ALLEY CROPPING WITH LEUCAENA IN SEMI-ARID CONDITIONS

by

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To the memory of Dolly Pretorius, who would have been so proud.

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DECLARATION

I, Christelle Charlé Botha, hereby declare that this dissertation for the degree M.Sc.Agric.(Pasture Science) at the University of Pretoria, is my own work and has never before been submitted by myself for any degree at any other university.

C.C.Botha
January 2001

ABSTRACT

Alley cropping with leucaena in semi-arid conditions

by

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A study was conducted on the use of *Leucaena leucocephala* in alley cropping systems in semi-arid conditions. Leucaena is a well known multi-purpose leguminous fodder tree and has been used with success in alley cropping in the tropical and sub-tropical regions of the world. The purpose of this study was to simulate such a cropping system, compare different pruning treatments of leucaena, investigate the yields and quality of the crops grown in the alleys, investigate possible competitive effects between the trees and alley crops and monitor changes in soil quality due to the application of leucaena prunings as mulch.

It was concluded that yield and the contribution of yield components can be manipulated by using different pruning treatments. Pruning to a single-stemmed tree provided a long, straight stem that could be used as fence poles, for construction purposes or fuel wood. Crops could also be planted nearer to the trees. Hedgerow pruning is a labour-intensive operation, but is justified by the very high forage yield.

Yield of alley crops was suppressed in 3m alleys, confirming that this is not a viable option under local conditions. It became clear that cropping should not be attempted within 2m of tree rows, as yield was also suppressed. Crude protein concentration, NDF concentration and *in vitro* organic matter digestibility of the alley crops compared favourably with that of the fertilised control.

Row orientation and alley width played a definite role in competition for available moisture and light. It was found that an east-west row orientation provided a more evenly spaced distribution of sunlight. Soil water content increased from a distance of ± 1.5m from the trees.

The addition of prunings had a definite effect on the soil fertility status. The ideal, however, would be to monitor soil quality over a longer period, with and without the effect of nutrient removal by cropping, in order to make more accurate estimates of changes in soil chemical properties.

The use of leucaena in alley cropping systems definitely has potential in South Africa, especially in the semi-arid rural regions. It can provide much-needed fuel wood and forage, and also aid in ameliorating soils without the use of expensive inorganic fertilisers.

UITTREKSEL

Gangverbouing met leucaena onder semi-ariede toestande

deur

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Die gebruik van *Leucaena leucocephala* in gangverbouingstelsels onder semi-ariede toestande is ondersoek. Leucaena is 'n bekende veeldoelige voerboom en is reeds met sukses in gangverbouingstelsels in die tropiese en subtropiese streke van die wêreld gebruik. Die doel van hierdie ondersoek was om 'n gangverbouingstelsel te simuleer, verskillende snoeibehandelings te vergelyk, die opbrengs en kwaliteit van aangeplante gewasse in die gang te ondersoek, moontlike kompetisie-effekte tussen die gewasse en bome te ondersoek en verskille in grondkwaliteit gevolg van die plasing van leucaena-materiaal as 'n deklaag te ondersoek.

Opbrengste en die bydraes van die onderskeie komponente tot die opbrengs kan gemanipuleer word deur verskillende snoeimetodes. Enkelstambome het 'n lang, reguit stam gelewer, wat aangewend kan word as heiningpale, vir konstruksiedoeleindes, sowel as vuurmaakhout. Gewasse kan ook nader aan die bome geplant word. Om tot 'n heining te snoei is arbeidsintensief, maar word regverdig deur die hoë voeropbrengste.

Die opbrengs van gewasse is onderdruk in die 3m gange, wat bevestig dat hierdie nie 'n volhoubare opsie onder plaaslike toestande is nie. Dit was duidelik dat gewasse nie binne 2m van die bome aangeplant moet word nie, omdat opbrengste onderdruk word. Die ruproteïeninhoud, neutraalbestande veselinhoud en *in vitro*

organiese materiaal verteerbaarheid van die gewasse het gunstig vergelyk met dié van die bemeste kontrole.

Ry-oriëntering en gangwydte speel definitief 'n rol in kompetisie vir beskikbare vog en lig. In 'n oos-wes oriëntasie was sonlig meer eweredig versprei. Grondwaterinhoud het toegeneem van 'n afstand van ± 1.5m van die boomry.

Die toevoeging van die snoei-opbrengs as 'n deklaag het die grondkwaliteit definitief beïnvloed. Dit sou egter ideaal wees om grondkwaliteit oor 'n langer periode te monitor, met en sonder die effek van nutriëntverwydering deur gewasverbouing, ten einde 'n meer akkurate beraming van veranderinge in grondkwaliteit te maak.

Die gebruik van leucaena in gangverbouingstelsels het definitief potensiaal in Suid-Afrika, veral in die semi-ariede landelike gebiede. Dit kan voorsien in die noodsaaklike behoefte aan vuurmaakhout en voer, en kan aangewend word om grondkwaliteit te verbeter sonder die gebruik van duur anorganiese kunsmis.

1 Alley cropping with *Leucaena leucocephala* - a literature review

1.1 Introduction

In developing countries the low availability of input technologies and high costs of fertilizer too often result in poor crop yields and low productivity. Poor tillage methods and agricultural practices lower the productivity of land even more. This again results in lower yields and the cycle keeps repeating itself. Part of rural life is the constant search for fuel wood and as trees are continuously felled for this purpose, the natural ability of the land to prevent erosion is reduced. Wilson and Kang (1981) referred to predictions made by the Food and Agricultural Organization (FAO) in the seventies that by the year 2000, 60% more food will be required to meet the demands of the world population. That time has been reached, and the demand may even be greater than expected.

It has been recommended that marginal or degraded areas can be made more productive and self sufficient by integrating trees, crops and animals and combinations thereof in different components. The benefits of introducing or maintaining a tree component in land use systems are becoming more attractive for land rehabilitation and sustainable production purposes. Increasing evidence supports the view that multiple production systems involving trees have some beneficial economic and environmental consequences in many land use programs. Trees have deeper, better developed root systems and, therefore, provide better access to sub-surface water and nutrients. They aid in withdrawing nutrients in large volumes from the soils and recycle it by means of leaf drop, which leads to a higher pH beneath trees (Gholz, 1987; Farrell 1990; Bisschop, 1994). More scientists have focused on this principle, with the result that agroforestry as a science has grown in leaps and bounds.

Agroforestry may be the most important solution towards sustainable development in Africa, as it can be used to address three important problems associated with Third World development, *viz.* low production, soil erosion and sufficient quantities of fuel wood (Cameron, Gutteridge & Rance, 1991; Fenn, 1995). In arid and semi-arid areas, agroforestry could help provide insurance against climatic extremes. Shrubs and trees could provide food, fodder and fuelwood, windbreaks and live fences; and reduce surface runoff, evaporation and soil erosion (Swaminathan, 1987).

1.2 A general overview of agroforestry

1.2.1 Definition

The International Center for Research in Agroforestry (ICRAF) defined agroforestry as "...a collective name for all land-use systems and practices in which woody perennials are deliberately grown on the same land management unit as crops and/or animals. This can be either in some form of spatial arrangement or in a time sequence...". To qualify as agroforestry, a given land-use system or practice must permit significant economic and ecological interactions between the woody and non-woody components. Another definition used by ICRAF reads "...land use that involves deliberate retention, introduction or mixture of trees or other woody perennials in crop/animal production fields to benefit from the resultant ecological and economic interaction..." (Lundgren, 1987; MacDicken & Vergara, 1990, as cited by Cameron *et al.*, 1991).

Agroforestry is credited with improving the utilization of space by improving recycling of nutrients and organic matter. This translates into improved soil chemical, physical and biological characteristics with a reduction in the use of chemical fertilizers and improved infiltration of rainfall. Higher aggregate biomass production is obtained from an agroforestry mixtures than from monoculture. Microclimatic extremes are reduced, as is soil erosion. Limited resources can be used more efficiently in the following manners: sunlight by multistoried levels, soil nutrients by deep roots, water by providing shelter and the retaining of moisture by mulch, land by sustaining soil fertility. Agroforestry thus provides a more favourable environment for sustained cropping, the creation of habitat diversity and provides a more continuous flow of more products over time (Cameron *et al.*, 1991; Anonynous, 1992).

The practice does, however, hold disadvantages. Most important of these is the increased competition of trees with agricultural crops for water, nutrients and light. This competition could lead to reduced yields of both trees and associate crops. The useable crop area is reduced due to tree alleys/plots, which could also act as a habitat for pests. Allelopathic effects by trees could reduce crop yields. Importantly, agroforestry systems are usually labour intensive, which could be a deterrent to the adoption of the practice. There is also the fear that certain species may become invasive or provide favourable conditions for the habitation of pests.

It is, however, increasingly accepted that the advantages of agroforestry, particularly the environmental aspects, clearly outweigh the disadvantages, and that many of the disadvantages can be eliminated or minimized by manipulating management practices.

1.2.2 Classification and examples of agroforestry systems

Agroforestry is practised in several different formats, but can be classified in four main groups (Swaminathan, 1987): agrosilvopastoral, multi-level plantations or homegardens, silvopastoral or agrisilvicultural.

Agroforestry principles can be incorporated in the farming system or home garden in various ways. Borders around farmland form a significant niche in which trees may be planted. Traditionally this niche has been one of those most exploited for tree planting by small-scale farmers. As farm borders typically include unproductive land, tree planting in this niche can increase overall farm outputs. Living fence-post trees are typically planted further apart and managed less intensively than hedges. The tree is used together with other materials (barbed wire, wooden slats, etc.) to form a barrier. Hedges and living fences protect crops, define borders, provide privacy, and act as small windbreaks. By slowing wind speeds, windbreaks help conserve soil moisture and prevent wind erosion, and therefore increase crop yields. Crops immediately next to the windbreak may be adversely affected by competition. Windbreak trees do not necessarily require intensive management. Planted close together hedges require frequent trimming to encourage secondary branching and to create an impenetrable hedge. Yields include fuel wood, fodder production and green manure. Hedges can also be planted in rows with cash crops or pasture planted in the alleys between the rows (alley cropping).

ICRAF published a comprehensive account of agroforestry in dryland Africa, where trees are used as hedges, windbreaks, for soil/water conservation, improved fallow systems and in homegardens (Rochelau, Weber & Field-Juma, 1988). At least 755 of shrubs and trees in Africa serve as browse plants and many of these fix nitrogen (Skerman, 1977). Research in Africa has concentrated mainly on *Leucaena leucocephala* and *Gliricidia sepium*.

1.3 Alley cropping

Alley cropping, also known as hedgerow intercropping, has been the subject of intensive "alley farming" research at the International Institute for Tropical Agriculture (IITA) in Nigeria (Kang, Wilson & Nangju, 1981; Kang, Wilson & Sipkens, 1981; Read, Kang & Wilson, 1985; Wilson, Kang & Mulongoy, 1986; Kang & Wilson, 1987; Kang & Van den Belt, 1990; Palada, Gichuru & Kang, 1990; Palada, Kang & Claassen, 1992). The concept of alley cropping was formalized at IITA where the term was defined as "... the growing of crops, usually food crops, in alleys formed by trees or woody shrubs that are established mainly to hasten soil fertility restoration and enhance productivity. The trees and shrubs are cut back at crop planting and maintained as hedges by frequent trimming during the cropping..." (Wilson & Kang, 1981). The leaves and twigs from the cut trees are added to the soil as green manure or mulch.

Alley cropping was first developed for humid tropics as a replacement for the traditional bush fallow slash-and-burn system. Shrubs and trees retain the same functions of recycling nutrients, suppressing weeds, and controlling erosion on sloping land as those in bush fallow. In addition, other tree products such as fuel wood and animal feed can be produced.

It is a management-intensive system that can lead to increased crop yields and productivity of the land. Trees are planted in rows anything from 2 to 20 meters apart, usually with cash crops cultivated between the rows or in the "alleys" formed by the trees. Wide spacing between rows (e.g. 10 - 20 m) may be used to avoid negative impact on the associated crops when the trees are permitted to grow to large sizes. During the cropping season, the trees are kept pruned – mostly to a hedgerow - and the leaves and green stems are applied to the soil surface or incorporated into the soil. The soil and micro-environments are enriched by the fallen leaf material or mulch, directly affecting associated crops (Fig. 1)

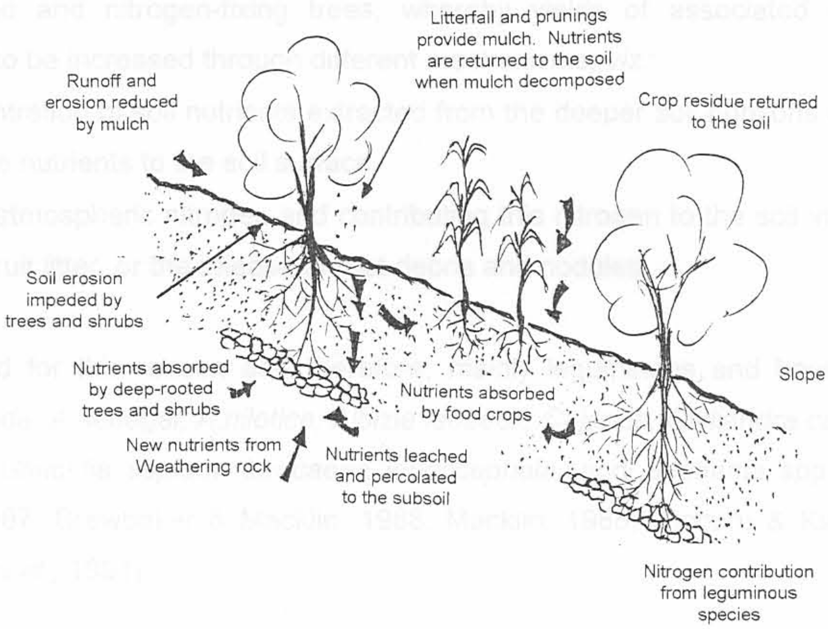

Figure 1 Schematic representation of the functioning of a typical alley cropping system (Kang, Van der Kruijs & Couper, 1986).

Hedgerows are preferred as shading of the cash crops is minimized and competition between the trees and crops limited. Hedgerows can be allowed to grow out between cropping seasons to produce fuel wood. On sloping land, hedgerows are planted densely (5 -10 cm within rows) along the contours to form a barrier against soil erosion. Grass strips planted beside hedgerows will create an even more effective barrier.

Cash crops used have included beans, maize, cassava, grasses, rice and pigeon peas. Animals/vehicles can be used for tillage and harvesting if the tree rows are planted far enough apart. Animals can feed directly off the trees if they are not pruned, but this may entail damage to the cash crops in the alley. However, trees take up space, compete for light, moisture and nutrients with cash/pasture crops. (Brewbaker, MacDicken & Withington, 1985).

Alley cropping depends on nutrient recycling through decomposition of leaves from deep-rooted and nitrogen-fixing trees, whereby yields of associated crops are perceived to be increased through different mechanisms, *viz.*:

- Concentration of soil nutrients extracted from the deeper soil horizons and return of these nutrients to the soil surface.
- Fixing atmospheric nitrogen and contributing this nitrogen to the soil via leaf and fallen fruit litter, or the release of root debris and nodules.

Trees used for this reason are, therefore, mainly leguminous and have included *Acacia albida, A.senegal, A.nilotica, Albizia lebbeck, Cajanus, Calliandra calothyrsus, Erythrina, Gliricidia sepium, Leucaena leucocephala,* and *Sesbania* spp. (Kang & Wilson, 1987; Brewbaker & Macklin, 1988; Macklin, 1988; Gichuru & Kang, 1990; Cameron *et al.,* 1991).

1.3.1 Effects of alley cropping:

Results reported over the past 20 years have indicated the advantages that may be reaped from alley cropping. Except for influencing crop yields, beneficial effects on soil physical and chemical properties may be expected. Alley cropping reduced soil exchangeable calcium and pH and increased total acidity mainly through the greater demand for calcium by the hedgerow species (a major constituent of woody tissues) (Hulugalle, 1994). Soil physical properties were not significantly affected, contrasting with suggestions that alley cropping can improve soil physical properties. However, intensive mechanization of alley cropping over a long period of time may compact and pulverize the soil, thereby negating any beneficial effects of these cropping systems on soil physical properties (Lal & Couper, 1990, as cited by Hulugalle, 1994).

1.4 The use of *Leucaena leucocephala* in alley cropping systems

When selecting trees for use in alley cropping systems, certain characteristics should be considered (Rachie, 1983, as cited by Cameron *et al.*, 1991):

1. Ease of establishment from seeds or cuttings
2. Rapid rate of growth
3. Ability to withstand frequent lopping
4. Deep root system with different root distribution to that of crop

5. Multiple uses such as firewood, fence posts and wood chips
6. Ability to withstand environmental stress such as drought, waterlogging, extremes of temperatures, etc.
7. High leaf:stem ratio
8. Small leaves or leaflets
9. Dry season leaf retention
10. Freedom from pests and diseases.

Leucaena leucocephala (leucaena) fits most of these characteristics and has been extensively used in alley cropping.

1.4.1 Background

Leucaena (sub-family Mimosoideae, family Fabaceae) is a tropical nitrogen-fixing tree, native to Central America and Mexico. Nine families of flowering plants include woody species that are able to fix nitrogen, for a total of about 650 species. The legumes (Leguminosae) dominate this list (± 80%) (Brewbaker & Macklin, 1990).

The genus Leucaena is one of the most widely grown tropical fodder trees and is the subject of extensive research. This is mainly due to its long life span; high productivity even under regular defoliation; its adaptation to wide climatic and edaphic tolerances; excellent palatibility and digestibility and many uses including wood for timber and fuel wood (Gutteridge, 1995). *L. leucocephala* is highly rated internationally, but has been notably limited to non-acid soils and warm tropics. Several other species among the 13 or more in this genus are of interest in breeding to improve these traits, including *L. collinsii, L. diversifolia, L. lanceolata and L. pulverulenta.* All known species of leucaena have been collected and hybridized, in the most intensive ongoing international breeding program of N-fixing trees (Brewbaker, 1987).

Leucaena has played an important role in developing agriculture in Third World countries, primarily for use as fuel and fodder. The young pods may be eaten as vegetables by humans and the leaves have been used as a fish food in fish farming systems.

Leucaena thrives on well-drained soil that is moderately alkaline. It is well adapted to rainfall varying between 600 – 2000 mm per year, but will also succeed in dry regions if it is well established. The optimum temperature range varies between 25-30° C. Leucaena is susceptible to frost and is, therefore, usually limited to lower lying frost-free areas within its global range of distribution. It will, however, recover quickly from frost damage to grow back vigorously to a multi-branched tree. Leucaena seeds need scarification before it will germinate (Brewbaker *et al.*, 1985; Brewbaker, 1987). It grows rapidly, is not thorny and produces masses of seeds. Leucaena produces firewood with little ash and smoke.

1.4.2 Quality and yield

Leucaena has shown good potential as a high-protein fodder with good digestibility that could substitute for conventional concentrated feeds for cattle. The leaves and young stems provide good leaf forage for a range of domestic and wild ruminants. The high digestibility (60-75% IVDMD) and crude protein (20-28%) content of the leaves can be compared to that of alfalfa (lucerne) hay. Biomass yields from 3.5 to 80 t/ha from across the ecological spectrum have been reported (Brewbaker, 1987; Tejwani, 1987; Furoughbakhch, 1992; Ramirez & Garcia, 1996; Hughes, 1993, as cited by Castillo, Cuyugan, Fogarty & Shelton, 1997).

The proteins in tropical grasses are mainly digested in the rumen and insufficient amounts reach the small intestine. Legumes are retained in the rumen for a shorter time than grasses, and so considerable quantities of undegraded protein could leave the rumen to be hydrolyzed in the small intestine and absorbed with greater benefit for animal production. Tannins in leucaena prevent the formation of foam and thus bloating, as well as aiding in the creation of bypass protein. Leucaena supplementation significantly increased milk production as well as daily gain of cattle, and this could most possibly be attributed to the greater resistance of proteins to deamination in the rumen (Aii & Stobbs, 1980; Sumberg, 1984; Castillo, Ruiz, Puentes & Lucas, 1989; Kasthuri & Sadasivam, 1991; Richards, Brown, Ruegsegger & Bates, 1994; Ramírez, Foroughbakhch, Hauad & Uresti-Ramos, 1996).

In dryland farming, contour planting of leucaena improved soil fertility and crop production by up to 10%. The deep root system and leaf litter from trees aid in improving soil fertility and water holding capacity of denuded lands. Its nitrogen fixing potential can result in the eventual release of as much as 656 kg N/ha/year (Blair, Catchpole & Horne, 1990). Inoculation with vesicular-arbuscular mycorrhiza had a positive effect on plant height, stem dry mass as well as leaf dry mass. It also increased nutrient uptake by the trees (Atayese, Awotoye, Osonubi & Mulongoy, 1993). Leucaena produces fuel wood that burns slowly, has a low ash and smoke content and makes an excellent charcoal (Brewbaker, 1987).

1.4.3 Establishment

Leucaena seeds need to be scarified before establishment. The simplest way to accomplish this is by immersion of the seeds in hot water (97°C) for one minute, followed by immediate quenching in cool water. For effective nodulation, leucaena should be treated with a specific *Bradyrhizobium* bacteria before planting. Planting should be done in rows, with row spacing depending on intended usage. Weed control is essential during the first few months, as the small seedlings cannot compete effectively with weeds. Leucaena should not be utilized in the first year of establishment.

1.4.4 Limitations

Despite the advantages, a number of limitations of leucaena have become apparent:

- Leucaena contains mimosine (β-[N-(3-hydroxy-4-oxopyridil)]-α-aminopropionic acid) (DHP), a toxin to farm animals causing hair loss, slow growth rates, goitre and spontaneous abortion. For better utilization of this forage, the level of the toxic substance should be limited, which can be achieved to a certain extent by proper cutting management and management of animal intake (< 30% of total intake). Ruminants inoculated with the specific rumen bacteria develop a tolerancy to mimosine (Brewbaker *et al.*, 1985; Jones, 1986; Jones & Megarrity, 1986; as cited by Gutteridge, 1995). Ruminants that are adapted to a leucaena diet can graze directly (hedges) or be fed hay (on a cut and carry basis).
- Some leucaena species are susceptible to the psyllid insect (*Heteropsylla cubana*). The productivity of leucaena decreased dramatically in Kenya after the arrival of the psyllid in 1992 (Paterson, Dzowela, Akyeampong, Niang & Otsyina,

1995). *Leucaena diversifolia, L. esculenta* and *L pallida* has shown some degree of resistance to the psyllid (Dzowela *et al.,* 1994; as cited by Paterson *et al.*, 1995).

- In cool environments, growth is relatively poor. (Hughes, 1993; as cited by Castillo *et al.*, 1997).
- Growth is reduced in poorly drained and highly acidic soils, particularly when associated with high exchangeable aluminium.
- It is slow to establish and susceptible to weed competition in the seedling stage.

1.5 Experiences with leucaena in alley cropping

As mentioned in section 1.3, leucaena has been widely used in alley cropping systems and positive results have been reported. Maize grown in alley cropping with leucaena responded significantly to the addition of tree leaves to the soil, as compared to treatments where the leaves were removed. Yields of 4 to 8 t DM/ha, yielding 100-250 kg N/ha, were reported. The addition of such leucaena prunings as mulch could sustain maize yields for at least two years. Soil organic matter and nutrient status were maintained at higher levels than in non-alley cropped plots. Earthworm activities were higher under the shade of trees than in soils that are not shaded. Leucaena has also been interplanted successfully with fruit trees. It provided forage at a time when the fruit trees did not yet give economic returns and served as a shelter for the young trees against the sun and hot winds (Kang, Wilson & Sipkens, 1981; Atta-Krah, 1990; Palada, Gichuru & Kang, 1990; Rowland & Whiteman, 1993; Gill, Deb Roy & Bajpai, 1995).

Salazar, Szott and Palm (1993) reported a nett export of P from the system which was exhibited by declining soil P levels and decreasing crop yields. Compared with four other hedgerow tree species, intercropped with maize and cowpea, leucaena showed the lowest measure of soil compaction under a minimum tillage system. The lowest soil temperatures were also observed with leucaena (Hulugalle & Kang, 1990).

In a trial comparing leucaena at different alley widths, and with varying distances between hedges and crops, it was found that leucaena was progressively more competitive with the annual crop, causing substantial yield reduction (Rao, Sharma & Ong, 1990). The growth of leucaena was not sufficient to compensate for reduced crop yields. Land equivalent ratio's (LER's) calculated on the basis on grain yield of crops and leucaena fodder yields showed that hedgerow intercropping was advantageous over sole crops only during the first two years using wide alleys, but disadvantageous in the last two years. LER's calculated on the basis of total dry matter yield indicated only a small advantage for hedgerow intercropping (13 – 17 %) over sole crops in winter (>4m alleys). Leucaena yields stabilized at 5-6t/ha of dry fodder and 2.5 – 3 t/ha of wood from 3rd year in 4-5 m alleys. The authors suggested the need for examining the scope of hedgerow intercropping beyond 5 m alley width due to the tendency for improved LER's and returns with increasing alley width (Rao, Sharma & Ong, 1990).

Pruning of leucaena affected rooting depth, but not density. In various investigations roots were observed up to a depth of 1.5 m, filling the alley very densely. Roots >30 mm were not found within 0.5 m of leucaena hedgerows in regular alley cropped plots at any depth (Rao, Muraya & Huxley 1993; Akinnifesi, Kang & Tijani-Eniola, 1995).

Lal (1989) reported significant improvements in available water capacity (AWC) of the soil in both *Leucaena* and *Gliricidia* based hedgerow systems. In comparison with a no-till system, increase in AWC was 42% by weight for 0-5 cm depth and 12% by weight for 5-10 cm depth.

There is little scientific data on the performance of alley cropping in terms of soil fertility improvement under farmer-managed conditions in the tropics, despite considerable on-station research. Earlier analysis of the adoption potential of alley cropping was based mainly on *ex ante* analysis of on-station trial results. Few on-farm trials have been reported and these are mostly from sub-humid to humid areas of west Africa. Limitations during these trials included: inappropriate targeting as farmers' main priority was not usually soil fertility; farmers' participation was obtained through incentives, such as free fertilizer and crop material; and monitoring was limited with regard to labour requirements (Sheperd, Ndufa, Ohlssons, Sjögrens & Swinkels, 1997). Oude Hengel (1995) found that farmers were not aware that leucaena leaves could be used as a fodder. They planted it as a live hedge that was cut once a year. It was also planted to use as support for climbing beans.

1.6 Application in semi-arid areas of the world

As most work on alley cropping was conducted in the humid and sub-humid zones, some debate occurs about the applicability of the technology in semi-arid areas.

The ecological potential of an area is the primary factor determining the extent of a specific agroforestry system. Aridity is generally expressed in terms of the amount of rainfall received. Semi-arid can thus be classified as receiving an annual rainfall of ≤1000 mm (Nair 1989; Nair, 1993). Aridity can also be expressed as the ratio of the average annual precipitation to annual potential evapotranspiration (UNESCO, 1977, as cited by Ffolliott, Gottfried & Rietveld, 1995). In a literature study by Arnon (1992) different means of classification were mentioned: according to vegetation units, seasonal distribution of rainfall, and temperature, the number of arid months per year, water balance, the amount of humid months in the year. Semi arid zones cover 12.2 % of the land area of the world. In these areas, cattle depend mainly on protein-rich material obtained from shrubs and trees (Okafor, 1989), which is the case for up to 33% of all fodder in the Sahel (Cook & Grut, 1989).

Three different semi-arid zones are identified:

a) tropical and subtropical frost free savanna with summer rainfall
b) middle latitude steppe continental climate with definite warm and cold seasons and mostly summer rainfall
c) mediterranean climates with mild winters, occasional frost, winter rainfall and hot summers.

The term "semi-arid" term can be misleading in that it implies a climate that is intermediate - between dry and humid - in the amount of precipitation received, while it is actually seasonally arid! Thus a more appropriate name to refer to these areas, would be "seasonally dry climates".

"Dry Africa" includes all parts of the continent receiving less than 1500 mm of annual rainfall (Von Maydell, 1987). It includes a variety of climates and landscapes having in common a pronounced water deficiency and limited carrying capacity. In South Africa, semi-arid regions can further be characterized by a minimum rainfall of 150mm and a maximum of 600 mm per year (Nair, 1989; Nair, 1993). Two thirds of South Africa are actually arid or semi arid. In these areas with a low natural productivity, agroforestry practices could be incorporated in agricultural systems with beneficial results.

1.7 A local perspective

In many rural areas of South Africa, subsistence farming is the typical livelihood (Fig. 2). Cattle are seen as a sign of wealth and not necessarily a source of income, resulting in excessive numbers being kept. Provision is seldom made for planted pasture and while cattle may be kept in kraals for short periods, they are mostly left free ranging on communal range.

Fig. 2 Cattle kept in kraals in Dikgale village, Northern Province

Grazing consists of poor quality veld that has been denuded of vegetation by overgrazing and land clearing (Fig.3). Trees are felled for fuel wood and those that remain are either totally unpalatable and not browsed, or severely stunted by continuous lopping.

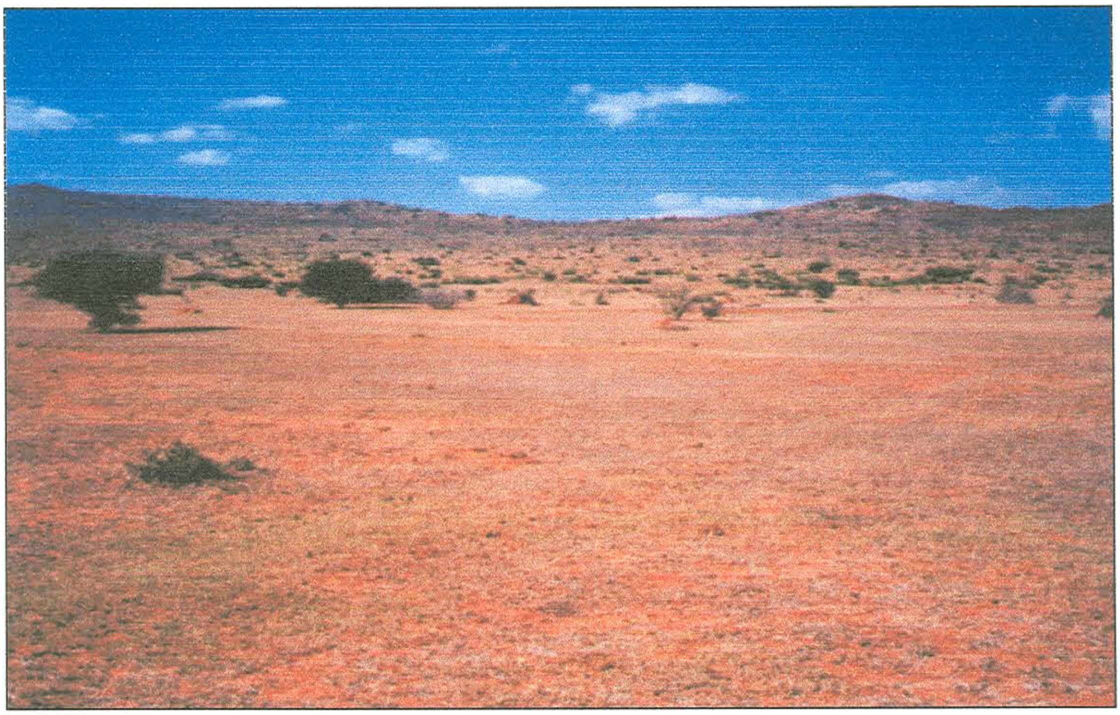

Fig 3. Typical grazing, Dikgopheng village, Northern Province

Maize and sorghum are the most common crops planted. Cropping is usually rainfed and little provision is made for supplementation with inorganic fertiliser. The soil is depleted year after year of its nutrients, resulting in lower yields of lower quality. Subsistence agriculture in this context is neither economically nor ecologically sustainable and it is in such situations that a system such as alley cropping could be incorporated with the three-fold purpose of providing fuel wood, providing fodder and aiding in ameliorating soil quality.

The University of Pretoria has been conducting research on fodder trees for the past decade. Leucaena has proved especially promising with its high fodder yields and nutritive quality. Although it was found to be susceptible to frost, resulting in the yearly cutting of above-ground growth, within a year the regrowth would reach a height of 4m and canopy closure in 3m wide rows. Once established, the trees did not require additional irrigation or fertiliser. The possibility of alley cropping with leucaena in semi-arid parts of South Africa was thus investigated and an existing leucaena stand converted into a trial to simulate alley cropping conditions.

The aim of the investigation was to:

- simulate an alley cropping system, comparing two alley widths and incorporating an alley crop
- compare different pruning treatments of leucaena with regard to total yield
- investigate the yields and quality of the crop grown in the alleys
- investigate the possible competitive effects between the trees and crops, with special reference to moisture and light interception
- monitor changes in soil quality due to leaf drop or the application of leucaena leaves as mulch.

Field work commenced in November of 1995 and laboratory analyses were completed in May 1998. The main results are presented in this dissertation, while related topics will be presented in separate scientific reports. Each chapter of the dissertation was prepared as an independent report, to be submitted to scientific journals.

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2 Pruning treatments of *Leucaena leucocephala* in alley cropping systems

2.1 Introduction

The use of *Leucaena leucocephala* (leucaena) in various agroforestry systems has been extensively researched in tropical countries. These agroforestry practices are mostly based on cut-and-carry systems and include fodder banks, tree plots on wastelands, border or dense lines, and tree stands in home gardens. The trees are usually harvested and not grazed directly in the field. The cut leaf material (fodder) may be used to supplement low quality roughage (e.g. crop residues) to improve intake, palatability, and nutritive value of the whole ration. Fodder refers to stems, shoots (including soft shoots and stems of woody plants that can be utilized by game and cattle), as well as fruit, pods and seed (Gutteridge & Shelton, 1994; Gutteridge, 1995).

Leucaena is also often intercropped with a range of food or fodder crops; a system referred to as alley cropping or (hedgerow) intercropping. Different cutting methods are used for the harvesting of leucaena and different cutting heights have been used, the most common being regular pruning to a hedgerow. The leaf yield is often used as a green manure (ploughed into the soil before planting of intercrops), mulch (layering the green material on the soil surface) or animal feed. These practices are reported to have a beneficial effect on the quality and yield of the alley crop, as well as an ameliorating effect on the soil (Brewbaker, MacDicken & Withington, 1985; Brewbaker, 1987). The latter has been attributed to the nitrogen fixing ability of leucaena and the build-up of organic matter in the soil.

From available literature it would appear that yields obtained from harvesting leucaena depend on cutting regime and cutting height. Yields reported vary from 4 to 80 t/ha across the climatological spectrum (Blair, Catchpoole & Horne, 1990; Brewbaker, 1987; Tejwani, 1987; Furoughbakhch, 1992). Wood biomass production was the highest when leucaena was grown alone (Korwar, 1995).

Yields have generally been reduced when the trees were cut to low stubble heights. As the pruning height increased, the yield of adjacent rows of crops fell. The best compromise for most situations lies in the range of 60 to 100 cm (Ezenwa & Cobbina, 1991; Paterson, Dzowela, Akyeampong, Niang & Otsyina, 1995; Kheertisena & Gunawardana, 1996). Alley widths (the space between the tree rows) used have ranged from a narrow 2.5 m up to 9 m, with a preferred width of 4 m (Brewbaker, 1987).

Harvest interval has played a significant role in determining forage yield and quality and different results are reported. Low hedge management with two to four month cutting intervals is standard practice. Less frequent harvesting resulted in significantly higher yields, due to the fact that more woody material was produced. The hypothesis is that, in general, total yield (leaf + stem) increases with longer cutting intervals but is associated with a decrease in leaf:stem ratio (Brewbaker *et al*, 1985; Brewbaker, 1987, Gutteridge, 1988; Ella, Jacobsen, Stür and Blair,1989; Calub, 1996).

Confirmed by these results, general guidelines as set by Brewbaker *et al* (1985), could serve as a recommendation for the implementation of a leucaena harvesting system:

- Harvest plants only after they are well established, usually six months.
- Cut the growth back to 20-30 cm to stimulate coppicing and increase yield in later harvests.
- The optimal time to harvest is at a branch height of 1-1.5m.

In cut-and-carry systems, hedge management is preferred. Trees should be cut at a height of 80-100 cm and cut low again after two or three years. Hedges should be maintained at a height above 60 cm (Brewbaker, 1987), to ensure the retention of some green foliage and to minimize possible stress from cutting too low.

In light of the above results, the response of leucaena to different pruning treatments was studied under local conditions. The purpose of the trial was to determine what effect pruning might have on the total forage yield over a full growing season, compared with no pruning, and whether the traditional method of pruning (hedgerow) would produce higher yields or not.

2.2 Materials and methods

An alley cropping field experiment was conducted on the Hatfield Experimental Farm of the University of Pretoria (Table 1).

Table 1 Site description on Hatfield Experimental Farm

Locality	28°16'E, 25°45'S
Altitude	1372 m
Av. annual rainfall	709 mm
Av. max. and min. temp.	30°C (Jan), 2°C (Jun)
Soil type	Sandy clay (37 % clay), Hutton, homogenous to a depth of 0.66 m after which it becomes gravelly (MacVicar, Loxton, Lamprechts, Le Roux, De Villiers, Verster, Merryweather, Van Rooyen & Von M. Harmse, 1977).

The study was laid out in a 2x3x3 factorial randomized complete block design with five replications, involving two alley widths (3m and 6m), three pruning treatments (Table 2), and a split plot for three alley crops (maize, grain sorghum, fodder sorghum). Tree-spacing within the row spacing was 1 m. Blocking was done across the length of the plot, on an east-west axis, based on previously observed differences in growth (Lindeque, 1997). Statistical analysis did not compare yields between the two years, as treatments were adapted by experience after the first harvest season.

Table 2 Pruning treatments applied to *L. leucocephala* in the alley cropping trial

S1	Control - no pruning
S2	Pruning to a single stemmed tree (± every 6 weeks), clearing the undergrowth up to 1 m. In 1998 the interval was changed to 8 weeks.
S3	Hedgerow (± every 4 weeks), cut back to 1m height and ±0.75 m width

An existing leucaena stand, planted at a tree density of 3 333 trees per ha, was used. Before the start of the 1996/1997 growing season, the trial was converted to an alley cropping trial by removing selected alternate rows. The plant populations of the 3m and 6m treatments were 3333 and 1667 trees per ha respectively. Pruning of the trees started in November 1996 and was repeated at fixed intervals thereafter, until April 1998 (Figure 1 & 2).

Except for the first harvest, yields of the different pruning treatments were applied as a mulch between the alley crops. No irrigation or fertilizer was applied. Trees of the S1 treatment were harvested at the end of the growing season to compare the full season's growth with the accumulated forage yield of the pruned trees (Figure 3).

The prunings were weighed in the field to assess the total fresh yield. Except for the first harvest, forage yield consisted of leaf and young, green stems. Wood yield was only measured with the final harvest of the 1996/1997 season. Representative samples for the determination of dry mass yield and dry mass concentration were taken at each harvest and dried at 60° C for 24 hours, before being weighed again. The same samples were used to separate the yield into leaf and stem material. In 1996/1997, samples were taken only from the 3m alleys. In 1997/1998, samples were taken from both alleys. Data was analyzed using PROC GLM (1996/1997 and 1997/1998) and PROC ANOVA (1997/1998) of the SAS Program (Statistical Analysis Systems, 1994). Significant differences were taken at $P \leq 0.05$.

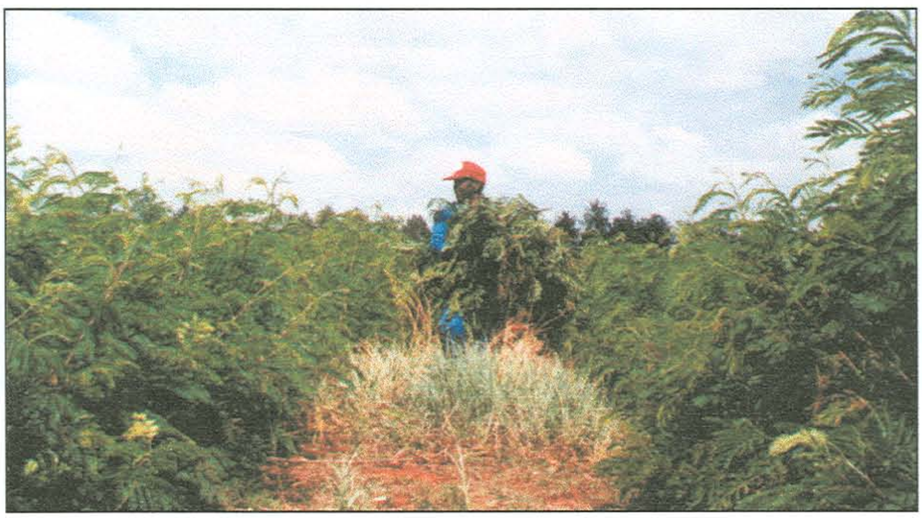

Figure 1 Trees were pruned manually. Unpruned trees in foreground.

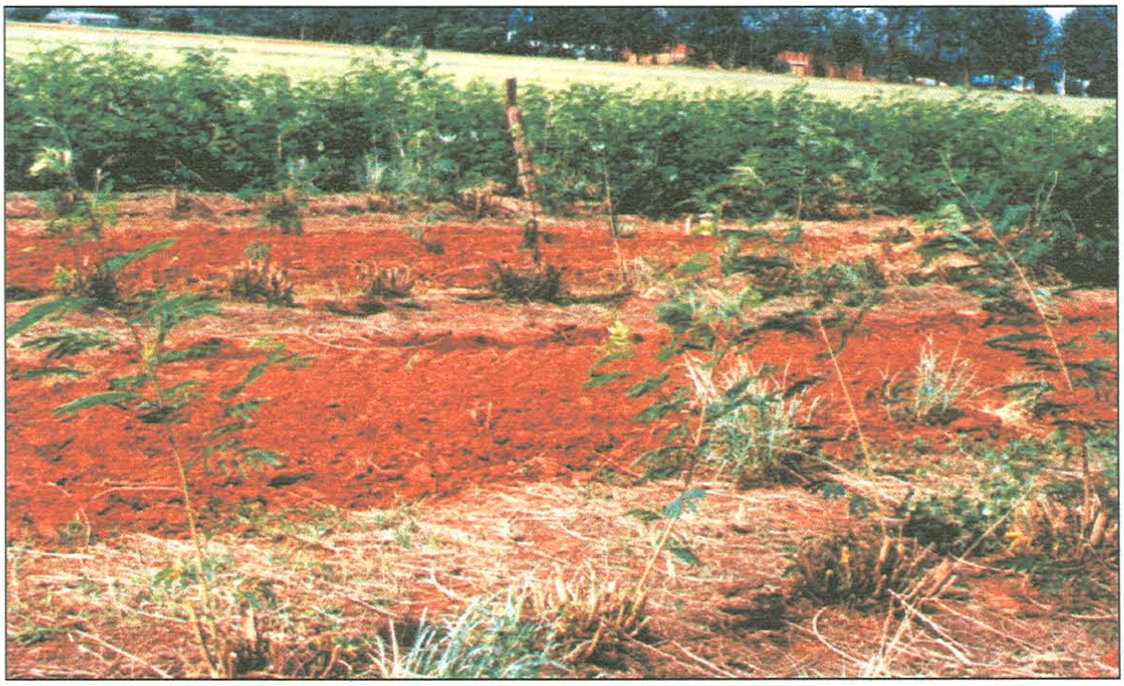

Figure 2 **First pruning of S2. Hedgerows of S3 in background.**

Figure 3 **Development of the stems in S2. Unpruned trees of S1 in background.**

2.3 Results and discussion

2.3.1 1996/1997 Season

Total yield

The highest total yield per individual tree was obtained from the S2 treatments (Table 3), while S3 and S1 had similar yields. Only the S2 treatment had significantly different yields between the row widths, whereas the yields obtained from the 3 m and 6 m alleys did not differ in the S3 treatment. Within the 3 m alleys, S2 produced the highest yield, with the second highest yield obtained from S3. This was also the case in the 6 m alleys. The 3 m alleys had a higher yield per ha. The highest total yield per ha was obtained from the S2 treatment (23.448 t/ha).

Table 3 Total yield of *L. leucocephala* as affected by spacement and pruning treatment

Treatment	kg/tree		t/ha	
	3m	6m	3m	6m
S1	4.549†	-	15.162†	-
S2	7.035†*	10.518*♦	23.448*†	17.534*♦
S3	5.445†	6.702♦	18.148†	11.172♦
R^2	0.939	0.939	0.978	0.978
CV	14.681	14.681	8.803	8.803
	* Significant differences between alley widths † Significant differences between pruning treatment in 3m alley ♦ Significant differences between pruning treatments in 6m alley		* Significant differences between alley widths † Significant differences between pruning treatment in 3m alley ♦ Significant differences between pruning treatments in 6m alley	

Forage yield

The forage yield of S1 tended to be low compared to other treatments (Table 4). As the soft, green young stems were not separated from leaf material, this could explain the relatively high value for S2, where, after six weeks of growth, longer (and, therefore, heavier) stems were harvested than after four weeks on S3.

Table 4 Total forage yield of *L. leucocephala* as affected by pruning treatment

Treatment	kg/tree	t/ha
	3m	3m
S1	0.857	2.856
S2	4.742	15.805
S3	3.537	11.789

Wood yield

Wood production was only assessed with the final harvest of the season. During the season only the odd twig thicker than 6 mm was pruned and these were discarded. S1 tended to have the highest wood yield (± 82% of total biomass per tree), which could be expected as the stems were left to grow undisturbed through the season (Table 5). Brewbaker (1987) reported results from undisturbed tree growth, while in alley cropping systems the trees are pruned early and frequently, resulting in the reduction in stem production (Keerthisena & Gunawardana, 1996). "Wood" yield obtained from S2 and S3, represented twigs *just* not qualifying as shoots, which might be better described as kindling.

Table 5 Total wood yield of *L. leucocephala* as affected by pruning treatment

Treatment	kg/tree	t/ha
	3m	3m
S1	3.692	12.305
S2	2.293	7.643
S3	1.908	6.359

2.3.2 *1997/1998 Season*

Total yield

In this season, the highest total yield per individual tree was obtained from the S3 treatment (Table 6). The yields obtained were nearly double those of the previous year, due mainly to the increased harvest frequency (6 harvests, compared to 4 in 1997). Only the S1 treatment had significantly different yields between the row widths. Within the two alley widths respectively, all three pruning treatments differed significantly. The total yield of the S1 harvest was lower in the 3m alley than the previous season. This may be mainly attributed to the fact that less stem material was produced on this treatment (± 56 % of total yield, compared to ± 82 % during 1997). Lindeque (1997) reported total seasonal yields of 8-11.5 t/ha, consisting of 75 % woody material and 25 % shoots.

The total yield from the S2 treatment was lower after four harvests were taken in 1998, compared to three in 1997. Harvesting of treatments 2 and 3 started earlier in the 1997/1998 season, resulting in the first harvest at an earlier stage, and therefore harvesting of softer material. Six harvests, compared to four in 1996/1997, were taken from the S3 treatment, the last cutting taken almost a month and a half later than in 1996/1997. This resulted in higher yields being recorded.

The highest total yield per ha was obtained from S3 where both alley widths produced a higher yield than any of the other treatments. The yields per ha of S1 did not differ significantly between the two row widths, although the yields per ha obtained from S2 and S3 differed significantly ($P \leq 0.05$) between row widths.

Forage yield

The highest forage yield per tree was obtained from S3 (Table 7). The two additional harvests compared to the 1997 season yielded more leaf material. The yield obtained from S3 was much higher than S2 (167% in the 3m alley and 122% in 6m). Yield per ha tended to be higher at the 3m spacing and when applied as green manure or mulch, the rate of application per unit area is even higher.

Table 6 **Total yield of *L. leucocephala* as affected by spacement and pruning treatment**

Treatment	kg/tree		t/ha	
	3m	6m	3m	6m
S1	2.799*†	5.373*♦	9.329†	8.957♦
S2	5.471†	6.646♦	18.235*†	11.079*♦
S3	11.579†	12.020♦	38.593*†	20.037*♦
R^2	0.971	0.971	0.988	0.988
CV	10.071	10.071	7.995	7.995
	* Significant differences between alley widths † Significant differences between pruning treatment in 3m alley ♦ Significant differences between pruning treatments in 6m alley LSD = 0.956		* Significant differences between alley widths † Significant differences between pruning treatment in 3m alley ♦ Significant differences between pruning treatments in 6m alley LSD = 1.837	

Table 7 **Total forage yield of *L. leucocephala* as affected by espacement and pruning treatment**

Treatment	kg/tree		t/ha	
	3m	6m	3m	6m
S1	0.933	3.110	3.110	5.184
S2	3.501	4.318	11.669	7.198
S3	9.350	9.607	31.164	16.015

Table 8 **Total wood yield of *L. leucocephala* as affected by espacement and pruning treatment**

Treatment	kg/tree		t/ha	
	3m	6m	3m	6m
S1	1.866	6.219	6.219	10.367
S2	1.970	2.328	6.566	3.881
S3	2.229	2.413	7.429	4.022

Wood yield

The highest wood yield per tree in this season was obtained from the 6m alleys in treatment S1 (Table 8). The yields obtained from S2 and S3 were relatively similar. Again, the "wood" yield from these two treatments, consisted essentially of lignified twigs (kindling), while the wood obtained from S1 were large enough to use for fuel wood.

2.4 Discussion

It is generally confirmed that the total yield obtained from leucaena will increase with lower harvesting or cutting frequencies (Brewbaker *et al.,* 1985, Stür, Shelton & Gutteridge, 1994 and Lindeque, 1997). Lower cutting frequencies resulted in higher yields containing a larger percentage of woody material, while higher cutting frequencies resulted in lower yields, containing forage of a better quality. Lindeque (1997) also observed higher yields obtained with the first cutting than with subsequent cuttings. If the aim is fuel wood production, a pruning regime should not be followed. Without any pruning, there would be a small, once off, forage harvest at the end of the season, but the wood yield would be sufficient for fuel wood (logs) purposes. Pruning to a single stemmed tree resulted in the formation of a long stem that could be used for construction or fence-making purposes, while the shorter, multi-stemmed woody growth of a hedgerow would be more suitable for fuelwood (kindling) purposes, with slightly lower yields. The forage yields of both S2 and S3 pruning treatments provided a regular supply of fodder, green manure or mulch throughout the season, depending on the specific site conditions.

From this study it may be concluded that yield and the contribution of yield components can be manipulated by using different pruning methods. No pruning results in a low, once-off forage yield, while the wood yield can be used for fuelwood. Pruning to a single stemmed tree may appear laborious, but the advantages lie in the fact that crops or pasture could then be planted nearer to the trees, without shading, in addition to producing more versatile wood and a higher yield of shoots. Hedgerow treatments would be relevant to both labour intensive small scale farming enterprises and mechanized larger scale operations, as it is indeed a labour intensive procedure. However, the very high forage yield obtained may well justify the effort.

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3 Yield and nutritional value of alley crops

3.1 Introduction

Leucaena leucocephala (leucaena) has the potential to increase agricultural production, especially in developing countries where fertilisers are expensive, availability of technology is restricted and productivity low. The adoption of techniques such as alley cropping can result in increased productivity, thereby also improving income and living standards of subsistence farmers (Blair, Catchpoole & Horne, 1990).

Leucaena was found to be compatible with a number of forage- or crop production systems, ranging from fruit trees, vegetables and cash crops, the most common being maize. Hedge trimmings from leucaena can be carried as excellent green manure to row crops like maize and rice. Leucaena leaves mature over a period of 2 – 4 weeks and the leaflets, pinnae and midribs dehisce in 3 – 5 months. The litter is fragile and quickly decomposed, with a N-half life of 7 days if buried (Guevarra *et al.*, 1978; Kang *et al.*, 1984; both cited by Brewbaker, 1987). The continuous removal of pruning biomass reduces soil fertility, while the incorporation of prunings as green manure, or mulch, enriches soils, especially sandy soils that are exposed to leaching of soluble fertilisers in tropical environments (Mwange, Mbaya & Luyindula, 1997). Repeated application of leucaena prunings maintained higher soil organic matter levels and increased the soil moisture retention capacity. The deeper root system of leucaena also appears to extract more soil moisture from lower soil horizons (>50 cm) than the maize crops which taps the surface layers (<50 cm depth), and thereby reduces competition for moisture (Kang, Grimme & Lawson, 1985).

Dommergues (1987) referred to results by Sanginga, Mulungoy & Ayanaba (personal communication), who found that leucaena fixed 98 – 134 kg N_2/ha in 6 months. The high nitrogen-fixing potential of this tree is related to its abundant nodulation under specific soil conditions.

Application of leucaena prunings could supply enough N to maize plants to significantly reduce the degree of N deficiency (Xu, Saffigna, Myers & Chapman, 1993) but cannot provide enough N to be *equivalent* to those recommended when using inorganic fertilisers in order to get maximum yields of maize. However, the significant positive interaction between N fertilizer and leucaena prunings in increasing maize yield, suggested that application of leucaena prunings could improve the efficiency of use of N fertilizer. The application of N fertilizer could also increase the benefits of leucaena prunings for maize production (Xu *et al.*, 1992; Xu, Myers, Saffigna & Chapman, 1993). The addition of leucaena prunings significantly increased N uptake of seedlings, N percentage in ear leaves of maize, and the dry matter yield of maize. With pot experiments, incorporating the prunings appeared to be more effective than applying it as mulch. This can possibly be attributed to NH_3-N volatilization loss during decomposition under high temperature conditions in the field. Field trials, however, failed to show any difference between incorporation as opposed to surface application of leucaena leaves. Although leucaena was not as efficient as inorganic fertiliser, it had a significant residual effect on the succeeding maize crop (Kang, Sipkens, Wilson & Nangju, 1981; Read, Kang & Wilson, 1985).

Although results varied, cropping in association with leucaena invariably resulted in higher total biomass production than compared to monocropping systems and reduced fertiliser requirements (Gill & Patel, 1983 as cited by Singh, 1987; Palada, Kang & Claassen, 1992). In some instances the addition of prunings alone would only maintain crop yield, requiring supplementary fertilisation in order to increase yields (Kang, Wilson & Sipkens, 1981; Kang, *et al.*, 1985; Kang & Fayemilihin, 1995). The contrary has also been reported: that prunings alone could result in increased yields (Brewbaker, 1987; Singh & Singh, 1987, as cited by Singh, 1987). It could generally be accepted that yield may be increased with the addition of prunings, but to obtain optimal yield, additional fertiliser would be required. Kang and Fayemilihin (1995) concluded that when the availability of N was limited by removing hedgerow prunings, and not applying fertiliser N, proximity to leucaena hedgerows improved maize yield, possibly due to litter fall, which overrode the competitive effects such as partial shading. Szott, Pall & Sanchez (1991) observed that crop yields generally increased with distance from the hedges and declined with time, despite crop residue return and hedgerow intercropping.

There is a perception that some of the evidence of the high productivity of legumes in the tropics is indirect and inferential, with a paucity of information from controlled experimentation and research. Much of the information on cutting management of leucaena for forage is conflicting, and there are few reports of the yields of nitrogen that can be obtained when forage is cut from leucaena (Blair *et al.*, 1990). To date, much of the work of alley cropping has been in context of continuous cropping, which is not sustainable on acid, infertile soils. Szott *et al.* (1991) emphasized its use in situations where it is clearly beneficial, for example, in areas where land availability is severely limited, erosion control (aiding terrace formation on slopes) and/or as a "head start" to fallow regrowth in improved shifting agriculture systems.

It has been stressed that leucaena is not a miracle tree. Brewbaker (1987) remarked that with an average tropical maize yield of only 1.2 t/ha, however, any procedure increasing grain yields to 2 t/ha under continuous rather than periodic cropping could have a substantial impact on tropical maize production. It is generally concluded, however, that in view of the escalating costs of inorganic fertilisers, the role of these trees as a supplementary source of N can not be ignored, and could be especially important for smallhold farmers. The principle is just as applicable in areas receiving less rainfall, where available moisture is yet another restrictive factor in agricultural production.

The objective of this paper was to assess yield and quality responses of alley cropped grains and fodder, receiving leucaena mulch, in a semi-arid setting.

3.2 Materials and methods

An alley cropping field experiment was conducted on the Hatfield Experimental Farm of the University of Pretoria (Table 1). The study was laid out in a 2x3x3 factorial randomized complete block design with five replications, involving two alley widths (3m and 6m), three pruning treatments (Table 2), and a split plot for three alley crops (maize, grain sorghum, fodder sorghum). Blocking was done across the length of the plot, on an east-west axis, based on previously observed differences in growth (Lindeque, 1997). Statistical analysis did not compare yields between the two years, as treatments were adapted by experience after the first harvest season. An analysis of variance with the GLM and ANOVA models (Statistical Analysis Systems, 1994) was used to determine the significance between different cutting treatments, rows, blocks and the interaction between treatment and rows and season effects for unbalanced data. Least square means (LSM) and standard errors (SE) were calculated. Significance of difference ($P \leq 0.05$) between LSM was determined with the Bonferroni test (Samuel, 1989).

Table 1 **Site description on Hatfield Experimental Farm**

Locality	28°16'E, 25°45'S
Altitude	1372 m
Av. Annual rainfall	709 mm
Av. Max. and min. temp.	30°C (Jan), 2°C (Jun)
Soil type	Sandy clay (37 % clay), Hutton, homogenous to a depth of 0.66 m after which it becomes gravelly (MacVicar, Loxton, Lamprechts, Le Roux, De Villiers, Verster, Merryweather, Van Rooyen & Von M. Harmse, 1977).

Table 2 **Pruning treatments applied to *L. leucocephala* in the alley cropping trial**

S1	Control - no pruning
S2	Pruning to a single stemmed tree (± every 6 weeks), clearing the undergrowth up to 1 m. In 1998 the interval was changed to 8 weeks. Prunings returned as mulch.
S3	Hedgerow (± every 4 weeks), cut back to 1m height and ±0.75 m width. Prunings returned as mulch.

An existing leucaena stand, planted at a tree density of 3 333 trees per ha, was used. Before the start of the 1996/1997 growing season, the trial was converted to an alley cropping trial by removing selected alternate rows. Pruning of the trees started in November 1996 and was repeated at fixed intervals thereafter, until April 1998. Maize, grain sorghum and fodder sorghum were planted between the leucaena rows at a row espacement of 60 cm. The 6m alley contained 7 rows of crops, and the 3m alley 2 rows of crops respectively. The first crop row was located 1.2 m away from the hedgerow. The crops received no irrigation or fertiliser. Yields of the different pruning treatments were applied as mulch between the alley crops (Fig. 1). Control plots receiving no mulch were planted of each crop, at the same plant density. The control was also not irrigated, but received supplementary fertiliser as follows:

1997: N1 = 21 kg N/ha 3 weeks after plant, 42 kg/ha N as top dressing
1998: N0 = no fertiliser
N1 = 15 kg N/ha at plant, 50kg/ha N as top dressing

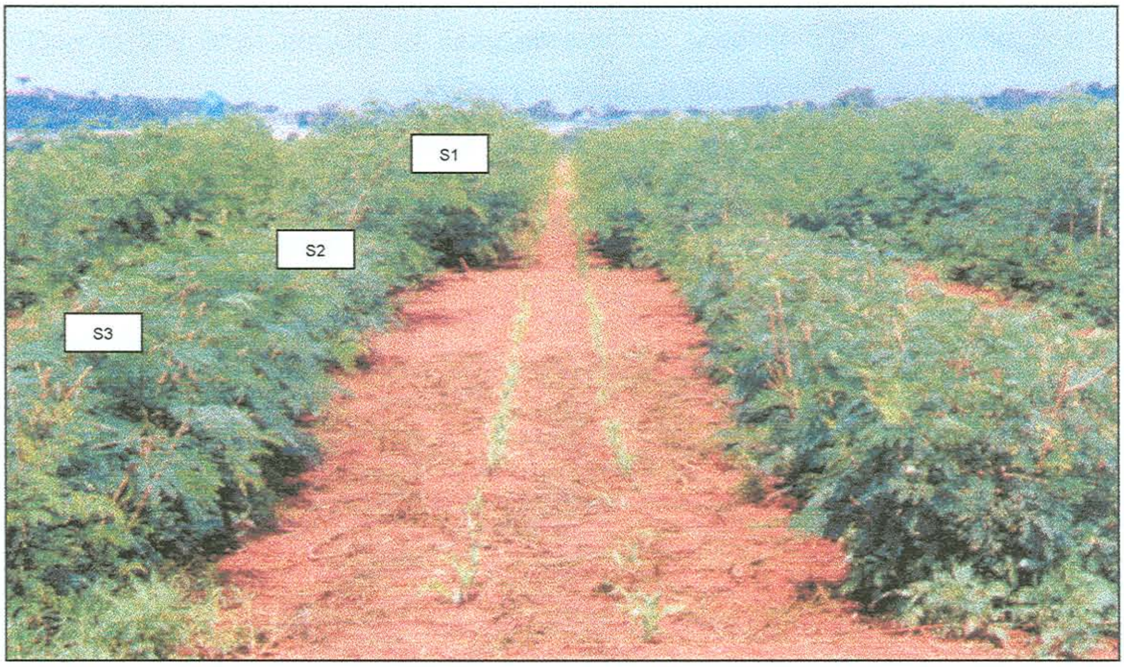

Fig. 1 Layout of plot. Three pruning treatments are visible (front to back: S3, S2, S1) as well as the first mulch application.

Observations envisaged included:

- Maize : Grain yield, stubble yield, stubble quality (CP, NDF, IVOMD)
- Grain sorghum : Grain yield, stubble yield, stubble quality (CP, NDF, IVOMD)
- Fodder sorghum : Plant height before harvest, fodder yield, fodder quality (CP, NDF, IVOMD)

Because of bird damage to both the maize and grain sorghum in 1996/1997, only fodder sorghum was planted in 1997/1998.

Samples for the determination of dry matter yield and dry matter concentration were taken at each harvest and dried at 100° C for 24 hours, before being weighed again. Samples for the determination of nutritive value were taken at each harvest and dried at 60° C for 24 hours, before being weighed again. The following analyses were conducted:

- N content as determined by the micro-kjeldahl method (% CP = %Nx6.25) (AOAC, 1984).
- Neutral Detergent Fibre (NDF) (Van Soest & Wine, 1967)
- *In vitro* digestible organic mattter (IVDOM) (Tilley & Terrey, 1963, as adapted by Engels & Van der Merwe, 1967).

Due to the large amount of samples and the accompanying time and financial implications of the costs of nutritional analyses, it was decided to pool the harvested material of some rows of the alley *after* the dry mass yields were determined. Rows 1,2, 6 & 7 were pooled and are hereafter referred to as group 1 (Fig. 2). Rows 3 and 5 were pooled as group 2 and row 4 remained as group 3. Samples for the analysis of nutritional value were taken from the pool, therefore no statistical analysis were conducted on the nutritional values.

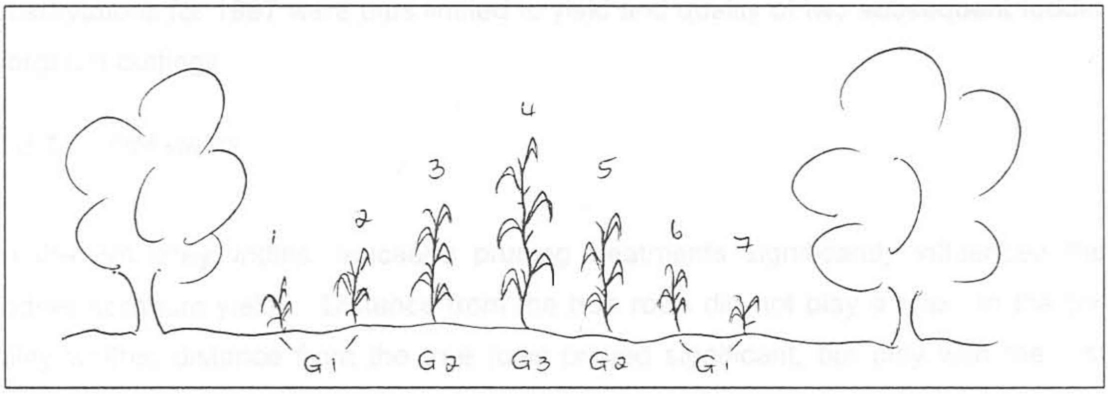

Fig. 2 Schematic representation of alley crop layout and combination of rows for analytical purposes

3.3 Results and discussion

After being weighed, the leucaena prunings were placed in the alleys as a mulch in the respective treatments where it was harvested. Crude protein content was determined at each harvest (Table 3). The results of the yield determination and chemical analyses are presented in Fig. 3 to 21 and Tables 4 to 12.

Table 3 Total biomass yield (t/ha) and nitrogen concentration (%) of leucaena prunings applied to alley crops (DM basis)

Treatment	1997		1998	
	3m	6m	3m	6m
S1	-	-	-	-
S2	23.448	17.534	18.235	11.079
S3	18.148	11.172	38.593	20.037
Ave. [N]	3.64		4.69	

3.3.1 *1996/1997 season*

The 1997 potential harvest was lost to a great extent due to damage to the crops by birds. The maize crop was destroyed by guinea fowl within days of being sown and could thus not be harvested. The grain sorghum crop was severely damaged by birds at the time of grain development, and no grain could be harvested. Although the stubble was harvested, it was decided not to use the results as nutrient allocation to the leaves would not be representative of a post-grain-harvest situation. The observations for 1997 were thus limited to yield and quality of two subsequent fodder sorghum cuttings.

3.3.1.1 DM yields

In the 3m alley widths, leucaena pruning treatments significantly influenced the fodder sorghum yields. Distance from the tree rows did not play a role. In the 6m alley widths, distance from the tree rows proved significant, but only with the first harvest. The pruning treatment was significant throughout.

With both cuttings in the 3m alleys, the lowest yields were obtained in the S1 treatment (no pruning) (Table 4). In S2, the yields seemed to decrease towards the second cut, while the opposite was observed in S3. The trees of S3 were kept pruned to a height of ±1m, thus allowing light to reach the fodder sorghum, whereas the trees of S2 already cast a shade over the alley crops. This may have depressed yields.

In the 6m alleys, yields in S1 also tended to be lower, although not significantly lower than S3 (Table 5). Yields in both S2 and S3 tended to increase towards the second cut. A monocrop stand of fodder sorghum at the same density tended to have higher yields (DM1 = 0.203 kg/m and DM2 = 0.318 kg/m). The lower yields of the monocrop in the first cutting could be attributed to the fact that fertiliser was only applied three weeks after planting, resulting in sub-optimal growth conditions.

Definite effects were observed with regard to row position in the 6 m alleys with the first cutting (Table 6). The rows nearest to the tree rows (r1 and r7) had the lowest yield, followed by the second rows (r2 and r6). It must be noted that yield increases towards the middle of the alley (r3-r5, >2.4m away) could have been induced by the removal of a tree row the previous year, in order to create the 6m alley. Nitrogen could be released by the decomposing plant material, creating a carry-over effect that, together with the application of prunings, could have induced higher yields.

Table 4 Effect of mulching in different pruning treatments on the dry mass yields of fodder sorghum in 3m alleys

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
S1	0.0400	0.0094	0.0020	0.0081
S2	0.1065[a]	0.0094	0.0990	0.0081
S3	0.0775[a]	0.0094	0.1548	0.0081

LSM with the same alphabetical superscript in columns do not differ significantly (P≤0.05) (Bonferroni)

Table 5 Effect of mulching in different cutting treatments on the dry mass yields of fodder sorghum in 6m alleys, 1997

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
S1	0.2063[a]	0.0087	0.0832[a]	0.0213
S2	0.2542	0.0087	0.1669[b]	0.0213
S3	0.2099[a]	0.0087	0.1449[ab]	0.0213

LSM with the same alphabetical superscript in columns do not differ significantly (P≤0.05) (Bonferroni)

Table 6 Effect of distance from tree rows on the dry mass yields of fodder sorghum in 6m alleys,1997

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
r1	0.0977[a]	0.0131	0.1204	0.0325
r2	0.2229[b]	0.0131	0.1453	0.0325
r3	0.3237[c]	0.0131	0.1349	0.0325
r4	0.3098[cd]	0.0131	0.1547	0.0325
r5	0.3314[cd]	0.0131	0.1266	0.0325
r6	0.1959[b]	0.0131	0.0862	0.0325
r7	0.0832[a]	0.0131	0.1534	0.0325

LSM with the same alphabetical superscript in columns do not differ significantly (P≤0.05) (Bonferroni)

Based on the above values, the total yields for the season were calculated and represented graphically. In the 3m alleys, S2 and S3 yielded approximately 80% and 82% more than S1 respectively. In the wide alleys, this perceived advantage was ± 31% and ± 18% respectively. The total yield from the monocrop was ± 20% higher than the highest obtained in either of the two alley widths (Fig. 3).

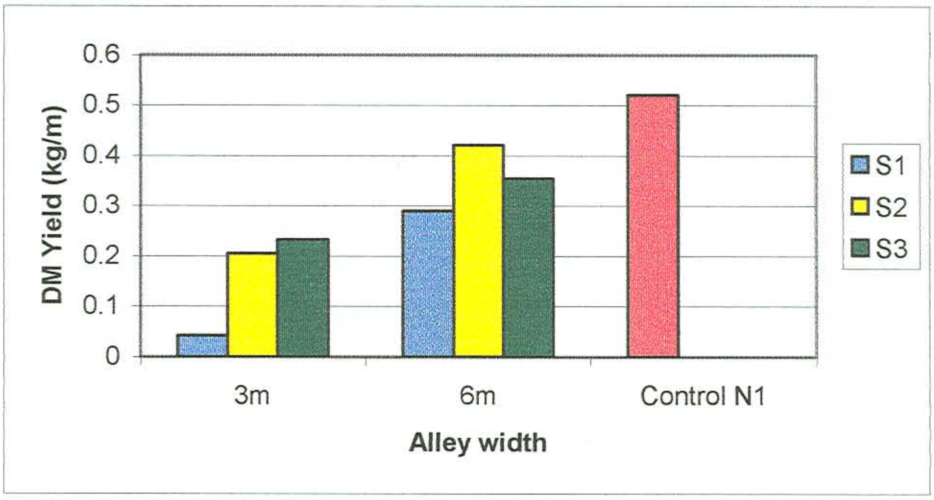

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Fig. 3. Total yields obtained in pruning treatments

When considering the total yields obtained in the different row positions, a clear trend could be observed for lower yields nearer to the tree rows (Fig.4). Rows 3-5 (at least 2.4 m from the trees) tended to have relatively similar yields. Rows to the south of the trees tended to have lower yields than the corresponding rows to the north of the trees.

Fig. 4 Total fodder sorghum yields observed in different row positions in 6m alleys, 1997

3.3.1.2 Nutritional value

- *Crude protein*

The CP concentration appeared to increase from group 1 towards group 3 in the middle of the alley (Fig.5). The relative higher values in the middle of the alley could have been induced by a carry-over effect of N released by decomposing material, the remainder of a tree row that was removed. The CP concentration of the 3m treatment appeared to be the highest. This was possibly induced by the high incidence of leaf drop from the unpruned treas.

The CP concentrations observed at the second harvest were higher, except for the 3m plots in S1, where growth was severely stunted, possibly due to competition from the trees, where canopy closure had occurred by this time (Fig. 6).

- *Neutral detergent fibre*

Neutral detergent fibre (NDF) provides an indication of cell wall material and is negatively correlated with digestibility (Van Soest, 1982, Van der Merwe, 1992). At the first harvest (Fig. 7), NDF content ranged between ±50-60%. The control was relatively higher at almost 65%. The values increased at the second harvest, implying that digestibility decreased slightly, but that of the control was marginally lower (Fig. 8).

- *In vitro digestibility (organic matter)*

The digestibility of the second harvest was lower than the first (Fig. 9 & 10), corresponding with the higher NDF content of the second harvest. This as especially evident in S1, where the few surviving plants tended to adopt a more shoot-like growth habit, attempting to reach the available light. More lignification had evidently taken place by this stage, resulting in lower digestibility, higher NDF and lower N values.

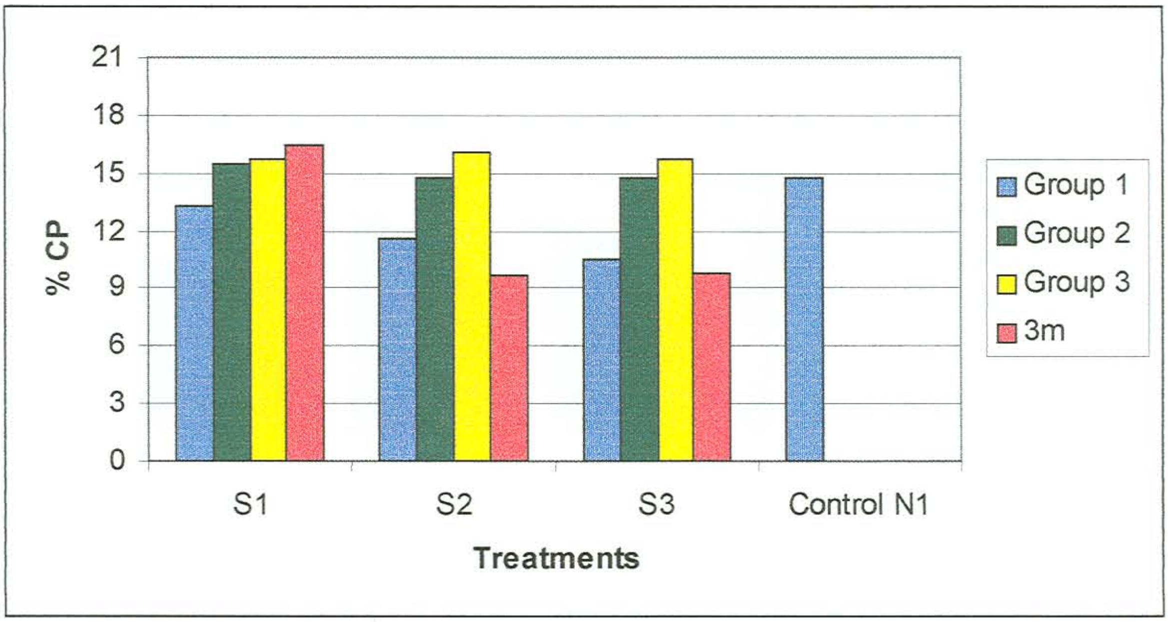

Fig. 5 Crude protein concentration of first fodder sorghum harvest, 1997

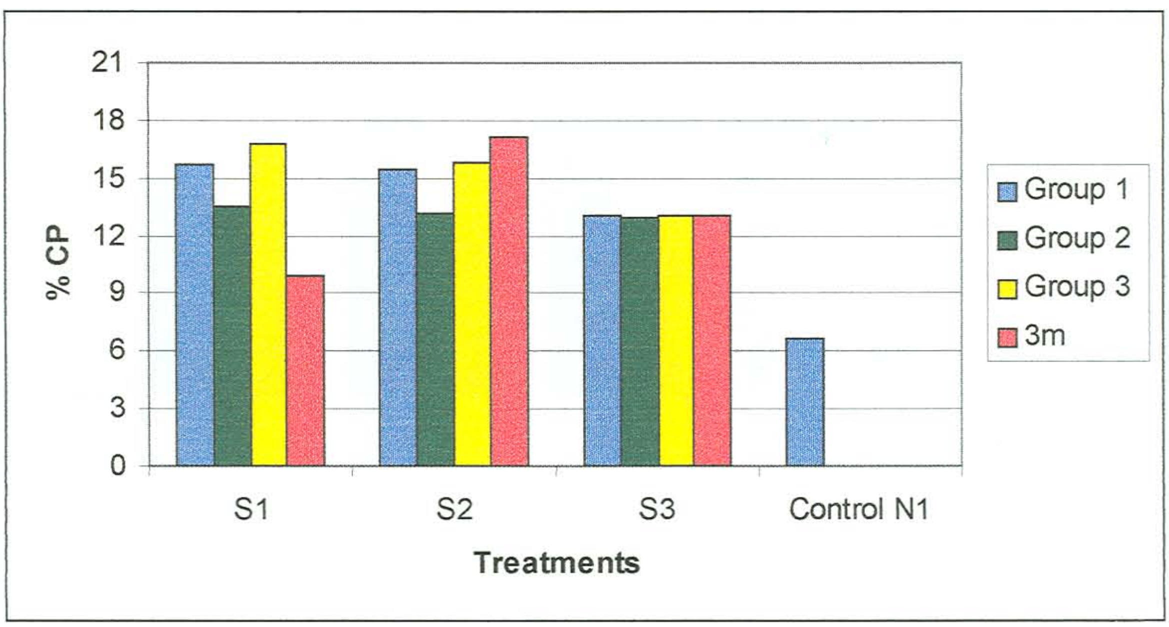

Fig. 6 Crude protein concentration of second fodder sorghum harvest, 1997

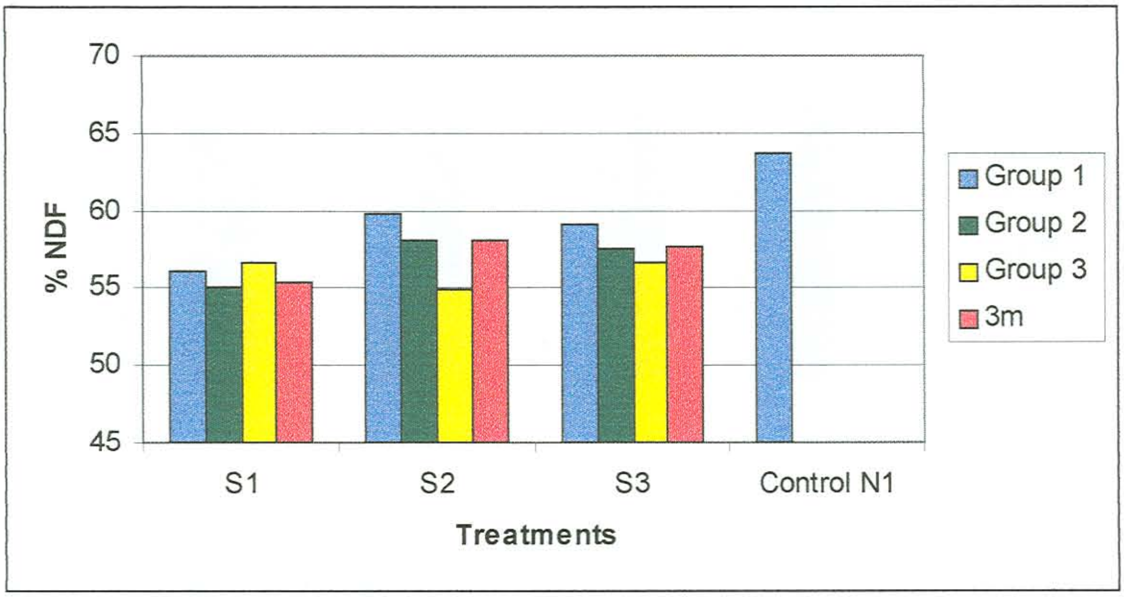

Fig. 7 NDF concentration of first fodder sorghum harvest, 1997

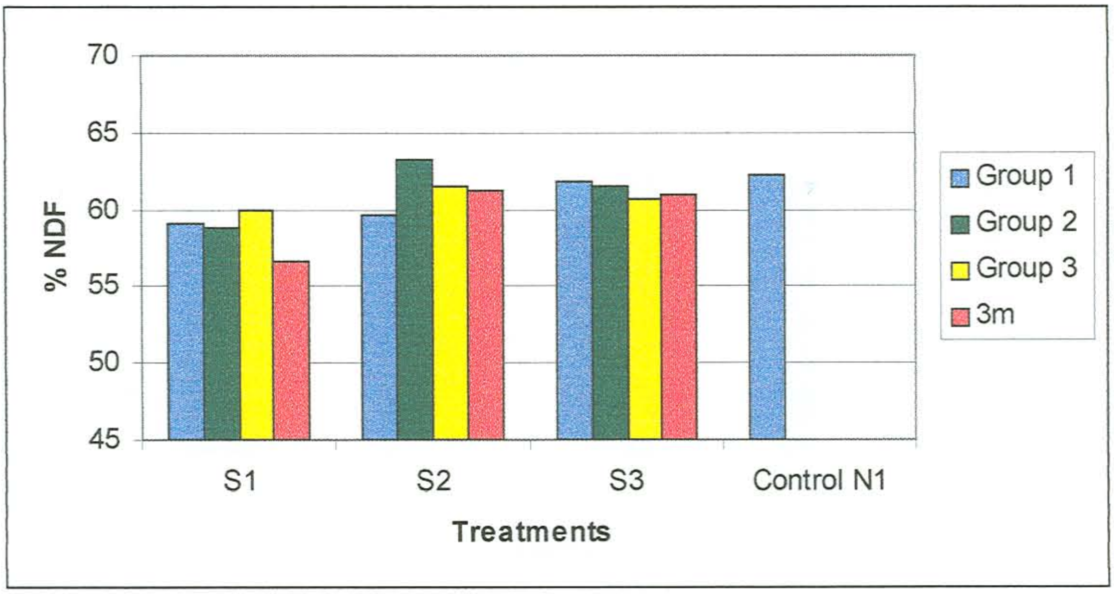

Fig.8 NDF concentration of second fodder sorghum harvest, 1997

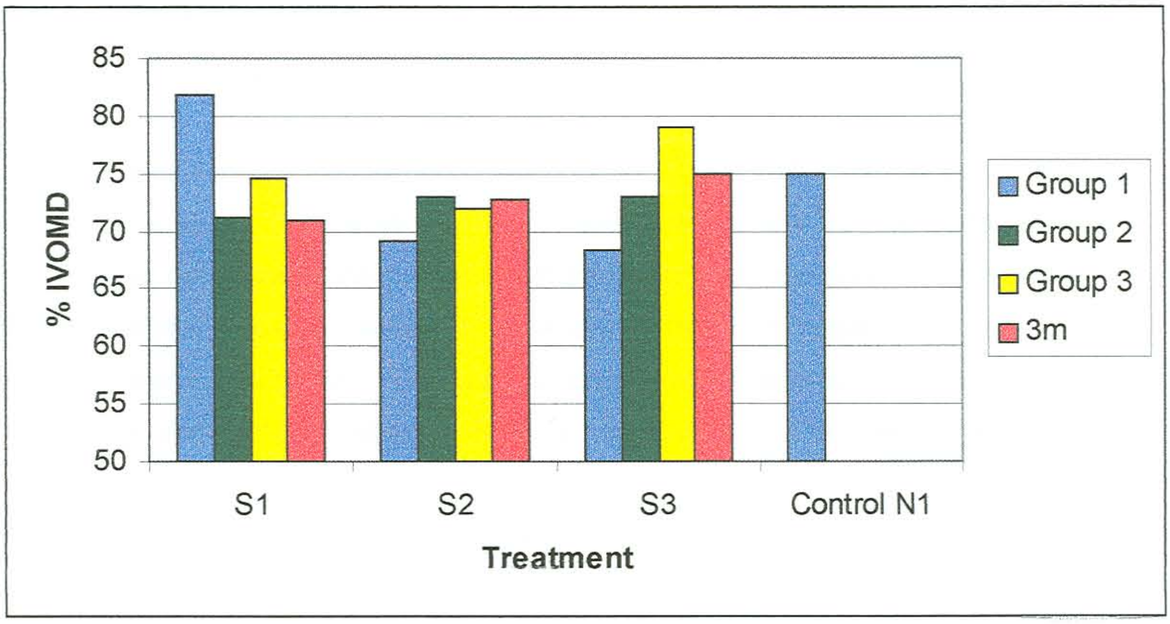

Fig.9 ***In vitro* digestibility (OM) of first fodder sorghum harvest, 1997**

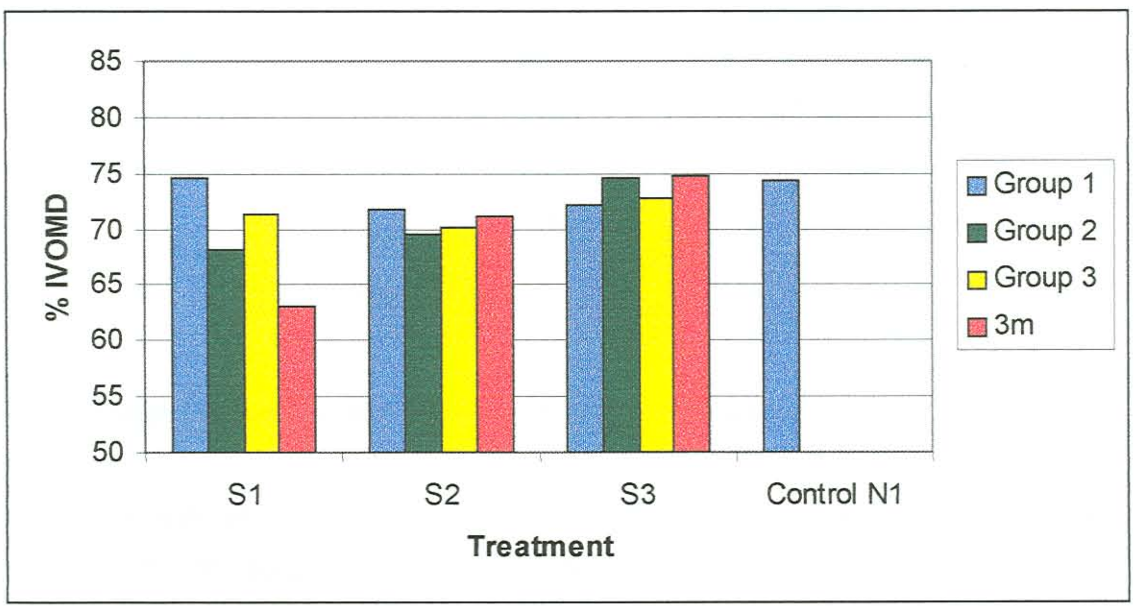

Fig. 10 ***In vitro* digestibility (OM) of second fodder sorghum harvest, 1997**

3.3.2 1997/1998 season

3.3.2.1 Plant heights

Plant heights were measured before each cutting in the 1997/1998 season. In both alley widths, plants in S1 were significantly shorter that in the S2 and S3 treatments. As S1 was not pruned, the fodder sorghum plants were exposed to more shading and therefore limited in received in receiving the light required for successful photosynthesis and growth. This is most possibly also the reason why little regrowth were observed in the 3m alleys of S1 (Fig. 11) (Table 7). The average plant height tended to be higher in the 6m alleys (Table 8), especially at the second cutting, where more light could penetrate the alley crops.

Fig. 11 Single surviving plants of group 1 in the S1 treatments

Only in the wide alleys did distance from the tree row played a significant role in the growth of fodder sorghum (Table 9). The rows nearest to the tree rows were especially stunted in growth, both with the first cutting and the regrowth before the second cutting (Fig. 12 & 13).

Table 7 Effect of mulching in different cutting treatments on the plant height of fodder sorghum in 3m alleys just before cutting, 1998

Treatment	H1 (cm)	± SE	H2 (cm)	± SE
S1	61.67	6.14	No regrowth	-
S2	143.33	6.14	138.33	6.35
S3	102.5	6.14	136.67	6.35
LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni)				

Table 8 Effect of mulching in different cutting treatments on the plant height of fodder sorghum in 6m alleys just before cutting, 1998

Treatment	H1 (cm)	± SE	H2 (cm)	± SE
S1	129.05	5.37	101.76	5.90
S2	164.76^{a}	5.37	140.47^{a}	5.69
S3	149.05^{a}	5.37	134.76^{a}	5.69
LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni)				

Table 9 Effect of distance from tree rows on the plant height of fodder sorghum in 6m alleys just before cutting, 1998

Treatment	H1 (cm)	± SE	H2 (cm)	± SE
r1	100.00^{a}	8.21	84.11^{a}	9.42
r2	152.22^{b}	8.21	115.56^{ab}	8.69
r3	176.67^{bc}	8.21	145.56^{bc}	8.69
r4	182.22^{bcd}	8.21	161.11^{cd}	8.69
r5	166.67^{bcde}	8.21	153.33^{bcde}	8.69
r6	143.33^{bce}	8.21	132.22^{bcde}	8.69
r7	112.22^{a}	8.21	87.78^{ab}	8.69
LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni)				

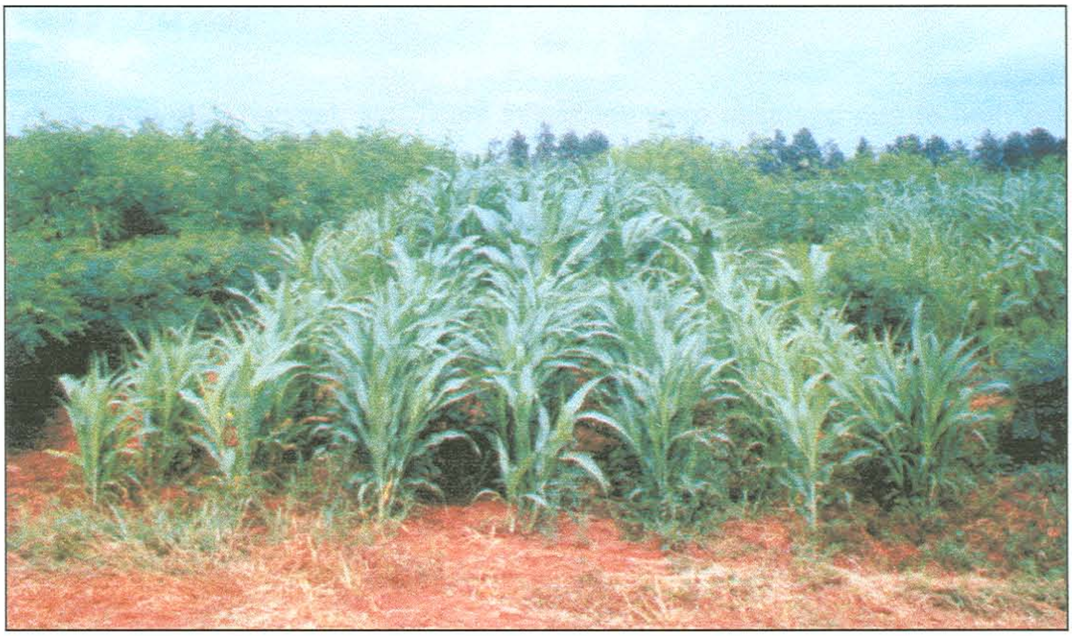

Fig. 12 Differences in plant height across the 6m alley

Fig. 13 Shading of plants nearest to the tree row

3.3.2.2 DM yield

During the 1998 harvest, significant influences were observed due to both pruning treatment and row position within the 6m alleys. Only treatment played a role in the 3m alleys.

In the 3m alleys, the highest yield was obtained from S 2 with the first cutting and S3 with the second cutting (Table 10). At this time, S3 was still kept pruned to a 1m high hedgerow and thus allowed more penetration of sunlight. The poor regrowth of S1 was not measurable at this stage. In the 6m alley, the highest yield was obtained in S3 (first and second cutting), although not significantly higher than S2 (Table 11). Stunted growth in S1 could again be attributed to shading.

With regard to the total yields for the season, S2 and S3 yielded respectively ± 96% and ± 95% more than S1 in the 3m alleys. In the wide alleys, this perceived advantage was ± 55% and ± 45% respectively. A higher yielding trend was observed in both the fertilised and unfertilised monocrops over the pruned treatments in both alley widths (Fig. 14). The unfertilised plots yielded 0.252 kg/m and 0.219 kg/m respectively at both cuttings and the fertilised plots yielded 0.226 kg/m and 0.332 kg/m respectively. Comparing these yields with the highest obtained from the alley crops (S3 in 6m), the yield from the unfertilised control was 30% higher and those from the fertilised control 41% higher.

When comparing total yields for the season across the different rows, an interesting trend was observed. Again the two rows nearest to the trees tended to have the lower yields, but especially so for the rows on the southern side of the tree row (Fig. 14 & 15) (Table 12). A clear tendency was observed towards lower yields from the rows to the south of the tree rows.

Table 10 Effect of mulching in different cutting treatments on the dry mass yields of fodder sorghum in 3m alleys, 1998

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
S1	0.0085[a]	0.0121	No regrowth[a]	-
S2	0.1303	0.0137	0.0272[a]	0.0199
S3	0.0358[a]	0.0121	0.1632	0.0199

LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni).

Table 11 Effect of mulching in different cutting treatments on the dry mass yields of fodder sorghum in 6m alleys, 1998

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
S1	0.0472[a]	0.0121	0.1022	0.0172
S2	0.1169[ab]	0.0121	0.1523[b]	0.0172
S3	0.1611[b]	0.0121	0.1704[b]	0.0172

LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni)

Table 12 Effect of distance from tree rows on dry mass yields of fodder sorghum in 6m alleys just before cutting, 1998

Treatment	DM1 (kg/m)	± SE	DM2 (kg/m)	± SE
r1	0.0883[a]	0.0184	0.1757[a]	0.0253
r2	0.1154[ab]	0.0184	0.1294[ab]	0.0293
r3	0.1517[bc]	0.0184	0.2098[bc]	0.0253
r4	0.1382[abcd]	0.0184	0.1678[abcd]	0.0253
r5	0.1070[bcde]	0.0184	0.1938[bcde]	0.0253
r6	0.0984[abcdef]	0.0184	0.1290[abcdef]	0.0253
r7	0.0597[abdf]	0.0184	0.0859[abdef]	0.0275

LSM with the same alphabetical superscript in columns do not differ significantly ($P \leq 0.05$) (Bonferroni)

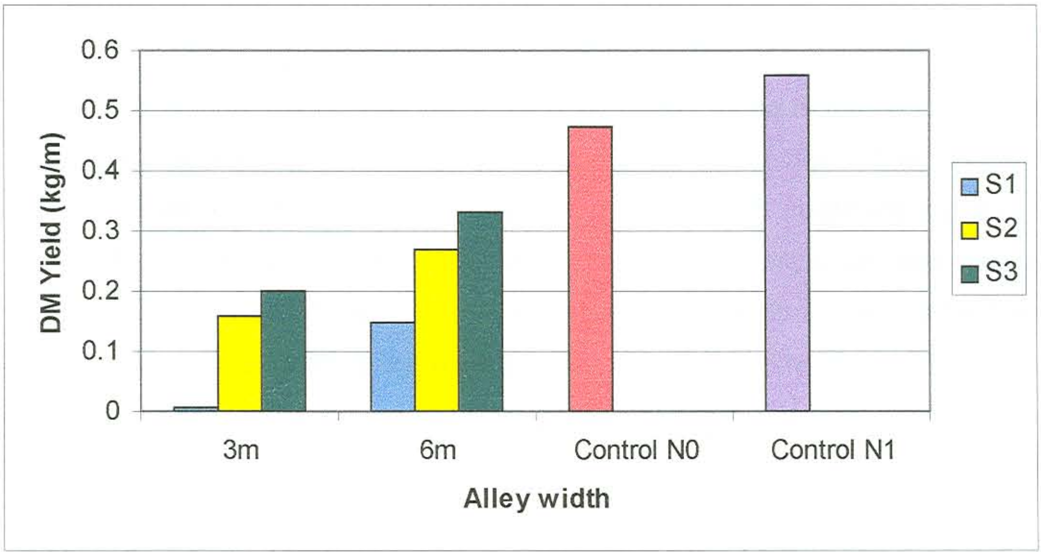

Fig 14 Total fodder sorghum yields observed in different cutting treatments, 1998

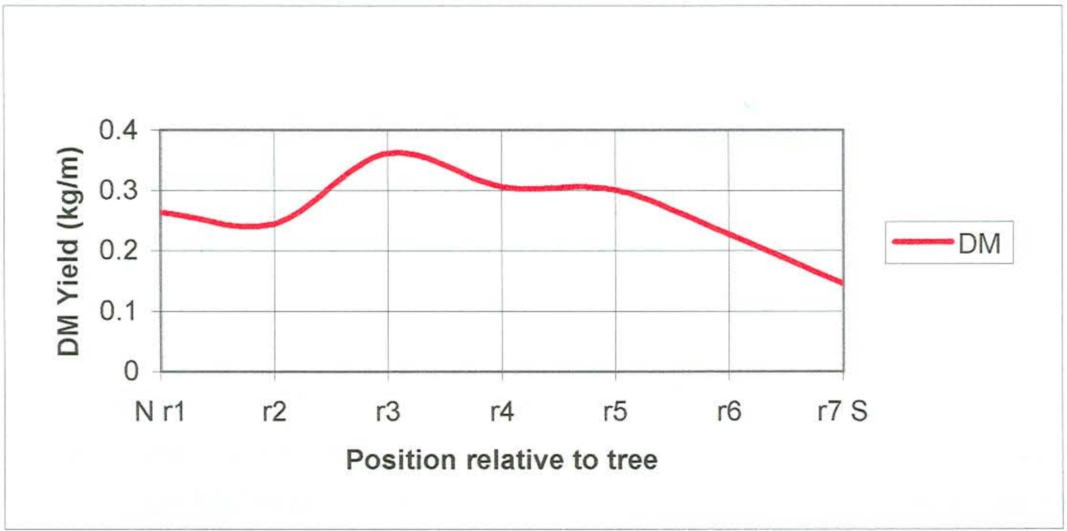

Fig. 15 Total fodder sorghum yields observed in different rows of the 6m alleys, 1998

3.3.2.3 Nutritional value

- *Crude protein*

At the first cutting, the highest CP concentration was found in the S1 treatments (Fig. 16). The three groups of S3 had almost the same CP content. The values were in general lower with the second cutting (Fig. 17). In both treatment S2 and S3, the values for the 3m alley were higher than the 6m alley. Although approximately the same amount of mulch was placed in the two alley widths, the concentration per surface area in the 3m alley was double that of the 6m alley. The crops thus received much more nitrogen from the leucaena mulch. It is interesting to note that the highest protein content was obtained in a treatment not receiving any mulch (S1 3m). This phenomenon could not be explained.

- *Neutral detergent fibre*

The NDF concentration of the first cutting was found to be in a relatively small range, with the fertilised control having the higher value (Fig. 18). The values increased in the second cutting with group 1 generally having the lower values. The plants of group 2 and 3 were generally much taller and more mature by this stage, compared to group 1 (Fig. 19), as they were exposed to better growth conditions (experienced less competition with the adjacent trees for water, nutrients and sunlight).

- *In vitro digestibility (organic matter)*

The digestibility of the first cutting was high for all treatments, but was dramatically lower in the second cutting (Fig. 20 & 21). As observed with the 1997 harvest, more lignification had evidently taken place by this stage, resulting in lower digestibility, higher NDF and lower N values. The plants in S1, experiencing much more shading, did appear to have softer stems (visual observation), indicating less cell wall material, although this is not supported by the NDF data.

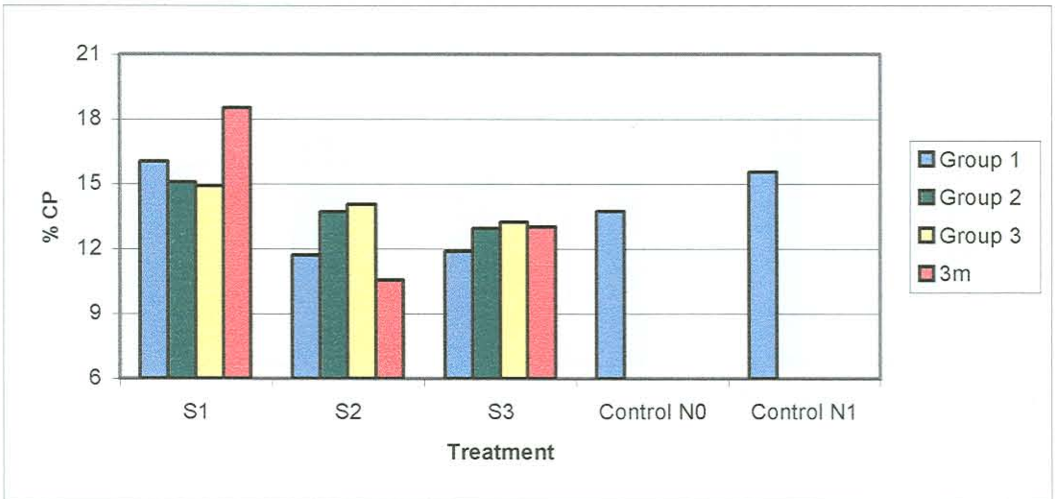

Fig.16 Crude protein concentration of first fodder sorghum harvest, 1998

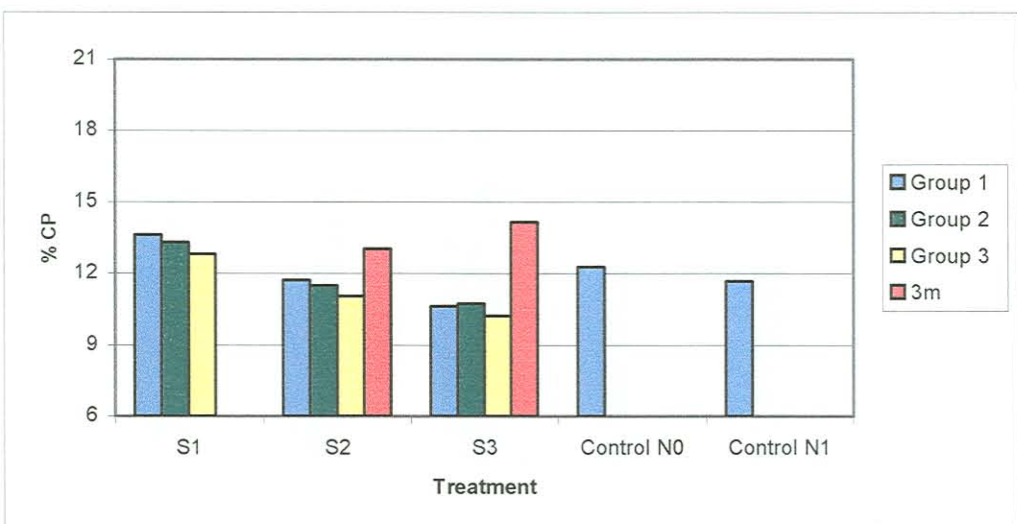

Fig.17 Crude protein concentration of second fodder sorghum harvest, 1998

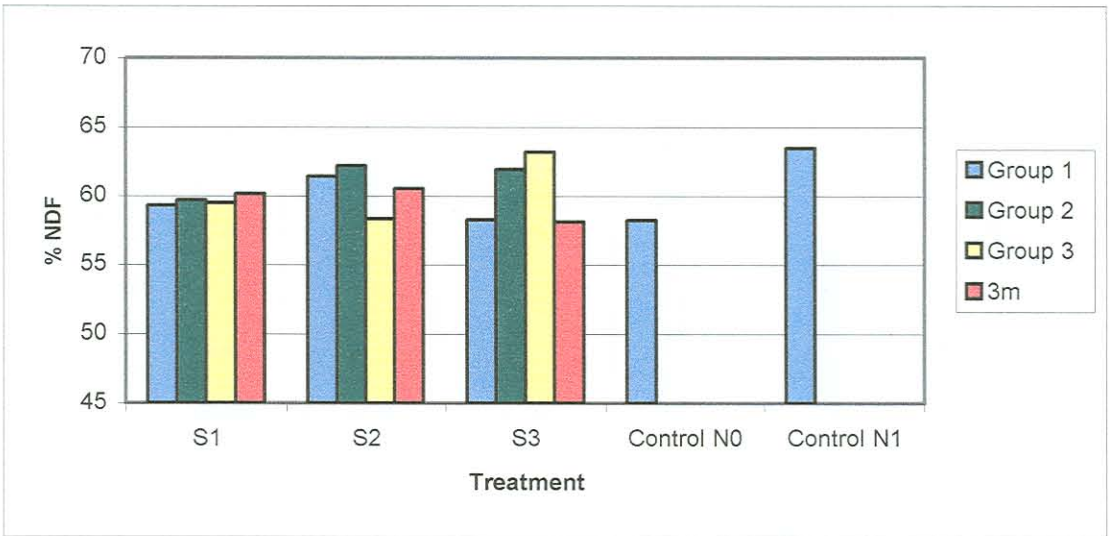

Fig.18 NDF concentration of first fodder sorghum harvest, 1998

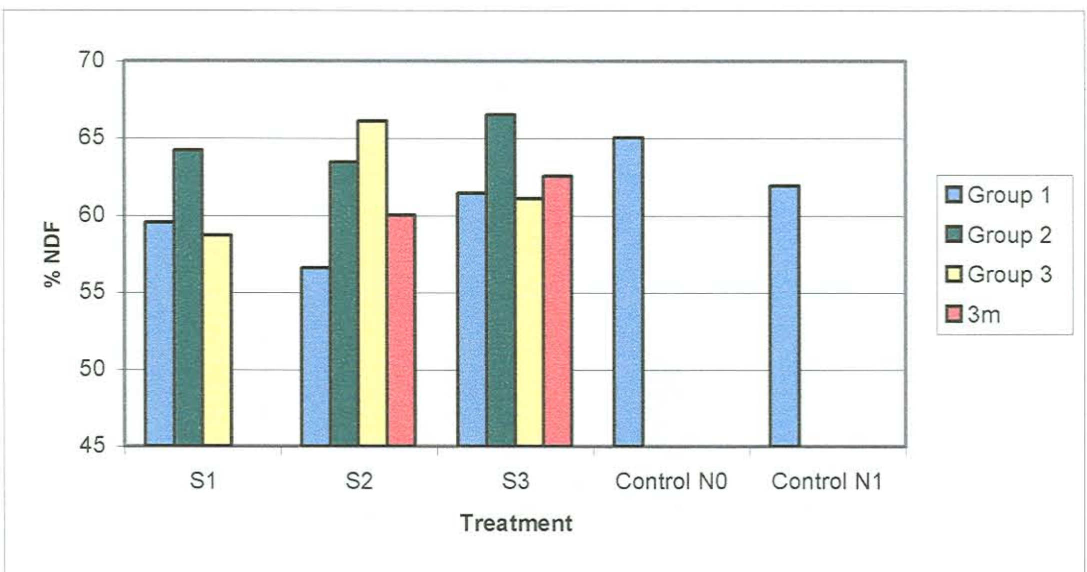

Fig.19 NDF concentration of second fodder sorghum harvest, 1998

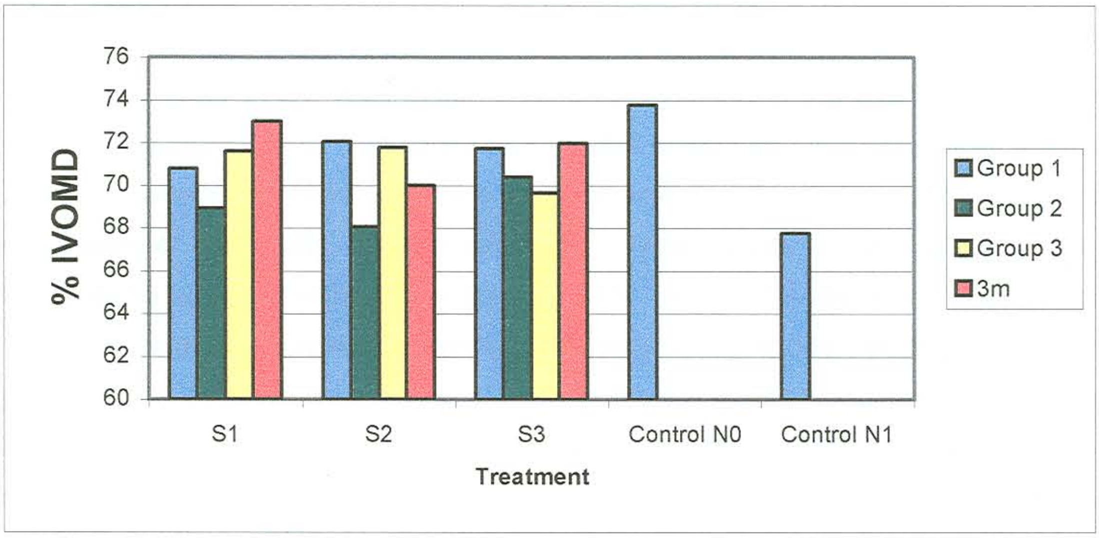

Fig.20 ***In vitro*** **digestibility (OM) of first fodder sorghum harvest, 1998**

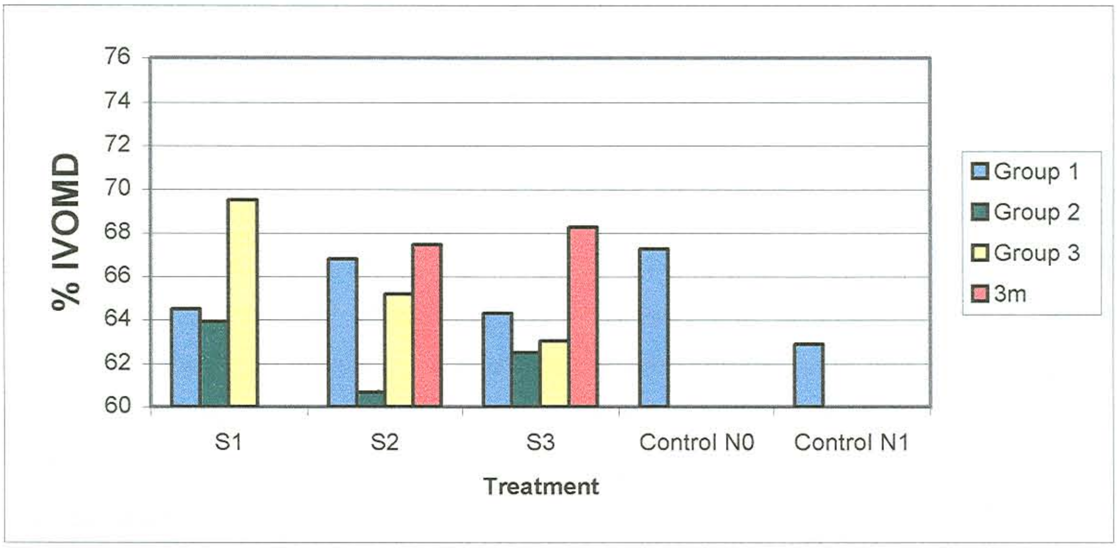

Fig. 21 ***In vitro*** **digestibility (OM) of the second fodder sorghum harvest, 1998**

3.4 Conclusion

The forage value of any feed depends on a combination of the palatability, nutrient content and digestibility. The intake of sufficient energy and nutrients by an animal, however, cannot be predicted from a separate analysis of a plant's nutrient content, digestibility or palatability. These can serve only as a guide to the value of species, but must be regarded with caution (Lefroy, Dann, Wildin, Wesley-Smith & McGowan 1992). Chemical analyses commonly overestimate digestibility, particularly that of protein, as it does not take into account that protein is often bound to tannins and lignin, which can prevent its breakdown in animals. Palatability can vary seasonally and between animals and cannot, therefore, be assessed on the basis of the occasional consumption of browse.

Both yield and quality of fodder sorghum in S2 and S3 compared favourably with each other and the monocrops crops, although an advantage could not be attained over the monocrops. Balasubramanian & Sekayange (1991) also reported only a marginal yield effect with sorghum after mulching with leucana in semi-arid Rwanda. General results reported from the tropics and sub-humid regions indicated to improved yields from alley cropping compared to monocropping (Kang *et al.*, 1981; Brewbaker, 1987; Palada, *et al.* 1992; Mugendi & Nair, 1997).

Improved yields with increased distance from the tree row, as observed in the 6m alleys, were previously confirmed by Szott *et al* (1991), who also reported that yields declined with time. As observed by Kang *et al* (1981) and Read *et al* (1985), a CP advantage was obtained after mulching with leucaena prunings. Lower yields obtained to the south of tree rows was an interesting observation and most possible due to competitive factors with regard to available sunlight and soil moisture. Plant heights also tended to be slightly lower in the southern rows of the alley, indicating a possible lower growth rate.

From the results it became clear that the use of a 3m alley is not really an option under local conditions. Results reported by Rao, Sharma & Ong (1990) in semi-arid India confirmed reduced sorghum yields in alley widths closer than 3m. The yields obtained in this alley were too low to favourably compare with the other treatments. It was also clear that cropping should not be attempted within 2m of tree rows, as especially yields of plant material would not be satisfactorily.

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4 The competition aspect of alley cropping

4.1 Introduction

Alley cropping is recommended as a strategy to increase productivity. The system aims to integrate soil amelioration with the production of wood and fodder by the production of cash crops or pastures between rows of trees that are periodically pruned. The prunings can be used as a fodder, or returned to the soil as a mulch or green manure in order to improve soil fertility.

The cultivation of these different crops in close proximity may entail some measure of competition between the crops. Shading of the alley crops is expected, as well as competition for nutrients and water. Especially in moisture deficient areas, the availability of and competition for water is an aspect to be considered when designing an alley cropping system.

4.1.1 Competition for light

Plants compete for the light that is available at a specific moment to be intercepted for photosynthesis. Light cannot be "accumulated" and stored, but that which is available at a given moment can be intercepted and used, or be lost. Light interception is influenced by factors such as the vertical distribution of the leaf surface area, leaf form and size, spatial arrangement of leaves and the number of leaves/lateral branches. More light will be intercepted by taller, fast growing plants. Other characteristics contributing towards successful light interception include C4-photosynthesis, creeping growth form, reduction in dark respiration and a high leaf:stem ratio (Trenbath, 1976, as cited by Van den Berg, 1987.)

The pruning of alley crops has the dual purpose of obtaining and stimulating biomass production, as well as reducing the shading effect of the trees on crops grown in the alleys. Based on light interception data, it has been inferred that the shorter the crops grown within the alley, the more frequent the need to prune in order to reduce the level of shading (Kang, Grimme & Lawson, 1985). Pruning of the alley trees/shrubs is, therefore, not only necessary to provide nutrient and dry matter for mulching the crop but also to reduce the competition for light.

A high degree of shading associated with leucaena and closer inter-hedgerow spacing resulted in corresponding decreases in crop yield. Larger amounts of hedgerow biomass production were found to be associated with significant decreases in crop yields owing to increased hedgerow shading (Lawson & Kang, 1990; Corlett, Black, Ong & Monteith, 1992). Competition in alley cropping is not only from the trees, but a mutual phenomenon. In a newly established plot, maize had a significant negative influence on the growth and yield of leucaena. At full maize canopy development, the photosynthetic active radiance (PAR) reaching the leucaena was reduced in all treatments, resulting in a 75% yield reduction in leucaena (Jeanes, Gutteridge & Shelton, 1996).

4.1.2 Competition for water

Competition for water actually refers to the competition between root systems. It is influenced by light, as shady conditions will induce less developed root systems. In the same way, drier conditions will result in a poorer plant that will not be able to compete sufficiently for light. With mixed cultivation, the soil profile is utilised more effectively (Trenbath, 1984, as cited by Van den Berg, 1987).

Through the phenomenon of "mutual avoidance", the deeper soil layers will increasingly be utilised by roots as population pressure increases. Plants with a deep root system will grow even deeper when cropped with plants with a shallower root system. The type of root also plays a role, as will the length of the root and the presence of root hairs (Mengel & Steffens, 1985, as cited by Van den Berg, 1987.)

In alley cropping, the deeper root system of leucaena appears to extract more soil moisture from the lower horisons (>50 cm depth) than maize, which taps the surface layers (<50 cm depth), and thereby reduces their competition for moisture. The repeated application of leucaena prunings also increased soil moisture retention capacity (Kang, Grimme & Lawson, 1985; Lawson & Kang, 1990) as well as increased yields (Gicheru, Gachene & Biamah, 1998). These results were obtained in more tropical environments. McIntyre, Riha & Ong (1997) noted that there may be little opportunity for increasing water uptake in hedgerow intercropping systems in semi-arid environments. Their results indicated that annual crops in monoculture took up water at similar rates and depths as the multistem hedge monoculture and intercropped systems. There was no evidence that root density restricted water uptake in the surface 0.45 m in any of the treatments and there was no increase in uptake below 0.45 m in intercropped treatments compared to monocropping systems

Szott, Palm & Sanchez (1991) found that yields generally increased with distance from hedges, suggesting that below-ground competition for water and nutrients reduce crop yields near the hedges. Supporting this, under water-limiting conditions, alley cropping was found to be detrimental to crop yield because competition of the trees for water outweighed the likely soil fertility or crop yield benefits (Govindarajan, Rao, Mathuva & Nair, 1996).

As part of an evaluation of the applicability of alley cropping in semi-arid South Africa, the possible competitive effects in an alley cropping system were investigated, with specific reference to water availability and light interception.

4.2 Materials and methods

An alley cropping field experiment was conducted on the Hatfield Experimental Farm of the University of Pretoria (Table 1). The study was laid out in a 2x3x3 factorial randomized complete block design with five replications, involving two alley widths (3m and 6m), three pruning treatments (Table 2), and a split plot for three alley crops (maize, grain sorghum, fodder sorghum). Within-row spacing was 1 m. No statistical analysis was conducted, as the purpose of the investigation was to determine possible trends between the different observations.

An existing leucaena stand, planted at a tree density of 3 333 trees per ha, was used. Before the start of the 1996/1997 growing season, the trial was converted to an alley cropping trial by removing selected alternate rows. The plant populations of the 3m and 6m treatments were 3333 and 1667 trees per ha respectively. Pruning of the trees started in November 1996 and was repeated at fixed intervals thereafter, until April 1998 (Table 2). Except for the first harvest, yields of the different pruning treatments were applied as mulch between the alley crops. No irrigation or fertilizer was applied.

Table 1 **Site description on Hatfield Experimental Farm**

Locality	28°16'E, 25°45'S
Altitude	1372 m
Annual rainfall	709 mm
Av. max. and min. temp.	30°C (Jan), 2°C (Jun)
Soil type	Sandy clay (37 % clay), Hutton, homogenous to a depth of 0.66 m after which it becomes gravelly (MacVicar, Loxton, Lamprechts, Le Roux, De Villiers, Verster, Merryweather, Van Rooyen & Von M. Harmse, 1977).

Table 2 **Pruning treatments applied to *L. leucocephala* in alley cropping systems**

S1	Control - no pruning
S2	Pruning to a single stemmed tree (± every 6 weeks), clearing the undergrowth up to 1 m. In 1998 the interval was changed to 8 weeks.
S3	Hedgerow (± every 4 weeks), cut back to 1m height and ±0.75 m width

An additional leucaena stand was established in order to compare different row orientations. Single rows of leucaena seedlings were planted at two orientations: north-south and east-west, replicated three times. The taking of measurements commenced one year after planting.

4.2.1 Light measurement

Fractional interception of PAR by leucaena trees was measured across both alley widths with a Sunfleck Ceptometer (1991), three times a day at the beginning, in the middle and towards the end of the growing season.

4.2.1.1 *Alley cropping trial*

Measurements were taken in all three pruning treatments of both alley widths immediately north of a tree row, immediately south of the next tree row, and in the middle of the alley between the tree rows. These readings were taken above the tree canopy and below the tree canopy, above the alley crops

4.2.1.2 *Orientation trial*

Measurements were taken at set distances on both sides of the leucaena row at 0.5m, 1.0m, 1.5m, 2.0m and 3m. The trees were not pruned. Readings were taken above the tree canopy and on ground level.

4.2.2 *Water measurement*

Available water content (volumetric) across two alley widths was measured with a neutron water meter. Measurements were taken at depths of 0-20cm, 20-40 cm and 40-60cm.

4.2.2.1 *Alley cropping trial*

Galvanised steel pipes were inserted in the S3 treatment at 0.5m, 1.0m, 1.5m, 2.0m and 3m to the north of a tree row and at the same distances to the south of the next tree row in the 6m alley; and at 0.5m, 1.0m and 1.5m in the 3m alley. Measurements were taken at three depths (0-20 cm, 20-40 cm, 40-60 cm). A reference measurement was taken in dry soil before the onset of the rainy season, and monitoring began after a rainy episode in December 1997 on day 1,3,5 and 12 after a precipitation of 42 mm was received.

4.2.2.2 *Orientation trial*

Measurements were taken at set distances on both sides of the leucaena row at 0.5m, 1.0m, 1.5m, 2.0m and 3m, at three depths (0-20 cm, 20-40 cm, 40-60 cm).

4.3 Results and discussion

4.3.1 Light penetration

4.3.1.1 Alley cropping trial

Results are presented in figures 1-9:

December

In both alley widths light interception by S1 was the highest, translating into less PAR being available for the alley crops. This was especially pronounced in the 3m alley where a shading effect in the middle of the alley was observed in the morning and afternoon readings. The lowest FI was observed in the S2 treatments, where the single stems of the trees had the least restrictive effect on light penetration and light was let through the stems.

February

By February the effect of the developing tree canopies could be more strongly observed. In the 3m alley, S1 intercepted most of the available PAR. Light penetration was only restricted in the mornings in S2 and S3. In the 6m alley light penetration in S1 was especially restricted in the mornings, more so just to the north of tree rows. S2 and S3 were not restrictive.

April

By April, canopy closure in the 3m alley restricted almost all light penetration in S1, and intercepted a large fraction in S2 and S3 in the mornings. In the 6m alley, FI was low in S2 and S3 and in S1 light penetration was only relatively successful in the middle of the alley. At this stage of the season, more of the available PAR was intercepted to the south of the tree rows.

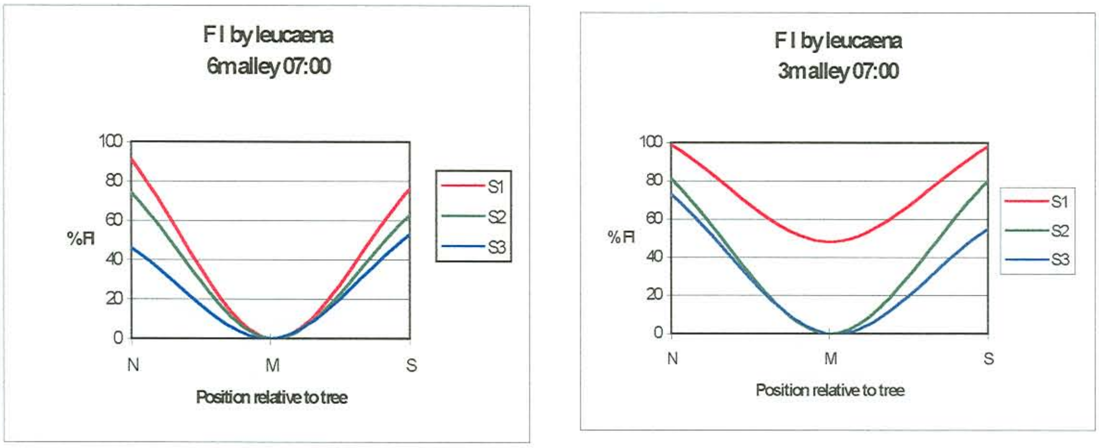


Fig. 1 Fractional interception by leucaena at 07:00 early in the growing season (December)

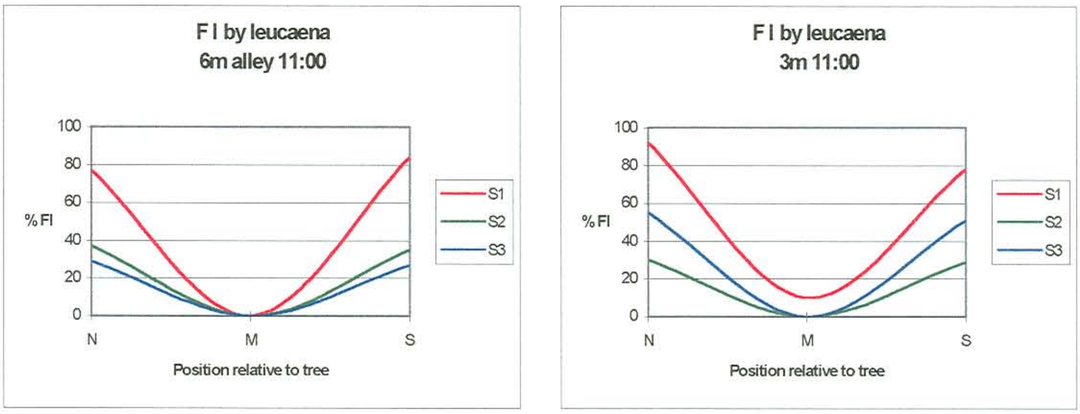


Fig. 2 Fractional interception by leucaena at 11:00 early in the growing season (December)

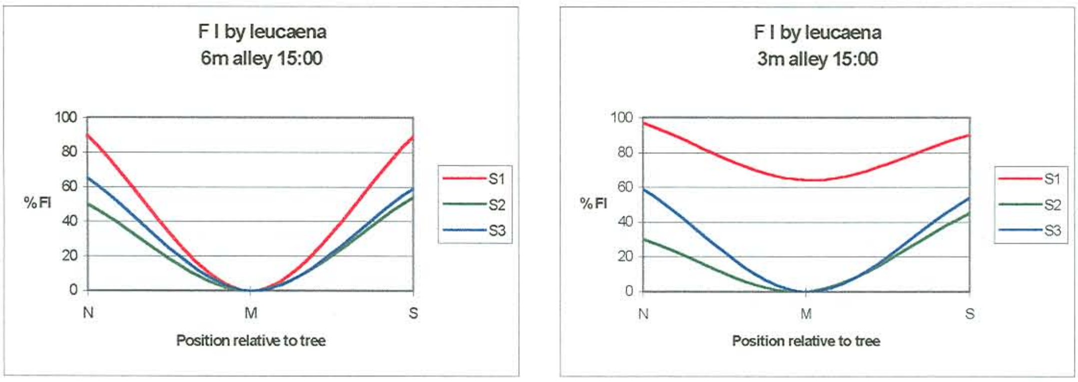
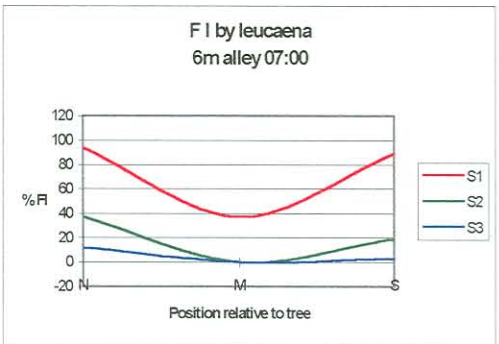


Fig. 3 Fractional interception by leucaena at 15:00 early in the growing season (December)



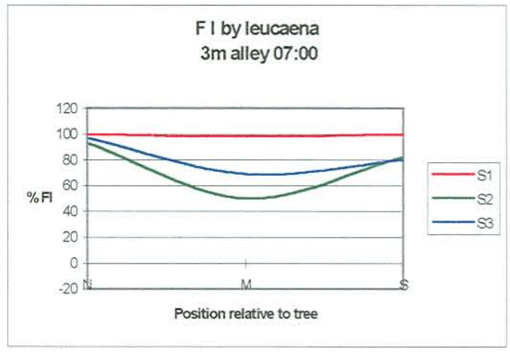
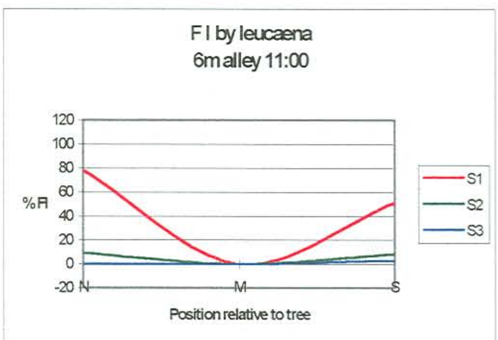


Fig. 4 **Fractional interception by leucaena at 07:00 in the middle of the growing season (February)**



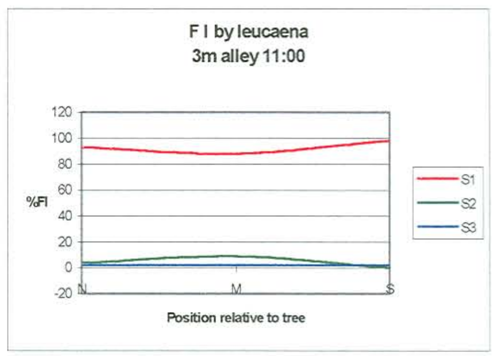
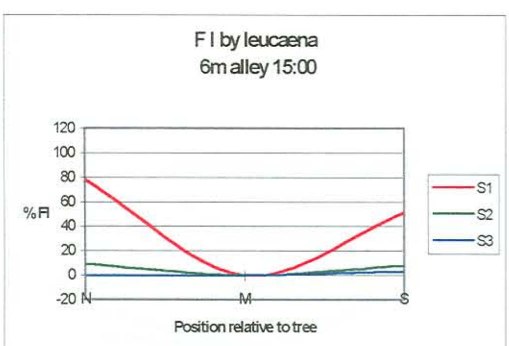


Fig. 5 **Fractional interception by leucaena at 11:00 in the middle of the growing season (February)**



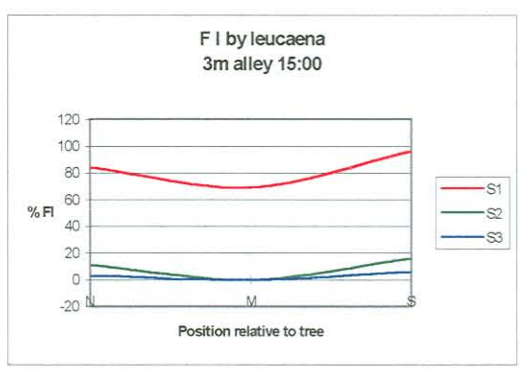


Fig. 6 **Fractional interception by leucaena at 15:00 in the middle of the growing season (February)**

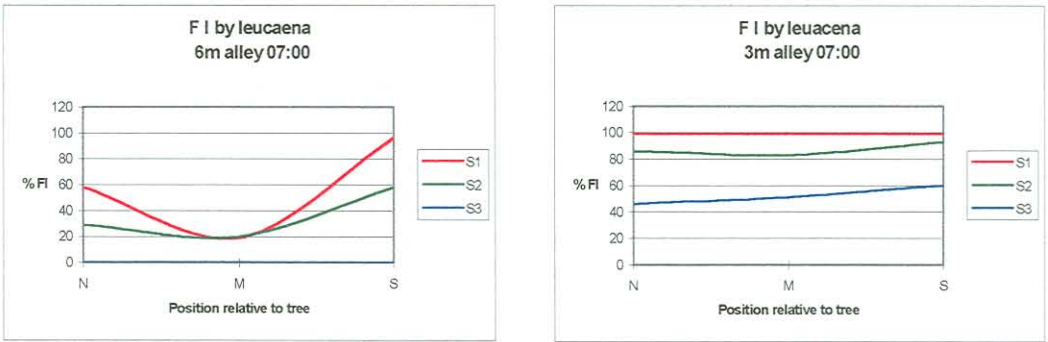


Fig. 7 Fractional interception by leucaena at 07:00 at the end of the growing season (April)

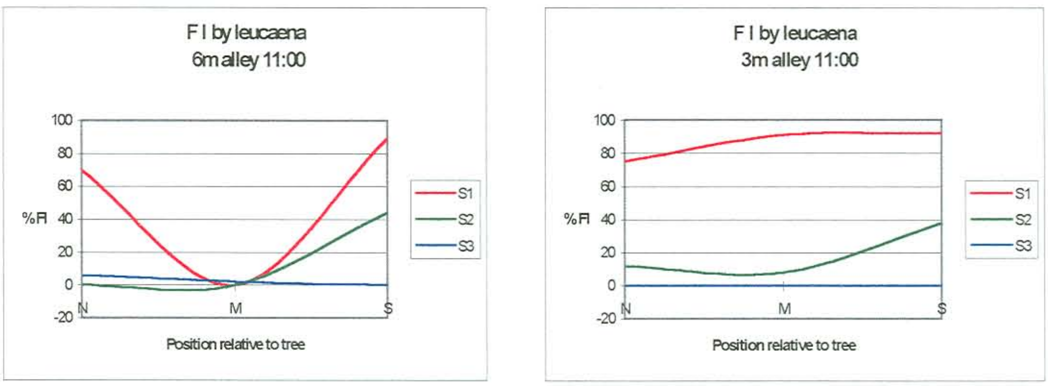


Fig. 8 Fractional interception by leucaena at 11:00 at the end of the growing season (April)

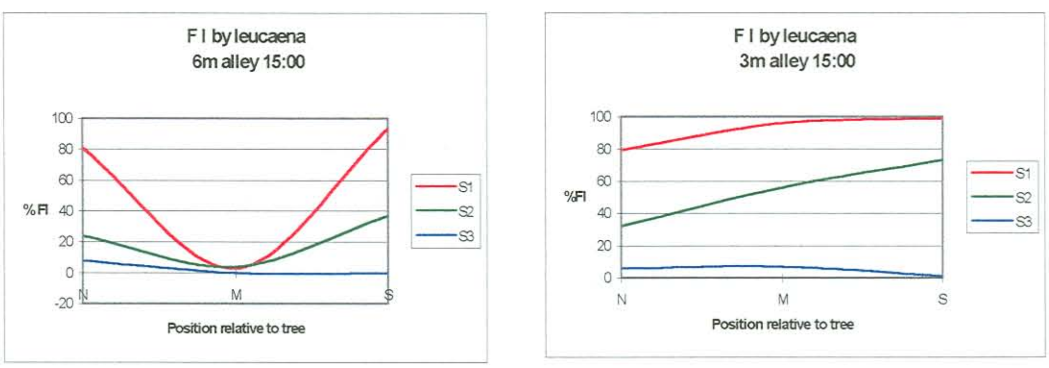


Fig. 9 Fractional interception by leucaena at 15:00 at the end of the growing season (April)

4.3.1.2 Orientation trial

Results are presented in figures 10-13:

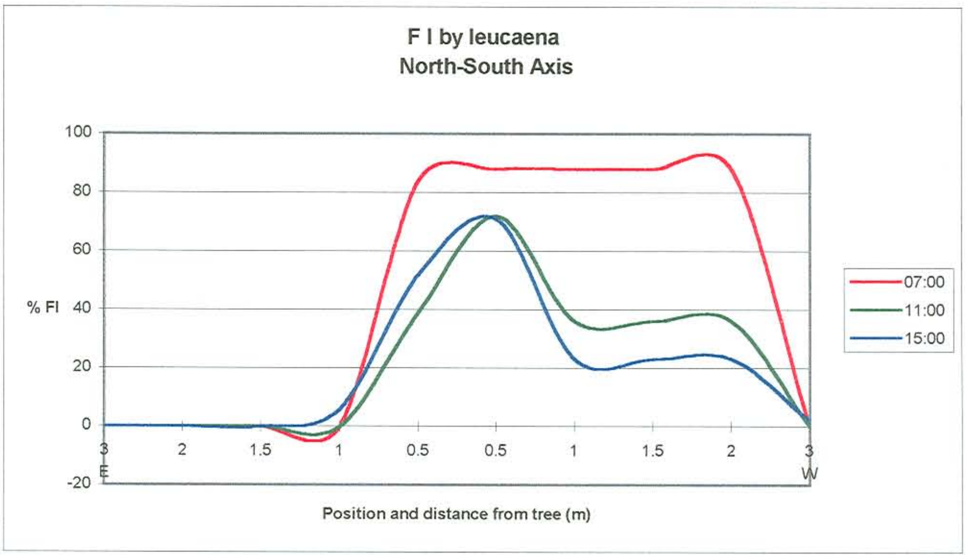


Fig. 10 **Fractional interception by leucaena in an north-south orientation (middle of growing season)**

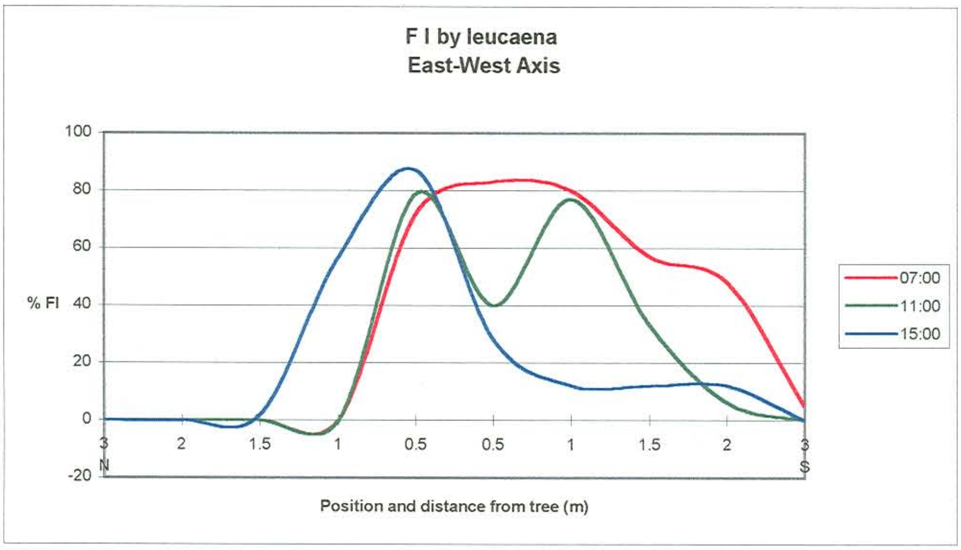


Fig. 11 **Fractional interception by leucaena in a east-west orientation (middle of growing season)**

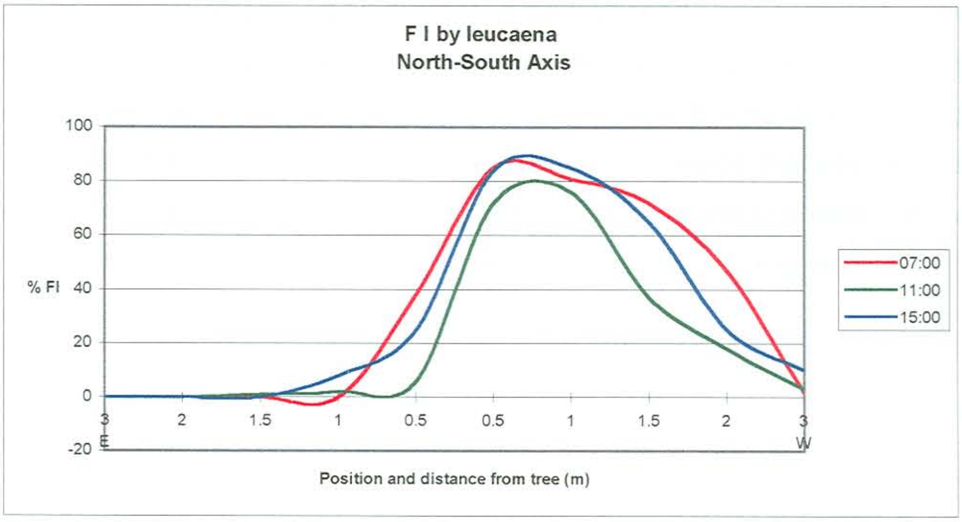


Fig. 12 **Fractional interception by leucaena in an north-south orientation (at the end of the growing season)**

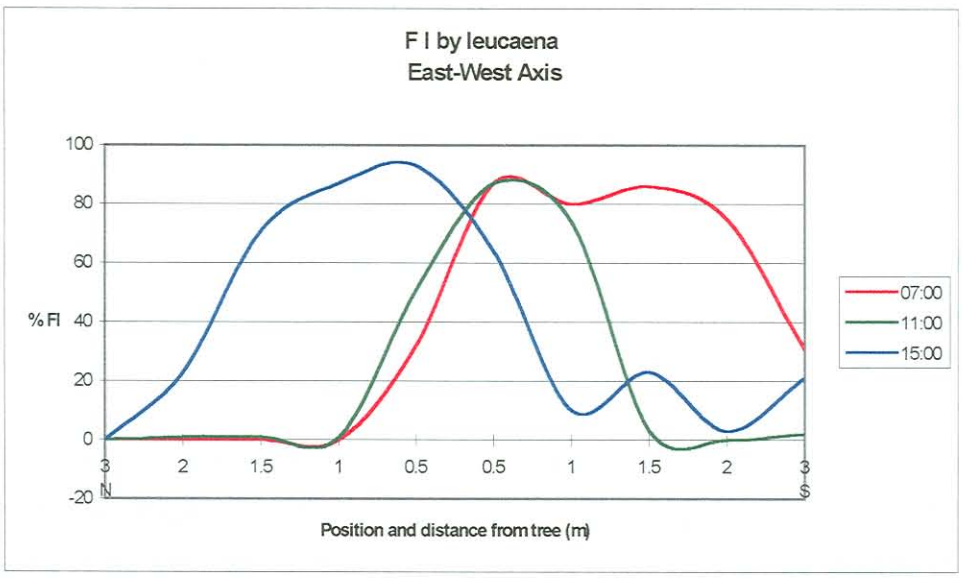


Fig. 13 **Fractional interception by leucaena in a east-west orientation (at the end of the growing season)**

Readings were not taken at the onset of the growing season, as the young leucaena did not yet cast any shade. By February, a definite shade effect could be observed, especially towards the west and south of the tree rows. The effect was the greatest in the mornings and lessened towards the afternoon. By the end of the growing season, the shade effect was still more pronounced towards the west and south of the tree rows. FI was very high throughout the day towards the west. In the east-west orientation, FI was high towards the south in the morning and at noon, and shifted towards the north in the afternoon.

4.3.2 Water availability

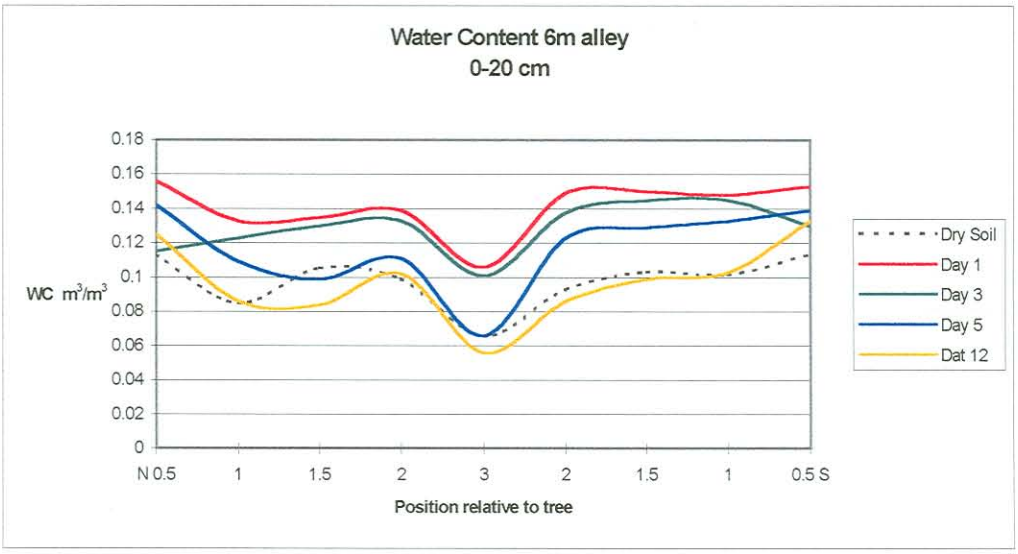
4.3.2.1 Alley cropping trial

Results are presented in figures 14-16:

Water content (WC) in the upper 20 cm of the 6m alley followed a fixed pattern. The highest WC was observed immediately next to the tree rows, declining slowly towards the middle and dipping at 3m from the tree. The distribution pattern stayed the same after the rainy episode, right through the drying-out period until 12 days after the rain. In the 3m alley, the distribution was more even.

The pattern was less pronounced at the 20-40 cm depth. Water content was higher in the dry soil than in the upper 20 cm, and after the drying-out period, was still higher by the same fraction. The increase in WC in the 3m alley was smaller.

At the 40-60 cm depth, the effect of the leucaena roots could be seen, where WC reached a minimum at 1.5m south and 1.0m north of the tree row. The effect of leucaena roots extended throughout the 3m alley with no marked change in WC at any distance from the trees.



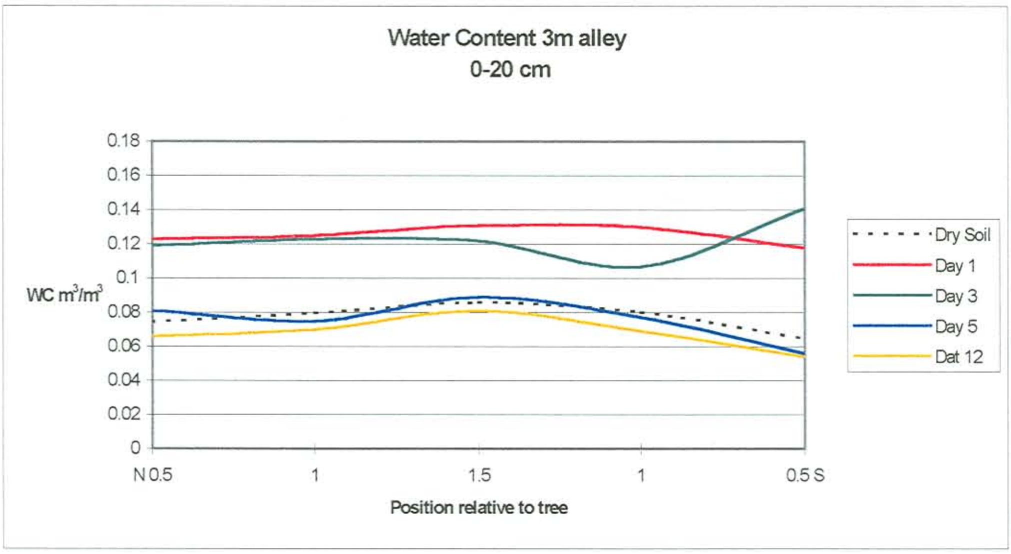
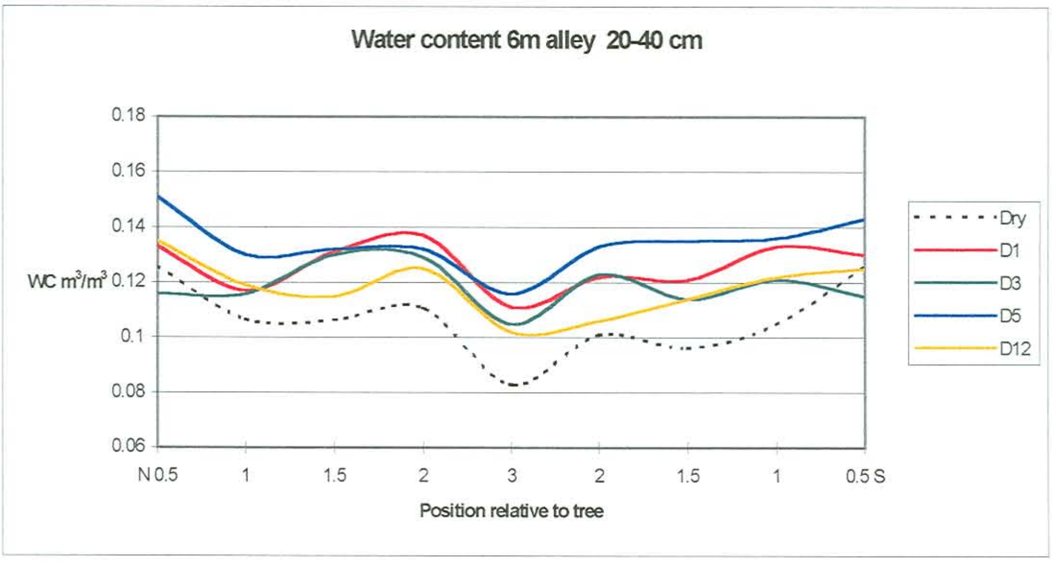


Fig. 14 **Comparative water content at a depth of 0-20cm : alley cropping trial**



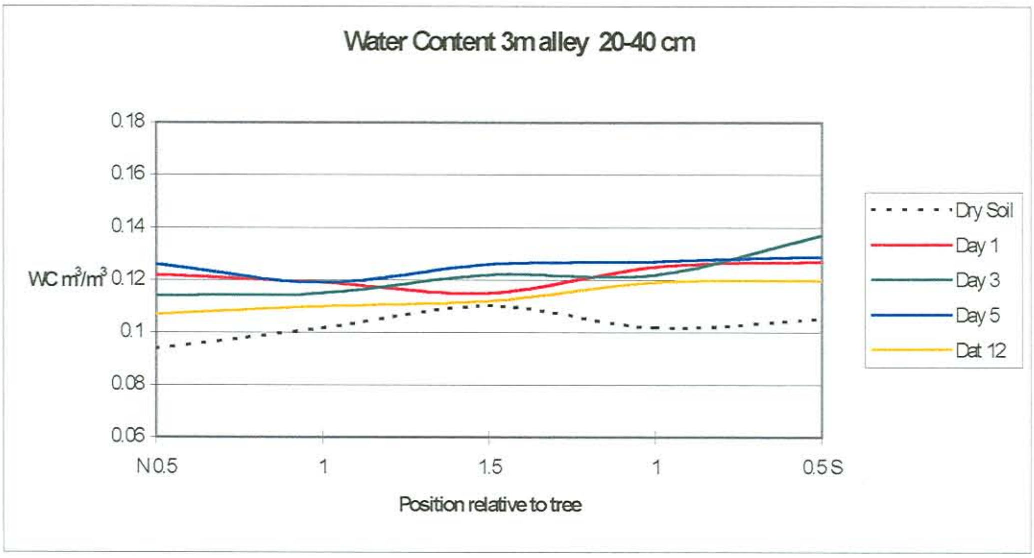
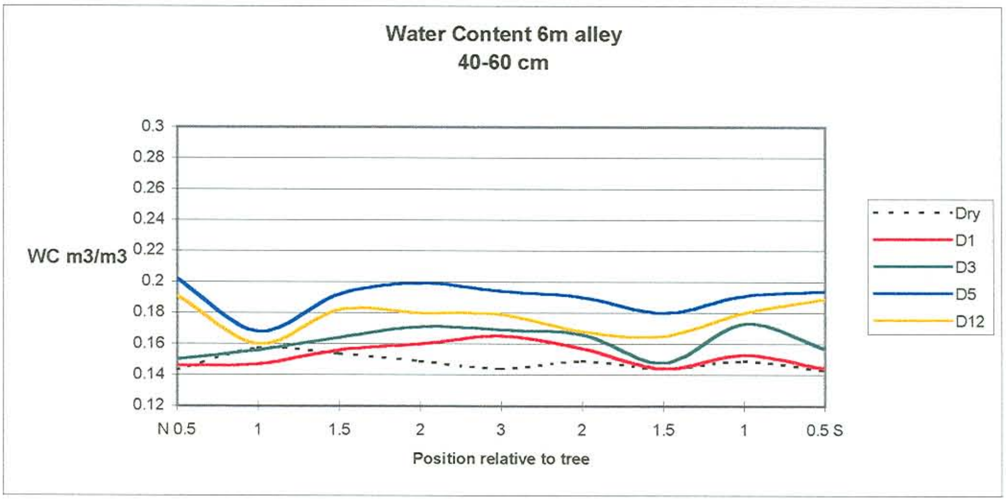


Fig. 15 **Comparative water content at a depth of 20-40cm : alley cropping trial**



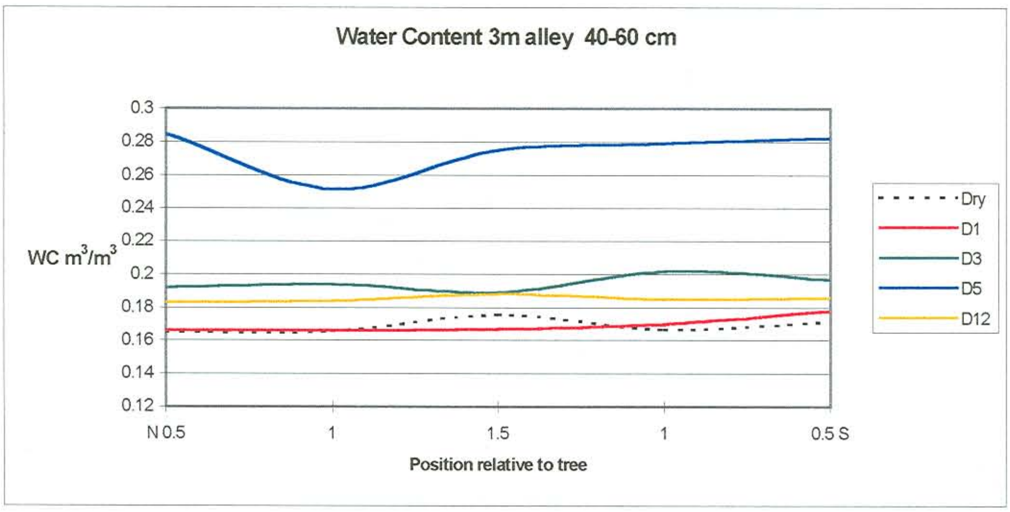
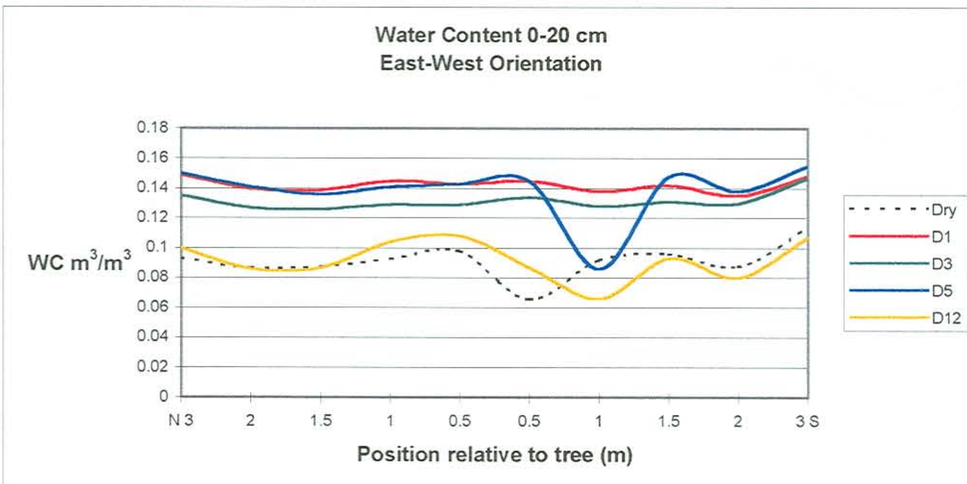


Fig. 16 **Comparative water content at a depth of 40-60cm : alley cropping trial**

4.3.2.2 Orientation trial

Results are presented in figures 17-19:



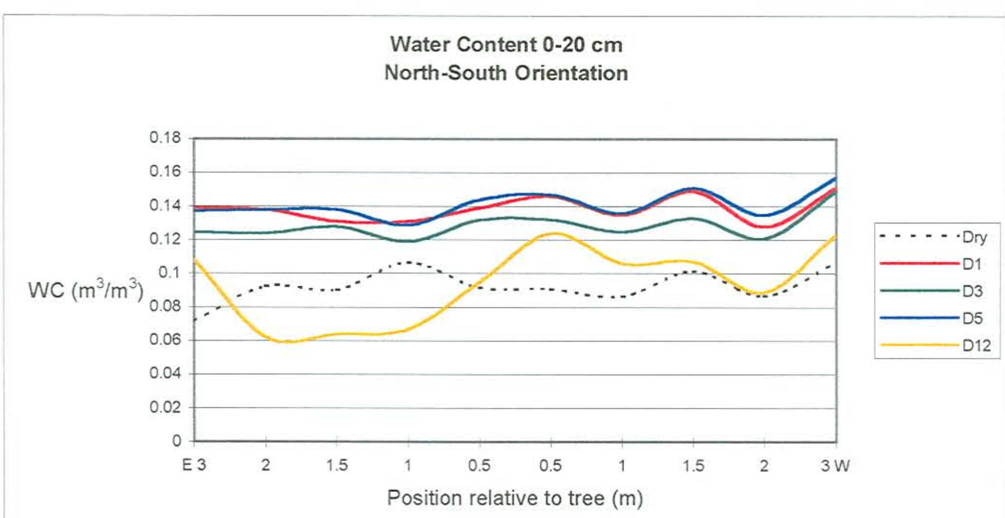
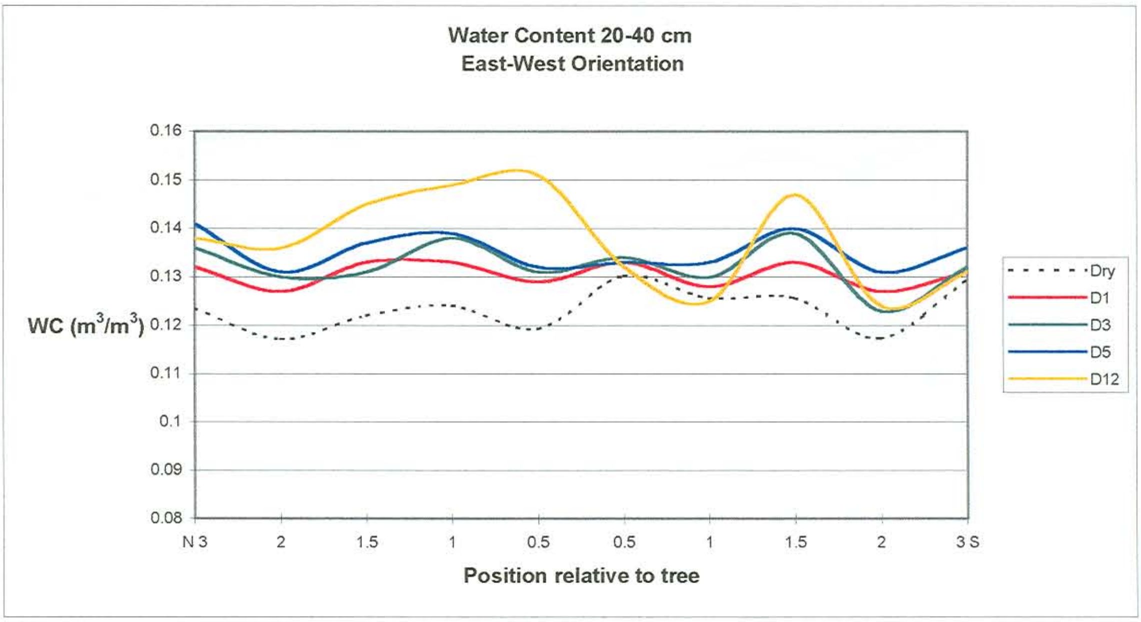


Fig. 17 Water content at a depth of 0-20cm : orientation trial



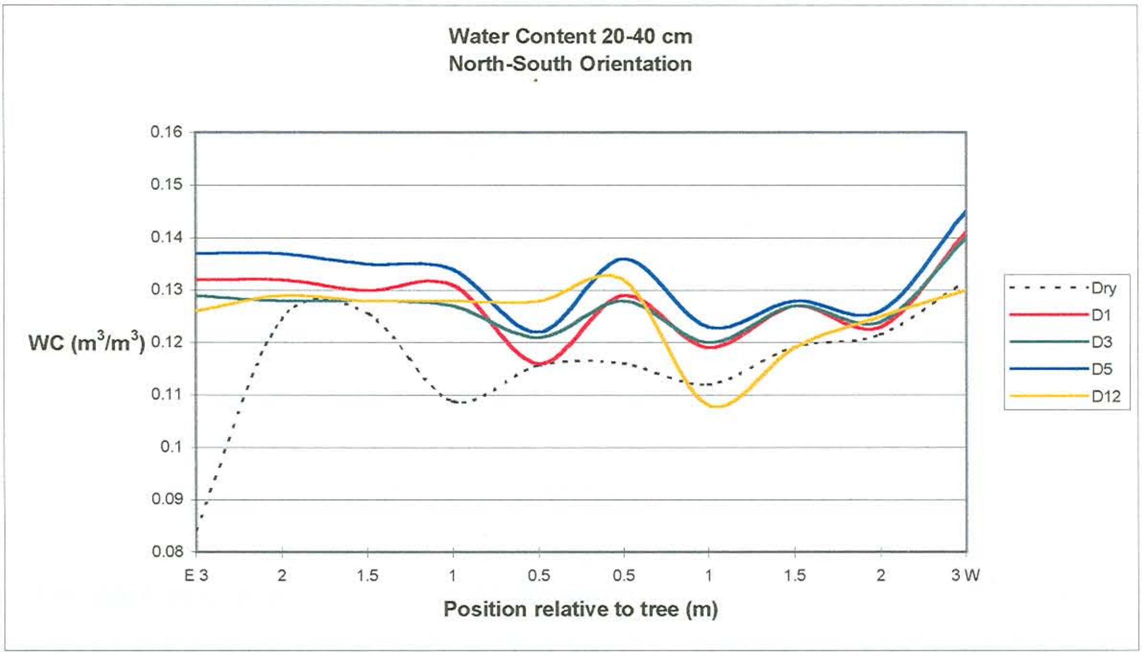
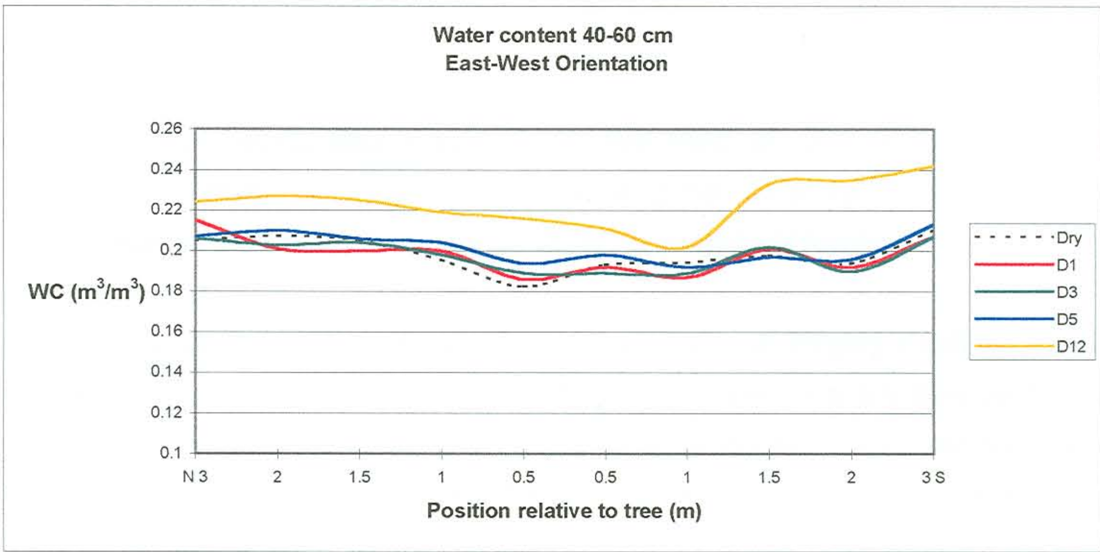


Fig. 18 Water content at a depth of 20-40cm : orientation trial



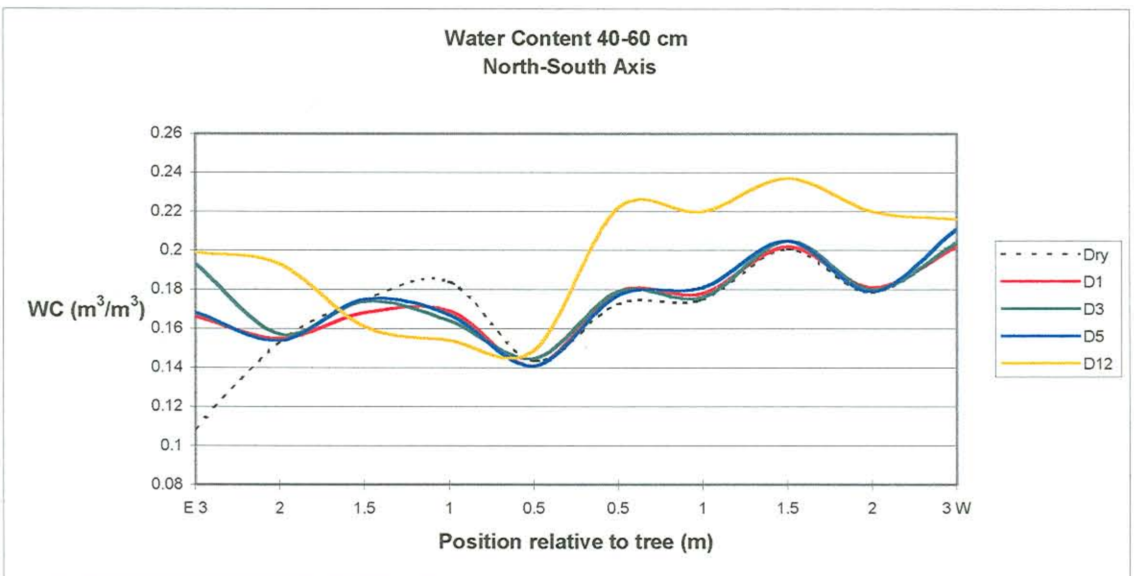


Fig. 19 **Water content at a depth of 40-60cm : orientation trial**

In the east-west orientation, a slight decrease in WC of the upper 20 cm was observed to the south of the tree row after day 5. The same dip was present in the dry condition. At the deeper levels, however, WC tended to be lower on the north of the tree row. In the north-south orientation, WC was lower by day 12 to the east of the tree row. This effect was, however, not observed at the 20-40 cm level but was again present at the 40-60 cm level.

4.4 Conclusion

Lindeque (1997) speculated about the possible effect of row orientation on light interception. Tendencies were observed indicating that horizontal distribution and/or development of the tree could be the critical factor in light interception.

From this study, it seems as if row orientation and alley width play a definite role in competition for water and light. The shading experienced in a 3m alley confirmed that this alley width is unsuitable to use under local conditions. During the first 2/3 of the growing season, more available PAR was intercepted to the northern side of the trees in the alley crops. During the latter part of the season the situation changed and more shading was experienced to the south of the trees. In the orientation trial, this was the case late in the season with afternoon sun. It was also clear that shading was more pronounced towards one section of the stand and that the east-west row orientation provided a more evenly spaced distribution of sunlight.

Available water content increased with depth, but distribution of this WC differed across the alley. In the upper horizon, distribution was more even, while in the lower horizon less moisture was available next to the leucaena trees. From approximately 1.5 away from the trees, WC increased. The distribution of WC did not differ much through the 3m alley, indicating that the effect of the leucaena roots reached at least up to 1.5 m on both sides of the tree rows.

With regard to the orientation trial, it would seem as if WC were slightly lower south of the tree row. A clearer trend could be observed in the north-south orientation, where a definite decline was observed towards the east of the tree row.

Distance from the tree rows played a definite row in competitive effects. From the results it could be concluded that cropping should only start at least 1.5 m away from tree rows in order to minimise competition, especially by shading. It was also concluded that competitive effects were influenced by different row orientations – a topic open for investigation. The purpose of the current investigations was only to observe trends, and more detailed surveys could provide useful information for the design of alley cropping systems.

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5 Soil Quality In Alley Cropping

5.1 Introduction

Leucaena leucocephala (leucaena), a multi-purpose fodder tree, has been studied extensively with regard to its use as an animal feed, source of fuel wood, green manure or mulch and ameliorating effect on soil in topical climates. Widely used in alley cropping systems because of its nitrogen fixing ability, prunings of leucaena are reported to provide nitrogen and organic matter when used as a mulch or green manure between the alley crops (Wilson & Kang, 1981; Yamoah, Agboola, Wilson & Mulongoy, 1986; Balasubramanian & Sekayange, 1991; Xu, Saffigna, Myers & Chapman, 1993; Matta-Machado, Neely & Cabrera, 1994).

Kang, Grimme and Lawson (1985) concluded that although large amounts of N were obtained from prunings, supplementary rates of fertiliser N were still needed to obtain high maize yields. Application of only leucaena prunings could sustain the main season maize yield for up to five years. Repeated application of leucaena prunings also maintained higher soil organic matter levels.

Larbi, Jabbar, Atta-Krah, & Cobbina (1993) reported that available phosphorus tended to increase with increasing proportion of prunings applied as mulch, whereas Atta-Krah (1990) and Haggar (1994) found that soil P was lower than with conventional cropping. Organic carbon accumulation is higher under NFT's – a reflection of continuous addition of leaf litter and dead roots below tree cover. Soil pH was also higher under NFT's than in control plots (Dalland, Våje, Matthews, & Singh, 1993; Leal, Pavan, Chavez, Inoue & Koheler, 1996; Mishra & Bhola, 1996). Atta-Krah (1990) reported no changes in soil pH after fours years of alley cropping.

Apart from soil chemical properties, bulk density, mean aggregate diameters and water holding capacity were also improved in alley cropped sites (Kang *et al.*, 1985; Yamoah *et al.*, 1986; Hulugalle & Kang, 1990). It was concluded that hedgerow species that frequently produce large quantities of prunings, which decompose slowly, might be the more desirable for alley cropping systems.

Hagger (1994) noted that there is now substantial evidence that alley cropping maintains soil fertility above levels found in pure annual cropping systems. The question, however, remained regarding the origin of increased availability of N to the crop. The author came to the conclusion that the soil contains considerable reserves of organic N that becomes available to plants slowly. The loss of N by leaching might also be reduced, due to the presence of a deeper and perennially active tree root system. Finally, the fixation of atmospheric N by leguminous trees is the most obvious source of N (Hagger, 1994).

In order to understand the various reported results, it is necessary to be reminded of the basic principles behind soil chemistry as summarised by Arnon (1992):

Most of the N in soil is in an organic form (OM has about 5% N). The amount of N in soil is not an indication of amounts of this nutrient which are immediately available to the crop, but constitutes a reserve from which nitrogen may become available to the plants - and not necessarily at a rate commensurate with the requirements of an actively growing crop. The fraction of N in the soil tends to remain constant at a level, which depends on the nature of the parent material, the leaching characteristics of the soil (mainly determined by its texture), and on the management system adopted.

P is present in mineral and organic forms. At low concentrations of soil phosphorus, the supply of P is insufficient for the requirements of plants and soil micro-organisms and competition occurs. Bacteria in the rhizosphere assimilate labile inorganic P and P uptake by plants is thereby restricted. Where intensive cropping, including P fertilisation, has been practised for a number of years, the phosphorus content of the soil has generally been built up, frequently to a level at which farmers can stop using P fertilisers for a number of seasons.

Even when there is adequate P in the soil, it may not be all available to the plants. Deep roots may be able to absorb P from deep soil horizons and release it to the surface soil during organic matter decomposition. K is brought to the surface in a similar manner, BUT, soil K is highly susceptible to leaching. This may be the reason for lack of change in soil K levels before and after NFTs'.

K is usually an abundant element in soils. Semi-arid soils may become depleted of K by the cropping and removal of crop residues. K occurs in a number of forms in the soil:

a) water soluble - in the soil solution. It constitutes a very small fraction and even in very fertile soils is not enough to meet crop requirements.
b) exchangeable - held by the exchange fraction of the soil. A small part of the total K.
c) non-exchangeable - slowly available. Native soil K from partly weathered minerals forms the reserve from which water-soluble K is gradually replaced. The higher the temperature, the greater the rate of release.
d) in unweathered K-bearing parent minerals, the element is released at an extremely slow rate.

Ca content varies more than any other element. It produces several specific effects, which result in the improvement of soil structure and increased crop production.

Large amounts of Na may accumulate in the soils of arid and semi-arid regions.

The availability of soil plant nutrients may be influenced by certain soil conditions, e.g. microbial N-fixation when C:N ratios are high. The amount of organic matter in arid and semi-arid soils is generally very low, being limited to mere traces in certain instances. This is due mainly to a sparse plant cover. The little organic matter that is not rapidly mineralised, is quickly dispersed by wind. Animal manure makes a small contribution and in many instances organic residues are used for fuel.

Blair, Catchpoole & Horne (1990) estimated that only 7,6 % of the N_2 fixed by *Leucaena leucocephala* shrubs are transferred to the herbage layer. The availability of N for annual plant growth may be increased by applying prunings of Leucaena as a green manure, leading to increased crop production.

At the University of Pretoria, alley cropping with leucaena was evaluated under semi-arid conditions. As part of the evaluation, soil fertility was also monitored. In 1996 the trial was converted into an alley cropping trial, during which leucaena was pruned and the prunings placed in the alleys as a mulch. Soil fertility was determined once a year. The objective was to determine if leucaena mulching would have any effect on soil fertility under lower rainfall conditions.

5.2 Materials and Methods

An alley cropping field experiment was conducted on the Hatfield Experimental Farm of the University of Pretoria (Table 1).

Table 1 Site Description on Hatfield Experimental Farm

Locality	28°16'E, 25°45'S
Altitude	1360 m
Annual rainfall	650 mm
Mean min. & max. temperature	2°C (June) - 26°C (June
Soil type	Sandy clay (37 % clay), Hutton, homogenous to a depth of 0.66 m after which it becomes gravelly (MacVicar, Loxton, Lamprechts, Le Roux, De Villiers, Verster, Merryweather, Van Rooyen & Von M. Harmse, 1977).

The study was laid out in a 2x3x3 factorial randomised complete block design with five replications, involving two alley widths (3m and 6m), three pruning treatments (Table 2), and a split plot for three alley crops (maize, grain sorghum, fodder sorghum). Within-row spacing was 1 m. Blocking was done across the length of the plot, on an east-west axis, based on previously observed differences in growth (Lindeque, 1997).

Table 2 Pruning treatments applied to *L.leucocephala* in the alley cropping trial

S1	Control - no pruning
S2	Pruning to a single stemmed tree (± every 6 weeks), clearing the undergrowth up to 1 m. In 1998 the interval was changed to 8 weeks.
S3	Hedgerow (± every 4 weeks), cut back to 1m height and ±0.75 m width

An existing leucaena stand, planted at a tree density of 3 333 trees per ha, was used. No fertiliser had been applied for the previous five years. Before the start of the 1996/1997 growing season, the trial was converted to an alley cropping trial by removing selected alternate rows. The plant populations of the 3m and 6m treatments were 3333 and 1667 trees per ha respectively. Pruning of the trees started in November 1996 and was repeated at fixed intervals thereafter, until April 1998. Except for the first harvest, yields of the different pruning treatments were applied as a mulch between the alley crops. The amount and nitrogen content of this mulch is illustrated in Table 3. No irrigation or fertiliser was applied. Soil samples were previously taken in 1993. Samples were again taken at the onset of the trial, and after each growing season from 1996, in the S3 treatment (hedgerow pruning) and 3m alley, at a depth of 0-20 cm (topsoil) and 20-40 cm (subsoil). Soil parameters included pH, Ca, P, K, Mg and total N.

Table 3 Total yield and quality of leucaena prunings in hedgerow treatment

	Pruning yields (t/ha)	Prunings Nitrogen Content (%)
1997	18.148	3.64
1998	38.593	4.69

5.3 Results and discussion

Results of the soil analyses are represented in Figures 1 – 5.

A steady decline in macro-nutrient content was noted from the first analysis in 1993 until 1996. During this time, crop removal predominated, with little or no recycling. The only organic matter returned to the soil was due to leaf drop from the trees. The sharper decline of nutrients in the subsoil represented "mining" from the subsoil (at least up to a depth of 1.5m), resulting in relatively higher values in the topsoil. After 1996, the macro-nutrient content increased once mulching commenced. The values declined again towards the end of the 1998 season, after two years of cropping between the leucaena trees. Phosphorus in the subsoil was depleted, similar to observations by Attah-Krah (1990) and Haggar(1994). The decrease after 1996 could be attributed to usage by fodder sorghum. N-fixation was not as good as would be expected from leguminous species. The C:N ratio of 14:1 was representative of cultivated conditions. The pH initially increased after the addition of mulch to the soil, confirming results cited in most literature, but then declined to an even lower level than before, when sampled after the 1998 mulch application.

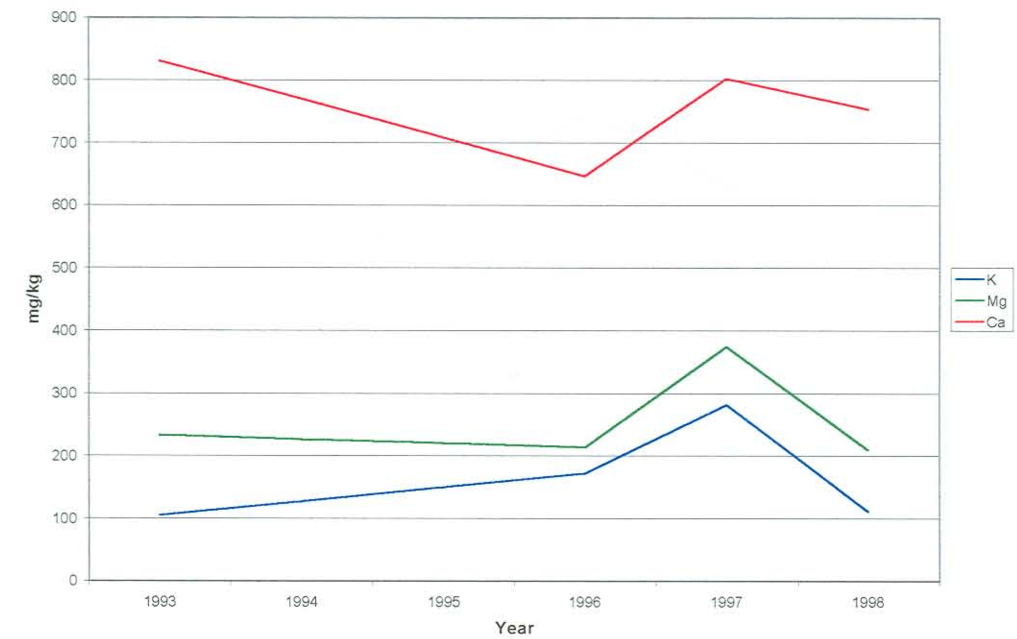

Fig. 1 Macro-nutrients in topsoil

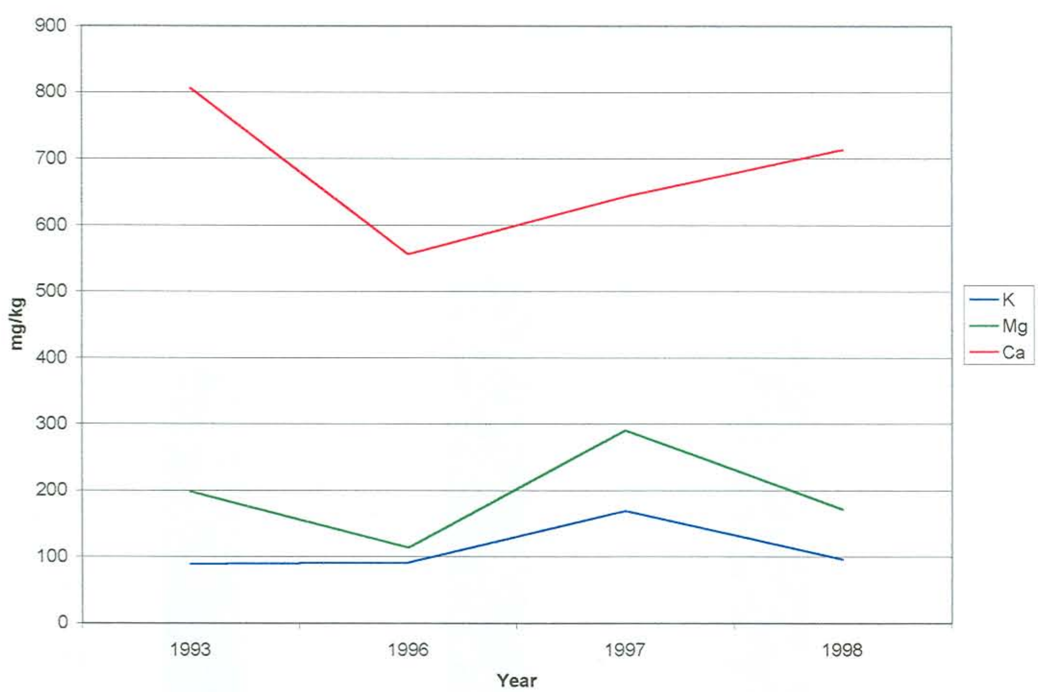

Fig.2 Macro-nutrients in subsoil

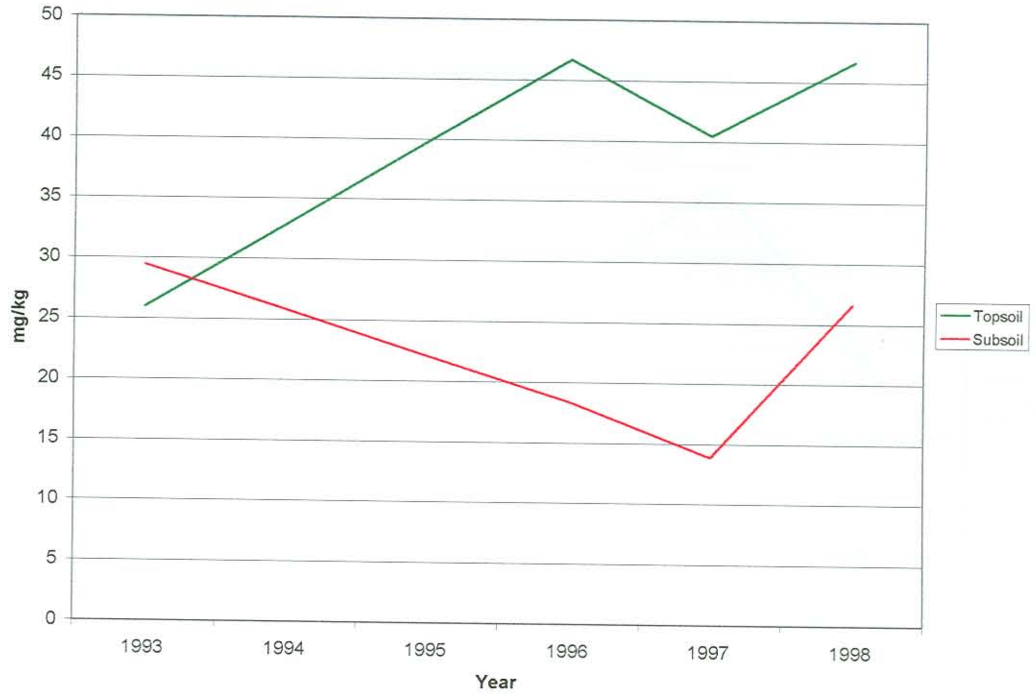

Fig. 3 Concentration of phosphorus

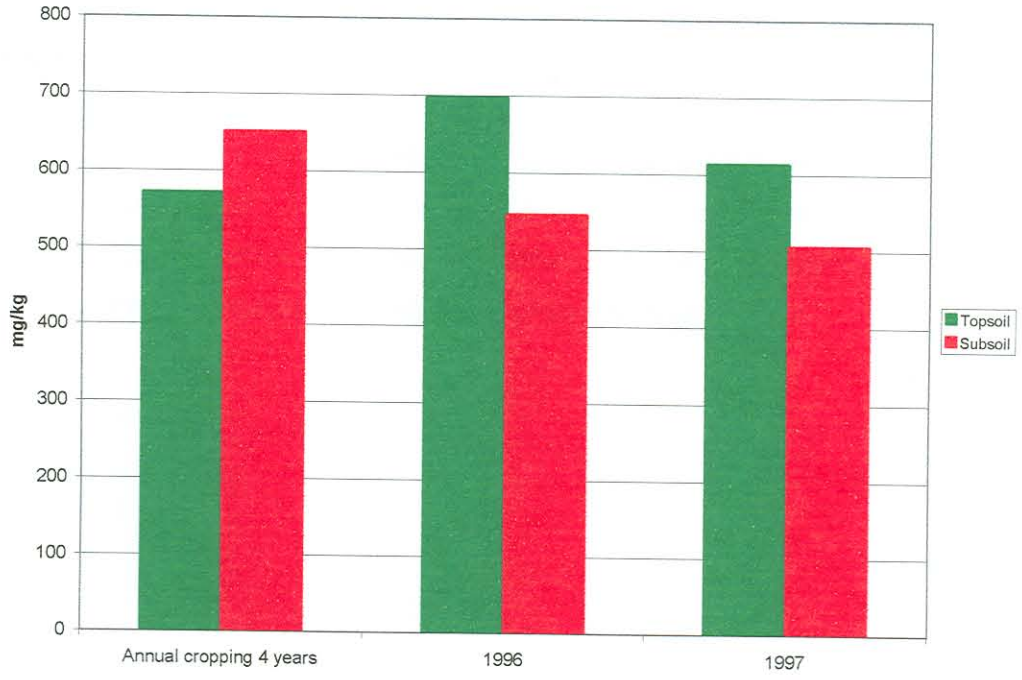

Fig. 4 Total nitrogen

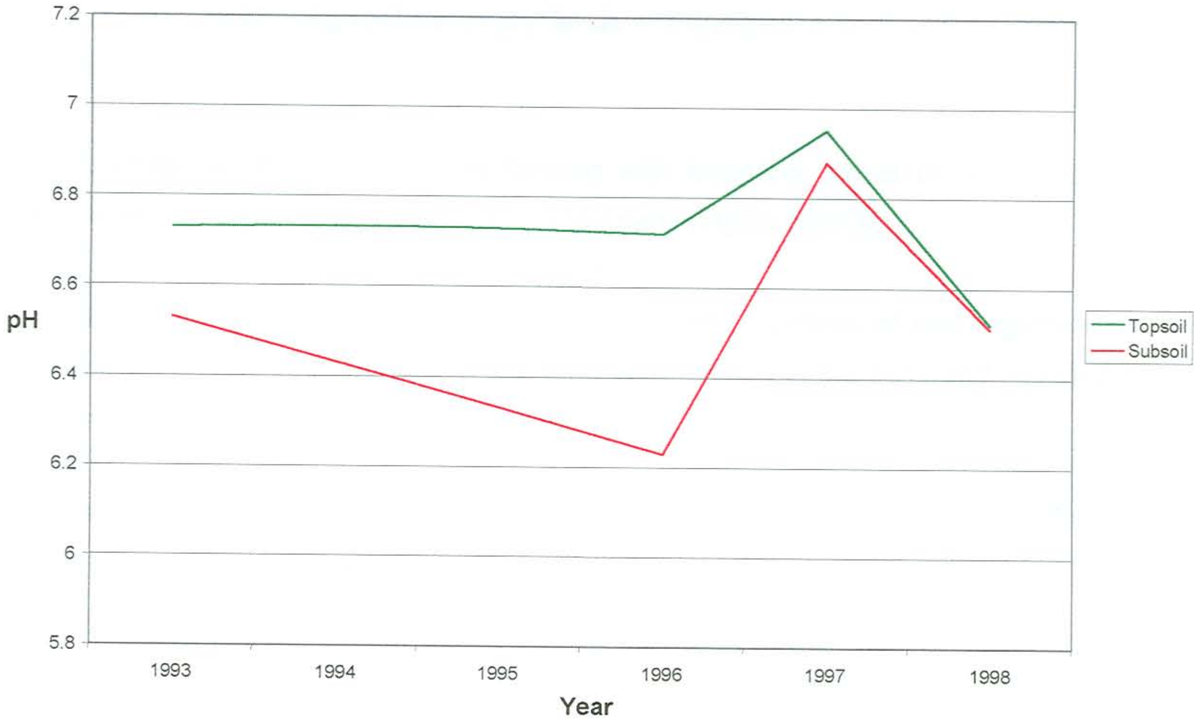

Fig. 5 pH levels

5.4 Conclusions

The addition of prunings had a definite effect on the soil fertility status, as had the crops planted in the alleys. The ideal would be to monitor soil quality over a much longer period, with and without the effect of nutrient removal by cropping, in order to make more accurate estimates of changes in soil chemical properties.

5.5 References

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6 Application

6.1 Introduction

Why make use of mixed cropping or integrated systems such as alley cropping? Mixed cropping (e.g. a grass/legume sward) is already an established practice in fodder production. Leguminous crops are included for the addition of nitrogen, which also improves nutritional value and intake. The advantages include improved yield per unit surface area, improved quality, improved combined use of resources (light, water, nutrition, space), improved stability of yields and intake and animal production (Van den Berg, 1987).

The effectiveness of a mixed cropping system may be evaluated by calculating the Land Equivalent Ratio (LER). LER refers to the ratio of the *area* under sole cropping to the area under intercropping, at the same level of management, that gives an equal amount of yield. The sum of the fractions of the yields of the intercrops relative to the sole crops provides a measure of the overall effectiveness of the mixed system – where LER=1, there is no advantage to intercropping over sole cropping; and where LER<1, more land is needed to produce a given yield by each component as an intercrop. As indicated by Ong (1996), the choice of the denominator or sole treatment of each crop should be the *optimal* treatment for the site. However, LER has also been calculated using only yields obtained from the crops involved (Rowland, 1975, as cited by Rowland, 1993), which is the method that will be used to calculate the LER's of the alley cropping trial at Hatfield (Table 1). No pure stand of leucaena was harvested, thus previous experimental results obtained on the same site were used (Lindeque, 1997). These yields were calculated as the total seasonal yield obtained in an unpruned leucaena stand. It is not the most satisfactory manner by which to calculate LER, but at least provides a reference point.

The alleycrop LER for the S2 treatment was calculated as 3.109, and the LER for the S3 treatment as 19.574. It is clear that the alley crop system was more productive than a tree monocrop, although sorghum would be produced more productively in a monocrop.

Table 1 **LER's of alley cropping trial, 1997/1998 season (6m treatment)**

Crop yields (forage)			
Crop	**Pure stand (t/ha)**	**In alley (t/ha)**	**LER (Components)**
S2			
Fodder Sorghum	34.334	20.784	0.605
Leucaena	2.875	7.198	2.504
S3			
Fodder Sorghum	34.334	23.48	0.684
Leucaena	2.875	16.015	18.89

6.2 Application of alley cropping with leucaena

The use of hedges in alley cropping can aid in protecting crops from roaming wilfdlife, domestic animals and people. Hedgerows define borders, provide privacy and act as small windbreaks. They may be planted and managed for fuel wood, fodder production, or to provide green manure or mulch. The hedges should be widely spaced in order to avoid a negative impact on associated crops, when trees are grown to large sizes. Living fence posts can be used in the same manner as above; the trees planted further apart and managed less intensively (e.g. cut less often). The trees can be used with other materials to form a barrier and are allowed to grow to larger sizes than hedges. Windbreaks are single or multiple rows of trees planted along windward field boundaries. The purpose is to slow wind speed and thus conserve soil moisture and prevent wind erosion and crop damage. Hedgerow intercropping is, however, management and labour intensive (Macklin, 1988; Prinsley, 1993).

6.2.1 Wood production

Approximately 2 billion people are dependant on fuel wood and charcoal for 90% of their energy requirements, another 1.5 billion for 50% of their requirements (Gutteridge & Shelton, 1994). Approximately 90% of the wood used in Africa, is for the purpose of fuel, with the remainder being used for construction or other purposes (Cook & Grut, 1989). The problem is that the demand is much higher than the production capacity. This has led to massive deforestation, increased water and wind erosion and the depressed productivity of agricultural land. In 1994, 4 % of the rural community in South Africa had access to electricity, while ± 40 % of the population was still dependent on wood for their energy requirements. Approximately 11 million t wood are being used annually in South Africa, as fuel wood (Cooper & Fakir, 1994; Gandar, 1994, as cited by Shackleton, 1994).

The inclusion of alley cropping principles in rural community gardens, can help alleviate this problem. Fuel wood and/or kindling can be produced throughout the year, ensuring a steady supply. Unpruned tree rows could be harvested to provide logs that would be suitable for fuel wood, while hedgerows could be harvested to provide kindling. Pruning to single stemmed trees could yield a useable pole for fencemaking or construction purposes, but could also be harvested for fuel wood.

6.2.2 Fodder production

Fodder banks refer to intensive plantings of trees spaced to maximise leaf production and provide a source of "cut and carry' fodder (Macklin, 1988). This could also be applicable to alley cropping systems. In Tanzania it was found that 2 kg/day fresh leucaena leaves may result in a notable improvement in the body condition of animals. Under grazing and zero-grazing systems, supplementation with leucaena resulted in an average daily live weight gain (DLWG) of 52.8 g/day after 28 days, and 53.47 g/day after 48 days (N'Jai, 1995).

The use of the leaves as fodder in such a "cut and carry" system holds the disadvantage that soil nutrients may be depleted, as the nutrients taken up by the plant are not circulated. It is also not a well known concept in certain parts of the world. In Australia, only ±2% of farmers who practise agroforestry do so for fodder. This increases to 4% in the drier zones (Prinsley, 1993). It is, however, of interest to note that mechanisation of harvesting and feeding of coppice growth of *Albizia* species in the USA has improved the feasibility of such zero-grazing systems (Rethman, personal communication)[1].

6.2.3 Mulch/Green manure

Low water availability has been known to adversely affect N fixation (Tewari, 1995). Apart from possibly increasing soil fertility, the addition of mulch could actually reduce the loss of moisture by preventing evaporation from the surface. Other

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favourable effects mentioned by Arnon (1992) include the reduction of run-off and erosion, reduction of salinity and improvement of soil temperature by changing the radiant energy balance of the system (mulched soil are usually warmer and cooler than bare soil, depending on the situation, because of the insulating effect).

Problems associated with mulched soils were also mentioned, including sanitary problems due to the harbouring of disease, pathogens and pests.

6.2.4 *Weed control*

The presence of mulch has been reported to suppress weed growth (Lal, 1975, cited by Kintomo, Agboola & Mutsaers, 1995). Weed suppression may, however, be influenced by morphology of the leaves used for mulch. The leaves of leucaena are bipinnate (small leaflets) and will almost immediately fall from the rachis when drying starts and be easily blown away. Unless the mulch layer is laid relatively thick, the effect might, therefore, be lost.

6.2.5 *Windbreaks*

The principle effect of windbreaks is to reduce wind velocity and turbulence. When used in wide alleys, single stemmed trees could act as windbreaks (Arnon, 1992). In semi arid and dry temperate areas, planting of 5% of the land to shelter could reduce windspeed by 30-50% and soil losses by up to 80%(Bird, Bicknell, Bulman, Burke, Leys, Parker, Van der Sommern & Voller, 1993).

To aid farmers in the decision making process, an agroforestry computer simulation model - "Farmtree" – is available, that estimates the likely costs, effects on agriculture, tree growth, timber value, directs effects on farm income and nett rate of return. It uses the input details of site, layout, species, intended harvest age and proposed management (Farmtree, undated). The model does not, however, have an adequate data base for tree and plant interactions.

6.3 Conclusion

All of the above mentioned points fit neatly into two well known concepts, which may aid in the adoption of the technology (Arnon, 1982), *viz.* "LISA" and organic farming.

- *LISA (Low Input Sustainable Agriculture)*

This technology seeks to minimise the use of external production inputs, such as purchased fertilisers and pesticides, wherever feasible and practicable, to lower production costs, to avoid pollution of surface and groundwater, to reduce pesticide residues in food, to reduce a farmer's overall risk, to increase both short- and long term farm profitability. Arnon (1992) noted that the slogan "low input agriculture " is misleading and counterproductive because it diverts attention from the really important goal of increasing the farmers' awareness that further deterioration of the natural resource base must also be prevented.

- *Organic farming*

Organic farming is not exactly a new approach, having been actively propagated since the 1940's and experiencing a revival the past few years. The system ascribes most of the ills of modern agriculture to the use of "artificial" chemicals, such as soluble fertilisers, insecticides, fungicides, herbicides and others. It is claimed that the chemicals destroyed soil fertility, by replacing organic manure and poisoning the soil organisms. This, in turn, caused an increase in the incidence of plant diseases and thereby adversely affected the health of humans and domestic plants using the contaminated and diseased plants for food. Although the amounts of organic food produced still constitute only a fraction of total food production, the numbers of organic farmers are increasing, mainly as a result of the increase of consumers' interest in environmental problems, improved quality of life and health-giving food (Arnon, 1992).

However positive the results obtained and possibilities of leucaena, some concern exists about the status of leucaena as a weed in South Africa, as it has reached invader status in some countries. The plant is perceived as a "noxious" weed by many, so much so that some authors believe the "conservation of environment" vs. "agricultural production" debate to be swinging towards conservation (Partridge, 2000), therefore discouraging the production of leucaena. In South Africa, amendments to the Conservation of Agricultural Resources Act (Act 43 of 1983) have been proposed by the National Department of Agriculture, that will regulate the use of potential invading plant species. According to these proposed regulations leucaena will be classified a Category 2 invader (plants that are useful for commercial plant production purposes but are proven plant invaders under uncontrolled conditions outside demarcation areas). Plantings thereof should be confined to demarcated areas, where controlled conditions of cultivation and care prevail. Plants or products derived from the plants must serve beneficial purposes including uses for own consumption, esthetic value, ornamentation, building material, animal fodder and fuel. Precautionary measures should be taken to reduce the spread of seed or any other propagating material outside the demarcated areas. An additional condition stipulates that the trees shall not be planted within 30 m from the outside boundaries of the flood areas of perennial watercourses and wetlands. The regulations have not yet been promulgated, but are expected to be finalised during the course of 2001.

Leucaena is widespread in sub-tropical areas of South Africa, but invasion has been prevented by management strategies such as pinching off the flowers in order to prevent the production of seed (personal observation, Northern Province) and utilisation by grazing animals. At this stage it would seem as if leucaena has only been invasive in disturbed coastal urban areas and lowveld areas with high rainfall (>900 mm per year) (Underwood, 1986 and Fenn, 1987, as cited by Pauw, 1994).

Pauw (1994) provided a summary of factors regulating the spread of leucaena, including:

- Altitudes higher than 500 m
- Rainfall of less than 900 m per year
- Frost
- Well established vegetation and associated competition
- Acidic soils

Useful guidelines regarding the control of leucaena have been published by the Tropical Grassland Society of Australia (Partridge, 2000):

- Only plant leucaena if you need it and are prepared to manage it
- Do not plant leucaena near streams or major waterways. Maintain a dense grass buffer between the leucaena and the high water mark of the river bank.
- Control unwanted seedlings that establish outside camp fence or in areas where cattle do not normally have access.
- Plant leucaena in a carefully fenced paddock, at least 10 m away from external fence lines.
- Do not allow ripe seed to drop to the ground.
- Graze or cut leucaena to keep it within reach of animals.
- Graze leucaena in summer so as to minimise flowering and seed set.
- Do not plant leucaena in pure stands without grass (this system will be more to erosion).
- Assist your local government identify any stands of escaped leucaena so that action can be taken to control it.

Although results obtained from alley cropping differ widely, and have been mainly obtained in tropical areas receiving a higher rainfall, the system offers the potential of increased productivity to developing agriculture. Results from various locations differ, as many of the interactions with environmental factors are not yet fully understood. Each system should be evaluated on its own merits, taking into account the locality-specific conditions. Adaptations should be made along the way, streamlining the management of the system in order to obtain the goal of increased and sustained production.

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