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)

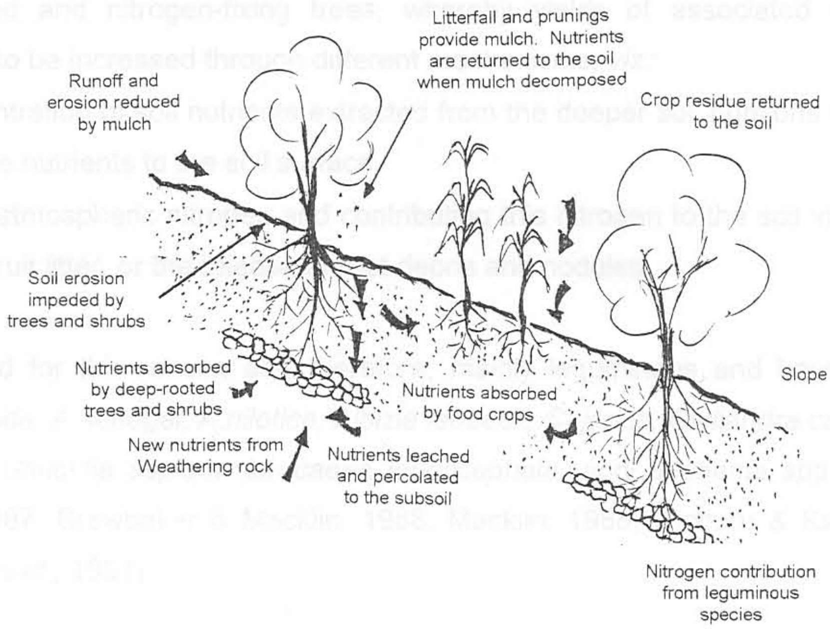

Figure 1 **Schematic representation of the functioning of a typical alley cropping system (Kang, Van der Kruijs & Couper, 1986).**

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.

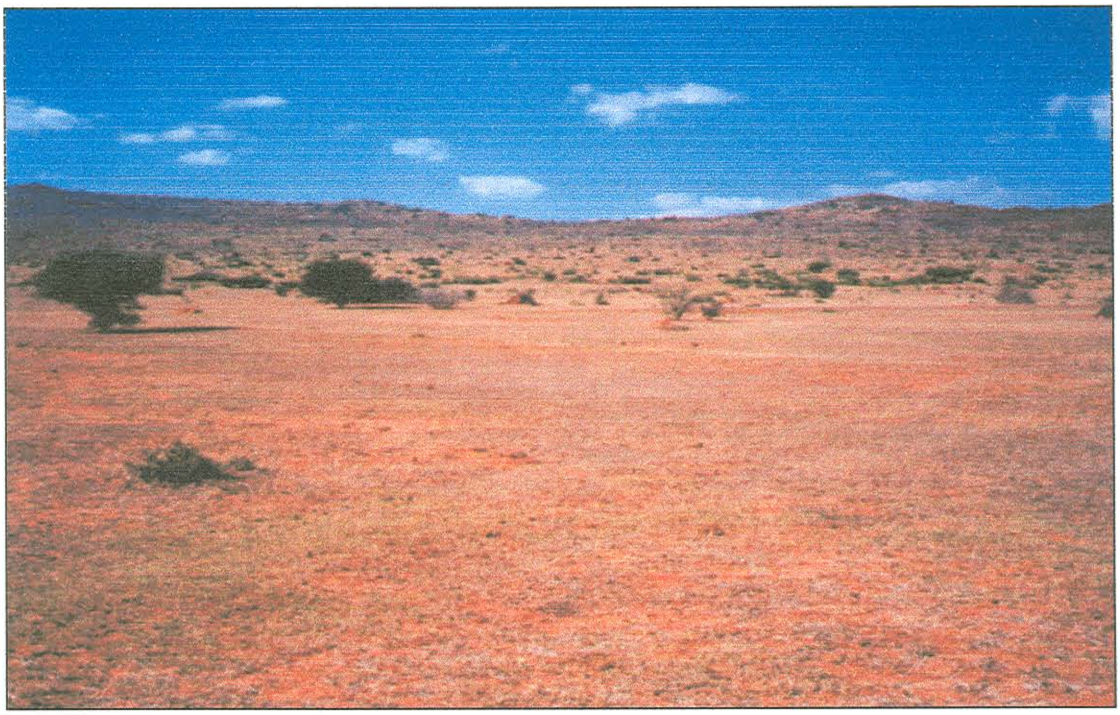

Fig 3. Typical grazing, Dikgopheng village, Northern Province

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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