# POLLARDING AND ROOT PRUNING AS MANAGEMENT OPTIONS FOR TREE-CROP COMPETITION AND FIREWOOD PRODUCTION

by

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A Thesis submitted to the University of Stellenbosch, for a Master of Science Degree in Forestry

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# Declaration

I the undersigned hereby declare to the best of my understanding, that the work contained in this thesis is my original work and has not previously in its entirety been submitted at any other University for a degree.

Signature

March 2003

Date

# Summary

Planting of upperstorey trees along boundaries has been introduced in Kabale-Uganda with good reception from local farmers. Trees have been planted along agricultural fields, but both *Alnus acuminata* and *Grevillea robusta* out-compete food crops. Managing competition between trees and crops for water, light, and nutrients to the benefit of farmers is a determinant of successful agroforestry. The scarcity and fragmentation of farmland coupled with the hilly nature of Kabale, highlights the need to address the question of tree-crop competition for resources if the technology of on-farm tree planting is to be widely disseminated and adopted in its different guises.

Five-year old trees of *A. acuminata* and *G. robusta* were subjected to treatments of pollarding, or a combination of pollarding and one side root pruning and compared with unpruned controls. The objectives were to assess their potential in reducing competition with food crops and providing firewood to farmers as well as their effects on tree growth. Pollarding has many benefits to farmers because it provides firewood and stakes for climbing beans, it reduces competition for resources between trees and crops and enables continued tree planting on-farm. Continued on-farm tree planting alleviates problems associated with limited land and contributes to environmental resilience. To ensure this, effect of pollarding and root pruning of upperstorey boundary trees of *A. acuminata* and *G. robusta* was tested on 12 farmers' fields in Kabale.

Food crops (beans and maize) grown in the sequence beans-maize-beans, grew very well at less than 50 cm from trees that had been pollarded and root pruned one side. In general, pooled data from 12 sites over 5 m away from trees indicated that a combination of pollarding and root pruning increased bean yield by 240% and maize by 154%, while pollarding alone increased bean yield by 181% and maize yield was increased by 123% in comparison to non-pruned trees. However, pollarding and root pruning treatments reduced tree growth rates.

Notable was more competition with crops by *A. acuminata* than by *G. robusta.* This was attributed to differences in root architecture, diameter at breast height (dbh) sizes, crown spread and crown density between the two species. Five-year-old *A. acuminata* had bigger dbh (12.40 cm), wider crown spread (6 m) and a dense crown, while *G. robusta* had dbh 10.82 cm, 3 m crown spread and a light crown. *A. acuminata* also had more branches per tree (34) compared to *G. robusta* with only 25. These factors influence water uptake, light penetration through the canopy and transpiration rates, and thus affect tree-food crop competition.

It is concluded that pollarding and root pruning have a great potential to reduce tree-crop competition, thereby paving the way for continued on-farm tree planting. The effect of pollarding on timber quality, moisture seepage into timber through the cut surface, if any, and the extent of its damage are areas for further research. The rate of root recovery is also to be followed closely to determine an appropriate frequency for cutting back of roots to recommend to farmers how often they need to prune their trees. It is also suggested that a thorough study be conducted on the amount of water uptake from the soil by each of the species *Alnus acuminata* and *Grevillea robusta.* This will help further explain the differences in competition between the two species.

# Opsomming

In Kabale, Uganda word dominante bome langs grense aangeplant wat die goedkeuring van die plaaslike boere wegdra. Bome aangeplant langs landbougrond het tot gevolg gehad dat *Alnus acuminata* en *Grevillea robusta* voedselgewasse onderdruk het. Die bestuur van kompetisie tussen bome en landbougewasse vir water, lig en voedingstowwe is 'n gegewe vir suksesvolle agrobosbou. Die beperkte en gefragmenteerde landbougrond asook die heuwelagtige terrein van Kabale beklemtoon die noodsaaklikheid om die kompetisie van bome te ondersoek indien boomaanplanting op plase op 'n groter skaal toegepas moet word.

Vyf jaar oue *A. acuminata* en *G. robusta* bome was onderhewig aan behandelings van knotstambehandeling, of 'n kombinasie van knotstambehandeling en wortelsnoei aan een kant van stamme, in vergelyking met ongesnoeide kontroles. Die doelstellings was om die potensiaal van hierdie behandelings te meet in terme van verminderde kompetisie met voedselgewasse en terselfdertyd brandhout aan boere te verskaf, asook die uitwerkings daarvan op boomgroei te bepaal. Knotstambehandeling verskaf brandhout en stokke vir rankbone, dit verminder kompetisie tussen bome en ander gewasse en maak volgehoue aanplanting van bome op plase moontlik. Hierdie praktyk verlig probleme betreffende beperkte grond en is tot voordeel van die omgewing. Dus is die uitwerking van knotwortelbehandeling en wortelsnoei van dominante *A. acuminata en G. robusta* op grense van 12 boere se landerye in Kabale bestudeer.

Voedselgewasse (boontjies en mielies) wat in die volgorde boontjies- mielies- boontjies gekweek is, het baie goed gegroei binne 50 cm van bome wat knotwortelbehandeling en wortelsnoei aan een kant ontvang het. Op groeiplekke wat meer as 5 m weg van die bome was, het 'n kombinasie van knotwortel en wortelsnoei boontjie opbrengste met 240 % en mielies met 154 % verhoog, terwyl knotwortelbehandeling alleen boontjie opbrengste met 181 % en mielie opbrengste met 123 % verhoog het in vergelyking met ongesnoeide bome.
Knotwortelbehandeling en wortelsnoei het egter boomgroei nadelig beinvloed.

A. *acuminata* het meer as *G. robusta* met die landbougewasse gekompeteer. Dit is toegeskryf aan verskille in wortelargitektuur, deursnit op borshoogte (dbh), kroonwydte en kroondigtheid van die twee boomsoorte. Vyf jaar oue *A. acuminata* het groter dbh (12.40 cm), wyer kroonverspreiding (6 m) en 'n digte kroon gehad terwyl *G. robusta* 'n dbh van 10.82 cm en 'n ligte kroon met 'n wydte van 3 m gehad het. *A. acuminata* het ook meer takke per boom (34) in vergelyking met *G. robusta* (25) gehad. Hierdie faktore beïnvloed wateropname, lig penetrasie deur die kroon en transpirasie tempo's. Dus word kompetisie met voedselgewasse affekteer.

Daar is tot die slotsom gekom dat knotwortelbehandeling en wortelsnoei groot potensiaal inhou om kompetisie tussen bome en-voedselgewasse te verminder en dus die weg te baan vir volgehoue boomaanplanting op plase. Die uitwerking van knotwortelbehandeling op houtkwaliteit, insypeling van vog in die hout deur snoeiwonde en die mate van skade wat dit moontlik kan aanrig, vereis verdere navorsing. Die tempo van wortelherstel moet ook ondersoek word om 'n geskikte frekwensie van wortelsnoei aan te beveel. Die opname van grondwater deur *A. acuminata* en *G. robusta*.moet deeglike ondersoek word. Dit sal help om die verskille in kompetisie tussen hierdie twee boomsoorte te verduidelik.

# Dedication

To my Dear Mother Catherine Mazaaga Buhwamatsiko for the invaluable love, care and advice to me throughout my life.

To my only wife Catherine Beatrice Sande and the two precious twin children God has graciously given to us for care and appreciation of His Creative power: Abaho Sande Dickens Junior and Abaho Sande Elizabeth Chloe.

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# Acronyms

| | |
|---|---|
| AFRENA | Agroforestry Research Networks for Africa |
| CABI | Centre for Agricultural and Biosciences International |
| DAB | Diameter At tree Base |
| DBH | Diameter at Breast Height |
| FORRI | Forestry Resources Research Institute |
| ICRAF | International Centre for Research in Agroforestry |
| LG | Local Government |
| LCs | Local Councils |
| MPTs | Multipurpose Tree species |
| NARO | National Agriculture Research Organization |
| NEMA | National Environment Management Authority |
| NGOs | Non Governmental Organisations |
| RCs | Resistance Councils |
| UGADEN | Uganda Agroforestry Development Network |
| USAID | United States Agency for International Development |

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# Chapter 1

# 1 Introduction and Literature survey

## 1.1 General background information

This thesis is an output of a study, which forms part of the Agroforestry Research Programme, jointly implemented by the Government of Uganda through its Forestry Resources Research Institute (FORRI) of the National Agricultural Research Organisation (NARO), and the International Centre for Research in Agroforestry (ICRAF). The programme is currently funded by the United States Agency for International Development (USAID), the European Union (EU) and the funds for the field experiments of this study were provided by the Department for International Development (DFID-UK).

This study was carried out on farmers' fields in the Katuna Valley of Kabale District in the South Western Highlands of Uganda. The sites on which the study was conducted belong to some of the farmers who have been in close contact with the FORRI Agroforestry Research site in Kabale. The study focuses on farmer initiated research and experimentation. According to den Biggelaar (1996), top-down research strategies have proven inappropriate for community forestry and agroforestry, with very low adoption rates by farmers, of the technologies presented by research stations dealing with agroforestry. As such therefore, it became important that research is carried out in constant liaison with local farmers.

Within the Katuna Valley and elsewhere in Kabale District, the FORRI Agroforestry Programme, in collaboration with farmers, the Local Government (LG), Non-Government Organizations (NGOs), and Development Organisations (DOs), have widely planted trees on farms for various purposes. Twelve farmers' fields were selected for this study. These were planted with *Grevillea robusta* and *Alnus acuminata* on boundaries for poles, fuelwood and timber production in 1995 (ICRAF, 1998). These trees were five years old when this study started.

The study involved testing options of shoot and root pruning of trees growing with food crops in simultaneous agroforestry systems to minimize tree-food crop competition for growth resources. Pruning was not only to solve the problem of competition but also to provide fuelwood and other products as would be appropriate to individual farmers. Tree based products are in high demand in Kabale (Okorio and Peden, 1992). For over ten years of agroforestry research in Kabale (AFRENA, 2000) and elsewhere in the world (e.g. Akonde *et al.*, 1996; Cannel *et al.*, 1996, and Rao *et al.*, 1998), it has become increasingly clear that as trees increase in size, they suppress companion food crops. Weaver and Clements (1929) stated that the ideal tree root system is one that fully occupies the soil to an adequate depth and throughout a radius sufficient to secure enough water and nutrients at all times. Plants exhibiting different growth characteristics occurring on the same unit of land will most likely demand the same growth resources often at the same time and from overlapping niches.

Tree root systems progressively occupy as much space as they can to access growth resources, ramifying in all directions and thus suppressing food crops. This counteracts the benefits of trees in the overall tree-crop (agroforestry) system and therefore farmers may not widely adopt on-farm tree planting. This study explored root and crown effects on food crop growth and yield as they were suspected to determining the levels of tree competition with food crops. Similar studies have been reported elsewhere, for example, Singh *et al.* (1989); Ong *et al.* (1991a); Jackson *et al.* (1998a); and Jackson *et al.* (2000). However, most of these were on-station studies and focused on strategic research with limited translation of results into practical farm management situations.

Some important revelations from such studies however, form the basis of this study. An example is ICRAF (1991), in which it was concluded that in dry tropical climates, water is the most limiting resource for crop growth but competition for light can also cause significant reduction in crop yield, e.g. 30% reduction in maize (Howard *et al.*, 1997), and 27% in groundnut (Stirling *et al.*, 1990). Competition for resources in agroforestry occurs mainly because of overlapping growth cycles of trees and crops, both of which exploit the same soil and space.

Considerable attention has been given to tree-food crop competition in recent years (Rao *et al.*, 1998), such as Lott *et al.* (2000 a, b, and c) who studied the allometric above ground biomass and leaf area of *Grevillea robusta* in agroforestry systems as well as its long-term productivity in agroforestry, measured basing on crop growth and performance and tree growth. They concluded that subsequent technology transfer to farmers is hampered by the long lead periods required for agroforestry systems to establish and mature. Apart from the long periods required for systems to establish, strategic research cannot be adopted by farmers in its complex form. Results need to be synthesized and translated into forms that can be understood and applied by farmers into their farm situations. Given the opportunity of a well-established system in Kabale, where farmers were willing to offer their "established" trees-food crop systems for experimentation, this study resulted to bridge the gap between strategic research and farmers.

## 1.2 Background to Kabale District

### 1.2.1 Location and history

Kabale District is found in what is referred to as "the South Western Highlands of Uganda"- a term used to describe what was the colonial District known as Kigezi, as described by Rwabwoogo (1997). The highlands cover the present day Kabale, Kisoro, Rukungiri, Kanungu and part of Ntungamo Districts. Kabale District, where this study was conducted, is located at the Ugandan borders with Rwanda and the Democratic Republic of Congo (Former Zaire).

The district is an area of undulating hills with occasional steep slopes and gently sloping hills where cultivation and homesteads sometimes stretch to the tip of hills (Plate 1.1). Many of the valley bottoms were once papyrus swamps, although most have been drained during the past 50 years and are now cultivated or used for pasture. Soils of the district are derived from the Karagwe-Ankolean series and are largely red loam soils (Rwabwoogo, 1997). Detailed description of Kabale District as a study area is given in Chapter 2.

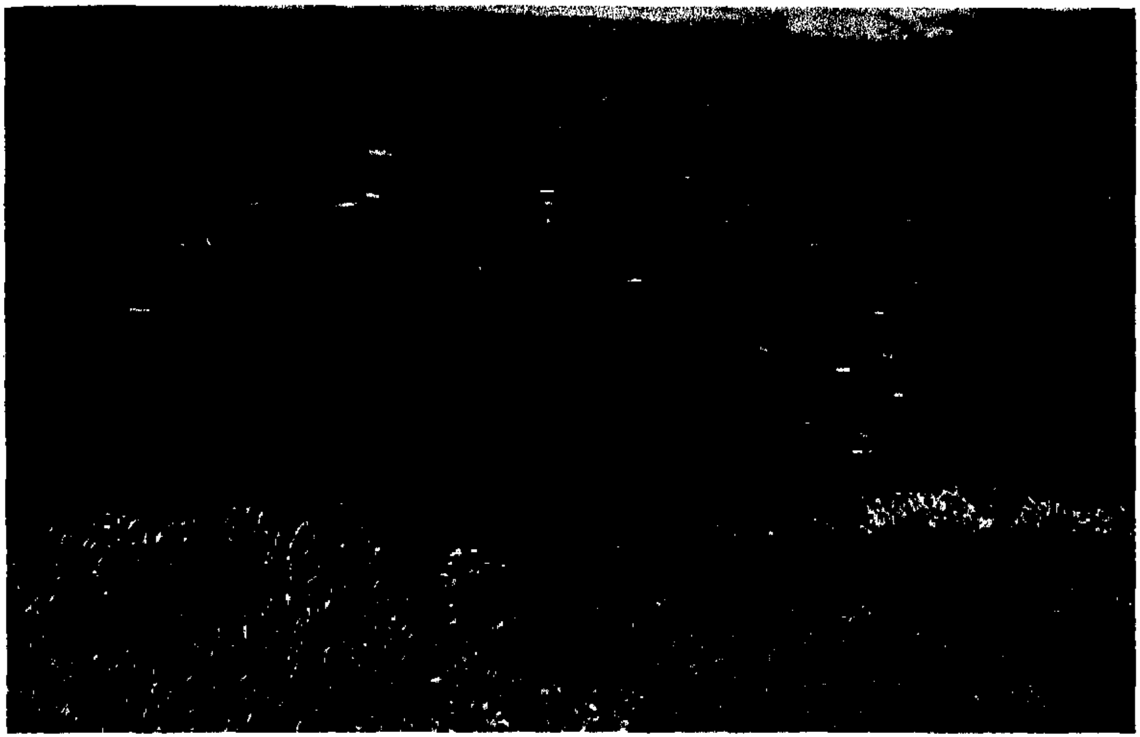

**Plate 1.1** *Typical Kabale District landscape. In the foreground are two sorghum terraces, and in the background are a series of cultivated terraces and homesteads. Cultivated terraces stretch to the hilltop* (AFRENA, 2001).

### 1.2.2 People and farming practices of Kabale

The people of Kabale are predominantly Bakiga, with a small proportion of Bafumbira (Banyarwanda) and Banyankole. Other tribes and groupings do exist in the district mainly due to employment and or settling in from elsewhere for various reasons. The Bakiga are of Bantu origin and have traditionally been agriculturalists (Rwabwoogo, 1997). Farming practices in the area are still based on hoe cultivation; neither animals nor machines are used in land management. Very few commercial farms exist; those that do are generally based on livestock and milk production.

The district is densely populated, and has experienced high rates of immigration over a sustained period since 1921 to-date. Concerns over population growth, poverty, and environmental degradation in Kabale begun with the colonialists who perceived similar problems throughout Africa. Recent publications, such as Rwabwoogo (1997), have reiterated these beliefs to the extent that they are no longer questioned. It is now conventional knowledge that population growth has led to environmental and poverty problems in Kabale. High densities imply that relatively small areas of land are available for farming, and the system of land inheritance in Kabale results in fragmentation[1] of land holdings and scattered plots. The land inheritance system is traditionally that all the sons and sometimes daughters in a family inherit an equal proportion of their father's land.

### 1.2.3 Challenges faced by Kabale farmers

Human population explosion in recent years has aggravated pressure for agriculture and forestry in Uganda, and Kabale is no exception. The sustainability of traditional agricultural and forestry systems in Kabale and elsewhere has diminished with time, forcing farmers to move to environmentally sensitive areas in a bid for arable land (Plate 1.2). Many serious interrelated problems have resulted, including deforestation, land degradation, soil erosion, decreased soil fertility, and reduction in crop yields (NEMA, 1998).

**Plate 1.2** *Degraded landscape. Most landscapes in Kabale District have been cultivated from bottom to top, are now bare of trees, leading to land degradation, low diversity and few or no wood products. Only a few shrubs can be observed scattered on terraces. In the foreground is a papyrus swamp and annual food crops cover most of the terraces* (Raussen, 2000).

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[1] Land fragmentation: Small pieces of land (plots or terraces) are located at least 1 km from each other, owned by one person of a family.

The major problems of natural resource management faced by Kabale farmers are: land shortage, shortfall of fuelwood, shortage of poles for construction, soil erosion and declining fertility, low income, hunger and nutritional deficiencies. The level of forest encroachment by the local people in search of forest products and land for cultivation is shown in Plate 1.3. Agroforestry has a potential of meeting these and related challenges.

**Plate 1.3** *Encroached forest. The so-called "Bwindi impenetrable forest" has now been "penetrated" for cultivation and other tree-based products. There is no buffer zone between the forest and agricultural land and the boundary is virtually a straight line. The planted trees in the foreground (right) are an effort to provide farmers with forest products outside the forest reserve* (AFRENA, 2001).

## 1.3 The need for agroforestry

Agroforestry is a dynamic, ecologically based, natural resource management system that, through the integration of trees on farms and in the agricultural landscape, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Leakey, 1996). It is regarded as an effective, low-cost means for minimising the degradation of cultivated land and for maintaining or even increasing the productive capacity of agricultural ecosystems (Chuntanaparb and MacDicken, 1991).

On-farm trees have many benefits for farmers; some being direct while others are indirect. They provide products that enable farmers to reduce dependency on climatically vulnerable short-term crops and diversify their outputs. They enable farmers to get income from extra products (Anderson *et al.*, 1988), and they provide a wide range of environmental services such as recycling of leached soil nutrients through root decomposition and litter fall, and protect soils from erosion by crowns breaking raindrop impact and roots holding soil particles together (Rao *et al.*, 1998). Such benefits are increasingly being recognised, and while population density is increasing and farm size per household is decreasing, tree planting by farmers is increasing in many areas (Tiffen *et al.*, 1994; Scherr, 1997). This follows the pattern that household demand for tree products in general and for firewood[2] in particular, necessitates that tree planting density increases (den Biggelaar and Gold, 1995). In Kabale, where land area per family is low, agroforestry is not a choice, but a necessity if fuel, timber, and food requirements are to be met.

About 1.5 billion people in the tropics currently apply agroforestry; hence, about 24% of the world's population depend to a major extent on agroforestry products and services (Sanchez, 2000). Whereas for thousands of years the human population extracted what they needed from the forest, in future most of tree planting efforts will focus on farms, because currently the human population far exceeds the extractive capacity (Arnold and Dewees, 1997). For example, in 1850, the world population was 1 billion, but today it is 6 billion, the original global forest cover was 80%, but currently it is estimated at 26% (Sanchez, 2000).

Ugandan forests have suffered severe degradation due to logging and fuelwood gathering (Hamilton, 1984). In 1986, firewood and charcoal constituted about 96% of Uganda's energy consumption, equivalent to 18.3 million m$^3$ of wood per annum (World Bank, 1986). The current Uganda Forest policy (2001) estimates that 18 million tonnes of firewood, 500 000 tonnes of charcoal, 800 000 m$^3$ in furniture and 875 000 m$^3$ of poles are consumed annually. This by far, is the

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[2] The term "firewood" is used throughout this thesis to denote wood that is domestically burned and "fuelwood" for the total of wood used as firewood and charcoal.

greatest pressure on the forests, and the greatest challenge to those responsible for forestry planning (Howard, 1991). Pressure on land, insufficient wood production for various uses and declining soil fertility are serious issues affecting small-scale farmers in Kabale. There is need to increase the availability of tree species that will yield forest/tree products to the local farmers. The goal of agroforestry is to provide tree species that can be planted by farmers to yield a variety of tree products and services, thereby providing both domestic and marketable products.

### 1.3.1 Importance of agroforestry to Uganda

In addressing the problems of decline in forest resources, the Ugandan Government has identified agroforestry as one of the key approaches for reducing the over-exploitation of natural resources while sustaining food production (Uganda Forestry Policy, 2001). Agroforestry features prominently in Uganda's national policy for poverty alleviation and rural development through the modernisation of agriculture. The current Uganda forest policy also encourages farmers to grow and protect their own trees for meeting the increasing demand for tree products and services. Forests and trees growing on agricultural and natural land play a crucial role in Uganda's national economy, both in satisfying energy and industrial product needs, and in providing essential environmental services that support the country's agriculture, sustain her water supply and protect her soil (Howard, 1991; Obua, 1996). Ugandan farmers grow trees for various products, including timber, fuel, poles, shelter, herbal medicine, fodder, fruits, and nitrogen-fixing species to improve soil fertility and crop yields.

Agricultural practices, especially on rural and peri-urban land holdings of the majority of Ugandans, are not conducive for sustainable land productivity (Falkenberg and Nsita, 2000). In this respect, agroforestry can play a major role in restoring soil fertility and preventing soil loss. The challenge is providing the components that are socially acceptable and economically affordable in the predominantly rural, small-scale farming environments. Furthermore, 73% of all the districts in Uganda experience a deficit of woody biomass for fuelwood and restoring the balance lies in increasing fuelwood stocks on the farm and ensuring their profitable management (Falkenberg and Nsita, 2000). These must be fast growing tree species able to blend well with food crops or be managed to do so.

Timber consumption in Uganda is beyond the capacity of its current forest supply. The current timber consumption stands at 750 000 $m^3$ per year. Sustainable production has been estimated at 250 000-300 000 $m^3$ per year implying a deficit of 500 000 $m^3$ per year (Falkenberg and Nsita, 2000). A bigger challenge has come from putting some of Uganda's forest reserves out of timber production in the interest of biodiversity conservation, yet the construction and energy use industries continue to grow at the rate of 10-15% per year (NBS, 1996). Agroforestry can go a long way in increasing sawlog production outside the protected areas through new establishments and management of existing trees on the farm.

### 1.3.2 Agroforestry activities in Uganda

Uganda's agroforestry programmes are being implemented through the activities of Government research projects and many NGOs. The activities of several community-based organisations are supported and coordinated by the Uganda Agroforestry Development Network (UGADEN) that has recently (September 2001) been established by all the national stakeholders to answer the call of Uganda Government. Most of the activities in the country have previously been running under the Agroforestry Research Network for Africa (AFRENA), co-ordinated by the International Centre for Research in Agroforestry (ICRAF). Through AFRENA, a number of multipurpose tree and shrub species, indigenous and exotic, have been introduced on farmlands in the country (Okorio *et al.*, 1994; ICRAF, 1996, 1997; Aluma, 1998).

In Kabale, more than 850 farmers have adopted the use of upperstorey trees and boundary plantings for the production of poles and timber and the principle tree species in use are *G. robusta* and *A. acuminata* (ICRAF, 1998). These species provide side branches, which are pruned periodically for fuelwood while the main stems are left to develop as poles (ICRAF, 1997). In addition, *Alnus* species are important for soil improvement through mulch and nitrogen fixation in the soil by *Frankia* and watershed management (NAS, 1980; Russo, 1989, 1990, 1995).

Efforts are underway to support the expansion of *A. acuminata* in Uganda, especially in Kabale (Raussen, pers. comm.) because it is one of the fastest growing tree species in Kabale. Farmers have expressed increasing interest in the species not only because of its high quality firewood and because of stakes for climbing beans, but also due to the fast growth it has exhibited, which provides timber in a shorter period compared to other common tree species. A farmer evaluation of growth characteristics of agroforestry tree species revealed that *A. acuminata* is the most preferred species in Kabale. The results are presented in Table 1, indicating that *Alnus* was ranked number one in terms of growth rate and wood biomass, i.e. *Alnus* is preferred because it has been observed to outgrow *Grevillea* which till recently was regarded by local farmers as the fastest growing species (AFRENA, 1998). *Cedrela serrata* was completely rejected by farmers mainly because its survival was very poor. However, it has very few branches, with correspondingly less shading to food-crops.

**Table 1** *Ranking of upperstorey tree species by farmers in Kabale District (1: best and 3: lowest)*

| Criteria | *Alnus acuminata* | *Grevillea robusta* | *Cedrela serrata* |
|---|---|---|---|
| Growth rate | 1 | 2 | 3 |
| Growth form | 3 | 2 | 1 |
| Pole strength | 2 | 1 | 3 |
| Wood biomass | 1 | 2 | 3 |

*Source: AFRENA, 1998, p.15.*

### 1.3.3 History of agroforestry in Kabale

Shifting cultivation has been practised in Kabale since time immemorial and this farming system, as opposed to short fallow and permanent agriculture, is the most ancient form of agroforestry (Gujral, 1991). However, there are now agroforestry systems that have developed over time in response to particular combinations of agro-ecological and socio-economic circumstances. Most of these systems are yet in different stages of development through research and early extension efforts. Kabale District has become a point of reference for successful agroforestry in Uganda. The various agroforestry practices in the district can broadly be classified into traditional and scientific agroforestry, briefly described in sections 1.3.3.1 and 1.3.3.2.

#### 1.3.3.1 Traditional agroforestry

Typical traditional farming systems in Kabale is the integration of several enterprises such as growing of food crops along with livestock rearing, fruit cultivation, vegetable farming, raising of fodder and fuelwood within the boundary of gardens. This is the predominant agroforestry practice in Kabale today where agricultural activities are dominated by small-scale production of food and cash crops, and livestock. Staple food crops include mainly maize (*Zea mays*), beans (*Phaseolus vulgaris*), potato (*Ipomoea batatas*), millet (*Eleusine coracana*) and sorghum (*Sorghum bicolour*). Livestock consist mainly of cattle, goats, sheep and more recently pigs and rabbits (Rwabwoogo, 1997). These agroforestry systems have been intensified in recent years, due to land shortage.

In Kabale District, trees are mainly found around homesteads and boundaries rather than integrated in cropland (ICRAF, 1988). The home gardens are characterised by multi-layers of a wide range of species and dense association, with no organised planting arrangement. Most farmers give priority to planting fruit trees in the homestead area. As stated by Tuladhar (1991), the presence of trees and shrubs on farmland indicates resource stress of some degree where accessibility to 'free' forest resources is limited and unreliable, and at times not available at all. Trees and shrubs like *Erythrina* species, *Euphorbia* species, and *Acacia* species are common as live fences or boundary markers. Some fodder trees and shrubs, especially *Calliandra calothyrsus*, *Sesbania sesban* and *Acacia* species are being incorporated in livestock farming for zero grazing (Aluma, 1998).

#### 1.3.3.2 Scientific agroforestry

Although existing for centuries as an array of traditional land-use practices, agroforestry emerged in the late 1970s as a modern system for scientific study (Mercer and Miller, 1997). The challenge in agroforestry is to find and develop the relevant combination of woody and non-woody components in relation to the land users' problems, aspirations, and potential. It is also to develop spatial arrangement and management practices, which minimise the competitive interactions between the components and maximise the productive and service functions of the trees and shrubs (Lundgren, 1993).

The science of agroforestry is rather recent in Uganda and is largely under experimental trials. In 1988, ICRAF through AFRENA initiated multipurpose tree species (MPTs) trials to identify various potential tree/shrub species for agroforestry purposes (Aluma, 1998). This research has brought in new tree and shrub species such as *Grevillea robusta*, *Alnus acuminata*, *Alnus nepalensis*, *Markhamia lutea*, *Gliricidia* species, *Sesbania* species, *Acacia* species and *Casuarina* species on farms for different purposes with practices such as zero-grazing, intercropping and fodder banks becoming very popular (Okorio *et al.*, 1994; Aluma, 1998).

Results from upperstorey screening and intercropping trials in Uganda have shown that most tree species grown as upperstorey trees will result in some competition with food crops (Peden *et al.*, 1993; Okorio *et al.*, 1994). However, a few species such as *Grevillea robusta* and *Cedrela odorata* do not suppress crop yields significantly (ICRAF, 1995, 1997). One species, *Alnus acuminata*, was observed to have positive interaction with food crops, whether established as upperstorey trees or as a hedge in cropping fields (Peden *et al.*, 1993; Okorio *et al.*, 1994; ICRAF, 1996) and farmers continued to express interest in it (ICRAF, 1997). This observation is mainly because *A. acuminata* is host to nitrogen-fixing actinomycete *Frankia* (Tarrant, 1983; Russo, 1990, 1995).

Since 1988, agroforestry research in Kabale has focused on identifying tree species that could be incorporated on agricultural land without significantly interfering with the associated food crops. ICRAF's on-farm research started in 1990, focusing on farms in the Katuna Valley, Kabale District (ICRAF, 1997). Results of a recent survey conducted in the district, rank *A. acuminata* and *G. robusta* as the most preferred species by farmers for on-farm planting (AFRENA, 2000). However, their abilities to severely out-compete associated food crops for growth resources as they increases in size, may outweigh the observed advantages in their early years (1-3 years) of establishment.

### 1.3.4 Agroforestry technologies in Kabale

This study has focused on one of the many agroforestry technologies in common practice in Uganda, especially in Kabale. A brief description of the most common agroforestry technologies and how they relate to boundary upperstorey tree planting in general, and this study in particular, are presented below.

#### 1.3.4.1 Boundary upperstorey tree planting

This refers to planting trees along farm boundaries and is a promising agroforestry technology that can reduce pressure on indigenous forests. The technology has the potential of benefiting about 20 million people (Djimde and Hoekstra, 1988) in the East and Central African Region. It makes use of areas usually under-utilised and can provide tree products such as timber, poles, firewood, mulch, windbreaks and fodder.

Many farmers practice boundary planting because it is less complex than other agroforestry practices. The main drawback of the practice, however, is the competition that occurs between trees and adjacent crops for light, nutrients, and water (Ong *et al.*, 1992). This study has been conducted on this particular technology. Research results (Okorio *et al.*, 1994; Akyeampong *et al.*, 1999), and on-farm surveys (Nielsen *et al.*, 1996) have shown that competition for growth resources affects crop growth and yield in areas influenced by boundary upperstorey trees. Species commonly used in this technology are *G. robusta, A. acuminata*, and *C. odorata* (Plate 1.4).

**Plate 1.4** *Boundary tree planting. A typical example of on-farm upper-storey boundary tree planting in Kabale.* Grevillea robusta *is nearest to the camera and further on is* Alnus acuminata *in the same line. In the lower terrace is a banana plantation while the upper terrace is ploughed and ready for bean sowing. Also further on in the field is a maize crop growing next to trees* (AFRENA, 2001).

### 1.3.4.2 Trees scattered in cropland

In this system, trees may be dispersed widely, either spaced systematically or scattered at random (Plate 1.5). Crops are grown in the understorey. The tree species involved may be based on protection and management of selected mature trees already on site, planting new ones, or managing selected seedlings on site through natural regeneration. In Uganda, tree species commonly observed in such arrangements are *Albizia* species, *Ficus* species, *Maesopsis eminii*, and fruit trees such as Jackfruit (*Artocarpus heterophyllus*) and Avocado (*Persea americana*).

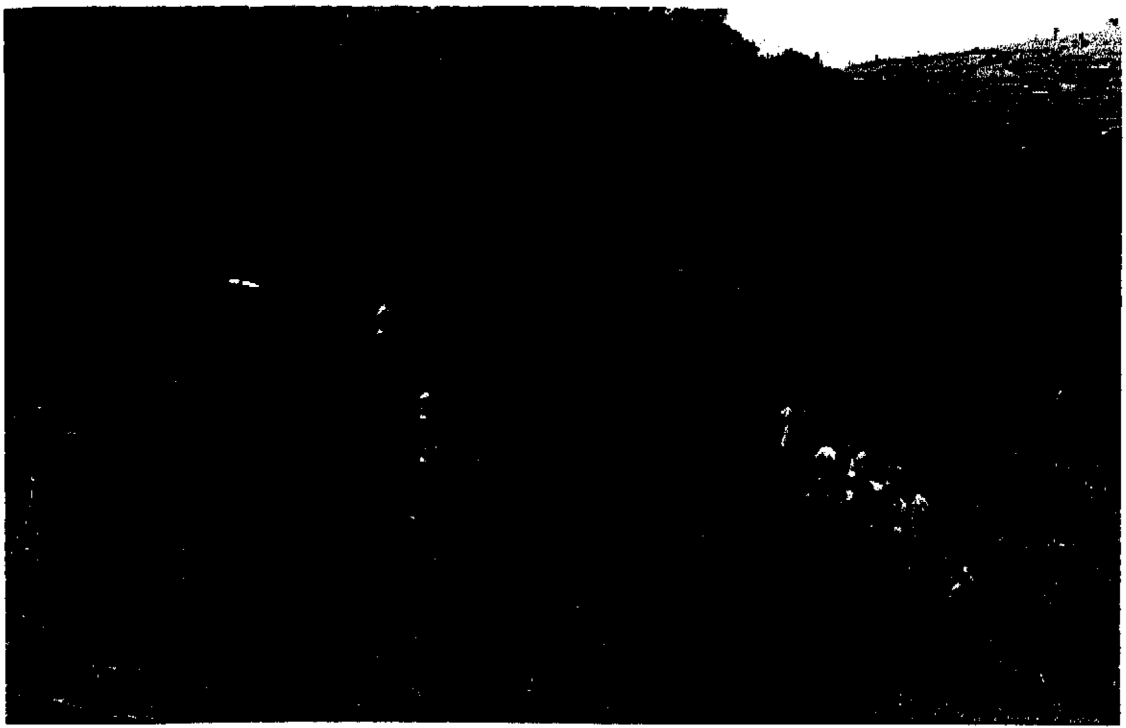


**Plate 1.5** *An example of trees scattered in cropland. Wheat is being harvested in the understorey of different tree species in Kabale* (Raussen, 1999).

### 1.3.4.3 Improved fallows

This system uses preferred tree species as fallows in rotation or simultaneously with cultivated crops. The main objective of fallows is to improve the rate of soil amelioration besides producing the economic products. It is an improved form of shifting cultivation by shortening the fallow period and increasing benefits, e.g. biomass production (firewood and stakes for climbing beans), and nutrient accumulation. *Alnus acuminata*, is a valuable fallow species in Kabale and has been ranked by farmers second to *Sesbania sesban* in nutrient accumulation and value of firewood (Siriri and Raussen, 2001).

### 1.3.4.4 Contour hedges

This is a horizontal vegetation strip used as a soil erosion control measure on sloping farmland. The primary objective is to prevent soil run-off, but it also provides products such as firewood, stakes for climbing beans, mulch and soil enrichment. Again, in this system, *A. acuminata* features prominently in the Kigezi Highlands. Other most commonly used species are *Calliandra calothyrsus* and *Leucaena leucocephala* (Raussen *et al.*, 2001).

Other agroforestry technologies commonly practised elsewhere are hedgerow intercropping, taungya systems, plantation-crop combinations, home gardens, and shelter belts/windbreaks, but these are not common in Kabale District.

## 1.4 The need for on-farm research

The success of applied research is when farmers who are the final users apply it. Probably, the most important objective of research that is rarely made clear is "has it reached the target audience (or customer)?" The first step towards successful agroforestry is to realize that farmers' agricultural practices are not random, but rather deliberate, well-reasoned choices based on extensive experience and observation of locally available resources (den Biggelaar, 1996). Management approaches and innovations that are sustainable must be developed but should be demand driven with a "minimum external input" from researchers (Raussen *et al.*, 2001). This is because farmers in Kabale are willing to plant trees but their farms are small (sometimes much less than 1 ha), and they cannot set aside areas specifically for trees. Therefore, they know what they need, when they need it and in what form they need it, but could be assisted how to get it.

Farmers have been observed to develop agricultural systems that are performing better than what science could offer them without the aid of fancy laboratories, plant breeding techniques, field trials, and no statistical analyses (den Biggelaar, 1996). The dynamism and creativeness of farmers therefore formed the backdrop of this on-farm study. One of the underlying goals of this study was to bridge the gap between strategic research and farmers, by involving them in a tree-food crop management research process and to support them with scientific knowledge relevant to their situations.

However, on-farm research has many challenges that require attention. For example, farmers consider each crop season as an "experiment" in which new knowledge is obtained and new ideas are generated (den Biggelaar, 1996). This study and others in Kabale, have shown that agroforestry research requires more space than a farmer is prepared to offer in experimentation. Individual farmers appear not interested in replication but they use past experience to estimate uncertainty, surprisingly in most cases, with a high degree of accuracy. Hocking and Islam (1994) also noted that farmers had difficulty accepting ideas of randomization and replication as well as the concepts of "control" treatments. Furthermore, some comparisons they wish to make differ from those of the researchers (Swinkels and Franzel, 1997).

It is thus difficult and inappropriate for researchers to give farmers instructions on how to manage their farms. Researchers should rather assess what can work in particular situations and base their research designs on such assessments. It is not easy to separate the complex interacting factors involved in agroforestry systems (Anderson and Sinclair, 1993). On-farm agroforestry research complicates this even much further, e.g. the choice of treatments becomes very complex because agroforestry technologies involve more options to compare than sole crop systems (Coe, 1998). Secondly, the advantages of agroforestry to the farmer cannot be quantified in terms of productivity alone, e.g. soil erosion control and increase in organic matter content cannot be measured in a few seasons (CABI, 1996), yet farmers need something tangible from each season on which they can base their judgments.

Agroforestry systems are spatially complex in nature (Jackson, 2000) and the complexity increases when a study is conducted with farmers. There are socio-economic, traditional and cultural factors that need due attention when a study is conducted with farmers. These factors limit the level of qualitative biophysical data obtained, but the advantage is that highly valuable socio-economic information is obtained and this is vital for wide scale adoption of the technology being tested.

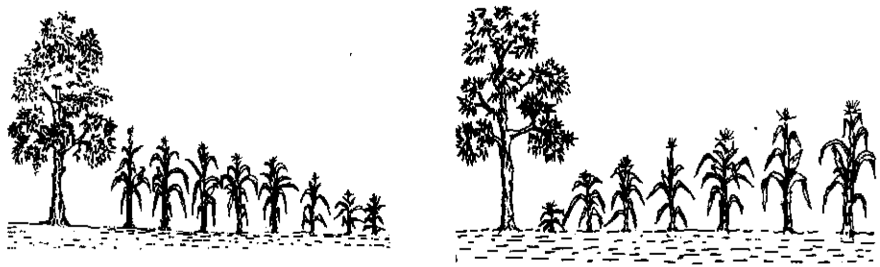
During the course of this study, farmers were asked to freely offer their fields for this experimentation. It was agreed that they would protect trees and crops from grazing animals and other agents of destruction. Other inputs such as ploughing, Labour, seeds, sowing and harvesting were to be met by the grant supporting the study. However, it was observed that not all farmers were willing to wait until final harvesting of dry crops. For example, some wanted to harvest fresh beans while the study preferred dry weight assessments. During pruning of trees, each farmer carried away the branches for firewood immediately after pruning; for fear that others would take it, thus making it difficult to assess dry weights of the pruned branches.

In addition, the study of competition between crops and trees on farm is complicated by the proliferation of tree roots into nearby plots or by the effect of shading, especially with tall trees (Huxley *et al.*, 1989a; Rao *et al.*, 1991). This has been a matter of concern in this study because trees neighboring experimental sites could not all be cut down. Another complexity observed by Ong (1991) is the choice of an appropriate control for both trees and crops to provide a reliable basis for the assessment of competition on crop yields. A simple but effective, method for determining competition was proposed by Huxley (1985), i.e. to measure crop and tree yields across the tree-crop interface.

## 1.5 Tree-crop interactions in the same field

### 1.5.1 General overview

When trees and crops grow together on the same piece of land (simultaneous systems), trees may have positive (complementary) and negative (competitive) effects on crops. These interactions are both below and above ground. Belowground factors include root distribution, effects on soil nutrition and competition for soil water. Above ground factors include energy balance of the system where the tree canopy causes shading and sheltering of the crops below. This influences the under-storeys' light interception and microclimate, such as air temperature, humidity, and wind speed. Changes in microclimate will affect the aerodynamic transfer within and above the under-storey, influencing performance of the under-storey component negatively or positively such as illustrated in Figure 1.1. It could also be possible that there may be no effect at all.



| Positive effects | Negative effects |
|---|---|
| Improve soil fertility | Compete for soil water |
| Improve microclimate | Compete for light |
| Reduce run-off and erosion | Compete for nutrients |

**Figure 1.1** *Schematic illustrations of positive and negative effects of trees on crops in simultaneous agroforestry systems* (Modified from AFRENA, 2001).

### 1.5.2 Positive interactions -complementary

Effects of trees on crops are not always negative; some positive belowground impacts of the tree component include creation of biopores, enrichment of soil organic matter (Schroth and Zech, 1995) and nutrient cycling (Nambiar, 1987). Crop yields under trees in the boundary planting agroforestry system may be unaffected during the early years of tree growth, but could increase or decrease when the trees grow large, depending on the tree species. Some tree and shrub species such as *Faidherbia albida* are well known to improve crop growth under their canopies (Kho *et al.*, 2001). This phenomenon is attributed to improved soil fertility; improved microclimate and better soil physical properties resulting from decayed leafy biomass (nutrients availability) and increased water availability (Depommier *et al.*, 1992; Kamara and Haque, 1992; Rhoades, 1995). However, in Uganda, the positive effect of *A. acuminata* on crop yields was noted only after 3 years of growth (Peden *et al.*, 1993). Similar observations of positive effects have been reported for *G. robusta* in Burundi (Akyeampong *et al.*, 1999).

### 1.5.3 Negative interactions - competition

On the other hand, the negative effects of trees in the system due to competition for growth resources of water, nutrients, and light can be noted as trees progressively increase in size. The slow growing trees, such as *Faidherbia albida* and *Acacia* species, may not influence crop yields for many years after their establishment (Okorio and Maghembe, 1994). However, fast growing trees such as

*Alnus acuminata* and *Grevillea robusta* reduce crop yields as they increase in girth and canopy size and their abilities to capture resources become more established (Raihan *et al.*, 1992; Okorio *et al.*, 1994; Akyeampong *et al.*, 1995). This shows that the effects of trees on crops are cumulative over time and their importance depend on climate, management, soils and species involved (Rao *et al.*, 1998). It also reflects the observations made by van Noordwijk *et al.* (1996) who stated that the twin goals of fast-growing trees and low competitivity appear to be mutually exclusive, especially if nutrients and water are confined to the topsoil. In addition, conclusions of positive effects on crops of fast growing species is a likely error, since most strategic research is based on small plots and normally based on short term investigations lasting 2-3 years (Rao *et al.*, 1998).

Positive and negative effects of trees often occur at the same time. This makes it difficult for a local farmer to clearly discern and take appropriate decision and action. Of the negative effects, competition for soil water is the most important in the drier tropics (Ong *et al.*, 1992) because nutrients must be dissolved in water for tree uptake. The goal of good agroforestry practice is to enhance the positive effects while reducing the negative ones. Consequently, sustainable agroforestry ensures balance and trade-offs between crop productivity, tree products, and environmental functions. This can be through one of two ways: -

1. Choice of the right tree species, i.e. one that does not suppress crops, regardless of age and growth characteristics.
2. Management of the tree on-farm, e.g. pruning a tree's canopy to manipulate its water demands, and shade effects on associated understorey food crops.

The second option has become the focus of study in agroforestry in recent years because not only does it reduce shade, but also limits water use (transpiration) by trees and thereby its competition for soil water. Some local farmers believe that removing branches of a tree or even removing the whole canopy (pollarding[1]), provides firewood from the removed branches, enhances timber quality and reduces competition with crops, while having little effect on tree growth rates (Spiers and Stewart, 1992). In recent surveys in East Africa, similar "art of pruning" was found in Western Kenya (Siaya), and in Uganda (AFRENA, 2000). Generally, three main concepts do exist as to what may happen when upperstorey trees are planted in association with crops. They are classified as: -

There may be no effect at all.

Trees may suppress the growth and consequently the yield of associated crops.

Trees may increase crop yield and performance (Rao *et al.*, 1998).

### 1.5.4 Events leading to tree-food crop competition

In boundary planting, tree-food crop interactions can be classified broadly in three zones as: a zone of light and root competition (under tree crown), a zone of root competition (a distance beyond tree crown), and a zone of open cropped areas with minimal tree interference (Rao *et al.*, 1998). The major tree-food crop interactions that affect crop yields are mainly soil fertility (nutrients), soil physical properties and water relations, and microclimate, i.e. shading. This study is focused on water relations and shading since these determine water availability to crops that is a major limiting factor in drier tropical agroforestry systems (Ong *et al.*, 1992).

Root distribution of both trees and crops determine water-sharing processes in agoforestry systems (Persson, 1983). However, root production and death do not always relate directly to dynamics of water uptake since trees sometimes produce a greater root system than is necessary under normal water conditions (Gregory, 1994).

Soil water is the major belowground resource required for plant survival, because water plays an important role in soil chemical reactions, e.g. the movement of solutes, the redistribution of air and weakening of the soil matrix to facilitate root

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[1] The term "Pollarding or Pollard" is used throughout this thesis to denote a tree management technique of cutting off all tree branches and the top to reduce shading and photosynthesis rates. This practice encourages new branches to grow and therefore can provide firewood to farmers on a regular basis.

growth and elongation (Russell, 1988). In many tropical-farming systems, plants can survive on stored soil moisture (Russell, 1988), which is recharged by seasonal rainfall, and to a small extent by inter-layer soil moisture transfer. Vertical moisture distribution in the soil profile after a rainfall event varies with infiltration; soil surface evaporation and plant activity, while horizontal distribution is mainly due to plant root activity (Pidgeon, 1972). Water is held in soil by capillary forces through a system of interconnected pores (Russell, 1988). Pores are responsible for soil matrix potential, which is the most important factor in controlling water movement or hydraulic conductivity, apart from osmotic pressure and gravity.

Hydraulic conductivity depends on the size and continuity of soil pores and on the viscosity of water (Eeles, 1969). The distribution of these micro-pores depends on soil particle sizes (London, 1991), on which also soil water potential is dependant. Field capacity (FC) is when soil suction is minimal and plants can easily access water and benefit from aeration in drained pores. Root growth occurs mainly at this stage (Box *et al.*, 1989), and is normally attained when free drainage from macro pores is complete after thorough wetting of soil (London, 1991). High soil temperature reduces water viscosity and consequently soil moisture content through surface evaporation (Pidgeon, 1972). Through the above processes in combination with factors such as amount and frequency of rainfall, soil water holding capacity, relative humidity and tree water use, account for soil moisture content under tree canopy as reported by Jackson *et al.* (2000).

High organic matter in upper horizons causes soil aggregation, porosity and enhances soil water drainage, and increases water retention at field capacity (Russell, 1988). In boundary planting, organic matter arises from tree leaf fall and decay and in this case *A. acuminata* is well known for large amounts of organic matter under canopy (Siriri and Raussen, 2001). Finer soil particles also increase available soil water if they are well mixed with coarser particles (Holliday *et al*, 1965). Plants modify the amount of water available to them by exerting variable suctions depending on species and stage of growth expanding their rooting, or transpiring faster than the rate of soil drainage during infiltration (Fiscus and Kaufmann, 1990).

Movement of water in soil is caused by gradients due to gravity, solute concentration, temperature, surface tension and plant root activity. Root water uptake is substantially faster than inter-layer water flow and contributes greatly to soil water distribution within the soil. When initially dry soils are wetted, movement of soil water is at first due to matrix potential differences, then as wetting progresses, gravity becomes a significant driving force (Russell, 1988).

Soil water is lost into the atmosphere through evapotranspiration, which involves transfer of water within the soil matrix, within the plant system, and conversion of liquid water to vapour in leaves (Russell, 1988). Soil water is also lost due to soil surface evaporation which slows down substantially when the surface 1 to 2 mm depth dries because then water vapour has to diffuse through pore spaces at low concentration gradients before it reaches the atmosphere (Penman and Schofield, 1941).

Plants require water for photosynthesis of sugars, maintenance of cell turgidity, transport of soluble material and as a solvent of cell biochemical reactions. Transpiration and gas exchange occur when stomata are open (Swanson, 1994), i.e. when leaf stomata open to allow entry of $CO_2$ into the chloroplasts, water is lost. Air in leaf intercellular spaces is always near saturation even in drought-stressed plants (Ong *et al.*, 1996). Therefore, loss of water from open stomata depends on the vapour pressure gradient between the atmosphere and the intercellular spaces.

Water uptake from the soil into the plant is driven by linked potential differences between the bulk soil, the root xylem, transpiring leaves and the atmosphere. Stem water content rarely changes except in severe drought (Jarvis, 1975). When soil water is low, atmospheric conditions govern leaf and root water potentials. Leaf expansion is more sensitive to water stress than most other processes (Paez *et al.*, 1995). Leaf water potential becomes more negative with increasing height within the canopy due to difference in irradiance, low conducting ability of juvenile leaves at the shoot tips or the accumulation of xylem resistances as the hydraulic path length increases (Weatherley, 1979).

The flow of water from the soil matrix towards the root is driven by potential difference between xylem sap, high solute potential between the root stele and the soil solution at the root surface (Baker, 1984). At high transpiration rates, steep gradients of soil water potential develop dynamically around individual roots. When transpiration rates are decreased, leaf water potential can recover completely, disguising soil moisture stress levels within the overall soil profile, due to perirhizal equilibration as soil water at the root surface is refurbished to near field capacity levels (Weatherley, 1979). Water uptake by roots also depends on their size, health and location in the soil matrix. Roots smaller than 2 mm diameter (fine roots) take up water all along their lengths, though the maximum uptake occurs just behind the root tip where xylem vessels have developed and suberisation of the endodermis has not yet taken place (Russell, 1988). In multi-storey agroforestry systems, crop roots normally grow within depletion zones of tree roots.

Water movement in a plant occurs when atmospheric evaporative demand at the leaf surfaces causes water potential gradients to occur within the plant and between its roots and the soil. Therefore, water flow is closely related to transpiration. In addition, water flow, leaf area index (Werk *et al.*, 1988), sapwood area (Thorburn *et al.*, 1993) and stem basal area are closely related (Cermak and Kucera, 1987).

Light transmission through upper-storey canopies depends on their leaf area and light extinction coefficients (Jackson and Palmer, 1989). Shade has been shown to cause poor yield in legumes. Shaded leaves tend to operate at greater light use efficiency, but they suffer from premature senescence (Stirling *et al.*, 1990; King, 1994). Tree canopies also contribute to loss of rainfall through evaporation of canopy interception, stem flow and canopy drip (Wallace, 1996). It has also been reported that the greater amount of water entering the soil closest to the tree is rarely available to crops since it is rapidly depleted either through root abstraction or drainage (Jackson *et al.*, 2000).

In summary, the above several mechanisms should enable agroforestry systems to use available water more effectively than sole plant stands. Cannell *et al.*

(1996) proposed that agroforestry systems might increase productivity if trees can capture resources that are under-utilised by associated crops. However, the benefits of reduced soil evaporation due to tree canopy cover, improved microclimate due to reduced air movement, improved soil chemical and physical properties, and increased soil moisture, are outweighed by detrimental competition for light, water and nutrients between trees and crops.

## 1.6 Tree pruning

### 1.6.1 Shoot pruning and pollarding

Tree pruning is defined as the removal of live, dying, or dead branches, from the standing tree with one or more objectives in mind. Some of the objectives of tree pruning in plantation forestry are to gain knot-free timber and to reduce competition for space and shading in the plantation. On the other hand, pollarding is a tree management technique in which the top is cut off to encourage the growth of new branches. Pollarding is commonly used in amenity trees to shape or form the crown (Julian and Katherine, 1996).

Pruning is an aid to proper development of certain forms of plant life, and without it, some plants would not grow satisfactorily, though it creates wounds, which are areas of weakness in wood (Dallimore, 1945). Whatever the size, scars must be minimised on trees grown for saw log production, thereby eliminating their influence in the final timber (Shepherd, 1986). It is fortunate that when trees are in good health, pruning scars heal without any serious injury to the wood (Dallimore, 1945). The rate of healing (occlusion) depends on the size of the branch pruned (smaller ones, faster rate), thickness of the bark (thicker bark, slow rate of occlusion), the diameter increment, i.e. rate of tree growth, the age of the pruned branch (younger branches heal faster), injury to the cambium and the tools used (Jacobs, 1938). Furthermore, Pudden (1957) reported that the rate of occlusion depended on the available soil moisture, especially in areas where water is vital for fast tree growth, i.e. it is the only limiting factor.

On-farm large tree canopies shade crops growing under them. Competition for light has been observed to reduce crop yields in various agroforestry systems, e.g. *Leucaena leucocephala* with maize (Kang *et al.*, 1981 and Srinivasan *et al.*, 1990). Shading by *L. leucocephala* caused reduced yield of *Zea mays*, *Ipomea batatas* and *Vigna sinensis* growing adjacent to it (Karim *et al.*, 1991). Light transmission through upper-storey canopies depends on their leaf area and light penetration (tree canopy density) coefficients (Jackson and Palmer, 1989). The effect of shading on the understorey depends on their light requirements. Most annual food-crops prefer full sunlight to shaded conditions for their fast growth rates (CABI, 1996).

To ensure the success of agroforestry combinations, the management of competition for a limited resource in the systems that farmers have chosen must be ensured. This requires an understanding of the processes underlying any management option taken. One such option that has been observed on farmers' fields (Tyndall, 1996), and has been explored in this study is pollarding to reduce competition for water use. Overall, sustainability of agroforestry can be achieved by identifying and minimising competition for the most limiting resource in the system through proper management of species combinations (Huang and Wang, 1992; Schroth, 1995).

*Grevillea robusta* has been reported in a survey of farmers' tree management practices in the highlands of Kenya (Tyndall, 1996) that it is normally pollarded once every two to three years. The main thrust behind this pollarding lies in lowering competition with crops but at the same time, obtaining fuelwood and improving the quality of timber produced, all of which are important for income generation on small farms. Since pruning is practiced for purposes of timber production, mulching, e.g. with *Alnus*, firewood production, stakes for climbing beans and fodder, adding the objective of minimizing competition for water, nutrients, and light, simply involves an alteration in its timing, intensity, and frequency.

Intensively pruned trees invest proportionally more of their belowground biomass in the form of fine roots rather than bigger ones because they require less structural roots for their small above ground structures (Gholz and Fischer, 1982;

Gholz *et al.*, 1986). This implies that on recovery, the crop and pruned tree root systems are even more intimate. Kramer and Kozlowski (1979) reported that it is common practice to prune back tops (pollarding) of transplanted trees to reduce the transpiring surface. This is done to compensate for loss of roots during transplanting, but reduction in the transpiring surface also reduces the photosynthetic surface, which is undesirable except when conservation of water is preferred to the possible maximum photosynthetic capacity.

Some of the factors required for pruning scar healing have been observed on both *Grevillea* and *Alnus* species, further justifying this study. The species are fast growing, for example at 10 years of age they have been converted to timber yielding quality products (AFRENA, 2000). Stem boles of both *A. acuminata* and *G. robusta* healed from pruned scars are presented in Plate 1.6. Plate 1.7 shows furniture products from the two species with spots indicating healed scars in wood, but also as proof that at 10 years of age, quality products can be obtained from the two species.

**Plate 1.6** *Lower stem boles of* Alnus acuminata *and* Grevillea robusta *showing healed scars of pruning. In* Alnus, *almost all the scars have completely disappeared while in* Grevillea *some scars can still be observed* (Photo by Sande, 2001).

**Plate 1.7** *Furniture products from* Grevillea robusta *and* Alnus acuminata *trees in Kabale. The trees were pruned regularly, harvested at 10 years of age, and converted to timber. Farmers too, harvest their own trees on farm* (AFRENA, 2001).

Whereas *A. acuminata* produces many branches along the stem as it grows, which would have been a disadvantage for timber production, it has indicated a high degree of occlusion from scars of pruning completely covering the scar where branches are cut. *G. robusta* produces relatively less branches along the stem in its growth and also heals very well from scars of pruning unless severely injured.

### 1.6.2 Root pruning

In addition to removal of branches, this study has explored root pruning on one side of trees in croplands, with the objective of reducing tree-crop competition. In boundary planting, crops are grown on one side of the tree and this is the side where roots were cut back to reduce their interference with food-crops. An advantage with boundary planting is that tree can only have influence on crops growing on the same terrace and not the lower terrace (Figure 1.2).

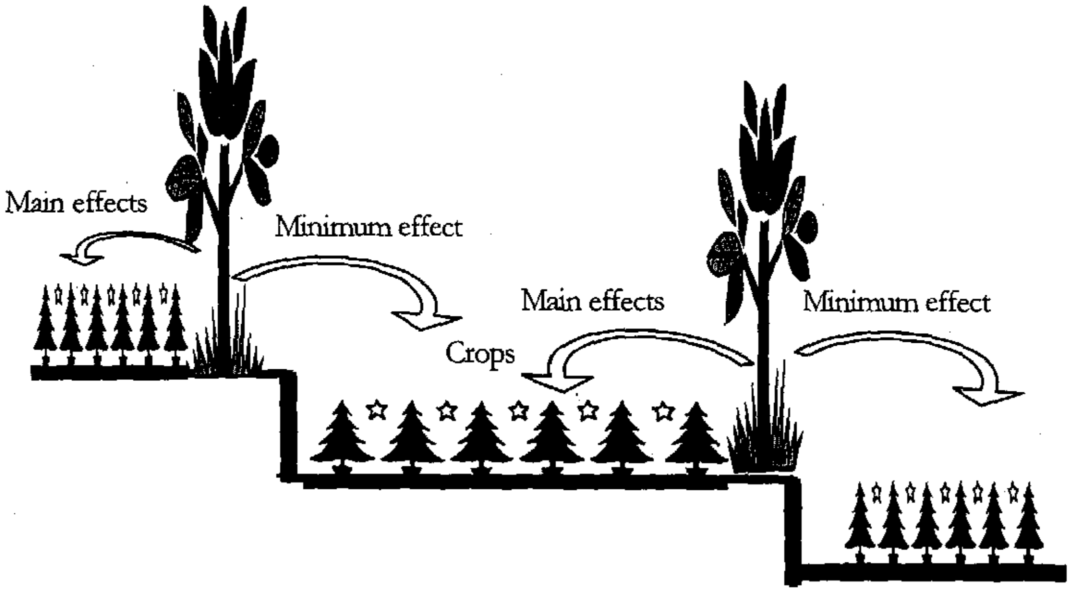

**Figure 1.2** *Illustration of boundary tree effect on crops. In Kabale, there is no field evidence so far to show that boundary trees affect crops on the lower terrace apart from minimum shading effects* (Sande, 2002).

As trees in croplands mature, the growth resource sharing system becomes imbalanced as the difference in tree-food crop size increases. Trees, being larger, increase not only their ability to capture resources, but also to suppress associated food crops. For example, trees have the advantage of a well-established root system at the beginning of each crop-planting season, and extract resources from deeper soil horizons than the roots of the associated crops for their normal growth or survival (Caldwell, 1987).

Normally, the greater percentages of tree fine roots occur in the topsoil horizon, which is also the crop-rooting zone (Dhyani *et al.*, 1990, Ruhigwa *et al.*, 1992). Root growth of both trees and crops follow seasonal wetting regimes (Schroth, 1995) and preferentially deplete soil surface layers of soil water and shift to lower horizons after the surface dries (Comerford *et al.*, 1984; Lehmann *et al.*, 1998). In an agroforestry system such as boundary planting, pruning can be extended to roots as a means of reducing competition with associated crops. Okorio *et al.*, (1994) found, by root pruning to 50 cm depth, that root competition was responsible for most of the reduction in crop yield. Competition increases over time when trees grow larger, intensifying their demand and ability to capture resources (Goldberg and Werner, 1983) while the crop component, occurring in terminal short-term rotations, continues to be suppressed. This study agrees with similar root pruning experiments in semi-arid areas of India on *Leucaena leucocephala* (Singh *et al.*, 1989; Korwar and Radder, 1994) and on *Cajanus cajan* (Daniel *et al.*, 1990).

Younger roots extract water more rapidly from soils than older roots, creating regions of low water potential, hence low soil hydraulic conductivity according to Simmonds and Kuruppuarachchi (1995). In multi-storey systems, crop roots normally grow within depletion zones of tree roots. Since trees have deeper roots than food crops apart from their surface roots, deeper roots can sustain the tree in case surface roots are pruned. When moisture in the soil is expected to be less, most surface roots can be pruned to allow associated crop roots to utilise the region. Pruning of tree surface lateral roots 1 m away from tree trunk was done to reduce water uptake from horizons exploited by food crops, thereby forcing the tree to acquire water that the crop would not otherwise acquire (Cannel *et al.*, 1996), i.e. from deeper horizons.

About 80% of crop roots occur in the top 60 cm (beans) to 100 cm (maize) of the soil profile with a maximum root density at 10 to 40 cm depth (Howard *et al.*, 1997). Although differences in root systems architecture occur, it is clear that root systems of the majority of tree species extract water from the crop-rooting zone, creating substantial tree-crop competition (Wilson *et al.*, 1998). Thus, pruning all tree roots occurring in the 50 cm depth of soil ensures utilization of moisture in this zone by crop roots. Ong *et al.* (1989) suggested that options for managing water competition might include pruning of tree roots to reduce their dominance, or manipulating tree canopy size to reduce their water use.

Some farmers appreciate tree-food crop competition and others often do not because of the informal layout of many planting systems and intermixing of species. Farmers may control competition for resources on-farm by selecting complementary species or provenances or by pruning tree roots. Introduction of trees on cropland represents a long-term commitment by farmers with high hopes and expectations of multiple needs to be met from these trees. However, dry spells of up to three months, as was experienced during 1999 to 2000 (Kabale meteorological station, 2002), could be disastrous for individual farmers' food production and sustainability of trees on-farm.

## 1.7 Statement of the problem

The main problem in managing agroforestry is how to retain the positive effects of trees on soil physical and chemical properties while reducing the negative effects of belowground competition between trees and crops (Ong, 1995; Schroth, 1995). On-farm trees are increasing in Kabale and elsewhere in Uganda. Tree planting is encouraged due to lack of enough land to establish separate woodlots to meet the ever increasing demand of wood products and tree services (Falkenberg and Nsita, 2000). However, trees can have undesirable and detrimental impacts on cropland such as competition with food crops for growth resources. Given the permanence of trees and their potential to grow to large sizes, they definitely out-compete food crops. Such competitive effects have been observed in many farmers' fields (pers. obs.), though it is difficult to separate effects of above and belowground competition.

Competitive effects of trees on food crops could be reduced by pruning (Schroth and Zech, 1995). Previous studies reported that trees that had been 50% defoliated, managed to maintain their shoot growth rates (Hoogesteger and Karlson, 1992). This led to the speculation that a reduction in root biomass must have occurred due to translocation of carbohydrates from roots to maintain shoot growth rate. Through excavation of soil in the rooting zone of intercropped cowpea (*Vigna unguiculata*), Howard *et al.* (1997) observed that *Grevillea* obtained about 85% of its water requirements below the crop-rooting zone. Though this could have been an artefact of the experimental design, due to compensation for severed shallower roots by deeper ones, it shows the scope of reducing niche overlap by disabling tree roots in the crop-rooting zone.

Ways of managing trees to reduce water use and concomitant competition with crops must be found if agroforestry in all its different guises, such as boundary planting, is to be widely adopted. Little attention has been paid to on-farm tree-crop competition in Kabale, yet farmers are being encouraged to plant boundary trees. There is an urgent need to balance tree transpiration with site water budgets. A simple option to reduce tree water use, which could be readily adopted by farmers, is pollarding and root pruning.

## 1.8 Justification of the study

Reducing the extent of tree-crop competition by means of crown and root pruning will enable tree planting on cropland to continue. Shoot pruning reduces transpirational demand and promotes straight and smooth tree boles free of knots, which are important attributes for quality timber production (Shepherd, 1986). Quality timber is one of the major purposes for on-farm tree planting for Kabale farmers. Knots are undesirable in timber since they cause cracks during changes in moisture content, do not take paint well, and interfere with timber processing (Evans, 1992).

Furthermore, shoot pruning provides firewood for the household given the shortage of firewood in Kabale. A recent survey (AFRENA, 2000) reveals that 90% households in Kabale use firewood as first priority fuel. Shoot pruning also reduces auxin supplies and therefore induces the end of dormancy though it temporarily reduces radial growth (Adlard, 1964). However, Banks and Prevost (1976) stated that the loss of increment will depend on the degree of reduction of the length of the living crown for a given species, site, spacing, age and intensity of pruning.

Pruning of surface lateral roots enables manipulation of water uptake zones so that the tree water uptake from areas exploited by crop roots is reduced, thus reducing competition. Reducing the extent of tree-crop competition will enable farmers to maintain crop yields and at the same time obtain tree products. It also leads to wide adoption of boundary planting technology; resulting into diversified and increased farm output, reduced pressure on protected areas and more sustainable land use systems in Kabale. While pollarding large trees is an option for reducing their competitivity, there is little published information on the response of large trees of different species to pruning. Some species such as *G. robusta* are known to withstand severe shoot pruning (Tyndal, 1996), but the response of *A. acuminata* was not known. Information on this topic has been gained from this study, in which large *Alnus* trees have been pollarded.

Some farmers prune their trees, often badly, to provide products such as firewood and to improve timber quality. The need to study in detail effects of pollarding on diameter increment and to demonstrate them to farmers on their farms has been worth the efforts of this study. Likewise, the potentials of deliberate root and pollarding to reduce tree-crop competition for both above and belowground resources were investigated and demonstrated to farmers.

## 1.9 Objectives of the study

The general objective of the study was to gain improved understanding of the biological interactions between trees in croplands and food-crops, and to be able to demonstrate the results to farmers for incorporation into daily land use planning and strategies for sustainable agroforestry practices. The specific objectives were: -

1. To explore the potential of pollarding and root pruning to reduce tree-food crop competition.
2. To evaluate the effects of pollarding and root pruning on the growth of *G. robusta* and *A. acuminata.*
3. To determine the value of pollarding for on-farm firewood production.

## Hypotheses

Ho: Pollarding and root pruning do not have the potential to reduce tree-crop competition.

Ha: Root pruning and pollarding have the potential to reduce tree-crop competition.

Ho: Pollarding and root pruning on one side do not influence tree growth.

Ha: Pollarding and root pruning on one side severely retard tree growth.

Ho: Shoot pruning does not yield branches for farmers to use for firewood.

Ha: Shoot pruning yields branches for farmers to use for firewood.

# Chapter 2

## 2 Study area description

This chapter describes the location, climatic and edaphic profiles, demography, and major economic activities in Kabale District where this study has been conducted. The chapter also presents an overview of the tree species on which the study has been carried out and their potentials in agroforestry.

### 2.1 Location and description of Kabale District

Kabale District is in South-western Uganda, neighbouring the districts of Kisoro in the west, Rukungiri in the north, Ntungamo in the northeast and the Republic of Rwanda in the south (Figure 2.1). Kabale lies approximately between latitudes 1°S and 1°30'S, and longitudes 29°18'E and 30°9'E and covers an area of 1,827 km$^2$.

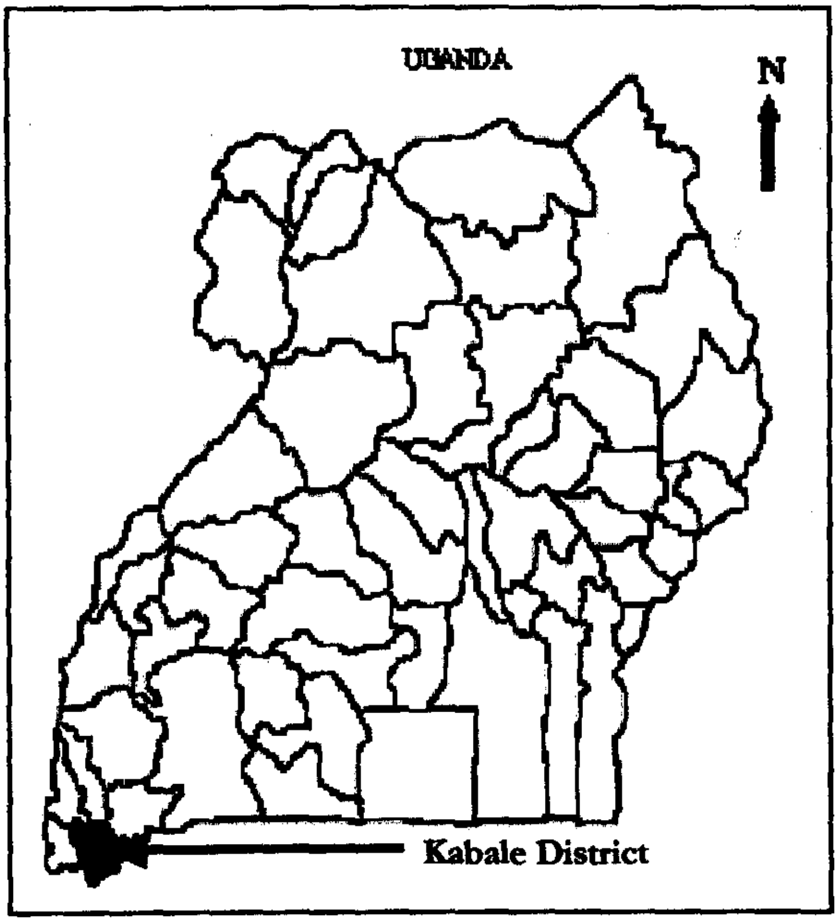

**Figure 2.1.** *Map of Uganda showing Kabale and other districts.* Source: AFRENA, 2002.

Rwabwoogo, (1997) described Kabale District as dominated by conical shaped interlocking hills (the Kigezi Highlands) with altitudes ranging from 1220 to 2500 m above sea level (Fig. 2.2). The topography is rugged, characterised by broken mountains, scattered Rift valley lakes, deeply incised river valleys, steep slopes of 10-60°, and gentle slopes of 5-10° adjacent to reclaimed papyrus swamps (Raussen *et al.*, 2001). It is partly due to these factors that the two species being investigated have become of importance to Kabale District. *Alnus acuminata* has performed best in Kabale compared to other parts of Uganda where it has been tested, and the exceptionally excellent performance in Kabale has been attributed to the high altitude ranges. *Grevillea robusta* has been observed to perform well across all landscapes.

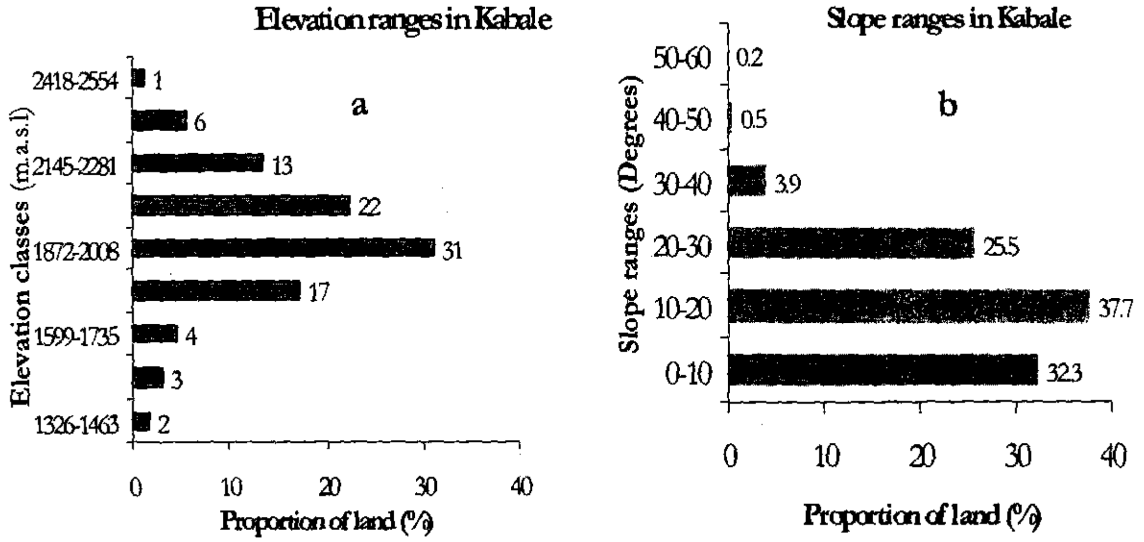

**Figure 2.2** *Distribution of land elevation classes (**Fig. 2.2a**) and slope ranges (**Fig. 2.2b**) in Kabale District* (AFRENA, 2001).

## 2.2 Soils of Kabale

About 70% of the district is covered with ferralitic sand clay loams (Harrop, 1960). Clay loams developed from phyllites and are predominant on the slopes, while silty clays and peat developed from peaty clay alluvium, occur in the valleys. More than 50 years ago, farmers begun developing the bench terraces along the contours of the hills to protect soils from run off, and these are now a common feature in Kabale District farming systems (Raussen *et al.*, 2001).

## 2.3 Climatic description

Kabale District receives bimodal rainfall, with highest peaks in March and April, and October-November averaging 1000-1500 mm annually. Mean annual maximum and minimum temperatures are 23°C and 10°C, respectively (Department of Meteorology, 1997). A brief dry spell occurs in January and a drier period from June to August. Rainfall was, however, much below average from April to July 1999 and from May to July 2000. In contrast, exceptionally high rainfall was recorded in August 1999 (Fig. 2.3). This is the period when this study was running and certainly, the effects of such unusual weather have been reflected in the crop yields. Although the area is mountainous, the favourable climate and the originally fertile soils, coupled with historical factors, have led to high population densities of 246 people per km$^2$ (Rwabwoogo, 1997).

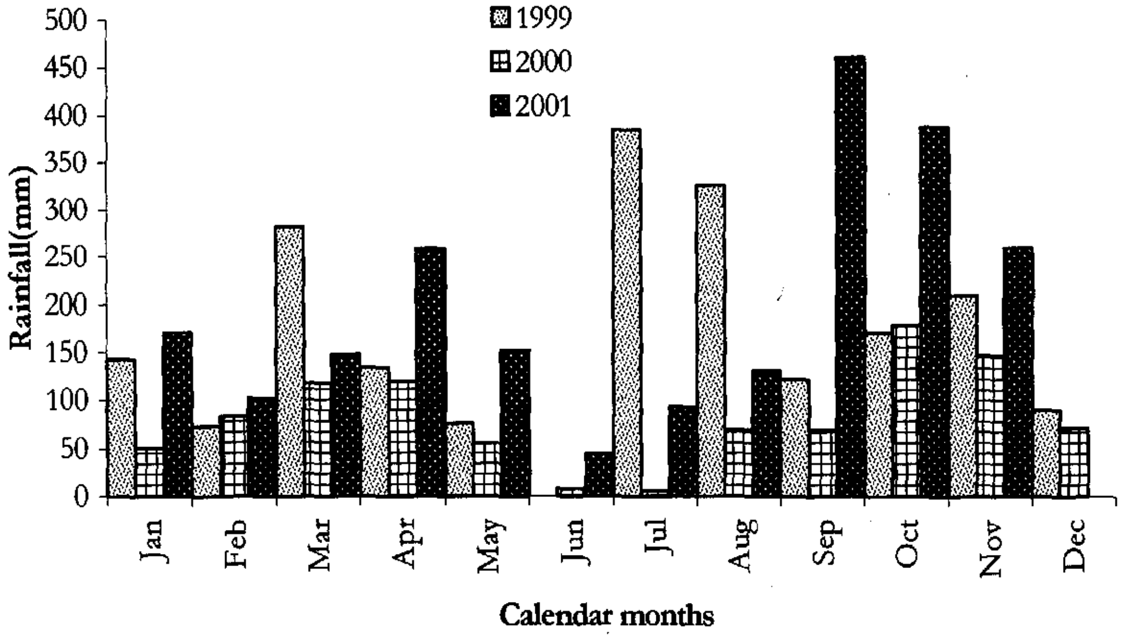

**Figure 2.3** *Rainfall profile in Kabale District from 1999 to 2001 and during this study. Raw data were obtained from Kabale District Meteorological Department through* FORRI *agroforestry programme, Kabale.*

## 2.4 Economic activities

Agriculture is the major economic activity in the district. The most prevalent form of agriculture is smallholder agriculture based on annual crops of sweet potatoes (*Ipomoea batatas*), Irish potatoes (*Solanum tuberosum*), sorghum (*Sorghum bicolour*), maize (*Zea mays*), beans (*Phaseolus vulgaris*), pigeon peas (*Cajanus* *cajan*), tomatoes (*Lycopersicon esculentum*), cabbages (*Brassica oleracea*) and bananas (*Musa* species) on a much smaller scale. The high population pressure has pushed people to farm on very steep fragile hillsides (Plate 2.1), destroying contour bands and practising continuous cultivation with a very short fallow. Livestock include mainly cattle, goats and sheep with dairy farming becoming more prominent in valley bottoms and zero grazing units.

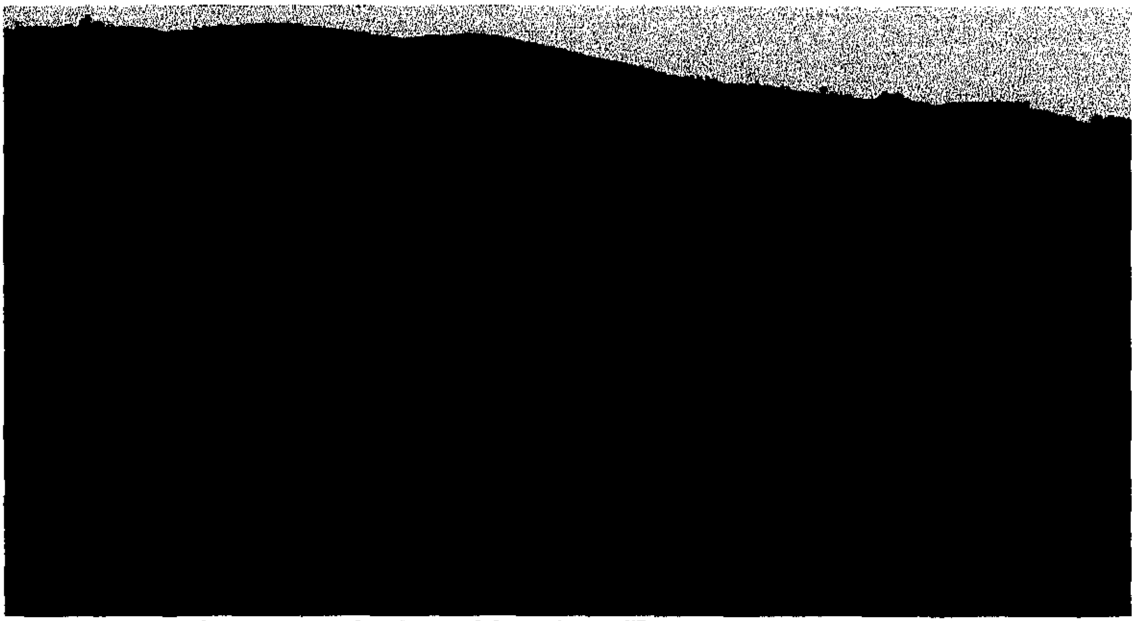

**Plate 2.1** *Bench terraces and cultivated hillsides in Kabale District. A landscape showing how cultivation stretches to the tip of the hills and most of the hills are void of tree cover exposing them to all agents of degradation. Ridges or contour bands can be observed throughout the hillsides. These are the areas (boundaries) where boundary planting takes place* (AFRENA, 2001).

## 2.5 District administration

Kabale District is one of the 56 districts of Uganda governed on a decentralised form of government. Local governance has particularly become important in Uganda since the late 1980s when "Resistance Councils"(R.Cs), currently called Local Councils (L.Cs) were established to help stabilise the security after more than a decade of civil unrest. The Local Government Act of Uganda (Uganda, 1997), however, initiated a much broader decentralization programme. Government functions were strengthened not only at district level but also at lower administrative levels. Fiscal responsibility as well as legislative power has been decentralised. The Local Government Act specifies functions and services of the district and other lower councils in the district, e.g. the Local

Council 3 (L.C. 3-formerly R.C.3). Relevant to this study are the functions for managing natural resources; and these include:

1. Providing agricultural ancillary field services such as extension services;
2. Controlling soil erosion and protecting local wetlands;
3. Protecting the environment;
4. Preventing and containing food shortages, and providing germplasm (planting material).

All these functions and services are relevant to wide spread adoption of agroforestry, some directly and others indirectly.

Traditional agroforestry has been practised for a long time in Kabale. Recently (since 1988) scientific efforts have focused on agroforestry in Uganda, and Kabale was among the first areas to receive attention. The research findings have indicated a number of multipurpose tree species that potentially hold a future in agroforestry in the district. Such species include *A. acuminata* and *G. robusta,* whose potential in agroforestry are further reviewed in the sub-sections of 2.6.

## 2.6 Description of tree species in the study

### 2.6.1 Biology, ecology, and propagation of *Alnus acuminata*

*A. acuminata* is one of 30 *Alnus* species in the family Betulaceae (Russo, 1990). *A. acuminata* is a fast-growing tree native to central and South America extensively cultivated in Costa Rica, Columbia, Bolivia, Peru, and Venezuela (NAS, 1980; Russo, 1990, 1995). In its native habitat (extending from latitude 60° southward to latitude 34°), the species is found at moderate to high altitudes (1200-3200 m) with average annual rainfall ranging between 1000 to 3000 mm, and mean temperatures ranging between a minimum of 4°C and maximum of 27°C (Russo, 1995). In this region, *A. acuminata* grows naturally along slopes, ravines, roadsides, stream banks on hills and mountain ranges. It is usually found on deep, well-drained loams or loamy sands of alluvial origin.

A morphological description of *A. acuminata* was given by NAS (1980) and Russo (1990, 1995). The species varies in height from 15-30 m and up to 50 cm

DBH under natural conditions, while in plantations it reaches a height of 40 m. It has a broad spreading root system close to the soil surface. The leaves are simple, alternate, elliptical, 6-15 cm long, 3-8 cm wide; border double dentate, deciduous or semi-deciduous (Plate 2.2). The upper leaf surface is dark green; the lower is whitish light green. However, in Kabale, *Alnus* leaves are attractive to insects, which cause leaf perforations and lesions (see Plate 2.2), but no major negative effect of leaf perforation has been recorded so far on the growth of the species.

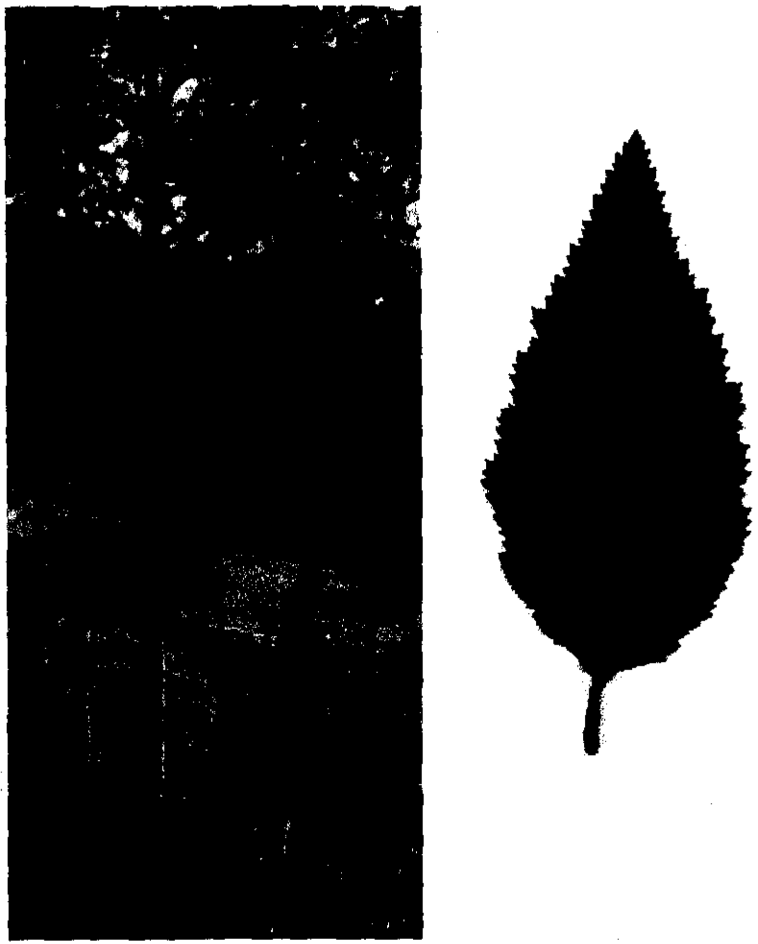

**Plate 2.2** Alnus acuminata *(left) and its leaf (right). This is from a farmer's field in Kabale showing* A. acuminata *with simple elliptical leaves in large numbers. When leaves fall and decay, they produce good soil mulch* (AFRENA, 2001)

The crown shape of *A. acuminata* is open rounded to pyramidal. The trees have light-grey or silvery bark with yellowish lenticels, lignified cones, and male and female flowers in separate catkins on the same branch. Inflorescences are cone-like and bear more than 100 fruits per cone. The fruit is a small membranous-winged samara, 2-3 mm long, which contains one seed, mainly dispersed by wind. Seeds are small, with more than 2 million seeds per kilogram.

The species is propagated by seeds without pre-treatment, but seed viability decreases very rapidly if not properly stored in cold conditions. Germination of *A. acuminata* seeds starts 6-7 days after sowing and completes within 15 days. Observations over the years in Kabale District show that the germination percentage is low (less than 50%) when sown in seedbeds. Farmers in Kabale still find real problems germinating *A. acuminata.* Pre-germinated seedlings are currently provided by the FORRI agroforestry programme in containers for farmers to prick out and transplant. Seedlings can be pricked out 20 days after germination. In Costa Rica and Columbia, seedlings 20-100 cm in height (4-8 months old) are transplanted. Besides nursery stock, seedlings from natural regeneration can be used (Russo, 1995). For a long time in Kabale, no seedlings from regeneration had been observed until 2001 when farmers from hilltops (approximately 2300 m.a.s.l.) reported that *A. acuminata* seedlings from natural regeneration were growing well on their farms.

### 2.6.2 Potential of *Alnus acuminata* in agroforestry

*A. acuminata* is used for timber, fuel wood, watershed protection, and soil improvement. It produces good wood with even burning characteristics and has long been used for firewood in its native region (NAS, 1980). A number of *Alnus* species enhance ecosystem nitrogen supply, increase the rate of carbon and mineral nutrient cycling, and stimulate growth of associated vegetation (Tarrant, 1983). *A. acuminata* is one such species that shows great potential for restoration of extreme environments and impoverished soils (Dawson, 1986). The species grows well on slopes and its root system tends to be lateral, extended rather than deep, and confined. These characteristics make *A. acuminata* a very useful species for controlling erosion in steep and unstable soils (NAS, 1980).

*A. acuminata* is host to the nitrogen fixing actinomycete *Frankia* (Tarrant, 1983; Russo, 1990, 1995). Clusters of light-yellow nodules occur on the base of the roots of *A. acuminata* seedlings as young as 2 months old and are found from the base of the roots to the end of the rootlets (NAS, 1980). Its roots are also infected by endomycorrhizal fungi, resulting in a tripartite symbiotic association, i.e. *Alnus*, *Frankia*, and arbuscular mycorrhizae (AM). The ability of the species to fix atmospheric nitrogen was first reported by Rodriguez-Barrueco (1966). Russo (1990) contends that AM in *A. acuminata* roots play a functional role in nodule formation because they act as phosphorus pumps and help in the active meristematic processes of new nodule tissue formation. By fixing nitrogen, *Alnus* trees enhance soil fertility and benefit crops grown with them. Similarly, reports on agroforestry trials in Uganda indicate increased yields of crops grown in association with *A. acuminata* (Peden *et al.*, 1993; Okorio *et al.*, 1994; ICRAF, 1997).

Because of its multiple uses and ability to both fix nitrogen and grow on soils with low phosphorus, *A. acuminata* is a prime candidate for expanded use in silvicultural plantations and agroforestry systems in highlands (Russo, 1995). It has been introduced in a number of countries, including Chile, New Zealand, Rwanda, and Uganda (NAS, 1980; ICRAF, 1997). ICRAF through AFRENA is planning to introduce more provenances of *A. acuminata* to increase the genetic base of the species in Kabale.

### 2.6.3 Biology, ecology, and propagation of *Grevillea robusta*

*G. robusta* is a tree of Australian origin, which has become very important for on-farm agroforestry in the tropical highlands of East and Central Africa (Harwood, 1992). Its use as a shade tree and for ornamental purposes is wide spread in the tropical highlands and in subtropical and warm temperate regions around the world. Recent scientific study of agroforestry has increased the level of scientific interest in this species, in recognition of its economic importance.

*Grevillea* has been termed *robusta* meaning strong or stout in allusion to its vigorous growth. Growing among the thick moist woods on the banks of Brisbane River, it was described by Lebler (1979) and Harwood (1989) that "with the exception of Araucarias, none of the forest trees surpassed *Grevillea* in height". *G. robusta* is mostly propagated from seed. Seed fall occurs two months after flowering (Harwood, 1992), and seed production occurs every year. Trees as young as six years produce fertile seed, but may not be able to repeat the process for one or two years following, implying year-to-year fluctuations in quantity produced (Harwood, 1989). *Grevillea* seed can be stored for two years at room temperature and germination usually takes place 20-28 days after sowing (Egli and Kalinganire, 1998). Seedlings can be transplanted to the field at about 20 cm high or between 6-9 months after sowing. Farmers no longer find problems raising seedlings of *Grevillea*. In Kabale, *Grevillea* seedlings are now raised bare rooted on farmers' fields.

*Grevillea* was probably introduced to Uganda about 1901 (Okorio and Peden, 1992) as shade tree for coffee and tea, and as an ornamental (Tothill, 1940). During the 1940s and 1950s, the Ugandan Forest Department established several species trials in different parts of the country and *Grevillea* was included among them. The main objective of the trials was to observe and assess the performance of those species in plantations. More recently, ICRAF-AFRENA programme in Uganda initiated research on *Grevillea* as a possible agroforestry species for on-farm planting in the Ugandan Highlands (Plate 2.3). Its leaves are compound with the upper surface being green while the lower surface is whitish grey. Kabale farmers reported that *Grevillea* leaves take too long to decompose and in some cases too many *Grevillea* leaves in a given place lead to poor crops. The branching pattern is rather vertical than horizontal in orientation explaining why it has a smaller canopy spread than *Alnus acuminata*. According to Spiers and Stewart (1992), farmers in Embu (Kenya) are generally aware that dense stands or large unpruned *Grevillea* trees can reduce crop yields. However, the effects can be reduced or eliminated by good management in the form of shoot pruning or pollarding.

Annual growth rates of 2 m (height) and 2 cm (diameter) over the first 5 years are commonly recorded in a number of countries where climate and soils are suitable. The species can persist in a wide range of climates, but grows much slower in less suitable environments. *G. robusta* performs best on reasonably fertile, deep, open soils, and less well on heavy clays, and does not tolerate water logging. It appears to tolerate a wide range of pH levels from acid to mildly alkaline, although manganese toxicity and boron deficiency have been noticed on acid (pH 4.2) soils in Kenya, in southern India, Papua New Guinea and Hawaii (Harwood, 1989; Harwood and Booth, 1992).

**Plate 2.3** Grevillea *grown with maize on-farm Kabale. On-farm boundary planting of* Grevillea *in Kabale is increasingly becoming attractive to farmers like Mzee Rwansheija (lower terrace) standing below his boundary trees. Inset is* Grevillea *leaf lying on its stem.* (AFRENA, 2001).

According to Booth and Jovanovich (1988) the following range of climates are suitable for good performance of the species:

| | |
|---|---|
| Mean annual rainfall | 600-1700 mm |
| Rainfall regime | Uniform/bimodal, summer or winter |
| Length of dry season | 0-6 consecutive months <40 mm rainfall) |
| Mean maximum temperatures (Monthly) | 25-31°C |
| Mean minimum temperatures | (Monthly) 1-12°C |
| Mean annual temperature | 13-20°C |
| Absolute minimum temperature | Not lower than –10°C |

However, information from some sites in Africa suggest that satisfactory growth is possible with mean annual temperatures well in excess of 20°C; for example Okorio and Peden (1992), Habiyambere and Musabimana (1992). There are also interactions between individual climatic limits; for example, a bimodal annual rainfall pattern may be more effective than a unimodal pattern supporting growth and survival in semi-arid areas.

### 2.6.4 Potential of *Grevillea robusta* in agroforestry

*G. robusta* is popular with African farmers because the species provides economically viable products, it is easy to propagate and establish, grows in low-fertility soils, does not compete strongly with adjacent crops, and tolerates heavy pruning of its roots and branches (Harwood and Booth, 1992). It has been reported that *G. robusta* mainly possesses roots oriented in the vertical plane (deep rooted) with very few shallow roots and correspondingly low levels of competition with associated crops for water and nutrients (Howard *et al.*, 1997). Over the last century, *G. robusta* has become well established in the tropical and subtropical highland environments (Harwood, 1989). The first main use was as shade tree for tea and coffee plantations. Meanwhile, farmers have developed a new role for the species as a multipurpose tree for small mixed farms, particularly in Africa, where it is grown in rows and as isolated trees on the farm boundary and within the farm. Its cultivation on small farms makes a substantial contribution to national and individual wood production in several African countries and locations, for example in Kenya (Milimo, 1988 ex Harwood and Booth, 1992). In Uganda, it has been reported to perform well at altitudes ranging from 1,300 to 2,400 m.a.s.l, but its performance in terms of diameter increment was poorer at higher altitudes than at low altitudes (Peden *et al.*, 1996).

# Chapter 3

## Materials and methods

This chapter reports materials and methods employed in this study between late 1999 and August 2001 in Kabale District, to assess the effect of pollarding and one side root pruning on crop yield next to tree rows on farm boundaries and on the growth (girth increase) of *Alnus acuminata* and *Grevillea robusta*. The study has been conducted on farmers' fields to enable their participation in the research process so they gain could confidence in putting the results to practice. Trees established 5 years previously were experimented on because it was expected that at this age and beyond, they compete severely with associated food-crops. Better and well designed field layouts, and more comparisons would have been preferred than was used in this study, but this would mean setting up new experiments and waiting for another 5 years before providing a solution to farmers. Some of the farmers had abandoned their fields due to severe competition from trees that have been tested in this study. Demonstrating to farmers, on their farms, how to continue growing crops with large trees was the most treasured part of this study.

Recognising that much attention has been given to the subject of tree-crop competition in recent years, this study intended to explore tree-crop competition of practical on-farm situations where farmers were involved, since most of the work reported has been mostly strategic research. For example, water balance in agroforestry has been reported elsewhere, e.g. soil water evaporation (Jackson and Wallace, 1999), soil water storage and retention (Jackson *et al.*, 2000), tree and crop transpiration (Lott *et al.*, 1997). On-farm tree-food crop competition has not been frequently reported. Therefore, this study focused on this important aspect. Other examples of related studies are Huxley *et al.* (1989b); Teklehaimanot and Jarvis (1991); Ong *et al.* (1991b); Wallace *et al.* (1995); Jackson *et al.* (1998b); Smith *et al.* (1998); Miller and Pallardy (2001); Ong *et al.* (2002). The methods that were used in this study are based on what was described by Huxley (1985), where crop yield in rows next to trees was assessed on dry weight basis. Tree growth (yield) was assessed by means of both Diameter At tree Base (DAB) and Diameter at Breast Height (DBH), which were periodically assessed at 30 cm and 130 cm from ground level respectively. In addition, tree yield in terms of fresh firewood from pollarded branches was measured to determine how much firewood a farmer gets. Details of methods and materials are outlined in sections that follow.

### 3.1 Tools used

Tools used were selected basing on the fact that they are generally acceptable and locally available to farmers. The only relatively new tool to the farmers was a "Lotus" pruning saw but some farmers were already familiar with it. The advantages with the pruning saw are that it minimises damage to trees during pruning and it has a disposable blade, which is available on the market. Details of other tools and how they were applied are provided in sections 3.3 and 3.4.

### 3.2 Experimental layout

The study was carried out on sites established in 1995 on several farmers' fields in Kabale District with assistance from AFRENA but have been under farmers' management. Twelve farmers' sites were used for this study. These farmer sites are located in the Katuna Valley, in which soils, rainfall, and farming practices do not differ significantly. The experiment is a Randomised Complete Block Design (RCBD) with farmer sites as replicates. Two tree species were tested for pollarding and a combination of pollarding and one side root pruning in this experiment, i.e. *Grevillea robusta* and *Alnus acuminata*. These species are the most widely used for agroforestry and reforestation in Kabale. The field layout of the experiments and the tree treatments are illustrated in Figure 3.1 (Page 47).

### 3.3 Treatments

Each site (replicate) had 6 trees of each species (12 individual trees in total per site). Three treatments were imposed per species, i.e. two trees per treatment. All the treatments were imposed before crop sowing. The three treatments reported here comprised of:

1. Pollarding, i.e. all the branches and the top cut off,
2. Pollarding and root pruning (on one side where crops are growing),
3. Control (no pruning, i.e. trees left intact).

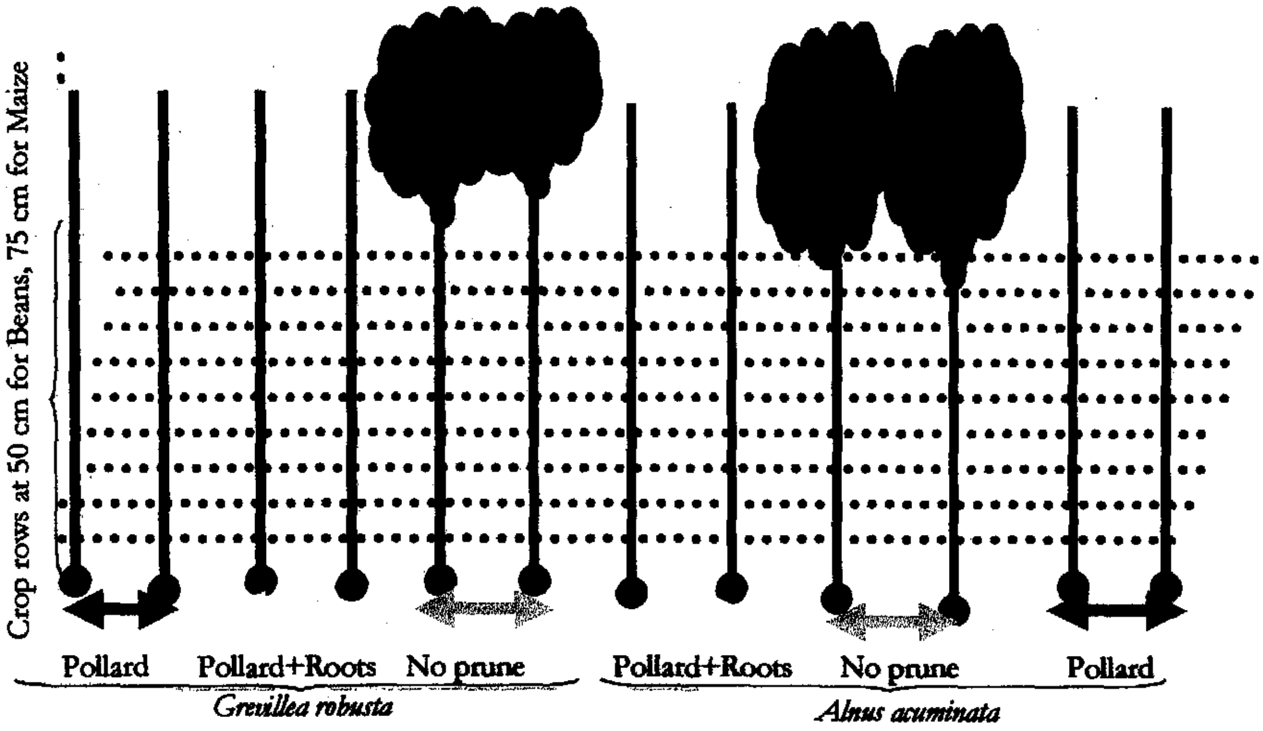

**Figure 3.1** *Illustration of the field lay out. Each site had six trees of each species, planted at 2.0 m spacing in a row. For each species, two neighbouring trees selected at random received the same treatment. In addition, sole crop plots (without trees) with similar length, existed in-between the two species (not indicated in sketch)* (Sketch by Sande, 2000).

In charts, sketches, graphs and tables, treatment names were adopted in short form to ease writing as:

1. Pollarding referred to as "Pollard."
2. Pollarding plus root pruning referred to as "Polloots."
3. No pruning referred to as "Control."

### 3.3.1 Pruning and pollarding

Some of the farmers were familiar with pruning, with the aim of producing good timber. Precautions were taken to make pollarding simple to minimize the possibility of farmers perceiving it as an "extra" added task to the heavy load they already have. Pollarding was done using a pruning saw taking care to prune as close to the stem and as smooth as possible. The typical on-farm scenario during the study is illustrated in Plate 3.1.

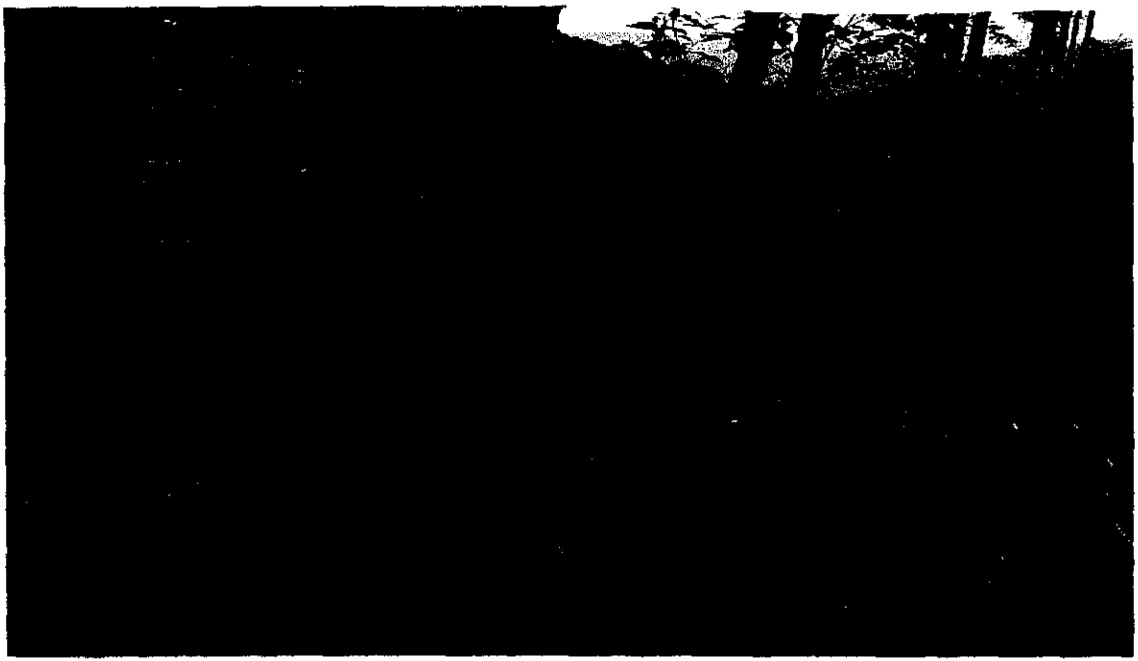

**Plate 3.1** *On farm experiment layout. Two months old beans growing in rows next to* Alnus acuminata *trees (nearest to camera) and* Grevillea robusta *(further on). At an early age of crops, the competition between trees and crops is not strong, especially when there is enough moisture for the food crops. On some trees, epicomic shoots resulting from pruning can be observed* (AFRENA, 2001).

The top was removed (pollarding) by making a slanting cut to minimize the possibility of water seepage incidence into wood through the cut surface. There was no standard height of pollarding since some farmers felt it may be possible to get two logs from some of their trees. However, no tree was pollarded at less than 5 m height, given that the standard length of timber known to Kabale farmers was 4.7 m. The difference between 5 m and 4.7 m was an allowance for stumps and errors that may occur during logging. Ladders were used to pollard trees that were not easy to climb. Pollarding and the procedure followed are illustrated in Figure 3.2.

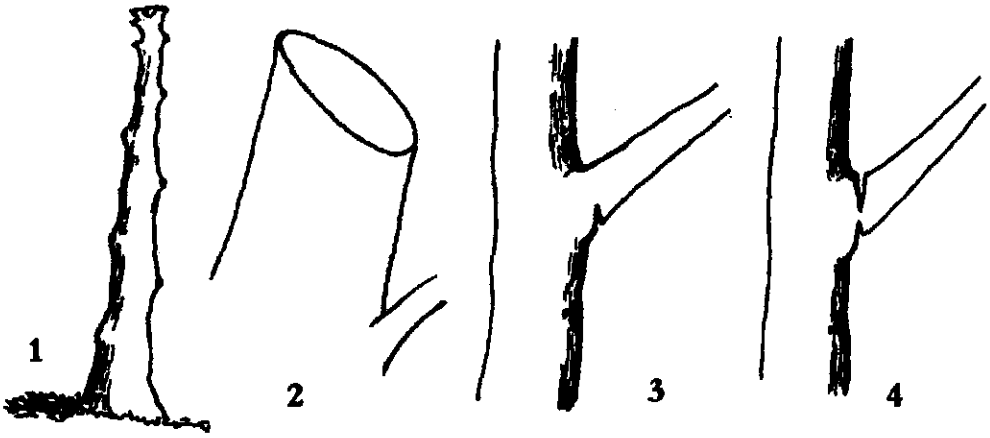

**Figure 3.2** *Illustration of the pruning and pollarding procedures. Number* 1 *shows a completely pollarded tree, 2 shows a slanting cut to avoid water seepage into wood,* 3 *and* 4 *show steps of branch pruning. Cutting starts from the lower side of the branch* (3) *to avoid bark injury and then from upper part* (4) *as close to the stem as possible* (Modified from AFRENA, 2001).

### 3.3.2 Root pruning

In boundary planting, crops are only grown on one side of trees and therefore, root pruning was done on one side of the tree, i.e. between trees and crops. Root pruning was done using both a hand hoe for the surface and a forked hoe to access tree roots. Trenches were dug at 50 cm from the tree base to 50 cm deep. Trenching was carried out at 50 cm away from trees to cater for the scepticism of farmers who felt that cutting tree roots might cause it to fall, but also to avoid difficulties in trenching near trees without damaging the stems. The trenching depth of 50 cm was based on the fact that farmers have been observed to normally dig to such depth and even deeper, but also this was because most root competition occurs in topsoil (Howard *et al.*, 1997). All root trenches were refilled after cutting and roots (≥2 mm) crossing each trench were counted.

From each root-pruning trench the number of roots equal to or greater than 2 mm (≥ 2 mm), measured using a Vernier calliper, were counted and recorded. It was reported that surface fine roots have limited longevity (Kummerow *et al.,* 1978), but extract more water from soils than older roots (Simmonds and Kuruppuarachchi, 1995). Therefore, by severing all tree roots found to a depth of 50 cm, the tree could still acquire water from deeper horizons by means of deeper roots and the associated crop acquires the water within the root-pruned zones.

### 3.4 Other assessed parameters

1. **Firewood mass.** All branches per pollarded tree were counted and recorded, a branch being defined as having a diameter ≥1 cm at its base. Branch biomass removed was quantified in terms of fresh firewood mass (kg) to determine how much a farmer gets in a single pruning. Leaves were first removed before weighing, and weighing was done using a scale calibrated in kilograms. Firewood was assessed twice, at first pruning and second pruning. The second pruning took place after 18 months from the first pruning. Since farmers took most of the branches for firewood, samples of three average sized branches were taken from each site per species and oven dried at 85°C to constant mass to obtain firewood dry mass. The dry firewood

mass was compared for the two species and used to calculate the amount of dry firewood mass obtained from pollarding per site.

2. **Diameter at Breast Height** (DBH) was measured in cm taken at 1.3 m from ground surface with a diameter tape and recorded to the nearest 1 mm. DBH was assessed three times during the study, i.e. at 63, 73 and 83 months after planting. The point of measurement was obtained using a 1.3 m long stick held vertically along each individual stem and the point was marked for subsequent measurements. The purpose of DBH assessment was to determine the effect of pruning on tree growth, i.e. rate of diameter increase.

3. **Diameter At tree Base** (DAB) was measured at 30 cm from ground surface. The same procedure used for DBH was applied to DAB and all readings were recorded to the nearest 1 mm. This was also assessed to determine the effect of pruning on tree growth.

4. **Crown diameter** (spread) was measured in meters. This was measured using a 50 m measuring tape. Two people held the tape stretched to the crown perimeter with the tree being the centre in a North-South direction, and a second measurement in the East-West direction and the mean of the two values was recorded to the nearest 0.1 m. This was only assessed and recorded before the first pruning.

### 3.5 Timing of treatments and sowing

The sequence of measurements started with tree assessment of DBH, DAB and crown diameters. Then followed first pollarding (imposing treatments) together with firewood assessments. Crops were planted in the sequence of beans-maize-beans. DBH and DAB were assessed before the pruning treatments at tree age 63 months after planting. Subsequent second and third assessments of DAB and DBH were carried out at ten months interval, i.e. at 73 and 83 months of age respectively. The first DAB and DBH assessments took place from July to September 1999. Tree pruning treatments were imposed during October-December 1999 before any crops were sown. Trees were pruned during the rainy season to minimize tree stress that could result from pruning. The first bean crop season lasted from late April 2000 to early August 2000, while the maize season lasted from late September 2000 to late March 2001 and the second bean crop season from mid May 2001 to late August 2001. The second pruning was carried out after the second bean season, i.e. during the months of September and October 2001. Sowing of beans was done at a spacing of 50 cm between rows (from row to row) and 15 cm within rows while for maize it was at 75 cm between rows and 30 cm within rows. The sequence of these events is illustrated in Figure 3.3(page 52).

### 3.6 Crop harvesting and sample processing

Harvesting and sampling was done on an area of 3 m x 1 m (3 $m^2$) for beans (Figure 3.4) and 3 m x 1.5 m (4.5 $m^2$) for maize (see Figure 3.4 page 53), i.e. two crop rows harvested and bundled together in each case. The influence of distance from trees on crop yield was measured from 1 m to 5 m in the first bean season. In the second bean season, harvesting was extended to 8 m away from trees. Since between rows spacing of maize was 75 cm, harvesting was in increments of 1.5 m (2 rows) from tree bases.

For the first bean season, data were not collected from sole crop plots (plots without trees) because it was left for farmers as their share harvest. However, in the second bean season and the maize season, it was found necessary to compare sole crop plots with tree plots, and farmers agreed that they would receive back their harvest after oven dry weight assessments. Therefore, in the second bean season and in the maize season, data were collected from sole crop plots for comparison with data from plots with trees. Nevertheless, sole crop plots were not uniformly distributed since they only existed between the two species per site. This resulted in non-balanced experimental analysis. In each harvesting plot, bean pods were collected and shelled in the field to obtain seeds, weighed and recorded to the nearest 1 g. Oven dry weight was obtained by drying the samples to constant mass at 70°C. Similarly, maize cobs were harvested from each 4.5 $m^2$ plot in the field, shelled and weighed to obtain grain weight (g) and recorded to the nearest 1 g. Oven dry weight was obtained following the same procedure as for beans. All the data obtained were recorded on standardised forms and entered into excel database in preparation for statistical analysis.

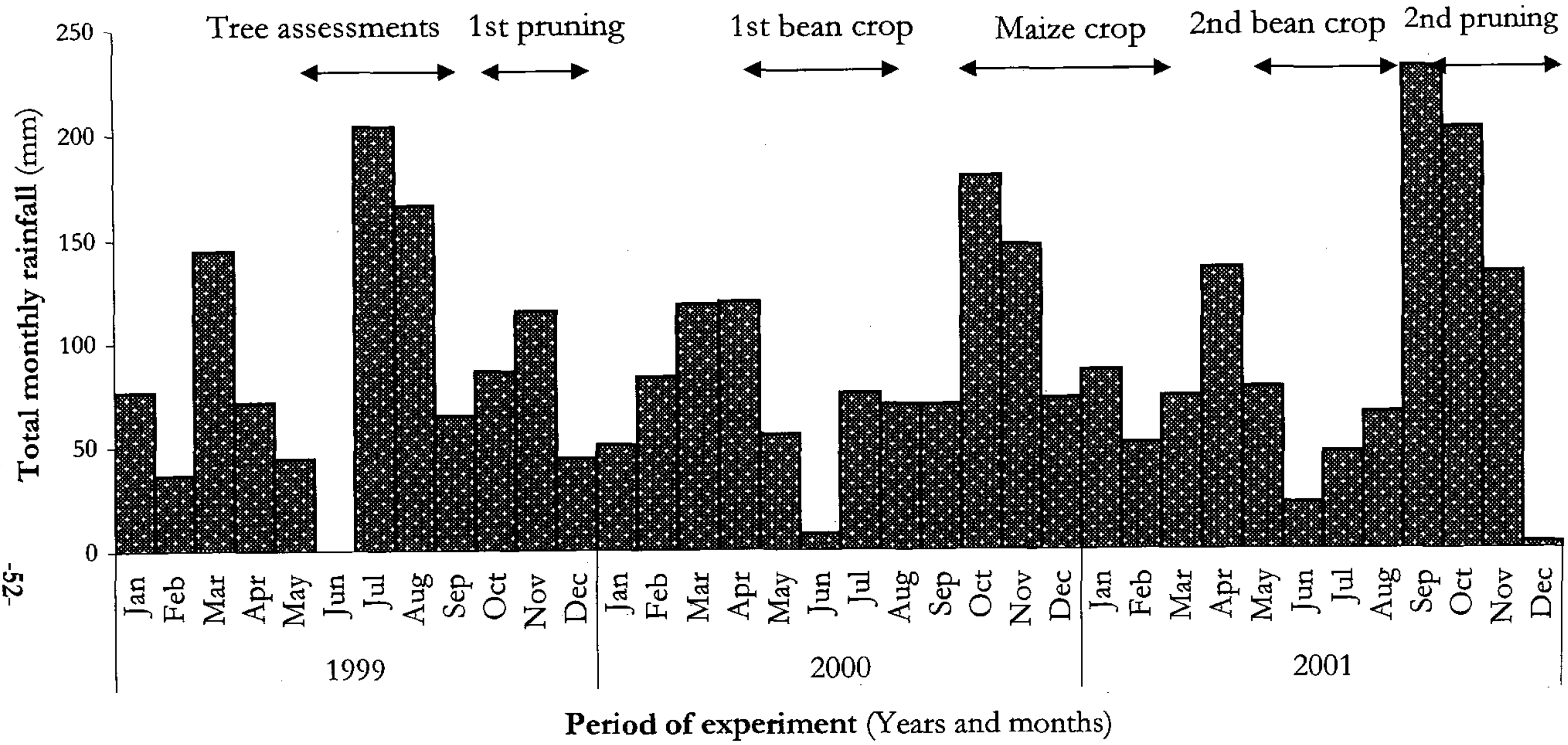

**Figure 3.3** *Chart showing monthly rainfall for Kabale District for the period January 1999 to November 2001 and the schedule of events, treatments and cropping systems during the study.*

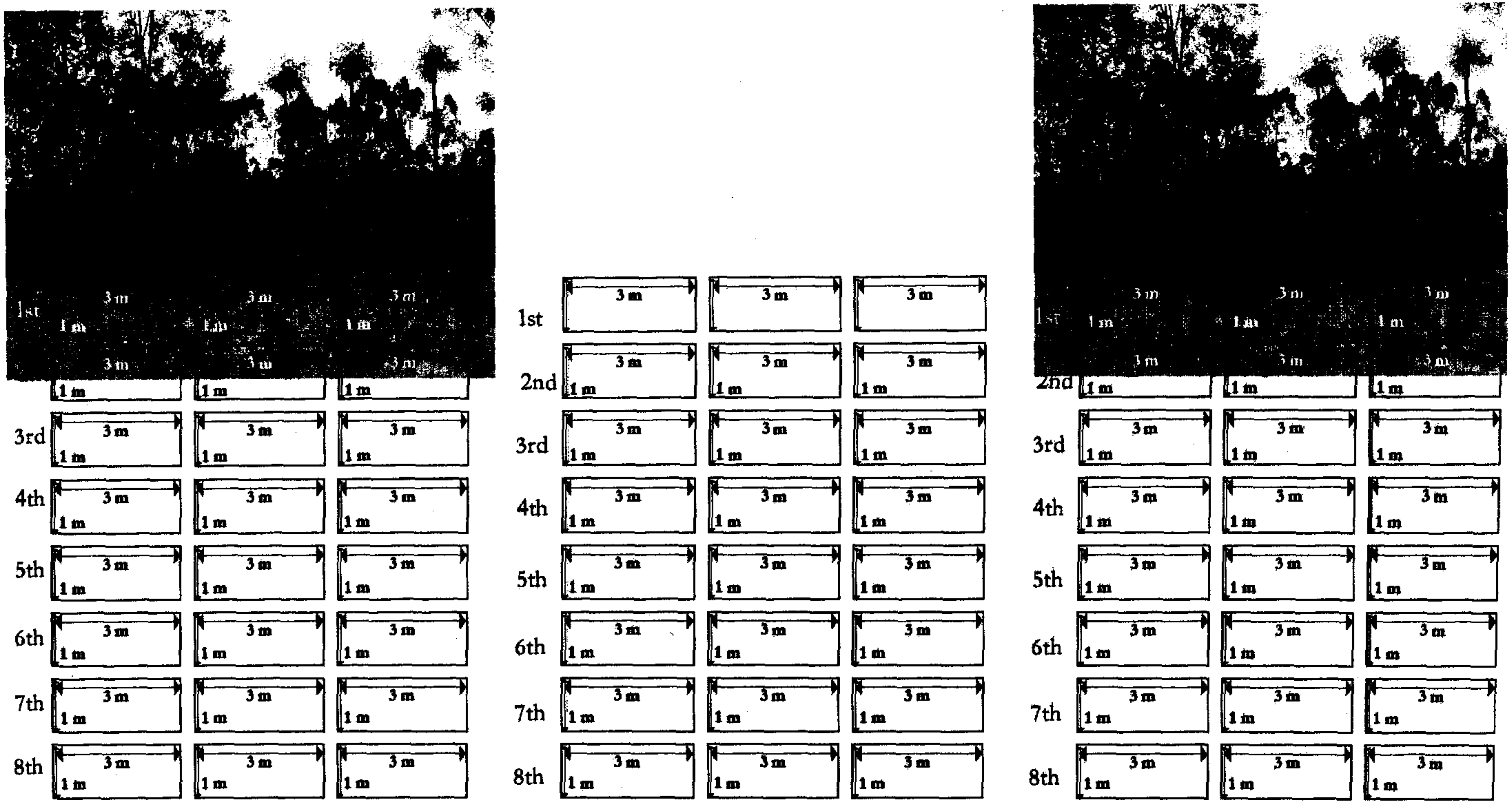

**Figure 3.4** *Illustration of harvesting plots and field layout. This illustration uses only a* Grevillea *plot. A typical site consisted of a* Grevillea *plot like one above, and then a sole crop plot of similar size followed by a similar* Alnus *plot. Harvesting plots for beans were 3 m × 1 m and maize plots were 3 m × 1.5 m. 1 m and 2 m from trees (on the left), represent the sequence of distances away from tree bases.*

### 3.7 Farmer field evaluation

At each stage of new development in the field, farmers were invited for field observation, appreciation, and evaluation of the pruning technology (Plate 3.2).

**Plate 3.2** *Farmers and local leaders introduced to the idea of tree-crop competition and how to reduce it through pollarding and root pruning, during field evaluation days* (AFRENA, 2001).

This was an effort to get them involved in the research process as much as possible with a view that they can easily adopt the technology. Farmers took part in the pruning exercise from which they benefited through firewood. Towards the end of the field experiments, a more representative audience of farmers were invited to evaluate the fields when there were crops visibly affected by tree pruning and when trees had fully re-sprouted and regained branches fit for firewood.

During field evaluation, farmers who own the fields on which the experiments were conducted explained to their colleagues the idea of competition between crops and on-farm timber trees the way they understood it. Invitation to the field evaluations targeted men. This was because husbands traditionally own timber trees even if planted by wives. The objectives of such evaluation were that farmers might appreciate the positive effects of pollarding and root pruning in reducing competition, thereby increasing crop performance. It was also intended to get useful comments about the whole experiment because such information would guide future on-farm research. Direct beneficiaries from such activities are those who actually attended the field evaluations. Nevertheless, farmers and local leaders can be a good means of extending a technology to many other people. This was therefore viewed as an outlet of information to the communities. Observations of competition with crops from *Grevillea robusta* and *Alnus acuminata* were made and appreciated by the farmers in the field. A discussion of what would be their preference followed and their decisions were based on what they observed in the field.

### 3.8 Data analysis

Data entry for all the various parameters measured was carried out in Microsoft Excel 2000 worksheets, and analysed with STATISTICA 6.0 system (StatSoft, Inc. 2001). In relation to the first objective of this study, the first analysis was to test statistically how trees affected crop yields, i.e. testing for crop yield differences between control plots (trees left intact) and sole crop plots (without trees). This was in the second bean season and the maize season since data were not collected from sole crop plots in the first bean season, and this was carried out using factorial ANOVA procedure, to test for both effects of trees and influence of distance from tree bases. This analysis was carried out by excluding the pollarding and the combination of pollarding and root pruning (polloots) treatments from the analysis. To determine which factor group parameters were different from each other; unequal number homogenous significant difference (Unequal N HSD) test was used (Statsoft, Inc. 2001). The effect of trees on crop yields in comparison with sole crop plots was determined using the following model:

$$Yij = \mu + \alpha_i + \beta_j + (\alpha\beta)_{ij} + \varepsilon_{ij}$$

Where

**Yij** =Yield due to i$^{th}$ level of the species and the j$^{th}$ distance from tree bases

$\mu$ =the overall mean

$\alpha_i$ = the effect due to the i$^{th}$ level of species

$\beta_j$ = the effect due to the j$^{th}$ level of distance from tree bases

$(\alpha\beta)_{ij}$ =the effect due to the interaction between the i$^{th}$ level of species and the j$^{th}$ level of distance from tree bases

$\varepsilon_{ij}$ = random error due to the i$^{th}$ level of species and the j$^{th}$ level of distance from trees.

Analysis was also carried out in relation to the second objective of the study. This was to test for the effect of pollarding and a combination of pollarding and root pruning on crop yield compared to the control in which trees were not pruned. Yields from the two bean seasons were analysed together, while maize was analysed separately. Since data were only collected over a distance of 1 to 5 m away from tree bases in the first bean season and 1 to 8 m in the second season (see Figure 3.1 and section 3.6), yield from 6-8 m in the second season was excluded from this analysis. Values for crop yields were expected to vary widely within and across seasons and years as it was influenced by each individual farmer's practices and variations between site characteristics. Such variations have been indicated by the 95% confidence intervals "vertical bars" in all graphs, according to Statistica 6.0 (Statsoft, Inc., 2001).

Tree growth data as influenced by pollarding were analysed using ANOVA repeated measures procedure of STATISTICA System (StatSoft, Inc. 2001) to test for significant differences between the three treatments, i.e. control, pollarding, and the combination of pollarding with root pruning. Significant differences between tree species and various treatment combinations were tested using the t-test procedure, as this was vital to show the differences between the two species in response to treatments and how their growth rates were affected. All significant results are reported at $p<0.05$. Rate of growth for each of the species was calculated from the DBH and DAB values using the Excel RATE functional argument, and the values obtained were analysed using the STATISTICA 6.0 ANOVA procedure to test for differences in rates of growth between the treatments. Differences in rates of growth between the two species were tested using t-test and presented graphically using box and whisker plots.

# Chapter 4

## 4 Results and discussion

This chapter presents results of a series of studies conducted between August 1999 and August 2001 on farmers' fields in Kabale, first to assess in general, the effect of trees on crop yields in comparison to sole crop of maize and beans. Secondly, the chapter highlights the effect of treatments of extreme shoot pruning (pollarding) or a combination of pollarding and root pruning on one side on crop yields, in comparison with non-pruned controls. Thirdly, results are presented on the effect of the above treatments on tree growth and the benefits of pruning to farmers in terms of firewood.

### 4.1 Effect of trees on crop yields

Analysis was carried out to determine statistically how on-farm trees reduce crop yields. Comparison was made between crops growing next to trees that were left intact (control treatments) and those grown in plots with sole crops (plots without trees). Results of the effects of two tree species on crop yields are summarized in Table 4.1 for the second bean season and the maize season. Data were not collected from sole crop plots in the first bean season, and consequently the first bean season has been excluded from Table 4.1.

**Table 4.1** *Mean values of crop yields (kg/ha) as affected by* A. acuminata *and* G. robusta

| **Factors** | | **Mean yields (kg/ha)** | |
|---|---|---|---|
| | Factor level | 2nd beans season | Maize |
| Species | *Alnus acuminata* | 138a | 1132a |
| | *Grevillea robusta* | 147**b** | 1191a |
| | Sole crop | 235c | 1541**b** |
| Distance (m) from tree bases | 1 | 55a | 837a |
| | 2 | 96**ab** | 946**ab** |
| | 3 | 160**bc** | 1253**abc** |
| | 4 | 182**cd** | 1258**abc** |
| | 5 | 203**cd** | 1396**abc** |
| | 6 | 213**cd** | 1548**bc** |
| | 7 | 234**d** | 1678**bc** |
| | 8 | 217**cd** | 1691**c** |

*Values followed by the same letters in the same column were not significantly different from each other at the 5% level of significance. The data represent mean values for 12 sites.*

ANOVA results showed that bean yields from sole crops were significantly higher than yields from plots of both *Alnus* and *Grevillea* with $p<0.001$ (Appendix 1, Table 1). This implied that bean yields were significantly reduced due to competition from non-pruned trees (Figure 4.1**a** and **b**). However, yield reduction as affected by the two tree species, i.e. *Alnus* and *Grevillea* were significantly different from each other for the second bean season, but were not significantly different in the maize season (Figure 4.1b).

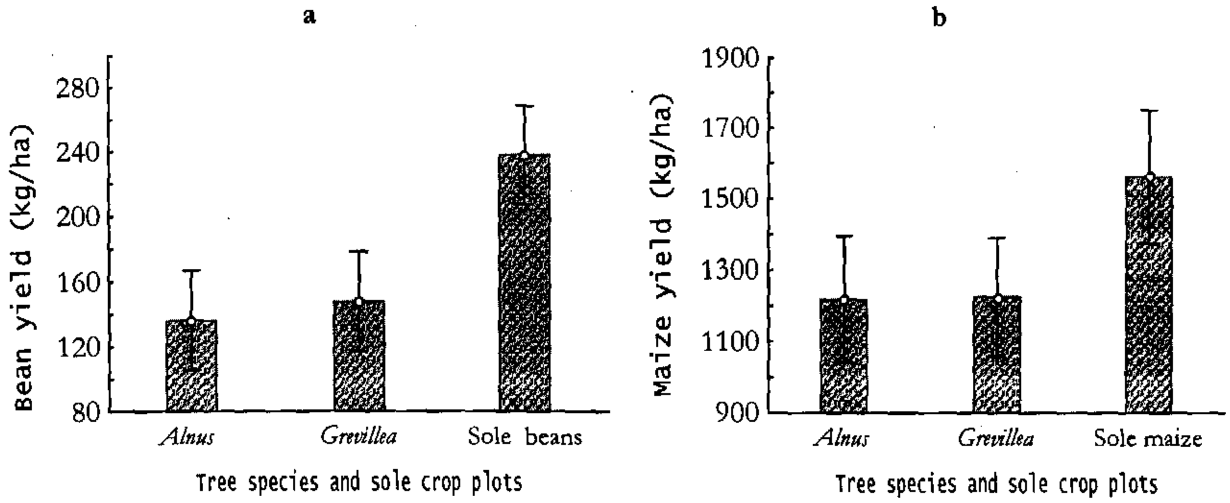

**Figure 4.1** *Effects of* A. acuminata *and* G. robusta *on the second bean season yields* (**a**) *and maize yields* (**b**) *in comparison to sole crop plots. Data represent mean yields for 12 sites over distances 1 to 8 m from tree bases.*

This analysis also indicated that trees suppressed yields of different crops. Trees significantly reduced maize yields in comparison with sole crop plots, and the reductions as influenced by either *Alnus* or *Grevillea*, were not significantly different from each other (Table 4.1). *Alnus* suppressed maize yield by 29% while for *Grevillea* it was 23%, showing no significant differences in competitiveness between the two species.

Regarding general competition between trees and food crops, these results correspond with previous observations. For example, in maize (*Zea mays* L.) inter-cropped with black walnut (*Juglans nigra* L.) in south-eastern Indiana, USA, root trenching with or without root barrier installation slightly increased soil water content and elevated maize yields adjacent to tree rows, while in the non-trenched plots maize yields were significantly reduced (Gillespie *et al.*, 2000). It was then concluded that the reduction in maize yield was due to tree root competition for water with the associated crops. A similar example in similar climates, which also showed that trees out-competed associated crops for water, was maize grown with black locust (*Robinia pseudoacacia* L) alleys (Ssekabembe and Henderlong, 1991).

On the other hand, a study in Uganda (different climate from above two studies) by Okorio *et al.* (1994), found that maize yields adjacent to tree rows were 20% of yields from open areas (sole crops), i.e. plots without trees. When root mesh was installed to 0.5 m depth and 0.5 m away from trees, yields increased by 152% adjacent to *Maesopsis eminii*, 57% adjacent to *Markhamia lutea* and 16% adjacent to *Casuarina cunninghamiana*. Since these examples were from different climatic conditions, there is some evidence to suggest that trees generally reduce crop yields when grown together and such reductions are probably due to competition between trees and crops for soil water besides soil nutrients.

A t-test comparison between the two species *A. acuminata* and *G. robusta* indicated that they were significantly different in their effect in the second beans season ($t_{550}$=3.35, p<0.001, Figure 4.2) but not significantly differently for maize with $t_{513}$=0.005, p=0.995.

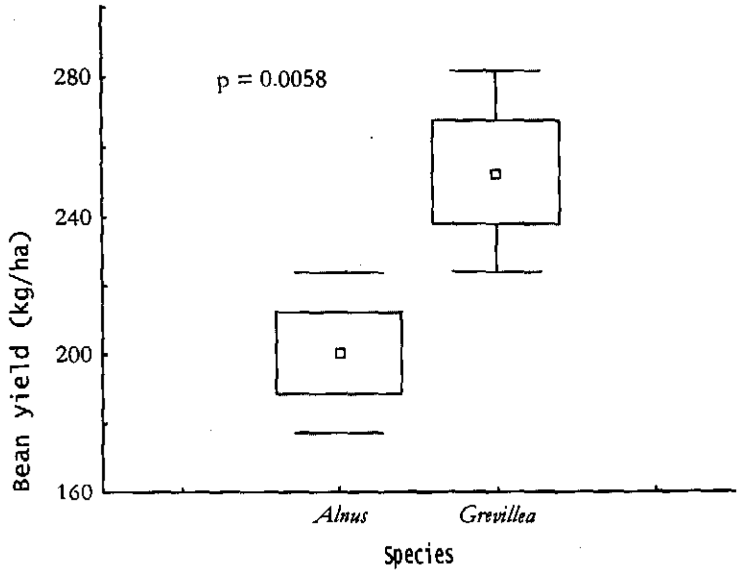

**Figure 4.2** *T-test comparison showing competitive differences between* A. acuminata *and* G. robusta *and how they affected bean yield in the second bean season. Data are for 12 sites averaged for distances from 1 to 8 meters from tree bases.*

The mean yields from *G. robusta* were significantly higher than the mean yields from *A. acuminata* (Figure 4.2). This observation is in agreement with Howard *et al.* (1997), who reported that *G. robusta* was mainly deep-rooted, with few shallow fine roots, while the larger roots tended to penetrate in a vertical plane with correspondingly low levels of competition with associated crops for water and nutrients. Other studies reported similar observations on *Grevillea* roots such as Laycock and Wood (1963) in Malawi, who observed that *Grevillea* produced few superficial lateral roots and most roots were oriented in a vertical plane. Root distribution studies by Johnson *et al.* (1988) and by Mwihokeme (1993), suggested that *Grevillea* was unique among commonly used agroforestry species due to the orientation of its roots in the vertical plane.

However, it is also reported that fine roots are capable of proliferating rapidly when soil resources permit, to control the dynamics of resource capture and ultimately, the magnitude of tree effect on associated crops (Eissenstat, 1992). This to some extent explains why *Grevillea* still shows competition with crops despite being deep-rooted, e.g. in the maize season where its competitive effects were similar to those of *Alnus.* In addition, the presence of deep roots alone does not guarantee complementarity in water use, and knowledge of root distribution may be limited evidence for less competition in the absence of information regarding water and nutrient uptake by individual trees (Howard *et al.*, 1997).

*Alnus* is highly competitive because it has a broad spreading root system close to the soil surface that tends to be lateral, extended rather than deep, and confined to the upper soil horizons (Russo, 1990, 1995). Such root characteristics are likely to cause competition, since they utilize much of the incoming rainfall and prevent water from percolating to lower soil layers (Smith *et al.*, 1998). Since most of *Alnus* roots are confined to the upper soil layers, (Russo, 1995) it could be expected that they deplete much of the moisture before it is available to crop roots in the same region. The differences in competition observed in the yield results of this study were also clear in the field and are further demonstrated in Plate 4.1.

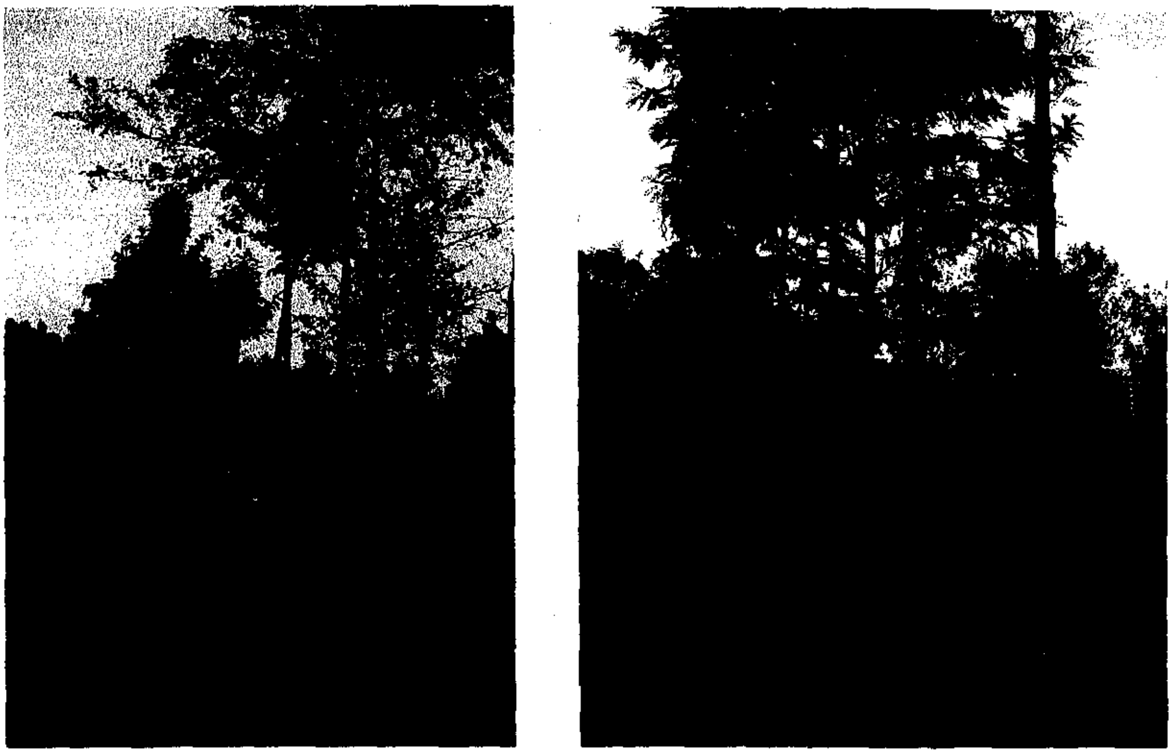

**Plate 4.1** *Competition effects of* A. acuminata *on beans (left) and those of* G. robusta *on beans (right) on the same field demonstrating that competition on beans is more pronounced by* Alnus *than by* Grevillea. *The picture on the right is a close-up of the* Grevillea *plot, which is in the background of the picture on the left* (Sande, 2000).

On the other hand, a possible reason why there was no significant difference in maize yield reduction between *Alnus* and *Grevillea* could be due to higher rainfall during the maize season compared to the second bean season (Figure 3.3). Ssekabembe and Henderlong (1991) reached a similar conclusion when they observed that there was no influence of belowground competition from tree roots on maize yield unless soil water content declined due to drought. Therefore, in periods when soil moisture is high, less crop yield reduction could be expected.

Similar trends were reported by Lott *et al.* (2000c) who obtained high yields from maize growing with *Grevillea* and attributed it to high rainfall (628 mm) that occurred during the experiment, and provided relatively high soil moisture for crop yield. There was also relatively high rainfall (641 mm, Figure 3.3) during the maize season (September 2000-March 2001) compared to both bean seasons. This rainfall enabled high maize yields but did not eliminate effects of competition from trees. This implies that water was one of the major limiting factors, though not solely responsible for the entire yield losses observed in the experiments. The competitive differences observed between the two tree species probably suggest that water uptake by *Alnus* from the upper soil layers was higher than for *Grevillea*, resulting in higher competition by *Alnus*.

Competitive differences between *Alnus* and *Grevillea* have been reported from other experiments, though they tend to depend on altitude. For example, from an experiment in Uganda (altitude of 1,250 m a.s.l), Okorio (2000) reported a 33% yield reduction by *Grevillea* and 25% reduction by *Alnus* in a maize experiment indicating higher competition by *Grevillea* than *Alnus*, though not significantly different from each other. When maize was substituted with beans in the same experiment, the reductions were 22% and 23% for *Grevillea* and *Alnus* respectively indicating almost no difference in competitiveness.

In a similar experiment, preliminary results (AFRENA, unpublished) indicated similar trends where *Grevillea* competed more than *Alnus* (Figure 4.3).

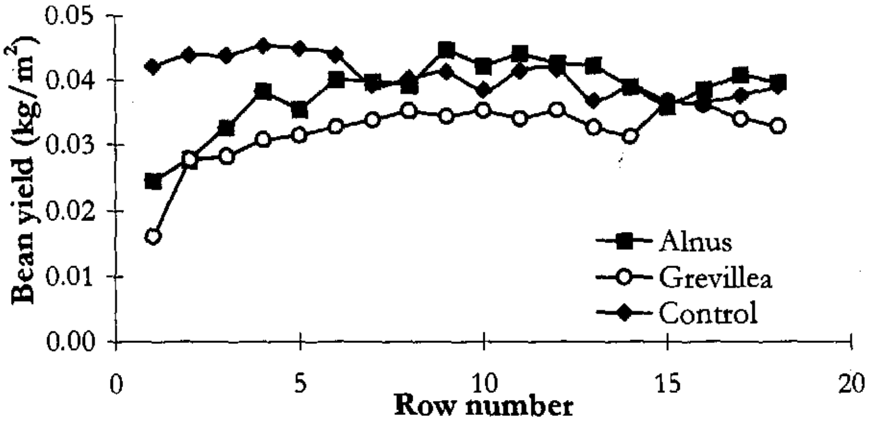

**Figure 4.3** *Competition differences between* Alnus acuminata *and* Grevillea robusta *in association with beans* (AFRENA, unpublished).

These results differ from what was observed in the current study. However, literature shows species niche preference in terms of land elevation. Both Okorio (2000) and AFRENA (unpublished) were conducted at altitude 1,250 m above sea level (latitude 0°48' N, longitude 32° 46' E), which is lowland, while the current study was conducted at altitude 2000 m above sea level (latitude 1° 30' S, longitude 30° 9' E), which is highland. *Alnus* performs best on highlands with altitudes of up to 3200 m above sea level close to the equator (NAS, 1980; Russo, 1990, 1995). Although

*Grevillea* also performs reasonably well at similar altitudes, it is clear from this example that at low altitudes it significantly outgrows *Alnus*, while at high altitudes the reverse is true. There is thus evidence to suggest that at low altitude *Alnus* competes less than *Grevillea* due to its slower growth rate, while at high altitudes *Alnus* competes more than *Grevillea,* due to niche preference.

The relationships between yield and distance from tree bases for individual tree species were significantly different as distance increased radiating from tree bases (Figure 4.4 for second bean season and Figure 4.5 for the maize season, Pages 64 and 65 respectively). Corresponding ANOVA results are also presented in Appendix 1 Table 2. The coefficients of determination ($r^2$) in all the graphs are relatively low, implying that the relationships between yield and distance away from tree bases becomes less predictable and the trend disappears fast as distance from tree bases increases. The trends in the yield intercepts (y-intercepts in the equation of the form $y= a+bx$) are such that *Alnus* has the smallest, *Grevillea* has an intermediate one while sole crops have the largest *"a"*(both Figures 4.4 and 4.5). In addition, trends for the coefficient of the rate of change, i.e. "*b*" (in the equation $y = a + bx$), in all regression equations are such that *Alnus* has the largest, *Grevillea* has an intermediate one and sole crops have the smallest *"b"*. It indicated that near tree bases, *Alnus* had the least yields due to high root activity in the upper soil layers (Russo, 1995), but moving away from tree bases yields may increase more rapidly than for *Grevillea* and for the sole crop plots. A possible reason for this is that there is mineralization of *Alnus* leafy biomass, which is beneficial to the soil and consequently crops (Siriri and Raussen, 2002), besides the possibility of *Alnus* fixing nitrogen by *Frankia.* This is not the case with *Grevillea*, whose leaves reportedly take too long to decompose (as reported by farmers) and is not leguminous (not nitrogen fixing). This may explain why sole crop plots have the lowest coefficient of the rate of change "*b*"; since there was less or no leafy biomass in sole crop plots to be mineralized for crop uptake.

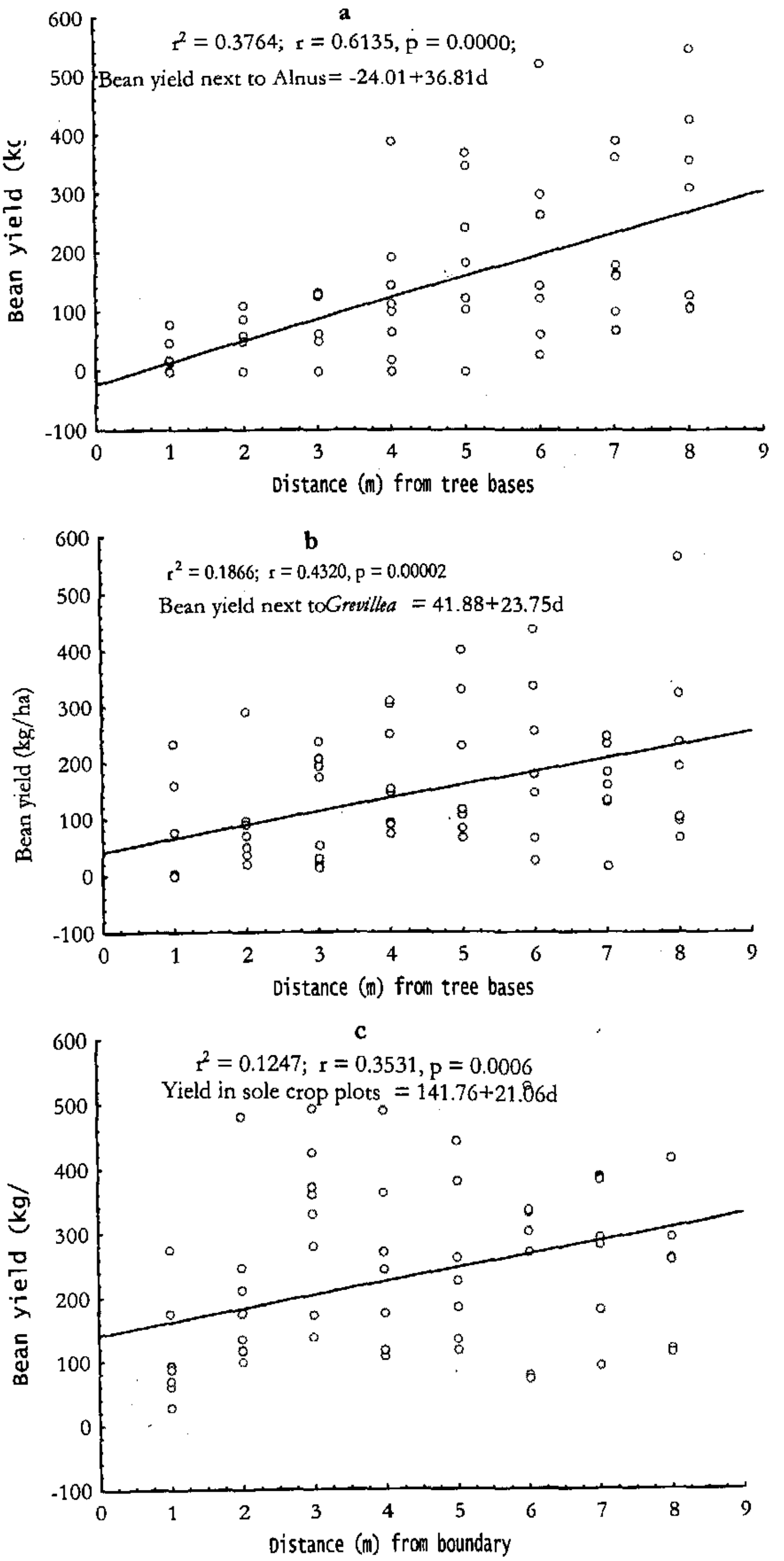

**Figure 4.4** *Regression of distance (m) from tree bases on bean yield for 2nd bean season, showing the effects of* Alnus acuminata *(Fig 4.4a),* Grevillea robusta *(Fig. 4.4b) in comparison with the sole beans (Fig. 4.4c). Data represent mean values for 12 sites.*

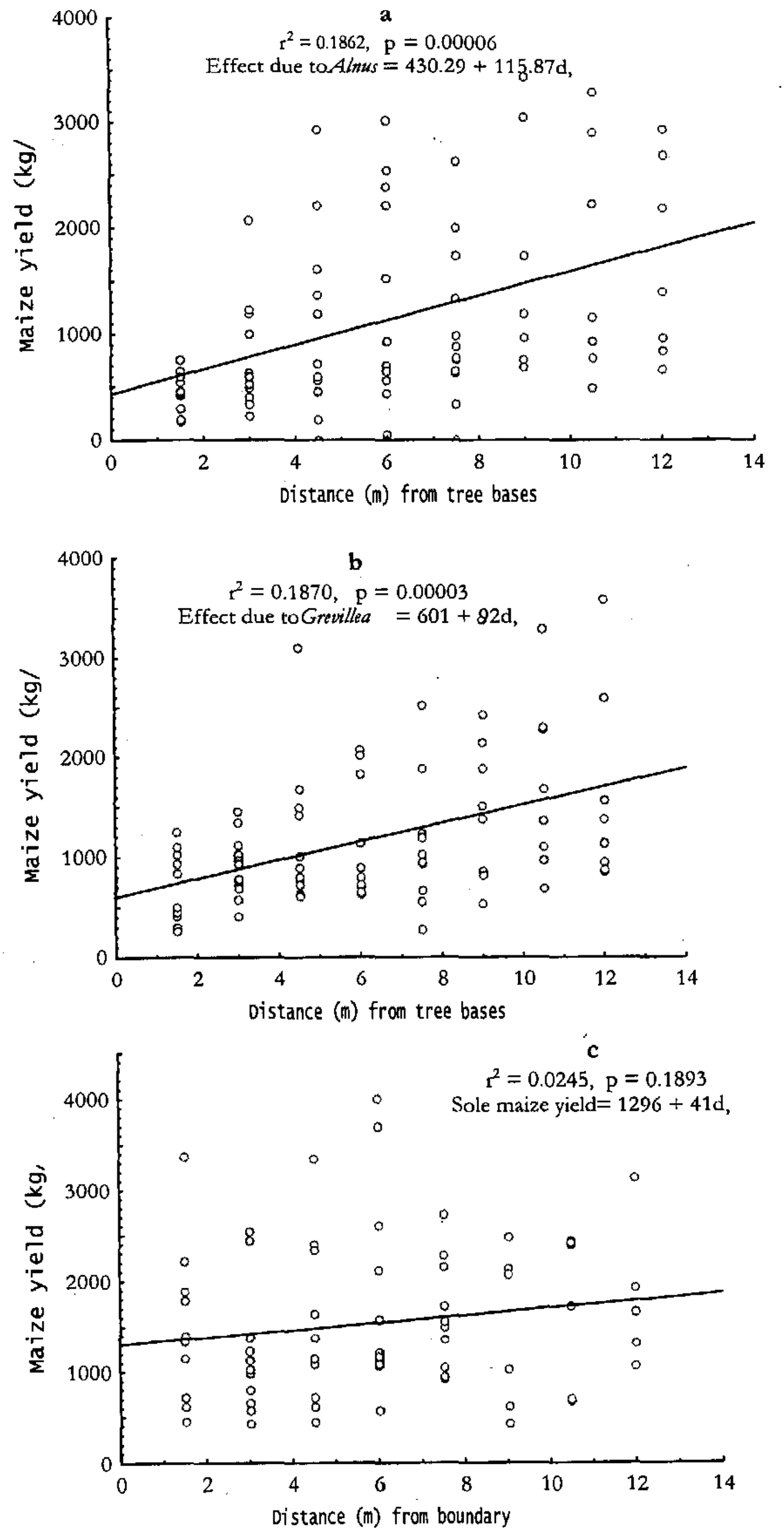

**Figure 4.5** *Regression relationships between maize yields and distance (m) from tree bases showing the effects of* Alnus acuminata *(Fig 4.5a),* Grevillea robusta *(Fig. 4.5b) in comparison with the sole maize crop (Fig. 4.5c). Data represent mean values for 12 sites.*

Related results were obtained by Miller and Pallardy (2001) when maize grain yields were depressed in rows closest to Silver maple (*Acer saccharinum*) rows planted at 0.75 m spacing, compared with rows far away from trees. By root pruning and installing a root barrier at 1 m distance from trees, maize yields were elevated in the first seven maize rows (5.25 m) from tree bases. This showed that root competition was most pronounced in the first 5.25 m from tree bases, but was significantly reduced by the root barrier. Similarly, one side root pruning to 50 cm, significantly reduced root competition in the first 5 m from tree bases. Similarly, Jackson *et al.* (2000) reported that there were zones of decreasing soil water depletion radiating out from tree bases unless such depletion was due to soil surface evaporation. There is ample evidence therefore to suggest that root activity decreases as distance from tree bases increases.

Trees significantly reduced bean yields over a distance of 5 m away from tree bases. This effect was seen as influenced by both roots and crowns since crown shading significantly influences microclimates (Rao *et al.*, 1998; Jackson, 2000). This observation agrees with studies by Miller and Pallardy (2001), who reported that top ear height of maize was only significantly reduced in the border rows compared to rows further away from trees. Additionally, Jackson *et al*, (2000) reported that there was a zone of decreasing depletion of soil water radiating out from tree bases. It implies that tree root and shade effects decrease with distance from tree bases. Furthermore, rates of soil water evaporation have been reported to be lower closer to tree canopies, but there were clear differences on water distribution down the soil profile (Wallace, 1999). This suggested that possibly tree roots rapidly depleted the greater amount of water entering the soil closest to trees. There is therefore a conflict of benefits and losses in that whereas the presence of trees on cropland reduced soil water evaporation and kept soil moisture high, this soil moisture is rarely available for food crops since it is rapidly depleted by tree roots.

This conflict of benefits and losses forms the basis on which root pruning was recommended as a means of ensuring niche differentiation between trees and food-crops for resource capture. Agroforestry research has focused on fast growing tree species with the result that trees capture most of the available resources (Ong and Leakey, 1999). The potential microclimatic benefits for understorey food-crops are outweighed by reductions in soil moisture and nutrient availability to crops resulting from increased uptake by fast growing trees, interception losses and water use by trees.

## 4.2 Effect of pollarding and root pruning on crop yield

Trees were subjected to treatments of pollarding, pollarding and root pruning (polloots), and compared to non-pruned controls. Two seasons of the bean crop and one maize season grown in sequence, beans-maize-beans (Fig. 3.3) were summarised, and the results presented in Table 4.2.

Table 4.2 *Summary of tree pruning effects on crop yields* (kg/ha) *for two bean seasons and one maize season. The data represent mean values for 12 sites (replications).*

| Crop seasons | Distance from trees (m) | *Alnus acuminata* | | | *Grevillea robusta* | | | Sole crop |
|---|---|---|---|---|---|---|---|---|
| | | Control | Pollard | Polloots | Control | Pollard | Polloots | |
| 1st Bean season | 1 | 68 | 244 | 335 | 142 | 294 | 339 | - |
| | 2 | 98 | 317 | 348 | 181 | 277 | 501 | - |
| | 3 | 229 | 478 | 673 | 249 | 495 | 601 | - |
| | 4 | 317 | 507 | 690 | 226 | 430 | 595 | - |
| | 5 | 428 | 598 | 821 | 375 | 526 | 642 | - |
| 2nd Bean season | 1 | 20 | 109 | 128 | 60 | 91 | 211 | 111 |
| | 2 | 38 | 82 | 189 | 85 | 150 | 267 | 197 |
| | 3 | 69 | 188 | 288 | 117 | 260 | 354 | 322 |
| | 4 | 129 | 153 | 239 | 179 | 306 | 311 | 254 |
| | 5 | 196 | 245 | 254 | 192 | 320 | 366 | 250 |
| Maize season | 1 | 638 | 1116 | 1383 | 978 | 1202 | 1293 | 1336 |
| | 2 | 755 | 1357 | 2009 | 1069 | 1494 | 1552 | 1474 |
| | 3 | 1085 | 1373 | 1881 | 1197 | 1607 | 1844 | 1516 |
| | 4 | 1307 | 1551 | 2007 | 1076 | 1488 | 1689 | 1843 |
| | 5 | 1059 | 1342 | 2007 | 1143 | 1239 | 1730 | 1600 |

*NB: "Polloots" describes a combination of pollarding and root pruning. Data represent 12 sites (replications) for both tree species. Data are only for distances 1 to 5 meters away from tree bases.*

Treatments were significantly different (Appendix 2, Table 1) with p<0.001. Yields from plots where trees were pollarded, or pollarded and root pruned, were significantly higher than yields from control plots (p<0.001) (Appendix 2, Table 2). This was true for both bean seasons as well as the maize season (Figures 4.6 and 4.7), except that for the maize season, control and pollarding treatments did not differ significantly (Table 4.3), probably due to higher rainfall received during the maize season (Oct, 2000-Mar, 2001). Marginal differences were also observed between effects of pollarding and "polloots" of *A. acuminata* in the first bean season and between control and pollard for *G. robusta* in the maize yields. Table 4.2 also shows an apparent increase in bean and maize yields from plots where trees had been pollarded and roots pruned one side, relative to sole crop plots (no trees planted). This was attributed to improved microclimate due to tree crown shade, perhaps protection of understorey crops against heavy rains by crowns and in some cases the Nitrogen fixing of Alnus roots by *Frankia*, all of which had positive effects on bean and maize crops.

**Table 4.3** *Effect of pollarding and a combination of pollarding and root pruning (polloots) on crop mean yield* (kg/ha) *for two bean seasons and the maize season.*

| Treatments | Beans 1 | Beans 2 | Maize |
|---|---|---|---|
| Control | 234.90**a** | 89.90**a** | 1131.93**a** |
| Pollard | 444.80**b** | 160.14**b** | 1358.78**a** |
| Polloots | 581.84**c** | 223.84**c** | 1785.93**b** |

*Values followed by the same letter within the same column were not significantly different from each other at the 5% level of significance. Data for both* Alnus *and* Grevillea *have been pooled for particular treatments.*

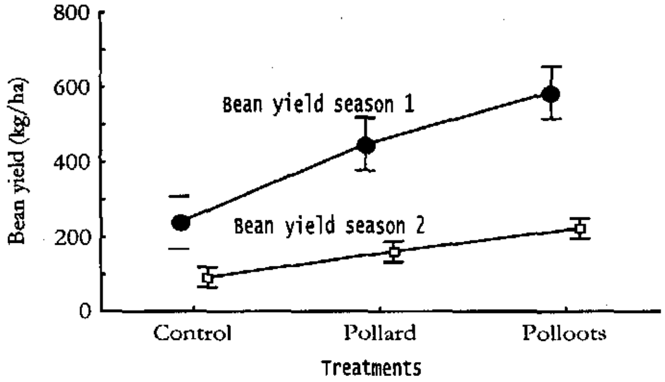

**Figure 4.6** *Effect of tree pollarding and a combination of pollarding with one side root pruning (polloots) on bean yields over two seasons in comparison to non-pruned control. Data for both* Alnus *and* Grevillea *have been pooled for particular treatments.*

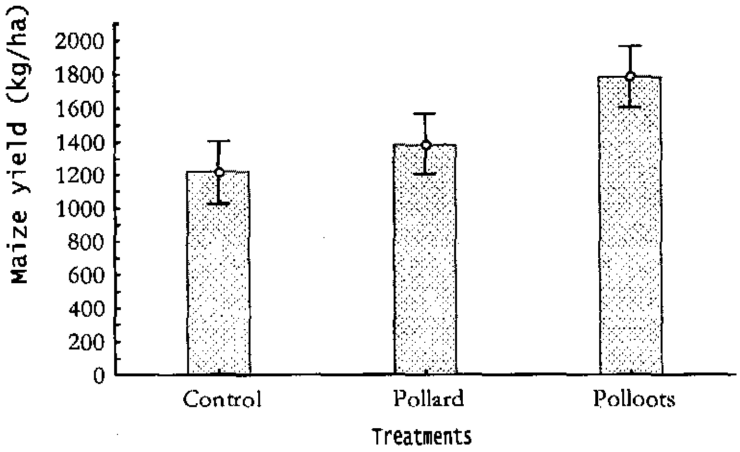

**Figure 4.7** *Effect of pollarding and a combination of pollarding and one side root pruning (polloots) of* A. acuminata *and* G. robusta *on maize yields for one season in comparison to non-pruned control.*

These results indicated that it could be possible to pollard either *Alnus* or *Grevillea*, and obtain crop yields which are almost twice those from non-pruned trees (control), i.e. there was 189% yield increase for the first bean season and 178% yield increase in the second bean season as a result of pollarding. The combination of pollarding and root pruning (polloots) more than doubled bean yields from control plots (248% in first season, 249% for second season).

Generally, low yields were obtained from the second bean season compared to the first bean season (Figure 4.6) despite high precipitation in the second beans season. Perhaps the precipitation was too high for beans, i.e. 183 mm in second beans season compared to 86 mm rainfall in the first season. Another possible reason for low yields in the second bean season could be that there was nutrient depletion due to three crops in rapid succession without any fallow period, or fertilizer application. It could also be possible that trees had recovered from pruning and regained their crowns and surface roots thus out competed the bean component, since the second bean season was planted after a period of one and a half years after the first pruning. Therefore, the rates of transpiration (loss of water through leaves) and consequently soil water demand by trees could have been higher in the second bean season than in the first bean season.

Further comparisons between tree treatments (for both *Alnus* and *Grevillea*) are shown in Figures 4.8a (first bean season) and 4.8b (second bean season). They generally show that both pollarding and a combination of pollarding with root pruning have advantages over the non-pruned control treatments as regards bean yields. They also indicate that the combination of pollarding with root pruning has advantages of higher bean yields over pollarding alone. It is also clearly shown in Figures 4.8a and 4.8b that yields from either pollarding or combined pollarding and one side root pruning (polloots) were significantly higher than yields from control (non-pruned) trees for both bean seasons.

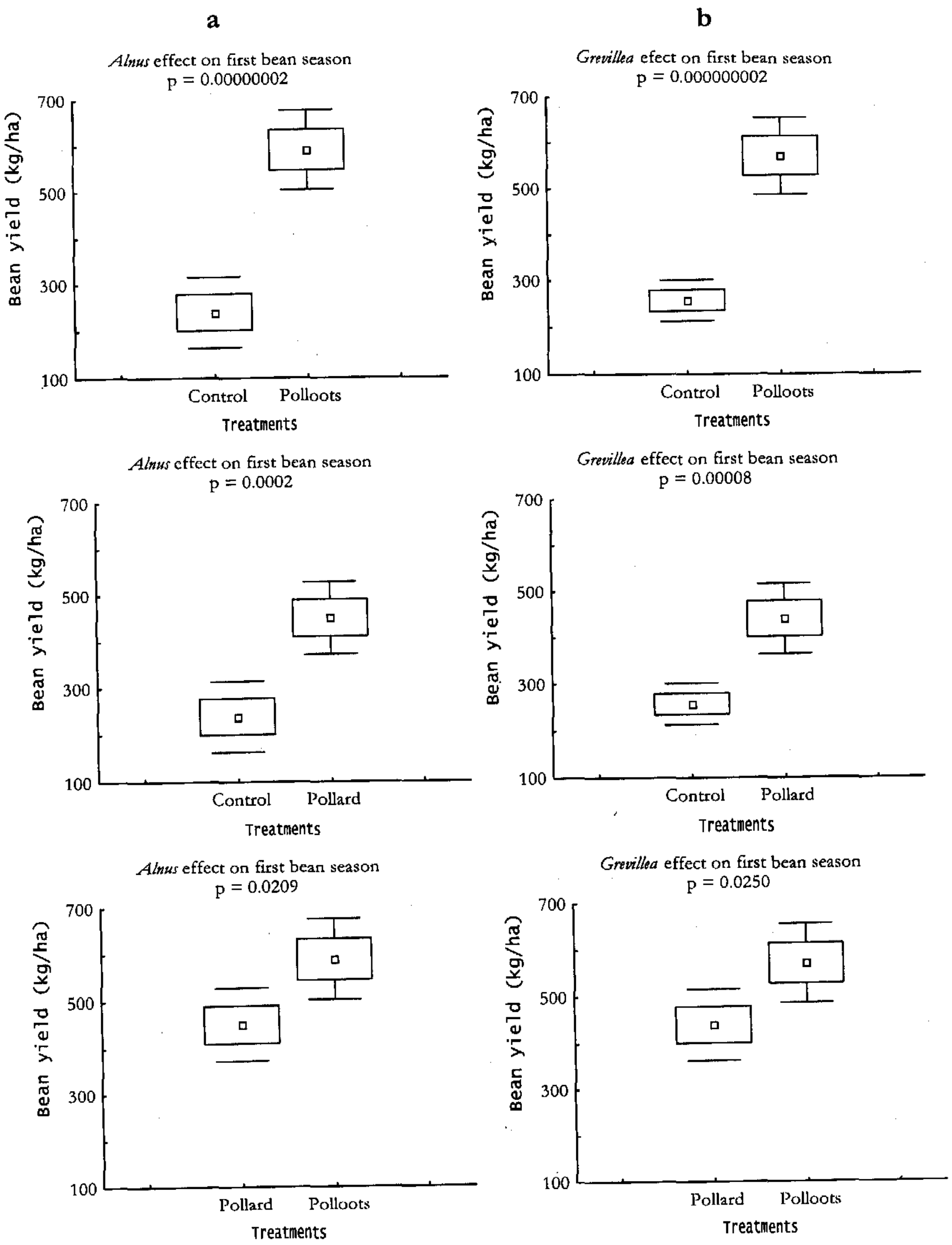

**Figure 4.8a** *Box and whiskers plots showing t-test comparisons between various treatments and their affect on the first season bean yields.* Alnus *treatments are on the left (a) and* Grevillea *ones on the right side (b).*

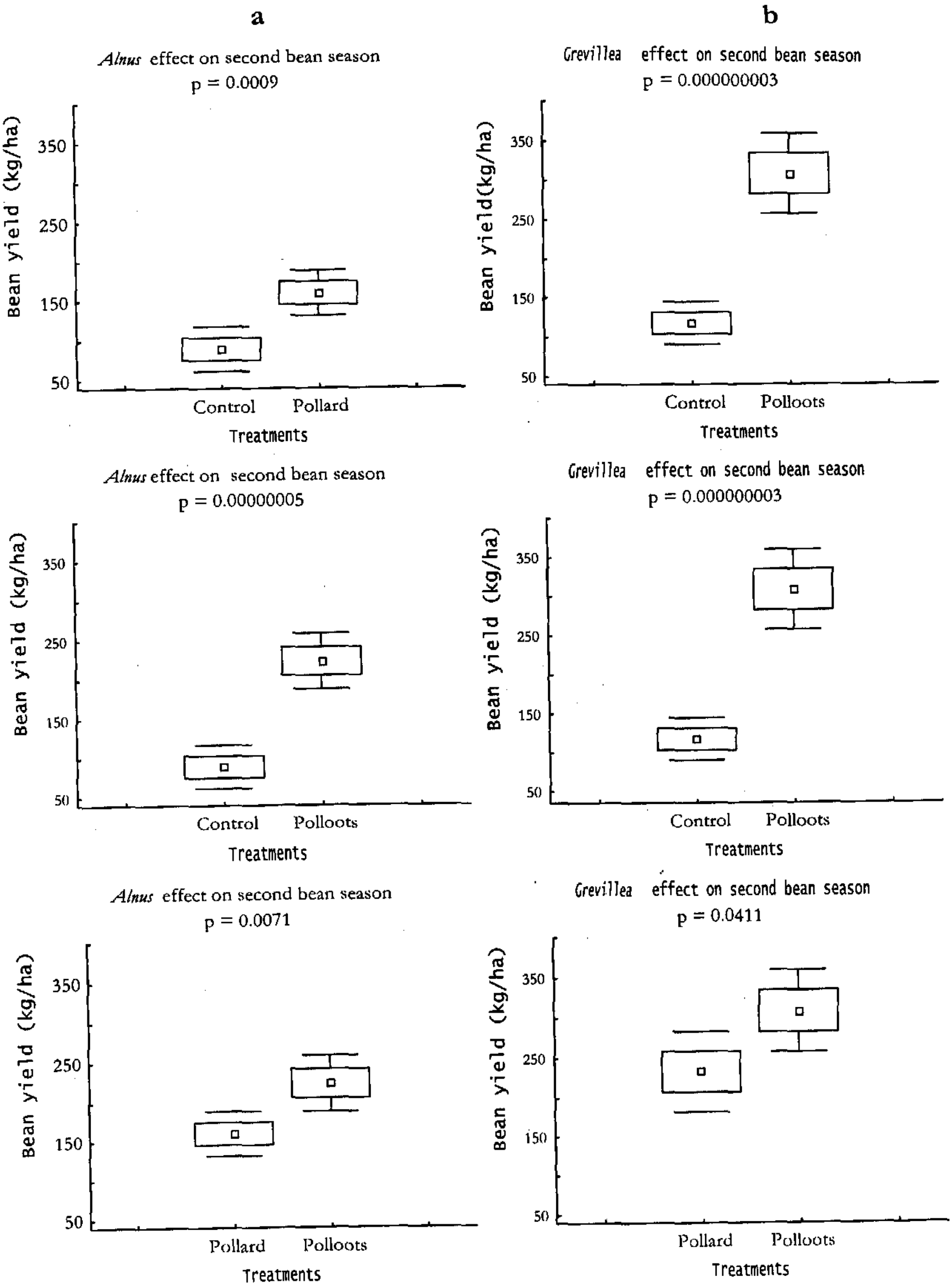

**Figure 4.8b** *Box and whiskers plots showing t-test comparisons between various treatments and their effect on the second bean season yields.* Alnus *treatments are on the left (a) and* Grevillea *ones on the right side (b).*

In addition, Table 2 Appendix 2 indicates that pollarding *Alnus* increased yields by 189% (p<0.001) in the first bean season, 178% (p=0.000858) in the second bean season and 120% (p=0.077459) for the maize season in comparison to control. Pollarding *Grevillea* increased yields by 171% (p=0.000083) in the first bean season, 198% (p=0.000124) in the second bean season and 123% (p=0.021404) in the maize season in comparison to the control. However, the comparisons between pollard and polloots for both *Alnus* and *Grevillea* showed marginal differences, indicating that a farmer may not benefit much by carrying out a combination of pollarding and root pruning which may require additional cost in terms of labour.

Similar trends were observed in the maize season. The percentage increases in yields for the maize season were 120% for pollarding alone, and 158% for the combination of pollarding and root pruning (polloots). However, maize yields obtained from pollarding *Alnus* were not significantly higher than those from the non-pruned controls (p=0.077459), while those from pollarding *Grevillea* were significantly higher than those from non-pruned controls (p=0.021404) at the 5% level of significance (Figure 4.9). On the other hand, maize yields from the combination of pollarding with one side root pruning (polloots) were significantly higher (p=0.000007 for *Alnus*, p=0.000464 for *Grevillea*) compared to non-pruned controls at the 5% level of significance (Figure 4.9). Furthermore, Figure 4.9 also shows that the comparisons between pollard and "polloots" for the maize season were significantly different for *Alnus* (p=0.001317) but they were not for the two treatments with *Grevillea* (p=0.188663). This observation is related to previous findings such as Howard *et al.* (1997) that *Grevillea* has few roots in the upper soil horizons, and Laycock and Wood (1963) that *Grevillea* produced few superficial lateral roots while most of its roots were oriented in a vertical plane. It implies that the few roots of *Grevillea* which were root pruned did not significantly affect its competition with crops as was in the case with *Alnus* whose roots are predominantly confined to the upper soil horizons (Russo, 1995).

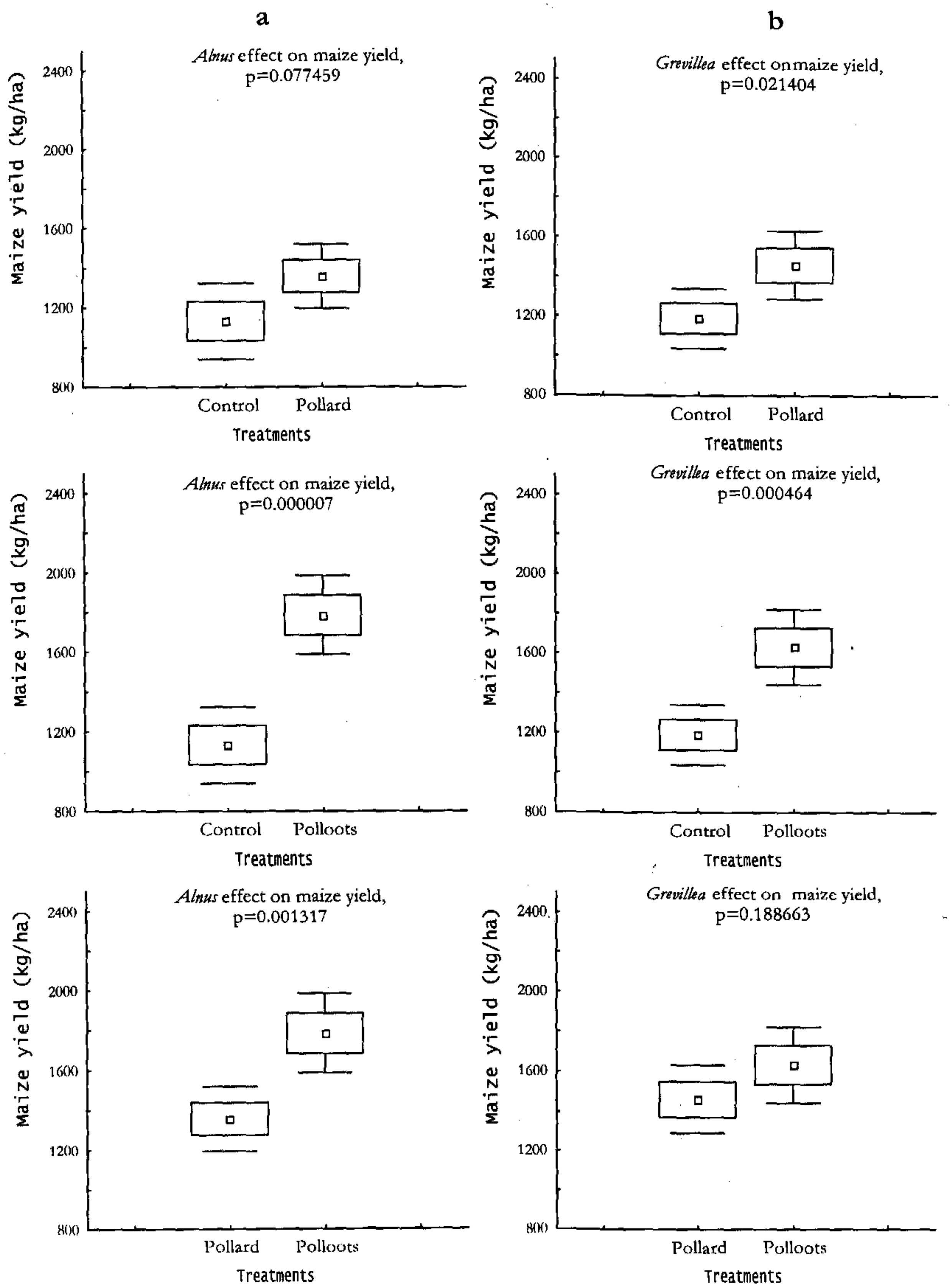

**Figure 4.9** *Box and whiskers plots showing t-test comparisons between various tree treatments and their affect on the maize season yields.* Alnus *treatments are on the left (**a**) and* Grevillea *ones on the right side (**b**).*

As already noted, the maize season received reasonable (above average) amounts of rainfall, which possibly kept enough moisture in the soil for the high yields observed. However, competition from non-pruned trees still significantly reduced maize yields. It could be possible that this competition from trees during the maize season was due to root and crown recovery since maize was planted one year after pruning. By this time, roots had possibly started recovering from pruning. Since soil moisture was probably enough to encourage root recovery and growth, fine roots could rapidly proliferate in the upper soil layers (Eissenstat, 1992) and strongly compete with the maize for soil water and nutrients (Jackson *et al.*, 2000).

Though tree fine roots were not assessed for recovery during the second bean season and the maize season, it is reported that fine roots proliferate rapidly when soil resources (e.g. water, air and nutrients) permit to control the dynamics of soil resources capture (Eissenstat, 1992). Since soil moisture was high during the maize season, roots might have recovered and were able to capture much water from the soil in the second bean season and in the maize season. Such possibility of root recovery after approximately two years could provide an estimate of how often farmers should carry out root pruning and pollarding. This observation relates to a report by Harwood and Booth (1992) that *Grevillea* tolerates heavy pruning of its branches and roots. In addition, Tyndal (1996) reported that *Grevillea* is normally pollarded every two to three years. Although there is limited literature on the tolerance of *Alnus* to heavy pruning (pollarding), results of this study indicate that it may be more tolerant to pollarding than *Grevillea,* given that *Alnus* apparently recovered from pollarding much faster than *Grevillea* during this study.

In the second bean season, treatments were significantly different at the 5% level of significance except for the comparisons between pollard and "polloots" where there were marginal differences (Figure 4.9b). Pollarding increased bean yields by 181% for *Alnus* while for *Grevillea* it was 197% in comparison to control plots (Table 2 Appendix 2). As was the case in the first bean season, the comparisons between control (non-pruned) plots and the combination of pollarding and one side root pruning, were highly significant with $p<0.001$ and yields being more than double compared to yield from control plots.

Generally, pollarding caused an increase in bean yields in the first season more with *Alnus* than *Grevillea* while in the second bean season and in the maize season pollarding resulted in higher yields from *Grevillea* than from *Alnus*. Furthermore, the combination of pollarding and one side root pruning elevated crop yields much more for *Alnus* in the first bean season than for *Grevillea*, while in the second bean season higher yields were obtained from *Grevillea* plots than from *Alnus* plots with the same treatment (Figure 4.10). However, in the maize season pollarding and root pruning *Alnus* elevated yields much more than was obtained from *Grevillea* (Figure 4.11).

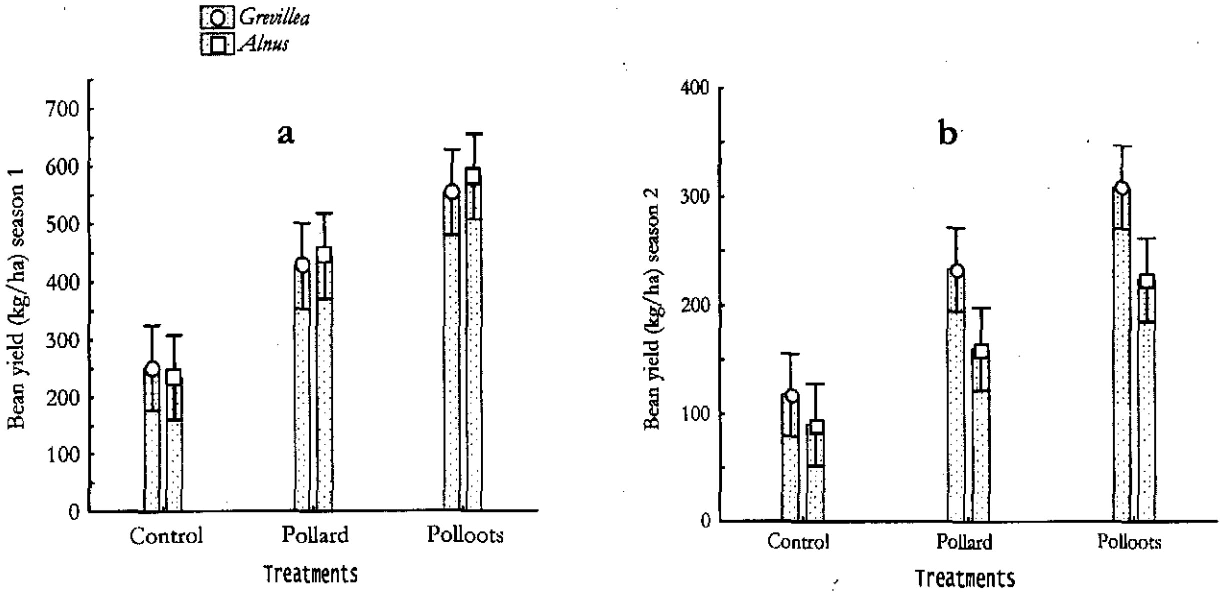

**Figure 4.10** *Graph showing the effects of various tree treatments and how they influenced bean yields over two cropping seasons, first bean season (a) and the second bean season (b) growing next to trees. Data represent mean yields over 12 sites for distances 1 to 5 meters from tree bases.*

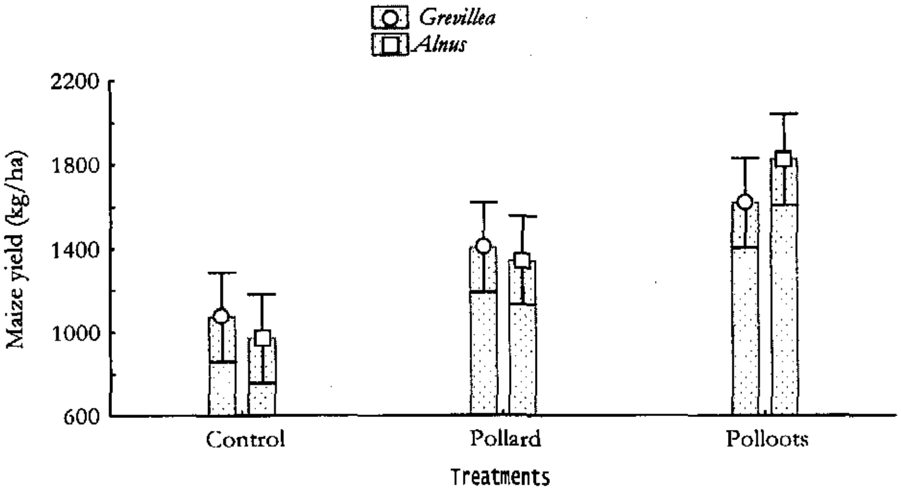

**Figure 4.11** *Graph showing the effects of various tree treatments and how they influenced maize yields growing next to the trees. Data represent mean yields over 12 sites for distances 1 to 5 meters from tree bases.*

These observations are consistent with those in the previous section whereby in the second bean season and in the maize season trees were already recovering from pruning, implying that their transpiration rates and consequently water and nutrient demand were higher than in the first season. There were also some effects of shading due to the new crown. In the first bean season, pollarding seems to have eliminated tree effects on bean crop yield since the root and shoot systems are functionally related (Brouwer, 1983), implying that pollarding could have caused tree root dieback as reported by Jones *et al.* (1998) and Scroth and Zech (1995). This may partly explain why higher bean yields were obtained from *Alnus* than *Grevillea,* possibly because *Alnus* lost more roots to one side root pruning in the upper soil layers compared to *Grevillea.* However, the benefits of pollarding were limited in the maize season and the second bean season. This was possibly due to the development of superficial root systems during root recovery (Hairiah *et al.*, 1994), because the reduction in the shoot system could have triggered a relocation of growth resources to re-establish the root system (Brouwer, 1983).

The average number of roots (≥ 2 mm diameter) per tree in the top 50 cm soil, 50 cm from tree stems was ten for *Alnus* and eight for *Grevillea,* in the current study. This difference in the number of roots between the two species was not significant. However, higher yields were obtained from the combination of pollarding and one side root pruning for *Alnus* in the first season but were lower than for *Grevillea* in the second bean season (Figure 4.10). Therefore higher bean yields could be obtained by carrying out pollarding or the combination of pollarding and one side root pruning on *Alnus* than on *Grevillea.* However, the benefits could probably be limited to a period of about 2-3 years, after which they begin to diminish as tree shoot and root systems re-establish.

The results of this study supplement previous studies by Dhyani *et al.* (1990) and Ruhigwa *et al.* (1992) that tree fine roots occur in the topsoil horizon, which is also the crop-rooting zone. Roots of both trees and crops deplete upper soil horizons first and then shift to lower horizons after the surface dries (Comerford *et al.*, 1984; Lehmann *et al.*, 1998). When the surface is rewetted, it again becomes the zone of maximum depletion (Russell, 1988). Tree components increasingly become dependant on rainfall (since soil water would have been reduced) and reducing the amount that would be available to associated crops, which increases the risk of yield failure to associated under-storey crops).

Generally, higher yields were obtained from the combination of pollarding and root pruning than pollarding alone. Since *Alnus* has indicated a higher growth rate than *Grevillea* at higher altitudes (according to the current study results) and has more of its roots confined to the upper soil layers (Russo, 1995), it could be expected that root pruning to 50 cm depth elevated crop yields more in *Alnus* than in *Grevillea* (first season) and that on recovery, more competition could be expected from *Alnus* than *Grevillea* (second season). This therefore suggests that it is more worthwhile managing competition by a combination of pollarding and one side root-pruning lateral roots. This observation relates to a report by Howard *et al.* (1997) that *Grevillea* was able to extract 80% of its water requirements beneath the crop-rooting zone when it had been side root pruned to a depth of 60 cm.

Maize yields obtained from plots where pollarding had been conducted were significantly higher than those from non-pruned controls for both tree species. However, by pollarding alone, higher maize yields were obtained from *Grevillea* than from *Alnus* plots (Figure 4.11). On the contrary, the combination of pollarding and one side root pruning resulted in higher maize yields in *Alnus* than in *Grevillea*. Pollarding *Alnus* alone did not eliminate its competitive effects since most of its roots are located in the upper soil horizons, and they were actively re-establishing at the time of the maize season, despite the possibility of dieback due to pollarding (Jones *et al.*, 1998; Scroth and Zech, 1995). This is possibly why higher maize yields were obtained with the combination of pollarding and one side root pruning of *Alnus* than for *Grevillea*. The difference between maize yields from pollarding *Grevillea* and from *Alnus* was insignificant (only 10%), suggesting that *Alnus* root activity which had been reduced by pollarding and resulted in higher bean yields in the first season (April-August, 2000), had possibly started recovering in the maize season (October, 2000-March, 2001), resulting in poorer bean yields in the second bean season (April-August 2001, see Figure 3.3, Page 52).

Higher maize yields were again obtained with the combination pollarding and root pruning of *Alnus* than for *Grevillea.* This observation is in harmony with Jackson and Wallace (1999), who observed significant positive effects on under-storey microclimate due to tree canopy shading, i.e. higher soil moisture than in the open areas. Since there was reasonably high (above the expected average) rainfall during the maize season, it could be possible that soil moisture for the under-storey maize crop was enough. On the other hand, pollarding could have reduced competition with crops for light and soil water, increasing the chances of obtaining reasonable crop yields that were observed. This observation supplements Ong *et al.* (1992) that agroforestry increases productivity by capturing a proportion of annual rainfall that would otherwise be lost.

In terms of crown diameter, *Alnus* would shade more of under-storey crops than *Grevillea.* Shading causes crop yield decline relative to yields in the open, treeless fields (Rao *et al.*, 1998). However, the effect of the crown can be both negative as in the context of Rao *et al.* (1998) and positive as in the case of Jackson and Wallace (1999) where soil at 0.3 m from tree bases only lost 2.9 mm while the soil at 2.5 m lost 4.1 mm of moisture. The high moisture content under tree canopy was due to shading possibly because of reduced evapotranspiration from the soil surface, since by pruning canopies, Jackson and Wallace (1999) were able to detect changes in the microclimate beneath trees. These changes were attributed to increase in radiation and wind speed, which decreased the aerodynamic resistance to water vapour, thereby increasing bare soil evaporation.

Nevertheless, observations made on the maize yields in the current study on the influence of distance from trees on crop yield and those made by Miller and Pallardy (2001), would require caution before a sound conclusion can be made because there is no consistency in maize responses to tree competition. More contradictory maize responses to tree competitions have also been reported elsewhere, e.g. Ssekabembe and Henderlong (1991) reported no influence of below-ground competition from Black locust (*Robinia pseudoacacia*) roots on maize grain yield unless soil water content declined because of drought. In other words it was only during periods of moisture stress that the effects of competition for soil water were observed. It could therefore be expected that competition would be most pronounced within distances 1 to 5 m away from tree bases, especially during periods of moisture stress. Secondly, the effects of pollarding and one side root pruning had significantly higher positive impacts on crop yields when carried out on *Alnus* than on *Grevillea*, and such effects appeared to diminish within a period of about 2 years, disappearing possibly in the third year when trees are in good health.

Pollarding significantly increased crop yields compared to the control where trees were left intact with their canopies and root systems. This observation was attributed to the fact that shoot and root systems are functionally related and a reduction in one causes a reduction in the other (Eissenstat, 1992). In addition, as a response to shoot pruning, tree root death reportedly occurs starting at the root tips and causing loss of apical dominance and a potential proliferation of small-diameter roots (van Noordwijk and Purnomosidhi, 1995). This phenomenon could provide an advantage to companion food-crops since both tree root activity and negative crown shading effects would have been significantly reduced as a result of pollarding.

However, these benefits seem to have been short-lived (about 18 months) in the current study, especially with *A. acuminata* due to predominant roots in the upper soil horizons. This also complements the observations of Jackson *et al.* (2000) that although tree canopy pruning reduced competition for light between trees and food-crops, it was limited in its reduction of water demand by the tree component. In addition, Tesch *et al.* (1993) observed that relocation of growth resources to root growth as a result of root pruning occurred only in the first year with Douglas fir (*Pseudotsuga menziesii*) and thereafter, shoot growth was favoured. Therefore, the benefits of pollarding and root pruning could be short-lived, possibly due to rapid root re-growth.

The relocation of growth resources to root re-growth (Tesch *et al.*, 1993) also provides a hint that the stem diameter growth, which was significantly reduced by pollarding and root pruning, would be regained once the root system is established to capture soil resources. However, rooting patterns are largely determined by the plant's genetic composition (Kramer and Kozlowski, 1979) and soil physical and chemical factors (e.g. soil permeability), implying that different responses of the root system to pruning would be expected, depending on the species, site conditions, intensity and timing of pruning.

Combining pollarding and root pruning enabled significantly higher crop yields in comparison to pollarding alone. This indicated that it would be worthwhile managing competition by combining pollarding and root pruning of tree lateral roots in the upper soil horizons to redirect root function. However, Ong *et al.* (2002) commented that the downward displacement of tree root function must not be allowed to affect tree safety by denying it soil nutrients, water and anchorage. This is why boundary planting offers a great opportunity since food-crops are grown on one side of trees and root pruning was carried out at 50 cm away from tree bases to ensure that anchorage is not compromised. Secondly, boundary tree planting is more advantageous for root pruning since boundary trees rarely extend their roots to plots occurring on the lower part of the bench terrace (Figure 1.2, Page 29).

Whereas *Alnus acuminata* fixes nitrogen through *Frankia* thereby stimulating growth of associated vegetation (Tarrant, 1983), the effects of nitrogen fixation may be outweighed by its competition for water and nutrients and its negative shading effects. Furthermore, many experiments are conducted on small plots and are based on short-term trials (Rao *et al*, 1998). This is extremely erroneous for agroforestry research that involves various interacting components, some of which would require longer periods of experimentation than has always been done. For example, the effects of trees such as *Grevillea* and *Alnus* on under-storey crops are cumulative and their effects may not be fully visible in less than 5 years. Most reported experiments lasted less than 5 years, yet farmers are keeping their trees on farm for more than 10 years.

### 4.1.5 Effect of pollarding and one side root pruning on tree growth

Pruning is a known practice in forestry and is recommended for purposes of promoting a relatively small knotty core surrounded by clear timber (Anderson, 1966 ex Hinze, 1984; Shepherd, 1986). However, it is also known to impart side effects to trees, some of which may not be desirable, e.g. reduced radial growth McKinney (1974 ex Hinze, 1984). This section presents results in which *Alnus acuminata* and *Grevillea robusta* were subjected to pollarding, and or a combination of pollarding with one side root pruning to 50 cm depth. The objectives were to control tree competition with crops, to evaluate the effects of such treatments on the growth and the potential of pollarding as an option for firewood production.

Tree diameters at base (DAB) and diameters at breast height (DBH), measured periodically at intervals of 10 months starting from 63 months after planting and how they were affected by either pollarding or the combination of pollarding and root pruning (polloots) in comparison to non-pruned controls are indicated in Figure 4.12. It was observed that trees which were not pruned (controls) had significantly higher DAB and DBH increments compared to those that were only pollarded for both *Alnus* and *Grevillea* with p<0.001 (Fig. 4.12 and Table 4.4). It is also clear from Table 4.4 that at the initial measurements (at 63 months after planting), there was no significant difference between DAB and DBH for either *Grevillea* or *Alnus*.

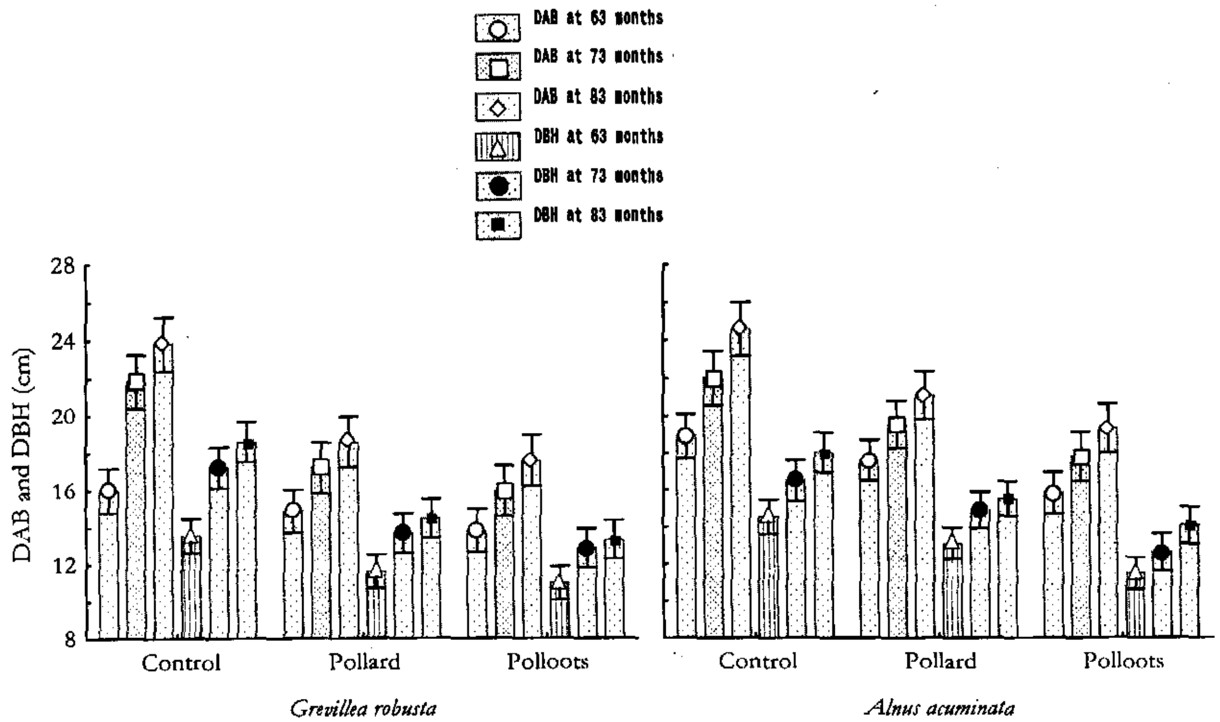

**Figure 4.12** *Effect of pollarding and a combination of pollarding and one side root pruning (polloots) on increment of DAB and DBH for* Grevillea robusta *and* Alnus acuminata *in comparison to non-pruned controls. Data represent mean values for 12 sites (replicates).*

However, subsequent measurements indicate that pollarding had a highly statistical significant effect (especially with *Grevillea*) on both DAB and DBH except in *Alnus* where there were less significant differences (p=0.0249290) at the 5% level of significance.

**Table 4.4** *T-test comparisons showing the effects of pollarding on the increment of both DAB and DBH of* Grevillea robusta *and* Alnus acuminata *in comparison to non-pruned control plots.*

| | Parameter and age when assessed | Control (cm) | Pollard (cm) | t-value | DF | p |
|---|---|---|---|---|---|---|
| *Grevillea robusta* | DAB at 63 months | 15.99 | 14.84 | 1.12040 | 45 | 0.2684870 |
| | DAB at 73 months | 21.25 | 17.13 | 3.83252 | 45 | 0.0003910 |
| | DAB at 83 months | 23.30 | 18.76 | 4.02891 | 43 | 0.0002240 |
| | DBH at 63 months | 13.28 | 11.85 | 1.91516 | 45 | 0.0618410 |
| | DBH at 73 months | 16.77 | 13.81 | 3.65128 | 44 | 0.0006900 |
| | DBH at 83 months | 18.87 | 14.18 | 5.86895 | 43 | 0.0000010 |
| *Alnus acuminata* | DAB at 63 months | 19.25 | 17.60 | 1.74575 | 45 | 0.0876790 |
| | DAB at 73 months | 22.01 | 19.56 | 2.32192 | 44 | 0.0249290 |
| | DAB at 83 months | 24.64 | 21.12 | 3.27627 | 44 | 0.0020560 |
| | DBH at 63 months | 14.56 | 13.15 | 1.99807 | 44 | 0.0519130 |
| | DBH at 73 months | 16.66 | 14.93 | 2.23776 | 45 | 0.0302320 |
| | DBH at 83 months | 17.97 | 15.55 | 2.98831 | 44 | 0.0045760 |

*NB: DAB refers to Diameter At Base of tree measured out at 30 cm from the ground surface while DBH refers to Diameter at Breast Height measured out at 130 cm from the ground surface. Data represent mean values for 12 sites (replicates).*

This implied that pollarding significantly retarded the growth and increment of tree diameters (both DAB and DBH). Furthermore, the less significant effect of pollarding on *Alnus* may imply that it probably has a higher capacity to withstand pollarding than *Grevillea*. The comparison between the non-pruned trees (control) and the combination of pollarding and root pruning showed that there was a high significant effect on both DAB and DBH increments (Table 4.5). Again it was observed that the differences increased with subsequent measurements at 73 months to those at 83 months for both *Grevillea* and *Alnus*. This observation seems to suggest that the combination of pollarding and root pruning had a bigger impact on *Alnus* than Grevillea. As was observed earlier, pollarding alone had a higher impact on *Grevillea* than *Alnus*, while the combination of pollarding and one side root pruning had a bigger effect on *Alnus* than *Grevillea*. This is possibly related to the findings of Russo (1995) who reported that *Alnus* has most of its roots in the upper soil layers. It therefore implies that when such roots were cut during one side root pruning, this significantly reduced diameter growth more in *Alnus* than in *Grevillea,* which is reported to be mainly deep rooted with few shallow fine roots (Howard *et al.*, 1997).

**Table 4.5** *T-test comparisons between non-pruned controls and a combination of pollarding and root pruning ("polloots") showing the effects on the increment of both DAB and DBH of* Grevillea robusta *and* Alnus acuminata.

| Tree species | Diameters (cm) | Control | Polloots | t-value | DF | p |
|---|---|---|---|---|---|---|
| *Grevillea robusta* | DAB at 63 months | 15.99 | 13.87 | 2.0120 | 44 | 0.050363 |
| | DAB at 73 months | 21.25 | 16.15 | 4.7819 | 43 | 0.000021 |
| | DAB at 83 months | 23.30 | 17.47 | 5.3187 | 45 | 0.000003 |
| | DBH at 63 months | 13.28 | 11.02 | 2.8979 | 44 | 0.005836 |
| | DBH at 73 months | 16.77 | 12.73 | 4.8590 | 44 | 0.000015 |
| | DBH at 83 months | 18.87 | 13.19 | 7.1567 | 43 | 0.000000 |
| *Alnus acuminata* | DAB at 63 months | 19.25 | 15.72 | 4.2093 | 45 | 0.000121 |
| | DAB at 73 months | 22.01 | 17.74 | 4.0110 | 44 | 0.000231 |
| | DAB at 83 months | 24.64 | 19.36 | 5.0081 | 44 | 0.000009 |
| | DBH at 63 months | 14.56 | 11.58 | 4.2144 | 43 | 0.000126 |
| | DBH at 73 months | 16.66 | 12.64 | 5.3949 | 44 | 0.000003 |
| | DBH at 83 months | 17.97 | 14.00 | 4.4881 | 44 | 0.000051 |

*NB: DAB refers to Diameter At Base of tree measured out at 30 cm from the ground surface while DBH refers to Diameter at Breast Height measured out at 130 cm from the ground surface. Data represent mean values for 12 sites (replicates).*

Further comparison was between the effects of pollarding alone and that of the combination of pollarding with one side root pruning. There was no significant difference between their effects on either DAB or DBH in all the three successive measurements for *Grevillea* (Table 4.6). The similarity between the two treatments in their effects on *Grevillea* (no significant difference) is probably because one side root pruning did not significantly affect the growth of *Grevillea* since it has very few roots in the upper soil layers (Howard *et al.*, 1997). On the other hand, the two treatments were significantly different for *Alnus* at 73 months (DBH), while there were marginal significant differences between the effect of the two treatments on DAB and DBH for *Alnus* at 63 months (the initial assessments), and not significantly different at 83 months. This was possibly because the 83 months measurements were taken approximately 1.5 years after one side root pruning, and therefore roots could have recovered (Eissenstat, 1992) enough to support tree growth. However, there was a significant difference between the effect of pollarding and "polloots" on the DBH of

*Alnus* at 73 months, which is a period in which the effects of "polloots" on *Alnus* trees could be observed since its roots, predominantly in the upper soil horizons (Russo, 1995), had been interfered with by one side root pruning. Therefore the combination of pollarding with one side root pruning (polloots) significantly reduced *Alnus* DBH possibly because it has most of its roots in the upper soil layers (Russo, 1995) and their activity was reduced due to one side root pruning.

**Table 4.6** *T-test comparisons showing the effects of pollarding on the increment of both DAB and DBH of* Grevillea robusta *and* Alnus acuminata *in comparison to the combination of pollarding and one side root pruning ("polloots") treatments.*

| Tree species | Diameters (cm) | Pollard | Polloots | t-value | DF | p |
|---|---|---|---|---|---|---|
| *Grevillea robusta* | DAB at 63 months | 14.84 | 13.87 | 0.99788 | 45 | 0.323674 |
| | DAB at 73 months | 17.13 | 16.15 | 1.10596 | 44 | 0.274754 |
| | DAB at 83 months | 18.76 | 17.47 | 1.40679 | 44 | 0.166515 |
| | DBH at 63 months | 11.85 | 11.02 | 1.18998 | 45 | 0.240295 |
| | DBH at 73 months | 13.81 | 12.73 | 1.71388 | 44 | 0.093588 |
| | DBH at 83 months | 14.18 | 13.19 | 1.55368 | 46 | 0.127114 |
| *Alnus acuminata* | DAB at 63 months | 17.60 | 15.72 | 2.06556 | 46 | 0.044531 |
| | DAB at 73 months | 19.56 | 17.74 | 1.67056 | 46 | 0.101601 |
| | DAB at 83 months | 21.12 | 19.36 | 1.62379 | 46 | 0.111255 |
| | DBH at 63 months | 13.15 | 11.58 | 2.19344 | 45 | 0.033484 |
| | DBH at 73 months | 14.93 | 12.64 | 2.87877 | 45 | 0.006089 |
| | DBH at 83 months | 15.55 | 14.00 | 1.78955 | 46 | 0.080111 |

*NB: DAB refers to Diameter At Base of tree measured out at 30 cm from the ground surface while DBH refers to Diameter at Breast Height measured out at 130 cm from the ground surface. Data represent mean values for 12 sites (replicates).*

In general, seasonal increments and average growth (as measured at 63, 73 and 83 months after planting) were smallest for the combination of pollarding with one side root pruning, for pollarding they were intermediate and for the controls they were the highest, as would be expected (Tables 4.4, 4.5, and 4.6). It is therefore clear that both pollarding and "polloots" reduced rates of DBH and DAB increments, though the reductions were more pronounced in DBH than DAB. DAB is a rarely applied measurement in forestry (due to the excessive taper and therefore variability), but it was used in this study as possible additional evidence that actual growth influences do occur in tree girth due to treatments such as pollarding and root pruning on one side of trees.

It was indicated that the percentage changes in diameter as influenced by pollarding from 73 to 83 months for both *Alnus* and *Grevillea* were not significantly different, i.e. it was 4.2% by pollarding either *Grevillea* or *Alnus* (Figure 4.13). However, the percentage changes in diameter due to the combination of pollarding with one side root pruning were significantly different, i.e. for *Grevillea* it was 3.4% while for *Alnus* it was 10.5%.

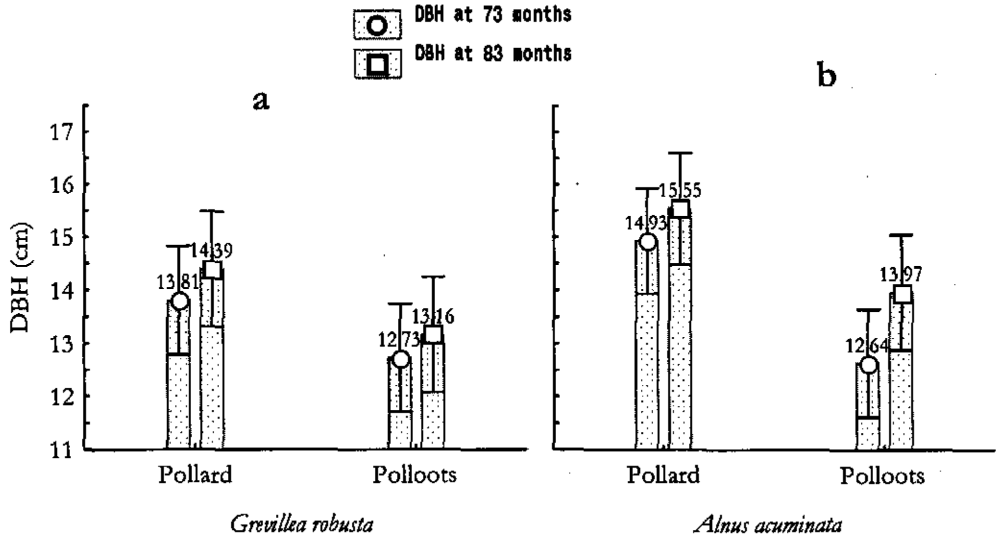

**Figure 4.13** *Comparisons of effects of pollarding and "polloots" on DBH measured at 73 and 83 months after planting, for* Grevillea robusta *(a) and* Alnus acuminata *(b). Data represent mean values for 12 sites (replicates).*

A t-test comparison between DBH values for *Alnus* and *Grevillea* showed them to be significantly different at 63 months, whereas the two species were not significantly different in DBH at 83 months (Figure 4.14 for the "polloots" treatment). These observations suggest that the influence of the "polloots" treatment was significantly higher in *Alnus* by reducing its growth rate (DBH increment per unit time, or change in size per time), thereby enabling the DBH of *Grevillea* to almost equalise with that of *Alnus* at 83 months (Figure 4.14). This observation relates to Jackson (2000) who reported that root and branch pruning discouraged radial growth, implying that the "polloots" treatment significantly reduced the rate of growth in *Alnus* (p=0.006089) while the reduction in *Grevillea* was not significant (p=0.093588), mainly due to their differences in root characteristics (Russo, 1995, Howard *et al.*, 1997). Therefore, it is clear that both *Alnus* and *Grevillea* continued to grow but *Alnus* was growing at a much slower rate that would be expected.

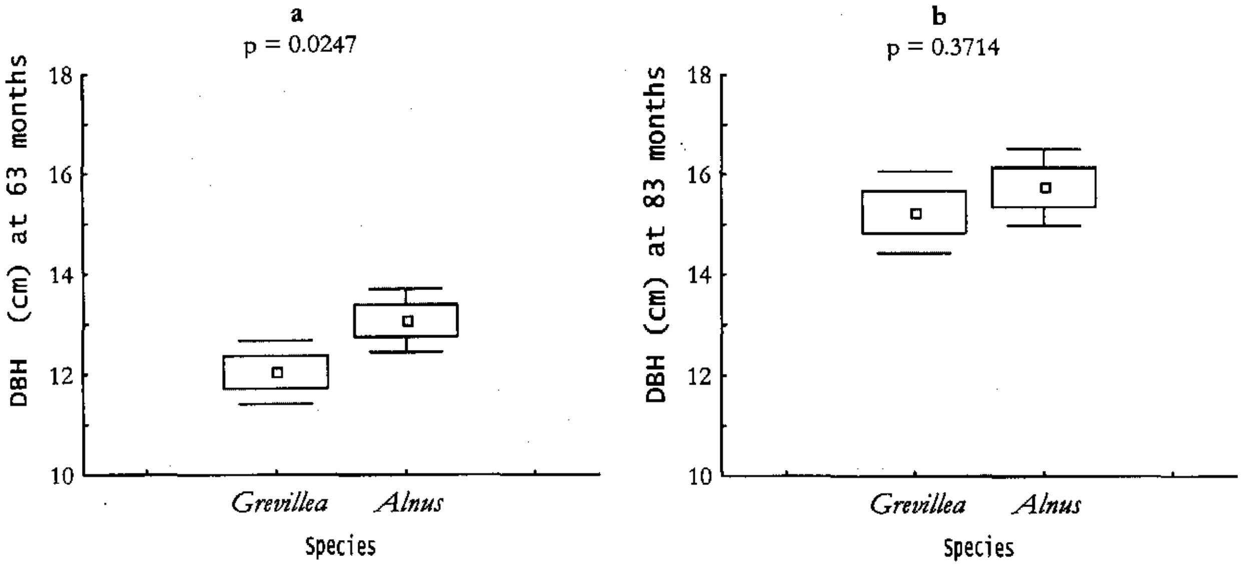

**Figure 4.14** *T-test comparisons between the effect of the "polloots" treatment on DBH values of* Grevillea robusta *and* Alnus acuminata *at 63(a) and 83 (b) months after planting. Data represent mean values for 12 sites (replicates).*

Generally, the combination of pollarding with one side root pruning (polloots) significantly reduced the rate of tree growth (DBH and DAB increment per unit time) for both *Alnus* and *Grevillea* compared to pollarding alone (Figure 4.15a). However, the reduction in tree DBH growth rates due to the "polloots" treatment was more pronounced in *Alnus* than in *Grevillea* (Figure 4.15b).

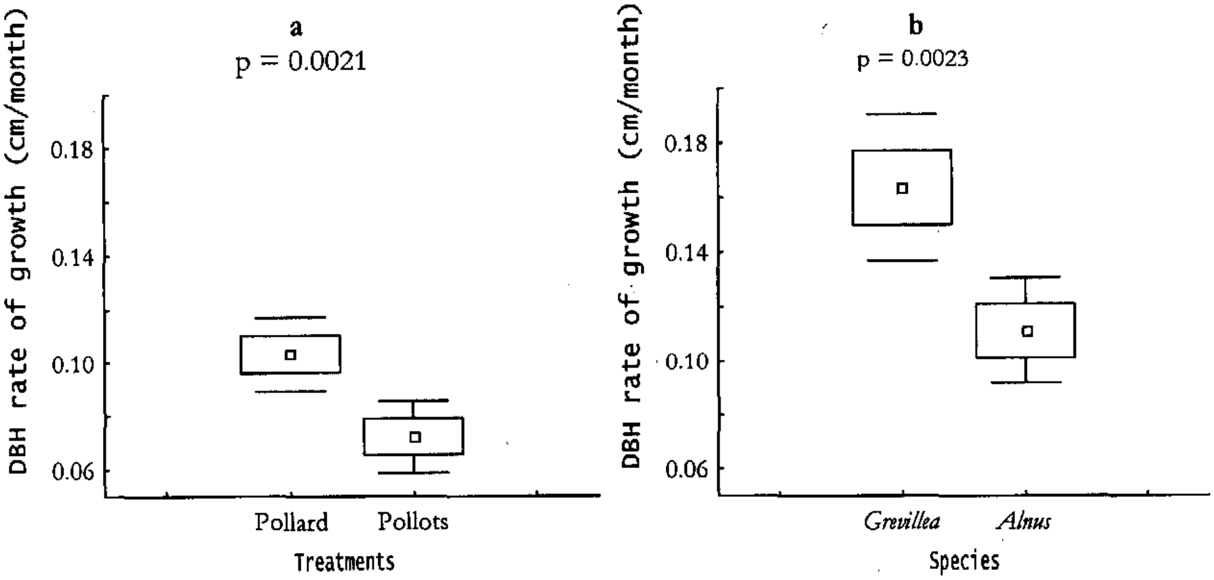

**Figure 4.15** T*-test comparisons between overall effects of pollard and "polloots" (Fig. 4.15a), on* Grevillea robusta *and* Alnus acuminata *and the differing ways the "polloots" affected DBH rate of growth for the two tree species (Fig. 4.15b).*

This observation also complements the findings of Russo (1995) that *Alnus* has most of its roots confined to the upper soil layers, and when they were root pruned, its growth was significantly reduced. Tree growth reduction due to reduced root activity was also observed by Miller and Pallardy (2001) who reported that the application of the root barrier to a 1 m depth significantly reduced radial growth of Silver maple (*Acer saccharinum*) in a temperate alley cropping in north-central Missouri, USA.

Although the rate of growth was significantly reduced in *Alnus* compared to *Grevillea*, their mean DBH values were not significantly different at the 83 months measurement, yet they were different at 63 months. This implied that both tree species continued to grow but *Alnus* was growing much slower than normal, and probably the growth rate of *Grevillea* was not significantly affected by one side root pruning since it only has a few shallow roots and its larger roots tend to penetrate in a vertical plane (Howard *et al.,* 1997). This also complements the observation made earlier that *Alnus* has a higher growth rate and consequently bigger DBH than *Grevillea* at high altitude. It also explains why *Alnus* competed more than *Grevillea* in both bean seasons and in the maize season because fast growing trees have higher capacities to capture and utilize soil water and nutrients (Rao *et al.,* 1988).

In general, treatments of pollarding and "polloots" significantly reduced DAB and DBH of both *Alnus* and *Grevillea.* This reduction was much more significant in DBH than in DAB. Additionally, the combination of pollarding and root pruning (polloots) significantly reduced tree growth rates but such a reduction was more significant in *Alnus* than in *Grevillea,* possibly because root pruning destroyed more roots in *Alnus* than in *Grevillea.* However, it was shown that tree diameters continued to increase despite root pruning and pollarding treatments. Pollarding and root pruning on one side only slowed down rates of growth but did not stop trees from growing.

It was observed that pollarding significantly reduced both tree DAB and DBH increment, compared to non-pruned controls for both tree species. The reduction in DAB and DBH increments were much more pronounced in the combination of pollarding with root pruning. Furthermore, such reductions were observed to affect *Alnus* more than *Grevillea*, but this could be expected since different species have varying responses of the root system to shoot pruning (Paez *et al.*, 1995). Miller and Pallardy (2001) made similar observations when the growth of Silver maple (*Acer saccharinum*) was reduced in trenched plots compared to non-trenched ones and this was attributed to the installation of the root barrier.

Both *Grevillea* and *Alnus* develop coppices at tree bases and epicormic branches along tree stems in addition to those developed at the top, following pollarding. *Alnus* demonstrated the ability of developing coppices at tree bases, along the stem (epicormic shoots) as well as at the top. *Grevillea* on the other hand, developed fewer coppices at tree bases and less epicormic shoots along the stem while most of its new shoots developed at the top. Epicormic shoots are undesirable if quality timber production is one of the objectives of tree planting, as is the case in Kabale District. They would require frequent removal, which then becomes expensive to the farmer. On the other hand, if the farmer has firewood as the major management objective of tree planting in croplands, then epicormic shoots and coppices are a great opportunity to increase firewood production.

## 4.4 Firewood production from pollarding

Agroforestry has potential to increase farm output since a variety of products can be harvested from the same piece of land. Trees in croplands are of high value to farmers in rural Africa where fuelwood constitutes 80-90% of energy consumption (Foley, 1987 ex Lott *et al*, 2000b). Recent observations from farmers indicate that they may be willing to sacrifice some crop yield to economic yields from marketable tree products such as timber and firewood, since these are direct and immediate (Ong *et al.*, 2002). This section presents results on firewood mass from pollarding *Alnus* and *Grevillea* during this study. Firewood mass obtained from coppices and branches after the first pollarding are presented in Table 4.7

**Table 4.7** *Fresh firewood mass from pollarding* Alnus acuminata *and* Grevillea robusta

| Species | Fresh mass of coppices* (kg/tree) *n=144* | Fresh mass of branches** (kg/tree) | Total fresh mass (kg/tree) |
|---|---|---|---|
| *Alnus acuminata* | 72.07 | 93.59 | 165.66 |
| *Grevillea robusta* | 99.28 | 103.22 | 202.50 |

Details of coppices per tree, number of branches per tree, as well as other parameters expected to influence tree growth and behaviour on-farm, and the periods when they were recorded, are presented in Table 4.8

**Table 4.8** *Coppices, branches, crown diameters and roots recorded per tree(n=144).*

| Tree species | No. of coppices after... | | No. of branches at... | | Crown diameter (m) | No. of roots cut |
|---|---|---|---|---|---|---|
| | 1st pruning | 2nd pruning | 1st pruning | 2nd pruning | at 1st pruning | 1st pruning |
| *A. acuminata* | 40 | 12 | 53 | 31 | 6 | 10 |
| *G. robusta* | 6 | 3 | 14 | 16 | 3 | 8 |

*NB: These parameters do not imply universal standard values and as such may bear an inevitable degree of subjectivism. They were used in this study to explain differences, which were observed between* Alnus acuminata *and* Grevillea robusta *during this study. Numbers of roots cut per tree were those with diameters ≥ 2 mm within the 50 cm depth at a distance of 50 cm from tree bases.*

It was observed from Table 4.7 that *Grevillea* produced much higher firewood mass than *Alnus* on fresh mass basis during the pruning period. However, on dry weight basis, *Alnus* had a higher mass than that of *Grevillea*, though not significantly different from each other (Table 4.9), since *Grevillea* had significantly higher moisture content at the 5% level of significance than that of *Alnus* (Table 4.9). This possibly explains why farmers would prefer *Alnus* to *Grevillea* for firewood.

**Table 4.9** *T-test comparisons between fresh mass, dry mass and moisture content of* Grevillea robusta *and* Alnus acuminata.

| Parameters | *Grevillea robusta* (Mean) | *Alnus acuminata* (Mean) | t-value | DF | P |
|---|---|---|---|---|---|
| Fresh mass (g) | 1522.00 | 1496.00 | 0.46798 | 18 | 0.645415 |
| Oven dry mass (g) | 701.89 | 758.00 | 1.81344 | 18 | 0.086472 |
| Moisture content (%) | 53.73 | 49.33 | 2.63851 | 18 | 0.016689 |

### 4.5 Firewood calculations

The calculations indicated below are based on average "sites" which refers to a piece of land 48 m length and 20 m width. These calculations provide an indication of potential firewood production from such a piece of land where crops are grown next to a line of boundary trees as illustrated in Figure 3.4 (Page 53).

The amount of fresh firewood obtained per site (an average area of 48 m x 20 m = 960 m$^2$, though trees are only planted in a single line at the lower boundary)

Each site had **12** trees, **6** of *Grevillea,* and **6** of *Alnus* (Figure 3.1).

On average, *Alnus* produced **40** coppice shoots and *Grevillea* produced **6** coppice shoots per tree after the first pruning (Table 4.8).

Average number of branches per tree was **53** for *Alnus* and **14** for *Grevillea* (Table 4.8).

Thus, *Alnus* produced **93.59 x 6 = 561.54** kg/site of fresh firewood mass from branches, and **72.07 x 40 = 2882.80** kg/site of fresh firewood mass from coppice shoots.

Total fresh firewood mass-produced from *Alnus* (crown) at first pollarding and coppice shoots after 18 months (second pruning) = **3444.34** kg/site.

Using moisture content of **49.33%** for *Alnus* (Table 4.9), amount of dry firewood mass from *Alnus* = **1745.25** kg/site.

*Grevillea* produced **103.22 x 6 = 619.32** kg/site of fresh firewood mass from branches, **99.28 x 6 = 595.68** kg/site of fresh firewood mass from coppice shoots

Total fresh firewood mass-produced from *Grevillea* (crown) at first pollarding and coppice shoots after 1.5 years (second pruning) **= 1215** kg/site.

Using moisture content of **53.73%** for *Grevillea* (Table 4.9), amount of dry firewood mass from *Grevillea* = **562.18** kg/site.

Total amount of dry firewood=**562.18** (*Grevillea*) + **1745.25** (*Alnus*)=**2307.43** kg/site.

At each site, trees were only planted at boundaries at a spacing of 2 m between trees. Each field had a length of 48 m and trees occupied only half the field length, i.e. 24 m (12 m for *Alnus* and 12 m for *Grevillea*) the rest of the land had crops. The boundary stretch on which trees were grown (both *Alnus* and *Grevillea*), and had visible influence, was therefore 24 x 5 m$^2$ (5 m being the distance from trees where competition was most pronounced according to this study). This is the main area utilized by the 12 trees without affecting the lower terrace neighbors (6 of *Alnus* and 6 of *Grevillea*) for their growth, the area occupied by trees ≐ **24 x 5 = 120** m$^2$ = **0.02964** ha.

Therefore **0.02964** ha produced **2307.43** kg of firewood over a period of 18 months, plus of course all the beans and maize, although at a reduced level.

Household fuelwood use per day was monitored by Muturi (1992), for a family of eight people over an eleven days period in Siaya District of Kenya and reported 8.5 kg of fuelwood per day. This suggests that the **2307.43** kg of firewood from **0.02964** ha would be sufficient for such a family for **272** days.

During this study, it was observed that most farmers in Kabale had at least two planting sites, while many others had five sites. However, this is increasing rapidly due to the attention that has been given to agroforestry under the current Uganda Government policy of Plan for Modernisation of Agriculture (PMA). Therefore most farmers with two planting sites (**0.05928** ha) could produce **4614.86** kg of firewood over a period of 18 months, sufficient for 542 days (1.5 years or 18 months). It implies that if tree management by pruning could be adopted, farmers with more than two planting sites would be able to produce extra firewood to sell in markets for income. Although some farmers do not plant trees on their farms with the sole objective of producing firewood, those who adopt agroforestry, use firewood as a by-product, and is increasingly being recognised as one of the major products of agroforestry (Teemba and Munyua, 1994).

The 0.05928 ha of land along farm boundaries is available for most farmers in Kabale. Agroforestry trees and shrubs provide a variety of tangible products to farmers besides other services. The most common products are firewood, timber, fodder, poles, fruits and mulch. However, it is not easy to combine the production of all these products in one field. This study suggests that on-farm pollarding has a potential of meeting at least three of these products, i.e. firewood production, mulch from pruned leaves (especially *Alnus* in this case) and timber.

Most importantly, results of this study suggest that it is also possible to continue producing crops together with trees on croplands through pollarding and root pruning. Tree growth was significantly but temporarily slowed down due to pollarding and root pruning. However, pollarding and one side root pruning do not seem to cause tree mortality since all trees were able to re-grow and produce new branches in a period of about 18 months fit to produce more firewood, though this may change as trees are continuously pollarded. Whereas pollarding and root pruning would interfere with growth rates of trees, this study suggests that pollarding and one side root pruning would offer farmers an opportunity to increase crop yields and benefits from both crops and tree products.

# Chapter 5

## 5. Conclusions and recommendations

### 5.1 Conclusions

Both *Alnus* and *Grevillea* significantly reduced crop yields when grown together on the same piece of land. *Alnus* competed significantly more than *Grevillea* and this was possibly due to factors such as differences in growth rate, root architectural difference, and crown spread (diameter). *Alnus* has a faster growth rate, which results in aggressive capturing of resources, thereby out-competing companion crops. In agroforestry systems involving fast growing trees and annual crops, the crops develop their roots when those of trees are already established, which puts trees at an advantage over crops in competition for water and nutrients. In this study the trees were 63 months old when the investigations were started.

Trees that were not pollarded, significantly reduced bean yields over a distance of 5 meters away from tree bases. This effect was attributed to root activity and crown shading. Crown shading prevents under-storey crops from receiving full sunlight, while tree roots probably utilise most of the water entering the soil close to trees. Jackson *et al.* (2000) reported a zone of decreasing depletion of soil water radiating out from tree bases, similar to results of the current study where bean yields nearest to tree bases (1 m) were significantly lower than yields at five meters away from tree bases.

Pollarding significantly increased crop yields compared to the control where trees were left intact with their canopies and root systems. This was attributed to the fact that shoot and root systems are functionally related (Eissenstat, 1992) and pollarding resulted in root death causing loss of apical dominance and a reduction of small-diameter roots (van Noordwijk and Purnomosidhi, 1995). Reduction of tree fine roots in the upper soil layers as a result of pollarding, could favour the companion food-crops, since both tree root activity and crown-shading effects would have been reduced as a result of pollarding.

This study revealed that the combination of pollarding and root pruning significantly reduced tree competition with crops but the benefits were limited in time, leading to the conclusion that fast growing tree species and complementarity are mutually exclusive goals to be achieved in croplands. If competition with crops has to be minimized, it could be done through pollarding and root pruning.

Combining pollarding and root pruning enabled significantly higher crop yields in comparison to pollarding alone. This indicated that it would be worthwhile managing competition by combining pollarding and root pruning of tree lateral roots in the upper soil horizons to redirect root function to deeper horizons. This is where boundary planting offers a great opportunity since food-crops are grown on one side of trees and root pruning could take place only on one side of trees (Figure 1.3). This means it is less complex for farmers to carry out and tree anchorage is not compromised.

In this study the combination of pollarding and root pruning significantly increased beans yields more in *Alnus* than in *Grevillea,* especially during the first bean season when roots had not started re-establishing. This indicated that root activity in the upper soil horizons was possibly more reduced in *Alnus* than in *Grevillea*. This is possibly why root pruning reduced tree growth more in *Alnus* than in *Grevillea.*

Pollarding has potential to significantly reduce tree-food crop competition in croplands compared to controls (non-pollarded trees), but much higher yields are obtained when pollarding is combined with root pruning to 50 cm depth, which is a realistic depth for farmers in their routine ploughing practices. Normal cultivation using hand hoes in Kabale sometimes goes much deeper than 60 cm (pers. obs.) and most seasonal crops utilize this depth for water uptake (Howard *et al.*, 1997). Maize roots can even penetrate to a depth of 80 cm (Okorio *et al.*, 1994).

It is also possible that farmers usually cut some of the smaller tree roots without noticing it and this explains why some farmers will insist that trees such as *Alnus* and *Grevillea* do not compete with crops. It is therefore concluded that pollarding and root pruning have the potential to meet the goal of on-farm boundary planting, i.e. continued and expanded tree planting on croplands, reducing the distance to the nearest source of firewood, and a shift in ownership of trees from communal or public to private tenure.

The benefits of root pruning and pollarding seem to have been short-lived (about 18 months) in the current study, especially with *A. acuminata.* This was possibly due to subsequent root system re-establishment in the upper soil horizons. This could provide an estimate of the frequency of pruning by farmers.

This study has revealed that pollarding and root pruning of *G. robusta* and *A. acuminata* significantly reduce tree growth rate. Tree growth rates decreased by interrupting tree photosynthesis through pollarding and increasing root turnover through root pruning, leading to limited tree lateral (DBH and DAB) increment. Therefore, where timber production is the major objective of management, a combination of pollarding and root pruning may not be appropriate since it prolongs the period before timber can be harvested. A comparative economic study is necessary to determine the optimum combination of treatments for different sets of circumstances.

Tree growth rates were reduced due to pollarding and root pruning on one side especially in *Alnus*, which has more roots than *Grevillea robusta* close to the upper soil horizons (Russo, 1995). However, there was no recorded tree mortality due to these treatments. This implied that *Alnus acuminata* and *Grevillea robusta*, could tolerate one side root pruning and pollarding, and could be managed to obtain their water requirements from deeper horizons so that companion crops can utilize upper soil horizons for water and nutrients.

After pollarding, both *Grevillea* and *Alnus* develop coppice shoots at tree bases and epicormic branches along tree stems in addition to those developed at the top. Epicormic shoots are undesirable if quality timber production is one of the objectives of tree planting, as is the case in Kabale District. They would require frequent removal, which then becomes expensive to the farmer. On the other hand, if the farmer has firewood as the major management objective of tree planting in croplands, then epicormic shoots are a good opportunity to increase firewood production.

Complete crown removal (pollarding) is only sound where firewood is of high priority since its benefits in reducing competition are limited, especially with *Alnus*. Alternatively, a combination of pollarding and root pruning would improve crop yields, in addition to supplying firewood. Both tree shoot and root systems were able to recover. Pollarding and root pruning on one side only slowed down rates of growth but did not stop trees from growing. In addition, as a result of pollarding, epicormic shoots and new branches resulted, which could be a firewood production strategy for farmers.

The advantage and suitability of the boundary tree planting technology to root pruning, is that food-crops can only be grown on one side of trees. The long-term effects of periodic and continuous tree pollarding and root pruning are not yet well known. However, root pruning is known as a management technique in orchards for fruit production (Schupp and Ferree, 1987), and pollarding is reported to be a common practice in Kenya (Tyndal, 1996), though little literature refers to the effects on timber quality and rate of tree growth.

Large trees in boundary planting systems significantly reduce crop yields. However, crop yields may be unaffected during the early years of tree growth as reported by Akyeampong *et al.* (1999) and ICRAF (1995, 1997), but they decrease when trees develop larger canopies and root systems. Positive tree-food crop interactions are only beneficial to crops when the tree component is not yet aggressive enough to out-compete associated food-crops.

Whereas *Alnus acuminata* fixes nitrogen through *Frankia,* thereby stimulating growth of associated vegetation (Tarrant, 1983), the benefits of nitrogen fixation are outweighed by its competition for water and other nutrients, and its negative shading effects.

In agroforestry, trees and shrubs may provide a variety of tangible products to farmers besides other services. The most common products are firewood, timber, fodder, poles, fruits and mulch. However, it is not easy to combine the production of all these products in one field. On-farm pollarding has a potential of partly meeting at least three of these products, i.e. firewood production, mulch from pruned leaves (especially *Alnus* in this case) and timber.

Results of this study have revealed that it is also possible to continue producing crops together with trees on croplands through pollarding and root pruning. Tree growth was significantly but temporarily slowed down due to pollarding and root pruning. However, pollarding and root pruning (on one side) did not lead to tree mortality.

## 5.2 Recommendations

It is recommended that pollarding combined with root pruning on one side of upper-storey boundary trees could be applied to manage below-ground competition, which is the most limiting in crop yields from agroforestry in tropical areas. Pruning of tree lateral roots could redirect tree root function from upper soil layers downwards and reduce their competition with food-crops in the upper soil layers.

Since all cultivation is done by hand hoes, to ensure that root pruning does not become an extra labour requiring task to farmers, it is recommended that during cultivation, farmers cut back all tree roots occurring within the 50 cm depth next to tree bases to allow crops to utilize this zone for nutrient and water uptake as tree roots grow to deeper horizons.

Farmers should be involved at all stages of the research process as much as possible. Involving farmers in the research process could be a means of shortening the research process and assurance to the farmers on the ownership of agroforestry technologies. The current administrative structures in Uganda offer a great opportunity to achieve this goal since the Decentralised Local Governments are now encouraged to empower farmers to demand the services they want.

Farmers who are already growing trees on croplands, especially those with whom this study was conducted, can be facilitated to reach fellow farmers for purposes of knowledge and experience sharing on practices of tree management on croplands. This is because farmers understand each other better than they would understand extension agents and development workers.

Although on-farm research is vital for agroforestry technology transfer to farmers and communities, strategic research should not be neglected. Whereas strategic research would produce quality biophysical information, on-farm research provides highly valuable socio-economic information integrated with biophysical information, which are important for wide scale adoption. Therefore, strategic research should be designed and reported in such a way that it can be understood and applied by the local community who in most cases are the target users.

The long-term effects of continuous pollarding and root pruning are not yet clearly known. Therefore, research should be conducted on the effects of tree pollarding and one side root pruning on timber production and tree root recovery and turn over. There is also need for further study on the amount of water uptake from the soil per unit time for each of the tree species to explain the differences observed in competition and their tolerance to pollarding.

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APPENDIX 1

**Table 1** *Factorial ANOVA comparing yield from sole crop plots and non-pruned trees with other treatments excluded for the second bean season and the maize season.*

| | Source of variation | SS | DF | MS | F | P |
|---|---|---|---|---|---|---|
| 2nd bean season | Intercept | 8455583 | 1 | 8455583 | 610.6167 | 0.00000 |
| | Species | 505018 | 2 | 252509 | 18.2348 | 0.00000 |
| | Distance | 1188371 | 7 | 169767 | 12.2597 | 0.00000 |
| | Species x Distance | 243601 | 14 | 17400 | 1.2565 | 0.23526 |
| | Error | 3475751 | 251 | 13848 | | |
| Maize season | Intercept | 400378061 | 1 | 400378061 | 662.7999 | 0.00000 |
| | Species | 5463604 | 2 | 2731802 | 4.5223 | 0.01191 |
| | Distance | 19490685 | 7 | 2784384 | 4.6094 | 0.00008 |
| | Species x Distance | 5256110 | 14 | 375436 | 0.6215 | 0.84579 |
| | Error | 130479299 | 216 | 604071 | | |

*NB: Data were not collected from sole crop plots in the first bean season.*

**Table 2** *ANOVA summaries for the regression univariate tests of significance for distance from trees bases with treatments restricted to comparison between non-pruned trees and sole crops (no tree plots)*

| | *Alnus acuminata* | Source of variation | SS | DF | MS | F | p |
|---|---|---|---|---|---|---|---|
| **Beans** | | Intercept | 325.71 | 1 | 325.71 | 96.28 | 0.000000 |
| | | Bean yield | 159.80 | 1 | 159.80 | 47.23 | 0.000000 |
| | | Error | 280.79 | 83 | 3.38 | | |
| | | Distance | 159.80 | 7 | 159.80 | 47.23 | 0.000000 |
| | | Residual | 280.79 | 83 | 3.38 | | |
| | *Grevillea robusta* | Intercept | 326.99 | 1 | 326.99 | 75.56 | 0.000000 |
| | | Bean yield | 89.82 | 1 | 89.82 | 20.75 | 0.000017 |
| | | Error | 372.18 | 86 | 4.33 | | |
| | | Distance | 89.82 | 1 | 89.82 | 20.75 | 0.000017 |
| | | Residual | 372.18 | 86 | 4.33 | | |
| | Sole beans | Intercept | 16.20 | 1 | 16.20 | 3.47 | 0.083777 |
| | | Bean yield | 18.56 | 1 | 18.56 | 3.97 | 0.06613 |
| | | Error | 65.44 | 14 | 4.67 | | |
| | | Distance | 18.56 | 1 | 18.56 | 3.97 | 0.06613 |
| | | Residual | 65.44 | 14 | 4.67 | | |
| **Maize** | *Alnus acuminata* | Intercept | 544.35 | 1 | 544.35 | 61.34 | 0.000000 |
| | | Maize yield | 160.41 | 1 | 160.41 | 18.07 | 0.000058 |
| | | Error | 701.09 | 79 | 8.87 | | |
| | | Distance | 160.41 | 1 | 160.41 | | |
| | | Residual | 701.09 | 79 | 8.87 | 18.07 | 0.000058 |
| | *Grevillea robusta* | Intercept | 363.04 | 1 | 363.04 | 39.15 | 0.000000 |
| | | Maize yield | 181.31 | 1 | 181.31 | 19.55 | 0.000029 |
| | | Error | 788.26 | 85 | 9.27 | | |
| | | Distance | 181.31 | 1 | 181.31 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Residual | 788.26 | 85 | 9.27 | 19.55 | 0.000029 |
| Sole maize | Intercept | 416.17 | 1 | 416.17 | 40.72 | 0.000000 |
| | Maize yield | 17.96 | 1 | 17.96 | 1.76 | 0.18926 |
| | Error | 715.41 | 70 | 10.22 | | |
| | Distance | 17.96 | 1 | 17.96 | | |
| | Residual | 715.41 | 70 | 10.22 | 1.76 | 0.18926 |

## Appendix 2.

**Table 1** *ANOVA tests of significance for the effects of tree treatments of pollarding and a combination of pollarding and root pruning on the yield of crops.*

| Crops | Factors | Source of variation | SS | DF | MS | F | p |
|---|---|---|---|---|---|---|---|
| 1st beans | *Alnus acuminata* | Intercept | 32782916 | 1 | 32782916 | 446.375 | 0.000 |
| | | Treatments | 3743207 | 2 | 1871604 | 25.4839 | 0.000 |
| | | Distance | 5319042 | 4 | 1329761 | 18.1061 | 0.000 |
| | | Treatments x Distance | 319363 | 8 | 39920 | 0.5436 | 0.82 |
| | | Error | 12118012 | 165 | 73442 | | |
| | *Grevillea robusta* | Intercept | 32350024 | 1 | 32350024 | 458.292 | 0.000 |
| | | Treatments | 2995982 | 2 | 1497991 | 21.2215 | 0.000 |
| | | Distance | 1816958 | 4 | 454240 | 6.4351 | 0.000 |
| | | Treatments x Distance | 220695 | 8 | 27587 | 0.3908 | 0.92 |
| | | Error | 11647072 | 165 | 70588 | | |
| 2nd beans | *Alnus acuminata* | Intercept | 4481146 | 1 | 4481146 | 400.682 | 0.000 |
| | | Treatments | 517163 | 2 | 258581 | 23.121 | 0.000 |
| | | Distance | 540354 | 4 | 135089 | 12.0789 | 0.000 |
| | | Treatments x Distance | 194473 | 8 | 24309 | 2.1736 | 0.03 |
| | | Error | 1811777 | 162 | 11184 | | |
| | *Grevillea robusta* | Intercept | 8633706 | 1 | 8633706 | 315.882 | 0.000 |
| | | Treatments | 1094501 | 2 | 547250 | 20.0223 | 0.000 |
| | | Distance | 708968 | 4 | 177242 | 6.4848 | 0.000 |
| | | Treatments x Distance | 94789 | 8 | 11849 | 0.4335 | 0.9 |
| | | Error | 4427797 | 162 | 27332 | | |
| Maize | *Alnus acuminata* | Intercept | 518826522 | 1 | 518826522 | 734.697 | 0.000 |
| | | Treatments | 13850759 | 2 | 6925379 | 9.8069 | 0.000 |
| | | Distance | 20804286 | 7 | 2972041 | 4.2086 | 0.000 |
| | | Treatments x Distance | 4621649 | 14 | 330118 | 0.4675 | 0.95 |
| | | Error | 161008403 | 228 | 706177 | | |
| | *Grevillea robusta* | Intercept | 532251803 | 1 | 532251803 | 832.016 | 0.000 |
| | | Treatments | 7658619 | 2 | 3829309 | 5.986 | 0.000 |
| | | Distance | 16726732 | 7 | 2389533 | 3.7353 | 0.000 |
| | | Treatments x Distance | 3354615 | 14 | 239615 | 0.3746 | 0.98 |
| | | Error | 150972446 | 236 | 639714 | | |

**Table 2** *ANOVA t-tests comparisons between different tree treatments and how they affected crop yields.*

| Tree Species | Variation source | Treatments | 1st bean season | 2nd bean season | Maize yield |
|---|---|---|---|---|---|
| *Alnus acuminata* | Mean | Control | 239.2656 | 89.90452 | 1131.933 |
| | Mean | Pollard | 451.0383 | 160.1373 | 1358.78 |
| | t-value | | 3.81089 | 3.42244 | 1.77671 |
| | df | | 118 | 116 | 165 |
| | p | | 0.000222 | 0.000858 | 0.077459 |
| | Mean | Control | 239.2656 | 89.90452 | 1131.933 |
| | Mean | Polloots | 589.9874 | 223.8362 | 1785.93 |
| | t-value | | 5.99659 | 5.83677 | 4.63285 |
| | df | | 118 | 116 | 164 |
| | p | | 0.000000 | 0.000000 | 0.000007 |
| | Mean | Pollard | 451.0383 | 160.1373 | 1358.78 |
| | Mean | Polloots | 589.9874 | 223.8362 | 1785.93 |
| | t-value | | 2.34096 | 2.73933 | 3.26686 |
| | df | | 118 | 116 | 169 |
| | p | | 0.020912 | 0.007129 | 0.001317 |
| *Grevillea robusta* | Mean | Control | 258.0361 | 117.6011 | 1190.67 |
| | Mean | Pollard | 441.128 | 233.1282 | 1460.48 |
| | t-value | | 4.07733 | 3.97142 | 2.32227 |
| | df | | 118 | 116 | 170 |
| | p | | 0.000083 | 0.000124 | 0.021404 |
| | Mean | Control | 258.0361 | 117.6011 | 1190.67 |
| | Mean | Polloots | 572.6461 | 308.6554 | 1633.479 |
| | t-value | | 6.47705 | 6.46219 | 3.56899 |
| | df | | 118 | 116 | 173 |
| | p | | 0.000000 | 0.000000 | 0.000464 |
| | Mean | Pollard | 441.128 | 233.1282 | 1460.48 |
| | Mean | Polloots | 572.6461 | 308.6554 | 1633.479 |
| | t-value | | 2.27036 | 2.06532 | 1.31981 |
| | df | | 118 | 116 | 171 |
| | p | | 0.025 | 0.041121 | 0.188663 |