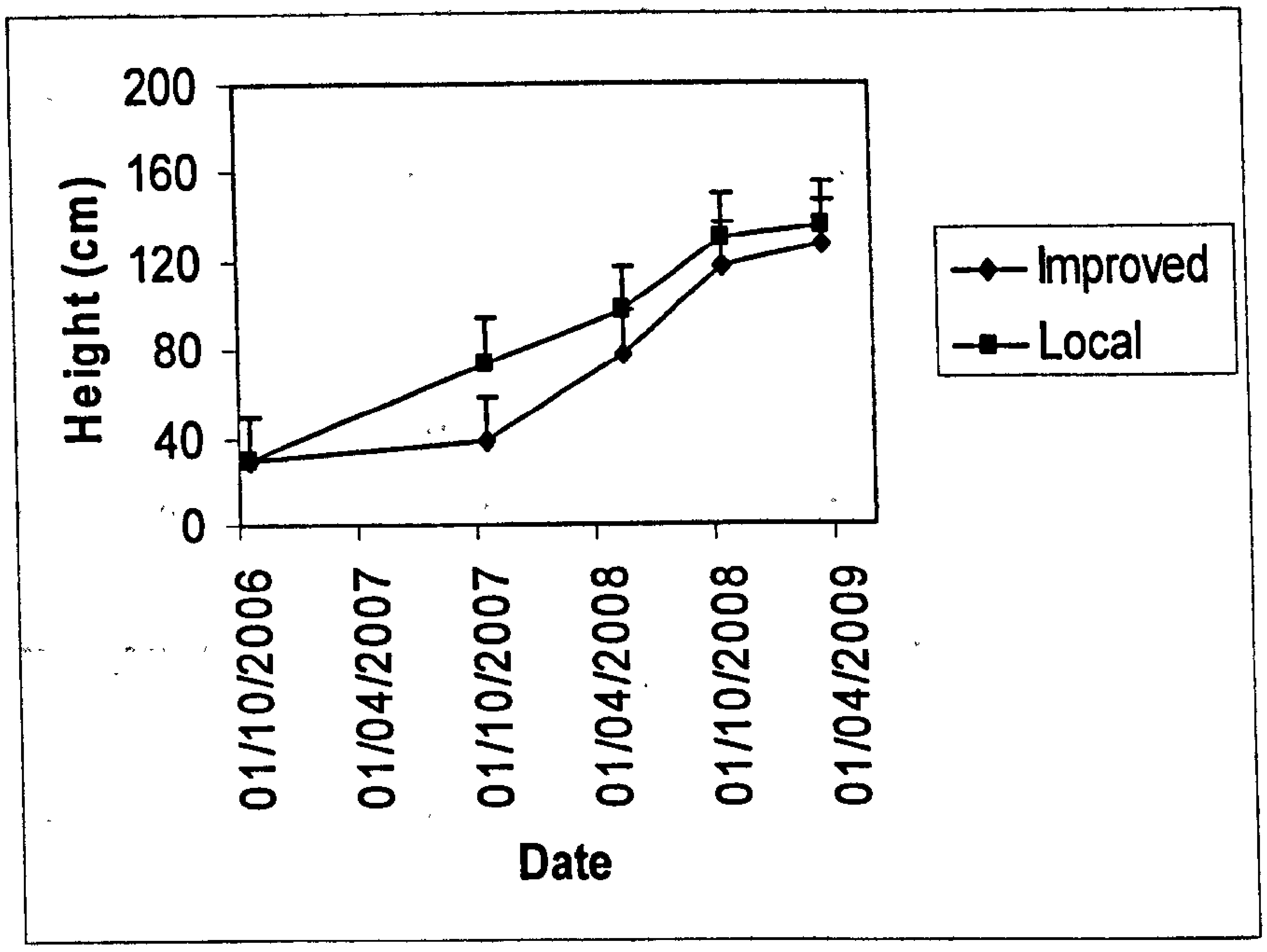
NB: Different letters in the same column are significantly different at $p<0.05$

5.3.2.2. Tree growth

There was a significant increase ($P<0.001$) in height growth of both varieties of Ziziphus between the first and third measurement dates (Fig. 5.2a). Between the two last measurement dates, however, there was no significant difference in height growth, suggesting the slow growth of the trees due to the dry season. The growth patterns of the two varieties presented in Figure 5.2a show that the height of the local variety was slightly superior but not significant to that of the improved one during the initial two measurement dates. The gap in height growth between the two varieties, however, started to close during the third measurement date.

The pattern of diameter growth of both varieties was also similar to the height growth pattern except that the diameter of the improved variety started to slightly overtake that of the local variety starting from the second measurement date as shown in Fig. 5.2 b.

a)



b)

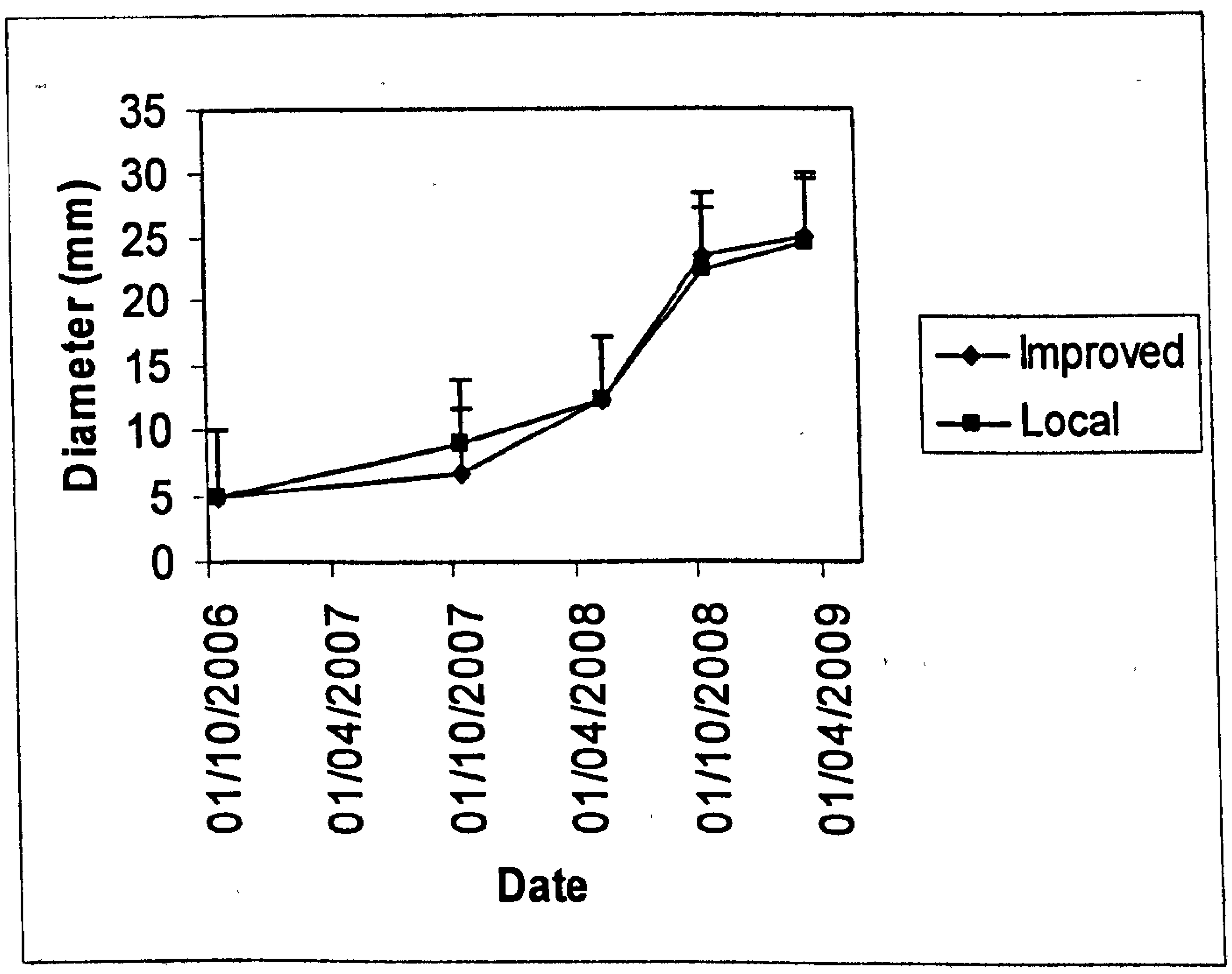


Figure 5.2: Ziziphus growth pattern in height (a) and diameter (b) in the agroforestry trial in Sanankoroba

Height, diameter and number of branches of Ziziphus, 30 months after planting, are presented in Table 5.4. There were no significant differences in height, diameter and numbers of branches between the two varieties of Ziziphus (Plate 5.2). Type of crop as well as spacing between trees had also no significant effects on height, diameter and number of branches of both the improved and local varieties of Ziziphus, 30 months after planting.

Table 5.4: Height, diameter and number of branches of Ziziphus, 30 months after planting (MAP), according to agroforestry treatments in Sanankoroba.

Variety	Agroforestry Treatment	Height (cm)	Diameter (mm)	Number of branches
	4IS	130.0±12.0	26.7±2.5	26±4
	6IS	123.6±11.7	24.4±2.4	20±4
	4IA	145.5±13.3	27.7±1.3	23±2
Improved	6IA	105.6±14.8	21.8±2.6	16±3
	4LS	126.2±10.8	22.2±2.8	20±2
	6LS	114.2±17.6	19.6±3.4	14±3
Local	4LA	135.2±11.6	24.7±3.2	19±1
	6LA	166.7±14.5	32.3±2.5	21±1
Mean improved		**125.2±12.9**	**25.2±2.2**	**21±3**
Mean local		**135.6±13.6**	**24.7±2.9**	**18.5±1.8**

As shown in Table 5.5, the mean annual increment in height of the improved variety (59.21±4.44 cm) was significantly higher ($P<0.001$) than that of the local one (42.10±2.72 cm). Although the mean diameter increment of the improved variety (12.36±0.73) was higher than that of the local variety (10.57±0.83 mm), the difference was not significant. Neither the type of crop nor the spacing between trees had any effect on both height and diameter increments in both varieties of Ziziphus.

Table 5.5: Mean annual increment in height and diameter growth of Ziziphus according to agroforestry treatments in Sanankoroba

Variety	Agroforestry Treatment	Height increment ($cm\ yr^{-1}$)	Diameter increment ($mm\ yr^{-1}$)
	4IS	57.03 ± 6.42^{ab}	13.44 ± 1.45
	6IS	58.72 ± 8.58^{ab}	12.00 ± 1.54
	4IA	65.70 ± 10.50^{a}	13.77 ± 0.95
Improved	6IA	55.40 ± 10.30^{ab}	10.22 ± 1.74
	4LS	43.36 ± 4.63^{b}	10.00 ± 1.77
	6LS	$36,67 \pm 6.24^{b}$	8.66 ± 1.79
Local	4LA	40.59 ± 5.57^{b}	10.78 ± 1.87
	6LA	47.79 ± 5.40^{ab}	12.83 ± 1.11
Improved	Mean	59.21 ± 4.44^{a}	12.36 ± 0.73
Local	Mean	42.10 ± 2.72^{b}	10.57 ± 0.83

NB: Different letters in the same column are significantly different at $p<0.05$

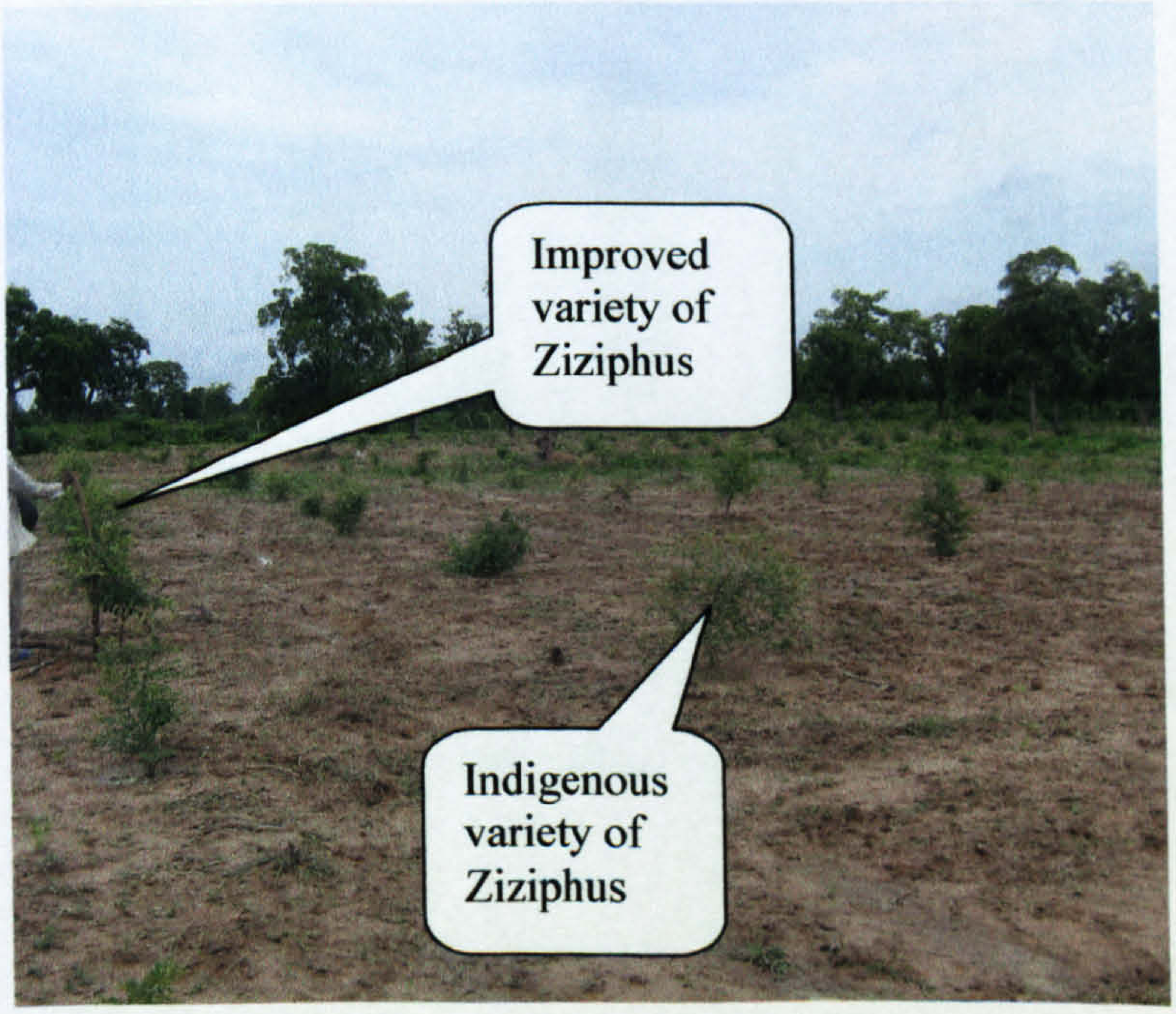


Plate 5.2: View of experimental field with indigenous and improved variety of *Z. mauritiana*

5.3.2.3. Fruit Production

The mean number of fruits per tree is given in Figure 5.3. The number of fruits per tree of the local variety (135±24.6) was significantly higher than that of improved variety (63±11.2) ($P < 0.01$). In contrast to fruit number, the mean fruit weight of the improved variety (13.46 ± 0.15 g) was significantly higher ($P<0.001$) than that of the local variety (0.75± 0.02. g) (Plate 5.3). Using the data on the mean weight per fruit, the number of fruits per tree and the density of trees per hectare, the total production of fruits in kg ha^{-1} was calculated and presented in Figure 5.4. The results of ANOVA showed that fruit production of the improved variety (866±158 kg ha^{-1}) was significantly higher ($P<0.001$) than that of local one (105±20.1 kg ha^{-1}). The type of crop and spacing between trees had significant effects ($P<0.001$, $P<0.001$, respectively) on fruit production in both varieties of Ziziphus. The highest fruit production was recorded in the treatment of 4 x 4 m tree spacing cropped with eggplant in both tree varieties (1948±454 kg ha^{-1} and 210±67 kg ha^{-1} in the improved and local varieties, respectively).

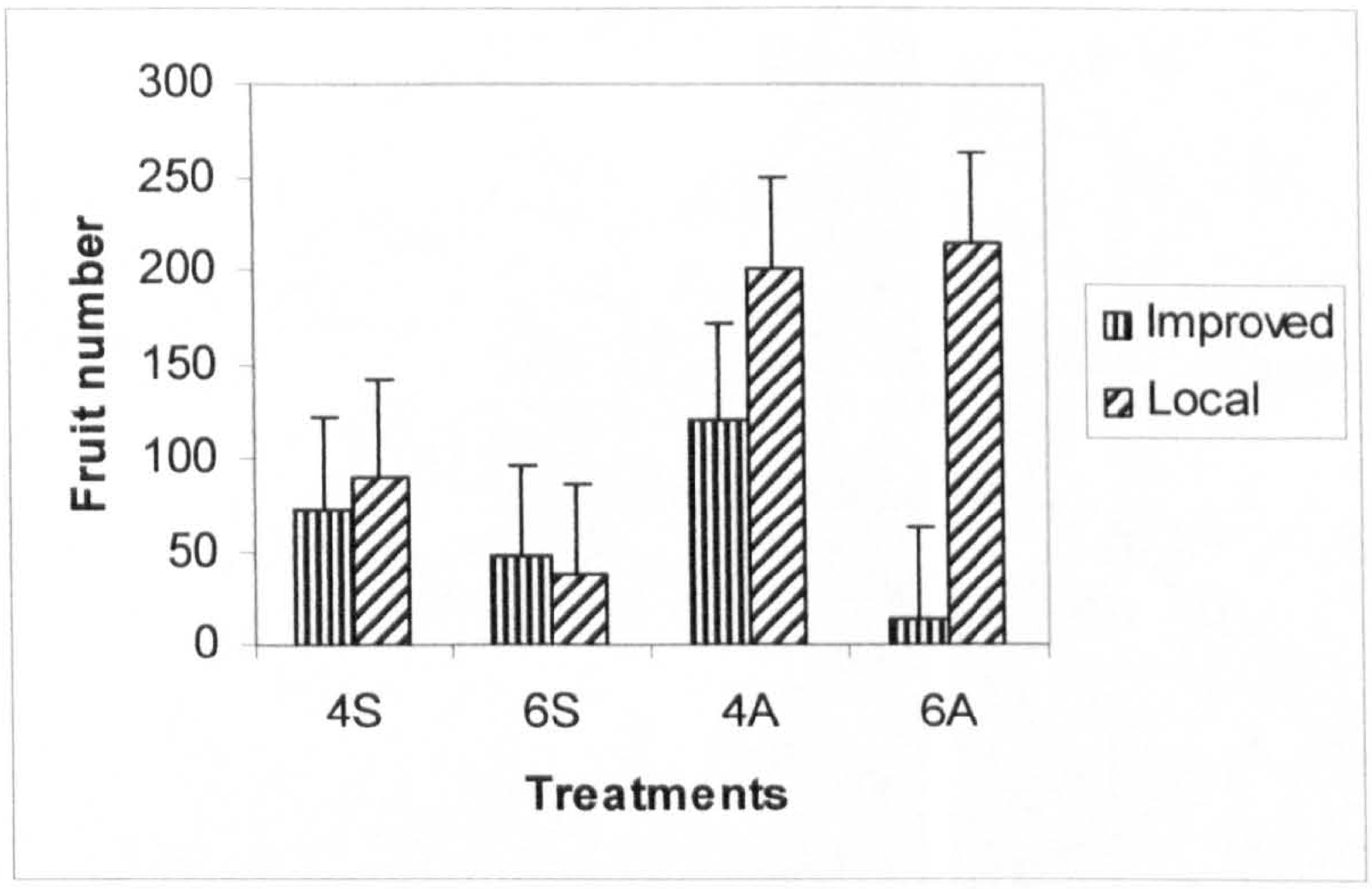


Figure 5.3: Mean number of fruits per Ziziphus tree, 18 months after grafting, according to agroforestry treatments in Sanankoroba.

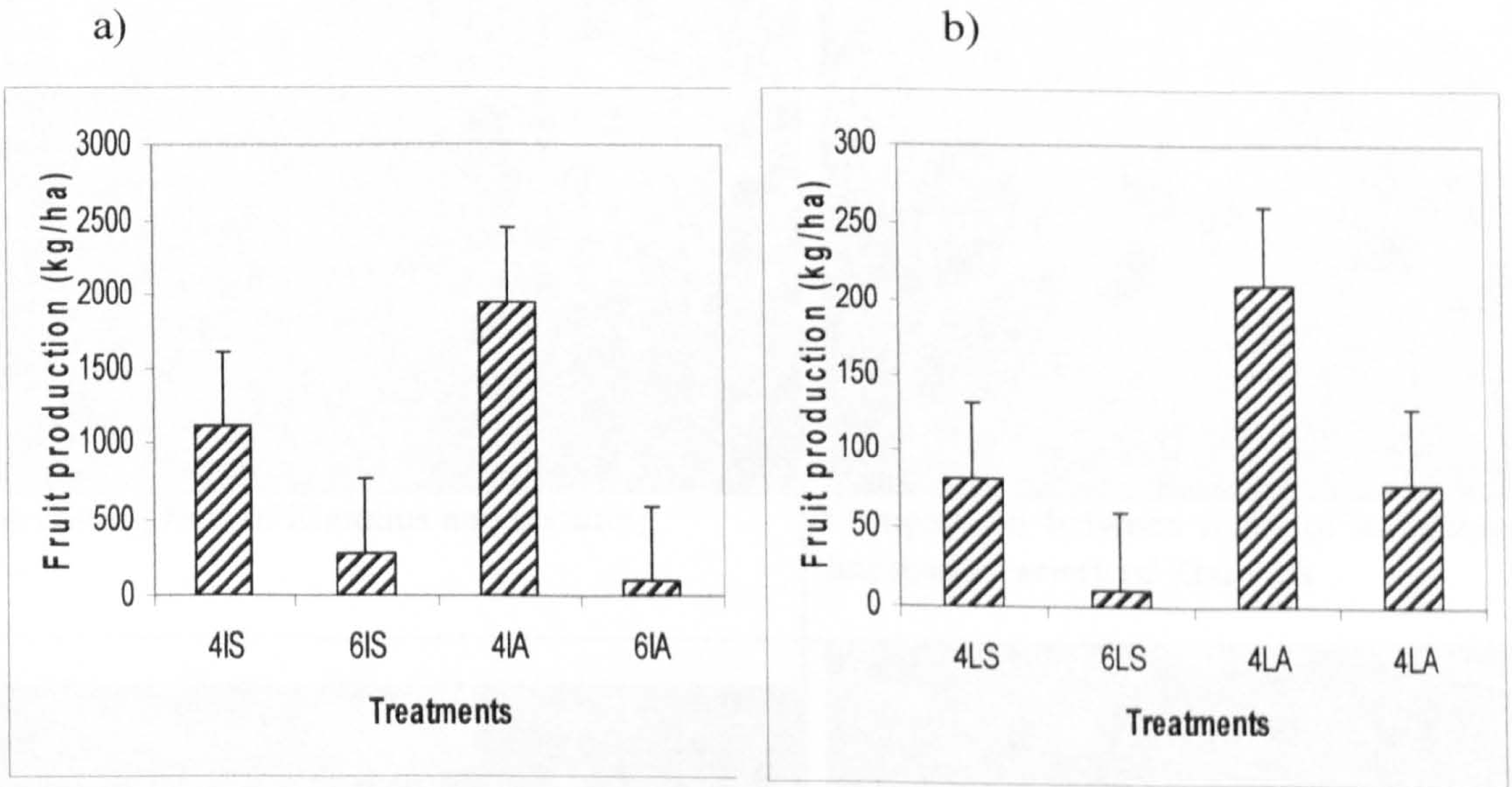


Figure 5.4: Fruit production (kg ha^{-1}) of improved (a) and local (b) Ziziphus varieties, 18 months after grafting, according to agroforestry treatments in Sanankoroba

Plate 5.3: Fruits of improved and indigenous variety of Ziziphus

Improved variety of Ziziphus with fruits

Indigenous variety of Ziziphus with fruits

Harvesting fruit of Ziziphus and counting

Comparison between fruits of indigenous and improved variety of Ziziphus

The weight of 41 fruits of improved variety of Ziziphus is 797g.

The weight of 120 fruits of indigenous Ziziphus is 66 g.

5.3.3. Sorghum yield and aboveground dry biomass

5.3.3.1. Sorghum yield

There was no significant difference in sorghum yield between the two years, although the yield in 2008 was slightly higher than in 2007 (861.6 ±78.95 and 677.6±71.59 kg ha^{-1}, respectively). The average yield of sorghum over the two years was 770.00±53.93 kg ha^{-1}. Varieties of Ziziphus had no significant effect on sorghum yield (Table 5.7), but spacing between trees did ($P<0.001$) (Table 5.8). There were also interactive effects of year and spacing ($P<0.01$) as well as varieties and spacing ($P<0.05$) on sorghum yield (Table 5.9). The highest yield was achieved in the 6 x 6 m spacing of improved variety in 2008 (1195.08±107.40 kg ha^{-1}) (Table 5.6).

5.3.3.2.. Sorghum above ground dry biomass

No significant difference was found between the two years in the above ground dry biomass of sorghum (1874.67±114.63 and 1624.25±158.53 kg ha^{-1} in 2007 and 2008, respectively). The average over the two years was 1749.00±98.15 kg ha^{-1}. Varieties did not have any significant effect on biomass. There was, however, a significant effect of spacing ($P<0.05$) as well as an interactive effect of year, variety and spacing ($P<0.05$) on biomass of sorghum, although they were of borderline significance. The highest biomass was achieved in the 6 x 6 m spacing of the local variety in 2007 (2500.75±263.28 kg ha^{-1}) (Table 5.6).

Table 5.6: Sorghum yield and aboveground dry biomass according to year, variety and spacing treatments in Sanankoroba.

Year	Ziziphus variety	Spacing	Yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
2007	Improved	4	742±178	2083±184
		6	596±128	1582±137
	Local	4	460±73	1332±169
		6	912±155	2501±263
2008	Improved	4	658±136	1445±335
		6	1195±107	1857±367
	Local	4	415±73	1301±210
		6	1179±174	1892±338

Table 5.7: Result of Two-way ANOVA analysis: Sorghum yield kg/ha versus Year, Tree variety

Source	DF	SS	MS	F	P
Year	1	813017	813017	2.93	0.090
Tree variety	1	76216	76216	0.27	0.601
Interaction	1	129320	129320	0.47	0.496
Error	92	25508526	277267		
Total	95	26527078			

Table 5.8: Result of Two-way ANOVA analysis: Sorghum yield kg/ha versus Year, Spacing

Source	DF	SS	MS	F	P
Year	1	813017	813017	3.67	0.058
Spacing	1	3871174	3871174	17.50	0.001
Interaction	1	1486450	1486450	6.72	0.011
Error	92	20356437	221266		
Total	95	26527078			

Table 5.9: Result of Two-way ANOVA analysis: Sorghum yield kg/ha versus tree variety, Spacing

Source	DF	SS	MS	F	P
Tree variety	1	76216	76216	0.33	0.570
Spacing	1	3871174	3871174	16.52	0.000
Interaction	1	1019919	1019919	4.35	0.040
Error	92	21559770	234345		
Total	95	26527078			

5.3.4. Eggplant yield and aboveground dry biomass

5.3.4.1. Eggplant fruit yield

There was no significant difference in the yield of eggplant between the two years. The average yield over the two years was 5740.00±344.78 kg ha^{-1}. There was also no significant effect of spacing on yield (Table 5.12). However, variety had a significant effect ($P<0.05$) (Table 5.11) and there was also a significant interactive effect ($P<0.01$) of variety and spacing on yield (Table 5.13). The highest yield was observed in the 4 x 4 m spacing of local variety (6772.46±818.92 kg ha^{-1}) (Table 5.10). Eggplant plant and fruits are presented in plate 5.4.

5.3.4.2. Eggplant dry biomass

There was no significant difference in the biomass of eggplant between year, in variety as well as spacing. There was however, a borderline significant interactive effect ($P<0.05$) of year and spacing on biomass of eggplant. The highest biomass was observed in 2007 in the 4 x 4 m spacing (583.96±66.19 kg ha^{-1}) (Table 5.10). The average biomass of eggplant over the two years was 516.00±30.69 kg ha^{-1}.

Table 5.10: Eggplant yield and aboveground dry biomass according to year, variety and spacing treatments in Sanankoroba.

Year	Ziziphus variety	Spacing	Yield (kg ha^{-1})	Dry biomass (kg ha^{-1})
2007	Improved	4	3551±483	680±120
		6	5674±1049	410±45
	Local	4	7428±1306	488±47
		6	6889±638	541±91
2008	Improved	4	3427±736	331±58
		6	7115±1071	530±76
	Local	4	6117±1010	534±96
		6	5717±755	616±109

Table 5.11: Result of Two-way ANOVA analysis: Eggplant yield kg/ha versus Year, Tree variety

Source	DF	SS	MS	F	P
Year	1	2044044	2044044	0.19	0.665
Tree variety	1	61120811	61120811	5.63	0.020
Interaction	1	21649211	21649211	1.99	0.161
Error	92	999291935	10861869		
Total	95	1084106001			

Table 5.12: Result of Two-way ANOVA analysis: Eggplant yield kg/ha versus Year, Spacing

Source	DF	SS	MS	F	P
Year	1	2044044	2044044	0.18	0.672
Spacing	1	35613839	35613839	3.14	0.080
Interaction	1	4354225	4354225	0.38	0.537
Error	92	1042093893	11327108		
Total	95	1084106001			

Plate 5.4: Eggplant fruit production in experimental plots in Sanankoroba


Young plant with flowers


Unripe fruit of eggplant


Eggplant in improved Ziziphus variety plot


Eggplant in local Ziziphus variety plot


Fruits harvested on a single plant.

Weight of a big fruit: 290 g.

Table 5.13: Result of Two-way ANOVA analysis: Eggplant yield kg/ha versus Tree variety, Spacing

Source	DF	SS	MS	F	P
Tree variety	1	61120811	61120811	6.12	0.015
Spacing	1	35613839	35613839	3.57	0.062
Interaction	1	68358334	68358334	6.84	0.010
Error	92	919013017	9989272		
Total	95	1084106001			

5.3.4. Nutritional composition of sorghum and eggplant

Neither the varieties of Ber nor the spacing between trees had any significant effect on the nutritional composition of sorghum and eggplant (Table 5.14). However, year had significant effect ($P<0.001$) on the nutritional composition of the two crops with the exception of iron, calcium, zinc and fibre contents. As expected, nutritional composition of sorghum and eggplant also differed significantly ($p<0.001$) except in Mg, Fe and Zn. Eggplant was richer than sorghum in protein, fibre, ash, nitrogen, potassium, sodium, calcium and manganese whereas sorghum was richer than eggplant in fat, carbohydrate and phosphorus (Table 5.15, 16, 17and 18).

Table 5.14: Significance level of nutrients according to year, Ziziphus cultivar, crop type and spacing between trees.

Nutrients	Year	Ziziphus cultivar	Crop type	Spacing
Protein %	0.001	NS	0.001	NS
Nitrogen%	0.001	NS	0.001	NS
P mg/g	0.001	NS	0.05	NS
K mg/g	0.001	NS	0.001	NS
Na mg/g	0.001	NS	0.001	NS
Ca mg/g	NS	NS	0.001	NS
Mg µg/g	0.001	NS	NS	NS
Mn µg/g	0.001	NS	0.001	NS
Fe µg/g	N.S	NS	NS	NS
Zn µg/g	NS	NS	NS	NS
Fat g g-1	0.001	NS	0.01	NS
Fibre g g-1	NS	NS	0.001	NS
Ash g g-1	0.001	NS	0.001	NS
Carbohydrate g g-1	0.001	NS	0.001	NS

NS: Not significant

Table 5.15: Mineral content of sorghum

Year	Ziziphus cultivar	Spacing	% N	P mg/g	K mg/g	Na mg/g	Ca mg/g	Mg µg/g	Mn µg/g	Fe µg/g	Zn µg/g
	Improved	4	2.14±0.07	2.59±0.18	1.34±0.155	13.29±0.76	0.06±0.01	0.28±0.04	0.43±0.06	1.33±0.29	1.23±0.2
2007		6	1.93±0.06	2.05±0.25	0.98±0.44	12.38±1.58	0.05±0.00	0.21±0.04	0.36±0.05	1.09±0.09	1.53±0.40
	Local	4	2.09±0.09	2.91±0.49	2.93±1.07	13.67±0.32	0.06±0.01	0.32±0.07	0.51±0.14	1.33±0.17	0.95±0.05
		6	2.13±0.09	2.26±0.13	1.11±0.15	12.17±0.85	0.06±0.01	0.24±0.03	0.40±0.06	1.13±0.16	1.02±0.12
	Improved	4	1.72±0.06	4.16±1.39	6.84±1.29	4.85±0.38	0.07±0.01	0.49±0.15	0.77±0.14	1.54±0.21	1.42±0.41
2008		6	1.75±0.03	5.52±0.79	6.55±2.09	3.78±0.33	0.09±0.01	0.66±0.09	1.09±0.12	1.84±0.16	1.82±0.47
	Local	4	1.80±0.02	2.77±0.32	3.02±0.75	7.24±3.96	0.07±0.01	0.35±0.06	0.70±0.11	1.52±0.18	0.86±0.07
		6	1.87±0.06	5.13±0.47	5.25±0.98	4.41±0.44	0.08±0.01	0.61±0.01	0.98±0.02	1.89±0.14	1.22±0.16
Mean			1.92±0.04	3.48±0.33	3.61±0.58	8.84±0.99	0.07±0.00	0.40±0.04	0.67±0.06	1.47±0.08	1.27±0.11

Table 5.16: Mineral content of eggplant

Year	Ziziphus cultivar	Spacing	% N	P mg/g	K mg/g	Na mg/g	Ca mg/g	Mg µg/g	Mn µg/g	Fe µg/g	Zn µg/g
	Improved	4	2.42±0.02	3.19±0.16	19.06±1.75	31.79±1.27	0.12±0.03	0.38±0.04	0.83±0.13	2.43±0.96	1.43±0.57
2007		6	2.35±0.08	2.91±0.04	16.22±1.64	34.24±1.52	0.09±0.00	0.42±0.01	0.56±0.11	1.42±0.35	2.23±0.64
	Local	4	2.27±0.26	2.68±0.44	19.23±4.39	26.92±5.30	0.09±0.01	0.36±0.03	0.75±0.18	1.44±0.13	1.48±0.63
		6	2.19±0.03	2.91±0.60	21.62±2.98	32.22±10.09	0.14±0.03	0.38±0.08	0.89±0.25	1.52±0.14	1.48±0.41
2008	Improved	4	1.79±0.02	2.67±0.17	23.62±4.18	4.82±1.18	0.08±0.00	0.38±0.02	1.16±0.18	2.37±0.62	1.25±0.29
		6	2.06±0.11	2.61±0.15	28.52±3.96	5.83±0.82	0.11±0.02	0.42±0.00	1.27±0.15	1.25±0.19	0.79±0.09
	Local	4	2.02±0.18	3.00±0.10	23.39±2.99	5.22±0.75	0.08±0.01	0.48±0.02	1.27±0.29	1.43±0.19	1.35±0.39
		6	1.98±0.23	2.87±0.07	25.47±6.12	5.96±0.91	0.08±0.00	0.47±0.05	1.09±0.34	1.45±0.02	1.21±0.42
Mean			2.12±0.06	2.86±0.08	22.58±1.41	16.56±3.01	0.09±0.00	0.42±0.01	1.01±0.08	1.69±0.18	1.36±0.15

Table 5.17: Proximate content of sorghum

Year	Ziziphus cultivar	Spacing	% Protein	Fat g g^{-1}	Fibre g g^{-1}	Ash g g^{-1}	Carbohydrate g g-1
2007	Improved	4	13.37±0.46	0.03±0.00	0.26±0.01	0.005±0.02	0.57±0.01
		6	12.07±0.40	0.04±0.00	0.18±0.01	0.011±0.005	0.64±0.03
	Local	4	13.1±0.59	0.03±0.00	0.21±0.02	0.009±0.002	0.61±0.02
		6	13.32±0.57	0.04±0.02	0.23±0.01	0.008±0.006	0.59±0.01
2008	Improved	4	10.78±0.36	0.06±0.01	0.19±0.07	0.030±0.012	0.60±0.05
		6	10.93±0.21	0.07±0.00	0.22±0.01	0.027±0.010	0.57±0.00
	Local	4	11.3±0.10	0.05±0.01	0.19±0.01	0.014±0.008	0.63±0.02
		6	11.68±0.39	0.08±0.00	0.23±0.00	0.009±0.004	0.56±0.01
	Mean		**12.01±0.24**	**0.05±0.00**	**0.22±0.01**	**0.01±0.00**	**0.59±0.01**

Table 5.18: Proximate content of eggplant

Year	Ziziphus cultivar	Spacing	Protein%	Fat g g^{-1}	Fibre g g^{-1}	Ash g g^{-1}	Carbohydrate g g^{-1}
2007	Improved	4	15.13±0.16	0.03±0.002	0.46±0.04	0.07±0.01	0.29±0.05
		6	14.71±0.53	0.03±0.009	0.48±0.00	0.08±0.00	0.27±0.01
	Local	4	14.18±1.65	0.03±0.003	0.46±0.09	0.08±0.00	0.30±0.10
		6	13.72±0.16	0.03±0.002	0.43±0.04	0.04±0.03	0.38±0.07
2008	Improved	4	11.24±0.12	0.04±0.006	0.46±0.02	0.09±0.01	0.29±0.01
		6	12.87±0.71	0.05±0.008	0.52±0.02	0.09±0.02	0.21±0.04
	Local	4	12.65±1.13	0.05±0.003	0.46±0.08	0.10±0.01	0.26±0.10
		6	12.41±1.47	0.05±0.014	0.51±0.06	0.11±0.01	0.21±0.09
	Mean		13.24±0.39	0.04±0.00	0.48±0.02	0.08±0.01	0.27±0.02

5.3. Discussion

5.4.1. There is no difference in performance between the local and improved varieties of *Z. mauritiana*

There was a highly significant difference in survival rates between the two varieties of Ziziphus. The mean survival rate of the local variety was significantly higher (95.31±1.36 %) than that of the improved variety (76.04±6.44%). In terms of height growth, the local variety was also slightly superior but not significantly different to that of the improved one during the initial two measurement dates. The gap in height growth between the two varieties, however, started to close during the third measurement date. Regarding diameter growth, although the local variety was slightly higher than the improved variety initially, the diameter of the improved variety began to slightly overtake that of the local variety starting from the second measurement date. At the last measurement date, there were no significant differences in height, diameter and numbers of branches between the two varieties of Ziziphus. This was due to the significantly faster increment rate in height and diameter growth of the improved variety. The low survival rate and slow growth rate of the improved Ziziphus observed during the first date of measurement may be due to the shocking effect of grafting on the seedling rootstock. It is worthwhile to mention that all the seedlings of the local Ziziphus were planted at the site at the same time and the grafting of half of them took place after the seedlings were well-established, ten months after planting. The terminal growth of the seedling rootstock was interrupted as a result of grafting and the growth of the scion began after the union between the seedlings' rootstock and the scion cambium was wel-established and acclimatised which may have taken several weeks. Once established and acclimatised, scions of the Ziziphus cultivar SEB have been reported to grow faster than the local variety by several workers as also observed in the present experiment (Ouédraogo *et al.* 2006; Cao *et al.* 1999).

The number of fruits per tree of the local variety (135±24.6) was significantly higher than that of improved variety (63±11.2). This may also be due to the initial shocking effect of grafting on the rootstock. In contrast to the fruit number, the mean fruit weight of the improved variety was significantly higher than that of the local variety. The mean weight per fruit recorded on the improved variety in the present study (13.5 g) is well within the range of values reported by Chovatia (1993), Lal (2001), Vashistha (2001), Mukherjee (2004) and Ouedraogo *et al.* (2006) (4.6 – 33 g per fruit). The low value of 0.75 g for the fruit weight of the local variety recorded in the present study was, however, slightly lower than the value of 1-2 g reported by Diallo *et al.* (2000). The mean fruit production of the improved variety of 866±158 kg ha^{-1}, which was significantly higher than that of the local one (105±20.1 kg ha^{-1}), was also slightly lower than that of Ouédraogo *et al.* (2006). The difference could be attributed to the fact that irrigation and fertilisation were applied in their study but not in the present study. Soils in arid subtropics are deficient in phosphorous and water which were reported to be the most limiting factors determining productivity and quality of jujube in dry areas (Pareek, 2001; Ouédraogo *et al.* 2006).

5.4.2. The performance of *Z. mauritiana* varieties is not affected by associated crops

Type of associated crop had no significant effect on survival rate, height and diameter growth and number of branches of the improved and local varieties of Ziziphus. However, the type of associated crop had a significant effect on fruit production in both varieties of Ziziphus. The highest fruit production was recorded in the treatment of both tree varieties cropped with eggplant. The high production of fruits, when trees were associated with eggplant, shows that eggplant may have less competitive effect on trees than sorghum.

Spacing between trees had no significant effect on survival rate, height and diameter growth and number of branches of the improved and local varieties of Ziziphus. However, higher production of fruit was achieved in the 4 x 4 spacing than 6 x 6 spacing. The higher production in the 4 x 4 tree spacing may be due to the high density of trees which was used in the calculation of fruit production.

5.4.3. The yield of associated crops are not affected by *Z. mauritiana* varieties

Variety of Ziziphus had no significant effect on yield or aboveground biomass of sorghum. The average yield of sorghum over the two years of 770.00±53.93 kg ha^{-1} was in very close agreement with the average yield of sorghum in Africa of 800 kg ha^{-1} reported by FA0 (2001). It was even higher than the value of 700 kg ha^{-1} reported by Ratnadass *et al.* (2007) for Mali. The yield of sorghum obtained in the present study was also comparable to those of Bayala (2002) who reported in his study that the highest yield was achieved under Karité (810±125 kg ha $^{-1}$ $year^{-1}$). The fact that sorghum yield in some of the treatments in the present study was higher than the mean yield of 700 kg ha-1 (Ratnadass *et al.*, 2007) reported for Mali, suggests that Ziziphus trees had a positive influence on sorghum performance through probably soil and microclimate improvements. Ziziphus has been reported to improve soil and microclimate by several researchers (von Carlowitz, 1986). The very high mycorrhizal status of Ziziphus has also been reported by Bâ *et al.* (2000) and Ouédraogo *et al.* (2006) that may have improved the soil's phosphorous content which has been reported to be a major limiting factor for crop production and particularly the productivity of Ziziphus in dry lands (Pareek 2001; Ouédraogo *et al.* 2006).

In the case of eggplants, however, there was a borderline effect of variety on yield of eggplant. The highest yield of 6772.46±818.92 kg ha^{-1} was observed for the local variety. This shows that eggplant is indeed shade tolerant because the local variety of Ziziphus was taller in height than the improved variety. As a result, the local variety may have casted more shade which improved the production of the eggplant.

The average yield of eggplant of 5740.00±344.78 kg ha^{-1} (5.7 t ha^{-1}) over the two years was within the range of values reported by Lester and Seck (2004). They reported that without irrigation, eggplant yields were 5–8 t ha^{-1}.

Spacing between trees had a significant effect on sorghum yield and above ground biomass. The highest yield and biomass were achieved in the 6 x 6 m spacing of local variety. Spacing had also significant effect on eggplant yield and biomass. But contrary to sorghum, the highest yield and biomass of eggplant were obtained in the 4 x 4 m spacing. These results reinforce the fact that eggplant is more shade tolerant than sorghum. In a study of intercropping in a temperate region, Reynolds *et al.,* (2006) found that the yields of soybeans and maize were reduced approximately by half when the crops were grown at 2 m from the trees compared to those grown at 6 m. The trees used in their study were relatively high (7 to 12 m). Raddad and Luukkanen (2007) did an intercropping study with sorghum and sesame associated with *Acacia Senegal*. They found that sorghum and sesame yields were not influenced by tree density and they argued that the agroforestry system used was 4 years old and at this stage *A. senegal* has no negative effect on crop yield.

5.4.4. The nutritional composition of associated crops is not affected by *Z. mauritiana*.

Neither varieties of Ziziphus nor the spacing between trees had any effect on the nutritional composition of sorghum and eggplant. However, year had significant effect on composition. This may be due to depletion of some of the nutrients such as Ca, Na and Fe in soil with time.

There were also significant differences in composition between sorghum and eggplant. Eggplant was richer than sorghum in protein, fibre, ash, nitrogen, potassium, sodium, calcium and manganese whereas sorghum was richer than eggplant in fat, carbohydrate and phosphorus. Such differences in nutritional composition between cereals and vegetable crops have been reported by previous workers (Boukari *et al.*, 2001; Rubaihayo, 2002).

The mean value of protein (13.37±0.46) in sorghum was slightly higher than the value reported by Barikmo *et al.* (2004) who found that the protein content of sorghum was 10.4±0.7 g/100 g. Their results of carbohydrate and fibre (73.5 g/100 g and 4.7 g/100 g respectively) were, however, slightly higher than those found in the present study (0.59±0.01 g g^{-1} and 0.22±0.01 g g^{-1}respectively). The values of iron and zinc (5.8 and 2.1 mg/100 g respectively) reported by Barikmo *et al.* (2007) were also higher than those reported in the present study (1.47±0.08 µg/g and 1.27 ±0.11 µg/g). These may be due to differences in varieties or land races of sorghum. Barikmo *et al.* (2004, 2007) found considerable differences in nutrient content for sorghum between geographical regions.

Our results on the nutritional content of eggplant (Table 5.16 and 18) are higher than those reported by Grubben *et al.* (2004). The nutritional content per 100 g of eggplant reported by Grubben *et al.*, (2004) were respectively: protein (1.5 g), fat (0.1 g), carbohydrate (7.2 g) and fibre (2.0 g).

5.5. Conclusion

The present study shows that SEB, the improved variety of Ziziphus as well as the local variety of Ziziphus tested in the present study, had no detrimental effect on either eggplant or sorghum, both in terms of yield and nutritional quality, two years after establishment. In fact a beneficial effect of trees was found on the performance of both crops (yield, dry matter production). This may be due to the absence of competition for water and soil nutrients between the trees and crops even though water and nutrients are known to be limiting factors for crop growth in drylands (Ong and Leaky, 1999; Feng and Epstein, 1995) and also perhaps due to the soil improving property of Ziziphus because of its high mycorrhizal status reported by Bâ *et al.* (2000) and Ouédraogo *et al.* (2006). The type of crops grown in the present study also did not have any detrimental effect on the growth and productivity of both varieties of Ziziphus. The results of the present study, therefore, suggest complementarities in resource use between the trees and the crops. Although the trees in the present study were young (two years old), it is expected that similar results may continue to be observed for several years more. Similar suggestions have been made by previous researchers who studied other soil improving tree species. For example, Raddad *et al.*, (2007) found that sorghum yield in agroforestry systems with *Acacia senegal* were higher compared to the yield of sorghum grown alone for the first four years of the tree establishment stage in Sudan. Based on general information available in the region, Raddad *et al.* (2007) suggested that intercropping with *A. senegal* could possibly continue for more than five years without a risk of yield reduction. Nitrogen fixing trees have been reported to enhance N and P cycling and are suitable for soil fertility restoration (Muthuri *et al.*, 2005). Ong *et al.* (2000) also reported that maize grain yield was unaffected by *Gravellia robusta* for the first three years after planting. Similarly, Lott *et al.* (2000) found that the aboveground biomass and yield in understorey crops were not affected by *G. robusta* during the first four cropping seasons. Therefore, due to the high mycorrhizal status of Ziziphus, it may be possible that the complementarities in resource use between trees and crops observed in the present study may be maintained for several years more. In other words, the reduction in crop and tree fruit yield expected in the long run may simply be negated by the benefits that arise from the mycorrhizal properties of Ziziphus.

The high level of fruit production of the improved variety of Ziziphus on farms under rain-fed conditions may be a source of additional income and diversification of diet for rural communities in Africa, because not only can farmers maintain traditional crop cultivation on their farms but they can also obtain the additional product of Ziziphus fruits which they can consume to improve their diet as well as sell in local markets to generate income. The fruit of Ziziphus has been reported to be rich in vitamin A, C, calcium and carotene (Ouédraogo *et al.*, 2006). Furthermore, the present study showed that Ziziphus can be successfully grown on farmers' fields without high inputs such as irrigation and fertilisation which are scarce resources in the drylands of Africa. Therefore, it may be concluded that the adoption by farmers of the agroforestry practice of domesticating improved Ziziphus varieties in association with food crops, successfully tested in the present study, may help considerably in alleviating poverty in the region.

CHAPTER VI:

THE USE OF MYCORRHIZAL INOCULATION IN THE DOMESTICATION OF *ZIZIPHUS MAURITIANA* AND *TAMARINDUS INDICA*

6.1. Introduction

Ziziphus mauritiana Lam. (Ber) and *Tamarindus indica* L. (Tamarind) are two major indigenous fruit tree species of agroforestry parkland systems of West Africa and they play a significant role both in terms of ecological services and as a source of food and income to the people of the region. Despite their important roles, there are no reports in the literature of their domestication on farms in West Africa.

The domestication of indigenous fruit tree species of agroforestry parkland systems has now become a priority for research in Africa (Nair, 1993; Teklehaimanot 2004; Leaky *et al.,* 1998; Jama *et al.,* 2008; Sanchez and Leakey, 1997). One of the approaches that can be used in the domestication of indigenous fruit trees of parklands is Arbuscular mycorrhizal fungi (AMF) inoculation.

Arbuscular mycorrhizal (AM) associations with a wide range of annual and perennial plant species are widespread in the tropics (Le tacon *et al.,* 1987; Sieverding, 1991; Munro *et al.*, 1999; Bâ et al., 2000) and many plant species are dependant on them for growth and development (Bagyaraj *et al.* 1989; Munro *et al.*, 1999; Bâ *et al.*, 1998, 2000; Antunes *et al.*, 2007).It is well documented that mycorrhizal fungi improve the growth of plants that are important in agriculture, horticulture and forestry (Munyanziza *et al.*, 1997; Wilson *et al.*, 1991; Diagne *et al.*, 2001). Mycorrhizal fungi provide a greater absorptive surface than root hairs and thus help in the absorption of immobile ions such as phosphate, copper and zinc (Munyanziza *et al.*, 1997; Sailo and Bagyaraj, 2005). The increased growth of mycorrhizal plants is mainly due to an increase in phosphorus uptake (Munyanziza *et al.*, 1997; Sailo and Bagyaraj, 2005; Antunes *et al.*, 2007). Furthermore, mycorrhizal plants were reported to have a greater tolerance to toxic metals, drought, high soil temperature, root pathogens and transplant shock than non-mycorrhizal plants (Bagyaraj, 1990; Bagyaraj and Varma, 1995; Munyanziza *et al.*, 1997).

Mason and Wilson (1994) stated that soil disturbance can lead to the loss of mycorrhizal propagules (spores, mycelium and infected roots), inhibiting the renewal of vegetation cover in many deforested areas. This may be the case with agroforestry parkland systems which have been reported to be degrading due to population pressure (Gijbers *et al.*, 1994; Boffa, 1999). Due to loss of tree cover, most of the naturally occuring soil-borne mycorrhiza in agroforestry parkland systems may have been lost. In order to restore the loss of vegetation through domestication, plants can be inoculated with laboratory grown AM to enhance their establishment in agroforestry parkland systems (Bethlenfalvay, 1992, Miransari *et al.*, 2008). Responses of plants to AM inoculation differs with respect to functional compatibility, measured as mycorrhizal formation, root colonization, external hyphal length and relative mycorrhizal dependency (RMD) (Ravnskov and Jacobsen, 1995, Bâ *et al.*, 2000). Planchette *et al.* (1995) defined RMD as the degree to which a plant responds to inoculation. According to Munro *et al.* (1999), nursery inoculation can provide benefits to plants through: 1) growth promotion before out planting; 2) enhanced mycorrhizal development enabling the plant to withstand transplanting stress; and 3) compensating for mycorrhizal deficiencies at disturbed outplanting sites.

Naturally occurring unselected soil inoculum can also be used to promote mycorrhizal formation in non-sterile soils to improve plant growth as reported by Munro *et al.*, (1999), Varma *et al.* (1993), Michelson (1993), Sidibé and Dhillion (2001) and Ahmad and Maziah (1988). There are advantages of using unselected soil inoculum because the techniques require no sterilisation, no long term maintenance, no sophisticated laboratory equipment and methods and therefore the techniques could be easily taught to farmers through extension programmes (Munro *et al.*, 1999).

The objectives of the present research were, therefore, to investigate the effect of two selected AMF isolates: *Glomus aggregatum*, *Glomus fiscia*, and unselected naturally occurring nursery soil inoculums, used as a control, on the growth of *Ziziphus mauritiana* and *Tamarindus indica* seedlings in nurseries and to evaluate the extent of mycorrhizal formation on the roots of both tree species and the spore population in the soil.

The hypotheses tested were:

1) the performance of *Ziziphus mauritiana* and *Tamarindus indica* seedlings is not affected by any of the three types of mycorrhizal inocula (*Glomus aggregatum*, *Glomus fiscia* and unselected nursery soil inoculum), and

2) there is no difference in mycorrhizal formation on roots and spores in the soil between the three types of inoculum.

6.2. Materials and methods

The experiment was set up in the nursery of the Institut d'Economie Rurale (IER), Sotuba, Mali.

Seeds of *Tamarindus indica* and *Ziziphus mauritiana* were collected locally. Seeds of *Z. mauritiana* were pre-treated by soaking in water overnight. Seeds of *T. indica* were soaked in boiling water for 10 minutes and remained in hot water until it cooled down.

Two isolates of AMF were used: *Glomus aggregatum* and *Glomus fiscia.* These were obtained from the laboratory of Institut National de l'Environnment et de la Recherche Agricole (INERA), Burkina Faso. The soil medium used for growing the seedlings was the soil mixture commonly used in the nursery. It consisted of a mixture of local soil (1/3), sand (1/3) and compost (1/3). The soil was passed through a 2 mm sieve and transferred into polythene pots of 17 cm length and 10 cm width.

Three inocula were used: *Glomus aggregatum*, *Glomus fiscia* and unselected nursery soil inoculum as a control. Each inoculum of either *Glomus aggregatum* or *Glomus fiscia* consisted of 20 g of mixed sand and propagules (spores and infected root fragments).

Inoculation procedure for the application of the two AMF isolates involved the following steps:

- Seeds were soaked in 1 litre of tap water to which 20 g of inoculum was added (either G *aggregatum* or *G. fiscia*) for 24 hours before sowing;
- 5 ml of each inoculum mixed in tap water (20 g of inoculum in 1 litre of tap water) was poured using a syringe into seed planting holes in each polythene pot before seed sowing;
- Immediately after germination, another 5 ml of each inoculum mixed in tap water (either G *aggregatum* or *G. fiscia*) was poured into the rooting zone of each seedling. Care was taken in order to reach the rooting zone without disturbing the seedlings (Plate 6.1).

Plate 6.1: Inoculation of seedlings using syringes

In the case of the naturally occurring soil inoculum, the above procedure was not applied and the seeds were simply sown into the polythene pots without any treatment.

The experimental layout was a randomized complete block design with three replicates. Three sheds (benches), each with 7 m length, 2 m width and 1 m height, were constructed for each species. In order to avoid cross contamination each inoculum treatment was placed in one shed or bench. The sheds were separated enough to avoid splash during watering.

510 polythene pots were used for sowing seeds for each of *T. indica and Z. mauritiana*. The pots were placed on the six separate benches, each of which represented one inoculum and one tree species. Each bench consisted of 170 pots of each tree species per each inoculum treatment.

Two seeds were sown per pot and these were thinned to one seedling after germination. Seedlings were watered once a day. Growth parameters were recorded on 33 randomly selected seedlings from each treatment and each tree species. Measurements of *Z. mauritiana* growth started one month after germination and that of *T. indica*, two months after germination because of its slow growth. The following parameters were measured biweekly for *Z. mauritiana* seedlings and monthly for *T. indica*: Percentage of germination, height, collar diameter and the number of branches on seedlings.

Four (4) seedlings of each species were randomly selected in each inoculum treatment and destructively harvested, six months after sowing for Ziziphus and ten months for Tamarindus. The following parameters were measured on each harvested plant: height, diameter, number of branches, tap root length, total root length, number of spores in pots and the percentage of mycorrhizal infection of roots. The harvested plant materials were then oven dried at 80°C for 48 hours and the dry weight of shoot, root and leaves was measured.

For spore extraction from the soil, 100 g of soil was taken from each pot: 50 g was oven dried at 120 °C for 24 hours and weighed to obtain the dry weight of soil and the remaining 50 g was used for spore extraction. Spores were extracted using sucrose centrifugation methods (Sieverding, 1991). The assessment of the population of spores was done using the Petri dish method (Sieverding, 1991) and a stereo microscope. Spore number was then expressed per 100g dry weight of soil.

For mycorrhizal root infection measurement, 10 g of fresh fine roots were collected from the root system of each seedling. 5 g was used to estimate the total root length (Tennant, 1975) and from the remaining 5 g a sample of 100 fragments of roots was selected using a shallow sampling tray which was marked with 100 random dots to determine root infection. The selected roots were placed in a small Petri dish and cleansed with KOH, stained with trypan blue and assessed for percentage of root infection (Plates 6.2 & 6.3). The staining was carried out as described by Claassen and Zasoski (1992), using a screened syringe. The assessment of mycorrhizal infection was done using the grid line intercept method as described by Tennant (1975).

Plate 6.2. Utensils and chemicals used for washing and staining roots

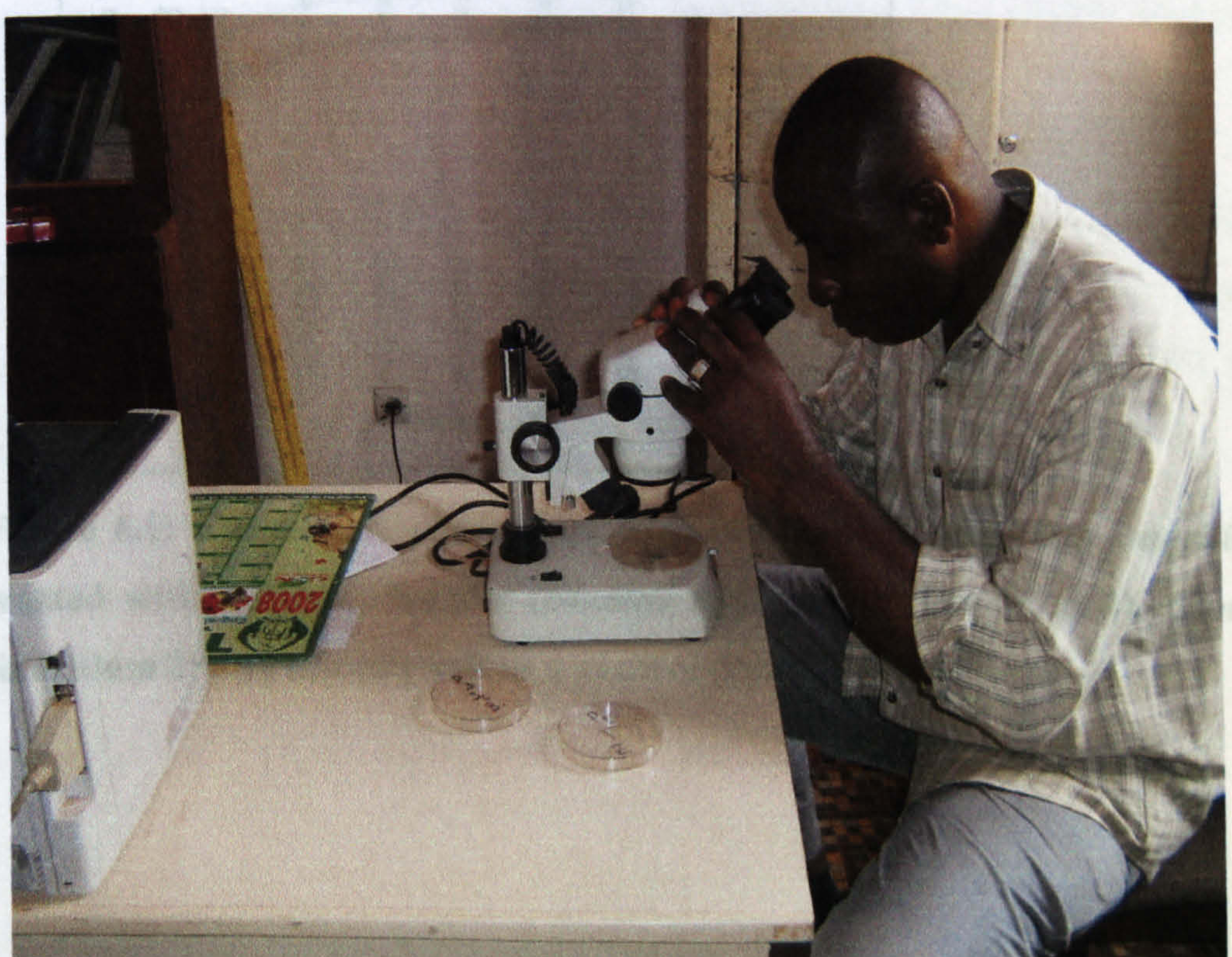


Plate 6.3. Staining, slide preparation and observation using an microscope

6.3. Results

6.3.1. Performance of *Ziziphus mauritiana*

6.3.1.1. Percentage of seed germination

The mean percentage of germination of the three inocula was 81.50±5.02% (Figure 6.1). The results showed that the percentage of germination was highest in the nursery soil inoculum (control) (91.49± 2.62%), followed by the *G. fiscia* inoculum (77.17±1.30%). The least percentage of germination was observed in the *G. aggregatum* inoculum (75.75±1.75%). More than 50% germination of seeds occurred four days after sowing for all the inoculum types: Inoculum 1 (53%), inoculum 2 (57%) and inoculum 3 (74%). The period for completion of germination also differed between inocula. The fastest completion time took place in the control (8 days) and longest in inoculum 1 (12 days).

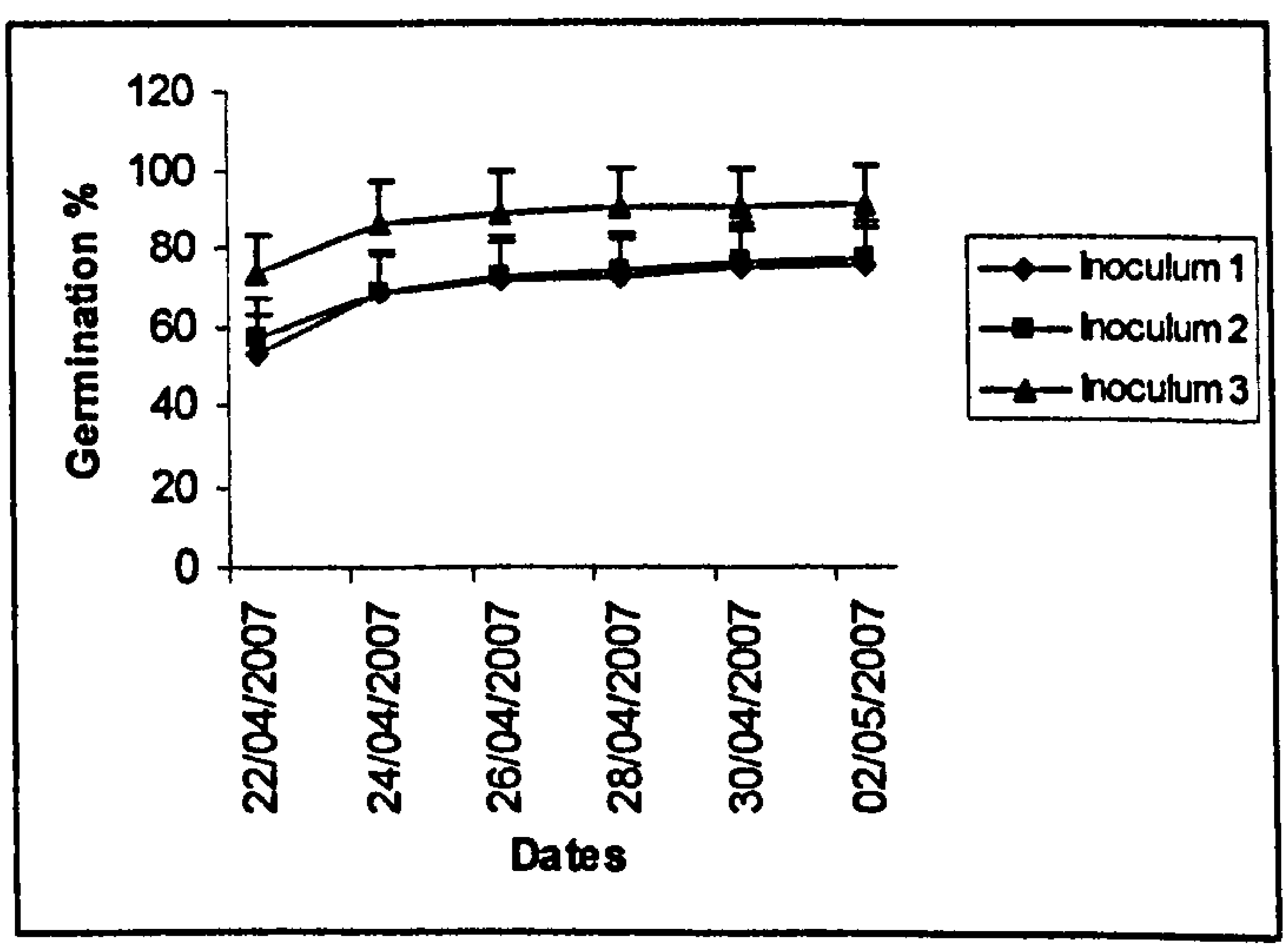


Figure 6.1: Cumulative percentage of germination of *Ziziphus mauritiana* seeds treated with different inocula (*Glomus aggregatum* (inoculum 1), *Glomus fiscia* (inoculum 2) and nursery soil as a control (inoculum 3).

6.3.1.2. Growth parameters

The treatment effect became apparent two months after germination (Figure 6.2). The height growth of seedlings treated with inoculum 1 was the highest in all dates of measurement and the lowest was in the control treatment (inoculum 3) but the gap in height growth between inoculum 2 and the control decreased with time and closed at the last date of measurement as can be seen in Figure 6.2. There was no significant difference in the mean monthly height increment of seedlings between the three inoculum treatments. The mean monthly height increment of seedlings inoculated with nursery soil (24.19±0.77 cm) was slightly higher than that of *G. aggregatum* (24.07±0.79 cm) and *G. fiscia* (22.19±1.04 cm).

The diameter of seedlings inoculated with *G. aggregatum* (inoculum 1) was lowest at the second date of measurement but overtook that of the other treatments starting from the third date of measurement (Figure 6.3). Diameter growth of seedlings inoculated with *G. fiscia* and the nursery soil inoculum followed the same pattern as height growth. There was no significant difference in the mean monthly diameter increment of seedlings between inoculum treatments. The mean monthly diameter increment of seedlings inoculated with *G. aggregatum* (0.42±0.10 cm) was slightly higher than that of nursery soil (0.26±0.0.02 cm) and *G. fiscia* (0.24±0.01 cm).

The increase in number of branches followed the same pattern as height growth (Fig.6. 4). The gap between the three treatments started to widen four months after germination. Seedlings inoculated with *G. aggregatum* had the highest number of branches, followed by those with *G. fiscia* and the least was in the control.

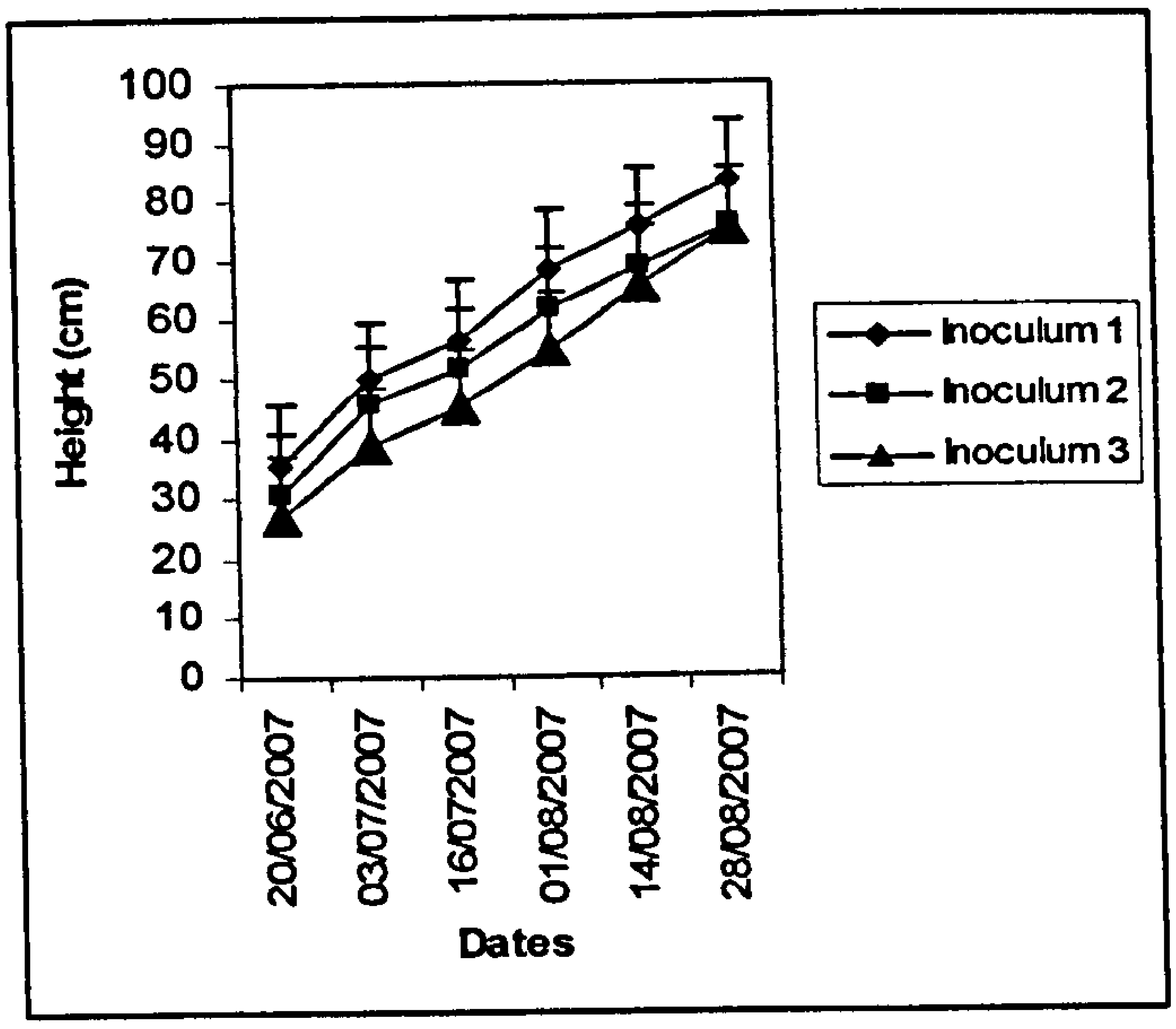


Figure 6.2: Height growth of *Z. mauritiana* seedlings inoculated with different mycorrhizal fungi.

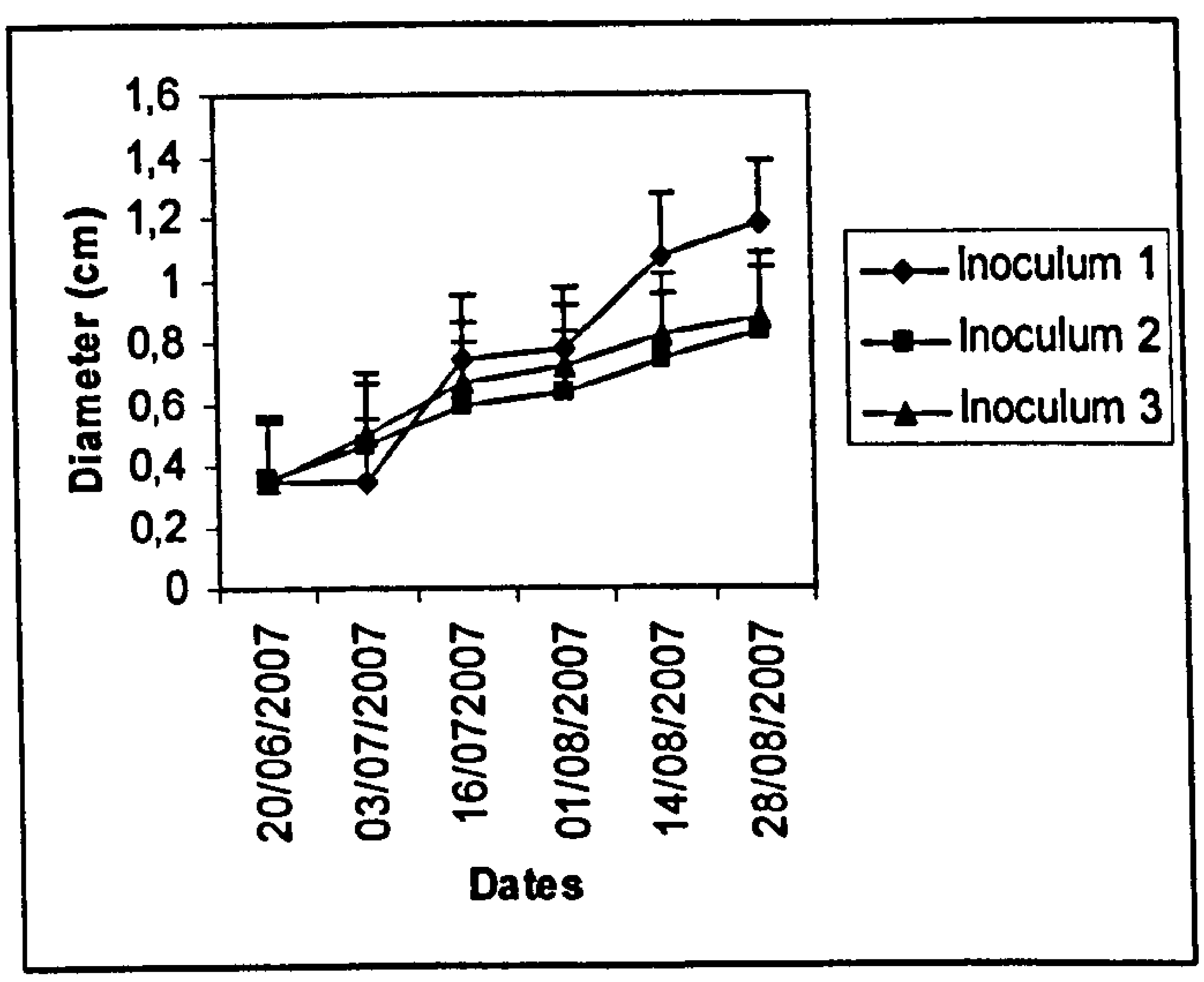


Figure 6.3: Diameter growth of *Z. mauritiana* seedlings inoculated with different mycorrhizal fungi.

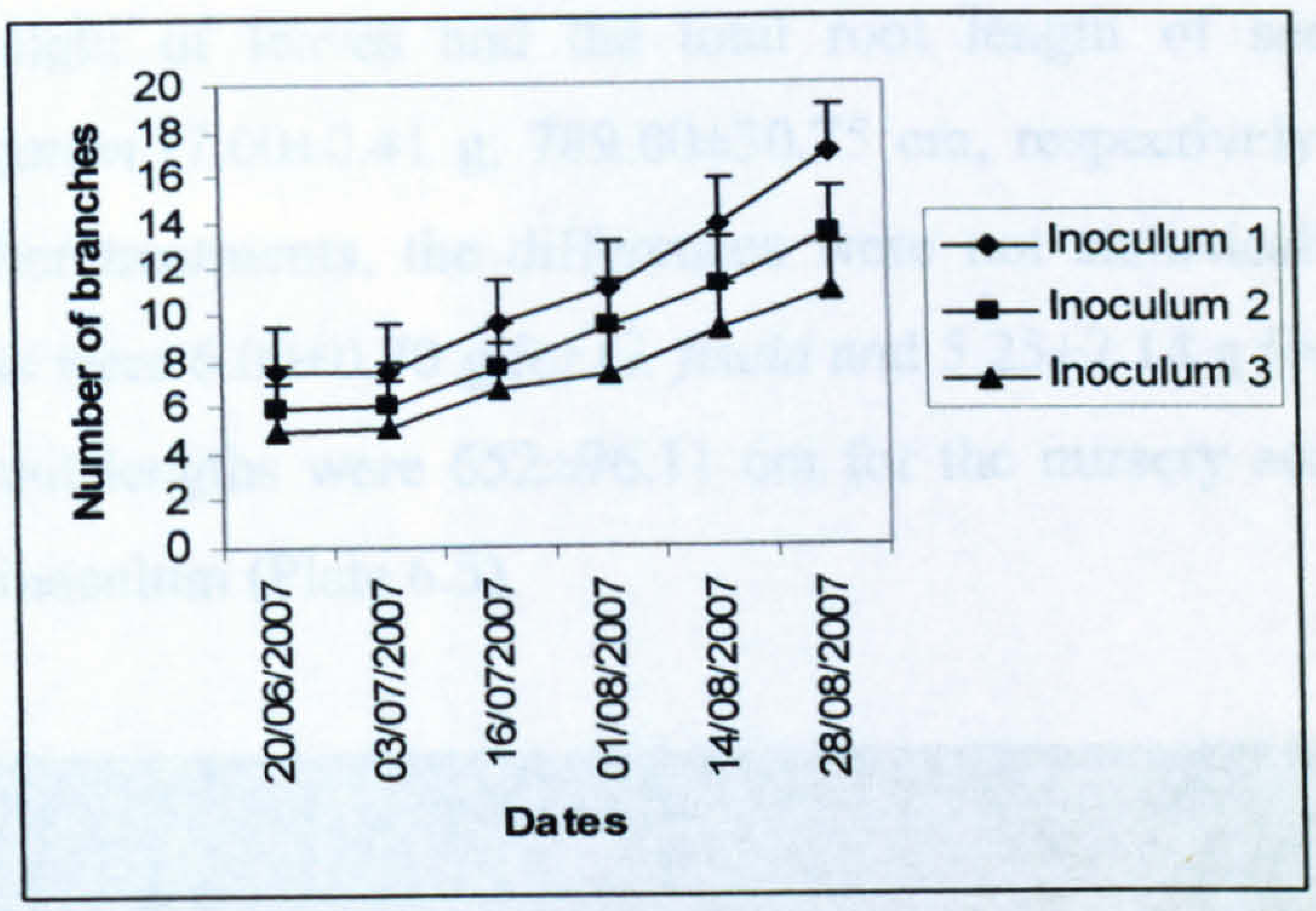


Figure 6.4: Number of branches of *Z. mauritiana* seedlings inoculated with different mycorrhizal fungi.

Plate 6.4: *Z. mauritiana* seedlings inoculated with *G. aggregatum*

The results of the destructive harvest of seedlings six months after sowing (Table 6.1, Plate 6.5) indicated that seedlings inoculated with *G. aggregatum* were significantly taller (64.00±6.92 cm; $P<0.05$) and bigger in diameter (2.2±0.07 cm; $P<0.05$) than those inoculated with *G. fiscia* and the control. Although the number of branches of seedlings inoculated with *G. aggregatum* (64.00±6.92) was higher than that of the other treatments, the difference was not statistically significant. The type of inoculum had a significant effect on shoot dry weight ($P<0.01$) and root dry weight ($P<0.01$) of seedlings. The shoot dry weight (15.37±0.40 g) and root dry weight (5.25±0.25 g) of seedlings inoculated with *Glomus aggregatum* were significantly higher than those inoculated with *G. fiscia* and nursery soil inoculum. However, the shoot and root dry weight of the later two inocula did not differ significantly (Table 6.1). Although the dry weight of leaves and the total root length of seedlings inoculated with *G. aggregatum* (7.00±0.41 g; 789.00±30.75 cm, respectively) were higher than those of the other treatments, the differences were not statistically significant. The leaf dry weights were 6.00±0.70 g for *G. fiscia* and 5.25±2.14 g for nursery soil inoculum. The total root lengths were 652±96.11 cm for the nursery soil and 595±68.78 cm for *G. fiscia* inoculum (Plate 6.5).

Plate 6.5: Roots of *Z. mauritiana* seedlings inoculated with *G. aggregatum*

The number of live spores per 100 g of soil (550.50±18.04) was significantly the highest ($P<0.001$) in soils where seedlings inoculated with *G. aggregatum* were grown. The number of live spores in nursery soil (338.75±19.21) was also significantly higher ($P<0.01$) than that of *G. fiscia* (122.00±10.16) (Table 6.1).

The percentage of mycorrhizal infection was significantly highest ($P<0.05$) in roots of seedlings inoculated with *Glomus aggregatum* (82.64±3.12). The percentage of mycorrhizal infection was also higher in nursery soil treatment (70.14±4.43) than that of *G. fiscia* (68.05±4.17) but the difference was not significant (Table 6.1) (Plates 6.6 & 6.7).

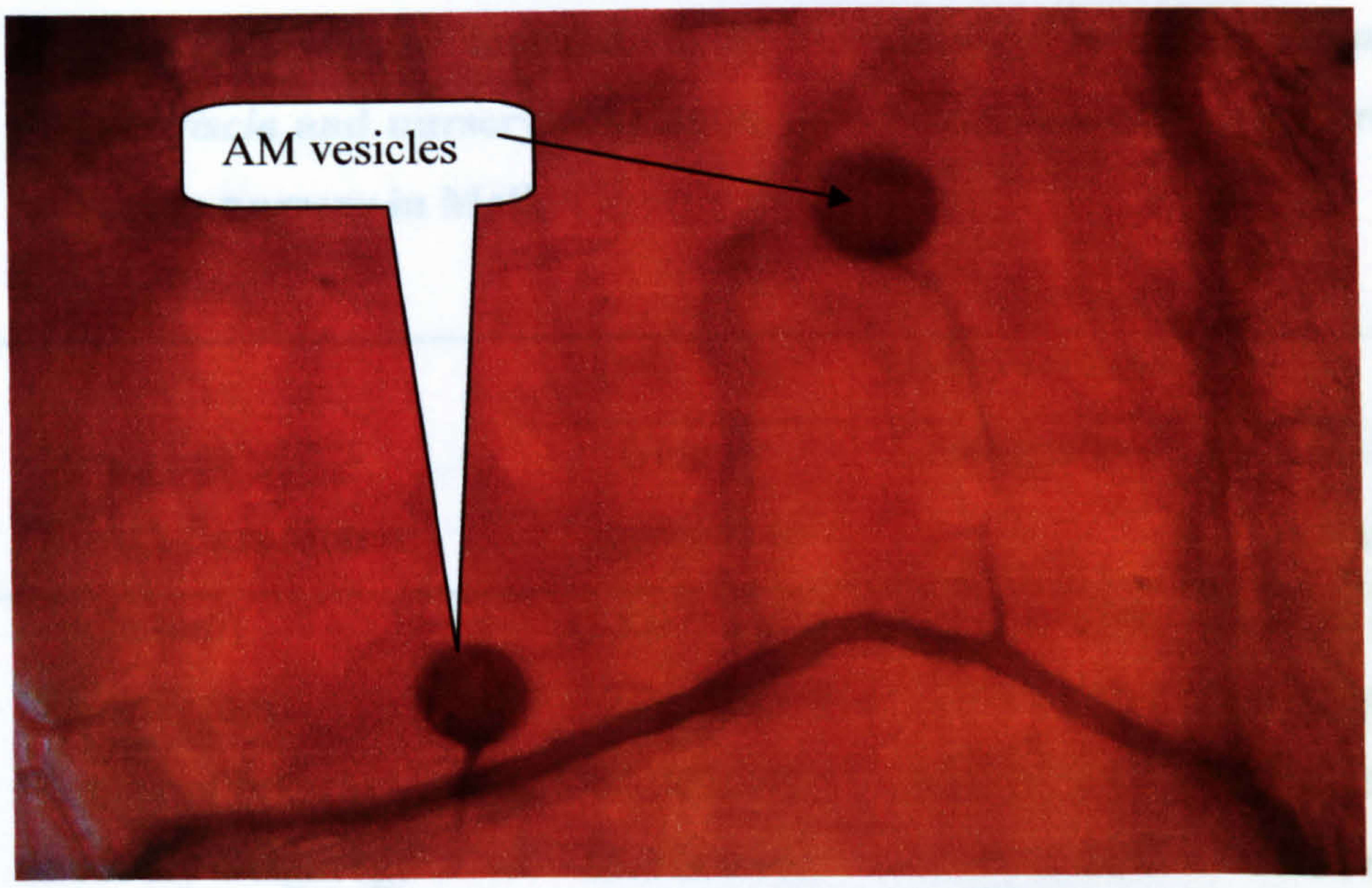


Plate 6.6: Mycorrhizal vesicle in the roots of Ziziphus

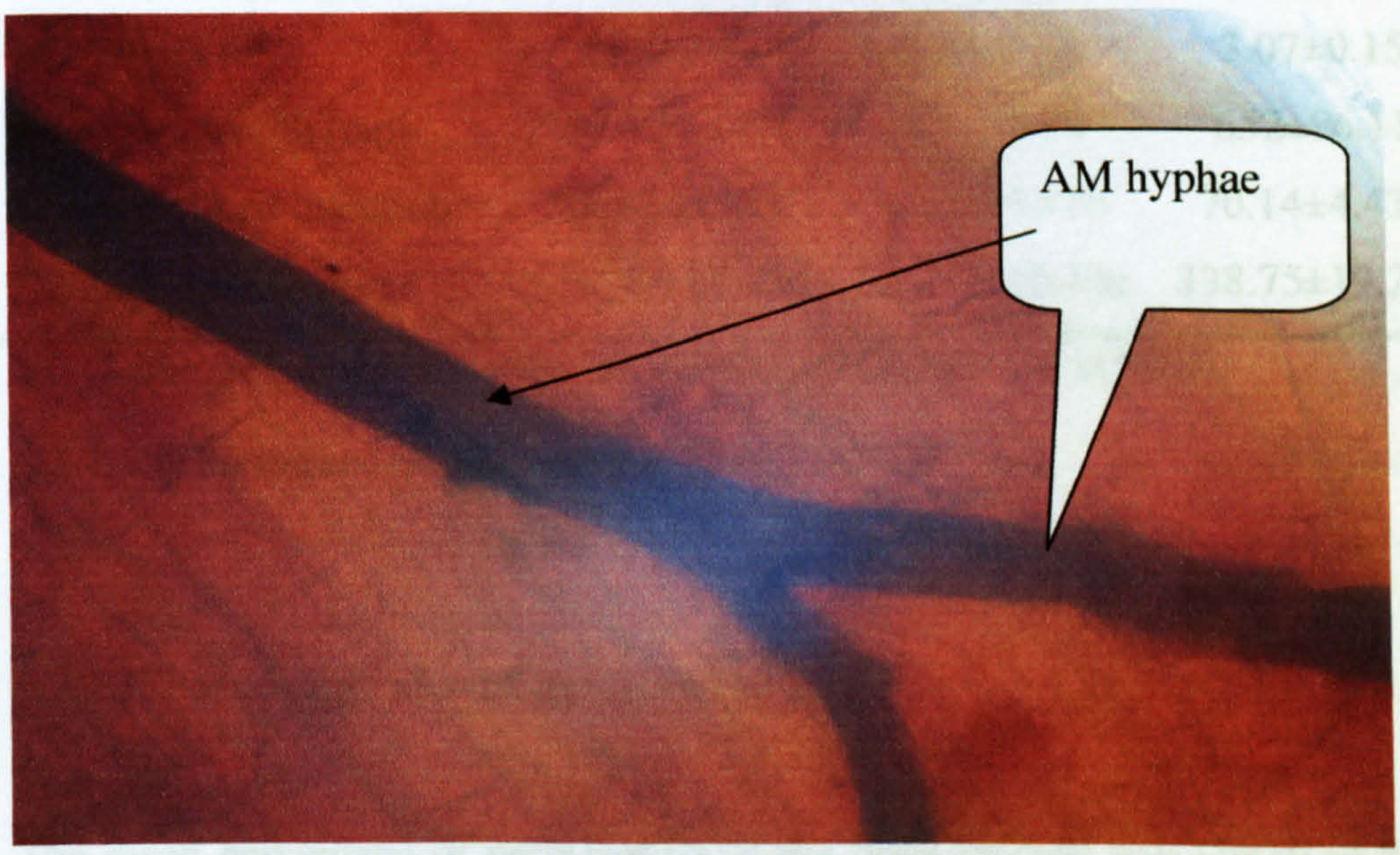


Plate 6.7. Mycorrhizal hyphae in the roots of Ziziphus

Table 6.1: Effect of inoculation with different inocula (*Glomus aggregatum*, *Glomus fiscia* and nursery soil) upon the growth of *Ziziphus mauritiana* after six months in nursery in Mali.

Growth Parameters	Inoculum type *Glomus aggregatum*	*Glomus fiscia*	Control inoculum	F Prob.
Height (cm)	135.07±3.52a	117.85±6.09b	112.67±5.01b	0.02
Diameter (cm)	2.2±0.07a	1.9±0.11b	1.83±0.07b	0.03
Number of branches	64.00±6.92	62.75±10.17	46.25±1.79	N.S.
Shoot dry weight (g)	15.37±0.40a	11.40±0.63b	11.36±1.12b	0.008
Leaf dry weight (g)	7.00±0.41	6.00±0.70	5.25±2.14	N.S.
Root dry weight (g)	5.25±0.25a	3.50±0.29b	3.75±0.49b	0.01
Root/shoot ratio	2.93±0.06	3.30±0.23	3.07±0.15	N.S.
Total root length (cm)	789.00±30.75	595±68.78	652±96.11	N.S.
% mycorrhizal infection	82.64±3.12a	68.05±4.17b	70.14±4.43b	0.02
Number of live spores	550.50±18.04a	122.00±10.16c	338.75±19.21b	0.001

NB : Different letters in the same line are statistically different at $P<0.05$

6.3.2. Performance of *Tamarindus indica*

6.3.2.1. Percentage of seed germination

The mean percentage of germination of the three inocula was (88.03±4.87%) (Figure 6.5).The results indicated that the percentage of germination was higher in the nursery soil inoculum (97.63±1.24%), followed by the *G. aggregatum* inoculum (84.7±2.9%). The germination of *T. indica* took longer time to complete than *Z. mauritiania* but the peak was reached five days after sowing and for *G. aggregatum* inoculum and seven days for *G. fiscia* inoculum. The total length of germination time was 12 days for all the inoculum types.

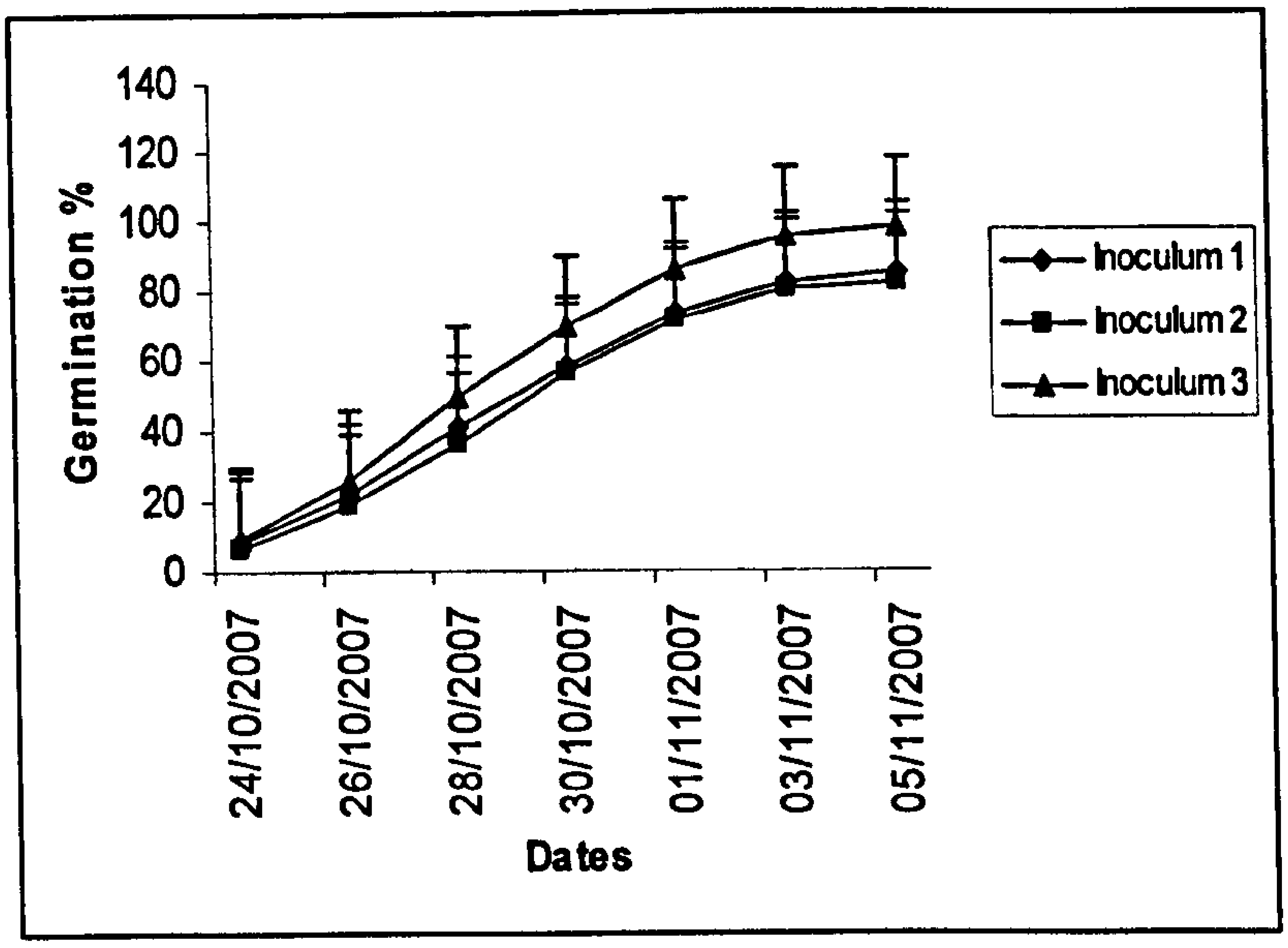


Figure 6.5: Cumulative percentage of germination of *T. indica* seeds soaked in different inocula (*Glomus aggregatum*, *Glomus fiscia* and nursery soil).

6.3.2.2. Growth parameters

The height growth of seedlings treated with inoculum 3 (nursery soil) was higher than those treated with inoculum 1 (*G. aggregatum*) and 2 (*G. fiscia*) (Figure 6.6, Plate 6.8). There were, however, no significant differences in the mean monthly height increments of seedlings between inoculum types, although the mean monthly height increment of seedlings inoculated with nursery soil (0.74±0.0.05 cm) was slightly higher than that of *G. aggregatum* (0.62±0.05 cm) and *G. fiscia* (0.58±0.04 cm).

The diameter of seedlings inoculated with nursery soil inoculum was consistently higher than those of inocula 1 and 2 (Figure 6.7). There were, however, no significant differences in the mean monthly diameter increments of seedlings between inoculum types. The mean monthly diameter increment of seedlings inoculated with nursery soil (0.052±0.00 cm) was slightly higher than that of *G. aggregatum* (0.045±0.00 cm) and *G. fiscia* (0.044±0.00 cm).

Concerning the increase in number of branches, in contrast to height or diameter growth pattern, seedlings inoculated with nursery soil had the lowest number of branches (Figure 6.8). Seedlings inoculated with inoculum 1 and 2 had the same branching pattern and the gap between them closed at the last date of measurement.

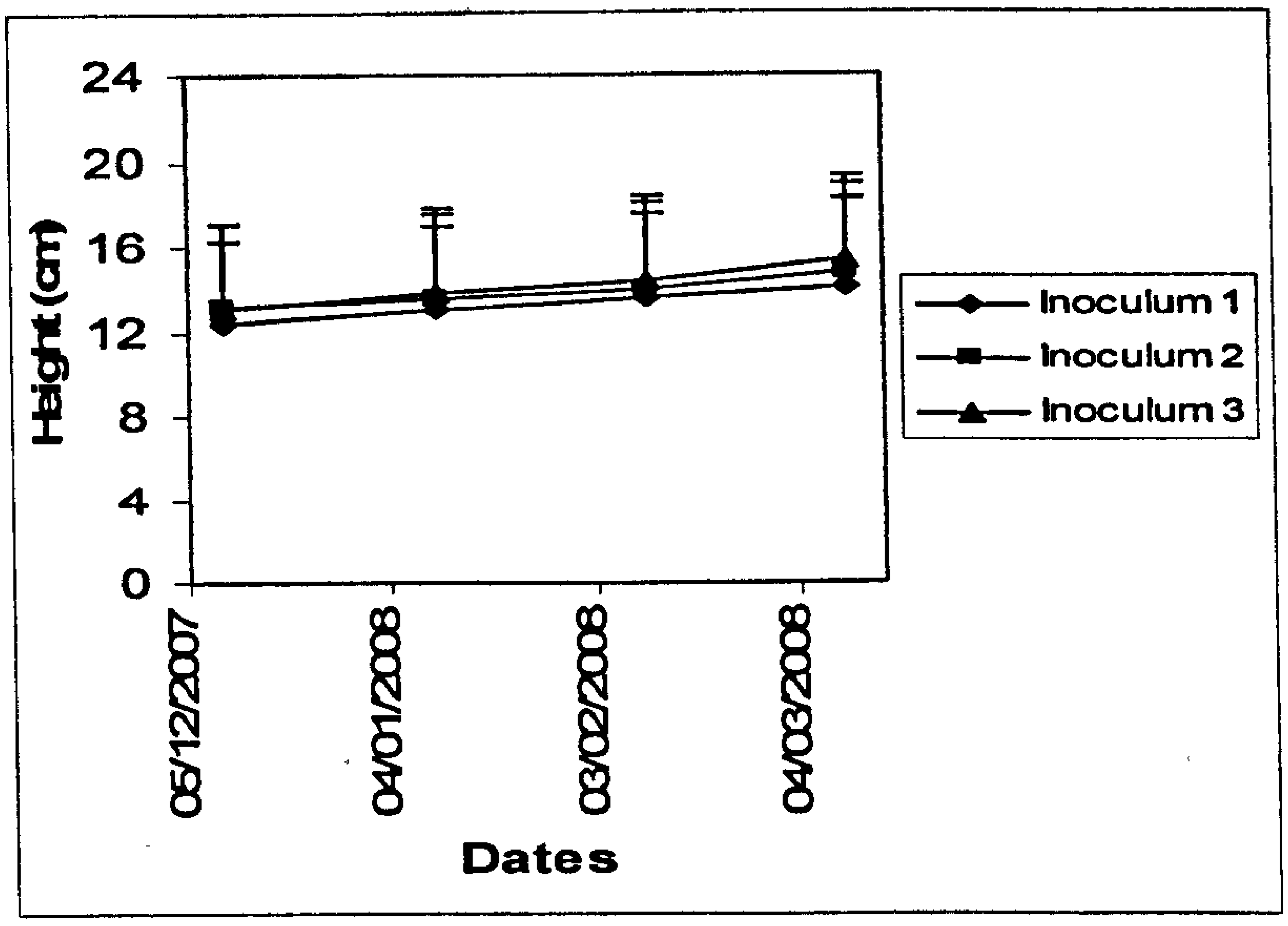


Figure 6.6: Height growth of *T. indica* seedlings inoculated with different mycorrhizal fungi.

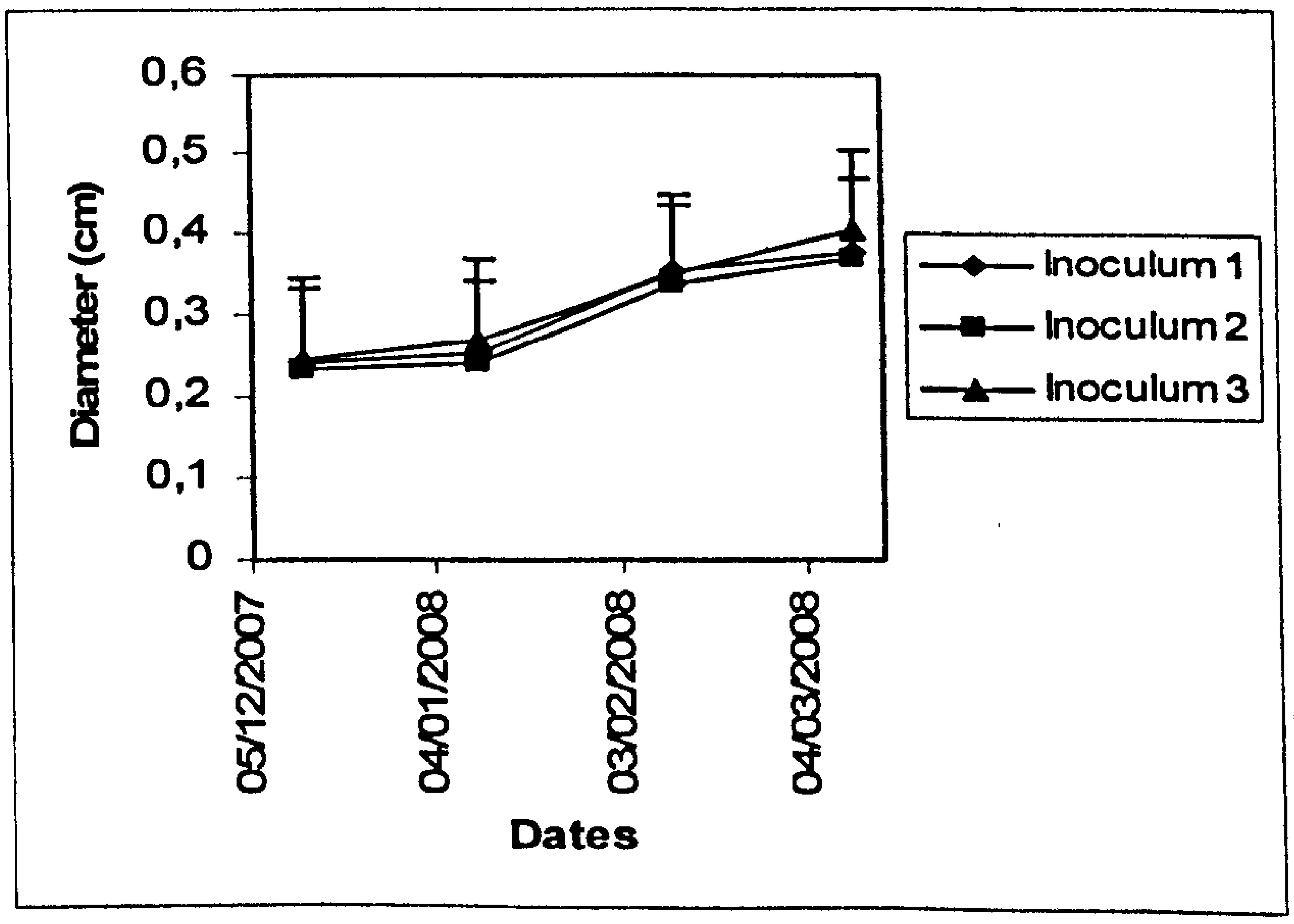


Figure 6.7: Diameter growth of *T.indica* seedlings inoculated with different mycorrhizal fungi in the nursery of IER, Sotuba, Mali.

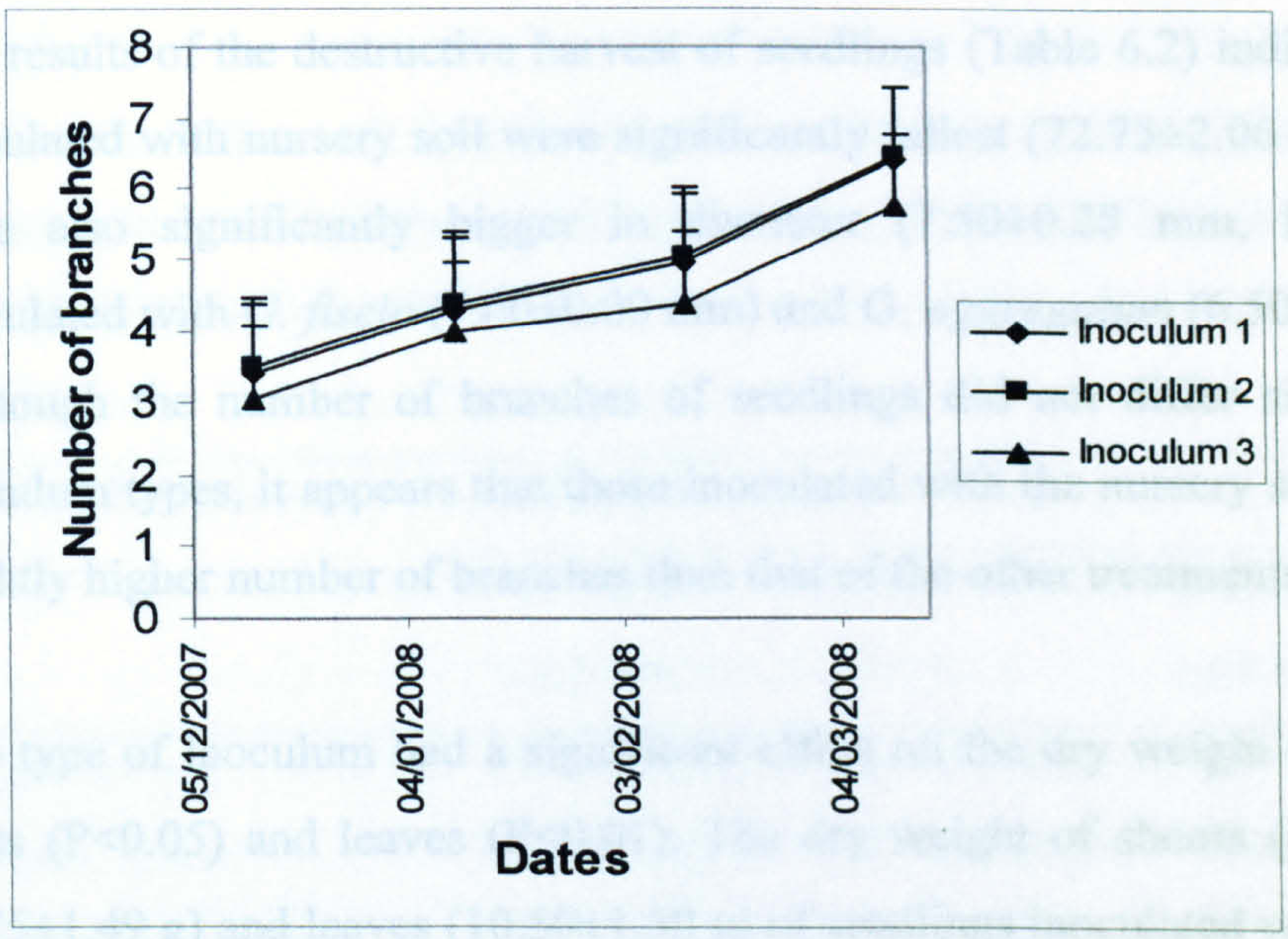


Figure 6.8: Number of branches of *T. indica* seedlings inoculated with different mycorrhizal fungi in the nursery of IER, Sotuba, Mali.

Plate 6.8. *T. indica* seedlings inoculated with nursery soil (control)

The results of the destructive harvest of seedlings (Table 6.2) indicated that seedlings inoculated with nursery soil were significantly tallest (72.75±2.06 cm, $P<0.001$). They were also significantly bigger in diameter (7.50±0.28 mm, $P<0.04$) than those inoculated with *G. fiscia* (7.00±0.00 mm) and G. *aggregatum* (6.50±0.20 mm). Although the number of branches of seedlings did not differ significantly between inoculum types, it appears that those inoculated with the nursery soil (26.75±3.70) had slightly higher number of branches than that of the other treatments (Table 6.2).

The type of inoculum had a significant effect on the dry weight of shoots ($P<0.001$), roots ($P<0.05$) and leaves ($P<0.01$). The dry weight of shoots (12.75±1.89 g), roots (7.75±1.49 g) and leaves (10.50±1.50 g) of seedlings inoculated with nursery soil were significantly higher than those inoculated with *G. fiscia* and *G. aggregatum* (Table 6.2). However, the differences between *G. fiscia* and *G. aggregatum* treatments were not significant.

The type of inoculum had a significant effect on root: shoot ratio ($P<0.01$). Seedlings inoculated with *G. aggregatum* had the highest ratio (1.40±0.10) while those inoculated with nursery soil had the lowest (0.67±0.18). There was, however, no significant effect of type of inoculum on the total length of roots of *T indica* seedlings, although the roots were longer in seedlings inoculated with *G. aggregatum* (6.90±1.47 m) followed by the soil inoculum (6.11±2.76 m) and *G. fiscia* (5.59±1.24 m).

The number of live spores was significantly highest ($P<0.001$) in soils where seedlings inoculated with *G. aggregatum* were grown (204.50±5.17). The number of live spores in nursery soil (111.50±4.29) was in turn significantly higher ($P<0.01$) than that of *G. fiscia* (56.75±0.85). The percentage of mycorrhizal infection was significantly higher ($P<0.001$) in roots of seedlings inoculated with nursery soil (63.19±1.91%). The percentage of mycorrhizal infection was also higher in the *G. aggregatum* treatment (55.63±2.31%) than in the *G. fiscia* treatment (50.69±2.26%) but the difference was not significant (Plate 6.9).

Table 6.2: Effect of inoculation with different inocula (*Glomus aggregatum*, *Glomus fiscia* and nursery soil) upon the growth of *Tamarindus indica* after 10 months in the nursery in Mali.

Growth Parameters	Inoculum type			
	Glomus aggregatum	*Glomus fiscia*	Control inoculum	F Prob
Height (cm)	47.25±1.31b	56.5±3.48b	72.75±2.06a	0.001
Diameter (mm)	6.50±0.20cb	7.00±0.00ab	7.50±0.28a	0.04
Number of branches	21.25± 0.95	22.50±2.17	26.75±3.70	N.S.
Shoot dry weight (g)	3.25±0.25b	4.75±0.49b	12.75±1.89a	0.001
Leaf dry weight (g)	4.00±0.48b	5.50±0.50b	10.50±1.50a	0.002
Root dry weight (g)	4.50±0.29b	3.25±0.25b	7.75±1.49a	0.02
Root/shoot ratio	1.40±0.10a	0.73±0.07b	0.67±0.18b	0.005
Total root length (m)	6.90±1.47	5.59±1.24	6.11±2.76	N.S
% mycorrhizal infection	55.63±2.31b	50.69±2.26b	63.19±1.91a	0.001
Number of live spores	204.50±5.17a	56.75±0.85c	111.50±4.29b	<0.001

NB : Different letters in the same line are statistically different at $P<0.05$

Plate 6.9: Mycorrhizal vesicle and hyphae in the roots of Tamarindus

6.4. Discussion

6.4.1. The performance of *Ziziphus mauritiana* and *Tamarindus indica* seedlings is not affected by mycorrhizal inoculum type

The above hypothesis is rejected because the results of the present study indicated that mycorrhizal inoculation could increase the growth of *Ziziphus mauritiana* seedlings in the nursery. Inoculation with *Glomus aggregatum* resulted in taller, bigger and heavier plants when compared with *Glomus fiscia* and the control. The mean monthly increments in height and diameter of seedlings inoculated with *G. aggregatum* were almost double those inoculated with *G. fiscia* and the control. Seedlings inoculated with *G. aggregatum* had also a higher number of branches than that of *G. fiscia* and the control but were not significantly different. The dry weight of shoots and roots of seedlings inoculated with *G. aggregatum* were also significantly higher than those inoculated with *G. fiscia* and nursery soils. The findings of the present study were in accordance with a study by Bâ *et al.* (2000) who reported that the growth of *Z. mauritiana* was more enhanced by *Glomus aggregatum* than *Glomus intraradices.* Guissou (1996) also reported that *Z. mauritiana* is strongly dependant on mycorrhizas, irrespective of the type of AM.

The monthly increments in height of 24.19 cm and diameter of 0.42 cm indicate that *Z. mauritiana* is a fast growing tree species which was also reported by Ouédraogo *et al.* (2006) and Bâ *et al.* (2000).

In the case of *Tamarindus indica,* however, inoculation of *T. indica* seedlings with nursery soil (the control) resulted in higher rate of seed germination and taller, bigger and heavier plants when compared with those inoculated with *G. aggregatum* and *G. fiscia.* These results indicate that *T. indica* did not respond positively to either of the isolates of AMF. It may be possible that it may respond to other types of inoculum. But according to the results of the present experiment it may be concluded that both *G. aggregatum* and *G. fiscia* did not have effect on the performance of *T. indica.* Thus, the above hypothesis may be accepted in the case of *T. indica.*

Although there appears to be little evidence of plant specificity for a particular VAM species (Huang *et al.*, 1983; Abbott and Robson. 1982), the results of the present study showed that VAM species differ in their ability to enhance plant growth. The growth of *Z. mauritiana* was significantly improved with *G. aggregatum* inoculum while *T. indica* growth was enhanced with nursery soil inoculum.

The mean monthly increments in height of 0.74 cm and diameter of 0.052 cm also indicate that *T. indica* is a much slower growing species than *Z. mauritiania.*

6.4.2. There is no difference in mycorrhizal formation on roots and spores in the soil between the three inocula

The results of the present experiment showed that *Glomus aggregatum* successfully formed better mycorrhizal associations with the roots of *Z. mauritiana* seedlings than *Glomus fiscia* and the control inoculum. The high percentage of infection of 82.6% found in *Z. mauritiana* roots is in close agreement with findings of Bâ *et al.* (2000) and Guissou (1996, 1998).

In the case of *T. indica,* however, the percentage of mycorrhizal infection was significantly higher in roots of seedlings in the control. This means that unselected local soil inoculum is more efficient in forming mycorrhizal associations with the roots of *T. indica* than the other two types of AM isolates. Bagyaraj *et al.* (1989) in a screening experiment on the effect of different inocula on the growth of cultivars of Leuceana found that the best mycorrhizal fungus for the species was a local isolate. The results of the study on *T. indica* suggests the need for isolating the local soil mycorrhizal fungi and including them in future screening experiments in order to select the best mycorrhizal fungus suited for *T. indica.* Similar suggestions were made by Bagyaraj *et al.* (1989) and Munro *et al.* (1999) and Bâ *et al.* (2000). By using a local isolate, the destructive effect of systematic sterilisation of nursery soil (common practice in mycorrhizal studies) while introducing new fungal isolates to the detriment of local species could be avoided. The lower level of mycorrhizal colonisation of the roots of *T. indica* than *Z. mauritiania* in the present study (maximum 63%) confirms the findings of Bâ *et al.* (2000) who stated that *T indica* and ***Parkia biglobosa***, another important agroforestry species are moderately dependant on mycorrhizal symbiosis.

The number of live spores per 100 g of soil was significantly higher in soils where seedlings of *Z. mauritiania* were inoculated with *G. aggregatum* (550.50±18.04). The number of spores found in soils is within the range of spores reported by Munro et al. (1999) and Mukerji and Kapoor (1986). Munro *et al.* (1999) found an average of 295 live spores per 50 g^{-1} soil in *Acacia tortilis* inoculum and 458 live spores per 50 g^{-1} soil in *Prosopis juliflora* inoculum. Mukerji and Kapoor (1986) stated that the number of free spores in the soil varied from 200-300 per 100 g of soil around plant roots. In a study on the effect of VAM inoculation on the number of spores conducted by Bagyaraj *et al.*, (1989) the number of spores varied from 160 to 285 per 25 ml soil in root-zone of Leuceana cultivars. Although spores are not the only infective propagule in the soil inocula, the difference in the number of spores observed may be responsible for the different infection rates on roots. *G. aggregatum* has been also reported (Schenk and Smith, 1982; Koske, 1985) to produce large number of spores which are always found aggregated in the soil and is the reason for its name "*aggregatum*". This may explain why there was larger number of spores in the soil but less infection of *T. indica* roots than that observed in the case of *Z. mauritiana.*

CHAPTER VII:

GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

7.1. General discussion

7.1.1. Local knowledge and practices on utilisation and management of agroforestry parkland systems in Mali: a base line survey

Seventeen (17) tree species were cited by respondents to be present in the parklands in Siramana Village, where the baseline survey was carried out. Similar high diversity of tree species has been reported for parklands in the literature (Samba *et al.*, 2001; Agea *et al.*, 2007; Boffa, 1999). Concerning the most preferred species, the top ranked species by respondents was *V. paradoxa* (Karité) followed by *T. indica* (Tamarind) and *P. biglobosa* (néré). Similar top raking species were reported by Bonkoungou *et al.* (1998) in West Africa, Maghembe *et al.* (1998) in Southern Africa and Teklehaimanot (2008) in Eastern Africa. As found in the present survey, the importance of local and indigenous fruit trees in rural people's diet and income has been widely documented by many previous workers elsewhere (Okafor, 1988; Hall *et al.*, 1997; Teklehaimanot, 2004; 2008; Boffa, 1999; Dhillion and Gustard, 2004). The high soil improvement property of leaves of Karité has been reported by Traoré (2003) and Bayala (2002), while that of *Faiderbia albida* was also reported by several other workers (Charreau and Vidal, 1965; Boffa, 1999; Poshen, 1986; ICRAF, 1996). The most frequently planted trees in parklands were exotic trees. Similar findings were reported by previous workers who found that farmers do not plant indigenous parkland tree species (Gerhardt and Nemarundwe, 2006; Campbell et al., 1998; Boffa, 1999; Teklehaimanot, 2004; Bayala, 2002; Hall *et al.*, 1999; Bonkoungou et, 1998; Ong and Leaky, 1992; Jama et al., 2008). The long juvenile phase was cited by large majority of the respondents as the main disincentive to planting of parkland indigenous species as also reported in the literature (Poschen, 1986; Ong and Leaky, 1999; Boffa, 1999; Gijsbers et al, 1994). Most of the respondents reported that addition of organic matter to the soil through litter fall was one of the positive effects of trees on crops. Similar findings were reported in the literature (Young, 1997; Kater *et al.*, 1992; Bayala *et al.*, 2002; Belsky *et al.*, 1989; Tomlinson *et al.*, 1995; Boffa, 1999; Cissé, 1995). Maintenance of high soil moisture beneath trees and protecting crops against desiccating winds were also mentioned by some respondents as the benefits of trees to crops which were also reported in the literature (Teklehaimanot, 2008; Belsky *et al.*; 1989; Boffa, 1999). According to majority of respondents, tree shade constituted the major negative effect of trees on crops. This finding is also in close agreement with reports in the literature (Kessler, 1992; Kater *et al.*, 1992; Boffa, 1999 and Bayala *et al.*, 2002). But it is worthwile to mention that shade was not unpacked in the present study.

The opinions of farmers were diverse concerning the density of *T. indica* trees on farms. The results given by farmers was not coherent, this is why they are not reported here. However, the general decline of densities of useful trees in parklands is now widely recognized (Bayala 2000; Bayala *et al.*, 2007; Teklehaimanot, 2004; 2008). During group discussions, farmers noted that many traditional spiritual practices that are performed only under Tamarind trees. As suggested by Boffa (1999) and Pearce *et al.*, (1989) non-marketable values, such as, environmental functions, cultural or religious values of parkland trees are difficult to evaluate economically. The opinion of farmers was also diverse concerning the compensation of loss of crop yield by tree products. The fact that this aspect was not investigated deeply constitutes one of the limits of the present study. Boffa (1999) concluded that tree products compensated by far their negative effect on associated crops. Women seemed to agree that *T. indica* fruits can compensate the crop loss under the tree. Women were reported to be the main actors involved in the exploitation of *T. indica* fruits. This finding is in close agreement with previous findings by Schreckenberg *et al.*, (2006); Boffa (1999); Jama *et al.*, (2008) and Swai (2005). Data were not dissagregated for gender discuss because gender issue came out as a result of the survey. The survey was not gendered. The fact that a majority of respondents preferred Tamarind- eggplant association than Tamarind- sorghum highlighted the use of shade-tolerant crops by farmers in parklands. Similar findings were also reported by previous workers (Kessler, 1992; Kater *et al.*, 1992; Teklehaimanot, 1997; Holmes, 1993). The main reasons cited by respondents for the preference Tamarind- eggplant are: more productive use of land under trees; increasing farmers' incomes by selling the fruit and leaves of eggplant;

income diversification and having the stapple food (sorghum or maize in open field) and sauce (eggplant under trees) on the same land. Respondents reported that the yield of sorghum was suppressed under trees.

Cutting was the most common management practice applied to Ziziphus (Ber) by farmers. The tree has an enormous capacity of regeneration probably due to its strongly developed root system (Maydell, 1990). Ziziphus is a drought-resistant species and therefore regenerates profusely in arid environments (Teklehaimanot, 2008). Micro-site improvement was quoted by some of the respondents as the beneficial ecological services of Ziziphus. Bâ *et al.* (2000), Guissou *et al.* (1996) and Ouédraogo *et al.* (2006) reported that Ber depends heavily on mycorrhizas. Mathur and Vyas (2000) also reported that *Z. mauritiana* has high dependency on mycorrhizas under water stress conditions. This could be a possible reason for soil fertility improvement in its surrounding and for its high resilience in drylands. It was pointed out by respondents that Ziziphus has a high medicinal value which is in agreement with reports of Maydell (1990) and Kalinganire *et al.* (2008) and can be used as insecticide (Cissé, 2004; Lehman *et al.*, 2007).

Crops cited by farmers as shade-tolerant crops included eggplant, pepper, potato, cassava, yam, okra and onion, while millet, maize, sorghum and peanut were cited as shade- intolerant species. The use of shade-tolerant crops by farmers in parklands has been reported by many previous workers (Kessler, 1992; Kater *et al.*, 1992, Teklehaimanot, 1997; Boffa, 1999). Among shade-intolerant crops grown in parklands, sorghum was cited as the main crop grown by majority of respondents. The main motivations for growing sorghum were household consumption and selling. Sorghum plays a significant role also in socio-cultural aspects of the lives of the local people as also reported by Kudadjie et al. (2004). Many varieties of sorghum were reported to exist in the village. Chakanda (2000) found that in Mali the origin and the function are important criteria in naming sorghum varieties. Seeds required for the following cropping season are generally stored in kitchens over smokes. Similar seed storage system was reported by Alvarez *et al.*, (2005) in Cameroon. The adaptation of sorghum to poor soils was well known among farmers. FA0 (1995) reported that sorghum and millet grow in harsh environments where other crops do not grow well. They are grown with limited water resources and usually without application of fertilisers or other inputs by a multitude of small-holder farmers in many countries (FAO, 1995). All the respondents reported that the shade of trees has a negative effect on sorghum yield. Kessler (1992), Kater (1992), Bayala, (2002) and Boffa (1999) reported similar findings. A majority of the farmers applied organic manuring in order to cultivate sorghum but some of them reported that they did not practice any fertilization for sorghum cultivation. The same feature of local farming system was reported in Burkina Faso by Boffa (1999) and in Ghana by Kudadjie *et al.*, (2004). According to the respondents, granaries are traditional efficient means to store sorghum. Most of respondents reported that sorghum is rich in vitamins but they could not name the vitamins. Sorghum and millets are rich in minerals, particularly iron, zinc and B vitamins (Hulse *et al.*, 1980). However, these nutrients are concentrated in the pericarp, which is removed by decortications resulting in deficiency in the flour (Hulse *et al.*, 1980, Pederson and Eggum, 1983). The main constraint to sorghum production according to respondents was insufficient and unreliable rainfall. The rainfall as a major constraint to crop production in West Africa was reported by many previous workers (Day *et al.*, 1992; Sultan *et al.*, 2005; Sultan et *al.*, 2003; Breman *et al.*, 2001; Kudadjie *et al.*, 2004). Sorghum yields reported by respondents from 500 to 1500 kg ha^{-1} were in close agreement with data found in the literature (Mendesil *et al.*, 2007; FAO, 1997; Kouressy *et al.*, 2008; Breman *et al.*, 2001).

Household consumption and selling were reported to be the main motivations for growing African eggplant. The majority of the respondents reported that eggplant is grown in home gardens. This finding is in close agreement with findings of Midmore *et al.* (1991) and Rubaihayo (2002). The traditional form of seed storage reported by farmers is air-drying of intact fruit containing seeds. This is in agreement with reports by Lester and Seck (2004). According to respondents, techniques of growing eggplant were transmitted from father to son. Such transmissions of local knowledge from elders to youth or through friendships or social relations were also reported by Somnasang *et al.* (1998). The use of organic manure to fertilize eggplant was for many of the farmers a tradition. Similar findings were reported by Rubaihayo (2002) and Lester and Seck (2004). It is important to mention that cow dung is not yet used for fire lighting in the study area. There is no firewood crisis in the village surveyed and there is no scarcity of manure. Many of the respondents reported that eggplant cannot be stored. This finding is in agreement with findings of Lester and Seck (2004). The only nutritional value of eggplant cited by farmers was vitamins. FARM-Africa (2006) reported that eggplant is an excellent source of Vitamins A and C, as well as iron, protein, minerals and fibre. Rainfall in the Sahel is unpredictable and erratic and constitutes a big constraint to eggplant production in West Africa (Sultan et al., 2005; Sultan et al., 2003; Day et al., 1992). The gendered division of tasks in households was perceived in the group discussions. Similar findings were reported by many workers (Boserup, 1970; Carr, 2008, Alvarez *et al.*, 2005, FARM-Africa, 2006). Yields of eggplant reported by respondents from 2 to 4 tons ha^{-1} were lower than that mentioned by Leister and Seck (2004) who stated that without irrigation, yields are 5–8 tons ha^{-1}. The quality thresholds for crops were not investigated in this study. The determination of crop quality threshold is very important but very difficult to evaluate in farmers survey since the concept is very relative. The lack of scientific data on the quality threshold of these crops affects considerably our documentation.

The choice of *Tamarindus indica* and *Ziziphus mauritiana* in the present study was based on the fact that both species have not yet been subjects of many scientific studies in the region. The results of this baseline survey also proved that *Tamarindus indica* and *Ziziphus mauritiana* were among the top ranked species in the study area. Thus, it was decided to use the two tree species for the tree-crop interactions studies. Earlier research on parkland trees was concentrated on *Faidherbia albida* because of the positive effect of this species on soil fertility and also because of its reverse phenology (Depommier, 1996, Bayala, 2002). Recently, *Vitellaria parodoxa* and *Parkia biglobosa* received many attentions by the research and development communities (Teklehaimanot, 1997; 2004; Bayala, 2002, 2006, 2009; Kater *et al.*, 1992, Traoré, 2003; Kessler, 1992). Therefore, it was found necessary to extend research attention on other useful parkland tree species such as *Tamarindus indica* and *Ziziphus mauritiana* which are of prime importance to farmers in the region. The choice of sorghum is based on the fact that this crop constitutes one of the main staple food crops in the village and it is highly appreciated by farmers. Eggplant was also chosen due to the fact that this crop was identified by farmers as one of the best shade-tolerant species which can be grown under both trees.

7.1.2. The effect of *Tamarindus indica* on the performance of associated shade-tolerant and shade-intolerant crops

In accordance with findings of the present study, the hypothesis stating that the performance of sorghum is not affected by *Tamarindus indica* tree crown was rejected. Tamarind had significant negative effect on sorghum grain yield because the yield in zone A, close to the tree trunk, was consistently the least yield under all trees as well as the yield in zone B was significantly lower than the control. In zone C, however, grain yield and biomass were higher than the control (1% and 7%, respectively). The relative yields of intercrop to sole crop using the arithmetic average were 57% in 2007 and 73% in 2008. The relative yields of intercrop to sole crop using the average weighted by zone area were 86% in 2007 and 94% in 2008. The relative yield of intercrop to sole crop using the average weighted by zone area over the two years was 90%. This indicates that only 10% was the reduction of sorghum yield under Tamarind. The relative yield of intercrop to sole crop using the average weighted by zone area should be used by interculture researchers since it is more realistic and convenient for expressing any yield advantage. Newman (1985) stated that one of the limitations to reseach on intercropping is the lack of published information on any yield advantage obtained from growing crops as mixtures. This statement holds true at present.

The mean yield reduction of 35%, taking into account all the three zones under Tamarind, was not as bad as the reduction of 50% and 70% in sorghum yield reported by Bayala *et al.* (2002) in Burkina Faso under karité (*Vitellaria paradoxa*) and néré (*Parkia biglobosa*) trees, respectively. Kater *et al.* (1992) also reported a yield reduction of 60% under canopies of both species in southern Mali. The results of Bayala *et al.*, (2002) and Kater et *al.*, (1992), however, corroborate the findings of the present study that Tamarind, compared to the above two common tree species of parklands, caused a moderate reduction in sorghum production due to perhaps a reduction in light availability under trees as also reported for the other trees of parklands by Bayala *et al.* (2002) and Kater *et al.* (1992).

The yield of sorghum in zone C (743.6±47.9 kg ha^{-1}) and the control plot (739±28.1 kg ha^{-1}) were in close agreement with the values reported in the literature. Ratnadass *et* *al.*, (2007) reported that the average sorghum grain yield in Mali was 700 kg ha^{-1}. FA0 (2001) also estimated the average yield of sorghum in Africa to be 800 kg ha^{-1}. Mendesil *et al.*, (2007) reported that the average sorghum yield in south-western Ethiopia was 810 Kg ha^{-1}. According to Breman *et al.*, (2001) the yield of sorghum in Mali was fluctuating between 500 and 800 kg ha^{-1}. The values of dry matter of sorghum in zone C (3243±219 kg ha^{-1}) and the control plot (3059±100 kg ha^{-1}) of the present study were also very close to the value of 3659±657 kg ha^{-1} $year^{-1}$ reported by Bayala *et al.* (2002).

The ecological ability of trees to combine with a given crop is species-specific, and is a characteristic related to branching pattern and root architecture of the trees (Boffa, 1999). Sorghum yield is generally reduced more under *Parkia biglobosa* than *Vitellaria paradoxa* (Kessler, 1992; Kater *et al.*, 1992). Similarly the drastic reduction of crop yield in zone A under Tamarind (adjacent to tree trunk) in the present study could also be explained by the characteristics of *Tamarindus indica*. In fact, *Tamarindus indica* has a low branching pattern and a very dense fine root system in the vicinity of the tree as described by DANIDA (2000) and also shown by the result of RLD of the present study.

The hypothesis stating that the performance of African eggplant is not affected by *Tamarindus indica* tree crown was also rejected based on the findings of the present study. Fruit yield reduction was very high in zone A where a reduction of 65% was observed. A similar drastic reduction was observed for the above ground dry biomass (67%). However, an increase in eggplant fruit yield of 38 % and 62% in zone B and C respectively and an increase in eggplant aboveground dry biomass of 83% in zone C were recorded in 2007. The relative eggplant yields of intercrop to sole crop using the arithmetic average were 120% in 2007 and 37% in 2008. The relative yields of intercrop to sole crop using the average weighted by zone area were 151% in 2007 and 51% in 2008. The relative yield of intercrop to sole crop using the average weighted by zone area over the two years was 101%. This indicates that in overall 1% was the increase of eggplant yield under Tamarind. When you extrapolate this result at a larger scale you will find out that some yield advantage could be gained by intercropping Tamarind and eggplant. The significant reduction of eggplant fruit yield in 2008 could be explained by the fact the rainy season lasted shorter in 2008 than in 2007 and the distribution of rainfall was also better in 2007. This means eggplant had to be harvested about one month earlier in 2008 due to lack of rain. So, eggplant in 2008 did not have sufficient length of period for fructification to achieve maximum production. Overall, the reduction of eggplant yield under Tamarind was much less than the reduction of sorghum yield. The significant reduction of yield and biomass of eggplant in zone A could be attributed to competition for moisture and nutrients between Tamarind and eggplant roots. Based on these results, it may be concluded that, despite the reduction in zone A, Tamarind could potentially increase the yield of eggplant when grown under zone B and C when compared with the area outside tree crown. This suggests that eggplant yield could benefit from the presence of mature tamarind trees and that further research is required in order to elucidate potential mechanisms. Eggplant production in the present study was not successful under tree number 4 essentially due to the termite mounds that were built under this tree after the experiment was set up. Nkansah (2000), based on a greenhouse study, concluded that high temperatures enhanced eggplant vegetative growth but suppressed reproductive activity such as flowering and fruiting, resulting in lower yield. This may explain why in the present study there was higher yield of eggplant under tree crown which could be due to the possible reduction in ambient temperature under trees. The fact that eggplants are produced by smallholder farmers in home gardens makes it difficult to obtain reliable statistical data on production for comparison with the results of the present study. But, the few available data indicate that the yields of the present study were much lower than the values reported in the literature. However if the yields in zone B and C under Tamarind under normal rainfall regime as in 2007 (5018 ± 390, 5898 ± 443 kg ha^{-1}, respectively) are considered, they are in close agreement with the values reported by Lester and Seck (2004) who found eggplant yields of 5-8 t ha^{-1} under rainfed condition in West Africa. Higher yield values are reported by Rubaihayo (1994) and Horna and Gruère (2006).

Tree could benefit from the agricultural practices needed to grow eggplant such as manuring and weeding which could improve soil fertility and soil moisture content under the tree crown.

Understory crop density can be manipulated under trees to reduce yield depression by choosing an appropriate crop density. This could be done by designing a trial with different spacings between crops. The objective will be to find out an appropriate spacing where there is no competition between individual plants. Spacing should not be also too wide to decrease crop density which will consequently reduce the yield.

According to the results of the present study, the hypothesis stating that the nutritive composition of associated crops is not affected by *T. indica* was accepted. The results of the present study showed that *T. indica* shade did not have significant effect on most of the nutrient contents of sorghum and eggplant, with exception of Mg and Mn. As expected the nutritional composition of sorghum and eggplant differed significantly. The nutrient content of eggplant was significantly higher than sorghum for the following nutrients: protein, fibre, ash, nitrogen, potassium, sodium, calcium, manganese and Fe. Sorghum was richer than eggplant only in fat and carbohydrate content. All the proximate components found in the present study for sorghum with the exception of carbohydrate are within the range reported by Hulse *et al.* (1980), Pedersen and Eggum (1983), Khalil *et al.*, (1984). The result on phosphorus content of the present study (5.06±0.53 mg g-1) was very close to that of Pedersen and Eggum (1983), who found 4 mg g^{-1}. Barikmo et al., 2004, 2007 found considerable differences in nutrient content for sorghum between geographical regions in Mali. Kulp *et al.*, (2000) also concluded that the composition of sorghum varied significantly according to genetic and environmental conditions. The proximate composition of eggplant found in the present study was higher than those reported in the literature (Grubben *et al.*, 2004; AVRDC, 2002; USDA, 2005). The mineral contents of eggplant in the present study were lower than those reported by Grubben et al., (2004) and Norman (1992). However, the results of mineral contents of the present study were higher than the values reported by Lawande and Chavan (1998). Again these variations could be due to different cultivars of eggplant analysed by previous workers.

Based on the findings of the present study, the hypothesis stating that there is no competition for nutrients and water between the roots of *T. indica* and the associated crops was rejected. There was very high competition for resources between Tamarind and the two crops because Tamarind had significantly higher root length densities (RLDs) in all concentric zones and soil depths than sorghum and eggplant. This means Tamarind had a very high competitive advantage over the two crops. The highest RLD of Tamarind was in zone A (0.38±0.04 cm cm^{-3}) and this may explain the high reduction of crop yield observed for both sorghum and eggplant in this zone. The reduction in yield in zone A indicates the existence of a high competition for nutrients and water. This result is in close agreement with the findings of Bayala *et al.*, (2004); Tomlisson *et al.*, (1998) and Odhiambo *et al.*, (2001). The fact that highest RLD was also found in upper layer in zone A confirms the existence of superficial extensive root distribution in Tamarind and high competition between Tamarind and the two crops for nutrient and water. This result is also in accordance with the finding of Kater *et al.* (1992), Lehmann *et al.* (1998), Schroth *et al.*, (1995), Das and Chaturvedi (2008). In contrast to RLD of Tamarind, the highest RLD of sorghum was observed in zone C, away from the tree trunk. This result reinforces the finding of the present study where sorghum yield and biomass increased with an increase in distance from the tree trunk. This result also corroborates the finding of Odhiambo *et al.* (2001) who observed a decrease of tree RLD with increasing distance from tree and an increase of crop RLD with increasing distance from the tree trunk. Significant difference was also found in RLD of sorghum and eggplant between soil depths. The results of RLD of both crops indicated that the maximum roots were found in the upper layer 0-10 cm of soil. About 70% of eggplant RLD was situated in the upper 0-10 cm layer. This showed that there was an overlapping of niche between the roots of *T. indica* and the crops (eggplant and sorghum). The fact that RLD of *T. indica* and both crops decreased with increasing depth may be due to a better water recharge and relatively good amount of nutrients in the upper layer of soil as explained by several authors (Pandey *et al.* 2000; Bayala *et al.*, 2002; 2004; Gupta *et al.*, 2008).

The hypothesis stating that there is no correlation between Tamarind roots and crop yield and nutritional composition was also rejected. The results of Pearson's correlation analysis showed that crop production was directly related to tree RLD. The fact that the production of both crops (eggplant and sorghum) was negatively correlated with *T. indica* RLD reinforces the suggestion that bellow ground competition existed between crops and tree roots (Bayala *et al.*, 2004; Lehmann *et al.*, 1998; Ong *et al.*, 2002). There were a significant positive relationship between roots of *T. indica* and protein and N contents of sorghum and between RLD of Tamarind and eggplant fibre content. The positive correlation between eggplant fibre content and Tamarind RLD was expected because RLD of Tamarind and eggplant yield were higher under trees than outside the tree crown. Higher yield of eggplant means proportionally higher fibre content. The positive relationship between sorghum protein content and Tamarind RLD may just be an artefact. Protein and N are positively related because the value of protein is derived from the value of N.

Based on the findings of the present study, the hypothesis stating that there is no correlation between soil properties and crop yield and nutritional composition was also rejected because significant correlations were found between soil properties and the performance of both crops. The reports in the literature are, however, contrary to the finding of the present study (Vrindts *et al.*, 2003; Ha-Lin Zhao *et al.*, 2007; Di Virgilio *et al.*, 2007). It is worthwhile to note that except the study of Asadu *et al.*, 2002, all the others studies were performed in completely different climatic zones.

The results of the survey concerning farmers' feedback on the experiment showed that growing eggplants under Tamarind has a great potential for adoption by farmers in Mali. The majority of respondents mentioned that the tree-crop association tested in the present project was a good idea and should be promoted for making more productive use of land under trees, improving crop yields and increasing farmers' incomes. The fact that the majority of the respondents mentioned that increased income and income diversification were the main advantages of the method highlights farmers interest in the tested method. Most of the constraints mentioned by respondents are due to the low income of farmers who cannot afford to invest in any of the required inputs to the tested systems. However, most of the inputs that respondents mentioned as constraints are not really needed. For example, fencing is not needed as the crops are grown in the open parklands like any other crops. Commercial fertilisers are also not needed because simple manuring, which is already a culture in the area, could suffice. As reported by Midmore *et al.*, (1991) and Rubaihayo, (2002) vegetables including eggplants can be produced cheaply using compost rather than commercial fertilizers.

At present, vegetables are gown in the study area by women in home gardens. The role of gender in agricultural production systems have been reported by several previous workers (Boserup, 1970; Carr, 2008; Rubaihayo, 1994). Rubaihayo (2002) reported that in Uganda, even though rural women are responsible for feeding the family, they have limited access to resources. This also holds true in the context of the present study because all trees are situated in men's crop fields and they are owned by them. Since women, who are the beneficiaries of the tested method, do not own the trees, they have to negotiate with men to be able to cultivate eggplants under trees. Extension workers may play a significant role in farmer's sensitization about this possible risk of misunderstanding in the family. The role of extension services in promoting new innovations has been mentioned by several previous workers (Okorio *et al.*, 2004; Bayala, 2002).

7.1.3. Domestication of improved cultivar of *Ziziphus mauritiana* on farm in association with food crops in agroforestry parkland systems in Mali

According to the findings of the present study, the hypothesis stating that there is no difference in performance between the local and improved varieties of *Z. mauritiana* was rejected. During the initial measurement dates, the growth parameters (diameter and height) of local Ziziphus were higher than that of the improved variety. At the last measurement date, there were, however, no significant differences in height, diameter and numbers of branches between the two varieties of Ziziphus. This was due to the significantly faster increment rate in height and diameter growth of the improved variety. The low survival rate and slow growth rate of the improved Ziziphus observed during the first date of measurement may be due to the shocking effect of grafting on the seedling rootstock. The terminal growth of the seedling rootstock was interrupted as a result of grafting and the growth of the scion began after the union between the seedlings' rootstock and the scion cambium was well-established and acclimatised which may have taken several weeks. Once established and acclimatised, scions of the Ziziphus cultivar SEB have been reported to grow faster than the local variety by several workers as also observed in the present experiment (Ouédraogo *et al.*, 2006; Cao *et al.*, 1999). The number of fruits per tree of the local variety was significantly higher than that of improved variety. This may also be due to the initial shocking effect of grafting on the rootstock. In contrast to the fruit number, the mean fruit weight of the improved variety was significantly higher than that of the local variety. The mean weight per fruit recorded on the improved variety in the present study (13.5 g) is well within the range of values reported by Chovatia (1993), Lal (2001), Vashistha (2001), Mukherjee (2004) and Ouedraogo *et al.* (2006) (4.6 – 33 g per fruit). The mean fruit production of the improved variety of 851±427 kg ha^{-1}, which was significantly higher than that of the local one (95±41.7 kg ha^{-1}), was also slightly lower than that of Ouédraogo *et al.* (2006). The difference could be attributed to the fact that irrigation and fertilisation were applied in their study but not in the present study.

The hypothesis stating that the performance of *Z. mauritiana* varieties is not affected by associated crops was accepted. Associated crops had no significant effect on survival rate, height and diameter growth and number of branches of the improved and local varieties of Ziziphus. However, the high production of fruits, when trees were associated with eggplant, shows that eggplant may have less competitive effect on trees than sorghum. The higher production in the 4 x 4 tree spacing is more attractive to farmers since they will gain in space and production. High spacing is used in tree-crop interaction experiment and also in tree plantation to minimize competition. It will be good to monitor this trial for a prolonged time (5 to 6 years) to see if tree crown will close and induce competition in the long term.

The hypothesis stating that the growth and yield of associated crops are not affected by *Z. mauritiana* varieties was accepted because the variety of Ziziphus had no significant effect on yield or aboveground biomass of sorghum. The average yield of sorghum over the two years of 770.00±53.93 kg ha^{-1} was in very close agreement with the average yield of sorghum in Africa of 800 kg ha^{-1} reported by FA0 (2001) and Bayala (2002). The fact that sorghum yield in some of the treatments in the present study was higher than the mean yield of 700 kg ha-1 (Ratnadass *et al.*, 2007) reported for Mali, suggests that Ziziphus trees had a positive influence on sorghum performance through probably soil and microclimate improvements. Ziziphus has been reported to improve soil and microclimate by several researchers (von Carlowitz, 1985). The very high mycorrhizal status of Ziziphus has also been reported by Bâ *et al.* (2000) and Ouédraogo *et al.* (2006) that may have improved the soil's phosphorous content which has been reported to be a major limiting factor for crop production and particularly the productivity of Ziziphus in dry lands (Pareek, 2001; Ouédraogo *et al.* 2006).
In the case of eggplants, however, there was a borderline effect of variety on yield of eggplant. The highest yield was observed for the local variety. This shows that eggplant is indeed shade-tolerant because the local variety of Ziziphus was taller in height than the improved variety. As a result, the local variety may have casted more shade which improved the production of the eggplant. The average yield of eggplant of

5.7 t ha^{-1} over the two years was within the range of 5–8 t ha^{-1} reported by Lester and Seck (2004).

Spacing between trees had a significant effect on sorghum yield and above ground biomass. The highest yield and biomass were achieved in the 6 x 6 m spacing of local variety. Spacing had also significant effect on eggplant yield and biomass. But contrary to sorghum, the highest yield and biomass of eggplant were obtained in the 4 x 4 m spacing. These results reinforce the fact that eggplant is more shade tolerant than sorghum. Comparatively, the intercropping study done by Raddad and Luukkanen (2007) in 4 years old agroforestry system showed that sorghum and sesame yields were not influenced by *A. senegal* tree density.

The hypothesis stating that the nutritional composition of associated crops is not affected by *Z. mauritiana* was also accepted because neither varieties of Ziziphus nor the spacing between trees had any effect on the nutritional composition of sorghum and eggplant. However, there were significant differences in nutrient composition between sorghum and eggplant as expected. Eggplant was richer than sorghum in protein, fibre, ash, nitrogen, potassium, sodium, calcium and manganese whereas sorghum was richer than eggplant in fat, carbohydrate and phosphorus. Such differences in nutritional composition between cereals and vegetable crops have been reported by previous workers (Boukari *et al.*, 2001; Rubaihayo, 2002). The proximate and the mineral content of sorghum and eggplant were discussed in section 7.1.2 in this chapter.

7.1.4. The use of mycorrhizal inoculation in the domestication of *Ziziphus mauritiana* and *Tamarindus indica*

The hypothesis stating that the performance of *Ziziphus mauritiana* and *Tamarindus indica* seedlings is not affected by mycorrhizal inoculum type was rejected in the case of Ziziphus but accepted in the case of Tamarind.

Inoculation of *Ziziphus mauritiana* seedlings with *Glomus aggregatum* resulted in taller, bigger and heavier plants when compared with *Glomus fiscia* and the control. The mean monthly increments in height and diameter of seedlings inoculated with *G.*

aggregatum were almost double to those inoculated with *G. fiscia* and the control. The findings of the present study were in accordance with a study by Bâ *et al.* (2000); Guissou (1996); Guissou *et al.*, (1998). The observation of the root system showed that *Z. mauritiana* had a coarse root system which is an indication of the high dependency of a tree species on mycorrhizas (Haselwandter and Bowen, 1996; Zandavalli *et al.*, 2004; Sidibe and Dhillion, 2002). The monthly increments in height and diameter indicate that *Z. mauritiana* is a fast growing tree species which was also reported by Ouédraogo *et al.* (2006) and Bâ *et al.* (2000).

In the case of *Tamarindus indica,* however, inoculation of *T. indica* seedlings with nursery soil (the control) resulted in higher rate of seed germination and taller, bigger and heavier plants when compared with those inoculated with *G. aggregatum* and *G. fiscia.* According to the results of the present experiment it may be concluded that both *G. aggregatum* and *G. fiscia* did not have effect on the performance of *T. indica.* Thus, the above hypothesis may be accepted in the case of *T. indica.*

Although there appears to be little evidence of plant specificity for a particular VAM species (Huang *et al.,* 1983; Joann *et al.* 1986), the results of the present study showed that VAM species differed in their ability to enhance plant growth. The growth of *Z. mauritiana* was significantly improved with *G. aggregatum* inoculum while *T. indica* growth was enhanced with nursery soil inoculum. The mean monthly increments in height and diameter indicate that *T. indica* is a much slower growing species than *Z. mauritiania.*

The hypothesis stating that there is no difference in mycorrhizal formation on roots and spores in the soil between the three inocula was rejected. The results of the present experiment showed that *Glomus aggregatum* successfully formed better mycorrhizal association with the roots of *Z. mauritiana* seedlings than *Glomus fiscia* and the control inoculum. The high percentage of infection of 82.6% found in *Z. mauritiana* roots is in close agreement with findings of Bâ *et al.* (2000), Guissou, (1996) and Guissou *et al.* (1998). In the case of *T. indica*, however, the percentage of mycorrhizal infection was significantly higher in roots of seedlings in the control. This means that unselected local soil inoculum is more efficient in forming mycorrhizal association with the roots of *T. indica* than the other two types of AM isolates. Similar results were reported by Bagyaraj *et al.* (1989). The results of the study on *T. indica* suggest the need for isolating the local soil mycorrhizal fungi and including those in future screening experiments. Similar suggestions were made by Bagyaraj *et al.* (1989), Munro *et al.* (1999), Bâ *et al.* (2000) and Zandavalli *et al.*, (2004). The lower level of mycorrhizal colonization of the roots of *T. indica* than *Z. mauritiana* in the present study (maximum 63%) confirms the findings of Bâ *et al.* (2000) who stated that *T indica* and *Parkia biglobosa* are moderately dependant on mycorrhizal symbiosis.

The number of live spores per 100 g of soil was significantly higher in soils where seedlings of *Z. mauritiana* were inoculated with *G. aggregatum* (550.50±18.04). The number of spores found in soils is within the range of spores reported by Munro *et al.* (1999), Mukerji and Kapoor (1986) and Bagyaraj *et al.* (1989). *G. aggregatum* has also been reported to produce large number of spores by Sieverding, (1991). *G. aggregatum* are always found aggregated in the soil and the reason for its name "*aggregatum*". This may explain why there was larger number of spores in soil but less infection of roots of *T. indica* than what was observed in the case of *Z. mauritiana.*

7.2. General Conclusion

The results of the baseline survey indicated that farmers have intimate knowledge about their environment including the names, uses, roles and importance of each parkland tree species; the harvesting and transformation methods of their products; the management techniques of each tree species; the interactions between trees and associated crops; the growing technique of crops; the techniques of storage of tree products and crops, the prices of tree products and crops at village and market level. Concerning farmers' preference on tree species, *V. paradoxa* was the most preferred species followed by *T. indica, P. biglobosa* and *Z. mauritiana.* Eggplant was the shade tolerant crop preferred by farmers. It is worthwile to mention that this survey was just a baseline survey and many aspects like for example economic evaluation and crop quality were not included in the questionnaires.

Based on the results of this baseline survey, it was decided to choose *Tamarindus indica* and *Ziziphus mauritiana* as tree species used for tree- crop interactions studies. The choice of these two species was based on the fact they have not yet been subjects of scientific studies in the region. Much of the research on local fruit trees is still concentrated on *Vitellaria parodoxa* and *Parkia biglobosa*. The choice of sorghum was based on the fact that this crop constitutes one of the main staple foods in the village and it is highly appreciated by farmers. Eggplant was also chosen due to fact that this crop was identified by farmers as one of the best shade tolerant species which can be grown under both trees.

Our results of the effect of *Tamarindus indica* on the performance of associated crops showed that Tamarind may have a positive effect on yield of eggplant but a negative effect on yield of sorghum. Howerver more studies are needed in the case of eggplant in order to confirm our conclusion. The large variations in the rainfall distribution between 2007 and 2008 which results in large variation in eggplant yield make it difficult to draw definitive conclusion. The use of the relative yield of intercrop to sole crop using the average weighted by zone area should be done in intercultures studies in West Africa. But unfortunately intercropping studies using these relative yields are scarce. Our results on the relative yield of intercrop to sole crop using the average weighted by zone area showed only a 10% reduction of sorghum yield over the two years. An increase of 51% of eggplant relative yield was observed in 2007 and a decrease of 49% in 2008. The relative yield of eggplant over the two years was 101%. It could be that at larger scale the relative yield of the two crops overyields that of the sole crop.

In addition to the effect of shade, competition for resources between Tamarind and the crops due to the difference in their rooting system was also shown to make a contribution to the performance of the crops. Tamarind was found to have higher RLD and superficial rooting system which gave it a competitive advantage over the two crops. Tamarind had no effect on crop nutritional composition. This means growing crops beneath trees as in agroforestry does not have detrimental effect on the quality of crops. Therefore, farmers in the region could gain more resources for household consumption and cash income if they adapt Tamarindus-eggplant association.

The results of farmer's feedback survey showed that growing eggplants under Tamarind has a great potential for adoption by farmers in Mali because majority of respondents mentioned that the tree-crop association tested in the present project was a good idea and should be promoted for making more productive use of land under trees, improving crop yields and increasing farmers' incomes.

The study on the domestication of an improved cultivar of *Ziziphus mauritiana* on a farm in association with food crops shows that SEB as well as the local variety of Ziziphus had no detrimental effect on either eggplant or sorghum, both in terms of yield and nutritional quality, two years after establishment. In fact a beneficial effect of trees was found on the performance of both crops (yield, dry matter production). The type of crops grown in the present study also did not have any detrimental effect on the growth and productivity of both varieties of Ziziphus. The results of the present study, therefore, suggest complementarities in resource use between the trees and the crops. Due to the high mycorrhizal status of Ziziphus, it may be possible that the complementarities in resource use between trees and crops observed in the present study may be continued for several years more.

The high level of fruit production of the improved variety of Ziziphus on farm under rain-fed condition may be a source of additional income and diversification of diet for rural communities in Africa, because not only that farmers can maintain their traditional crop cultivation on their farms but they can also obtain additional product of Ziziphus fruits which they can consume to improve their diet as well as sell in local markets to generate income. Furthermore, the present study showed that Ziziphus can be successfully grown on farmers' fields without high inputs such as irrigation and fertilisation which are scarce resources in the drylands of Africa. Therefore, it may be concluded that the adoption by farmers of the agroforestry practice of domesticating improved Ziziphus varieties in association with food crops, successfully tested in the present study, may help considerably in alleviating poverty in the region.

The results of the mycorrhizal studies showed that VAM species differed in their ability to enhance plant growth. The growth of *Z. mauritiana* was significantly improved with *G. aggregatum* inoculum while *T. indica* growth is enhanced with nursery soil inoculum. The results obtained on *T. indica* suggest the need for isolating the local soil mycorrhizal fungi in future screening experiments. Similar suggestions were made by Bagyaraj *et al.* (1989) and Munro *et al.* (1999) and Bâ *et al.* (2000). The fact that *Z. mauritiana* and *T. indica* seedlings responded differently to inoculation suggest that our inoculation procedure was effective and that there is a possibility to perceive the effect of inoculation without the obligatory use of sterile soil. The lower level of mycorrhizal colonization of the roots of *T. indica* than *Z. mauritiana* in the present study (maximum 63%) confirms the findings of Bâ *et al.* (2000) who stated that *T. indica* and *P. biglobosa* are moderately dependant on mycorrhizal symbiosis. Although spores are not the only infective propagule in the soil inocula, the difference in the number of spores observed may be responsible for the different infection rates on roots.

7.3. Problems and constraints

Economic compensation of crop yield reduction by tree fruit was not evaluated.
Tamarind tree densities reported by respondents were not at all coherent and therefore were not reported here. According to my personal experience, Tamarind density could vary from 3 to 5 mature trees per hectare in the study area.
Although the majority of respondents thought that tree shade is responsible of crop yield suppression, shade was not unpacked.
It came out after the survey that the cultivation of eggplant is mostly done by women in the study area. So while collecting the data, we did not put much emphasis on gender issues, so data could not be dissagregated for gender discuss.
Quality thresholds for crops were not studied because it was not possible to find scientific data in the study area which define clearly this concept.
In the present study site, most of the Tamarind trees were associated with termites. It was hard to find trees free of termites. Thus, this was the reason why only six trees were selected for the present study. There is no information in the literature that explains why termites preferred Tamarind more than other parkland trees. One of the six experimental trees was also infested by termites after the experiment was established and it was not possible to select another tree.
Environmental factors including light, soil moisture and transpiration rates were not measured in the present study due to lack of equipment and funding.

Improved cultivar of Ziziphus was attacked frequently by termites mostly in the dry season when water was scarce. These attacks may have slowed down the growth of the improved cultivar. Leaves of improved cultivar were also attacked by other insects which feed on the sap of the tree. Fruits of the improved cultivar (SEB) were also attacked by insects which may reduce the quality of the fruits. Similar problem was reported by Ouedrago *et al.,* (2006). Flowers of the improved cultivar produce a characteristic smell that attracts a multitude of insects including bees and flies. It is not known whether all the insects are pollinators or some are parasites. Leaves of Ziziphus and particularly those of improved cultivar are also highly appreciated by animals mostly goat and sheep, so there is a need for fencing in order to protect trees when they are young. After harvesting, fruits of improved cultivar decay quickly, so from marketing point of view, there is a need to develop storage techniques. All the above mentioned problems constitute potential areas for future research if the introduction of improved cultivar of *Z. mauritiana* is to be promoted at farm level.

The local mycorrhizal fungus responsible for the enhanced performance of *T. indica* could not be identified in this study. The chemical composition of nursery soil used as medium and the nutrients present in the leaves of seedlings were not analyzed. So, correlation analyses could not be performed between these parameters. Although the above studies were beyond the scope of the present research, they should be taken into account in future investigations. Adequate laboratory equipment such as electronic microscope equipped with camera is essential for such investigation.

7.4. Recommendations

7.4.1. The effect of *Tamarindus indica* on the performance of associated shade-tolerant and shade-intolerant crops

1) It is recommended that further investigations are carried out to study environmental factors (light transmission, tree transpiration, soil evaporation, soil moisture content) affecting crop performance under *T. indica*.

2) It is recommended that more shade-tolerant crops (taro, sweet potato or ginger) that may associate well with *T. indica* be investigated.

3) The characteristics of roots are used as criteria for tree suitability in agroforestry systems (Sinclair, 1994; Schroth, 1996) and yet root studies are laborious and time consuming, consequently studies are scarce. Therefore, it is recommended that more

studies on Tamarind root system as well as on most of the important agroforestry tree species and also associated crops be conducted.

7.4.2. Domestication of improved cultivar of *Ziziphus mauritiana* on farm in association with food crops in agroforestry parkland systems in Mali

1) The results of the present study suggest complementarity in resource use between trees and crops. It is not known whether this complementarity will be maintained or replaced by competition in the long run. Therefore, it is recommended that this research should be continued for more years in order to determine the stage when the complementarity ceases.

2) It is recommended that studies should be undertaken to identify and control the insects which are damaging the leaves and fruits of improved cultivar of Ziziphus.

3) Fruits of the improved cultivar of Ziziphus decay fast. This holds also true for the fruits of eggplant. Therefore, it is recommended that investigations are made to develop techniques for prolonging the shelf-life of the fruits of improved Ziziphus as well as fruits of eggplant. The development of conservation techniques should be coupled with market opportunities studies.

4) In order to broaden the choice of farmers and create a diversity of products, it is recommended that studies should be carried out on the introduction of other improved cultivars of Ziziphus (UMRAN, Sotubata and Gola) at farm level. This introduction could be coupled with investigations of associations of the improved cultivars with more shade-tolerant crops.

5) Given the high yield and high nutritional content of eggplant and the high fruit production of SEB (the improved cultivar of Ziziphus), it is recommended that the association of SEB-eggplant be promoted for farmers' adoption.

7.4.3. The use of mycorrhizal inoculation in the domestication of *Ziziphus*

mauritiana* and *Tamarindus indica

1) It is recommended that further screening trials on local fungal species should be given priority as well as the identification of the species.

2) It is recommended that research on the relative mycorrhizal dependency of associated crops should be encouraged. It is obvious that crop species with high mycorrhizal status could develop more complementarities with tree roots than those that are poorly associated with mycorrhizal fungi.

7.3.4. Prioritisation of recommendations:

Extension of SEB eggplant system should be given high priority because this study showed that the improved Ziziphus can be successfully grown on farmers' fields without high inputs such as irrigation and fertilisation. SEB can be grown in shorter time (2 years) and produce high number of fruits. There was no negative effect of SEB on eggplant production, 2 years after plantation. This means that farmers can get two products at the same time and in shorter period. This is one of main big aims of domesticating trees (Leaky and Simons, 1998; Leakey *et al.*, 1982; ICRAF, 1998; Teklehaimanot, 2004). SEB fruits could be a source of additional income and diversification of diet for rural population.

7.3.5. Reflections on sequence and amount of studies:

The first advice will be to conduct all the three experiments in one site. This would improve significantly the efficiency of the work in terms of time, logistics and management.

A. Pepper under Tamarind

1. Farmers survey:

The following aspects will deserve more indepth studies:

- Tamarindus tree density in parklands;
- Role of tree shade in relation to crop suppression;

- Collection of data which will allow gender discussion (I already know that women are more involved in pepper production than men);
- Economic compensation of crop suppression by tree fruits;
- Quality thresholds of all crops (this aspect need more analysis because quality is a relative concept) ;
- Economic evaluation (Cost- benefit analysis) of Tamarindus- pepper association compared to Tamarindus- sorghum for instance.

2) Tamarind –pepper intercropping experiment

A preliminary survey will be conducted in the region to find out where there are enough isolated healthy trees without termites infestation. It could be better to choose a village where there are traditional rules controlling the harvest of immature fruits; then the control for the sole tree crop could be included (For the present study we could not evaluate Tamarind fruits because women are collecting immature fruits without any control. There is an open access to tree product in the study area).

The experimental design could be improved by taking for instance for zone C one time the diameter of tree crown or a multiple of tree crown radius. This will allow more realistic analysis of the data.

The use of phytometer technique as described by Newman (1984) could be adopted as this technique gives important information on many environmental factors related to plant. Growing all the phytometers on the same soil of known composition and quality will help to segregate the soil factor which is very difficult to analyse in interculture studies.

The body size of invertebres should be studied as this technique gives information on the biological activities of organic matter decomposers. Then an evaluation of soil invertebres provides an idea about the health of the detritus community of the soil (Newman, 1994).

Sensors designed by Newman (1984) for monitoring the availability of solar radiation could be of big importance. Studies on light parameters are very complex and involve very expensive equipments. Such simple sensors could considerably help for collecting usefull data in intercropping studies in West Africa where research funds are scarce.

Data collection for crops: We will focus only on crop yield, crop dry biomass and tree fruit production.

Required duration of the study: 3 years. Due to large variations in climatic conditions mostly rainfall it would be better to conduct experiments during 3 years so that a good conclusion could be drawn from results.

B. Nursery extracts:

In case where there are enough funds, chemical composition of Ziziphus leaves according to different treatments should be analysed. The soils used for growing seedlings should be analysed for their chemical composition before and after the experiment. The fungi present in the natural soil should be identified.

C. Introducing improved mango

Sole crop (control) and sole tree (control) plots should be included.

The availability of land for planting tree is a big problem since farmers think that it is a mean to expropriate the land from them (this was the case in the present study).

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APPENDICES

Appendix1: Local knowledge on tree- crop associations: *Tamarindus indica*, *Ziziphus mauritiana* sorghum and African eggplant (baseline survey)

I. *Tamarindus indica*

Name of farmer:
Sex:............................Male.......................Female.....................
Village:.....................................
Number of persons in household..

1. Main occupation of the head of household:
   - Farmer...
   - Trader.....................................
   - Civil servant..
   - Others...

2. What crops do you cultivate this year and what are the surface cultivated (ha) used for each crop?
   - Field in the village...
   - Bush field.......................................

3. Do you have trees in your field? If yes which ones?
........................../../.....................................
..../...

4. What are the crops that can be cultivated under the trees shade?
....

5. What are the positive effects of trees on crops?
....

6. What are the negative effects of trees on crops?
....

7. What are the positive effects of crops on trees?
....

8. What are the negative effects of crops on trees?
....

9. What are the positive effects of animals on trees and crops?
....

10. What are the negative effects of animals on trees and crops?

11. Is it important to preserve/plant trees in the fields? If yes, why?
If no, Why?...

13. What are the most important tree species that you know?
Can you rank (classify) in decreasing order of importance
....

13. Do you know Tamarind tree?...

14. What are the management practices of Tamarindus in parklands?
(Old and new management practices).

....

15. Does the number of Tamarind tree has increased or decreased in parklands?

....

16. Do you practice Tamarind pruning?
* If yes, why? ....
* If no, why?...

17. Do you practice tree planting activities? Yes______No______
If yes, what are the planted species..

....

- Where?..
- If no Why?..

18. Do you maintain an optimum number of tamarindus in the field?..................

....

19. Do you think that Tamarind tree has an influence on soil fertility? If yes, how?

....

20. Do you know tree species which fertilise the soil?, If yes, which species?

....

21. Does the Tamarind crown has an influence on crop yields?
- If yes, how?...
....

22. Do you think that the use (cultivation) of spaces under trees crown could increase crop yield?
- If yes, what are the constraints to this practice?

....

23. Name other tree species having an influence on crop yields

....

24. What are the levels of influence of the different trees on crops?

....

25. What are the crops which yield increases when cultivated under Tamarindus crown?..

26. What are the crops which yield decreases when cultivated under tamarindus crown?..

27. Do you think that the value of Tamarindus products (fruit) could compensate the lost of crop yield?

....

28. What are you preferred tree-crop associations?

Tamarindus - sorghum ..../ Tamarindus - Eggplant...............

Why?: ....

Advantages: ....
Desadvantages:..

II. *Ziziphus mauritiana* (Ber)

1. Name of farmer
Sex:........................Male.......................Female.....................
Village:.....................................
Number of persons in household...

2. Main occupation of the head of household:
   - Farmer...
   - Trader.......................................
   - Civil servant...
   - Others...

2. What are crops cultivated this year and what are the surfaces cultivated (ha) used for each crop?
   - Field in the village.......................................
   - Bush field.......................................

3. Do you have trees in your field? If yes which ones?
........................./......................................./.....................................
..../...

4. Which are the crops that can be cultivated under the shade of trees?
....

5. What are the positive effects of trees on crops?
....

6. What are the negative effects of trees on crops?
....

7. What are the positive effects of crops on trees?...

8. What are the negative effects of crops on trees?
....

9. What are the positive effects of animals on trees and crops?
....

10. What are the negative effects of animals on trees and crops?
....

11. Is it important to preserve/plant trees in the fields? If yes, why?
If no, Why?...
....

12. What are the most important tree species that you know?
(Classify in decreasing order of importance)
....

13. Do you know *Z. mauritiana*?..

14. What are the management practices of Ziziphus in parklands?
(old and new management practices).
....

15. Does the number of Ziziphus tree has increased or decreased in the parklands?
....

16. Do you practice Ziziphus pruning?
   * If yes, why?
   ....
   ....* If no, why?..

17. Do you practice tree planting activities? Yes_______No______
   If yes, What are the planted species?...
....

Where? ....

   a. If no why?..

18. Do you maintain an optimum number of Ziziphus in the field?...............................
....

19. Do you think that Ziziphus tree has an influence on soil fertility? If yes, how?
....

20. Do you know tree species which fertilise the soil? If yes, which species?...

21. Does the Ziziphus crown has an influence on crop yields?
   ➢ If yes, how?..

22. Do you think that the use (cultivation) of spaces under Ziziphus trees crown will increase crop yield?
   ➢ If yes, what are the constraints to this practice?
....

23. Please give the names other tree species having an influence on crop yields
....

24. What are the level of influence of the different trees on crops?....

25. What are the crops which yield increases when cultivated under Ziziphus crown?..

26. What are the crops that the yield decreases when cultivated under Ziziphus crown ?
....

27. Do you think that the value of Ziziphus products (fruit) could compensate the lost of crop yield?

28. What are you preferred tree-crop associations?
Ziziphus - sorghum ..../ Ziziphus - Eggplant..............
Why?: ....
Advantages: ....
Desadvantages: ....

III. Sorghum

1. What are you motivation to cultivate sorghum?
   - High price..

- Easy to sell...
- Easy to grow...
- Familial tradition..
- Home consumption..
- others...

2. Where do you grow sorgum?...
....
3. Is sorghum cultivated under trees?...
4. What are the actors involved in sorghum cultivation?
   - Men...
   - Women...
   - Youth...
5. In which period of the year do you produce sorghum?
   - Rainy season...
   - Cold season...
   - Hot season..
6. Does tree shade has an influence on sorghum yield?...
....
7. Please give the names of crops which yield are influenced by tree shade
....
8. How the growing techniques of sorghum are transmetted?
   - From father to sons ....
   - Friendship relations
     ....
   - Extension services..
   - Others..
     ....
9. What the spacing used between sorghum plants?...
10. How many times exist between sowing and harvesting?..
11. Do you know the yield per hectare?...
12. What are the fertilisers used in the cultivation of sorghum? ....
....
13. What are the traditional fertilisation techniques used?
....
14. Is sorghum attacked by deseases?

    If yes;

    Wich one...
15. What are the end uses of the product harvested?
    - Self consumption...
    - Selling..
    - Benefit expected this year...
    - Echange..
16. What is the price of 1kg of sorghum?
    - Market...
    - Village..
17. What is the importance of sorghum in local food consumption?
....
18. What are the conservation techniques of sorghum?
....

19. Could you store sorghum for long time?
If yes, how many times?..
20. What are the nutritional values of sorghum?...
....
21. What are the main constraints to sorghum production
  - Lack of rainfal..
  - Lack of appropriate seeds..
  - Lack of interest..
  - Others...

IV. Eggplant

1. What are you motivation to cultivate eggplant?
   - High price..
   - Easy to sell...
   - Easy to grow..
   - Familial tradition..
   - Home consumption..
   - others...
2. Where do you grow eggplant?..
3. Is eggplant cultivated under trees?..
4. What are the actors involved in eggplant production?
   - Men..
   - Women...
   - Youth...

5. In which period of the year do you produce eggplant?
   - Rainy season..
   - Cold season...
   - Hot season...
6. Does tree shade has an influence on eggplant yield?..
....
7. Please give the names of crops which yield are influenced by tree shade
....
8. How the growing techniques of eggplant are transmetted?
   - From father to sons...
   - Friendship relations ....
   - Extension services..
   - Others...
9. What the spacing used between eggplant plants?..
....
10. How many times exist between seed sowing and transplanting?...................................
....
11. How many times exist between transplanting and fructification?..................................
....
12. How many harvest can be done in the same field?...
13. Do you know the yield per hectare?...
....
14. What are the fertilisers used in the cultivation of eggplant? ....
15. What are the traditional fertilisation techniques used?

…………………………………………………………………………………………

16. Is eggplant attacked by deseases?

If yes;

Wich one………………………………………………………………………..

17. What are the end uses of eggplant products harvested? :

- Self consumption………………………………………………………………
- Selling……………………………………………………………………….
- Benefit expected this year………………………………………………………
- Echange…………………………………………………………………………

18. What is the price of 1kg of eggplant?

- Market…………………………………………………………………………
- Village…………………………………………………………………………

19. What is the importance of eggplant in local food consumption?

………………………………………………………………………………………..

20. What are the conservation techniques of eggplant?

…………………………………………………………………………………………

21. Could you store eggplant for long time?

If yes, how many times?……………………………………………………………

22. What are the nutritional values of eggplant?……………………………………

23. What the main constraints to eggplant production

- Lack of rainfall…………………………………………………………
- Lack of appropriate seeds…………………………………………………
- Lack of interest…………………………………………………………
- Others……………………………………………………………………………

Appendix 2: Farmer's feedback on tree-crop interaction studies

Name of farmer:
Sex: Male.......................Female..........................
Village:.....................................
Number of persons in household:...

2. Main occupation of the head of household:
- Farmer...
- Trader..
- Civil servant...
- Others...

3. Do you know the tree-crop association studies undertaken in the village?
- Yes...
- No..

4. What is your opinion about this method?

....

5. What are the advantages of the method compared to traditional method?

....

6. What are the desadvantages of the method compared to traditional method?

....

7. What are the management practices needed to minimize competition between trees and crops?

....

8. What role women can play in the management of space under trees?

....

What could be the constraints to adoption of the new method developed?

....

9. What are your suggestions of modifications of the new method?

....

10. Which are the main actors who should be involved in the dissemination of the method developed?

- Men...
- Women..
- Youth...
- Gardeners..
- Extension technician...
- School teachers...................................

Appendix 3: Seasonal diagram of agricultural activities concerning sorghum, eggplant and Tamarind

Agricultural activities	Cold season		Hot season			Rainy season					Cold season	
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Sorghum sowing												
Eggplant sowing												
Eggplant Transplantation												
Sorghum harvest												
Eggplant harvest												
Tamarind fruit Harvest												
Evolution of Tamarind fruit price	C	C	C	C	C	H	H	VH	VH	L	L	L
Evolution of sorghum price	C	C	C	C	H	H	VH	VH	VH	L	L	L
Evolution of eggplant price	C	C	C	H	H	VH	VH	L	L	L	L	C

NB: C= constant price; H= High price; VH= Very high price; L= Low price.