

UNIVERSITY OF KWAZULU-NATAL

BLACK WATTLE
(Acacia mearnsii)
AND
THE FEVER TREE
(Acacia xanthophloea)

IN ALLEYCROPPING SYSTEMS

LUIS JEREMIAS NHAMUCHO

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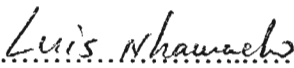
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REQUIREMENTS FOR THE DEGREE OF
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UNIVERSITY OF KWAZULU-NATAL**


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DECLARATION

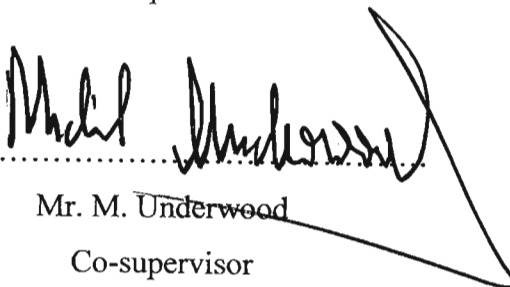
I, Luis Jeremias Nhamucho, do hereby declare that this thesis is entirely the product of my own original work, unless where it is acknowledged, and that it has not been submitted for the award of any degree in any other university

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DEDICATION

To my wife, Cremilde José Amone with whose encouragement I managed to overcome all the challenges faced during the long way towards the end of my studies for the intended degree. She always provided the necessary assistance for the success of my studies. I should not forget my daughter Cathya, who suffered a lot during my absence but remained my source of inspiration all the time. To my younger brother, Egas who perfectly sorted out all issues on my behalf while I was occupied with studies. To Parents, my daddy Jeremias Luis and my mom Albertina Capane Nhamuanzo for making me the man that I am.

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ABSTRACT

Alleycropping is an agroforestry technology of planting crops between rows of trees, preferable legumes to promote an interaction among them with positive benefits in terms of improving soil fertility and hence good crop yields. The technology has been tested with a variety of trees/shrubs species in association with crops (alleycropping) or with grasses (alleygrazing), sometimes with encouraging results and sometimes not, in a wide range of environmental conditions around the world. Research in alleycropping started in late 1970s and since then many publications have been released. However, little or nothing has been reported about this technology using black wattle and the fever tree, two nitrogen-fixing trees common in South Africa and reported as fast-growing species which produce a considerable amount of biomass within a short period of time. Due to that fact, a two-year trial was established in 2003 at the Ukulinga research farm, Pietermaritzburg, South Africa to evaluate the potential of the two tree species under alleycropping with maize and cowpeas as joint intercrops, under alleycropping with pumpkin, and under alleygrazing with *Eragrostis curvula* and with *Panicum maximum*. The trial assessed the crop yields and the biomass production from all the components, and their fodder digestibility using Neutral Detergent Fibre (NDF) and Acid Detergent Fibre (ADF) determinations. Additionally the changes in tree growth variables (diameter, total height, total volume and biomass) were monitored to produce regression equations to predict those variables, one from another, using regression analysis. The diameter was taken at ground level (dgl) and at the height of 1.3 m, normally called diameter at breast height (dbh).

The results showed that tree growth and biomass production were better in black wattle alleycropping than in association with the fever tree. The average dgl of black wattle after 12 months was 48mm and the average dbh was 36mm. Over the same period the total tree height was about 406cm. A tree pruning was done to one-year old black wattle in the whole trial and the prunings produced about 5.6t/ha of fresh foliage biomass in the association with maize and cowpea and 4.5t/ha in the association with pumpkin. In alleygrazing the growth variables were similar to those obtained in alleycropping but the biomass production was considerably different. The prunings produced about 7.66t/ha of fresh foliage biomass. The dry matter biomass from the prunings was 1.96t/ha, 1.58t/ha and 2.68t/ha in the association with maize and cowpeas, pumpkin and *E. curvula* respectively. The dry matter was obtained from 4-days-oven-dried samples and it was 35% of the fresh foliage biomass and 60% of the fresh woody biomass. The fever tree did not grow significantly during the study period and due to

that fact, the species was discarded from the study. Similarly, because after several endeavours using different seed lots, *P. maximum* had germinated very unevenly, and this grass was excluded from the experimentation.

Values of NDF and ADF less than 35% are considered good, between 35% and 60% fair and poor if greater than 50%. Using this classification the NDF and ADF values from this study were good in pumpkin (30.5% and 29.9%) and cowpeas (36.5% and 46.9%) biomass, fair in *E. curvula* (41.9% and 39.9%) and maize stover (53.6% and 42.1%) and poor in black wattle (76.58% and 68.1%) foliage. If black wattle is to be used as fodder, it must be mixed with highly digestible fodder like *P. maximum*, *Digitaria sp.*, and other legume plants, to increase animal intake and to avoid any risk of it becoming an animal hazard due to tannin effects.

The regression equations produced linear relationships between dgl and age, and biomass and dbh. The other interactions were not linear. The best equations were obtained in the interaction between dgl and age ($dgl = 4.8 * Age - 7.03$; $R^2 = 0.86$; $SE = 6.6$), dgl and height ($h = -0.03dgl^2 + 10.5dgl - 21.25$; $R^2 = 0.96$, $SE = 42.9$, $h =$ height), biomass and dbh ($lny = 2.409 * ln dbh$; $R^2 = 0.99$, $SE = 0.0$, $y =$ tree foliage biomass).

During the study, monkeys, cattle, birds and bushbucks posed a threat to the success of the study due to damage they caused to the crops. It was possible to keep the damage below the critical levels, although at high cost.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADF	Acid Detergent Fibre
Ca	Calcium
CP	Crude protein
Cu	Copper
CV	Coefficient of Variation
d	diameter
dbh	diameter at the Height
dgl	diameter at ground level
dkh	diameter at knee height
DM	Dry matter
FAO	Food and Agriculture Organisation
fb	fresh biomass
flb	fresh leaf biomass
fwb	fresh woody biomass
GCW	Global Compendium of Weeds
h	height
ha	hectares
ICRAF	International Centre for Research in Agroforestry
IITA	International Institute for Tropical Agriculture
K	Potassium
kg	kilograms
Mg	Magnesium
Mn	Manganese
N	Nitrogen
NAS	National Academy of Science
NDA	National Department of Agriculture
NDF	Neutral Detergent Fibre
NIRS	Near-infrared spectroscopy
nlt	number of Leaves per Twig
nt	number of Twigs per Tree
OM	Organic Matter
P	Phosphorus

R ²	Coefficient of Determination
SD	Standard Deviation
SE	Standard Error
SOM	Soil Organic Matter
t	tonnes
td	twig diameter
tfub	total fresh usable biomass
tl	twig length
tvol	total volume
uvol	usable volume
V	Volume
Zn	Zinc

CHAPTER 1

AGROFORESTRY - THE INTERFACE BETWEEN AGRICULTURE AND FORESTRY

INTRODUCTION

Agroforestry is defined as a farming system that combines trees and crop production in space and time, promoting positive interaction between these components to maximise benefits from the land use (Kang *et al.*, 1990; Nair, 1993; Thevathasan *et al.*, 2004). This practice is a sustainable land-use system that enhances soil fertility (Jordan, 2004; Sommer, 2000), helps in weed control (Rouw, 1995; Gallagher *et al.*, 1999; Jordan, 2004) and increases crop yields (Nair, 1993, Kang *et al.*, 1990). Additionally, it provides products such as fruits (Garret and Harper, 1999), wood and firewood (Sanchez, 1995), as well as fodder for livestock (Smith, 1991). With all those benefits, agroforestry can contribute to the improvement of rural economies (Shanker and Solanki, 2000; Atta-Krah *et al.*, 2004; Thevathasan and Gordon, 2004) thereby improving food security for the farmers' families in rural areas where agriculture is the main source of subsistence. In this way agroforestry also contributes to the alleviation of extreme poverty, one of the major problems in many developing countries. Apart from direct products, agroforestry can provide services such as being a windbreak for crops or shade for livestock, and can play a particular role in soil erosion control (Hoang Fagerström *et al.*, 2002; McDonald *et al.*, 2002). Additionally, the practice can promote conservation biology on the site through improving living conditions for other plants and animals and can make an important contribution to the provision of medicines (Rao *et al.*, 2004).

Depending on the climatic conditions there are two main categories of agroforestry: tropical agroforestry and temperate agroforestry (Jordan, 2004). Tropical agroforestry is practised in the tropical and sub-tropical regions where trees for intercropping are selected based on their contribution in terms of improving soil fertility while providing fodder and firewood (Kang *et al.*, 1990). Normally for this category, nitrogen-fixing trees are used because they are able to fix nitrogen from the atmosphere, which becomes available to the soil through diffusion and tree-litter decomposition (Kang *et al.*, 1990; Powell, 1996; Nygren *et al.*, 2002). According to Binkley and Giardina (1997), nitrogen-fixing trees are able to increase the content of nitrogen

in the soil pool as well as the content of carbon across a variety of ecosystems. Temperate agroforestry is practised in temperate zones, and trees for intercropping are mainly selected for their contribution in terms of provision of fruit, nuts and timber (Workman and Allen, 2003) for cash, while acting as environmental protectors for the associated crops.

In both tropical and temperate agroforestry, a wide range of tree-intercropping technologies such as alleycropping, also known as alleyfarming, contour edge rows, improved fallow and many more have been in use. Much research in those technologies has been conducted since the creation of the International Centre for Research in Agroforestry (ICRAF) in 1977/8. The results have been good and promising in terms of resource conservation and rural livelihood improvement. For example, in eastern and southern Africa, widespread adoption of agroforestry with N-fixing trees has led to a two- to threefold increase in maize crop yields (Garrity, 2004), securing food for many people in the process.

Accelerated work on agroforestry is achieving greater diversity and productivity on the smallholder farm, opening a wide range of business opportunities for the farmers and the economy at large (Garrity, 2004). Research has also demonstrated the role of agroforestry in the fight against HIV/AIDS and Kwesiga *et al.* (2004) have listed a number of ways in which agroforestry can contribute to that fight. Some plants used in agroforestry have both food and medicinal value that help in controlling opportunistic infections, thereby delaying the progression of the disease. Through improved income, agroforestry buffers vulnerable families from the sale of assets to cover medicine and funeral costs. Agroforestry technologies also provide labour-saving benefits that help mitigate the effects of labour shortage brought about by the HIV/AIDS pandemic.

MAKING A DIFFERENCE WITH AGROFORESTRY

Poor crop production and a shortage of forestry products in many communities around the world have been widely investigated and the conclusion has been reached that unsustainable agricultural practices lead to soil impoverishment and resource degradation (Sanchez, 2002; Garrity, 2004). Poor farmers with limited resources to afford high agricultural input technologies that require artificial fertilisers, herbicides and pesticides are compromised to grow crops that use low inputs based on natural soil fertility. These cropping systems provide

acceptable production for two to three seasons but thereafter the land becomes unproductive forcing the farmers to seek other cropland. This practice is commonly known as shifting cultivation (Kuhnen, 1982). When shifting from one piece of land to another the cropping area increases and the existing pool of natural resources decreases (Denich *et al.*, 2004). To manage shifting cultivation sustainably, a substantial amount of land is required. Due to human population growth, land has become a limited resource and shifting cultivation is no longer a sustainable option, because of its excessive pressure on land, which leads to a serious land degradation (Tiessen *et al.*, 1994; Shang and Tiessen, 2000; McDonald *et al.*, 2002; Denich *et al.*, 2004). Conversely, agroforestry is a low-input system by which natural soil fertility is enhanced and managed permanently by trees in the system (Nair, 1993). One of the most popular agroforestry systems is alleycropping, which is practised in many parts of the world.

THE ALLEYCROPPING SYSTEM

Alleycropping is a type of agroforestry system (Nair, 1993). Since the late 1970s when the technology was conceived by researchers at the International Institute for Tropical Agriculture (IITA) at Ibadan, Nigeria (Carter, 1995), alleycropping has been studied and introduced mainly in Africa, South America and Asia. In alleycropping, nitrogen-fixing trees are planted in rows or 'alleys', and the crops are planted between the rows, thus conferring on the system the name of 'alleycropping'. The trees are pruned periodically and the resulting mulch can be placed in the alleys to provide nutrients and to control weeds (Kang *et al.*, 1981 cited by Sanchez, 1995) or used for fodder supplements in a cut-and-carry system (Kang, 1994). The interactions between the trees and the crops are maximised by the specific spatial and temporal arrangement of those components. According to Nair (1993), alleycropping systems are categorised into four bases: structural, functional, socio-economic and ecological.

The structural basis refers to the status of the components, including the layout of the woody component, the vertical structure and the temporal arrangement of the components. The functional basis regards to the role of the different components in the system. For example, the tree component has a function of improving soil fertility, whereas the crop component has a role to provide food. The socio-economic basis takes into account the social and economical value of agroforestry to the people, whereas the ecological basis describes the

ecological benefits of agroforestry systems, such as soil erosion control and the improvement of the physical, biological and chemical properties of the soils.

Alleycropping is a suitable practice for farmers using both manual and mechanised agriculture (Jordan, 2004). Long-term results from alleycropping experiments at Ibadan have shown striking results when applying *Leucaena* sp. prunings in the alleys with maize. Even without the application of artificial nitrogen, maize yields could be maintained for many years at a reasonable level of approximately two tons per hectare (Kang, 1991). Various other experiments have also shown the positive effect of alleycropping using other nitrogen-fixing trees. The example in Table 1.1 provides the results of alleycropping of maize and *Alchornea glandulosa* Poepp., *Acacia* sp., *Gliricidia sepium* (Jacq.) Steud. and *Leucaena leucocephala* (Lamk.) De Wit, showing clearly the difference between alleycropping and shifting cultivation here considered conventional agriculture at different levels of nitrogen application.

Table 1.1. Results from maize alleycropping with *Alchornea glandulosa*, *Acacia* sp., *Gliricidia sepium* and *Leucaena leucocephala* on maize grain yield (ton/ha) compared to conventional systems after 5 years of cropping at Ibadan (Nigeria).

Technology		Nitrogen application	
		Nil	45 kg/ha
Conventional (without trees)		1.1	1.9
Alley farming using four tree species	<i>Alchornea glandulosa</i>	1.6	3.1
	<i>Acacia</i> sp.	2.0	3.5
	<i>Gliricidia sepium</i>	2.4	3.3
	<i>Leucaena leucocephala</i>	3.2	4.3

Source: Kang (1994)

The effect of alleycropping as compared to conventional systems is visible after at least three to four cropping seasons (see Figure 1.1.) when the trees have started to play their role in the system (Coe *et al.* 2003) and if the competition effect is properly managed. During the first two to three seasons, crop yields in alleycropping are likely to be lower than in conventional systems, but increase with time while those achieved with conventional systems will decrease with time.

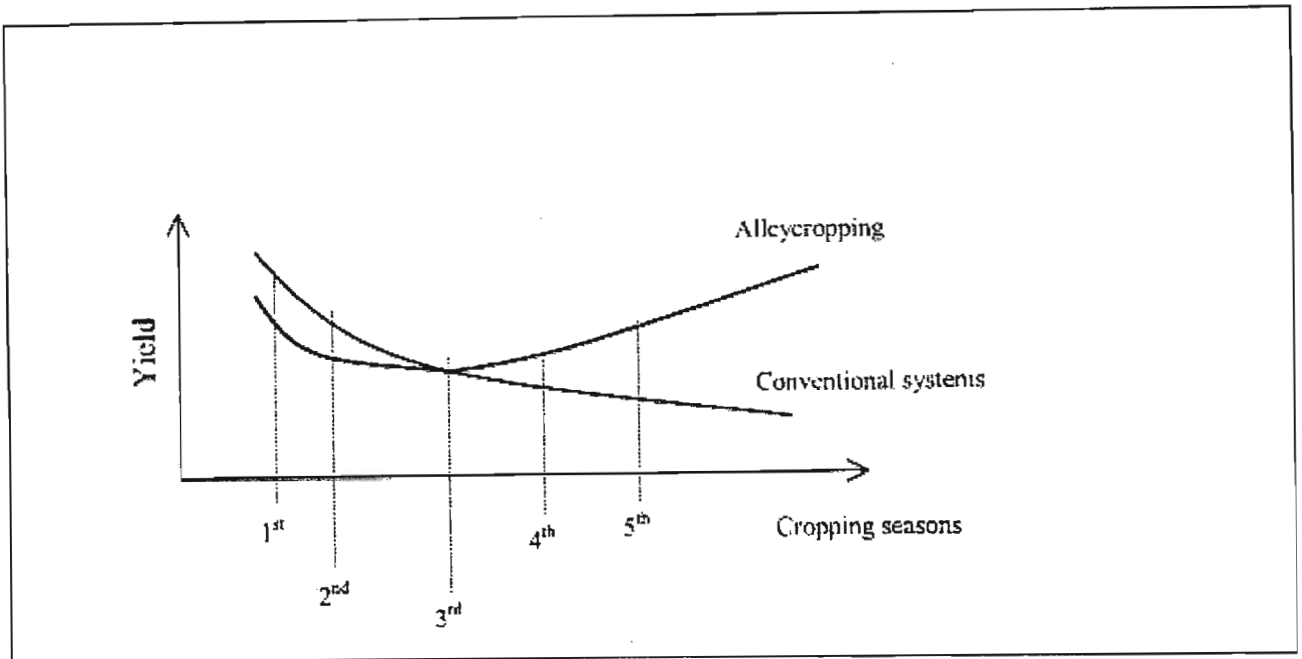


Figure 1.1. Alleycropping and conventional cropping during successive cropping seasons. In the first two seasons alleycropping may yield less than the conventional system, but from the third or fourth year alleycropping will yield more than conventional system if competition is properly managed. Adapted from Kang (1994).

TREES FOR ALLEYCROPPING

A tree for agroforestry must be multipurpose (Gupta, 1993). Multipurpose trees are those that can provide more than one product or service. Ideal multipurpose tree should be the ones that are ecologically/environmentally friendly, that are fast growing to start benefiting the farmers quickly and that are suitable for the local practices. The species do not necessarily have to be indigenous, but they should be known by local people to facilitate their acceptance and adoption (Wood and Burley, 1991).

The science of agroforestry has dedicated more investigation to some tree species than to others. In tropical agroforestry, species such as *Sesbania sesban* (L.) Merr., *Tephrosia vogelii* Hork. f., *Gliricidia sepium* (Jacq.) Stend, *Leucaena leucocephala* (Lam.) De Wit and *Cajanus cajan* (L.) Millsp have been well documented in various books and papers regarding their easy adaptability to poor soils, their ability to fix nitrogen and their fast growth potential while producing a considerable amount of direct products such as firewood and leaf biomass for fodder, within a short period of time after planting. Other species with considerable

potential for agroforestry have been less explored. This is the case with black wattle (*Acacia mearnsii* De Wild.) (Gupta, 1993; Du Toit, 2002; Hankey and Stern, 2002) and the fever tree (*Acacia xanthophloea* Benth.) (Hankey and Stern, 2002; Murdoch Magazine, 2003) reported to be very fast-growing trees and good nitrogen fixers. The species are also listed in the ICRAF database among more than 3000 species already documented in agroforestry (Burley and von Carlowitz, 1984). The full description of their potential is given below.

Black Wattle (*Acacia Mearnsii* De Wild.)

Black wattle is a very fast-growing nitrogen-fixer. The estimated annual increment in height is greater than 3 meters when growing in suitable environments (Little *et al.*, 2000; ICRAF, 2001). It can produce between 21 and 28 tonnes of wet leaves per ha per annum, containing 245 to 285 kg of nitrogen, from a 2-year-old stand at a planting density of 1400 trees per ha (NAS, 1980; Duke, 1983).

Some farmers have claimed that tobacco and vegetable yields are doubled in rotation with the black wattle in agroforestry systems due to the nitrogen enrichment of soils from which black wattle had been harvested (NAS, 1980; Duke, 1983).

In South Africa black wattle was introduced as a tree to be used for shade for livestock, shelter, windbreaks and for fuel wood, and it has become a major plantation species contributing significantly to the South African Forestry and Forest Products sectors (Dunlop and MacLennan, 2002). It has been widely grown in KwaZulu-Natal, Mpumalanga, the Eastern Cape, the Free State and on a smaller scale in the Western Cape. The total area covered with black wattle plantations is approximately 130 000ha (Beck, 1999) corresponding to 7% of the total area of South Africa planted to forest, and provides direct and indirect employment to over 36 000 people (Dunlop and MacLennan, 2002).

The bark of black wattle has a high economic value when used in the tannin industry (Duke, 1983; Schulze, 1997) and can also be used to manufacture adhesives and flotation agents (Duke, 1981). Black wattle is regarded as being among the best tannin-producing species in terms of both quantity and quality (Schulze, 1997; Beck, 1999).

The timber from the species is of high quality (De Laborde, 1984). It can be used in construction industry to make products such as parquet flooring blocks, furniture, hardboards, rayon and fencing poles. In the mine industry it is used as mining timber (Sherry, 1971; Dobson and Feely, 2002). It has been also used for firewood due to its relative density, which is about 670 kg/m³ on a bone-dry basis and between 550 to 850 kg/m³ on an air-dry basis, depending on the environmental conditions of the site on which it is grown (Dobson and Feely, 2002). In the midlands KwaZulu-Natal, the air-dry wood density of black wattle is about 890kg/m³ (Smith, 2002). The calorific value of the wood when dry is about 4600 kcal/kg equivalent to 19700 kJ/kg with an ash content of about 1.5%. It also produces high quality charcoal with a calorific value of 6,600 kcal/kg or 32000 kJ/kg with an ash content of only 0.4% (NAS, 1980; Dobson and Feely, 2002). Since the late 1990s black wattle timber has become a popular source of high-quality fibre for pulp production (Dobson and Feely, 2002).

The tree is used for erosion control on sloping terrain with poor soils unsuitable for agriculture (Duke, 1983). Dense wattle plantations are effective in preventing further erosion on 50° slopes (NAS, 1980).

Little *et al.* (2000) and Little (2002) have reported that small antelopes, rodents and livestock browse on the young trees. But according to Gupta (1993) black wattle is not suitable for fodder.

Unfortunately, black wattle is a strong invader and it can be found growing invasively from forest to grassland, from Low- to Highveld, from poor to fertile soil and from warm to cold areas (Sherry, 1971). When uncontrolled, black wattle can easily colonise unwanted lands becoming a serious weed. Due to that reason, in 1990s black wattle was declared a serious weed in South Africa (Duke, 1983; Esterhuysen, 1999; NDA, 1999; ICRAF, 2001; Jahn, 2001) and since then the species is part of the alien invader plants list and, as such, under strict governmental control.

According to the Agricultural Resources Act of 1983 (Act 83), all alien invader plants are subject to control to avoid undesirable propagation and invasion in the landscape. The South African government is conducting a special high-cost programme (NDA,

1999) aimed at eradicating all individuals of wattle found in inappropriate places to control black wattle invasion. The purpose of that programme is to reduce unwanted wattle jungles threatening farm and forestlands. The theory behind this strict control is that unwanted wattle jungles could be detrimental to the productive potential of those natural agricultural resources (Henderson, 2001; Beck and Dunlop, 2002).

When properly managed, black wattle has shown high potential to improve soil fertility and soil structure, and to reduce soil erosion particularly of infertile and acidic soils (Dunlop, 2002) and therefore it has a considerable potential for use in agroforestry (Du Toit, 2002).

The Fever Tree (*Acacia xanthophloea* Benth.)

The fever tree is a nitrogen-fixing species native to southern Africa (GCW, 2001) where it is used as a source of firewood (Duke, 1983). This species is a prominent tree in the Lowveld region of South Africa (Hankey and Stern, 2002) where rural people benefit mainly from its wood for fuel purposes, being one of the species most used for fuel in the rural bakery industry. The fever tree is reported to grow fast with an increment in height of about 1-1.5m/year (ICRAF, 2001; Hankey and Stern, 2002).

Like most of the members of the Mimosoideae sub-family, the fever tree has root nodules containing a nitrogen-fixing bacterium that plays an important role in the nitrogen enrichment of soils, which then has a positive impact on the growth of associated plants.

The foliage and pods of the fever tree can be feed for livestock because the leaves and fine twigs are browsed by wildlife (Hankey and Stern, 2002). The timber is a source of wood for building, crafting and furniture, and the roots and powdered bark from the stem are used as an emetic and as a prophylactic against malaria.

Other uses such as erosion control and the provision of shelter, shade, ornamentation or a living fence have been reported (ICRAF, 2001; Hankey and Stern, 2002). Birds often build their nests on the fever tree branches, promoting the biodiversity of the site. The fever tree is recognised as a stabiliser of swamplands, riverbanks and dams (GCW, 2001).

The fever tree occurs naturally in depressions and shallow pans where underground water is present or surface water is collected after summer rains. It is also found in low-lying swampy areas, along the margins of lakes and riverbanks where it often forms pure and dense stands of woodland in seasonally flooded areas on alluvial soils. This tree can be found from Kenya, in the North to KwaZulu-Natal, in the South (ICRAF, 2001; Hankey and Stern, 2002; Palgrave, 2002).

AIM AND OBJECTIVES

Much research has been done on agroforestry technologies, using a variety of trees and shrubs. However much more work is necessary in order to evaluate the agroforestry potential of other species. The aim of the study is to evaluate the potential of black wattle (*Acacia mearnsii*) and the fever tree (*Acacia xanthophloea*) in an alleycropping system to assess food, firewood and fodder production of the system. To achieve this aim four objectives were set up in this study. The objective one is to monitor the growth and behaviour of those species under alleycropping with maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* (L.) Walp.), pumpkin (*Cucurbita pepo* L.), weeping love grass (*Eragrostis curvula* [Schrad.] Nees.) and guinea grass (*Panicum maximum* Jacq.). The objective two is to assess crop yield and biomass production under alleycropping, while the objective three is to assess tree and grass biomass production from the in the system. Tree biomass will be divided into two categories: woody biomass used for example for firewood and foliage biomass used for mulching. The fourth objective is to analyse the soil nutrients change in the site due to the effect of alleycropping. This assessment will be done through analysing the parameters such as tree growth, tree and crop biomass, crop yield and the soil nutrients content, as shown in the next chapters.

RELEVANCE OF THE STUDY

One of the main limitations to crop productivity, in many areas particularly in the tropics, is nitrogen deficiency (Mokwunye and Vlek, 1986; Sanchez, 2002). Nitrogen-fixing species such as black wattle and the fever tree can play an important role in increasing crop yields in those nitrogen-deficient soils. Those trees can also provide wood and firewood for households and supply fodder for livestock, particularly during dry seasons characterised by unpalatable pasture and a shortage of grasses (Smith, 1991). With all the uses listed above, despite some negative aspects of black wattle, it is believed that those trees can be suitable for agroforestry, especially for alleycropping.

Additionally, agroforestry, as a scientific endeavour, is still making its first steps in South Africa, although this is an old farming practice in many parts of Africa. It is hoped that the results of this study will help achieve a better understanding of the importance of agroforestry as a land management technology using low inputs to achieve a high level of crop production, particularly in nitrogen-deficient soils. Research on the usage of black wattle and the fever tree can provide positive results as to how to influence positively the management of black wattle and fever tree lands. This can contribute to change the current perceptions about black wattle and help the farmers and the government to manage black wattle in a sustainable way.

LIMITATIONS

Alleycropping is a long-term farming system in which trees need to be well established in the soil before they start playing their role in soil fertility improvement (Kato *et al.*, 1999; Coe *et al.*, 2003; Denich *et al.*, 2004). Therefore, an increase in crop yield could take several years to be achieved. Time was the main constraint in the present study because the trials were only to be monitored for two seasons.

DISSERTATION STRUCTURE

The study comprises six Chapters. All the Chapters except number six are structured in article form to facilitate further publication of this work. Chapter 1 is an introduction to agroforestry in which the importance of this technology is highlighted. Chapters 2, 3 and 4 deal with several aspects of alleycropping systems. Chapter 2 reports the use of black wattle and the fever tree under alleycropping with maize and cowpea intercropped and pumpkin and

Chapter 3 focuses on the role of black wattle for fodder production under alleygrazing system with *Panicum maximum* and *Eragrostis curvula*. Chapter 4 presents the early-growth equations of black wattle under alleycropping and alleygrazing, whereas Chapter 5 discusses the constraints of animal damage in agriculture. The Chapter presents the constraints imposed by marauding monkeys from a neighbouring game reserve and the farm's cattle breaking down fences to reach the better grazing offered by the alleycropping plots at the Ukulinga farm. It describes how crucial and compromising animals can become for any experiment if they gain entry. Finally, a short summary of the study is given in Chapter 6.

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CHAPTER 2

BLACK WATTLE (*Acacia mearnsii* De Wild.) AND THE FEVER TREE (*Acacia xanthophloea* Benth.) UNDER ALLEYCROPPING WITH MAIZE, COWPEAS AND PUMPKIN

INTRODUCTION

In many parts of the humid and sub-humid tropics, particularly in Africa, the dominant food production pattern is the bush-fallow system, also called shifting cultivation or "slash and burn" (Kang, 1994; Denich *et al.*, 2004). This system consists of short cropping periods (1-3 years) alternated with long fallow periods (6 years or more) to replace soil fertility (Kang, 1994).

The bush-fallow system is sustainable if the fallow periods are maintained long enough for the soil to recover its fertility, impoverished during cropping periods. If the fallow is too long, then large tracts of land have to be involved in the system. Due to the rise in the human population, high food demand and other social changes, land became one of the limiting factors for agriculture world-wide (Boddey *et al.*, 1997; Schroth and Sinclair, 2003) and it has contributed to the failure of the bush-fallow system (Nair, 1998; García-Barrios and García-Barrios, 1992; García-Barrios, 2003; Denich *et al.*, 2004).

Alternatively, alleycropping can replace the bush-fallow system at short notice with low inputs. Alleycropping is a form of agroforestry by which food crops are grown in alleys formed by hedgerows of trees/shrubs in a specific spatial and temporal arrangement (Nair, 1993). When trees, preferably legumes, grow together with crops, they are able to improve soil fertility and soil structure, benefiting the associated crops (Atta-Krah and Kang, 1994; Jordan, 1995; Sanchez, 1995; Arachchi and Liyanage, 2003; Young, 2003; Jordan, 2004). Therefore, they can contribute to enhance the crop yields while concomitantly providing additional products such as wood and firewood, fruits and medicine and services like windbreaks, promotion of honey production, weed and erosion control, soil moisture and biodiversity conservation (Kang *et al.*, 1990; Smith, 1991; Nair, 1993).

Alleycropping, also known as alleyfarming (Okali and Sumberg, 1985) or hedgerow intercropping, has been practised in many parts of the world (Kang, 1994) in both tropics and temperate zones (Jordan, 2004). The technology has been tested with encouraging results in the humid and sub-humid tropics (Kang, 1994; Sanchez, 1995).

In alleycropping, trees or shrubs are regularly pruned and the prunings are placed between alleys to decompose and to release nutrients into the soil, which can be used by associated crops. If the system includes livestock, part of the prunings can be used for fodder (Kang *et al.*, 1990) and animals feeding on legume prunings are likely to increase their productivity due to the high nutritive value of leguminous fodder (Bogdan, 1977) and its role in protein supplementation especially in poor feeding programmes. The trees can also increase the availability of fresh fodder during the dry season, when grasses are dry and unpalatable. Additionally, animal manure can be integrated into the production cycle for increasing the soil fertility in those systems (Smith, 1991).

Alleycropping and Soil Fertility

The soil organic matter (SOM) falls significantly when land is brought into cultivation. If the cropping system does not include fertilisation, the rate of organic matter (OM) inputs decreases while the rate of nutrient uptake by plants increases with time (De Ridder and Van Keulen, 1990) and, consequently, a new SOM equilibrium is reached at a lower level of crop production (Feller *et al.*, 1991, Du Preez and Du Toit, 1995). To raise the new equilibrium to acceptable levels of crop production, extra OM has to be added to the soil. Among a long list of ways to increase SOM, the use of plant biomass, animal manure and artificial fertilisers has been highlighted (De Ridder and Van Keulen, 1990; Szott *et al.*, 1999).

Although the use of plant biomass has been mentioned as one of the most common forms of increasing SOM in traditional farming systems, research has shown that the amount of plant biomass necessary to raise the SOM to the acceptable levels for crop production depends on the type of soil. For example, in many southern African soils, about 10t/ha of dry matter (DM) from high-quality plant OM should be applied every year to maintain a minimum level of 1.72% of SOM (Snapp *et al.*, 1998). Assuming that the optimum level of SOM for good crop production is around 5% (Denich *et al.*, 2004), then about

29t/ha/year of plant DM should be incorporated into the soils so as to maintain desirable levels of SOM.

The climatic conditions have an influence on the process of organic matter oxidation as well as on the losses of SOM by erosion. In Africa, there are three different categories of soil distinguished by climatic conditions: the soils of humid climate regions, the soils of sub-humid climate regions and the ones of semi-arid climate regions. Studies by Young (1989) have shown that as much as 8.4t/ha of DM per year would be necessary to apply into the soil in humid regions, 4.2t in sub-humid regions and 2.1t in semi-arid regions to cover annual losses of soil fertility. Assuming that the DM is 20% of fresh biomass, then 42t, 21t and 11t of fresh biomass would be necessary to apply per hectare per annum in humid, sub-humid and semi-arid climate regions respectively. These figures show that a huge amount of plant biomass is required to maintain acceptable levels of SOM, particularly in poor soils. Although this poses a great challenge to traditional farming systems, it can be soundly managed under modified farming systems like alleycropping.

Alleycropping can provide enough biomass for soil fertility and for other uses (Jordan, 2004) if species of trees or shrubs are properly selected for a particular site (Gupta, 1993). For their selection, the behaviour of those species when intercropped with crops and their growth rate as well as their biomass production at such sites have to be considered. In addition, the quality of plant biomass from those species also has to be taken into account, because it has a significant influence on the process of biomass decomposition and nutrient release, as discussed in the next paragraph.

Plant Biomass Quality and Soil Fertility

As said before, the ability to improve soil fertility depends on the quality of OM from the tree biomass (Fox *et al.*, 1990; Gutteridge, 1992), which is influenced by the percentage of nitrogen (N), phosphorus (P), lignin and polyphenol in that material. Mafongoya *et al.*, (1997) have shown that plant OM containing less than 0.25% of P in its DM can cause net immobilisation of P in the soil. They have also observed that lignin and polyphenol could affect the release of N into the soil if those compounds exceed 15% and 4% respectively in plant DM. This shows that the quality of plant OM is an important issue in the context of

addition of SOM even if the objective is to protect soil physical functions rather than to improve soil fertility. Based on this information, Vanlauwe *et al.*, (2002) developed a guideline (Table 2.1) on how to integrate plant biomass into the soil. The guideline is based on the content of N, P, lignin and polyphenol in plant DM and it can help to decide on how to incorporate plant biomass into the soil to promote good crop yields.

Table 2.1. Guideline on how to use plant biomass to improve soil fertility, soil physical structure and soil biological properties based on the chemical content of plant DM

Options	N > 2.5%	P >0.25%	Lignin <15%	Polyphenol < 4%	Use as
1	Yes	Yes	Yes	Yes	Green manure (High quality organic matter should be incorporated as a green manure).
2	Yes	Yes	Yes	No	Integrated nutrient management (Low levels of N, P or N and P may cause net immobilisation of N or P or both N and P if incorporated immediately. Use it with N or P or both fertilisers. Alternatively, mix it with very high-grade organic matter to compensate for low levels of N or P or both).
	Yes	Yes	No	Yes	
	No	Yes	Yes	Yes	
	Yes	No	Yes	Yes	
3	Yes	Yes	No	No	Compost to improve soil structure (High levels of lignin and polyphenol may encourage immobilisation of N and P or reduce the rate of mineralization of organic matter despite high levels of N and P in plant biomass. In this case the organic matter should be composted to accelerate the breakdown process).
4	No	No	No	No	Surface mulch for erosion control (Low levels of N and P and high levels of lignin and polyphenol make this organic matter unsuitable for use as fertiliser. However it can be used as surface mulch to protect the soil against evaporative losses or to control surface water flow and to suppress weeds).

Source: Vanlauwe *et al.* (2002)

Gutteridge (1992) applied a variety of tree legumes at equal biomass rates and compared the crop response to the rate of N applied. In the treatment using *Sesbania sesban* (L.) Merr. 86% of N was released, producing about 60g of maize stover per pot, while *Leucaena leucocephala* (Lamk.) De Wit which also released 86%, produced only 40g of maize stover. The amount of N released was compared to the rate equivalent to 100N

kg/ha from artificial fertilisers. The difference in stover mass between the *Sesbania* sp. and *Leucaena* sp. could not be related to the amount of N released but to the difference in N release patterns. The time of N release will have a significant effect on the plant N use. For better N utilisation, it needs to be released by the time of high plant activity. The process of matching both times is called synchronisation. It seems that *Sesbania sesban* had better synchronisation with maize than *Leucaena leucocephala* or may be the N from *L. leucocephala* was somehow not available to maize for other unknown reasons.

The incorrect use of plant biomass can affect crop production negatively. In India, the use of wheat straw (low-quality organic matter) combined with urea reduced the yield of wheat, whereas the use of *Sesbania sesban* (high-quality organic matter) combined also with urea, increased considerably the yield of wheat, when both were compared to a treatment using only urea (Goyal *et al.*, 1992). Similar results were found in Kenya (Nandwa, 1995), and in Zimbabwe where researchers have observed that using maize stover (low-quality organic matter) as a source of organic matter in maize fields, could decrease the yield of maize grain between 3 to 30 % (Rodell *et al.*, 1980 and Muriwara and Kirchmann, 1993).

Trees and Crops for Alleycropping

The selection of trees/shrubs for alleycropping can be a problem if ecological information about the species is not available. When that information is available, it may still describe incompletely the behaviour of the species when associated with others in a specific environment. The performance of a particular species under alleycropping cannot be easily predicted without research. Some trees/shrubs can show allelopathic effects on the associated crops; they can host pests and diseases to the crops or even show strong competition that suppresses the accompanying crops. Although much research has been conducted on a wide variety of trees/shrubs and crops in different environmental situations, more is still necessary. Not all results can be extrapolated to other conditions or circumstances that differ from the original environments and the social structure from which those results were obtained (Palm, 1995; García-Barrios and Ong, 2004).

The current study aims to assess the potential of black wattle (*Acacia mearnsii* De Wild) and the fever tree (*Acacia xanthophloea* Benth.) in alleycropping with maize (*Zea mays*

L.) intercropped with cowpea (*Vigna unguiculata* (L.) Walp.), and pumpkin (*Cucurbita pepo* L.) grown by itself, given their potential already described in Chapter 1. The assessment is made through the evaluation of crop yields, crop biomass, tree growth, tree branching and tree biomass production.

MATERIALS AND METHODS

Experimental Design

The experiment was carried out on the Ukulinga research farm, University of KwaZulu-Natal, on the outskirts of Pietermaritzburg, South Africa (30°24' S and 29° 24' E) between September 2003 and March 2005. The experiment was laid out as a randomised complete block design with three replications. The main plots (10x10m) consisted of four alleycropping treatments: the black wattle and the intercrop of maize and cowpeas, the black wattle and pumpkin, the fever tree and the intercrop of maize and cowpeas and the fever tree and pumpkin. The control plots (5x10m) besides those of the two tree species, included plots of maize and cowpeas intercropped and pumpkin as sole crop. To avoid the influence of trees in controls plots, a buffer border of 50m width was left between the alleycropping and the controls as recommended by Coe *et al.* (2003).

Land Preparation and Plot Management

The experimental site was cleared, disked and ploughed with a tractor in August 2003. Clearing was necessary because the site was in fallow for some years and hence it was overgrown with grasses such as water grass or Chufa flatsedge (*Cyperus esculentus* L.), Kikuyu grass (*Pennisetum clandestinum* (Hochst.) Chiov.), Guinea grass (*Panicum maximum* Jacq.) and amaranthus (*Amaranthus retroflexus* L.). Disking, followed by ploughing was done to improve the physical structure of the soil which was followed by manual hoeing. The seedlings were planted in October and the crops in November 2003, without fertilisation. Although the trial was rainfed, watering was necessary during the first two weeks after planting to reduce water stress on seedlings due to the absence of rain in that period. The crops were protected against earthworm damage and other pests with the application of cutworm bait around the planting hill immediately after planting. Weed invasion was strong in the first cropping season because the reserves of weed seeds in the

soil were still large, as the land had just been converted from fallow. Weed control was done using different means: manually by hand hoes, through application of herbicide (Roundup) and by soil rotavation with a motorised rotavator. In March 2004, the first crops were harvested and the crop residues were left on the plots and used as mulch in the second cropping season, which started in October 2004 and extended into March 2005.

Sowing Rates

The tree seedlings were planted at a spacing of 4x2.5m (1000 trees/ha) in plots with three rows of five seedlings each. The tree rows produced two hedges per plot between which the crops were sown. Maize was sown at a spacing of 0.75x0.25m (53000 plants/ha), cowpeas at a spacing of 0.75x0.5m (26000 plants/ha) between maize rows and the pumpkin at a spacing of 1.5x0.5m (13000 plants/ha). This spacing was different from what Silwana and Lucas (2002) recommended because under alleycropping more space had to be given to the crops to reduce competition. Silwana and Lucas (2002) recommended a spacing of 0.1x0.5m for cowpeas based on the experience of Liebenberg (1989), a spacing of 1x1m for pumpkin based on the experience of Olivier *et al.* (1979) and a spacing of 0.5x0.5m for maize based on their own experience in the Eastern Cape Province. The distance between a row of trees and the closest line of crops was 0.5m. The crops lay-out in the plots is given in plates 1 and 2 (see appendix 2).

Crop Varieties

The maize variety used was **Mac Medium Pearl** open-pollinated white quality protein maize developed locally. The cowpea variety used was **Blue Mixed (GADG)**, a runner variety recommended for hay production (Van Rij, 1997) and the cultivar of pumpkin used was **Van Niekerk Cert S25047**, which is a vining type, slightly hairy with branched tendrils and rounded fruits. All those varieties were produced locally and suitable for Ukulinga conditions. The crops seeds were supplied by NatalAgri, a supplier of agricultural supplies whereas the seedlings of black wattle were obtained from a local nursery and the fever tree from Zululand.

Data Collection

The data collection consisted of soil sampling, crop yield and biomass, tree growth variables (diameter at ground level, tree height and the number of twigs per tree), tree biomass and fodder sampling.

Soil sampling

Soil samples were taken twice in each treatment. The first time was in October 2003, prior to planting; and the second time was in March 2005, just after the final harvest. The soil samples were collected using a soil auger drilling to a depth of 15-20cm. The samples were submitted for analysis to the laboratory of the Agriculture Research Station (Cedara), outside Pietermaritzburg. This consisted of the determination of mineral content, soil pH and soil texture using the near-infrared spectroscopy (NIRS) method.

Crop yields and crop biomass

The crop yields and crop biomass were determined at the end of each cropping season by weighing using a digital battery-operated scale. All the plants in the alleys/hedges were harvested per plot. In maize and cowpeas plots two outer lines (lines beyond the hedges in the alleycropping plots) were excluded to avoid the border effect (red lines in the diagram in the appendix 2). So, the plot size used for calculations was 8x10m instead of 10x10m. In pumpkin plots the border effect was managed by collecting fruits and the biomass inside the plots only, excluding the material outside plots because pumpkin grew beyond the plot limits. Here the plot size used in calculations was exactly 10x10m. The maize and cowpea grain yields were calculated from sun-dried material after reaching air equilibrium humidity (by the time the weight stopped decreasing/changing), whereas the pumpkin yield was assessed from fresh-fruit weight. Crop biomass was determined for fresh and dry material. The dry biomass was obtained from the samples oven-dried over 4 days at 65° C. Note that the size of control plots was 5x10m and this used in the calculations for those plots. The conversation unit from m² to ha was 1ha=10000m².

Tree growth variables

Morphological parameters such as tree diameter (mm) at ground level, tree height (cm) and the number of branches per tree were recorded at regular intervals of three months during the first year of tree development. There were four measurements: in January, April, June and October 2004, just before tree pruning. The data were used to determine the performance of the trees under alleycropping and to assess the influence of the crops on the tree growth. Tree diameter was measured at ground level because during the first measurement the seedlings were still too small and their height was below 1.3m (breast height), which is the position normally used by researchers to assess tree diameter. Therefore, it was decided to keep the same procedures for the measurements that followed. Van Laar and Theron (2004) have used the knee height diameter to establish the equations for biomass prediction of western coastal wattle (*Acacia cyclops* G. Don.) and golden wreath wattle (*Acacia saligna* (Labill.) Wendl.) in the Western Cape and the Eastern Cape provinces of South Africa.

Tree biomass and fodder sampling

The trees were pruned and topped to a height of 1.5m at the age of 12 months. The prunings were divided into two categories (woody and non-woody biomass) and weighed. Woody biomass consisted of the main stem and branches with a diameter of more than 1cm at their middle, while non-woody biomass included leaves and fine twigs with a diameter of less or equal to 1cm at their middle. After weighing, non-woody biomass was spread on the plots for mulching to enhance soil fertility, while the woody biomass was discarded from the study. Some samples of non-woody biomass were taken to the laboratory of Grassland Science at the University of KwaZulu-Natal for fodder digestibility analysis. The analyses consisted of the determinations of neutral detergent fibre (NDF) and acid detergent fibre (ADF).

Data Analysis

The data were analysed by GenStat 7.1 for Windows and SPSS 11.1 statistics packages. The analyses consisted of the calculations of means and standard deviations (SD). The treatments were compared using a two-way Anova variance analysis and where significant differences between treatments were found, the t-test (bilateral test) was used to compare treatments means.

RESULTS

As will be explained in the discussion section, through the frail results under Ukulinga conditions the fever tree seedlings failed to develop and remained too small to exercise an alleycropping effect. Therefore, the results of the fever tree growth and biomass production have been discarded and only those attained for black wattle alleycropping will be presented in this Chapter.

Soil Results

The full reports from the soil analyses are given in Appendix 1. The reports contain the recommendations for additional nutrients and lime necessary to apply to the soil to target different crop yields (Table 2.2). Note that before the experiment was started there were differences in the soil P and K content among treatments. This is due to natural differences in soil nutrient distribution in the site, although not relevant to be discussed in this report. In the first soil analysis to target a yield of maize grain of 4t/ha (the recommended yield at small-scale farm) the soil showed a shortage of 50kg/ha of N throughout and a shortage of 20kg/ha of P for the controls, 70kg/ha for alleycropping with black wattle and 100kg/ha for alleycropping with the fever tree. And in the second soil the shortage of N fertiliser was similar as it was in the first analysis but for P it was different. The shortage of P was 20Kg/ha for controls, 75kg/ha for alleycropping with black wattle and 95kg/ha for alleycropping with the fever tree.

The soil analysis also included the analyses of Potassium (K) content. The shortage of K was 10kg/ha under alleycropping with black wattle and 55kg/ha under alleycropping with the fever tree during the first sampling period. In the second sampling period the shortage of K was 70kg/ha and 100kg/ha under alleycropping with black wattle and under alleycropping with the fever tree respectively.

Table 2.2. The amount of additional nutrients recommended to target different crop yield

Nutrient requirement	Sampling	Maize Yield target						Cowpeas Yield target		Pumpkin Yield target	
		4.0 kg/ha		5.0 kg/ha		7.0 kg/ha		1.0 kg/ha		Optimum	
		1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd	1 st	2 nd
Nitrogen (N) (kg/ha)	Control	50	50	75	75	140	140	0	40	100	100
	Black wattle	50	50	75	75	140	140	0	40	100	100
	The fever tree	50	50	75	75	140	140	0	40	100	100

Phosphorus (P) (kg/ha)	Control	20	20	20	20	20	20	20	20	125	70
	Black wattle	70	75	70	75	70	75	70	50	140	55
	The fever tree	100	95	100	95	100	95	100	75	190	55
Potassium (K) (kg/ha)	Control	0	0	0	0	0	0	0	0	0	0
	Black wattle	10	70	10	70	10	70	10	70	35	0
	The fever tree	55	100	55	100	55	100	55	100	150	0

To target a yield of 1t/ha of cowpea grain, the soil N was fine in the first cropping season, but after the second cropping season there was a shortage of N at an amount of 40kg/ha for all the treatments. The amount of P in shortage was 20kg/ha for the control, 70kg/ha for black wattle alleycropping and 100kg/ha for the fever tree alleycropping in the first soil analysis. In the second analysis the shortage of P was 20kg/ha for the controls, 50kg/ha for alleycropping of black wattle and 75kg/ha for alleycropping of the fever tree. Potassium was found to be in shortage only in alleycropping plots. The shortage was at an amount of 10kg/ha under alleycropping of black wattle and 70kg/ha under alleycropping of the fever tree in the first cropping season. After the second cropping season the shortage was 55kg/ha and 100kg/ha respectively for alleycropping with black wattle and alleycropping with the fever tree.

For an optimum yield of pumpkin there was a shortage of 100kg/ha of N and 100kg/ha of P in both seasons. Potassium was found to be in short supply only in the first season under alleycropping.

The soil analyses included the determination of calcium (Ca), magnesium (Mg), zinc (Zn), manganese (Mn), copper (Cu), and the percentage of organic carbon and clay using the NIRS method. No deficiencies of these were reported. The soil pH was calculated as the amount of lime necessary to be applied to the soil for the correction of soil acidity and in this study lime was not necessary.

Maize, Cowpeas, Pumpkin Yields and Biomass under Alleycropping with Black Wattle

In general the crop yields and biomass were greater under conventional practice (control) than they were under alleycropping, and the difference was statistically significant ($P < 0.05$) for both seasons. Table 2.3 shows the crop yields for both seasons including the SD per treatment. The maize grain yields were 1.9t/ha and 2.6t/ha under alleycropping and

2.0t/ha and 5.7t/ha under conventional practice (control) in the first and second seasons respectively.

The grain yields of cowpeas were similar in both treatments in the first season (0.2t/ha) but different in the second season when the yield increased to 0.3t/ha under alleycropping and to 0.6t/ha under conventional practice. Seasonal variation was calculated as a percentage of the first-season yield, and was allocated a plus sign where there had been a yield increment, and minus sign where there had been a reduction.

Table 2.3. The yield of grain maize, cowpeas and pumpkin fruits in 2003/2004/2005 cropping seasons under alleycropping and conventional practice

Crops	Maize (t/ha)		Cowpea (t/ha)		Pumpkin (t/ha)	
	Alleycropping	Control	Alleycropping	Control	Alleycropping	Control
First	1.9±0.59	2.0±0.99	0.2±0.09	0.2±0.03	12.7±5.32	17.6±7.45
Second	2.6±0.72	5.7±0.47	0.3±0.12	0.6±0.15	8.5±4.04	11.5±1.25
Variation (%)	+36.8	+185	+50	+200	-33	-34.7

The yield of pumpkin under alleycropping was 12.7t/ha during the first season, decreasing to 8.5t/ha in the second season. Under conventional practice, pumpkin fruit yield was about 18t/ha in the first season and 11.5t/ha in the second season. The results are also presented in graphic form for clear illustration of the differences in treatments and seasonal variation (Fig. 2.1).

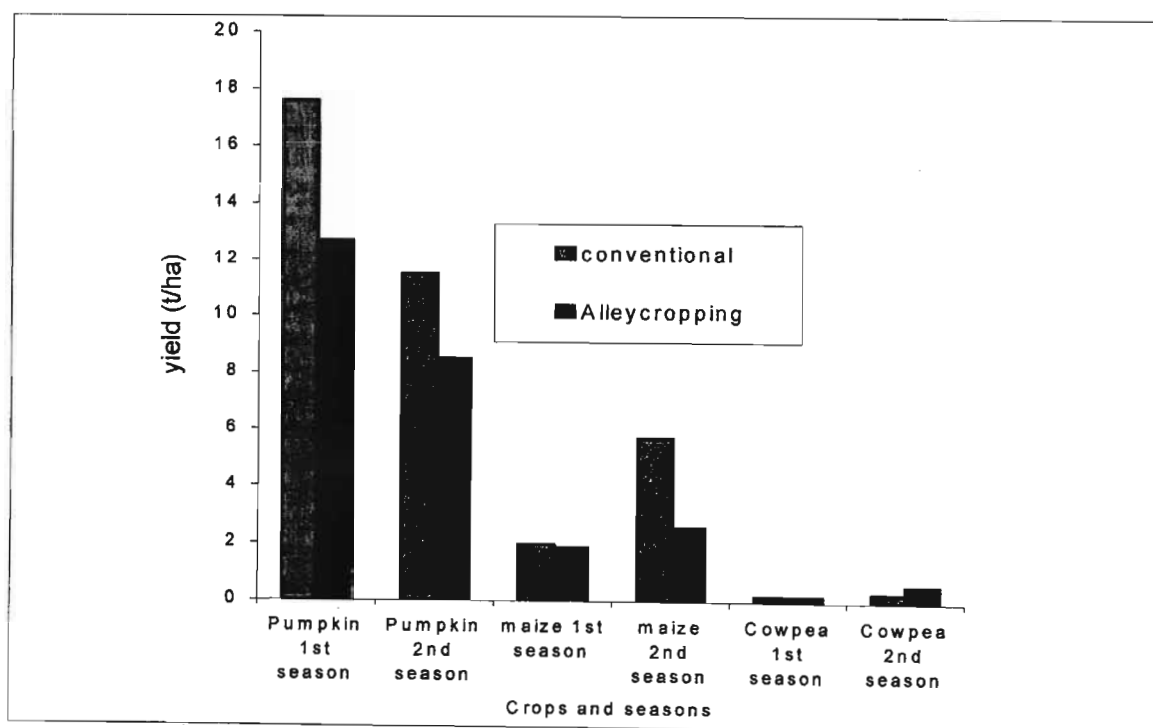


Fig. 2.1. Crop yields in the 2003/2004/2005 cropping seasons under alleycropping and under the conventional system

The results of crop biomass determination for the two seasons including the SD and seasonal variation are shown in Table 2.4. Seasonal variation was calculated as a percentage of the first-season biomass, and was allocated a plus sign where there had been a biomass increment and minus sign where there had been a reduction. Table 2.4 also shows the percentage of DM calculated from fresh biomass. The fresh biomass of maize in the first cropping season was 5t/ha under that attained with conventional practice and 3.5t/ha under that of alleycropping. The yield of cowpea grain was very low because the variety is specifically used for biomass production. Thus, the biomass production was considerable, being close to 7t/ha of fresh matter in the second season. Cowpea biomass was significantly different between the seasons ($P<0.05$) but not between the treatments. The cowpea fresh biomass was 2t/ha and 2.6t/ha in the first cropping season and 3.7t/ha and 7t/ha in the second season under alleycropping and conventional farming system respectively. The fresh biomass of pumpkin was 12.6t/ha under conventional practice and 11.2t/ha under alleycropping in the first season while in the second season it increased to 14.2t/ha under conventional practice and decreasing to 7.9t/ha under alleycropping. The percentage of DM was 20% in maize, 12% in cowpea and 8.4% in pumpkin.

Table 2.4. Fresh biomass of maize, cowpea and pumpkin produced in 2003/2004/2005 cropping seasons under alleycropping and conventional practice, including the % of DM. fb - fresh biomass

Crops	Maize (t/ha)			Cowpeas (t/ha)			Pumpkin (t/ha)		
	fb under Alley Cropping	fb under Control	DM (%)	fb under Alley Cropping	fb under Control	DM (%)	fb under Alley Cropping	fb under Control	DM (%)
First	3.5 ±2.14	5.0±3.09	20	2.6±0.70	2±1.01	12	11.2±2.89	12.6±2.18	8.4
Second	4.7±2.17	10±2.36		3.7±1.48	7±1.17		7.9±2.87	14.2±3.35	
Variation (%)	+34.3	+100		+42.3	+250		-29.5	+12.7	

Biomass from Black Wattle Prunings

The prunings of black wattle at the age of 12 months produced 5.6t/ha of fresh non-woody biomass under alleycropping of black wattle with maize and cowpea intercrop and 4.5t/ha under alleycropping with the pumpkin (Table 2.5). The fresh woody biomass was 1.3t/ha under alleycropping with maize and cowpea and 0.9t/ha under alleycropping with pumpkin. The percentage of DM in fresh non-woody biomass was 35% and 60% in fresh woody biomass.

Table 2.5. Fresh and dry biomass from woody and non-woody prunings, fb-fresh biomass

Associated crop	Non-woody (t/ha)			Woody (t/ha)		
	Fresh	Dry	DM	Fresh	Dry	DM
Maize and cowpea	5.6	1.96	35% of fb	1.3	0.78	60% of fb
Pumpkin	4.5	1.58		0.9	0.54	
Average	5.05	1.77		1.1	0.66	

The average non-woody fresh biomass from alleycropping was 5.05t/ha, which is equivalent to 1.77t/ha of DM and for woody biomass was 1.1t/ha of fresh biomass and 0.66t/ha of DM.

The biomass of black wattle in maize and cowpea alleycropping was greater than it was with pumpkin and the difference was statistically significant ($P < 0.05$). There was also a significant difference ($P < 0.05$) between woody and non-woody biomass of black wattle under alleycropping.

Changes in Black Wattle Growth Variables under Alleycropping

The results of ground level diameter, height and branch development are presented graphically in the Figures 2.2, 2.3 and 2.4. The graphs include the results from plots without crops (crop-less plots). Those results are included to illustrate the particular alleycropping effect of the intercropped maize and cowpeas, and pumpkin, on tree growth variables (competition effect). The means of black wattle growth variables were not significantly different ($P < 0.05$) between treatments (Table 2.6).

Table 2.6. Minimum significant differences in black wattle growth between alleycropping treatments and crop-less plots

Ground level Diameter									
Paired Samples Test									
		Paired Differences					t	df	Sig. (2-tailed)
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
Lower	Upper								
Pair 1	mcd - pd	.6100	1.20773	.60386	-1.3118	2.5318	1.010	3	.387
Pair 2	mcd - cd	-5.7800	4.84087	2.42044	-13.4829	1.9229	-2.388	3	.097
Pair 3	pd - cd	-6.3900	5.15882	2.57941	-14.5988	1.8188	-2.477	3	.089

mcd – ground level diameter (mm) of black wattle under alleycropping with maize and cowpeas as joint intercrops, pd- ground level diameter of black wattle under alleycropping with pumpkin; cd - ground level diameter of black wattle in crop-less plots (control)

Height										
Paired Samples Test										
		Paired Differences				t	df	Sig. (2-tailed)		
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower				Upper	
Pair 1	mch - ph	15.665	14.1026	7.0513	-6.775	38.105	2.222	3	.113	
Pair 2	mch - ch	-11.847	45.9038	22.9519	-84.891	61.196	-.516	3	.641	
Pair 3	ph - ch	-27.512	41.8262	20.9131	-94.067	39.042	-1.316	3	.280	

mch – height (cm) of black wattle under alleycropping with maize and cowpeas as joint intercrops; ph- height of black wattle under alleycropping with pumpkin; ch - height of black wattle in crop-less plots (control)

Number of twigs										
Paired Samples Test										
		Paired Differences				t	df	Sig. (2-tailed)		
		Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference					
					Lower				Upper	
Pair 1	mcb - pb	-.0333	3.06237	1.76806	-7.6407	7.5740	-.019	2	.987	
Pair 2	mcb - cb	-.5300	3.54784	2.04835	-9.3433	8.2833	-.259	2	.820	
Pair 3	pb - cb	-.4967	2.41738	1.39568	-6.5018	5.5084	-.356	2	.756	

mcb - number of twigs in black wattle under alleycropping with maize and cowpeas as joint intercrops; pb - number of twigs in black wattle under alleycropping with pumpkin; cb - number of twigs in black wattle in crop-less plots (control)

The ground level diameter changed from 6mm to about 48mm within 9 months. The great change on dgl growth was observed in crop-less plots and a smaller change was observed in alleycropping with pumpkin (Fig. 2.2). This shows that alleycropping had some negative effect in the dgl growth particularly in pumpkin plots, though it was not significant ($P < 0.05$). The dgl growth under alleycropping with maize and cowpeas intercropped was greater than it was under alleycropping with pumpkin.

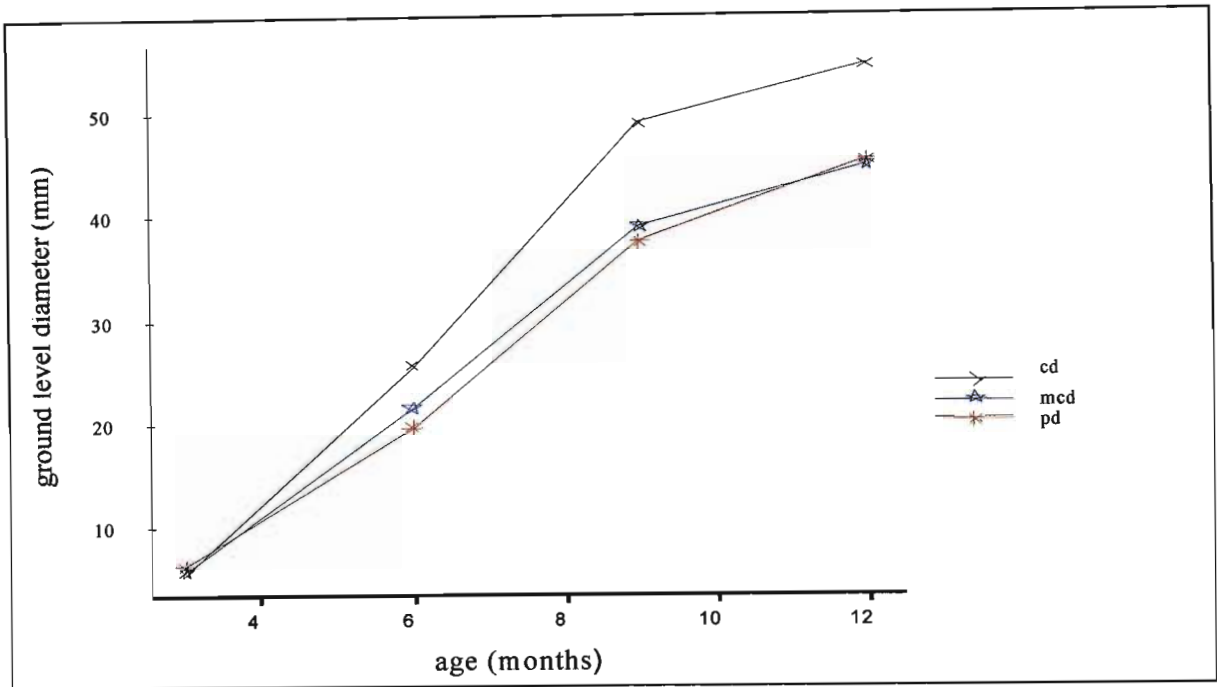


Fig. 2.2. Changes in ground level diameter (mm) of black wattle under alleycropping with maize and cowpeas as joint intercrops (mcd), under alleycropping with pumpkin (pd) and under crop-less plots (cd) (control)

The height of black wattle changed very quickly, from 50cm at 3 months after planting to about 406cm at the age of 12 months. The greatest change, as expected, was observed in the crop-less plot despite the fact that the change was not consistent during the study. A strange situation was observed in the height performance between the 9th and 12th month in black wattle growing without crops when the height increase slowed relative to that, which occurred in the other treatments. This might be due to a measurement error, the trees at that stage being so tall that accurate height measurements were no longer possible. The increase in height can be characterized in two distinct periods. The first, between planting time until 6months, when a large height increase was observed in black wattle under alleycropping with maize and cowpeas, and the second period, between 6 to 12 months, with a considerable increase in height being observed of black wattle in crop-less plots.

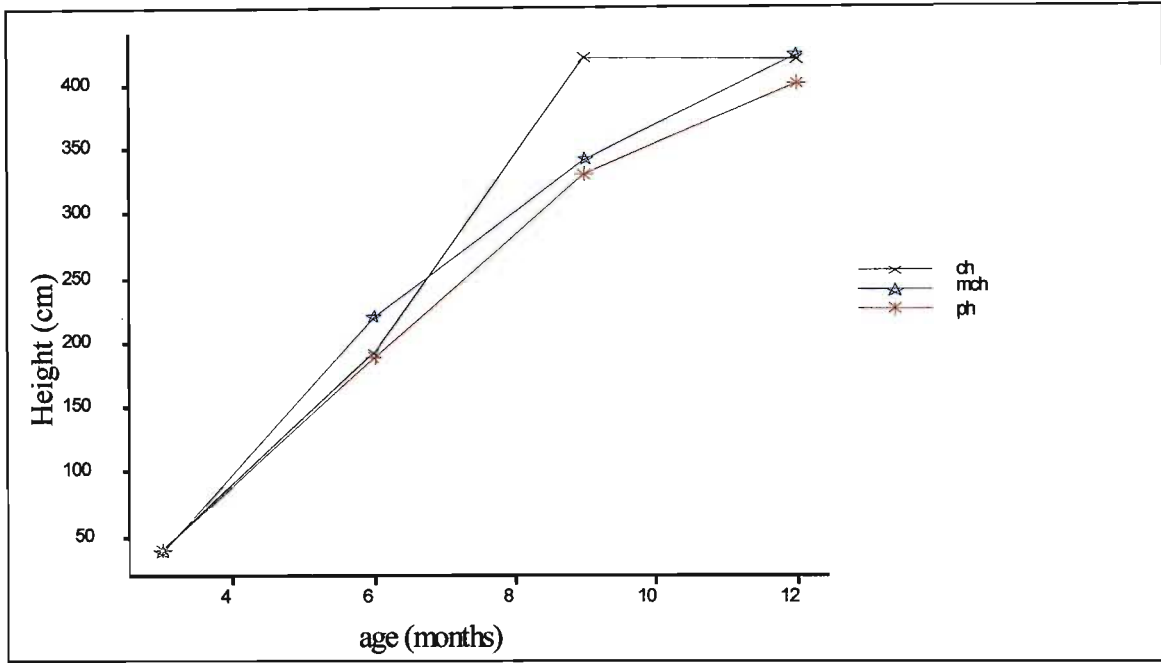


Fig. 2.3. Changes in height (cm) of black wattle under alleycropping with maize and cowpeas as joint intercrops (mch), under alleycropping with pumpkin (ph) and under crop-less plots (ch) (control)

The number of twigs increased considerably until the age of 9 months, from where it started decreasing. The highest numbers of branches was observed in crop-less plots but, in general, this parameter was not consistent.

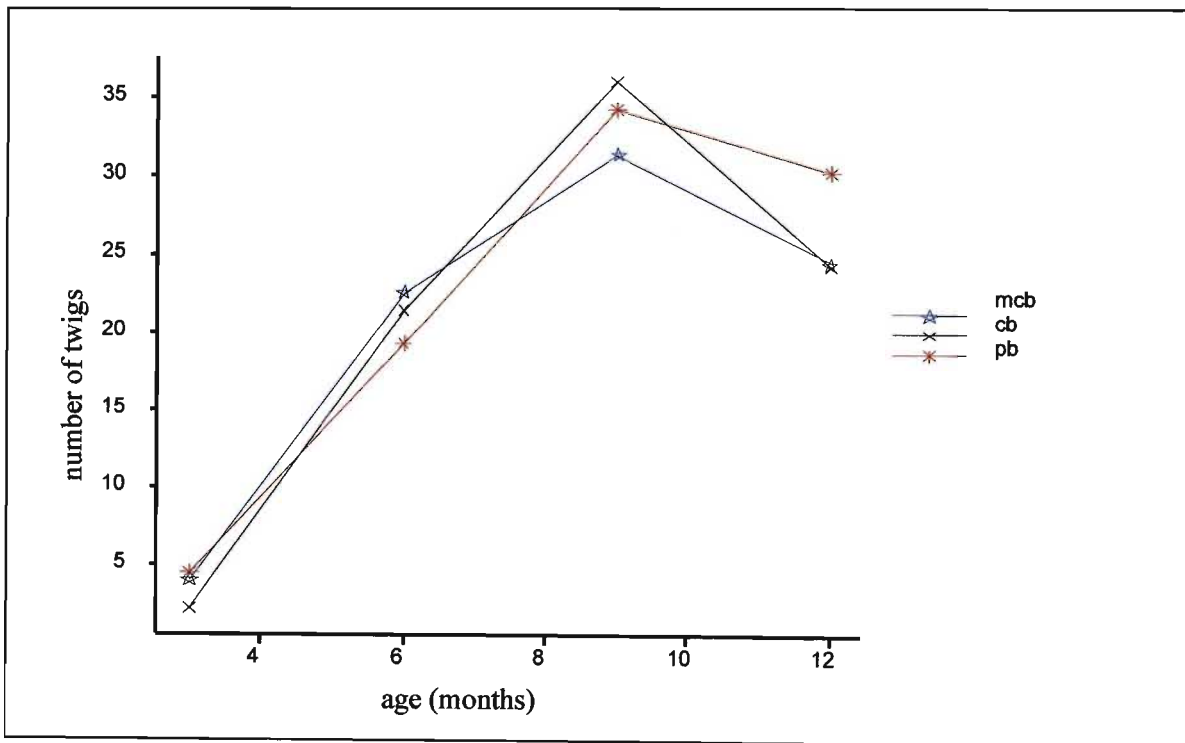


Fig. 2.4. Changes in number of twigs of black wattle under alleycropping with maize and cowpeas as joint intercrops (mcb), under alleycropping with pumpkin (pb) and under crop-less plots (cb) (control)

NDF and ADF of Black Wattle, Maize, Cowpeas and Pumpkin

The results of the fodder analyses are given in the Table 2.7. The results include neutral and acid detergent fibre digestibility (NDF and ADF) determinations. The black wattle values of the NDF and the ADF were 76.6% and 68.1% respectively. The NDF of maize stover was 53.6% and the ADF was 42.1% and for cowpeas the NDF was 36.4% and the ADF was 46.9% whereas for pumpkin the NDF was 30.5% and the ADF equal to 29.9%.

Table 2.7. Percentage of the NDF and the ADF of black wattle, maize, cowpeas and pumpkin

Crop	NDF (%)	ADF (%)
Black wattle	76.6	68.1
Maize stover	53.6	42.1
Cowpea biomass	36.4	46.9
Pumpkin leaves	30.5	29.9

DISCUSSION

In this study the application of N, P and K fertilisers was recommended to improve soil fertility for good yields of maize, cowpeas and pumpkin (Table 2.2). Silwana and Lucas (2002) have recommended the application of 320 kg/ha of NPK with Zn through band placement in intercropped maize and beans and intercropped maize and pumpkin in the Transkei area of South Africa. The application of fertilisers, especially P, to black wattle seedlings during the establishment phase, has shown good results in tree growth (Du Toit, 2002). However, no fertiliser was applied in this study because many farmers in rural areas do not use chemical fertilisers in their cropping systems.

The common problem of soil fertility in Africa is the net negative balance of N, P and K, which is responsible for the widespread nutrient depletion throughout the continent (Smaling, 1993) and hence poor crop yield particularly under the cropping systems of small-scale farmers. One of the main tenets of agroforestry is that leguminous trees maintain soil fertility (Palm, 1995) especially as related to nitrogen deficiency.

In alleycropping systems nutrient balances are usually negative, particularly for P (Palm *et al.*, 1989) and fertilizer responses are common. The concept of arable soil is relative, and additional soil nutrients are generally necessary to balance the nutrients pool, when the land is converted into cropping because soil nutrients are non-resilient components (Fresco and Kroonenberg, 1992). At an early stage of alleycropping, fertilisation is generally

recommended for the quick and effective establishment of trees and for good crop yields because the effect of trees on the system is still not present (Kang, 1994; Sanchez, 1995).

Sanchez (1995), when discussing the question concerning the need for the application of N fertilizers to crops in agroforestry systems, observed that it should depend largely on the expected crop-yield level. A typical maize crop on smallholder African farms, to yield about 1t/ha of grain, requires a plant accumulation of about 40kg N/ha. To target a crop yield of 4t/ha, about 80kg N/ha are required, while a crop yield of 7t/ha requires about 200kg N/ha. Topsoil nitrogen mineralization provides an average input of about 30kg N/ha, which approximates to the needs of a maize crop of 1t/ha (Sanchez, 1995).

Nitrogen inputs from 4t/ha of DM of leguminous leaves incorporated into the soil range from 60 to 150kg/ha, equivalent to the average of 105kg/ha or 26kg N/t of plant DM (Palm, 1995). The input of nitrogen from 4.2 t/ha of black wattle DM can produce 245kg/ha (NAS, 1980) or 58.3kg N/t of DM. This amount is more than two times N content of many nitrogen-fixing legumes reported by Palm (1995). The foliage biomass produced from wattle prunings under alleycropping with maize and cowpeas was 1.12t/ha of DM, which is equivalent to 65.3 kg N/ha. According to Sanchez (1995) this could support maize grain yields of 2 to 3t/ha (Palm, 1995) in soil where the limiting nutrient is nitrogen.

In the present study, the maize grain yield in the first cropping season was 1.9t/ha under alleycropping and 2t/ha using conventional procedures and 2.6t/ha and 5.7t/ha for alleycropping and conventional respectively in the second cropping season. These yields are similar to those reported earlier by Sanchez (1995) and Palm (1995). This seems to indicate that the soil at Ukulinga is still not deficient in nutrients and hence the effect of alleycropping is unlikely to be appreciable at this stage. However with continuous nutrient mining due to cropping, the soil fertility will gradually decrease and alleycropping will gradually replace the soil nutrients making its effect notable. Williams (1928) cited by Sherry (1971) has shown that black wattle stands contain lime, potash and phosphoric oxides that can be released into the soil to provide phosphorus and potassium and lime, three substances which are essential for plant nutrition and soil pH balance. The afore-going shows that black wattle can be an important agroforestry tree species in nutrient-depleted soils.

The biomass of one-year-old black wattle prunings (1.77t/ha of DM) did not meet the figures given by Young (1989), who estimated that 4.2t/ha/year of additional DM was necessary for

the maintenance of soil fertility in the sub-humid climate regions of Africa, which includes the Ukulinga area, although, under current soil conditions at Ukulinga, N is not a limiting factor, because the soil still carries some nutrients which support crop production. If N was a limiting factor the use of crop residues should be an alternative to increase the biomass for soil fertility, but in this particular case the total amount of biomass after the addition of the crop residues is still not enough to meet Young's figures for the region and extra biomass should be necessary. Additionally, when using crop residues for soil fertility, special attention has to be taken because some crop-residues, for example maize stover, have low-quality OM (Sanchez, 1995) and hence they may affect the soil nutrient dynamic negatively, decreasing crop yields (Rodell *et al.*, 1980; Muriwara and Kirchmann, 1993). To avoid this constraint, crop-residue with low quality OM should be used as mulch to protect the soil from erosion and to keep the soil moisture improving the soil's physical structure (Vanlauwe *et al.*, 2002).

The alleycropping showed good performance in this study. However, crop yield and biomass under alleycropping was not great as in the controls and the difference was statistically significant ($P < 0.05$), especially in the second cropping season. This difference is common at an early stage of alleycropping when the trees are still in the process of establishment (Nair, 1993; Coe *et al.*, 2003) and when competition between trees and crops is not properly managed. In this trial the design was to match small-scale farmer conditions, where normally fertilisers and irrigation are unaffordable and hence, competition for nutrients and for water between crops and trees was inevitable during the study.

Under alleycropping of black wattle with maize and cowpeas, intercropped competition for nutrients between crops and weeds and for light between crops and trees has contributed to low crop yield and biomass in the first season. Weeds were difficult to control because the site had been in fallow for years and the soil was still rich in weed seeds like those of water grass or Chufa flatsedge, Kikuyu grass, Guinea grass and amaranthus. Conversely, weed and shading control were much more efficient in the second cropping season and the result was the increase in crop yield and biomass of the maize and cowpeas. Intensive weeding was the mean to control the weeds and tree pruning was used to control shading. Silwana and Lucas (2002) have observed that weed control had a significant effect on crop yields. They observed that the yields of maize, cowpeas and pumpkin were often higher in weeded fields than in unweeded fields and the difference being significant ($P < 0.05$). Sherry (1971) reported that shading effect was crucial to maize yield under black wattle intercropped with maize if the

trees were not pruned. According to this author, the yield of maize was generally low under alleycropping with black wattle compared with controls, especially when grown on acid soils and under high rainfall, normally suitable growth conditions for black wattle. In those cases where maize grew well, the shading effect was deleterious to black wattle seedlings, and they often became spindly and etiolated by the time the maize was ready for harvesting.

Under alleycropping of black wattle and pumpkin, competition was not a problem in the first cropping season because the pumpkin grew very fast suppressing the weeds while tolerating the shading from the trees. On the contrary, in the second cropping season, competition for water between the trees and crop was very critical and the result was the decrease in the yield and biomass of pumpkin in this season compared to the first cropping season. Water was the main constraint to the pumpkin yield and biomass because there was a shortage of rainfall in that season, particularly at flowering.

The negative effect of competition has been also reported by Denich *et al.* (2004) in various alleycropping experiments particularly under no fertilised trials. According to the authors, competition is critical when cereal crops, such as maize, for example, are involved because they are known to be much sensitive to a shortage of nutrients, especially N than other crops. In opposition, if correct procedures are followed, alleycropping will gradually increase in yield during the following seasons until the maximum potential of the site is reached and then the crop production can be maintain in long-term (Sommer, 2000).

The proven ability of wattle to increase the N status of soils on which the tree has been grown suggests that it might be advantageous to use this species under alleycropping. However, due to competition, which is difficult to manage, the use of black wattle in simultaneous agroforestry systems, such as alleycropping, is usually fraught with difficulty. Alternatively, black wattle might be a suitable agroforestry species when used in temporal agroforestry systems, like improved fallow. According to Sherry (1971), the use of soil that previously carried black wattle for agriculture has shown good results in crop yields in two to three cropping season, even with limited fertilisers dressings.

The annual increase in the ground-level diameter of black wattle was about 48mm and the height increased by 4m/year. These results are supported by Little *at el.* (2000) who obtained similar rates (43mm for ground level diameter and 3.5m for height) in black-wattle stands

SUMMARY

Alleycropping of black wattle with intercropped maize and cowpeas, and pumpkin by itself, can be a useful alternative production system in places where black wattle grows well. The system needs to be well managed, however, in order to avoid competition among the trees and crops. Pruning can be useful to control competition between the alleycropping components.

The amount of biomass produced from the system can maintain maize grain yield at the level of 2t/ha in poor soil, but to target considerably higher yield levels more biomass will be necessary. It can be achieved if the system is maintained in middle and long-term.

The growth rate of black wattle seedlings was considerably higher under alleycropping, confirming the fast growing status of the species. The annual increase in ground-level diameter was about 48mm and the equivalent increase in height was approximately 4m.

The digestibility of black wattle was low. It can be improved, however, by mixing it with high-quality fodder, although the correct proportion in the mixture has to be investigated.

FUTURE RESEARCH NEEDS

To determine the frequency with which black wattle should be pruned in order to minimise competition, more and long-term studies must be conducted to assess the effect of tree shading and the real contribution of tree prunings on soil fertility, especially on its N relationship and its N-release synchronisation.

Research is also needed to determine the ideal proportion of black wattle in the fodder to avoid animal intoxication due to the excess of tannin.

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CHAPTER 3

BLACK WATTLE (*Acacia mearnsii* De Wild.) IN ALLEYGRAZING SYSTEMS

INTRODUCTION

Livestock play an important role in the livelihood of farmers in rural areas. Animals provide rich protein for the families' diet through meat and milk consumption (Macklin, 1990). Sales of animals, meat, milk, skins and other animal products represent a means of income generation and food security for farmer families (Reynolds *et al.*, 1988; Macklin, 1990). Animals, especially cattle are used in agricultural activities to increase productivity by providing draft power for ploughing which is one of the most labour-intensive tasks on manual agriculture. Additionally, animal manure can be used to improve soil fertility and hence increase crop yields (Smith, 1991; Jordan, 2004).

In tropical regions, small-scale farmers feed their livestock in an extensive free-grazing system in rangelands along forests or roadsides (Whiteman, 1980; Bayer and Waters-Bayer, 1998). Those areas are characterized by seasonal variation in pasture quantity and quality, which is associated with annual variations in precipitation (Hattersley, 1983) and temperature (Johnston, 1996). As a result, the productivity of those rangelands is high in wet seasons and low in dry seasons. During dry seasons when the pasture is not enough to satisfy the needs, farmers have to seek alternative pastures, normally on fertile and arable land. Due to a rapid increase in the human population density, the pressure on land for living, cropping and grazing has increased and grazing has been relegated to poor areas with low productivity. Consequently farmers are forced to graze their livestock in those areas for many years resulting in overgrazing and hence pasture degradation, which ends in weed encroachment on the pasture. This situation affects negatively the productivity of livestock and promotes instability in the economy of rural families depending on the livestock for their livelihood. In addition, social conflicts such as pasture disputes and animal damage can emerge among the communities as an outcome of pasture shortage and these can end in tragedy.

Fodder availability can be improved throughout the year at low cost and decreased land demand, if evergreen fodder trees or shrubs are planted in the pasturelands to provide additional fodder to the livestock while improving soil fertility and soil structure to benefit

the under-story species like grasses. Trees can provide supplementary and nutritive fodder especially during critical periods of fodder shortage (Macklin, 1990; Garrett *et al.*, 2004) while providing shade for the livestock in hot climates. In addition, if the trees/shrubs are leguminous species, they can provide nitrogen-rich fodder, which when fed to livestock increases animal productivity, and if part of that material is incorporated into the soil it can improve soil nitrogen (Smith, 1991), which is one of the main limiting factors of soil fertility (Mudahar, 1986).

The cropping systems that incorporate and manage trees/shrubs together with pasture grasses are called silvopastoral systems (Kang *et al.*, 1990; Nair, 1993). There are four types of silvopastoral systems. The first, called tree on pasture, incorporates tree on pastureland. The second, is called pasture on tree-land, because promotes the invasion of grasses in forestlands. In the third, both fodder trees/shrubs and grasses are sown in a specific spatial arrangement to optimise fodder production over the year. In this system, the trees are usually planted in rows and the grasses between the rows, also called alleys, conferring to the system the name of alleyfarming with grass or simply alleygrazing (Reynolds and Cobbina, 1991). The last type, involves the plantation of only high-quality fodder trees/shrubs in a density that maximise biomass production, and it is called fodder bank (Sinclair, 1999).

Among silvopastoral practices, alleygrazing is one of the most popular and it has been practised in many parts of the world, where it has shown encouraging results, particularly in Asia and Africa (Kang, 1994), due to ecological interaction between trees and grasses and the extraordinary animal growth and health as results of balanced diet. Alleygrazing is an innovative mean of overcoming the nutritional constraints faced by livestock production in many areas of tropical Africa (Reynolds and Cobbina, 1991).

Research on alleygrazing system has been concentrated on fast growing legume trees/shrubs (Kang, 1994) especially those able to produce high amount of green foliage over the year (evergreen species) while contributing positively to the soil chemical, physical and biological properties (Jordan, 2004) with benefit to the associated grasses in the system (Garrett *et al.*, 2004). Among various species already used in alleygrazing the highlight goes to *Leucaena leucocephala* (Lamk.), *Gliricidia sepium* (Jacq.) Kunth ex Walp., *Acioa barterii* (Hook F.), and *Alchornea cordifolia* (Schum and Thom) Muell. Arg (Euphorbiaceae), which have been widely used for alleygrazing with grasses like *Cynodon nlemfuensis* Vanderyst, *C. dactylon*

(L.) Pers., *Cenchrus ciliaris* L., *Pennisetum purpureum* Schumach., *Panicum maximum* Jacq., *Digitaria decumbens* Stent. and *Brachiaria decumbens* Stapf. in rotational or permanent system (Reynolds and Cobbina, 1991) to provide fodder for livestock like cattle, goats and sheep. The foliage from both species contains over 20% crude protein (3.4% nitrogen) and hence can supplement the livestock with valuable protein feed (Reynolds and Cobbina, 1991). Although, a long list of species have been tested under alleygrazing, few or none have been done with black wattle, despite being evergreen and one of best nitrogen-fixing trees (Burley and Von Carlowitz, 1984).

The current study aims to investigate the contribution of the black wattle under alleygrazing with *Panicum maximum* Jacq. (Guinea love grass) and *Eragrostis curvula* (Scribd) Nees. (Weeping love grass).

The motivation for this study is based on the hypothesis that black wattle jungles could be converted into productive fields under alleygrazing to mitigate the problem of fodder shortage in many rural areas in South Africa, where the species occurs abundantly while contributing to wattle jungles management as contribution to control black wattle invasions in unwanted landscapes. The *P. maximum* and *E. curvula* were selected for that purpose because they are usually found associated to wattle jungles and they have high nutritive and digestibility values especially in wet seasons (Van Rooyen, 2002).

The assessment is made by the evaluation of biomass production as well as fodder quality including a short observation of animal intake of black wattle fodder and the tree response for pruning.

The Role of Leguminous Trees in Silvopastoral Systems

The presence of legume in grasslands can improve the productivity of ruminants in both temperate and tropical regions (Ulyatt, 1981; Reynolds and Cobbina, 1991). The most important attribute of legumes is their digestibility, which declines much slowly comparing to the grasses (Minson, 1982; Reynolds and Cobbina, 1991; Van Rooyen, 2002). The productivity of animals feeding on legume has been reported to be greater than those animals feeding on grasses only (Thompson, 1977; Mannetje, 1984; Walker, 1987). However, the best option is usually obtained when both are mixed (Leng, 1997) as the legume leaves have high protein content (Mannetje, 1984) and the grasses have high

mineral concentrations (Ulyatt, 1981). FAO (1995) observed that for animal production the mineral composition of tree foliages is always superior to that of tropical grasses. The content of crude protein (CP) in most leguminous trees used under alleygrazing systems is about 20% of their dry matter (DM) weight (Reynolds and Cobbina, 1991) whereas for grasses like *P. maximum* and *E. curvula* it is less than 11%. The content of CP in *P. maximum* is about 8.7% in dry season and 10.4% in wet season and for *Eragrostis sp.* it is about 3% in dry and 6% in wet seasons respectively (Van Rooyen, 2002).

Although, trees have high content of CP than grasses, some plant secondary compounds present in some tree species can reduce the quality of fodder from those trees, due to their toxicity. Compounds like cyanide, nitrate, fluoroacetate, cyanogenic glycosides, saponins, oxalates, mimosine, tannins, various sterols and others can put livestock in danger, if taken in high dosage. Leng (1997) found that the concentration of saponins in the foliage feeding to cattle has been responsible to the low productivity in young cattle. In other study Wheeler *et al.* (1995) observed that mimosine, a compound presents in the leaves of *Leucaena sp.* has been responsible for hair losses in horses feeding frequently on *Leucaena sp.* foliage. Reynolds and Cobbina (1991) have suggested that the foliage from *Leucaena sp.* should not exceed 40% of the total ruminant diets to avoid animal poisoning. Tannin is another compound reported to affect the quality of fodder (Barry, 1983; Reed *et al.* 1985; Waghorn and Shelton, 1995) because it reduces the fodder intake (Marten and Ehle, 1984) and makes the nitrogen in the fodder unavailable to the animals (Bayer and Waters-Bayer, 1998) when it is at high concentrations in fodder material. If tannin content exceeds 9% of DM in the fodder, it may become lethal to livestock feeding frequently on such fodder (Kumar, 1983).

Black wattle bark is reported to have high concentrations of tannin, around 30-40% in its dry-weight (Dobson and Feely, 2002). The percentages of tannin in the other parts of the tree that was calculated from oven-dried samples are given in Table 3.1.

Table 3.1. The content of tannin in black wattle twigs and leaves at different ages

Nature and source of material	Percentage tannin content (moisture-free basis)
Twigs (without leaves, 4 years old trees)	4.7
Twigs (without leaves, 9 years old trees)	6.7
Leaves (4 years old trees)	6.5
Leaves (9 years old trees)	8.4

Adapted from Sherry (1971)

It is evident from the Table 3.1 that, although the bark of black wattle is extremely rich in tannin, the content of this compound in other parts of the tree that can be used for fodder, is too low to put livestock in danger. Additionally, tannin content in wet samples is likely to be less than is in dry samples. Beck and Goodricke (2002) have observed that wildlife and domesticated animals browse in the seedlings of black wattle where cattle and goats do browse even to older trees.

As said before, black wattle can improve soil nitrogen and hence improve yields of associated grasses. Sherry (1971) observed that the soil nitrogen content in soil which had been carried out with a stand of ten-year wattle crop, was adequate to produce yields of grain and maize silage over four successive seasons without the addition of nitrogenous fertilizer. Early experiments with black wattle and *E. curvula* date from 1956 (Sherry, 1971). In those experiments the grasses were sown at the land previous carried out with black wattle. The results showed that the residual nitrogen from the wattle crop still present in the soil should be sufficient to enable the fodder grass to be established with a minimal dressing of nitrogenous fertilizer.

MATERIAL AND METHODS

Designing and Managing the Trial

The experiment was carried out on the Ukulinga research farm, University of Kwazulu-Natal, on the outskirts of Pietermaritzburg, South Africa (30°24' S and 29° 24' E) between September 2003 and March 2005. It consisted in two treatments of alley farming with grasses plus controls with three replications. The alley farming treatments were: black wattle and *E. curvula* and black wattle and *P. maximum*. In the control plots the grasses were sown solely. The experiment layout was laid out in randomised complete block designed (RCBD). The plot size was 100m² (10x10m) in alley farming plots and 50m² (10x5m) in the control plots.

The experiment was set up in rainfed and non-fertilisation bases. It started with the plantation of seedlings in October followed by grasses in November 2003. The trees were planted first to avoid competition with grasses during transplanting period, because it could contribute to high seedling mortality. During this time the seedlings usually face

stresses due to transplantation and/or water shortage and additionally they are poor competitors against grasses, which quickly get profuse and fibrous roots (Reynolds and Cobbina, 1991). The seedlings were planted in rows at the spacing of 4x2.5m as done by Reynolds and Cobbina (1991) using *L. leucocephala* and *G. sepium* species. Each plot had 3 rows of 5 seedlings. The grasses were sown from seed drilled between the rows of trees in lines spaced 0.75m apart. The first harvest of grasses was done in March 2004 and the second in March 2005. The grasses were cut to the lowest height using a motorised bush-cutter and weighed using a digital scale for fresh biomass determination. At the same time some samples of fresh grass were taken and dried in the oven at the temperature of 65°C for dry matter determination. In October 2004, a year after tree planting, all the trees were pruned and topped to the height of 1.5m using a pruning-shears. The prunings were divided into two categories. The Foliage and fine twigs (with middle diameter less than 1cm) and the woody material including the remaining twigs and branches. The prunings were weighed separately in categories. Three big samples of non-woody material were taken. The first was used for tree DM determination, after drying it in the oven at the temperature of 65°C during 4 days. The second sample was used to observe back wattle intake in cattle and goats. And the last was taken to the laboratory of Grass Science at the University of KwaZulu-Natal for fodder analysis. The fodder analysis consisted in the determination of Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF). The survey was completed with the observation of tree sprouting after pruning.

Data Analysis

The data was analysed in GenStat 7.1 for Windows to calculate the means and deviations. The analyses included variance analysis (Anova) to determine the difference between treatments and where significant difference was found; the t-test (bilateral test) was used to compare treatments means.

RESULTS

During the study the germination of *P. maximum* was very poor. After several attempts with different lots of seed, the germination did not improve so much and hence it was decided to discard the species from the study. Therefore, this chapter will present only the results those that were attained to the alleygrazing of black wattle and *E. curvula*.

Biomass of Black Wattle and *Eragrostis curvula* under Alleygrazing System

The Table 3.2 shows the amount of fresh and dry biomass of black wattle produced under alleygrazing with *E. curvula*. The fresh biomass of foliage and fine twigs (foliage biomass) obtained from wattle prunings was 7.66t/ha whereas the woody biomass was 1.7t/ha. The DM of foliage and fine twigs was around 2.68t/ha (35% of fresh foliage biomass) whereas the woody DM was about 0.99t/ha (60% of woody fresh matter). The numbers in the brackets indicate the coefficient of variation (CV) between plots. The coefficient of variation in woody biomass was 53% and in foliage biomass about 42%. Both values of CV were considerably high, showing that there was a significant difference in tree growth between plots ($P<0.05$).

Table 3.2. Fresh and dry biomass from black wattle prunings

Species	Category	Biomass	Per plot (kg)	t/ha
Black wattle	Woody	Fresh	16.65 (53%)	1.7
		Dry	9.99	0.99
	Foliage and Fine twigs	Fresh	76.65 (42%)	7.66
		Dry	26.83	2.68

The biomass of *E. curvula* in the two seasons (2003/2004 and 2004/2005) under alleygrazing and controls is given in the Table 3.3. The table includes the DM as well as the cv values between the blocks (numbers in brackets).

Table 3.3. *E. curvula* biomass in two seasons under alleygrazing and the conventional systems

System	Season	Biomass	Plot (kg)	t/ha
Alleygrazing	2003/2004	Fresh	35.02 (46%)	3.5
		Dry	14	1.4
	2004/2005	Fresh	202.88 (29%)	20.29
		Dry	81.15	8.11
Control	2003/2004	Fresh	14.3 (59%)	2.86
		Dry	5.72	1.14
	2004/2005	Fresh	115.55(24%)	23.11
		Dry	46.22	9.24

The fresh biomass of *E. curvula* in the first season under alleygrazing was 3.5t/ha (CV=46%) and 2.86t/ha (CV=59%) in control. During the second season the biomass of *E. curvula* increased substantially reaching 20.29t/ha (CV=29%) and 23.11t/ha (CV=24%) under alley farming and the control respectively. The DM of *E. curvula* in the first season was 1.4t/ha under alley farming and 1.14t/ha in the control and 8.11t/ha and 9.24t/ha under alleygrazing and the control in the second season respectively. The DM represented 40% of fresh biomass in both seasons. The values of CV were high, especially in the first growing season.

NDF and ADF of Black Wattle and *Eragrostis curvula*

The values of NDF and ADF for black wattle and *E. curvula* are given in Table 3.4. For black wattle the NDF was 76.58% and the ADF was 68.1%. For *E. curvula* the NDF was 41.9% and the ADF was 39.9%. The values of NDF represent the percentage of non-digestible material in neutral detergent and it is used to estimate the percentage of fodder digestibility. The fodder digestibility is calculated using the formula (100 - NDF). In this case the digestibility of black wattle was 23.42% and for *E. curvula* it was 58.1%. The ADF is used to estimate the potential digestibility of NDF or the total forage digestibility. The total fodder digestibility is calculated by the formula (100 - ADF). The total digestibility for black wattle was only 31.9% while for *E. curvula* it was around 60.1%. Comparing the digestibility of both species it is clear that *E. curvula* had a higher percentage of fodder digestibility and total fodder digestibility than black wattle, at the time when the samples were taken and analysed (end of wet season).

Table 3.4. NDF and ADF of black wattle and *E. curvula*

Species	NDF (%)	ADF (%)
Black wattle	76.58	68.1
<i>E. curvula</i>	41.9	39.9

Feeding Cattle and Goats with Black Wattle Foliage

The observations on animals accepting the black wattle as fodder were conducted during 4 days. During that period goats and cattle readily accepted the fodder. In each feeding session, the animals were provided with black wattle prunings during 30 minutes/day and they did finish all the prunings available to them. Unfortunately, a baby goat died on the day of the last feeding session. However, the death was not related to the feeding because the goat was sick before the feeding session started. The plates in Fig. 3.1 show some moments during a feeding session where goats were feeding on black wattle prunings in a cut-and-carry feeding system at Ukulinga farm.



Fig. 3.1. Goats feeding on black wattle leaves

DISCUSSION

From an alley farming system involving grasses and legume trees in humid regions of Nigeria, a farmer can expect 10t of DM/ha/year (Reynolds and Cobbina, 1991). From the same area, Atta-Krah and Reynolds (1989) have reported yields of 20t DM/ha/year under alleygrazing of *Leucaena sp.* and *P. maximum* whereas Atta-Krah (1989) reports yields around 30t DM/ha/year from a combination of 0.5m inter-rows spacing with a cutting interval of 12 weeks in the same system. In this study the total DM/ha/year obtained in black wattle foliage and fine twigs was about 2.68t and 8.11t from *E. curvula* making an overall amount of 10.79t. These yields are low compared to those from *Leucaena sp.* and *P. maximum* but they are close to the average yields in various alley farming systems with grass practised in humid climatic regions.

According to Duke (1981), the annual productivity of *E. curvula* ranges from 1 to 10t/ha. The amount of fresh biomass of *E. curvula* obtained under alleygrazing with black wattle was about 3.5t/ha in the first season and 20.29t/ha in the second season while in the control plots the yields were 2.86t/ha and 23.11t/ha in the first and second seasons respectively. These results are better than those reported by Duke (1981). Similar results were reported by Bogdan (1977), who obtained yields of 11.8t/ha in the first year, 27.2t/ha in the second year, 22t/ha in the third year and 5.3t/ha in the fourth year in India on unfertilised plots.

According to the same author the DM from unfertilised stands ranged from 1 to 2t/ha. In the present study, during the first cropping season without the application of fertilizer or mulch, the DM of *E. curvula* ranged from 1.14t/ha to 1.4t/ha. Additionally, it was also observed that in the first growing season the *E. curvula* did yield less biomass than it did in the second growing season. Due to a more complete root development associated with the effect of mulch from tree prunings and grass residue, the yield of *E. curvula* increased from 1.4t DM/ha to 8.11t DM/ha under alleygrazing and from 1.14t DM/ha to 9.24t DM/ha in the control plots. It is likely that the enhanced root system contributed to a better absorption of soil moisture and of soil nutrients, resulting in better plant growth (Van Rooyen, 2002). Similar results were reported for a fertilised trial by Bogdan (1977) who observed that in India *E. curvula* could yield between 6-11t DM/ha after applying 140-450kg N/ha and in South Africa after the application of 160Kg of N/ha the yield of *E. curvula* could increase from 2 to 10.3t DM/ha.

The Anova test showed no difference in the yield of *E. curvula* between the treatments, but there was a difference between blocks ($P < 0.05$) in the first growing season. This difference is explained by high coefficients of variation observed in both treatments (46% in alleygrazing and 59% in control plots). Conversely, in the second season significant differences ($P < 0.05$) were observed in both treatments and blocks (Table 3.5).

Table 3.5. Anova analysis for *E. curvula* biomass

First season					
Source of variation	d.f	s.s	m.s	v. r.	F pr.
Block	2	6.34	3.17	1.47*	
Treatment	1	0.35	0.35	0.16	0.72
Residual	2	4.30	2.15		
Total	5	10.99			
Second season					
Source of variation	d.f	s.s	m.s	v. r.	F pr.
Block	2	132.30	66.15	113.08*	
Treatment	1	14.41	14.41	24.64*	0.038
Residual	2	1.17	0.58		
Total	5	147.89			

* Significant difference at the confidence level of 95% ($P < 0.05$)

In Fig 3.2 the fresh biomass under alleygrazing and for the control in the two seasons, are compared. The biomass under alleygrazing is the sum of black wattle foliage and *E. curvula* biomass. The graph shows that the biomass was greater in alleyfarming with *E. curvula* than it was in the control plots in both seasons. The fresh biomass from alleygrazing was 3.5t/ha in the first season and 27.95t/ha in the second season compared to 2.8t/ha and 23.11t/ha in the controls.

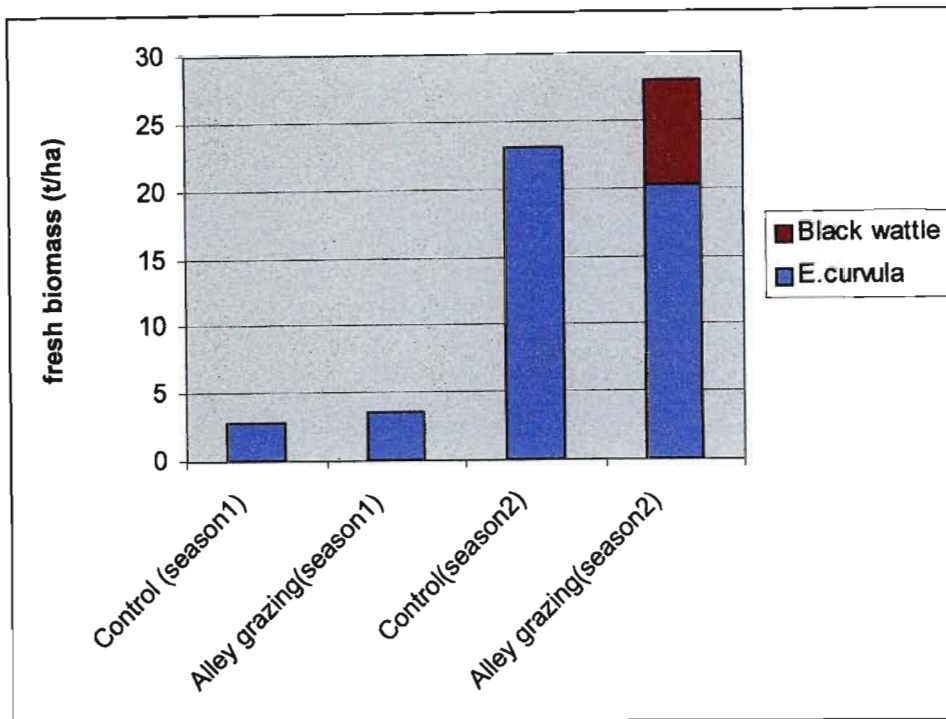


Fig 3.2. Fresh biomass of black wattle and *E. curvula* under alleygrazing and the conventional system in the 2003/2004/2005 growing seasons

The pruning of one-year's growth from the black wattle, produced 2.68t/ha of foliage DM in the first pruning. Kang and VanDenBeldt (1990) reported yields of 3.0t/ha/year in *Acioa barterii*, 4.0t/ha/year in *Alchornea cordifolia*, 5.5t/ha/year in *Gliricidia sepium* and 7.4t/ha/year in *Leucaena leucocephala* growing on an Alfisol at Ibadan in 4x0.5m spacing. In our experiment the black wattle yield was relatively low compared to the yields of other trees/shrubs at Ibadan. However, the comparison is not conclusive at this stage because black wattle was pruned only once while in Ibadan the trees were pruned 5 times a year. In general the first pruning will produce less biomass than the subsequent interventions (Kang and VanDenBeldt, 1990). Therefore the biomass of black wattle is likely to increase in the next prunings. The tree response to pruning after 4 weeks is a clear evidence of that (Fig 3.3).

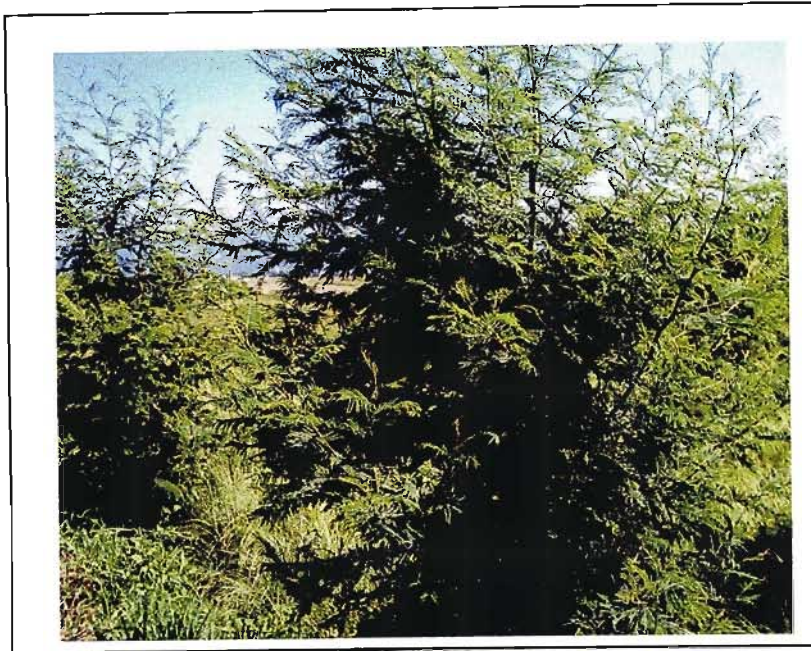


Fig 3.3. Black wattle showing strong sprouting four weeks after pruning

The digestibility of black wattle was poor whereas for *E. curvula* it was good according to Hoffman *et al.* (2001) who classified the NDF digestibility of forage species in five categories (poor: 20-35%, fair: 35-45%, average: 45-55%, good: 55-65% and excellent: 65-75%). However, these percentages are valid only for the wet season. Normally, the digestibility of *E. curvula* will decrease in the dry season to 24% when the grass gets dry (Van Rooyen, 2002). Black wattle being an evergreen tree is likely to maintain its digestibility throughout the year and both species can complement each other in different seasons. The results from this study confirm those of Gupta (1993), that black wattle is not a very good fodder species, although, it can be an alternative fodder species during critical periods. However, special attention is required when using black wattle for fodder purposes to avoid problems in livestock as a result of any tannin effect or other related compounds. Reynolds and Cobbina (1991) have recommended the mixture of *Leucaena sp.* with other fodder trees and grasses in a proportion of 1:2 to avoid animal poisoning by mimosine. The same recommendation can be used for black wattle, to avoid any tannin effect, despite the fact that the tannin content in black wattle foliage is too low to cause any problem to the animals (Sherry, 1971). Additionally, under normal circumstances animals are feed-selective and they won't feed on what is not good for them (Bayer and Waters-Bayer, 1998).

SUMMARY

The black wattle performed well under alleyfarming with *E. curvula*, producing about 7.66t/ha of fresh foliage equivalent to 2.68t DM/ha in the first pruning. The total amount of biomass produced from alleygrazing was 27.95t/ha. Although the system produced a huge amount of biomass, the digestibility of black wattle was low (30%). However, it was well accepted by goats and cattle during feeding sessions.

Black wattle can be used to feed livestock without problems if mixed at low proportion with high-fodder-quality trees or grasses or with commercial feed.

FUTURE RESEARCH NEEDS

In order to consider black wattle to be a fodder tree, the evaluation of other fodder parameters such as CP, True protein (TP), Nitrogen-free extractives (NFE), tannin content and the presence of other deleterious compounds, needs to be conducted. And if the results suggests the use of black wattle for fodder, then, the correct proportion of its foliage in the mix with high-fodder-quality foliage or commercial feed should to be investigated, as well as, the economical benefits of using black wattle in the feeding system.

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CHAPTER 4

EQUATIONS TO PREDICT EARLY GROWTH AND BIOMASS OF BLACK WATTLE UNDER ALLEYCROPPING

INTRODUCTION

Tree growth modelling is an important tool in forest and agroforestry systems management where it is used to predict changes in tree variables such as: tree diameter, tree height, growth rates and growth status, biomass production and crown shape during the growing period. Those variables are predicted by mathematical expressions developed from relatively few tree data and/or environmental information collected in the growing site. The use of mathematics models in agriculture helps to save time and money, which should be spent in direct measurements and it is a quick tool for decision-making about the use or not of certain tree species in a particular environment. Modelling is of interest to the farmers to assist them in the process of tree species selection for forest plantations as well as agroforestry uses. In agroforestry systems the selection of best tree species is based on criteria, which includes multiple purpose uses, tree growth rate and biomass production. And the best tree species must show high growth rate, must produce high amounts of biomass within short period of time and must have multiple uses and benefits. Differently from forestry, in agroforestry the benefits from trees are obtained at very early stage of tree growth. This, makes early growth assessment an useful instrument to maximise interactions between the components (trees, crops and soil) and hence to increase the benefits of the system. Early growth modelling can be used to predict whether a particular tree species is suitable or not for a specific agroforestry practice at early growing stage.

In alleycropping, one of the most popular agroforestry systems, the information from early growth modelling is crucial for farmers to make better decisions about the time for conducting management interventions such as thinning or pruning to maximise the output of the system. When those operations are done correctly, competition problems between the components can be reduced and productivity can be optimised. If growth models of different tree species are available, they can help the growers to compare and select the best species for their alleycropping according to their plans. Most growers need to be able to predict the benefits from a particular species under alleycropping before they spend money and time on

it. Tree growth equations produced from tree growth modelling can help the growers to answer the most common questions such as, "how much biomass can the system produce?" How fast can the trees grow in a specific environment? What will be the size of the trees at a given age?" and many more.

In tree growth equations, variables like diameter and height are the most used to predict the output of different tree products such as timber, biomass, bark, and others at different stage of tree growth using single or multiple tree variables (Van Laar and Theron, 2004). These variables are usually used because of their ease of measurement in the field and their strong correlation with related outputs. "Dimensional analysis" as described by Whittaker and Woodwell (1968) is the method often used by foresters and ecologists to predict individual tree growth and biomass. This method relies on the consistency of an allometric relationship between plant dimensions, usually diameter and/or height, and biomass for a given species, group of species or growth form. Using the dimensional analysis approach, a researcher samples many stems spanning the diameter and/or height range of interest, and then uses a regression model to establish the relationship between one or more tree dimensions (as independent variables) and tree-component volume or weight (as dependent variables) (Jenkins *et al.*, 2004).

Conventionally the tree diameter is taken at the height of 1.3m and it is called diameter at breast height (dbh). This is a convenient variable for predicting the tree growth of representative trees in a size-class model (Gadow and Hui, 1999) because dbh is closely correlated with the volume of the tree and hence is an essential parameter for economic and silvicultural decision-making. In early growth modelling, dbh is replaced by diameter at ground level (dgl) (Harsh *et al.*, 1998) or diameter at knee height (dkh) (Van Laar and Theron, 2004) for better prediction because the height of some trees is likely to be below 1.3m. Harsh *et al.* (1998) and Van Laar and Theron (2004) have found that the dgl and dkh were strongly correlated to the tree height and tree biomass and therefore correlated to the tree volume.

Tree height is measured from the ground level to the apex of the tree. The tree height is an indicator of the growth potential for the specie in a particular site. The growth potential of a given site is indicated by the dominant height of a particular species at the given age and it is called the site index (Gadow and Hui, 1999).

There are several studies regarding the issue of tree growth equations in commercial forests intended to predict timber yields at different ages of tree maturity for different species (Jenkins *et al.*, 2004) including black wattle (*Acacia mearnsii* De Wild.) (Smith, 2002). However, the present author could not find any literature on this topic for alleycropping expressing early growth patterns and biomass production of this species. The objective of this part of the study is to produce tree growth equations to predict tree biomass and volume from tree diameter and height as well as equations expressing the changes in tree diameter and tree height as a function of age during the early growing period. To achieve these aims various equations expressing tree growth pattern were tested. The test consisted in the calculation of the coefficient of determination (R^2) and the standard error (SE) of those models using data from the experiment as done by Jenkins *et al.* (2004), Van Laar and Theron (2004) and Wullschlegel *et al.* (2004). The R^2 indicates the fitness of the model for the data being analysed and the SE gives the standard error of the model.

Early-growth equations of black wattle can be used as a tool in managing black wattle plantations in South Africa where the species is regarded to be one of the serious weed invaders and being under strict control by the government. Early-growth equations can help to predict the woody and non-woody biomass able to be extracted from young jungles formed by invasive black wattle by just knowing their age, the average diameter and/or the height and number of the seedlings per unit of area in the those jungles. This information can be useful for the planners to make a better decision about thinning, pruning or even clear-cutting those jungles with economic justification as a strategy to control unwanted wattle invasion.

Diameter Growth

The future tree diameter d_n can be predicted if the initial diameter d_0 and the age of tree are known. This can be done by using the following relationship: $d_n = F(d_0, t) + \varepsilon$ (error). This relationship was first developed by Mitscherlich who observed that the tree diameter at age t_1 was related to the diameter at age t_2 by equation 4.1 (Gadow and Hui, 1999).

$$d_2 = d_1 \frac{1 - e^{-k(t_2 - t_0)}}{1 - e^{-k(t_1 - t_0)}} \quad (\text{Mitscherlich's equation}) \quad \text{Equation: 4.1}$$

With: t_1, t_2 = tree age (years) at the beginning and end of the projection period; d_1, d_2 = diameter (cm) at age t_1 and t_2 ; t_0 = age at which a tree reaches breast height (1.3m) ($t_0 = 469e^{-0.35379H}$); k = empirical parameter related to the maximum height (H) for the species in a particular environment ($k=0.003257+0.00016*H$) (Gadow and Hui, 1999)

The equation 4.1 is useful to predict the diameter at an early growing stage because it considers a uniform annual variation in diameter (constant growing rate), which is not true. When the tree grows larger, the growth rate increases with increasing time. The growth rate of a small tree is less than that of a large tree (Gadow, 1984). Therefore, when predicting the diameter of large trees, equation 4.2 (called equation of Bertalanffy), which is a modification of equation 4.1, should be used. This equation takes into account the effect of growth rate in diameter modelling. To further enhance the predictive of the equation 4.2, it can be developed into equation 4.3 known as the equation of Botkin. Both equations 4.2 and 4.3 do not give the predicted diameter directly, but the annual difference between two diameters (Δd), which can be converted by a simple arithmetical operation into the specific diameter one wishes to calculate.

$$\Delta d = 0.245d^{0.44} - 0.0147d \quad (\text{Bertalanffy's equation}) \quad \text{Equation: 4.2}$$

$$\Delta d = \frac{d - d^2 * \frac{137 + 50.9d - 0.167d^2}{611677}}{2.74 + 1.527d - 0.00668d^2} \quad (\text{Botkin's equation}) \quad \text{Equation: 4.3}$$

With: d = diameter (cm)

It is interesting to note that these equations represent curves, which grow from zero (when $d=0$) to a maximum point from which they start decreasing back to zero. This shows that the tree will not grow indefinitely. It will grow from its seedling stage to maturity at which time growth ceases (Gadow and Hui, 1999).

Height Increase

The average of 'dominant height' (by definition the height of the tallest 100 trees in the stand) is an important variable in even-aged forests. The increase in height is relatively independent of stand density and thus is not much affected by thinning itself (Gadow and Hui, 1999), but it is affected by top pruning, lopping, coppicing, bushing or pollarding.

The development of the stand height may be described using a 3-parameter asymptotic function, such as the Chapman-Richards model, equation 4.4 (Pienaar and Turnbull, 1973):

$$H = a_0(1 - e^{-a_1 t})^{a_2} \quad \text{(Chapman-Richard model)} \quad \text{Equation: 4.4}$$

With: H = dominant stand height (metres); t = stand age (years); a_0, a_1, a_2 = model parameters (Pienaar and Turnbull, 1973).

The scalar parameter a_0 , which is expressed in terms of the units of the dependent variable H, defines the height asymptote. The parameter a_1 scales the time axis, while a_2 offers further flexibility for the shape of the growth curve (Gadow and Hui, 1999).

The equation of Schumacher (equation 4.5) is also commonly used for the height model because of its simplicity.

$$H = a_0 e^{-a_1 \frac{1}{t}} \quad \text{(Schumacher's equation)} \quad \text{Equation: 4.5}$$

With: H = dominant stand height; t = stand age (years); a_0, a_1 = empirical model parameters (Gadow and Hui, 1999)

Diameter-Height Relationship

The relationship between tree diameter and height may be described using height regression or a bivariate diameter-height distribution. The development of this relationship can be analysed using generalised height regression models (Gadow and Hui, 1999). Height regression may be derived from stand's inventory. As this last methodology is costly, a practical alternative is to develop generalised height regressions, which embody certain basic characteristics inherent in all individual height regression (Gadow and Hui, 1999). Generalised height regression is an important element of size class models.

Diameter and height are essential for estimating the volume of timber for representative trees in different size classes. According to Gadow and Hui (1999) at least 30 different functions have been used for describing the relationship between tree diameter and height. Two of those equations were found particularly suitable for deriving generalised height regression. The first equation was derived on the basis of a function involving the logarithm of height as the dependent variable, and the reciprocal of the diameter as the predictor variable (equation 4.6).

$$\ln(h) = a_0 + a_1 (1/d)$$

Equation: 4.6

With: h= height; d = diameter; a₀, a₁ = parameters

The equation 4.6 has been modified to equation 4.7 and used by several authors (Gaffrey, 1988; Nagel, 1991; Goebel, 1992; Sloboda *et al.*, 1993) as a generalised height regression.

$$h_i = 1.3 + (\bar{H} - 1.3)e^{a_1(1 - \frac{\bar{D}}{d_i}) + a_2(\frac{1}{D} - \frac{1}{d_i})}$$

Equation: 4.7

With: \bar{H} = average stand height (metres); \bar{D} = average stand diameter (centimetres); h_i = height of i-th tree (metres); d_i = breast height diameter of i-th tree (centimetres); a₁, a₂ = parameters

Equation 4.7 has only two parameters, which makes it an attractive modelling tool (Gadow and Hui, 1999). Alternatively, Hui and Gadow (1993) have developed another equation for height prediction (equation 4.8) on the basis of the allometric growth theory, assuming that the growth rate is influenced by a stand attribute such as the dominant height.

$$h = 1.3 + a_1 H^{b_1} d^{a_2 H^{b_2}}$$

Equation: 4.8

With: H = dominant stand height (metres); h = height of tree (metres); d = diameter at breast height (cm); a₁, a₂, b₁, b₂ = parameters

The diameter-height relationship is useful to estimate the effect of top pruning the tree during its development, particularly when the tree is pruned above the breast height as happens in some alleycropping systems.

Volume Prediction

Tree yield is conventionally expressed in terms of the volume of the tree. Tree volume is expressed as a quotient of the basal area of the tree and its height. Normally a linear yield model is obtained by transforming the variables 'diameter' and 'height' into logarithmic form. There are many equations used to predict tree volume from a tree diameter and height database. The database is obtained from forest inventories. Table 4.1 shows some of the most-used equations.

Table 4.1. Equations to predict individual tree volume

Designation	Independent variables	Equation	Reference
Kopezky-Gehrhardt	d - one entry	$V=b_0+b_1d^2$	Equation: 4.9
Dissescu - Meyer	d - one entry	$V=b_1d+b_2d^2$	Equation: 4.10
Hohenadl - Krenn	d - one entry	$V=b_0+b_1d+b_2d^2$	Equation: 4.11
Husch (local volume table)	d - one entry	$\ln V=b_0+b_1\ln d$	Equation: 4.12
Brenac (logarithm form)	d - one entry	$\ln V=b_0+b_1\ln d+b_21/d$	Equation: 4.13
Spurr (constant form)	d, h - double entry	$V= b_1d^2h$	Equation: 4.14
Spurr (combined variable)	d, h - double entry	$V=b_0+b_1d^2h$	Equation: 4.15
Stoate	d, h - double entry	$V=b_0+b_1d^2+b_2d^2h+b_3h$	Equation: 4.16
Naslund	d, h - double entry	$V=b_1d+b_2d^2h+b_3dh^2+b_4h^2$	Equation: 4.17
Abbot et al.	d, h - double entry	$V=b_0+b_1d^2+b_2h$	Equation: 4.18
Meyer (comprehensive)	d, h - double entry	$V=b_0+b_1d+b_2d^2+b_3dh+b_4d^2h+b_5h$	Equation: 4.19
Meyer (modified)	d, h - double entry	$V=b_0+b_1d+b_2d^2+b_3dh+b_4d^2h$	Equation: 4.20
Schumacher-Hall	d, h - double entry	$\ln V=b_0+b_1\ln d+b_2\ln h$	Equation: 4.21
Spurr (logarithmic combined)	d, h - double entry	$\ln V=b_0+b_1\ln(d^2h)$	Equation: 4.22

d - diameter at breast height; h - total or cut height (adapted from Pereira and Nhamucho, 2003)

Schonau (1972) cited by NAS (1980) has developed equation 4.23 to predict black wattle volume from tree diameter and height using a Schumacher and Hall equation (equation 4.21 in table 4.1) and he found it to be an effective volume equation for black wattle trees with a height between 10-25m and dbh between 5-25cm.

$$\log V = 1.9532 (\log d) + 1.2315 (\log h) - 1.74059$$

Equation: 4.23

With: V= volume (m³); d = dbh (cm); h = height (metres) (Nas, 1980)

Smith (2002) has converted equation 4.23 using natural logarithms to equation 4.23a.

$$\ln V = 1.95322 (\ln d) + 1.9532 (\ln h) - 10.9156$$

Equation: 4.23a

With: V= volume (m³); d = dbh (cm); h = height (metres) (Smith, 2002)

Estimating Tree Biomass

Tree biomass is defined as the total amount of aboveground and belowground living organic matter in trees expressed as oven-dry tons per unit area (Brown, 1997). Some authors also express it as fresh weight and they call it fresh biomass. In many cases the biomass of interest is the aboveground biomass. There are two methods for estimating this biomass. The first method basically uses the information from existing inventories, by converting the tree volume into biomass using wood density. The second method estimates tree biomass using biomass regression equations. The regression equations are mathematical formulae that relate tree biomass to tree diameter and/or height. Once produced, the regression equations can be applied to produce stand tables to predict the biomass of individual trees in the stands or elsewhere (e.g. windbreaks, live fence posts, home gardens). The advantage of regression equations is the facility of estimating tree biomass without the calculation of tree volume. It also reduces the error due to the application of incorrect tree coefficients during the calculation of volumes (Brown, 1997). There are many equations to estimate tree biomass in different forest ecosystems worldwide. Some of them are given by Brown (1997) to estimate biomass in tropical forests. The equations are summarised in the table 4.2 including the parameters b_0 , b_1 and b_2 for each climate zone.

Table 4.2. Regression equation to estimate above-ground biomass of individual trees of black wattle

Climate zone	Equation	Parameters	Reference
Dry	$Y = e^{(b_0 + b_1 \ln d)}$	$b_0 = -1.996; b_1 = 2.32$	Equation: 4.24
	$Y = 10^{(b_0 + b_1 BA)}$	$b_0 = -0.535$	Equation: 4.25
Moist	$Y = b_0 + b_1(d) + b_2(d^2)$	$b_0 = 42.69; b_1 = 12.8; b_2 = 1.242$	Equation: 4.26
	$Y = e^{(b_0 + b_1 \ln d)}$	$b_0 = -2.134; b_1 = 2.530$	Equation: 4.27
Wet	$Y = b_0 + b_1(d) + b_2(d^2)$	$b_0 = 21.297; b_1 = -6.953; b_2 = 0.740$	Equation: 4.28

Adapted from (Brown, 1997); With Y = biomass per tree (kg), d = dbh (cm) and Ba = basal area in cm^2 .

MATERIAL AND METHODS

Tree Sampling

The study was conducted at the Ukulinga Research farm (30°24' S and 29° 24' E), Pietermaritzburg, South Africa. 108 specimens of black wattle were sampled out of 180 available trees in the alleycropping trial of black wattle with maize and cowpeas, pumpkin, *E. curvula* and *P. maximum*. The trial was composed of 12 plots each with 15 black wattle seedlings planted in rows at the spacing of 4x2.5m. Each plot had three rows with five seedlings. The three seedlings in the middle of each row were selected for the study. By the time of planting the seedlings were 45 days old with an average basal diameter of 4mm and a height of 10cm.

Data Collection

Every three months the diameter at ground level (dgl), total height (h), number of twigs (nt), twig diameters (td), twig lengths (tl) and number of leaves per twig (nlt) were measured for each sampled seedling during a period of year. The diameter was measured to the nearest 1mm, using a calliper, and the height to the nearest 1cm was assessed using a metric tape. At the time of the first measurement nt, td, tl and nlt were taken for the entire seedling while at the time of the following measurements these were assessed on sub-samples of three twigs per seedling to reduce measurement errors because the trees had grown considerably and they had many twigs. The sub-samples were randomly selected from the lower, middle and top parts of the tree. Tree dbh was measured in October 2004 just before pruning to a height of 1.5m using pruning-shears (see Fig. 4.1). After pruning the fresh biomass of each tree was weighed in the field using a battery-operated balance following Wullschleger *et al.* (2004) procedures. Before weighing, the biomass was divided into two categories: fresh woody biomass (fwb) and fresh foliage biomass (flb). Woody biomass consisted of all woody material with a diameter greater than 1cm, whereas the foliage biomass consisted of leaves and fine twigs a diameter less than 1cm. For both categories the dry biomass was determined by drying some samples of fresh biomass in an oven at the 65°C for 96h.

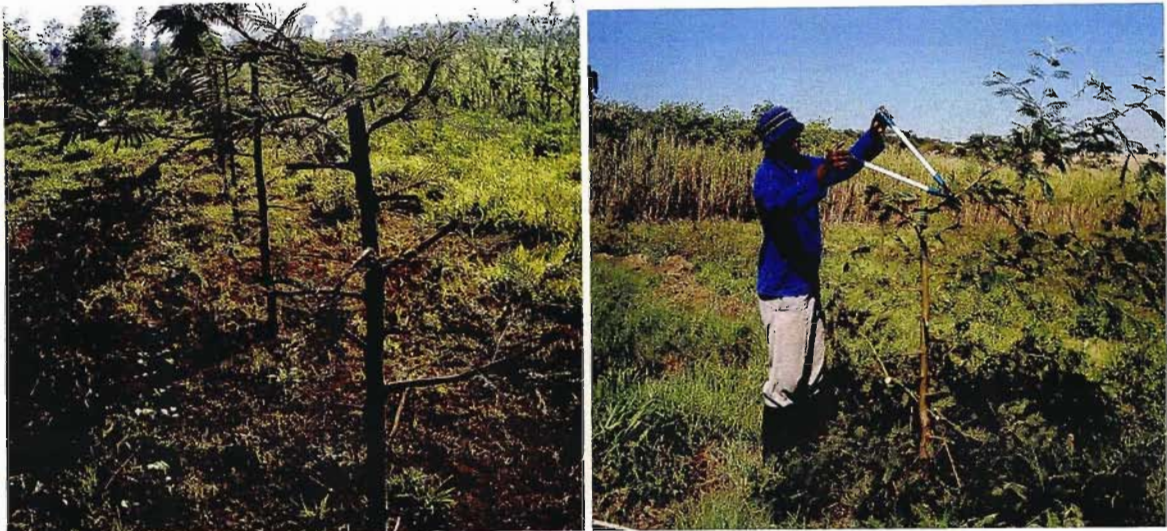


Fig. 4.1. Pruning black wattle trees

Data Analysis

All growth and biomass variables were analysed statistically by analysis of variance (Anova) to test for a significant ($P < 0.05$) difference among them. The analysis included correlation analysis, linear regression analysis and variables summary using the GenStat 7.1 statistical package and the determination of the best equation for a particular relationship using the Best Curve Expert 1.3 programme. A correlation analysis was done to establish the relationship between diameter, height and biomass and, where strong correlation ($R > 0.7$) was found, simple linear regression was done to determine the equations and the parameters expressing the relationship between the correlated variables. Many equations with one or two variables, simple or squared, normal or logarithmic transformed were tested. The best equations were considered those with the highest R^2 and least SE. In those cases in which two or more equations showing similar R^2 and SE, the simplest one (for example the equation with the least number of variables, or one not in logarithmic form) was considered to be the 'best-fit' equation. This study focused on the following relationships:

- i. dgl and age; height and age; dgl and height,
- ii. tree volume, dbh and height,
- iii. tree utilisable biomass, dbh and height at the age of 12 months.

The Curve Expert software was used to find the best curve between two variables (one dependent and another independent) and for this study it was used to draw the best curve between:

- i. $dgl * h$.
- ii. $dgl * age$.
- iii. $h * age$.

The following formulae were used to calculate:

a) Tree volume (V):

$V = (d/2)^2 \times \pi \times h \times ff$	equation: 4.29
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With: d - diameter; $\pi = 3.14$ (constant); h - height; ff - form factor (coefficient to adjust the cylinder volume to the tree shape)

b) Fresh woody biomass (fwb)

$fwb = V * WD$	equation: 4.30
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WD= wood air dry density. In KwaZulu-Natal midlands it is about 0.89 t/m^3 or 890 kg/m^3 Smith (2002).

c) Biomass from prunings or total utilisable fresh biomass (tufb)

$tufb = fwb + \text{fresh leaf biomass}$	equation: 4-31
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RESULTS

Changes in the Growth Variables of Black Wattle

Table 4.3 shows the changes in black wattle dgl, h, nt, td, tl and nlt. The Table includes the average dbh at the seedlings age of 12 months. The numbers in the brackets indicate the coefficients of variation (CV) in the samples.

Table 4.3. Changes in black wattle growth variables during the first year

Parameter	Age	3 months	6 months	9 months	12 months
Sample size (seedlings)		108	108	108	108
dgl (mm)		5.87 (20.0)	22.19 (22.0)	41.40 (19.5)	48.24 (16.6)
dbh (mm)		-	-	-	36.82 (16.77)
h (cm)		37.95 (30.8)	190.90 (23.7)	320.3 (21.4)	406.2 (19.7)
Nt		3 (64.85)	20 (29.56)	33 (20.49)	26 (30.7)
td (mm)		2.70 (20)	6.11 (21)	9.06 (17)	11.80 (66.9)
tl (cm)		19.96 (19.8)	66.27 (19.2)	90.12 (14.9)	104.72 (19)
Nlt		17 (44)	23 (44.8)	43 (35.8)	54 (35.2)

- Not measured , dgl - diameter at ground level, h- total height, dbh -diameter at breast height, nt - number of twigs, td - twig diameter, tl - twig length, ntl - number of leaves per twig

The dgl increased from 3mm at planting time to 48.24mm in 12 months with an annual increase in diameter of about 45mm, whereas the total tree height increased from 10cm to 406.2cm, equivalent to an annual increase in excess of 390cm. The nt per tree increased from three twigs in three months to about 26 units in 12 months. Note that the nt apparently decreased between third (9 months) and fourth (12 months) measurements. This was a result of measurement bias because by the time of the last survey the tree was considerably taller making it difficult to observe detail in the upper region of the tree and to count accurately the twigs there. The other reason for this situation could be the size of twigs that was large by the time of the last survey than was previously and hence some twigs which did not increase significantly in size, were likely to be bewildered with leaves, while previously they were counted as twigs. The td, tl and nlt did also increase. In the final measurements the td, tl and nlt were 11.8mm, 104.72cm and 54 units respectively, which can be considered to be the annual increments for these values since the value of these variables at the planting were close to zero. In general the CV values were not high with the exception of td (its last measurement), nt and nlt. These were high because of measurement inaccuracies associated with the height of the trees with increasing time. However it does not affect the quality of the information given for those variables because CV only evaluates the dispersion around the means and not the means themselves.

Correlation Analysis of Black Wattle Growth Variables

The correlation analysis between black wattle growth variables is summarised in Table 4.4. A two-tailed correlation analysis showed significant correlation ($P < 0.01$) between the variables in the analysis. Variables like dgl and tree height (h) were highly correlated with each other ($R = 0.962$). The dgl was also highly correlated to tl ($R = 0.932$), age ($R = 0.930$), nt ($R = 0.808$), and moderately correlated to the nlt ($R = 0.748$) and the td ($R = 0.620$). Poor correlation was observed between the nt and td ($R = 0.450$). In all the cases the correlation was positive.

Table 4.4. Correlation matrix for black wattle growth variables

Parameter	age	h	nt	td	tl	nlt
Dgl	0.930	0.962	0.808	0.620	0.932	0.748
Age	-	0.937	0.704	0.615	0.888	0.716
H	-	-	0.846	0.578	0.924	0.715
Nt	-	-	-	0.450	0.790	0.584
Td	-	-	-	-	0.619	0.840
Tl	-	-	-	-	-	0.766

dgl - diameter at ground level; h- height, nt- number of twigs, td- diameter of twigs, tl- twig length and nlt-number of leaves per twig

Equations to Predict Tree Diameter and Tree Height of Black Wattle at an Early Stage of Growth

The correlation analysis gave strong correlation between the variables and hence it was possible to proceed with regression analysis to identify mathematical expressions, which describe the relationship between correlated variables. This section presents the regression equations for the dgl and the total tree height as they were strongly correlated with each other.

The prediction of tree height from the dgl was done through testing the fitness of equations 4.6, 4.7 and 4.8. The results were not satisfactory (R^2 was too low) for the three equations. So it was decided to use the Curve Expert programme, which produced the following equation:

$$h = -21.25 + 10.5d - 0.03d^2 ; R^2 = 0.96 \text{ and } SE = 42.9 \quad \text{equation : 4.32}$$

With: h = tree height (cm), d = dgl (mm), R^2 = determination coefficient and SE = standard error

According to the criteria of validating regression equations, equation 4.32 is valid, because it had a high R^2 and low SE. In this case the equation can be used to estimate the height of trees with a dgl between 0.5 -5cm with less estimating error.

Equations of diameter and height in the monitored growth period (one year) were also produced from regression analysis and the best-fit equations are given below.

$dgl = -7.03 + 4.8 * age \quad R^2 = 0.86, S = 6.6$	equation: 4.33
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$h = 873.97e^{-9.18/age} \quad R^2 = 0.88, S = 54.18$	equation: 4.34
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With: dgl (mm), h (cm); age (months)

These equations are valid to predict the dgl as well as the h of black wattle growing under similar conditions to Ukulinga during the first year of growth specifically between 3 to 12 months. However the R^2 was not as good as should be expected and hence the equations did not fit properly in those relationships beyond the age limit of one year.

Equations to Predict Volume and Biomass of Black Wattle at an Early Stage of Growth

The correlation analysis for volume and biomass predictors is shown in Table 4.5. Strong correlation was observed between dbh and tfub ($R = 0.738$) while the height at the age of 12 months (h12) was weakly correlated to tfub ($R = 0.356$). The values of the other correlations are also given in the Table 4.5.

Table 4.5. Correlation matrix for biomass, dbh and height of one-year old black wattle

	flb	fwb	dbh	h12
tfub	0.977	0.621	0.738	0.356
flb	-	0.437	0.610	0.179
fwb	-	-	0.864	0.834
dbh	-	-	-	0.686

tfub – total fresh biomass or utilisable biomass, flb = fresh leaf biomass, fwb = fresh woody biomass, dbh – diameter at breast height, h12 – tree height at the age of 12 months

Seven equations from the Table 4.1 were selected and tested because of their simplicity. The results are presented in Table 4.6. The equation references are 4.9, 4.10, 4.14, 4.15, 4.18, 4.21 and 4.22. The ranking of those equations from greatest to poorest based on the value of R^2 and SE was: equation 4.14, 4.15, 4.22, 4.21, 4.18, 4.10 and 4.9 (Table 4.6). However due to the fact that equations 4.14 and 4.15 represent the generic formula of tree volume they could not be considered as volume predictors and they were excluded from the final selection. As a result the best equation to predict tree volume from dbh and height was equation 4.21. This equation is a simple linear expression and easy to use. The Anova test showed the significance of R^2 ($P < 0.05$).

Table 4.6. Equations to predict the volume of black wattle in its early growth stage

Equation	R^2	SE	Parameters	SE of parameter	Significance of the parameter	Reference
$V=b_0+b_1d^2$	0.936	452.88	$b_0 = -1173.77$ $b_1 = 3.64$	190.58 0.13	* *	4.9
$V=b_1d+b_2d^2$	0.989	450.93	$b_1 = -62.97$ $b_2 = 4.46$	10.12 0.257	* *	4.10
$V= b_1d^2h$	1	0.0	$b_1 = 7.85*10^{-3}$	0.0	*	4.14
$V=b_0+b_1d^2h$	1	0.0	$b_0 = -9.61*10^{-13}$ $b_1 = 7.85*10^{-3}$	0.0 0.0	Not significant *	4.15
$V=b_0+b_1d^2+b_2h$	0.992	162.28	$b_0 = -3841.28$ $b_1 = 2.82$ $b_2 = 11.04$	154.99 0.063 0.576	* * *	4.18
$\ln V=b_0+b_1\ln d+b_2\ln h$	1	0.0	$b_0 = -4.85$ $b_1 = 2.0$ $b_2 = 1.0$	0.0 0.0 0.0	* * *	4.21
$\ln V=b_0+b_1\ln(d^2h)$	1	0.0	$b_0 = -4.85$ $b_1 = 1.0$	0.0 0.0	* *	4.22

*- the parameter value is significant at the level of 0.05. V- tree volume (cm^3), d = dbh (mm), h - height (cm)

With the exception of equation 4.15 in which the coefficient b_0 is not statistically significant, the other coefficients showed significance in the models ($P < 0.05$).

The regression analysis of tfub from prunings showed a weak relationship with dbh when fitted to the equation 4.24 and 4.27 in Table 4.2. The R^2 , SE and the equation parameters are presented in Table 4.7. The value of R^2 was low while the SE was high, meaning that the regression between variables was poor.

Table 4.7. Equations to predict the biomass of prunings from one-year-old wattle

Equations	R ²	SE	Parameters	SE of the parameter	Significance	Reference
Y = b ₀ +b ₁ +b ₂ dbh ²	0.56	1643.52	b ₀ = 4603.85	6491.96	**	4.24
			b ₁ = -202.86	346.19	Not significant	
			b ₂ = 6.521	4.54	**	
Y = b ₀ e ^{b₁/ln dbh}	0.55	1647.24	b ₀ = 4.3*10 ⁷	Not estimated	Not estimated	4.27
			b ₁ = -23.62	Not estimated	Not estimated	
Ln y = b ₁ ln dbh	0.99	0.0	b ₁ = 2.409	0.01	*	4.35

* - Significant at the level of 0.05; ** - significant at the level of 0.1. With Y= tfub - total utilisable biomass (g) from prunings, d = dbh (mm), h - height (cm)

Due to this situation an alternative model had to be tested giving very good results (R² = 0.99; SE = 0.01). The tested model is called Hush equation with the intercept set at zero. The Hush equation is a logarithmic transformed function. In this study it was used in the natural logarithm of tfub and natural logarithm of dbh, resulting in the equation 4.35 in the Table 4.7.

The total fresh utilisable biomass was a sum of the fresh leaf biomass and the fresh woody biomass, and the relative proportions of each part are given in equation 4.36.

$$tfub = 0.82*flb + 0.18*fwb \quad \text{equation: 4.36}$$

With: tfub = total fresh utilisable biomass, flb = fresh leaf biomass, fwb = fresh woody biomass.

The relationship between total volume (tvol) and utilisable volume is shown in equation 4.37.

$$tvol = 0.55*uvol \quad \text{equation: 4.37}$$

With: tvol - total volume of the tree and uvol - utilisable volume in tree.

DISCUSSION

Black wattle growth was characterized by a rapid increase in dgl, height and tl. The increase for dgl was close to 5cm while for the height it was 4m in one-year growth. The values of tl was 1m. The td and other variables describing twig growth did change moderately. The increase in td was about 1cm per year. A maximum height of 3.1m in black wattle seedlings at the age of nine-months-old planted in a spacing of 4x2m was recorded in Argentina (Sherry, 1971). Dunlop (2000) evaluating the two methods of re-establishing wattle plantations in Bloemendal (outside Pietermaritzburg) by cuttings and by seedlings observed that the height of ten-months-old cuttings was approximately 2.50m, while trees planted as seedlings were 2.4m in height. In the present study nine-month-old seedlings had a height of 3.2m. The CV value of height was fairly high (25%) while the CV values for dgl and tl were relatively low 20% and 18% respectively.

There are no studies regarding early-growth modelling for wattle, and therefore there is no opportunity to compare the equations derived in the present study to those of other workers. Conversely there is quite a lot of information about modelling in commercial classes of trees, since the interest of commercial forestry is mostly orientated in timber production. Examples of such studies are those of Schulze (1997) and Smith (2002) who derived growth and yield model equations based on tree variables like dbh, height and the age at harvesting. The equations from Schulze (1997) use ecological information such as precipitation and temperature as inputs while Smith (2002) used tree dimensions.

The analysis of different equations for height regression given in the previous sections showed that equation 4.34 is the best estimator for tree height and it could be used to estimate tree height up to 8m. Under Ukulinga conditions this height is reached within 2 to 3 years after planting (Sherry, 1971). According to Sherry in the midlands of Kwazulu-Natal the species can reach a maximum height of 20m at the age of 8-10 years. The average height in the area is about 13-16m at tree maturity. The equation offers the best-fit estimation when the seedlings are 1-2 years old. The dgl showed a linear relationship with age while the height exhibited a modified exponential pattern also known as the Schumacher function. Godow and Hui (1999) have found this equation to be the best to estimate tree height by age in many tree stands world-wide. Equation 4.21, known as the Schumacher-Hall model was found to be the best-fit equation to predict single tree volume from dbh and height (Table 4.6) and it was also

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CHAPTER 5

THE PROBLEM OF ANIMAL DAMAGE AT THE UKULINGA FARM

ABSTRACT

Crop damage by animals became one of the major problems at the Ukulinga research farm. Animals, like monkeys and bushbucks coming from nearby game farm, the farm's cattle and birds were the most important species causing damage to the crops in trials.

This Chapter reports the problems of animals in the agroforestry experiment that investigated the effect of black wattle in association with maize and cowpeas as joint intercrops and in association with pumpkin. The cropping system is called alleycropping and the work was conducted between 2003 and 2005.

Among the marauding animals, monkeys were responsible for the most frequent incursions while cattle produced most damage. The problem of monkeys had been reported in the past at the farm and they were also regularly seen moving around the farm just before the beginning of the agroforestry trial. Conversely, cattle did not seem to present a threat at the onset of the trials. Therefore some measures to counteract monkeys in the trial were put in place. Those included the combination of human guarding with the use of scarecrows. However, due to high costs associated with human guarding, it had to be stopped a few months later and the use of scarecrows became the remaining option available, although ineffective.

Consequently a few weeks after stopping with human guarding the first signs of monkey damage were observed in maize in the field. Luckily, it was around the first cropping season harvesting time and the damage was minor.

In the second cropping season while the attention was concentrated on monkey control the damage came from the farm's cattle, which after breaking down fences separating their grazing plots and the agroforestry trial they grazed the experimental plots, mainly those with maize. During this season other damage by birds and bushbucks was also observed in maize and pumpkin.

The real cost associated with crop damage was difficult to estimate, because no price can be put on the destruction of scientific experiments, but the direct costs associated to monkey

chasing using human guards guarding against monkeys were calculated to amount to five thousands South African Rand (R5000,00) per month.

Some important lessons were learnt from this experience. The first lesson was that the unexpected events such as those reported here must be included in project planning and project budget to avoid project failure. Secondly because the efficient means to keep the animals away from the crops are expensive, crop damage could be avoided by using less-preferred/crops that are less damage-prone when that is possible, and in this particular case, only maize should have been excluded from the experiment. Finally, experimental crop and livestock fields should not be adjacent to one another, even if these are well fenced, because a small mistake can be crucial.

INTRODUCTION

Since humans began farming probably ten to fifteen thousands years ago in the Middle East, they established reliable sources of food throughout the year. But at the same time they started facing cropping problems due to diseases, animal damage and environmental constraints. In the category of animal damage, wildlife and domestic animals are most challenging (Conover, 2002) because they can destroy the production being expected in the field. The damage can encompass a few plants to the entire field, compromising the farmers' production. When the animals damage crops, they lead to major conflicts between them and the farmers. This is what happens at the Ukulinga farm and the problem background is given below.

Problem Background

The problem of animals and monkeys in particular started early 1990s when their population became excessive in the game reserve adjoining Ukulinga. As a result, they began facing food shortage forcing them to search for food outside the game farm. In their raids for food, they discovered the Ukulinga research farm where food was aplenty. At the beginning they were raiding the horticulture site, being the place with fresh crops during the winter season, the critical season in term of food shortage. At present they raid the entire farm and for the whole year.

Until the present experimentation there had been no history of cattle and bushbuck damage at Ukulinga, while the damage by birds, although these are always present, is usually below the critical level.

Why Do Animals Invade Farms?

Food, space and ecological imbalance are the main causes of human-animal conflict worldwide. According to Conover (1989) deer damage in plant nurseries usually does not begin until their ordinary fodder in the surrounding woodlots has been consumed. Elephants' can pose a difficult problem for people who farm close to parks or other wildlife conservation areas particularly if the farms are placed in the Elephants route (Hill, 1998). Additionally, exotic species can represent a serious problem to the environment in areas where they have been introduced, which includes game farms if no control of their populations is available at the new site (Williams et al, 1995). The population of animals can be controlled by predators, diseases and artificial means. In the situation of excessive

food availability the animals will respond positively by increasing their population (Ozoga and Verme, 1982; Conover, 2002) while in the situation of food shortage they will react in the opposite way, immigrating to suitable places for better feeding or dying. This could be the case in Ukulinga where monkeys after facing food shortage immigrated to the research farm where due to excessive food availability, they increased in number becoming a pest.

Keeping Animals Away from the Farm

Conover (2002) gave many methods to avoid human-animal conflict. Those include various methods such as lethal control, fertility control, animal translocation, fear-provoking stimuli, chemical repellents, diversion, exclusion and habitat manipulation. The description of each method is given below.

Lethal control

Human beings have used lethal means to reduce wildlife damage for thousands of years. Although it seems obvious that that killing animals should reduce the amount of damage they cause, the relationship between killing and damage reduction is unlikely to be linear because a quick increase through exponential growth in the animal population being reduced can be observed (McCallum and Singleton, 1989). When lethal means are used in wildlife damage management, they have to be selective as much as possible. The goal should be to stop the damage killing as few animals as possible rather than exterminating the entire population since the animals have high positive value for society. Lethal means would be restricted only to those animals causing damage, known as culprits.

Apart from controlling animal problems, selective wildlife culling is also a mean of wildlife utilization. Animals damaging human goods are killed for meat or for trophy (Conover, 2002).

Fear-provoking stimuli

Animals have an instinct to avoid unsafe areas and wildlife managers can reduce animal damage to agricultural crops or predation on livestock by taking advantage of that instinct. This is usually accomplished with the use of fear-provoking stimuli that increase the fear of the animals to go to the areas where crops or livestock are located. Using any objects that cause fear to the animals can produce fear-provoking stimuli, which can be visual, auditory or olfactory (Conover, 2002).

The most common visual practice of fear-provoking stimuli is the use of scarecrows with human shape. Scarecrows have been used for centuries to reduce bird predation on agricultural crops. Other objects such as flags, streamers, spotlights, flashing lights and strobe lights are often used to repel diurnal and nocturnal animals.

Auditory stimuli consists of the use of sound or noise to provoke fear in the animals. There are many ways of producing loud bangs, including the use of firecrackers or firearms specially designed for that particular effect.

Olfactory stimuli (odours) can also be used to repel animals. Many herbivorous animals are repelled by odour of their predators. By not foraging in areas where the scent of predators is strong, herbivores can avoid placing themselves in dangerous situations. The effectiveness of predator odours is greatly enhanced when the odour is sprayed directly on the resource needing protection (Sullivan *et al.* 1985, Swihart *et al.* 1991).

Chemical stimuli (poisons) are used to provoke fear in animals threatening human interests. It consists of applying some chemical poisons on the object to be protected. Poisons have negative effects on the health of animals and may even kill them. When animals feed on poisoned objects it will make them behaviour strangely to others scaring the rest of the animals willing to feed on the same source. However there is divergence among scientists about either chemical stimuli by poison scare or not the animals or it just kills them (Jaeger *et al.* 1983; Conover, 1994).

Other methods of fear-provoking stimuli include the use of live predators and guard dogs (Conover, 2002).

Animal translocation

Translocation or relocation consists of capturing, transporting and releasing of animals in a new place far from the area where they were captured. Translocation has been used for various purposes, including the reintroduction of threatened or endangered species to portions of their former range and the stocking of popular game species. In wildlife damage management, translocation has been used to remove individual animals causing

problems or to reduce animal population in specific areas by removing large numbers of them. Many people, who regard lethal means for controlling culprits as offensive, see translocation as a sound solution because it offers an opportunity to those animals to live elsewhere. Unfortunately, the biological realities of translocation are quite different and this technique is sometimes controversial (Conover, 2002). During translocation some animals may die due to stress involved in the process. Additionally, after release some animals may try to go back to the original habitats, neutralising the whole effort. However, translocation seems to be one of the best methods to control nuisance wildlife in many cases. The effectiveness of this method in many cases is rarely monitored and the fate of translocation is unknown (Barnes, 1995; Curtis, *et al.* 1993).

Fertility control

Fertility control is used to reduce the fertility of the wildlife population to control its numbers. Fertility control can be accomplished by interrupting the reproduction process at different stages, through contraceptive or abortive means. The contraceptive method is the one that prevents reproduction by avoiding egg fertilisation whereas the abortive method consists on killing the embryo before birth. Fertility control methods in wildlife can be conducted in three ways:

1. Mechanical and surgical techniques
2. Endocrine disruption and
3. Immunocontraception

Fertility control is not a panacea for all human-wildlife conflicts, but it can be used to reduce some wildlife populations.

Each of these methods described above has advantages as well as disadvantages that will affect its practicability in managing wildlife population. However before employing these techniques it is fundamental to understand the long-term effects on the target population (Kennelly and Lyons, 1983) and good results are achieved using combinations of different methods. This approach is known as 'integrative strategy' (Conover, 2002).

THE AGROFORESTRY TRIAL AND THE MARAUDING ANIMALS

The two-year agroforestry experiment was established in 2003 to assess the effect of black wattle on alleycropping with maize (*Zea mays* L.) and cowpeas (*Vigna unguiculata* (L.) Walp.) as joint intercrops and pumpkin (*Cucurbita pepo* L.) as a sole crop.

The presence of monkeys was noted before the experiment start and some strategies to reduce their negative impact on the trial were designed. The preliminary list of methods included the use of dogs, human guarding, electrical fence, the use of guns to produce noise, the use of scarecrows and the use of traps. Among those methods, electrical fencing was found to be expensive, while the use of guns and traps was considered less efficient. The use of dogs was considered not adequate for the situation because dog need a handler and nobody was staying at the farm to control them. Therefore the remaining options were the use of human guarding and scarecrows.

Those were techniques used to control monkeys. Human guarding consisted of the arrangement made with the local labour to work overtime in shifts regime. The shifts scheme were arranged to include all the available labour and, the first shift being from 05:00 to 7.30, the second from 15:30 to 19:00 during weekdays. During the weekends the first shift being from 05:00 to 12:00 and the second from 12:00 to 19:00. This scheme was set up in accordance with the behaviour of the monkeys, because they would come early before the labour arrived and then again after the labour vacated the premises until dark at around 19:00. Because no labour was present on weekends and holidays, the monkeys had a field day during such time.

The monkey guards, working overtime, needed to be paid 1.5 times the normal rates during weekdays and double time over weekends and holidays according to the labour policy. As a result human guarding became expensive and since it was not included in the project budget and the payments were made from the research funds, the costs became prohibitive after three months and these duties had to be halted. Consequently the use of scarecrows remained the only option available. At the beginning the method gave good results but after few weeks the monkeys realised that scarecrows were not people and then they started coming in. Fortunately, it was around the time for harvest and the damage was not severe.

In the second cropping season the attention was centred on planning new strategies for the control of monkeys. One of the solutions was to restart with human guards, this time with us, the experimenters, as guards. That implied temporal residence arrangements at the farm, but a month before we moved in, the trial was invaded by cattle, which broke the fence at one of its corroded points, causing damage to crops in the trial. However, it was still possible to record some data from the remaining crops, which were used for the second season analysis. Fig. 5.1 shows one of the plots damaged by cattle.



Fig. 5.1. Plot of maize and cowpeas damaged by cattle

The birds also caused some damage in maize cobs (Fig. 5.2) whereas the bushbucks damaged some pumpkin fruits (Fig. 5.3). In both cases the damage was nor critical.



Fig. 5.2. An ear of maize damaged by birds



Fig. 5.3. A pumpkin fruit nibbled by bushbucks

ECONOMIC IMPACT OF ANIMAL DAMAGE

The term damage means "loss" and loss in economics means negative profits, non-achievement or failure in any projected investment. This explanation shows clearly that animal damage has negative effects not only on the crop, also on the crop owner, in this case the experimenter. The impacts of animal damage in farming can be grouped in two categories: direct and indirect impacts. Direct impacts result from the depreciation of the value of the crop being damaged while indirect impacts represent any extra costs incurred to protect the crops from animal damage. Direct impacts are assessed by comparing profits between damaged and non-damaged fields while indirect impacts are deducted from the cost of crop protection against animal damage. There are two major methods used to obtain information about the extent of losses from animal damage. The first is to make visits to sites where damage is occurring and directly measure the extent of the losses. The second is to identify people who are suffering from damage and ask them about their losses. Direct assessment of damage is the most accurate way to collect data about economic losses but it is labour intensive and it is most practical only for small-scale or localised problems. Surveying people suffering from damage is a quick way to assess economic impacts of animal damage. However it is often difficult to get a high percentage of people to respond to a survey, and the researcher must then guess the answers from those who did not respond by extrapolation from those who did. Another limitation from survey is the perceptions of the respondents, which may not be accurate. They may be either overestimating or underestimating the real level of damage.

There are two reasons why perceptions may be inaccurate. When wildlife damage is very conspicuous, damage may be overestimated but if it is not easily noted then it can be underestimated (Conover, 2002). An alternative way of assessing economic impact of animal damage is the analysis of the lost opportunity cost. Although difficult to quantify, lost opportunity cost can be used to estimate the economic impact of animal damage. Farmers may forego an opportunity to make money because they know that animal damage would be too high. For instance, a farmer growing crops near a large bird roost might not plant sunflowers, because he knows that the birds would eat all the sunflower seeds (Conover, 2002). The same example is applied to the Ukulinga case where researchers can decide to stop using the most damaged crop like maize for example preferring those that would be less damaged. In both cases, there is no actual damage to measure but because sunflower and maize were not planted, the beneficiaries will suffer from a lost opportunity rather than from a physical loss.

Assessing Economic Losses Due to Animal Damage

The assessment of animal damage is not an easy task, but it is an important tool to evaluate whether the animals are or not economically compromising the objectives of the production. The economic assessment allows comparing the effects of damage from different animals in different fields and helps in decision-making about the time to start protecting the crops according to the level of damage incidence and its equivalent economic impact. According to Conover (2002) in the U.S. wildlife damage costs approximately 22 billion American dollars (US\$) per annum, 4.5 billion dollars being incurred in agricultural producers. The losses include the cost of property damaged, time and money that people spent on preventive means. In the agroforestry plots at the Ukulinga farm the losses due to animal damage were not estimated. Although the cost due to guards was R15000 in three months for salaries plus R10000 spent in the arrangements of the facilities to make the farm ready for temporary residence.

SUMMARY

Culprits like monkeys and cattle caused economic losses estimated at R25000 in our agroforestry trials in 2003 and 2004. Various strategies to keep the culprits away from the trial were tried being the most efficient, but expensive, being the use of human guards, and the use of scarecrows. The loss in terms of experimental detail and accuracy cannot be determined, but was vast and soul-destroying.

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CHAPTER 6

GENERAL CONCLUSIONS

This study investigated the effect of black wattle and the fever tree in alleycropping with maize, cowpea and pumpkin, and under alleygrazing with *E. curvula* and *P. maximum*. It also included tree growth modelling under those systems and the description of the constraint imposed by animal damaging crops during the fieldwork.

The best tree performance between the two used species was observed in black wattle whereas the performance of the fever tree was unlikely very poor contributing for the species to be discarded from the study.

Black wattle produced 5.6t/ha of fresh matter equivalent to 1.96t/ha DM in the first pruning 12 months after planting under alleycropping with maize and cowpeas as a joint intercrop. In the other alleycropping with pumpkin the black wattle prunings produced 4.5t/ha of fresh biomass.

The growth performance of black wattle under alleycropping was greater in maize and cowpeas intercrop than was under pumpkin. Despite the great performance of black wattle under the alleycropping with maize and cowpeas as a joint intercrop, the yield of those crops was not high as should be. In the first season crop yields were 1.9t/ha, 0.2t/ha and 12.7t/ha of maize grain, cowpeas grain and pumpkin fruit under alleycropping and 2t/ha, 0.2t/ha and 17.6t/ha in the conventional practice. In the second and last season in this study the yield was 2.6t/ha for maize grain, 0.3t/ha for cowpeas grain and 8.5t/ha for fruit of pumpkin under alleycropping and 5.7t/ha, 0.6t/ha and 11.5t/ha in the conventional practice respectively. Comparing yields of alleycropping and the conventional practice, the outstanding of the last is clearly observed. However, this is a normal outcome from this comparison at early stage of alleycropping because the contribution of trees is still absent and competition among the components in the system (tree and crops) is likely to be present.

In alleygrazing trial black wattle produced 7.66t/ha of fresh biomass and the *E. curvula* yields were 3.5t/ha and 2.86t/ha under alleygrazing and control respectively in the first season and 20.29t/ha and 23.11t/ha of fresh biomass in the second season. However, the digestibility of black wattle fodder was poor (30%). To increase the value of black wattle fodder, it has to be mixed at low proportion with other fodder from high quality fodder species or with improved feed.

In black wattle growth modelling various equations were produced to predict black wattle growth variables one from others, such as diameter at ground level (dgl) from age, tree height from dgl and tree prunings biomass (y) from diameter at breast height (dbh). The relationship between the dgl and age and the relationship between biomass (y) and dbh were expressed by linear models: $dgl = 4.8 * age - 7.03$ ($R^2 = 0.86$; $SE = 6.6$) and $ln y = 2.409 * ln dbh$ ($R^2 = 0.99$, $SE = 0.0$) respectively, whereas the relationship between dgl and height was expressed by a quadratic model: $h = -0.03 dgl^2 + 10.5 dgl - 21.25$ ($R^2 = 0.96$, $SE = 42.9$). Tree height was characterised by an exponential behaviour expressed by the Schumacher-function in the equation $h = 873.97 e^{-9.18/age}$, and the relationship of total tree volume and dbh was characterized by Schumacher-Hall model in the equation $ln V = 2 ln dbh + ln h - 4.85$. The equation expressing the relationship between the dbh and total fresh biomass from prunings was $ln y = 2.409 ln dbh$. The utilisable volume from black wattle prunings was 55% for the total tree volume whereas the foliage from prunings represented 82% of the total pruned biomass. The units are mm for diameter, cm for the height, cm^3 for the volume and g for biomass and the age is expressed in months.

During the present study monkeys and cattle have caused some damage in the trial where the losses were estimated in R25000. Among the used strategies to keep the animals away from the trial the most efficient mean was the use of human guards although it was expensive.

Appendix 1. Soil analysis Report

Fertilizer Advisory Service, KwaZulu-Natal Department of Agriculture

NUTRIENT AND LIME RECOMMENDATIONS

Farmer : Luis Nhamucho Jeremias

Advisor : BN Mkhize

Maize grain; dryland

Sample ID	Lab num	NITROGEN		PHOSPHORUS			POTASSIUM			LIME				ZINC
		Yield target t/ha	Req.N kg/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha	Lime type	Zinc fert reqd
A1	F23925	4.0	50	14	14	20	174	100	0	0	20	.0		No
		5.0	75	14	14	20	174	100	0	0	20	.0		No
		7.0	140	14	14	20	174	100	0	0	20	.0		No
A3	F23927	4.0	50	7	16	75	72	100	70	0	20	.0		No
		5.0	75	7	16	75	72	100	70	0	20	.0		No
		7.0	140	7	16	75	72	100	70	0	20	.0		No
A5	F23929	4.0	50	4	14	95	61	100	100	0	20	.0		No
		5.0	75	4	14	95	61	100	100	0	20	.0		No
		7.0	140	4	14	95	61	100	100	0	20	.0		No

Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Req.P and Req.K are the amounts of P and K required to raise the soil test to the target value. Lime required (Req. lime) is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS).

MANAGEMENT GUIDELINES :

- 1 LIME, IF REQUIRED, SHOULD BE APPLIED AT LEAST ONE TO TWO MONTHS BEFORE PLANTING. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.
- 2 In order to increase the time between liming operations, it is often advisable to apply more lime than recommended above. Liming to 10% acid saturation rather than 20% is a sound policy for maize lands.
- 3 Where soil test P levels are considered adequate, but are less than 120 mg/L, a starter application of 20 kg P/ha has been recommended to promote initial plant growth.
- 4 At least 20 kg of the recommended P should be applied in the band at planting.
- 5 Where the soil P test of a sample is abnormally high (>120 mg/L), and the sample is truly representative of the whole field, no fertilizer P should be applied until test levels indicate a P requirement.
- 6 Nitrogen recommendations given above should be used as a guideline only as there are many situations where lower N rates are more cost-effective. Details are given in the leaflet "Nitrogen fertilization: Allowing for N mineralization and residual N" which is available from Alan Manson or Vlatko Katusic (0331-3559100).
- 7 On all soils, applications of N should be split in order to improve efficiency of N use and minimise soil acidification. This is especially important on soils that tend to waterlog as well as on sandy soils. Topdressed N should be applied when the plants are knee high.
- 8 Ensure that the total combined N and K applied in the band at planting does not exceed 80 kg/ha.
- 9 N applications may be reduced by 40 kg/ha if the previous crop was soybean that yielded 2-3 t/ha.
- 10 This crop requires 20 - 30 kg S/ha. This can usually be supplied from the atmosphere and by the mineralization of organic S in soils, but supplementary S fertilizers may be necessary on sandy soils, where sulphate is lost by leaching.

Fertilizer Advisory Service, KwaZulu-Natal Department of Agriculture
NUTRIENT AND LIME RECOMMENDATIONS

Farmer : Luis Nhamucho Jeremias

Advisor : BN Mkhize

Dry bean (dryland)

Sample ID	Lab num	NITROGEN		PHOSPHORUS			POTASSIUM			LIME			Zinc fert reqd	
		Yield target t/ha	Req.N kg/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha		Lime type
A1	F23925	1.0	40	14	11	20	174	100	0	0	5	.0		No
		2.0	80	14	11	20	174	100	0	0	5	.0		No
		3.0	120	14	11	20	174	100	0	0	5	.0		No
A3	F23927	1.0	40	7	13	50	72	100	70	0	5	.0		No
		2.0	80	7	13	50	72	100	70	0	5	.0		No
		3.0	120	7	13	50	72	100	70	0	5	.0		No
A5	F23929	1.0	40	4	12	75	61	100	100	0	5	.0		No
		2.0	80	4	12	75	61	100	100	0	5	.0		No
		3.0	120	4	12	75	61	100	100	0	5	.0		No

Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Req.P and Req.K are the amounts of P and K required to raise the soil test to the target value. Lime required (Req. lime) is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS).

MANAGEMENT GUIDELINES :

- 1 LIME, IF REQUIRED, SHOULD BE APPLIED AT LEAST ONE TO TWO MONTHS BEFORE PLANTING. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.
- 2 Where soil test P levels are considered adequate, but are less than 120 mg/L, a starter application of 20 kg P/ha has been recommended to promote initial plant growth.
- 3 Where the soil P test of a sample is abnormally high (>120 mg/L), and the sample is truly representative of the whole field, no fertilizer P should be applied until test levels indicate a P requirement.
- 4 This crop requires 20 - 30 kg S/ha. This can usually be supplied from the atmosphere and by the mineralization of organic S in soils, but supplementary S fertilizers may be necessary on sandy soils, where sulphate is lost by leaching.

NUTRIENT AND LIME RECOMMENDATIONS

Farmer : Luis Nhamucho Jeremias

Advisor : BN Mkhize

Pumpkin (dryland)

Sample ID	Lab num	NITROGEN		PHOSPHORUS			POTASSIUM			LIME				ZINC
		Yield target t/ha	Req.N kg/ha	Sample soil test mg/L	Target soil test mg/L	Req.P kg/ha	Sample soil test mg/L	Target soil test mg/L	Req. K kg/ha	Sample acid sat. %	PAS %	Req. lime t/ha	Lime type	Zinc fert reqd
A2	F23926	opt.	100	16	23	70	233	135	0	0	5	.0		No
A4	F23928	opt.	100	20	26	55	240	135	0	0	5	.0		No

Sample soil test and sample acid saturation reflect the soil test values of the sample submitted. Req.P and Req.K are the amounts of P and K required to raise the soil test to the target value. Lime required (Req. lime) is the amount of lime needed to decrease the soil acid saturation to the permissible acid saturation (PAS).

MANAGEMENT GUIDELINES :

- 1 LIME, IF REQUIRED, SHOULD BE APPLIED AT LEAST ONE TO TWO MONTHS BEFORE PLANTING. It is assumed that the lime will be incorporated to a depth of 20 cm. Thorough incorporation is essential: discing followed by ploughing is recommended.
- 2 Where P levels are considered adequate, but are less than 120 mg/L, an application of 40 kg P/ha has been recommended to ensure adequate growth.
- 3 Where the soil P test of a sample is abnormally high (>120 mg/L), a response to P fertilizer is unlikely. However, P fertilizer may be applied to ensure that adequate P is available over the entire area to be cropped.
- 4 To ensure high yields, it is recommended that 30 - 40 kg/ha of sulphur be applied at establishment or soon thereafter.
- 5 Consult your adviser on the use of micronutrients such as zinc, boron and molybdenum.

Appendix 2. Crops lay-out in the plots

Plate 1. Diagram of crops lay-out in the plots

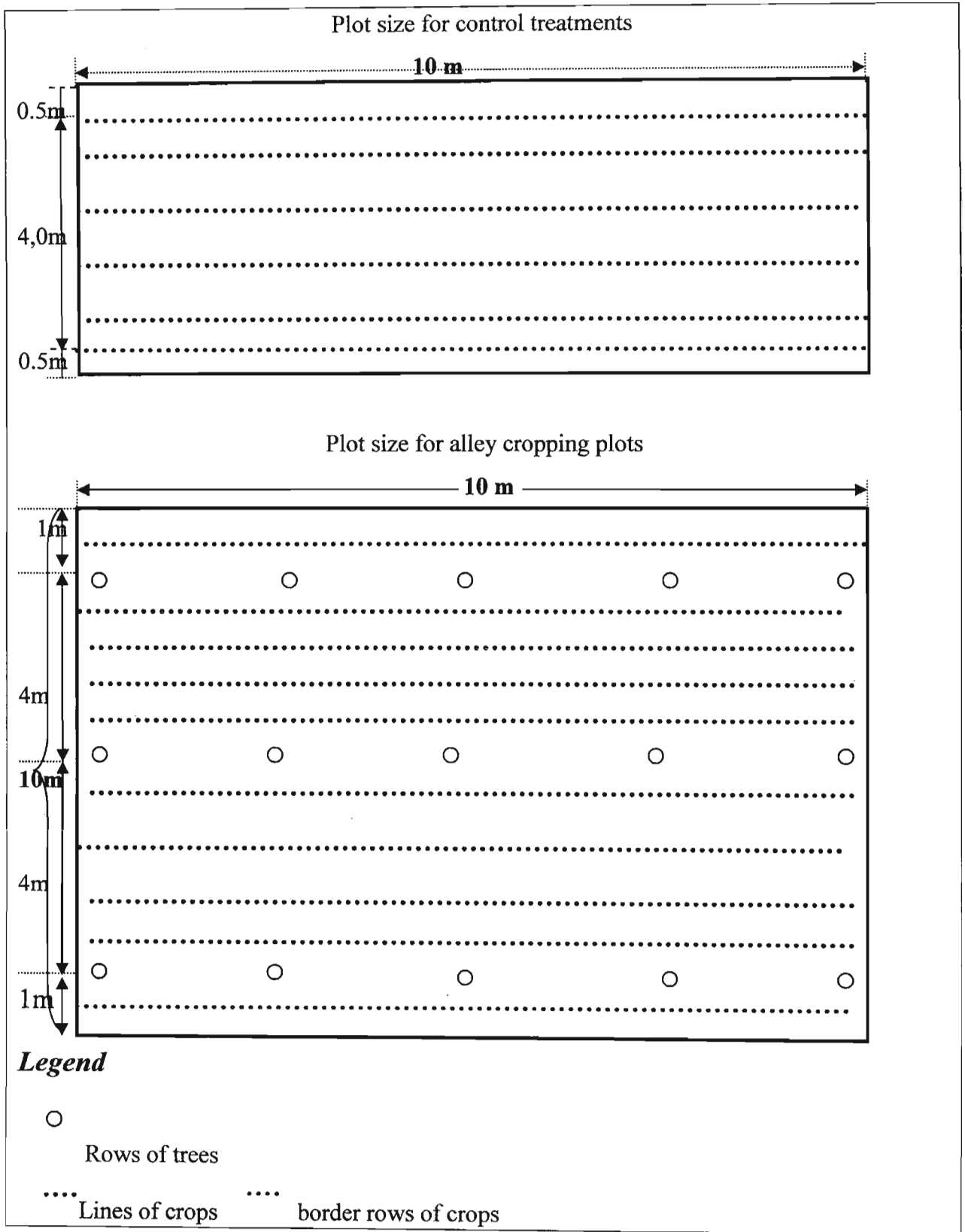


Plate 2. Photos showing the lay-out of crops and trees in the plots



Photo 1: Crops lay-out in maize and cowpea intercropping and black wattle alleycropping



Photo 2: Crop lay-out in the alleygrazing of *eragrostis curvula* and Black wattle